ARCHIVES OF TRANSPORT
Volume 74, Issue 2, 2025

ISSN (print): *0866-9546*
e-ISSN (online): *2300-8830*
DOI: *10.61089/aot2025.whr7qq76*

STANDARDS AND REQUIREMENTS CONCERNING REDUCTION OF CO_2 EMISSION FOR NEW PASSENGER CARS

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Abstract:

Imposed standards and requirements are supposed to make road transport cleaner, to achieve, defined by the European Union (EU), target levels of reduction of emission of greenhouse gasses since 2030 and contribute to achievement of the goals of Paris Agreement. Adopted requirements refer also to CO_2 emission for new passenger cars and new light commercial vehicles (vans). It was adopted that average annual level of CO_2 emission of the EU vehicle fleet, in comparison with 2021, to be reduced both for new passenger cars and new light commercial vehicles by 15 % for the years 2025–2029; 55 % for new cars and 50 % for new light commercial vehicles for the years 2030–2034 and 100 % since January 1, 2035. In 2025, the Commission will present methodology of reporting and assessing data concerning CO_2 emission in the whole life cycle of passenger cars and vans sold on the EU market. Since June 1, 2026, producers may commence data reporting based on this common EU method concerning CO_2 emission in life cycle of a vehicle. The authors of this article presented new regulation specifying the requirements concerning CO_2 emission for new passenger cars and new light commercial vehicles, which should contribute to achievement of EU target levels of reduction of emission of greenhouse gasses. Target individual levels of CO_2 emission for passenger cars in the years 2024-2035 were analysed. For ten most popular passenger cars registered in Poland, an analysis of reduction of level of CO2 emission was conducted in order to determine whether limit of CO_2 emission was increased to the level of 95g/km, 93,6g/km and 49,5 g/km.

Keywords: *passenger vehicles, CO2 reduction, fuel consumption reduction, target emission levels*

To cite this article:

Kozyra, J., Łukasik, Z., Kuśmińska-Fijałkowska, A., Folęga, P., Janota, A., (2025). Standards and requirements concerning reduction of CO_2 emission for new passenger cars. Archives of Transport, 74(2), 7-22. https://doi.org/10.61089/aot2025.whr7qq76

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1. Introduction

European green deal is a long-term EU strategy aiming at achievement of climate neutrality of Europe until 2050. To achieve this goal, Europe must until 2034 limit their emission by at least 55% in comparison with the levels from 1990. New standards of CO_2 emission require for all new passenger cars and delivery vans registered in Europe to be emission free until 20235. An indirect step towards zero-emission will be reduction of average level of emission of new passenger cars by 55 % until 2030, and new delivery vans by 50 %. It will make more possible to achieve zero-emission in road transport until 2050 (Erbach, 2023).
European Union works on development of infrastructure needed to charge zero-emission vehicles on short and long routes. Mandatory goals of distribution of infrastructure of electric charging and refueling hydrogen along European roads will be defined in near future (Soone, 2023). Capacity of public charging stations will be sufficient enough to meet demand of new and larger zero-emission vehicle fleet. The number of private charging stations at home or in a workplace is also going to increase.
Moreover, road transport will be covered by Emissions Trading System since 2027 and charges will be imposed in the event of environmental pollution and should translate into the use of more ecological fuels and investments in clean technologies.
Road transport is responsible for large part of emission. Moreover, emission from the sector of road transport shows an upward trend and levels are much above levels from 1990, increased by 25% (Jensen, 2020). If emission from road transport will still be growing, then such growth will eliminate reduction of emission achieved by other sectors in combating climate change. It is believed that transport has large potential within the scope of energy efficiency, which can be achieved by putting pressure on tightening standards of CO_2 emission for passenger cars and light and heavy commercial vehicles until 2030. Therefore, the levels of reduction of emission for the years 2025 and 2030 for new passenger cars and light commercial vehicles in the whole European Union must be determined, considering duration of renovating vehicle fleet and contribution of the sector of road transport to achieve the goals for 2030 within the scope of climate and energy. An application of such approach is also clear and early signal for the automotive industry to not delay implementation of energy-efficient technologies and zero-emission and low-emission vehicles.
New regulation specifying the requirements of CO_2 emission for new passenger cars and new light commercial vehicles was presented in this article. It may contribute to achievement of EU target levels of reduction of emission of greenhouse gasses, pursuant to the Regulation (EU) 2018/842, and goals of Paris Agreement, to ensure proper functioning of the market. Target individual levels of CO_2 emission for passenger cars and light commercial vehicles for the years 2025-2029 and since 2030 were analysed. On the basis of accepted reduction of CO_2 emission of passenger cars and light commercial vehicles and accepted computational equations, mass of fuel per unit of time of working engine and reduction of CO_2 emission for selected passenger cars was calculated.

