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# AN ANALYSIS OF ENGINE TYPE TRENDS IN PASSENGER CARS: ARE WE READY FOR A GREEN DEAL?

***Kamil Maciuk[1], Celso Augusto Guimarães Santos[2], Lukasz Kulesza[3], Agnieszka Gawlik[4], Anna Orzel[5], Mateusz Jakubiak[1], Paula Bajdor[6], Sławomir Pytel[7], Mariusz Specht[8], Karolina Krzykowska-Piotrowska[9], Sorin Nistor[10], Yana Wengel[11,12], Michal Apollo[7,12,13,*]***

*[1] AGH University of Krakow*
*Krakow, Poland, Mickiewicza 30, 30-059*
*maciuk@agh.edu.pl, jakubiak@agh.edu.pl*
*[2] Department of Civil and Environmental Engineering, Federal University of Paraíba*
*João Pessoa, Brazil, 58051-900 João Pessoa*
*celso@ct.ufpb.br*
*[3] Faculty of Environmental, Geomatic and Energy Engineering, Kielce University of Technology*
*Kielce, Poland, al. Tysiąclecia Państwa Polskiego 7, 25-314*
*l.kulesza@tu.kielce.pl*
*[4] WSB Merito University in Wroclaw Faculty in Opole*
*Poland, Kośnego 72, 45-372 Opole*
*agnieszka.gawlik@opole.merito.pl*
*[5] WSB Merito University in Wroclaw*
*Wroclaw, Poland, Fabryczna 29-31, 53-609*
*anna.orzel@wroclaw.merito.pl*
*[6] Faculty of Management, Czestochowa University of Technology*
*Poland, Armii Krajowej 19b, 42-201 Czestochowa*
*paula.bajdor@pcz.pl*
*[7] Faculty of Natural Sciences, University of Silesia in Katowice*
*Sosnowiec, Poland, Będzińska 60, 41-200*
*slawomir.pytel@us.edu.pl, michal.apollo@us.edu.pl*
*[8] Department of Transport and Logistics, Gdynia Maritime University*
*Poland, Morska 81-87, 81-225 Gdynia*
*m.specht@wn.umg.edu.pl*
*[9] Faculty of Transport, Warsaw University of Technology*
*Poland, Koszykowa 75, 00-662 Warsaw*
*karolina.krzykowska@pw.edu.pl*
*[10] Faculty of Construction, Cadastre and Architecture, University of Oradea*
*Romania, 410058 Oradea*
*sonistor@uoradea.ro*
*[11] HNU-ASU Joint International Tourism College, Hainan University*
*Haikou, China, Haikou 570228*
*yana.wengel@outlook.com*
*[12] Borneo Tourism Research Centre, Faculty of Business, Economics and Accountancy, Universiti*
*Malaysia Sabah - Kota Kinabalu, Malaysia, Jalan UMS, 88400*
*[13] Global Justice Program, Yale University, USA, New Haven, CT 06520*
** Correspondence: michal.apollo@us.edu.pl*

The air pollution of our planet is rising, and the contribution of road transport to global pollution has a serious impact on this phenomenon. Previous papers have analysed and recommended measures to reduce road transport's negative environmental impact and carbon footprint. However, some restrictions are impossible (or very costly) to meet, even in developed countries. Unfortunately, presenting the impact of transport on air pollution levels as a whole can only give a general picture. This paper provides a more detailed analysis and attempts to assess the impact of one of the most important elements shaping modern transport, that is, vehicle

engine types. Thus, the main objective of the study is to analyse and evaluate the different types of engines in vehicles from the point of view of technical, environmental, and economic aspects in European countries and to verify whether Europe is ready to implement the European Green Deal. The results indicate significant technological developments must occur in electric vehicles to become environmentally better than combustion engine-based cars. Additionally, in the case of some developing countries, owning a means of transport is still perceived as a symbol of a certain status, which is why it is still an important material asset. Thus, in rich countries, material status and environmental awareness (e.g. choice of public transport) will help to achieve climate neutrality, while poorer countries (even developed ones) may have severe problems in meeting EU requirements. Overall, while answering some questions, this article also poses new ones. Decision-makers often face challenging aspects. This article is intended to give them a basic knowledge to pursue an environmental policy that is viable and feasible for all countries.

**Keywords:** Ecology, transport, car engine, Europe, EU, carbon footprint, passenger car, green deal, green energy, energy, fuel

## 1. Introduction

The pollution of our planet is rising, and the human contribution to global pollution dominates this phenomenon (Apollo, 2020; Meinshausen *et al.*, 2011). Excessive anthropogenic $CO_2$ emissions in January 2023 reached a concentration of $CO_2$ in the air that exceeded 420 parts per million, and this value is still increasing (UCSD, 2023). This article focuses on one slice of human activity, namely, air pollution from means of transport using different engines. The air quality throughout the cities of Europe has become a pressing issue because a multitude of reports indicate poor air quality, which has deteriorated at an alarming rate during the last few years. This poor air quality has many side effects on human health and ecosystems, thus becoming a challenging issue all over Europe (Benbrahim-Tallaa *et al.*, 2012; Guerreiro *et al.*, 2014; Holman *et al.*, 2015; Jagiełło *et al.*, 2022).

Although there has been a significant emission reduction in different polluting sectors such as energy production, agriculture, transport, households, and industry, the road transport sector plays a crucial contributing role in the quality of air through the emission of a complex mixture of many air pollutants such as carbon dioxide ($CO_2$), nitrogen oxides ($NO_x$), and particulate matter ($PM_{2.5}$ and $PM_{10}$) (Hooftman *et al.*, 2018; Jang *et al.*, 2021; Zimakowska-Laskowska *et al.*, 2022). The fact that large numbers of people are directly exposed to this mixture of harmful gases constitutes an urgent problem affecting many communities. Despite various norms and successful legislation implemented all over Europe in the last decades, the share of diesel cars in Europe has not decreased at all, or not as expected, considering emission standards (Chen & Borken-Kleefeld, 2014; Sakno *et al.*, 2021). This problem translates into the fact that a broad part of the European population still has to breathe air that contains excessive levels of pollutants compared to the European Union (EU) standards and air quality guidelines recommended by the World Health Organisation (WHO AQG) (Guerreiro *et al.*, 2014).

Currently, in the EU, the existing targets for $CO_2$ reduction revolve around a single driving pattern, the New European Driving Cycle (NEDC) (Ntziachristos *et al.*, 2014). According to the Association des Constructeurs Européens d'Automobiles, or European Automobile Manufacturers Association (ACEA), regarding the fuel types of passenger cars in the EU, "40% of all new cars registered in the European Union run on petrol, while diesel accounts for 19.6% of registrations. 18% of new passenger cars in the EU are electrically-chargeable vehicles (9.1% battery electric + 8.9% plug-in hybrids), while hybrids account for 19.6% of total car sales" (ACEA, 2021). Thus, this status and developments in the automobile industry play an essential role in national and regional policy development and implementation due to their expected influence on air quality. Therefore, management and quality plans for air quality to be achieved in the near- and medium-term future must be carefully planned.

Discrepancies exist between type approval and "real-world" fuel consumption and $CO_2$. A critical problem faced every day and reported by drivers is that the measured fuel consumption during actual driving on the road and type-approval fuel consumption present significant discrepancies (Huo *et al.*, 2011). Thus, the fuel consumption on the actual road is higher than the fuel consumption reported by the vehicle manufacturer, creating significant policy implications. However, the emission targets over the regulatory procedure are met. Consequently, the question is whether the type-approval specific targets set, and real-world fuel consumption can be considered reliable for real improvement in line with $CO_2$ reduction targets. With the help of the integration of smart technologies, especially in car development, but also in traffic management, navigation or the more demanding eco-driving, the aspirational targets set for 2050 for decreasing $CO_2$ emissions and fuel consumption can be achieved (Galimova *et al.*, 2022; Husika *et al.*, 2022; Samaras *et al.*, 2012).

The subject of car engines in passenger vehicles has been discussed in the literature for many years. Recently, it has gained interest due to the introduction of new types of engines, hybrid and electric (Mosin *et al.*,2023; Wang *et al.*, 2022). The measures mentioned above serve the broadly understood protection of

the environment, especially in reducing carbon footprint. So far, road transport generates the highest emissions of harmful gases among all modes of transport and is responsible for about 70% of these emissions in transportation. Scientists are analysing and recommending measures to reduce road transport's negative environmental impact and carbon footprint. For example, Morfeldt *et al.* (2021) prepared a case study for Sweden and suggested that banning new internal combustion engine cars will reduce tailpipe $CO_2$ emissions, and also stated that a ban in 2030 is not sufficient for reaching Swedish climate targets for 2030. For this reason, an earlier ban year or increased biofuel use is needed to reach Swedish targets. On the other hand, d'Ambrosio *et al.* (Planella *et al.*, 2016) reviewed the regulations and techniques to eliminate toxic emissions from diesel engine cars together with an overview of exhaust gas after-treatment systems, evaluation of some EU exhaust gas legislation, and identification of types of gas emission control techniques. Holmberg and Erdemir (Holmberg & Erdemir, 2019) evaluate the impact of tribology on energy use and $CO_2$ emissions globally and in combustion engines and electric cars. Other researchers have shown results thet indicate the potential of the T-LPDi concept as a good alternative for environmental competitiveness. However, there is room for further improvement of engine control and optimisation of emission catalysts to meet more stringent future regulations (Cho *et al.*, 2019).

In addition to the natural, technological evolution of engines, for years their designers have also considered other aspects influencing the design of these elements. Dijk (2011) undertook the definition of a particular framework for the evolution of engines in the 1990–2005 period and analysed the technological frames (engine capacity, engine volume, torque) of a few types of car engines. It was proved that disposable income is the dominant factor in determining car engine size purchase probabilities. On the other hand, Fu *et al.* (2011) introduced some regional characteristics and the distribution of car engine sizes based on a case study of Ireland. Nevertheless, the issues of engine design are determined by several aspects that have also been discussed in the literature, i.e.:

[1] **cooling systems**: Umirov and Abdurokhmonov (2022) described the de-aeration properties of radiators of car engine cooling systems; Li *et al.* (2016) did an experimental study on the thermo-physical properties of car engine coolants. The study reports new findings on the thermal conductivity and viscosity of car engine coolants based on silicon carbide nanofluids;

[2] **fuel**: Bortel *et al.* (2019) studied the effects of HVO fuel mixtures on emissions and the performance of a passenger car-size diesel engine. The authors showed experimental results by comparing standard diesel fuel, pure hydrotreated vegetable oil (HVO), and a blend of 30% HVO and 70% standard diesel fuel. These experiments were conducted on a passenger-car size, single-cylinder compression ignition engine. Ternel *et al.* (2021) presented a life cycle assessment of mid-range passenger cars powered by liquid and gaseous biofuels, as well as a comparison with greenhouse gas emissions of electric vehicles and forecast to 2030;

[3] **compression systems**: Wittek *et al.* (2019) published a paper on an experimental investigation of a variable compression ratio system applied to a gasoline passenger car engine. Results show that a higher compression ratio variation range may reduce fuel consumption. López *et al.* (2020) continued studies on compression and showed results on the potential of a two-stage variable compression ratio downsized spark ignition engine for passenger cars. The results proved that there is a 3–4% lower fuel consumption compared to the fixed compression ratio;

[4] **noise**: d'Ambrosio *et al.* (2019) studied the dependence of combustion noise on engine calibration parameters in passenger car diesel engines, evidencing that it is possible to calculate the combustion noise as a function of the main engine calibration parameters, which is represented by low, medium and high load and speed conditions, while Deryabin (2022) researched reducing the noise of the motor vehicle internal combustion engine, proving that there is a possibility of reducing internal combustion engine noise by adjusting the clearances in the main and rod bearings of the ICE crankshaft.