2. Literature review

After decades of discussions, it's finally time to act because climate change is the crisis of our times. We are in a critical moment and data clearly illustrate the scale of permissible emission of 900-gigatonnes of CO_2 to keep global acceptable warming at the level of much below 2°C (Masson-Delmotte, et al., 2021). However, the sector of transport is still in the spotlight, becoming the most important factor contributing to emission of greenhouse gasses (Gross, 2020; Balyk, et al., 2021).
The largest global car companies have been taking actions aimed at reduction of CO_2 emission for all new cars and have been implementing Alternative Fuel Vehicles (AFV) powered mainly by electric energy from renewable sources (Delbeke, 2016; Gnann, et al., 2018). To make AFVs more popular, numerous incentives, for example, subsidies, reduced taxes and parking fees or exemption from highway tolls were implemented (Peters, et al., 2021; Lee, 2023; Higueras-Castillo, et al. 2024). The research on the impact of incentives and improvements, especially financial ones, showed notable impact on the use of AFV and reduction of emission from vehicle fleet (Hardman, S. (2019); Mekky, et al., 2024; Shang, et al., 2024). It was also found that they are not sufficient enough to achieve specified goals of CO_2 emission in the sector of transport (Münzel, et al., 2019; Jenn, et al., 2018; Kuppusamy, et al., 2023).
Looking for effective substitutes of fossil fuels, significance is attached to promotion of alternative

fuels and alternative drive units (Brach, 2016; Havrysh, et al. 2021). At present, at least a few really competitive alternative energy carriers and drive units can be distinguished (Breuer, et al. 2021; Clegg, et al. 2017). They include: biofuels – generated from natural products different than petroleum; biogases – gases that are not fossils; hydrogen; liquefied petroleum gas (LPG) and compressed natural gas (CNG); alcohols – methanol and ethanol (Matsuo, et al., 2016; Doğan, et al., 2019). Alternative drive units include: solar panels, fuel cells, hybrid-combustion-electric systems, fully electric systems, hybrid systems for alternative fuels (Hu, et al., 2018; Aguilar, et al., 2022). Despite above actions giving hope for good future of combustion engines by using synthetic e-fuels and biofuels as transitional fuel, these actions can only maintain status quo. The research showed that e-fuels do not solve both the problem of reduction of emission and air pollution generated by transport (Breuer, et al., 2021).
Successful transition to zero-emission mobility requires integrated approach and proper environment to stimulate innovations and maintain a leading position of the European Union in the field of technology in this sector (International Energy Agency, 2022; CLEPA, 2023). It includes public and private investments in scientific research and innovations, growing supply of zero-emission and low-emission vehicles, development of infrastructure of charging and fuel stations, integration with energy systems, as well as sustainable deliveries of materials and sustainable production, including reuse and recycling of batteries in Europe (Hoarau, et al., 2022; Toro, et al., 2023; Yuan, et al., 2021; Borowski, et al., 2023). It requires coherent actions at the EU, national, regional and local levels (Martins, et al., 2023).
One of the methods of reduction of emission is reduction of mass of light commercial vehicles powered by diesel engines (Cecchel, et al., 2018; Gohlke, et al., 2023). These actions were caused by adopted legislation aimed at assuring that average level of emission of new passenger cars in the European Union does not exceed 95 gCO_2/km until 2020 and for delivery vans - 147 gCO_2/km until 2020 (Regulation (EU) 2019/631). It will be supplemented with additional measures reducing emission by 10 g CO_2/km (Regulation (EU) 2023/851). Therefore, reduction of mass, energy consumption and reduction of emission of gases have become important topics for the producers from the automotive industry. Mass of vehicles was constantly growing in recent years, it resulted from adding materials to vehicles such as safety systems, comfort options etc. In the years 1996-2009, it increased by 13,2% (Lidstone, 2014).