Vitta summarises these research results by indicating that significant technological developments must occur in electric vehicles to become environmentally better than combustion engine-based cars (Vakulenko *et al.*, 2021; Vitta, 2021). However, this entire evolution aims to change engine design trends and consumer choices concentrated around electric cars. Inci *et al.* (2022) even present a choice experiment on preferences for electric and hybrid cars in Istanbul. Mutarraf *et al.* (2022) reviewed electric cars and ships. Cars and ships are the main contributors to emissions in the transportation sector, and the lack of charging infrastructure is the major obstacle to the extensive use of electric vehicles. Conductive, wireless, and swapping are ways to charge onboard batteries.

The main idea of the article is to present the results of analysis and evaluation of various types of engines in vehicles from the point of view of technical, environmental, and economic aspects in European

countries, and to determine if Europe is ready for the implementation of the European Green Deal. To try to answer this question, literature studies and analyses conducted in the field of:

- the number of registered cars in EU countries,
- the number of registered electric and hybrid cars in EU countries,
- the level of use of renewable energy,
- the relationship between the gender gap and renewable energy, the gender gap and renewable energy in transport, as well as the gender gap and the number of electric cars.

All these elements brought together in one article can be helpful for policy-makers, not only in the EU but also in other areas. Non-European areas can take the EU transformations as guidance and use some (not all) of the procedures in place. Additional considerations are included at the end, which provoke further fields of research, both quantitative and (more urgently) qualitative.

## 2. Passenger cars by type of motor-based energy source: a literature review on status, challenges, and prospects

### 2.1. Historical approach

Within 13 years, all new vehicles in Europe will have an electric or hydrogen engine. Such a significant change is driven by the regulations that will apply in Europe from 2035. However, the history of electric vehicles (EVs) is much longer, dating back to 1831, when Scottish inventor Robert Anderson (Guarnieri, 2012) built the world's first electric car. It was more like a carriage but was put into motion by an electric motor. Similar developments were made between 1834 and 1840, when Thomas Davenport, an American blacksmith from Vermont, constructed a prototype of an electric-powered vehicle. In 1835, Sibrandus Stratingh Groningen designed an electric car using the Volta cell (Jastrzębska, 2007). The construction of electric vehicles became more accessible in 1859 when Gaston Planté invented the lead-acid battery in Belgium. Ten years later (in 1869), Belgian electrical engineer Zénobe Gramme invented the commutator, and in 1871 the first direct current electric motor was developed. Radcliff Word built the first multi-passenger electric vehicle. In 1884, Thomas Parker presented his electric car, and it was the first car to be mass-produced and fed by rechargeable batteries. It covered a distance of about 50 km at speeds of up to 15 km/h (Guarnieri, 2012).

By 1900, before the heyday of the internal combustion engine, electric vehicles had broken many speed and distance records. One of the most noteworthy events of the time was the crossing of the 100 km/h speed barrier by Camille Jenatzy on 29 April 1899, while the electric vehicle La Jamais Contente reached a top speed of 105.88 km/h (Jastrzębska, 2007).

In 1899, Ferdinand Porsche designed his electric car for Lohner. It was an electric automobile with two motors driving one wheel each on the front axle. In 1900, a four-wheel electric car was made. The motors, this time, were hidden in the hub. The four electric motors were powered by electricity from an internal combustion generator. This design was extremely heavy; the vehicle weighed 1.8 tonnes but provided excellent performance. With a combined output of 56 hp, the car could accelerate to 60 km/h. Later, this concept evolved into hybrids. However, electric motors had a fundamental disadvantage; widely available vehicles usually reached a low speed of around 32 km/h. In addition, Thomas Edison's marketing campaign favouring DC over AC did not attract any followers. Electric vehicles also fell into disfavour with the mass production of the Ford T from 1908 to 1912. The Model T made gasoline-powered cars widely available and affordable. Expensive electric cars with limited ranges could not compete effectively on the market with combustion vehicles. The development of road networks gave the advantage to ICVs in covering longer distances.

Meanwhile, there was no infrastructure outside cities where EVs could charge. In 1912, Charles Kettering introduced the electric starter, eliminating the need for the hand crank and increasing gasoline-powered vehicle sales; this starter was an electrical device that allowed ICV cars to spread throughout the market entirely and finally overwhelm electrics (Anderson & Anderson, 2010; Wulder *et al.*, 2019).. Another important aspect was the establishment of lobbying companies in the United States, which successfully campaigned for combustion engines. Another contributing factor was access to new oil deposits. By 1935, the market share of electric cars had fallen, except for popular limited-range services such as golf carts in the US and milk delivery floats in Great Britain. This remained the case until the 1960s (Guarnieri, 2012). Table 1 selects the most important developments in electric vehicles up to 1990.

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**Table 1.** Selected events in the history of electric vehicles

| Date | Inventor | Development |
|---|---|---|
| 1800 | Alessandro Volta | Galvanic cell |
| 1822 | Peter Barlow | Prototype of the electric motor |
| 1829 | Ányos Jedlik | DC electric motor |
| 1834 | Jacobi Moritz Hermann | Commutator electric motor |
| 1835 | Sibrandus Stratingh | Electric-powered three-wheel vehicle |
| 1859 | Gaston Planté | Lead-acid rechargeable battery |
| 1881 | Camille Alphonse | Increasing the capacity of lead-acid batteries and enabling their mass production |
| 1884 | Thomas Parker | Electric car equipped with lead-acid batteries |
| 1888 | Andreas Flocken | First German electric car |
| 1890 | William Morrison | First electric car in the US |
| 1893 | Jeantaud | French company starts production of electric cars |
| 1897 | Walter Bersey/London Electrical Cab Company | Electric taxis – a fleet of 75 vehicles in London |
| 1899 | Camilie Jenatzy | Speed record – 105.8 km/h |
| 1901 | Ferdinand Porsche & Ludwig Lohner | Hybrid car |
| 1910 | Hartford Electric Light Company | EV battery exchange station |
| 1913 | Ford & Edison | Electric car with a maximum range of up to 160 km (100 miles) |
| 1947 | John Bardeen, Walter Houser Brattain & William Bradford Shockley | First transistor |
| 1947 | Nissan | Tama E4S-47 – range 96 km and top speed 35 km/h in Japan |
| 1971 | US - Apollo 15 mission | Manned electric vehicle on the moon – Lunar Rover |
| 1985 | Akira Yoshino | Lithium-ion cell prototype |

Occasionally, there have been returns to electric motoring, but this was primarily due to fuel shortages rather than innovative design solutions. During World War II, as a result of fuel rationing, electric vehicles in various segments were being developed in many countries. After the Second World War, electric cars were still a niche market. In Japan, the E4S-47 was developed in 1947 and equipped with a 4.5 hp electric motor that allowed it to accelerate to 35 km/h with a range of 65 km. The lead batteries had a capacity of 162 Ah and a voltage of 40V. This small vehicle was a response to the deficits associated with fuel rationing. Between 1949 and 1962, around 100 DKW Schnellasters were equipped with an electric motor. Lead batteries, which were located in boxes on the side of the van, provided electricity with a total capacity of 200 Ah and a voltage of 80V. They powered the electric motor with 5 kW (just under 7 hp) and allowed it to travel a maximum of 80 km on a single charge. The maximum speed the Elektro Schnellaster could reach was 40 km/h (Burton, 2015).

The global oil crisis in 1973 contributed to renewed interest in electromobility. Still, the fundamental shift toward electric cars can be traced back to 1990 when attitudes towards environmental pollution changed, and the world began looking for solutions that would care for the planet yet still be functional.

### 2.2. Carbon footprint, the environmental and economic impact on consumer EV purchasing decisions

Since 1990, electric cars have started to attract renewed enthusiasm. A symbolic turning point was reached in 1990 when, in the USA, electric-powered vehicles were recognised by the California Air Resources Board (CARB) as ZEV-zero emission vehicles (ZEVs). CARB has set an annual minimum number of electric vehicles to be produced. Efforts have begun to reduce what is known as the 'carbon footprint.' The carbon footprint is the total amount of greenhouse gases (including carbon dioxide and methane) created by our activities.

Due to their price, limited driving on a single charge, and still underdeveloped charging infrastructure, electric vehicles are used in cities over distances of around 200 km (Danielis *et al.*, 2022). Charging itself is only one of the problems, as in the case of electric propulsion, the main issue is the batteries, which store the electricity needed to power the engine. There are three distinct concepts for implementing electric propulsion (Gabryelewicz & Zając, 2023):

- the use of battery banks for energy storage,
- the generation of electricity on board the vehicle using fuel cells,
- the use of a battery backed up by an internal combustion engine (hybrid drive).

The oldest and most environmentally friendly solution is the battery-powered drive. These are Zero Emission Vehicles. Currently, lightweight lithium-ion batteries with a liquid or polymer electrolyte are most commonly used. Such batteries store about ten times more energy per unit mass than the lead-acid

batteries used in the past. Lithium-air batteries are also being used to increase range, but research is still ongoing to improve performance.

Research work and legislation will increase interest in electric or hydrogen-powered vehicles. It is essential that this approach does not exploit other raw resources beyond what is feasible. The market leaders for European electric cars are the Renault Zoe and Nissan Leaf. Both of these models maintain a sizable lead over their rivals. The third position, but still on the podium, belongs to the Tesla Model S. The choice of electric vehicles on the market is extensive at present, including about 72 models. The table below shows a selection of models by their distinctive features.

**Table 2.** Chronology of electric car history (Elektromobilni, 2020)

| Year | Manufacturer | Model characteristics |
|---|---|---|
| 1991 | Škoda | Škoda Favorit Eltra – all-electric, 21 hp engine with a range of 80 km |
| 1996 | General Motors | EV1 – first generation range up to 160 km/h, the second generation is 230 km/h |
| 1997 | Toyota | Prius – first mass-produced hybrid car |
| 2001 | Reva Electric Car Company | REVAi – Speed up to 80 km/h, range up to 120 km |
| 2007 | Daimler Chrysler | Smart – four generations of electric smarts unveiled as of 2020 |
| 2008 | Tesla | Tesla Roadster – first series-production electric car equipped with a lithium-ion battery. The vehicle has a range of approximately 400 km |
| 2009 | Mitsubishi | MiEV – serial production |
| 2010 | Worldwide | Electromobility support programmes – many countries around the world are beginning to introduce legal and financial instruments to support buyers and users of electric cars |
| 2010 | Nissan | LEAF – becomes the most popular electric car in history |
| 2011 | Chevrolet | Volt – first mass-produced plug-in hybrid |
| 2012 | Renault | Zoe – the most popular car on the market |
| 2012 | Tesla | Model S – first mass-produced premium electric sedan |
| 2013 | BMW | BMW i3 – an electric vehicle that is 95% recyclable |
| 2014 | KIA | KIA Soul EV – 390 km/h |
| 2015 | Tesla | Tesla Model X –507 km/h |
| 2015 | Worldwide | The number of electric cars worldwide passed the 1 million marks |
| 2016 | Worldwide | The number of electric cars worldwide passed the 2 million marks |
| 2016 | Hyundai | IONIQ – three types of electric drive – all-electric, as a classic hybrid, and with a plug-in hybrid drive |
| 2017 | Tesla | Tesla Model 3 |
| 2018 | Worldwide | The number of electric cars worldwide passed the 5 million marks |
| 2018 | IONITY Net | Opening of the first IONITY station, a high-power charging network established by Volkswagen Group, BMW Group, Daimler AG, and Ford Motor Company |
| 2019 | Porsche | Porsche Taycan – acceleration to 100 km/h in 2.8 seconds |
| 2020 | Mazda | MX-30 – range 200 km |
| 2021 | Mercedes | Mercedes EQS – range 700 km |
| 2022 | Worldwide | 72 electric car models |

The development of electric vehicles is about developing batteries for electric cars, and demand for EV batteries is forecast to increase fivefold in the next 20 years. Currently, the most prominent players in this market are China, Japan, Korea, and the US. It is in these countries where the top electric car battery companies Panasonic, LG Chem, Samsung, Beijing Pride Power, SB LiMotive, and Tesla are located.

From a consumer point of view, one of the greatest choice determinants in any purchase is comparative cost. In the case of EVs, the vehicle's most expensive component is the battery or, more correctly, the electrical energy storage system, as there may be multiple types of energy storage devices in a single vehicle (Berckmans *et al.*, 2017; Horn, *et al.*, 2019). The battery accounts for more than 30% of the value of a car. This is due to the price of the elements needed to build batteries, such as lithium, nickel, cobalt, and magnesium. The very high purchase price of EVs compared to combustion engine vehicles is a barrier to consumers with lower incomes (Biresselioglu *et al.*, 2018; Degirmenci & Breitner, 2017). It is, therefore, clear that the cost per unit of energy in batteries will have a critical impact on the EV market. We should expect a further decline in the cost of batteries, which will stimulate EV production due to the economy of scale. At the same time, ICV's market share will be reduced as the return on investment in this sector drops (Horn *et al.*, 2019). Another critical issue affecting consumer choice regarding EVs is their range (Biresselioglu *et al.*, 2018; Degirmenci & Breitner, 2017). Extending the range requires more energy to be stored, increasing cost, size, and weight. In addition, the range, speed, and availability of charging are essential from the consumer's perspective.

Refuelling petrol tanks takes only a few minutes and petrol stations are easily accessible. For EVs, this is still a challenge. The Nissan Lea has a fast-charging option, with a charging time of 30 minutes instead of 8 hours but this is still six times longer than in the case of ICVs. An extensive charging infrastructure for electric cars is also necessary. Customers do not want to make their travel route dependent on the location of the charging stations (She *et al.*, 2017). It can be assumed that developing countries with poor infrastructure and under-investment in public transport will have a higher number of cars per capita. As previous research suggests, price and range are the main predictors of EV purchase (Degirmenci & Breitner, 2017; Mersky *et al.*, 2016; Rezvani, *et al.*, 2015). In these countries, there may be less interest in electric cars due to the high costs of electric cars and insufficient infrastructure of charging stations.

Motivating factors to buy electric cars may include environmental benefits (Bobeth & Kastner, 2020; Degirmenci & Breitner, 2017; Mersky *et al.*, 2016), economic benefits, such as savings per kilometre (Biresselioglu *et al.*, 2018), and political support for promoting these vehicles, e.g., tax subsidies and reductions. Furthermore, consumer education as a public policy strategy is cited for improving knowledge and facilitating EV purchasing decisions (Bobeth & Kastner, 2020). It can be implied that the number of electric cars will increase in developed countries where environmental awareness is more significant.

### 2.3. EU policy and its trends

Reducing $CO_2$ emissions is one of the priorities for the EU. Both legislators and environmental advocacy organisations are working on regulatory changes that will unify and accelerate changes in environmental solutions. In order to reduce the emission of greenhouse gases, European countries have set targets for energy consumption efficiency and widespread use of renewable energy sources (RES). The transport sector is the primary consumer of petroleum products and accounts for about 25% of total energy consumption (European Commission, 2021). The European Parliament endorsed the net-zero greenhouse gas emissions objective in its resolution on climate change in March 2019 and its resolution on the European Green Deal in January 2020. These will make Europe the first climate-neutral continent by 2050. This means a 90 % reduction in transport-related greenhouse gas emissions is needed by 2050.

The European Commission has adopted a package of legislative proposals to adapt the EU's climate, energy, transport, and taxation policies to reduce net greenhouse gas emissions by at least 55% by 2030 compared to 1990 levels. Sustainable transport strategy calls for a 55% reduction of emissions from cars by 2030, a 50% reduction of emissions from vans by 2030, and 0 emissions from new cars by 2035. The Commission also promotes the growth of the market for zero- and low-emission vehicles by ensuring the infrastructure that can charge EVs. EU Member States will have to meet a requirement to increase charging capacity in proportion to sales of zero-emission cars and to install charging and refuelling points on major motorways at regular intervals: every 60 km for electric charging and every 150 km for hydrogen refuelling. Moreover, starting in 2026, road transport will be covered by emissions trading, putting a price on pollution, stimulating cleaner fuel use, and re-investing in clean technologies (European Commision, 2019).

Euro emissions standards set the emission limit for new cars within the EU and the European Economic Area. The standards have the aim of reducing the emissions of the following harmful chemicals into the atmosphere: carbon monoxide (CO), oxides of nitrogen ($NO_x$), hydrocarbons (THC), particulates (P), and volatile organic compounds (VOC). The first emission standards were introduced in 1993. Since then, due to the development of internal combustion engines, the average emissions have changed significantly, and standards have gradually become more restrictive. Subsequent limits set the direction for manufacturers and imposed new requirements. From 2017, every model must be evaluated for actual values on the road and not only under laboratory conditions. Table 3 presents Euro emission standards.

**Table 3.** Euro emissions standards for passenger cars

| Emission standard | Date (type approval) | Date (first registration) | CO | THC | VOC | NOx | HC+NOx | P | PN [#/km] |
|---|---|---|---|---|---|---|---|---|---|
| Diesel | | | | | | | | | |
| Euro 1 | Jul 1992 | Jan 1993 | 2.72 (3.16)* | – | – | – | 0.97 (1.13) | 0.14 (0.18) | – |
| Euro 2 | Jan 1996 | Jan 1997 | 1.0 | – | – | – | 0.7 | 0.08 | – |
| Euro 3 | Jan 2000 | Jan 2001 | 0.66 | – | – | 0.50 | 0.56 | 0.05 | – |
| Euro 4 | Jan 2005 | Jan 2006 | 0.50 | – | – | 0.25 | 0.30 | 0.025 | – |
| Euro 5a | Sep 2009 | Jan 2011 | 0.50 | – | – | 0.180 | 0.230 | 0.005 | – |
| Euro 5b | Sep 2011 | Jan 2013 | 0.50 | – | – | 0.180 | 0.230 | 0.0045 | $6\times10^{11}$ |
| Euro 6b | Sep 2014 | Sep 2015 | 0.50 | – | – | 0.080 | 0.170 | 0.0045 | $6\times10^{11}$ |
| Euro 6c | – | Sep 2018 | 0.50 | – | – | 0.080 | 0.170 | 0.0045 | $6\times10^{11}$ |

*Continuation of Table 3*

| Emission standard | Date (type approval) | Date (first registration) | CO | THC | VOC | NOx | HC+NOx | P | PN [#/km] |
|---|---|---|---|---|---|---|---|---|---|
| Euro 6d-Temp | Sep 2017 | Sep 2019 | 0.50 | – | – | 0.080 | 0.170 | 0.0045 | $6\times10^{11}$ |
| Euro 6d | Jan 2020 | Jan 2021 | 0.50 | – | – | 0.080 | 0.170 | 0.0045 | $6\times10^{11}$ |
| Petrol | | | | | | | | | |
| Euro 1[b] | July 1992 | Jan 1993 | 2.72 (3.16) | – | – | – | 0.97 (1.13) | – | – |
| Euro 2 | Jan 1996 | Jan 1997 | 2.2 | – | – | – | 0.5 | – | – |
| Euro 3 | Jan 2000 | Jan 2001 | 2.3 | 0.20 | – | 0.15 | – | – | – |
| Euro 4 | Jan 2005 | Jan 2006 | 1.0 | 0.10 | – | 0.08 | – | – | – |
| Euro 5a | Sep 2009 | Jan 2011 | 1.0 | 0.10 | 0.068 | 0.060 | – | 0.005 | – |
| Euro 5b | Sep 2011 | Jan 2013 | 1.0 | 0.10 | 0.068 | 0.060 | – | 0.0045 | – |
| Euro 6b | Sep 2014 | Sep 2015 | 1.0 | 0.10 | 0.068 | 0.060 | – | 0.0045 | $6\times10^{11}$ |
| Euro 6c | – | Sep 2018 | 1.0 | 0.10 | 0.068 | 0.060 | – | 0.0045 | $6\times10^{11}$ |
| Euro 6d-Temp | Sep 2017 | Sep 2019 | 1.0 | 0.10 | 0.068 | 0.060 | – | 0.0045 | $6\times10^{11}$ |
| Euro 6d | Jan 2020 | Jan 2021 | 1.0 | 0.10 | 0.068 | 0.060 | – | 0.0045 | $6\times10^{11}$ |
| Petrol and diesel | | | | | | | | | |
| Euro (proposed) | 2025 | 2025 | 0.1 to 0.3 | | | 0.030 | | | |

Values in parentheses are conformity of production (COP) limits.

Source: Council Directive 91/441/EEC, Directive 98/69/EC of the European Parliament and the Council, Council Directive 93/59/EEC, Directive 94/12/EC of the European Parliament and the Council, Directive 96/69/EC of the European Parliament and the Council, Commission Directive 2002/80/EC, Regulation (EC) No 715/2007 of the European Parliament and the Council, Commission Regulation (EU) No 459/2012, Commission Regulation (EU) 2016/646.