3. Target levels of CO_2 emission in road transport

Passenger cars and delivery vans, that is, light commercial vehicles generate about 12% and 2,5% of total carbon dioxide emission CO_2 in the European Union. Carbon dioxide is the main greenhouse gas. At the beginning of 2020, the Regulation (EU) 2019/631 defining standards of CO_2 emission for new passenger cars and delivery vans has come into force. It has replaced and repealed previous Regulation (EC) no. 443/2009 for passenger cars and (EU) no. 510/2011 for delivery vans. This Regulation was more rigorous when it comes to achievement of the goals of CO_2 emission. Average CO_2 emission for new passenger cars registered in Europe decreased in the years 2019–2020 by 12%, and in the years 2020–2021 by 12,5%. The main factor of reduced emission was the growth of registered zero emission passenger cars, 10% of total EU vehicle fleet in 2021. All these actions have turned out to be insufficient, and to achieve climate neutrality on April 19, 2023 European Parliament and the Council adopted the Regulation (EU) 2023/851 amending the Regulation (EU) 2019/631. The main goal is to tighten standards of CO_2 emission for new passenger cars and new light commercial vehicles in accordance with increased EU requirements. An amendment increases the goal of emission applicable since 2030 and determines the goal of reduction by 100% both for both passenger cars and delivery vans starting from 2035. Broader use of ecologically pure and inexpensive zero-emission vehicles should contribute to at least 55% reduction of net emission of greenhouse gasses until 2030 and is supposed to stimulate innovations in zero-emission technologies, strengthen leading technological position, simplify supply chain of components and stimulate employment in the European Union. Target goals of reduction of CO_2 emission adopted in the Regulation were presented in table 1. Since 2035, the EU goal of CO_2 emission for the whole fleet of passenger cars and delivery vans is reduction by 100%, that is, 0 g CO_2/km.

Table 1. Target goals of CO_2 emission for the whole EU fleet

Years	Passenger cars	Delivery vans
2020 - 2024	95 g CO_2/km	147 g CO_2/km
2025 - 2029	93,6 g CO_2/km	153,9 g CO_2/km
2030 - 2034	49,5 g CO_2/km	90,6 g CO_2/km

Achievement of such ambitious goal will be difficult. Motivating mechanism for zero-emission and low-emission vehicles ZLEV (Zero Low Emission Vehicle) will be applied to help to achieve this goal. It is the mechanism developing the idea of LEV (Low Emission Vehicle) for vehicles not manufactured yet and for emission will be taken into account not only at the stage of using, but also production of the very vehicle, its fuel and at the stage of withdrawing from service. ZLEV is a system of super credits and incentives for car producers to reduce emission of combustion engine vehicles. The first stage of this mechanism started in 2020, and the European Commission proposed to cover delivery vans by its mechanism since 2025. Motivating mechanism for zero-emission and low-emission vehicles will cease after 2030.

Before 2030, that is, until the end of the current decade, mechanism of incentives concerning zero-emission and low-emission vehicles will still be used to support marketing of vehicles generating level of emission between zero and 50g CO_2/km, including battery electric vehicles, electric vehicles powered by hydrogen fuel cells and plug-in hybrid vehicles characterized by good emission results. However, factors for zero-emission and low-emission vehicles must be changed to take into account faster marketing of zero-emission vehicles in the European Union. After January 1, 2030, plug-in hybrid vehicles will still be considered in target levels of emission for the EU vehicle fleet that producers are obliged to achieve.

Adopting new standards of reduction of emission for passenger cars and delivery vans is an introduction to heated political discussions on road transport. In autumn last year, the European Parliament adopted changes in the standards of exhaust emission (Euro 7), which will come into force for passenger cars and delivery vans with acceptable total mass up to 3,5 t since July 1, 2030 (and not since the beginning of 2025 as it was proposed by the European Commission), whereas for buses and motor trucks – since July 1, 2031.

The limits of nitrogen monoxide emission to 0,03 g/km or even 0,01 g/km were suggested (cars complying with EURO 6 standard had acceptable nitrogen monoxide emission at the level of 0,06 g/km NOx in the event of combustion engines powered by petrol or 0,08 g/km of nitrogen monoxide in the event of diesels). The requirements concerning carbon monoxide emission were limited to 0,3 or 0,1 g/km (from current 1 g/km for petrol engines, and 0,5 g/km for diesel engines). Average carbon dioxide emission CO_2 by all makes of specific producers was limited to 30 g/km. For comparison – current accepted average emission is 95 g/km, depending mainly on the mass of specific cars, these requirements may be a little bit higher or lower. To sum up, EURO 7 standards in its original form assumes reduction of exhaust emission to the level that would practically eliminate combustion passenger cars. The goal was to encourage drivers to replace their cars with electric ones. Therefore, it was required to resign from combustion trucks and buses.

4. The levels of CO_2 emission of passenger cars for the eu vehicle fleet in the years 2024-2035

In order to determine common EU method of assessment and coherent reporting of data about CO_2 emission in the whole life cycle of passenger cars and light commercial vehicles, a method has been developed to adjust calculations of target individual levels of CO_2 emission applicable to the producers responsible for CO_2 emission for light commercial vehicles built in many stages in order to consider changes in the procedure of determining CO_2 emission and masses of such vehicles.

For method of assessment of CO_2 emission to be harmonized for all assessed vehicles, we must apply new testing procedure of measurement of CO_2 emission caused by passenger cars and light commercial vehicles and consumption of fuel by them called Worldwide Harmonized Light Vehicle Test Procedure (WLTP), specified in the Commission Regulation (EU) 2017/1151 (Commission Regulation (EU) 2017/1151). This testing procedure includes the values of CO_2 emission and consumption of fuel, which are more representative of actual driving conditions. New goals of emission were based on CO_2 emission determined on the basis of this testing procedure. CO_2 emission has been determined on the basis of WLTP since 2021. New standards of CO_2 emission must be defined as levels of reduction determined

with respect to target levels in 2021 calculated on the basis of CO_2 emission measured for the purposes of emission tests within WLTP. In order to divide the efforts within the scope of reduction of emission in a neutral competitively way and fairly reflecting diversity of market of passenger cars and light commercial vehicles, considering also target individual levels of emission based on WLTP in 2021, the slope of limit values of individual levels of CO_2 emission must be determined. All new vehicles registered in 2024 were covered by these actions, taking into account the change of target levels of emission for the EU vehicle fleet between 2021, 2025, 2030 and 2035.
With reference to new commercial vehicles, the same approach must be used with reference to the producers of new passenger cars and new light commercial vehicles, and higher and constant slope for the entire period that target levels are applicable must be determined for car producers from heavier segments.
Target individual levels of emission of passenger cars for specific producer in the years 2021-2024 are determined based on the following equation (1):

$$\text{Specific emission target} = \text{WLTP}_{\text{reference target}} + a\left[\left(M_{\varphi} - M_0\right) - \left(M_{\varphi_{2020}} - M_{0,2020}\right)\right] \quad (1)$$

where:
$WLTP_{reference\ target}$ - reference individual level of emission according to WLTP procedure in 2021,
a – constant - 0,0333,
M_ϕ - average value of mass of new passenger cars of specific producers ready to drive registered in a given target year [kg],
M_0 - mass of a new passenger car in 2021 is 1 379,88 kg, and for the years 2022, 2023 and 2024 - its value was determined as average mass in a state ready to drive of all new passenger cars registered in 2017, 2018 and 2019.
$M_{\phi 2020}$ - average value of mass of new passenger cars of specific producers ready to drive registered in 2020 [kg],
$M_{0,2020}$ - mass of a new passenger car registered in 2020 is 1 379,88 kg.
In the event of a producer that exemption was granted to with reference to individual level of emission for 2021 based on NEDC (New European Driving Cycle), target levels as part of an exemption based on WLTP are calculated based on the following equation (2):

$$\text{Derogation target level}_{2021} = \text{WLTP}_{CO_2} \cdot \left(\frac{\text{NEDC}_{2021\ \text{target}}}{\text{NEDC}_{CO_2}}\right) \quad (2)$$

where:
$WLTP_{CO2}$ - average individual level of CO_2 emission in 2020 determined in accordance with annex XXI to the Regulation (EU) 2017/1151 and calculated for every producer, taking into account that percentage of new passenger cars of specific producers in 2020 was 95 %, and since 2021-100 %,
$NEDC_{CO2}$ - average individual level of CO_2 emission in 2020 determined in accordance with the executive order (EU) 2017/1153 and calculated in (EU) 2019/631 for every producer, taking into account that percentage of new passenger cars of specific producers in 2020 was 95 %, and since 2021 - 100 %,
$NEDC_{2021target}$ - target level of exemption for 2021 granted by the Commission in accordance with the executive order (EU) 2019/631.
Since January 1, 2025, target level of emission will be determined for the EU vehicle fleet $_{2021}$, which means average, weighted on the basis of the number of new passenger cars registered in 2021, reference values$_{2021}$ determined for specific producers that target average individual level of emission applies to in accordance with equation (1). Reference value$_{2021}$ is determined for every producer based on the following equation (3):