The Euro 7 standard is planned for 2025, but its stringent requirements should be relaxed. As proposed, the regulations completely excluded cars with internal combustion engines from production – Europe is not yet ready for such changes, especially in trucking.

### 2.4. Prognoses for the future

Care for the environment is the driving force behind the development of zero-emission energy. Even by combining different technologies in the search for innovative solutions with the support of regulatory requirements, the chance of achieving zero emissions by 2050 is slim. Still, any approach closer to zero will be a success. This brings us nearer to our ultimate goal of sustainable development. The concept of sustainability first appeared in the Report of the World Commission on Environment and Development: Our Common Future Towards Sustainable Development (1987). The UN clarified the concept of sustainable development in 2015 by establishing the 17 Sustainable Development Goals – the Global 2030 Agenda that guides action for governments and societies.

From the perspective of the further development of the passenger car sector, two goals are particularly relevant. These are Goal 7: Energy – to ensure access to sources of stable, sustainable, and modern affordable energy for all by 2030 and Goal 11: Cities – to make cities and human settlements safe, stable, sustainable, and inclusive. Goal 11 target 2 includes a specific objective – by 2030, to ensure that all people have access to safe, affordable, sustainable, and accessible transport systems, improve road safety, especially through the development of public transport, paying particular attention to the needs of vulnerable groups, women, children, people with disabilities and the elderly. As any action impacts other sectors of the economy, sustainable development characteristics can be expected to shape any trends. Most planned policies and measures in the transport sector focus on promoting low-carbon fuels or electric cars and encouraging a modal shift to public transport (EEA, 2021).

Delivering sustainability will require innovations that address the existing disadvantages of electric cars. The trends from which we can expect the development of electric vehicles are presented below.

[1] Charging the car while driving or parking directly from the roadway. This is one of the solutions offered by the Israeli company Electreon. This innovative start-up plans to build a road in the USA that will also function as a wireless charger. The principle is similar to charging smartphones via an induction pad. Special coils will be placed on the road surface, which will trigger charging when they connect to a receiver in an electric car and replenish the battery. When the receiver does not touch the coil, it will be unusable, i.e., the road will be just a road as before.

[2] Use of domestic green electricity generators for car charging. Photovoltaics is currently the most popular solution for domestic energy generation. Other domestic power generators, such as bio-waste processing, are being developed (Danielis *et al.*, 2022). This is one of the solutions being tested. More

should be developed by 2050. However, there is a danger of using the power grid, which might not be able to withstand such a load when many people use car charging in this way. The power grid was not designed for such use, and excessive loading could cause a blackout.

[3] Recycling of car batteries. Batteries will become increasingly efficient, and end-of-life processing is fundamental to sustainable transport, as the current supply of elements needed to build batteries for cars is also limited. We cannot deplete further resources; thanks to technology, solutions must be found to recycle in a closed cycle. The change in how batteries work will change the attitude of those who are still sceptical of new transport solutions. Furthermore, it is estimated that the price of lithium-ion batteries, which today cost around US$110/kWh, will be around USC 45/kWh in 2035 (Hemavathi & Shinisha, 2022).

[4] Reducing charging times. The new technology of supercapacitors is expected to make future charging a matter of minutes rather than hours (Horn *et al.*, 2019). One of the more advanced batteries that are fitted to cars is the BMW iX3, where the charging time is 10 minutes for every 100 km. The car maintains a range of 460 km at 286 hp.

[5] Level 5 of autonomous vehicles, i.e., driverless vehicles. Vehicles operated by artificial intelligence can safely travel closer together, and this may lead to a reduction in congestion, higher road capacity and greater overall efficiency, as well as increased travel comfort through reduced noise. Today's new cars have Level 3 of autonomy, which makes driving easier, but does not yet allow the systems to take over control completely.

[6] Co-sharing. Electric autonomous vehicles will also change the approach to ownership, turning it into co-sharing. In general, autonomous vehicles and smart devices will benefit from 5G mobile technology, transmitting data to the Internet of Things (IoT), enabling devices to communicate and act harmoniously. For example, autonomous vehicles will be able to communicate with each other and other road users (Borghetti *et al.*, 2022; Hensher *et al.*, 2022; Illgen & Höck, 2018; Mounce & Nelson, 2019).

[7] Hydrogen cells. The next trend will be cells in which hydrogen will be turned into electricity without a large and heavy battery. Furthermore, there will be no $CO_2$ coming out of the exhaust system – just steam. Currently, hydrogen cars are already on the market, and so, for example, the Toyota Mirai is based on the cooperation of hydrogen cells and an electric motor. Californian company SunHydrogen offers cutting-edge solutions in the form of the HyperSolar $H_2$ Generator, which uses a solar-powered particle system to deliver hydrogen from sunlight and water (Wilberforce *et al.*, 2017)

[8] Hyperloop. This is a concept proposed by Elon Musk, but its foundations go back much earlier. In 1825, the London and Edinburgh-based Vacuum Tunnel Company produced the idea of how to eliminate speed limits for high-speed trains. The trains were to be placed in tubes where there would be no air resistance (Fernandez Gago & Perez-Seoane, 2021; Museros *et al.*, 2021).

[9] Elon Musk significantly improved this design and assumed that the Hyperloop would reach the speed of sound, 1224 km/h. Dutch start-up Hardt Hyperloop is working on this form of transport, and by 2028 their delivery train is expected to reach 700 km/h. This is not a dizzying speed, as we already have magnetic trains in Japan that run at 600 km/h without the costly infrastructure that Hyperloop requires (Fernandez Gago & Perez-Seoane, 2021).

The future certainly belongs to clean energy, which will power our vehicles and make use of artificial intelligence and the Internet of Things. What we already know in theory requires a lot of research and testing to make the ideas implementable and safe. In addition to technology, we also need regulations and the favour of the European Union countries and the world. Regulators are playing a significant role in the massive development of electric cars. France, the UK, Germany, and India have already announced that they will completely phase out the sale of petrol and diesel cars between 2025 and 2050.

## 3. Methods and data

The European Union's statistical office, Eurostat, provides substantial information on general trends and differences between specific European Union countries in their approaches to low-carbon transportation. Changes in the fleet, whether cars, trucks or public transport, are driven by several social and economic factors, as well as by European Union and national policies. Low- or zero-emission transport is inextricably linked to renewable energy sources and environmental and climate protection (see Section 2).

In the study, the authors classified EU countries into four groups. The classification of countries into four groups applied in the study was based on the value of Gross Domestic Product (GDP) per capita in Purchasing Power Standards (PPS) and the value of the Human Development Index (HDI) published by the United Nations Development Program (UNDP). According to the classification based on the HDI, very highly developed countries have the highest income indicators and the highest GDP per capita. High-

income levels undoubtedly result in greater flexibility in the choice of technical parameters in purchasing a new car.

The classification:

- group I: very highly developed countries (GDP per capita PPS > 24.5 thousand Euro, HDI > 0.86) with a large area (above 300 thousand km$^2$): France, Germany, Italy, Poland, and Spain,
- group II: very highly developed countries (GDP per capita PPS > 24.5 thousand Euro, HDI > 0.86) with a small area (below 300 thousand km$^2$): Austria, Belgium, Cyprus, Czech Republic, Denmark, Estonia, Greece, Ireland, Lithuania, Luxembourg, Malta, Netherlands, and Slovenia,
- group III: highly developed countries (GDP per capita PPS < 24.5 thousand Euros, HDI < 0.86): Bulgaria, Croatia, Hungary, Latvia, Portugal, Romania, and Slovakia,
- group IV: Scandinavian countries with a large area: Finland and Sweden.

Data from Eurostat, the European Automobile Manufacturers' Association (ACEA) and the European Environmental Agency (EEA) were used for the analysis. The data covered EU countries in terms of the number of passenger cars per 1,000 inhabitants, GDP in the EU, number of electric cars, percentage of electric car passengers among all passengers, population density, share of renewable energy in transport per country, gender and renewable energy sources, gender and used electric cars. The data was then spatially analysed in terms of the countries analysed and the ratios. Furthermore, later presented on choropleth maps.

## 4. Real EU trends in passenger cars by type

### 4.1. An overview of passenger cars in the EU

More than 11.5 million cars were registered in the EU in 2021. Table 4 provides a detailed overview of the number of vehicle registrations (per vehicle type; cars, vans, trucks, and buses) for each European country, covering the 26 EU member states, Iceland, Norway, Switzerland, and the United Kingdom. The largest number is in France, Germany, and the United Kingdom.

**Table 4.** Motor vehicles registrations in 2021 in the EU, by country, and by vehicle type

| Country | Cars | Vans | Trucks | Buses | TOTAL |
|---|---|---|---|---|---|
| Austria | 239,803 | 58,806 | 6,680 | 887 | 306,176 |
| Belgium | 383,123 | 71,562 | 8,179 | 945 | 463,809 |
| Bulgaria | 24,537 | 6,659 | 3,073 | 203 | 34,472 |
| Croatia | 44,915 | 7,958 | 1,284 | 119 | 54,276 |
| Cyprus | 10,624 | 1,938 | 83 | 20 | 12,665 |
| Czech Republic | 206,876 | 19,660 | 8,679 | 1,006 | 236,221 |
| Denmark | 185,324 | 31,588 | 4,389 | 636 | 221,937 |
| Estonia | 22,336 | 4,142 | 772 | 269 | 27,519 |
| Finland | 98,481 | 12,893 | 3,536 | 382 | 115,292 |
| France | 1,659,003 | 431,385 | 45,030 | 6,857 | 2,142,275 |
| Germany | 2,622,132 | 265,732 | 78,981 | 6,474 | 2,973,319 |
| Greece | 100,916 | 10,426 | 568 | 454 | 112,364 |
| Hungary | 121,920 | 22,981 | 4,476 | 1,010 | 150,387 |
| Ireland | 104,669 | 28,741 | 2,272 | 444 | 136,126 |
| Italy | 1,457,952 | 183,093 | 24,807 | 3,495 | 1,669,347 |
| Latvia | 14,344 | 2,530 | 1,392 | 209 | 18,475 |
| Lithuania | 31,371 | 3,363 | 7,976 | 137 | 42,847 |
| Luxembourg | 44,372 | 4,560 | 1,054 | 167 | 50,153 |
| Netherlands | 322,831 | 68,443 | 11,744 | 338 | 403,356 |
| Poland | 446,647 | 73,926 | 32,684 | 1,356 | 554,613 |
| Portugal | 146,637 | 28,790 | 4,264 | 586 | 180,277 |
| Romania | 121,208 | 16,168 | 5,889 | 715 | 143,980 |
| Slovakia | 75,700 | 8,252 | 2,868 | 529 | 87,349 |
| Slovenia | 53,988 | 9,687 | 1,925 | 98 | 65,698 |
| Spain | 859,477 | 151,904 | 20,801 | 1,877 | 1,034,059 |
| Sweden | 301,006 | 36,238 | 5,910 | 728 | 343,882 |
| EUROPEAN UNION | 9,700,192 | 1,561,425 | 289,316 | 29,941 | 11,580,874 |
| Iceland | 12,755 | 1,162 | 274 | 30 | 14,221 |
| Norway | 176,276 | 34,070 | 6,035 | 1,083 | 217,464 |
| Switzerland | 238,481 | 29,375 | 3,565 | 646 | 272,067 |
| EFTA | 427,512 | 64,607 | 9,874 | 1,759 | 503,752 |
| United Kingdom | 1,647,181 | 355,380 | 42,372 | 4,097 | 2,049,030 |
| EU + EFTA + UK | 11,774,885 | 1,981,412 | 341,562 | 35,797 | 14,133,656 |