$$\text{Reference value}_{2021} = \text{WLTP}_{CO_2,\text{measured}} \cdot \left(\frac{\text{NEDC}_{2020,\text{Fleet Target}}}{\text{NEDC}_{CO_2}}\right) + a\left(M_{\varphi 2021} - M_{0,2021}\right) \quad (3)$$

where:
$WLTP_{CO2,measured}$ - average measured CO_2 emission (mixed cycle) for each new passenger car of specific producers registered in 2020, defined in the executive order (EU) 2017/1153,
$NEDC_{2020,Fleet\ Target}$ - CO_2 emission for the whole EU fleet in the years 2020-2024 - 95 [g/km],

$M_{\phi 2021}$ - average value of mass of new passenger cars of specific producers ready to drive registered in 2021 [kg],
$M_{0,2021}$ - average value of mass of all of new passenger cars ready to drive registered in 2021 by producers, for which target individual level of emission in calendar years 2021–2024 shall apply to.
Whereas, the levels of emission for the EU vehicle fleet starting from 2025 were accepted for the years 2025–2029 and will be determined by target level of emission for the EU vehicle fleet in 2025, which will be equal to target level of emission for the EU vehicle fleet in 2021 based on the equation (2) multiplied by reduction factor for 2025.
Reduction factor refers to the average level of emission of fleet of new passenger cars, for which target level of emission for the EU vehicle fleet is 15% of reduction of target level in 2021. Therefore, the following equation can be used (4):

$$\text{EU fleet} - \text{wide target}_{2025} = \text{EU fleet} - \text{wide target}_{2021} \cdot (1 - \text{reduction factor}_{2025}) \quad (4)$$

In order to determine reduction of emission in comparison with 2021, reference target individual level of emission since 2025 must be determined and the following equation should be used (5):

$$\text{Specific emission reference target} = \text{EU vehicle fleet} - \text{wide emissions target}_{2025} + a_{2025}(\text{TM} - \text{TM}_0) \quad (5)$$

where:
TM - average test mass of all new passenger cars of specific producers registered in a specific calendar year [kg],
TM_0 - average mass of all new passenger cars and new light commercial vehicles registered in two preceding calendar years, starting from 2022 and 2023. New TM_0 values shall be applicable since January 1 of a calendar year following the date of adjustment [kg].
Reduction factor with reference to the average level of emission of fleet of new passenger cars since 2025 is determined based on the equation (4), whereas the value of target level of emission for the EU vehicle fleet a_{2025} in (5) is determined based on the following equation:

$$a_{2025} = \frac{a_{2021} \cdot \text{EU flet} - \text{wide target}_{2025}}{\text{Average emissions}_{2021}} \quad (6)$$

a_{2021} - the slope of the best adjusted straight line determined using least squares method applied to test mass (independent variable) and individual level of CO_2 emission (dependent variable) of every new passenger car registered in 2021.
UE flet - wide target$_{2025}$ - 15 % of reduction of target level in 2021.
Average emission$_{2021}$ – average individual levels of CO_2 emission of all registered new passenger cars of these producers in 2021, for which target individual levels of emission based on the equation (1) are calculated.
Target levels of emission for the EU vehicle fleet after 2029, applicable in the years 2030–2034, will be determined in similar way as above. Therefore, the following equation can be used (7):

$$\text{EU fleet} - \text{wide target}_{2030} = \text{EU fleet} - \text{wide target}_{2021} \cdot (1 - \text{reduction factor}_{2030}) \quad (7)$$

Since January 1, 2030, reduction factor shall refer to the average level of emission of fleet of new passenger cars, for which target level of emission for the EU vehicle fleet is 55% of reduction of target level in 2021. Target level of emission for the EU vehicle fleet from 2021 was determined based on the equation (2). Whereas, to determine reference target individual level of emission for the years 2030 – 2034, the following equation was used (8).

$$\text{Specific emission reference target} = \text{EU vehicle fleet} - \text{wide emissions target}_{2030} + a_{2030}(\text{TM} - \text{TM}_0) \quad (8)$$

where:
$$a_{2030} = \frac{a_{2021} \cdot \text{EU flet} - \text{wide target}_{2030}}{\text{Average emissions}_{2021}}$$
a_{2021} – the slope of the best adjusted straight line determined using least squares method applied to test mass (independent variable) and individual levels of CO_2 emission (dependent variable) of each new passenger car registered in 2021,
UE flet - wide target$_{2030}$ - 55% of reduction of target level in 2021,
Average emission$_{2021}$ - average individual levels of CO_2 emission of all registered new passenger cars of

these producers in 2021, for which target individual levels of emission based on the following equation (1) are calculated.