Source: The automobile industry, pocket guide 2022/2023: www.acea.auto/files/ACEA_Pocket_Guide_2022-2023.pdf

However, considering all EU residents and passenger cars registered in the EU, the rate of cars per 1,000 residents is 554 (Figure 1). The first group has the highest mean number of cars per capita (592 cars per 1,000 people). Italy and Poland are the ranking leaders, with rates of 668 and 644 cars per 1,000 residents, respectively. In countries with large areas, public transportation is not always sufficiently developed. Hence, to facilitate daily travel to the workplace or school, citizens are determined to have at least one or more cars in the household. A dense transportation network is easier to build and maintain in a smaller area, especially if the population density is higher. The problem of access to public transportation seems to be much smaller in the case of countries classified in the study as the second group. This is one of the reasons why the ratio of passenger cars per capita in these countries is lower; the mean is 429 cars per 1000 residents. This indicator in some countries significantly deviates from the group mean. In Luxembourg, for example, it is 672.

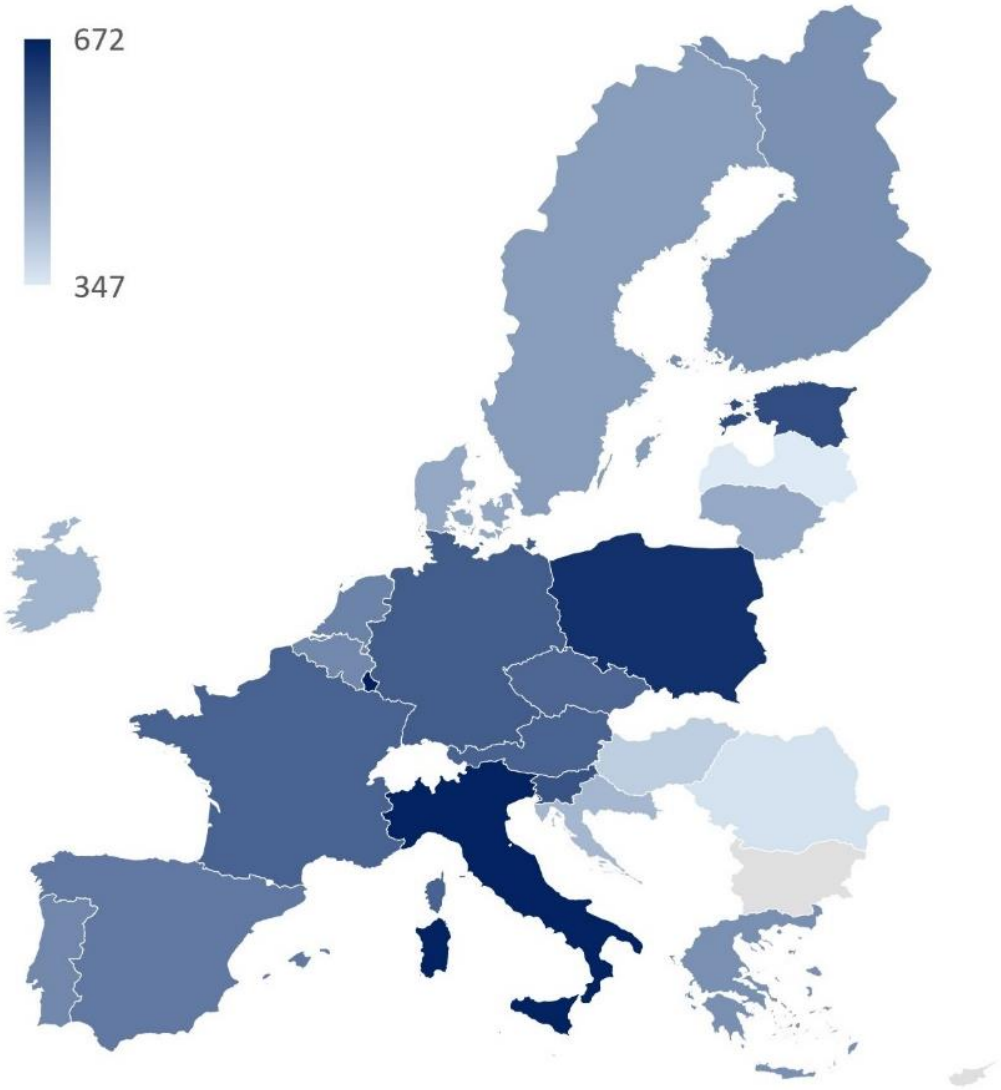



*Figure 1.* Number of passenger cars per 1000 citizens

The determinants of such a high ratio are undoubtedly the wealth of the population. Luxembourg is the wealthiest country in the European Union in terms of macroeconomic parameters per capita (Figure 2). Residents of countries included in the third category have far fewer vehicles – the mean for this group is 438 cars per 1,000 residents. One of the main reasons seems to be the level of household wealth. The large Scandinavian countries are included in a separate fourth group due to the much higher environmental awareness of residents and decision-makers than the rest of Europe. Finland and Sweden have an average of 478 cars per 1,000 residents.

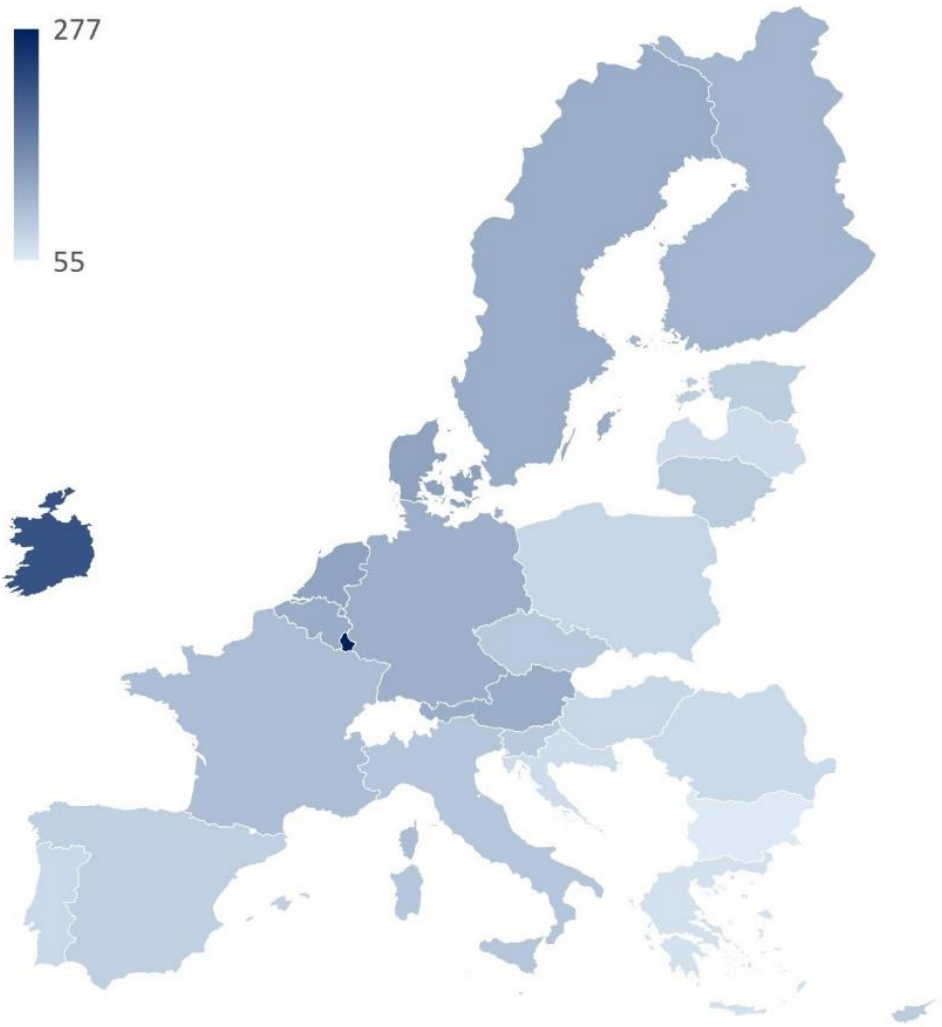



*Figure 2.* The GDP in PPS of EU countries. The volume index is expressed with reference to the European Union average set at 100

### 4.2. Types of car engines in EU countries

The effects of policies intensively promoting and supporting low- and zero-emission transportation are reflected in the use of renewable energy in transportation (Figure 3). Among electric vehicles, which are seen as an essential component of climate change mitigation strategies, two major groups can be identified: plug-in hybrid electric vehicles (PHEVs) and battery electric vehicles (BEVs). The PHEVs are powered by conventional internal combustion engines and electromotors that use energy from batteries in the vehicle. The BEVs are powered only by electromotors using electricity stored in the batteries in the vehicle. In both types of EVs, the batteries can be recharged from the power grid at home or a charging station. Due to their higher price, cars with such engines may not be accessible to lower-income households. Countries in Group 1 significantly different shares of EVs, depending on the residents' wealth, the policies pursued to develop the electric car market, and the environmental awareness of society. This group's average share of electric and plug-in hybrid cars is 7.07%. In individual countries, these values vary and are at the following levels: Poland – 1.87%, Italy – 4.32%, Spain – 4.52%, France – 10.87%, and Germany – 13.89%. In countries classified in Group 2, the average share of BEVs and PHEVs passenger cars in the fleet is 7.91%. This also varies significantly among countries. The lowest share is in Cyprus (0.59%) and the highest in the Netherlands (27.53%). In countries from Group 3, the average share of EVs is much lower: 4.54%. However, except for Portugal (13.63%) and Hungary (4.85%), the share oscillates around 2–3%. The statistics for Group 4 countries are different. The share of EVs has already exceeded one-fourth of the total passenger car market – 25,66% (Figure 3 and Figure 4). An additional factor determining the popularity of low-emission cars in Scandinavian countries are national and local policies and programs,

e.g., limiting the movement of internal combustion cars in city centres, a system of subsidies, and tax exemptions for the purchase of new cars with eco-friendly engines. An important role in shaping the automotive market is played not only by the level of affluence of society but also by public education focused on increasing environmental awareness. Consumers' green self-identity is built through the development of social and environmental awareness. Barbarossa showed that environmental self-identity positively and considerably influences consumers' intention to use electric cars. This impact can be direct or through environmental concern and moral obligation (Barbarossa *et al.*, 2017). A reflection of the public's green self-identity and state policies supporting the growth of the EV fleet can undoubtedly be found in the statistics for the Scandinavian countries.

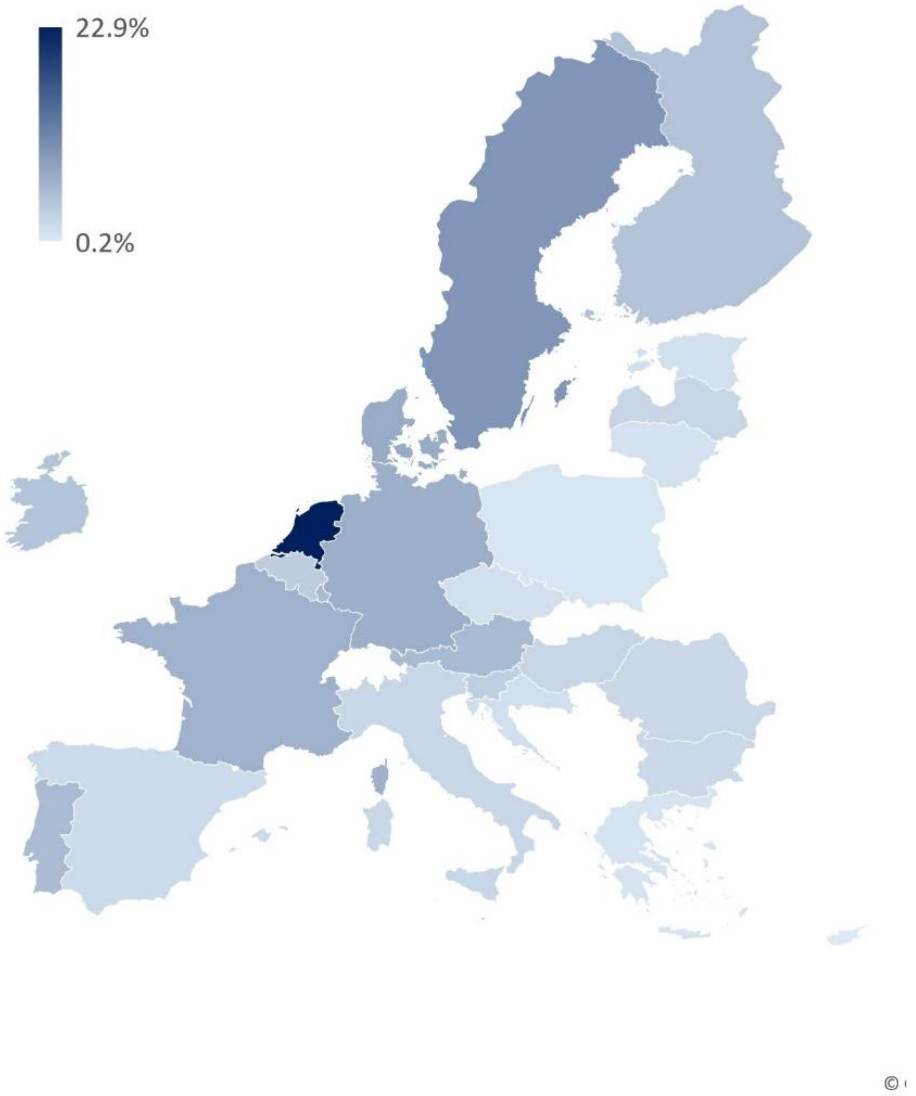



*Figure 3.* Percentage of BEVs among all registered passenger cars

Individual choices of passenger car users in Finland and Sweden are strongly polarised toward hybrid cars (Figure 4). In Sweden, PHEVs represent 22.96% of the passenger car fleet, while the BEV share is 9.69% of the fleet. In Finland, PHEVs have also become more popular (14.13% fleet share) than BEVs (4.53% fleet share) (Figure 3 and Figure 4). The much higher popularity of PHEVs in Sweden and Finland may be a consequence of the low population density and long distances between urban centres. The range of PHEVs is much greater than that of standard BEVs. Existing battery technologies allow for increasing the range of private vehicles to about 480 kilometres, while the range of typical BEVs with medium-level batteries is less than 260 kilometres (Shi *et al.*, 2019). It seems that in small countries, the difference in range is not that significant.

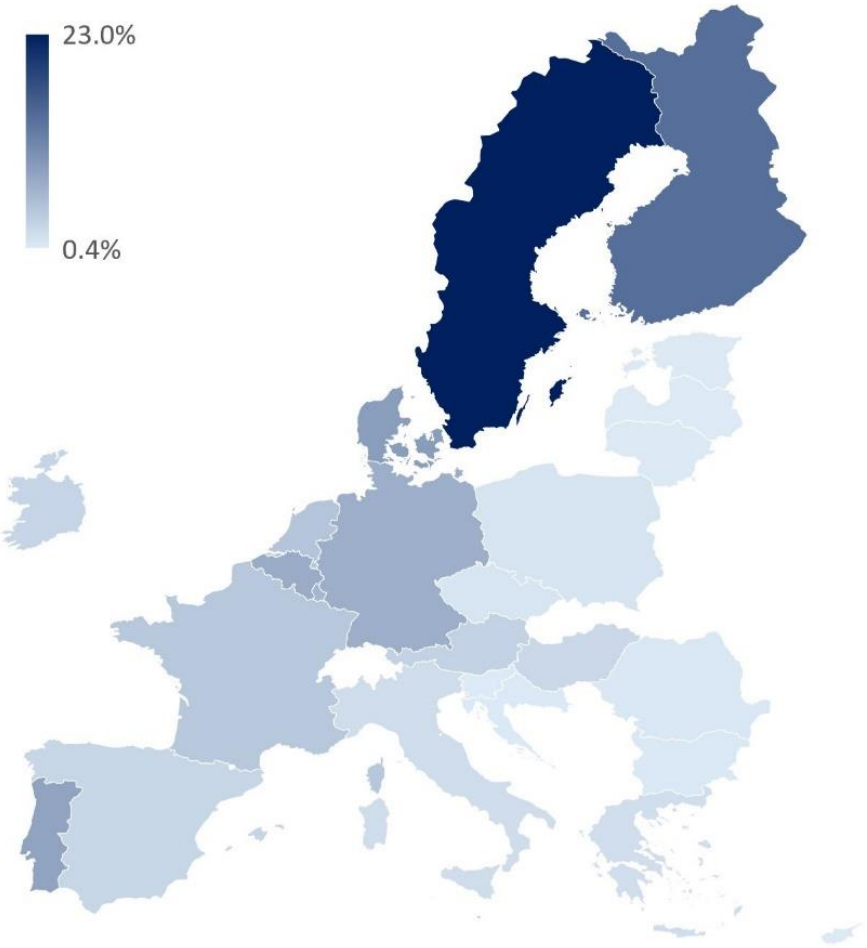



*Figure 4.* Number of PHEVs among all registered passenger cars

However, data from two Scandinavian countries that are not part of the EU are worth mentioning:: Norway and Iceland. Both countries' electric cars are much more prevalent than those in the EU. Battery electric cars predominate with 54.37% and 25.44% of fleet share in Norway and Iceland, respectively. The share of PHEVs is 20.50% and 20.10% in Norway and Iceland, respectively. Since electric cars have low-noise engines, use less gasoline, and emit fewer emissions than conventional fossil-fuel cars, they are socially considered environmentally friendly. In response to public demand, both countries have implemented several solutions to facilitate and support the transformation of automobile transportation. Although Norway has oil fields, the country leads the world in car electrification. The Norwegian tax system heavily influences the purchase of electric vehicles. Through the tax system and other incentives, the Norwegian government is significantly influencing the lowering of EV purchase costs and increasing the purchase and operating costs of fossil-fuel cars. EVs are not charged for driving through the city centre or parking in public places and can be charged for free at public charging stations. Electric cars can also move through bus lanes during rush hour (Figenbaum & Kolbenstvedt, 2015). Iceland is a country with abundant renewable energy resources. Therefore, electric vehicles can be powered by affordable and accessible electricity from renewable sources, geothermal, hydro, and wind. Among other initiatives, a system of fiscal incentives, including tax exemptions and emission-differentiated vehicle taxes, has been introduced in Iceland to promote EV purchases (Shafiei *et al.*, 2018).

In summary, automotive trends might be correlated to five main factors:

- the wealth of the citizens,
- level of society’s environmental awareness,
- government policies,
- the area of the country,
- population density (Figure 5).

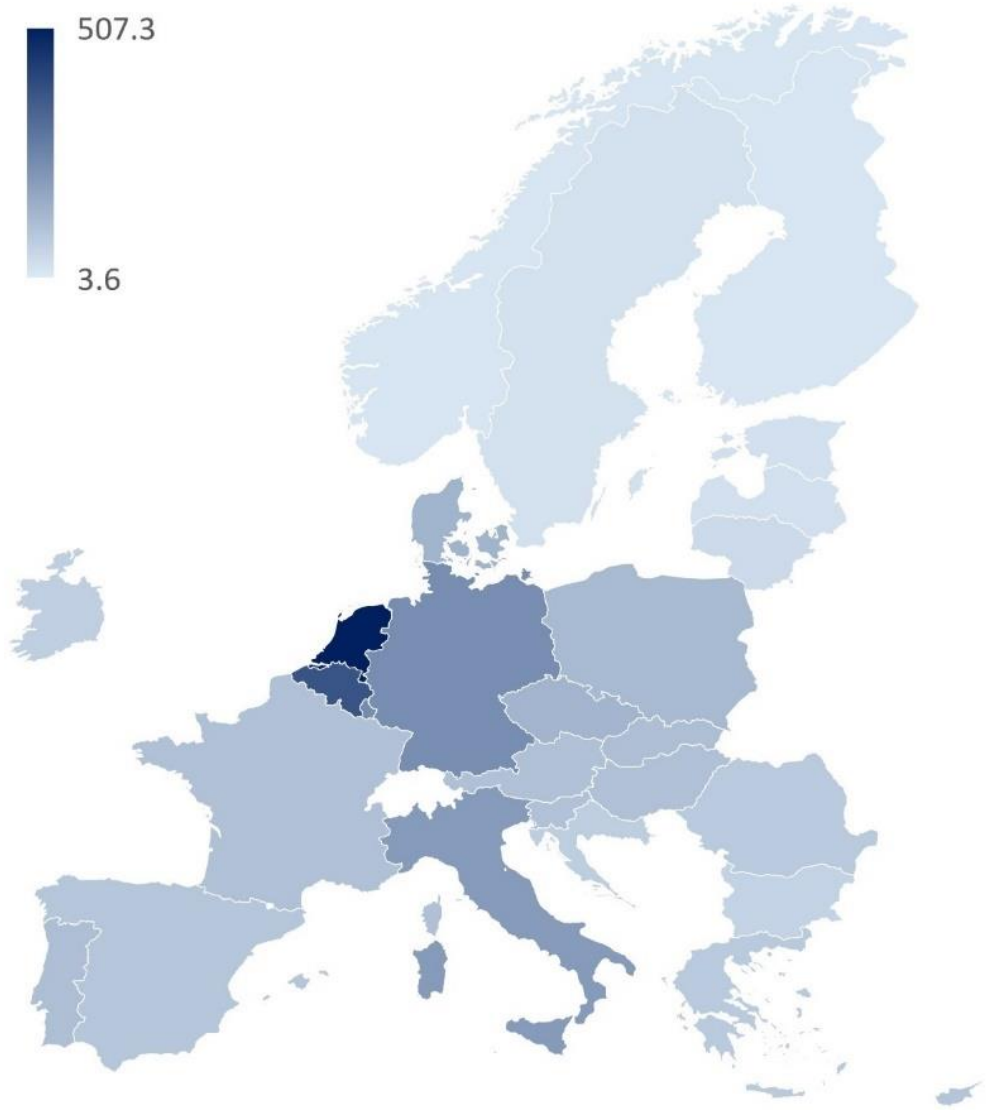



*Figure 5.* European countries by population density (per square km)

Revision of the directive established a common framework for promoting energy from renewable sources in the EU and set a binding target of 32% for the overall share of energy from renewable sources in the EU in 2030 (Zygierewicz & Sanz, 2021). Figure 6 shows the ranked countries by the share of usage of renewable energy in transport in 2020 with the same value as of 2005 for comparison. In 2020, renewable energy sources (RES) in the EU reached 10.2%, which means that collectively EU countries reached the target of 10%, compared to 2% in 2005. In contrast, the predominance of the Scandinavian countries, especially Sweden and Norway, in this comparison is overwhelming compared with other countries and is already over 30%. However, several rich Western European countries, led by Germany and Denmark, are below the 10% threshold. At the bottom of the list are Greece and the Central and Eastern European countries admitted to the EU at the beginning of the 21st century.

The authors also tried to find a correlation between the volume (share) of renewable energy sources in transport and the gender gap. The gender pay gap is the difference between male and female employees' average, gross, and hourly earnings. Figure 7 shows the gender gap and renewable energy in transport for the analysed countries. There is no spatial correlation between the gender gap for EU countries. For example, the gender gap is almost zero in Greece, Ireland, and Luxembourg, while the biggest gap is in Austria, Estonia, and Latvia, followed by Germany. Similarly, when comparing the two values above, no correlation between them is shown. The size of renewable energy sources is more a function of the population's wealth, not of the gender pay gap.

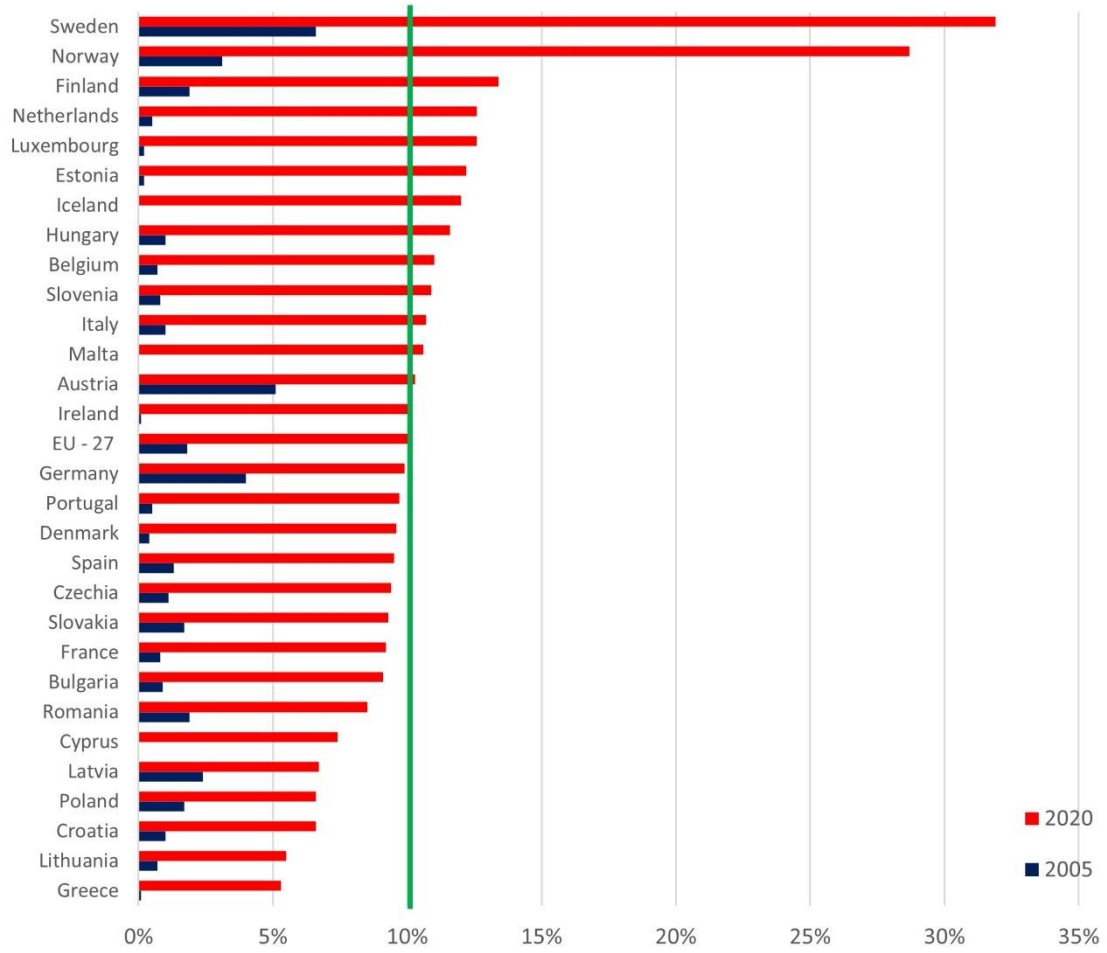



*Figure 6.* Country ranking in terms of the share of energy from renewable sources used in European transport

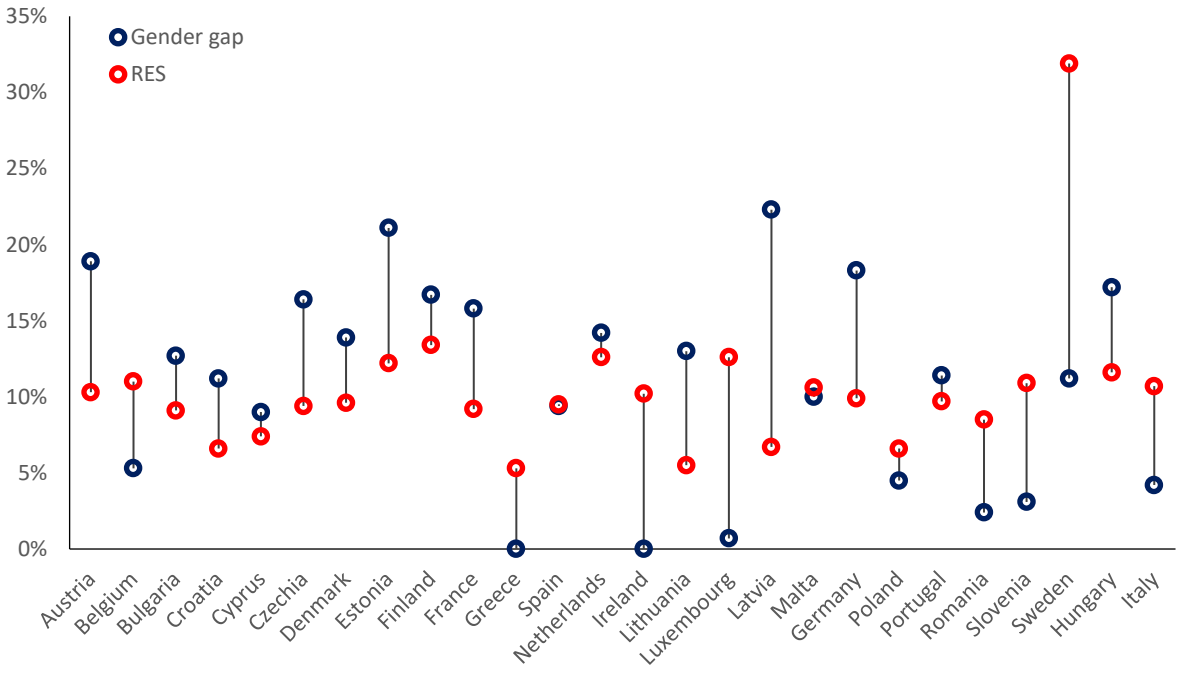



*Figure 7.* Gender gap and renewable energy sources (RES) in transport

Similar analyses were conducted for the gender gap and renewable energy sources in the overall economy (Figure 8). There is no correlation between these values, but for some countries, a large gap between the share of green energy and the share of green energy in transport should be noted. For example, in Austria, Latvia, and Portugal, renewables account for more than 30% of the energy market but less than 10% of transport.

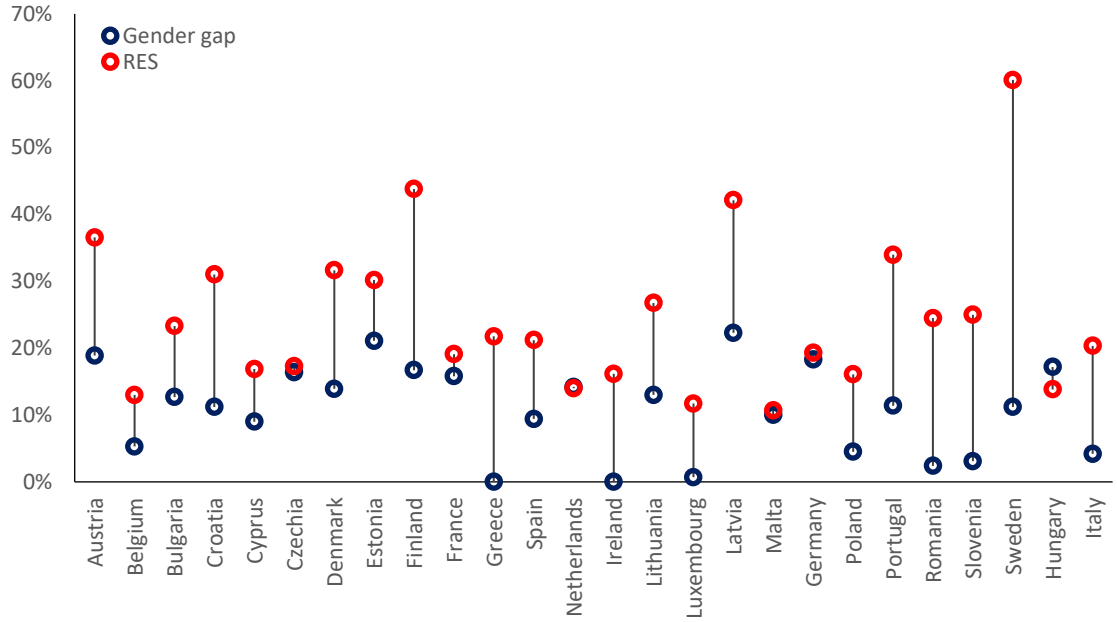



*Figure 8.* Gender gap and renewable energy sources (RES)

Figure 9 shows the percentage of the gender gap and electric cars in the total number of passenger cars in a country.

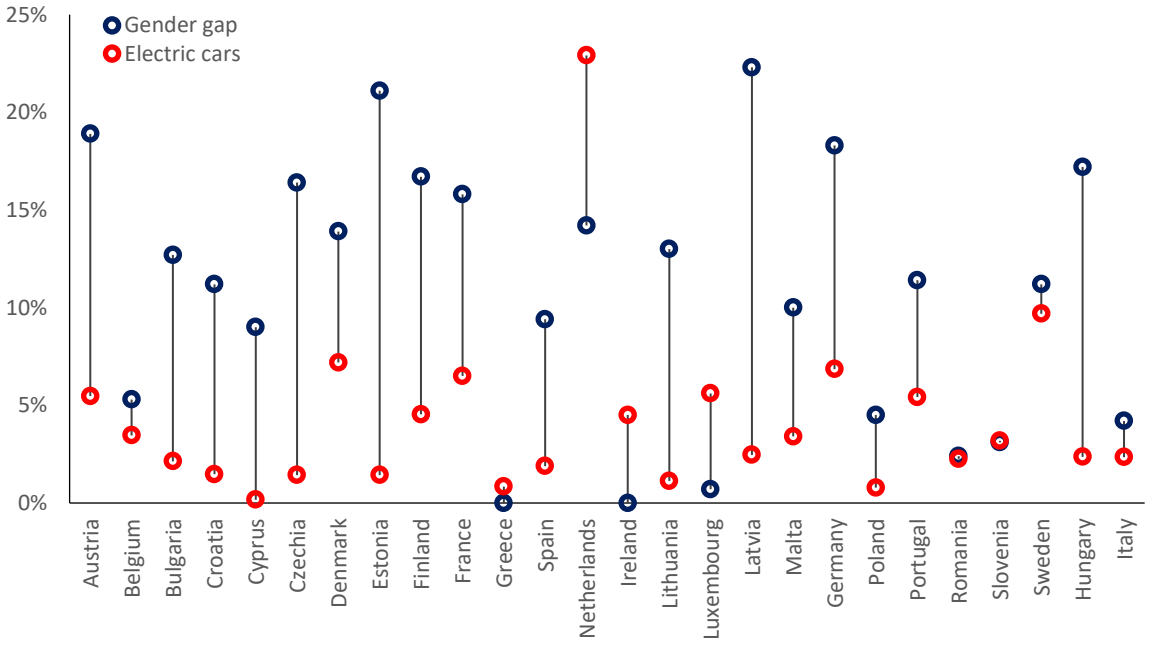



*Figure 9.* Gender gap and electric cars

So far, only in the Netherlands does the number of electric cars exceed 20%, which is due to the legal regulations in this country encouraging the use of this type of drive and not directly to the awareness of the population. Countries with the lowest GDP per capita have the lowest number of electric cars. No correlation was found between the gender gap and the number of electric cars in the countries analysed.

## 5. Discussion and Conclusion

Looking back, history has come full circle concerning electric cars. The first cars were powered by electric motors, which, over time, were replaced by cars with internal combustion engines. Now, electric cars are replacing petrol cars. The reason for this phenomenon is not only the fact that modern electric cars are characterized by the same performance (acceleration and distance) as petrol cars but that these cars are perceived as ecological and without emissions into the atmosphere, which is one of the EU's priorities.

As a part of the implementation of the European Green Deal, it was assumed that by 2050 Europe will be the first climate-neutral continent, and this is related to activities aimed at reducing greenhouse gas emissions to the atmosphere. The transport sector is responsible for approximately 25% of total greenhouse gas emissions in EU countries. It can be assumed that replacing petrol cars with electric cars will reduce greenhouse gas emissions.

The conclusions from the research and analyses presented above are a significant contribution to the scientific area devoted to the impact of transport on the natural environment and carbon footprint, allowing the following conclusions to be drawn:

[1] All automotive companies conduct research and development work on electric cars, which are increasingly replacing car models with internal combustion engines. Therefore, it can be assumed that over time (it is difficult to define the exact time period), electric cars will completely replace cars with internal combustion engines;

[2] The increasing share of electric cars in the total number of vehicles will also be the result of the regulations introduced by the EP regarding road transport in terms of emissions trading, changes in $CO_2$ emission standards, or alternative fuels infrastructure;

[3] Currently, the European countries with the largest number of registered cars include France, Germany, Italy, and Poland. The large number of cars in the top four countries results from the size of a given country and poorly developed public transport infrastructure, which encourages having one's own means of transport. Additionally, in the case of Poland, ownership of a means of transport is still perceived as a symbol of a certain status, which is why it is still an important material asset. However, in the Scandinavian countries, much more developed than Poland, their inhabitants have greater financial possibilities to buy cars, but they were in the last places. This is because these countries have a well-developed public transport infrastructure, making it possible to reach almost any place. Also, high environmental awareness encourages the inhabitants of these countries to decide to use public transport rather than buying their cars. On the other hand, in the case of purchase, electric cars are most often chosen. At the same time, incentives from the government in the form of subsidies for the purchase of electric cars, exemptions from parking fees, the possibility of entering the centre, or the possibility of using bus passes also play a significant role;

[4] 50% of European countries have achieved the goal of renewable energy share in the total energy, while the remaining 50% of countries are still striving to achieve it. It should be noted that the first group of countries includes highly developed countries, such as Austria, Belgium, Finland, Iceland, Italy, Luxembourg, Netherlands, Norway, Slovenia, and Sweden, as well as the developing countries Estonia and Malta. However, the second group of countries that have still not achieved the goal of renewable energy share in the total energy also includes fully developed countries, e.g., Denmark, France, Germany, Greece, Poland, Portugal, and Spain, as well as developing countries, Bulgaria, Croatia, Cyprus, Czech Republic, Latvia, Lithuania, Romania, and Slovakia. It is worth noting that in the first group, Poland is the only country that joined the EU in 2004, being the youngest member. The second group includes those countries that also joined the EU in 2004, 2007, and 2013;

[5] There is no noticeable relationship between the gender gap and renewable energy, the gender gap and renewable energy in transport, or the gender gap and the number of electric cars. Therefore, it can be concluded that the difference between the average gross hourly earnings of female and male employees does not affect the use of renewable energy, renewable energy in transport, or the number of electric cars. In terms of renewable energy in transport, it can be noted that Sweden stands out from the other countries, with an almost 35% share of renewable energy in transport, compared to the 5–15% share in other countries.

The analyses that were conducted do not fully exhaust the topic of trends in road transport, particularly regarding passenger cars. Further important issues to be examined may be the relationships between employment level, GDP per capita, length of highways, level of public transport infrastructure, new car prices, number of enterprises, salary level, and the number of registered electric cars. It is also worth looking at electric cars in terms of battery life during winter periods, which – especially in northern and central Europe – can sometimes be long and cold. However, global warming may eliminate this problem.

## 6. Additional consideration

An critical element is the demonstration of the groups of main polluters. Because as the Transport & Environment Report has shown, in 2017, 203 cruise ships alone emitted about 20 times more sulphur oxide ($SO_X$) along European coasts than all of Europe's 260+ million passenger vehicles (Abbasov *et al.*, 2019). Thus, knowing the seriousness of the pollution of individual transport groups is extremely important. Otherwise, the limited resources at our disposal will be directed towards reducing pollution in a group that obviously causes it, but not in the same quantity as other groups, such as the aforementioned ships. The sustainability lens of green transport, therefore, focuses on creating transportation systems that not only reduce environmental impact but also enhance social inclusivity and economic viability. It involves evaluating transportation systems, technologies, and policies through the prism of environmental (emission reduction, energy efficiency and resource conservation), social (accessibility and equity, safety and health and job creation) and economic sustainability (cost efficiency, innovation and economic growth and reduced externalities).

There is also a need to change the approach to the very nomenclature and terminology so often used and misleading to the public. The best example of this is, for example, 'zero emission cars'. There is no such thing as a zero-emission car. Some convention cars may be 'more' eco-friendly if we look at the product life cycle. For example, according to data from the Trancik Lab at MIT, a Tesla Model S P100D saloon driven in the US Midwest produces 226 grammes of carbon dioxide (or equivalent) per kilometre over its lifecycle – a significant reduction to the 385g for a luxury BMW 7-series. However, the Mitshubishe Mirage emits even less, at just 192g (Miotti, Supran, Kim, & Trancik, 2016). What is more, the lifecycle emissions are directly associated with the country's electricity mix of. When charging the battery of the electric vehicle and producing the battery in countries with "bad" electricity mix, the results clearly showed that a large amount of carbon dioxide was produced. Whilst in countries with "good" electricity mix (like Sweden) the electric vehicle was by far the better alternative compared to the conventional vehicle (Maroof, 2018).

What is more, the changes in attitude towards green energy and the modernisation of existing modes of transport must not only concern the developed countries – rich (compared to other corners of the globe) Europe, which is not so easy to achieve– but above all the countries of the Southern Hemisphere. We need to change our behaviour as a species and act on a planetary scale (Pogge, 2008; Stern, 2007).

Policymakers of highly developed countries need to understand that the Earth's ecosystem is interconnected and that giant investments burdening certain societies with restrictions (e.g. the EU) and leaving poor countries to fend for themselves may not be of much use. Solutions exist (see e.g. Green Impact Found For Technology (Pogge, 2023)), although politicians are reluctant to use them. Moreover, the EU is not covered by a glass dome. In addition, some European countries (by disregarding EU climate policy for many years) may soon find themselves in the tail of the EU. Poland is a perfect example here, which looks to place the blame for high energy prices on the EU and not on its own authorities. Upon joining the EU, Poland knew the climate targets in advance. Thus, the poor energy transition in some EU countries has resulted in the EU's greenhouse gas emission fines being reflected in their energy prices (e.g. Poland), which even the inhabitants of those countries which are better adapted (e.g. France) will not notice.

Moreover, the costs of transformation are always most affected by 'ordinary' people, who often have no influence on the transformation process led by (often irresponsible and populist) governments. On the other hand, European decision-makers overlook the differences that divide European countries (even within the most developed ones). This could consequently lead to changes in public sentiment and the breakdown of relative European unity in the green deal. This is currently the case in the state of Wyoming (USA), where a resolution expressing support for phasing out the sale of new electric vehicles in Wyoming by 2035 (State of Wyoming, 2023).

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