Target level of emission for the EU vehicle fleet starting from January 1, 2035 will be determined based on the following equation (9):

$$\text{EU fleet} - \text{wide target}_{2035} = \text{EU fleet} - \text{wide target}_{2021} \cdot (1 - \text{reduction factor}_{2035}) \quad (9)$$

Reduction factor refers to average level of emission of fleet of new passenger cars, for which target level of emission for the EU vehicle fleet is 100% of reduction of target level in 2021. Target level of emission for the EU vehicle fleet from 2021 was determined based on the equation (2). Reference target individual level of emission after 2035 is determined based on the following equation (10).

$$\text{Specific emission reference target} = \text{EU vehicle fleet} - \text{wide emissions target}_{2035} + a_{2035}(\text{TM} - \text{TM}_0) \quad (10)$$

where:

$a_{2030} = \frac{a_{2021} \cdot \text{EU flet}-\text{wide target}_{2035}}{\text{Average emissions}_{2021}}$

UE fleet-wide target$_{2035}$ - 100 % of reduction of target level in 2021.

Achieving such ambitious goals will be difficult but motivating mechanism for zero-emission and low-emission vehicles (ZLEV) may be useful. Therefore, ZLEV factor recommended by ACEA (European Automobile Manufacturers Association) allows in an easy and clear way monitor and limit actual level of CO_2 emitted by passenger cars. As it was shown by bad examples in the automotive market in recent years, average emission factor from new vehicles may not be a reliable parameter. Therefore, target individual levels of emission between 2025 and 2034 were determined. Target individual levels of emission for passenger cars for the years 2025-2029 are determined based on the following equation (11).

$$\text{Specific emission target} = \text{specific emissions reference target} \cdot \text{ZLEV factor} \quad (11)$$

In the equation (11), reference target individual level of emission means reference target individual level of emission for specific producer determined based on the equation (5). ZLEV factor is determined based on the equation (12) unless 1+y-x is higher than 1,05 or lower than 1,0, then ZLEV factor is 1,05 or 1,0, depending on the case:

$$\text{ZLEV factor} = 1 + y - x \quad (12)$$

where:

x - is 15 % in the years 2025–2029 and 30 % starting from 2030,

y – the share of zero-emission and low-emission vehicles in the producer's fleet of new passenger cars calculated as total number of new zero-emission and low-emission vehicles, when each of them is calculated as *ZLEV*$_{specific}$ based on the equation (13), divided by total number of new passenger cars registered in a specific calendar year:

$$\text{ZLEV}_{\text{specific}} = 1 - \left(\frac{\text{specific emissions of CO2} \cdot 0{,}7}{50}\right) \quad (13)$$

With reference to new passenger cars registered in the EU member states, in which the share of zero-emission and low-emission vehicles is below 60 % of the average EU level in 2017 and less than 1 000 new zero-emission and low-emission vehicles registered in 2017, *ZLEV*$_{specific}$ until 2030 is calculated based on the following equation:

$$\text{ZLEV}_{\text{specific}} = \left[1 - \left(\frac{\text{specific emissions of CO2} \cdot 0{,}7}{50}\right)\right] \cdot 1{,}85 \quad (14)$$

The share of zero-emission and low-emission vehicles in a fleet of new passenger cars of a specific EU member state in 2017 is calculated as total number of new zero-emission and low-emission vehicles registered in 2017 divided by total number of new passenger cars registered in the same year. When the share of zero-emission and low-emission vehicles in a fleet of new passenger cars registered in specific EU member state in the years 2025–2028 exceeds 5 %, such member state does not qualify to use multiplier 1,85 in subsequent years.

Target individual levels of emission for passenger cars after 2030 were also determined , that is, for the period between 2030 and 2034, the equation (15) and since January 1, 2035, the equation (16):

$$\text{Specific emission target} = \text{EU vehicle fleet} - \text{wide emissions target}_{2030} + a_{2030}(\text{TM} - \text{TM}_0) \quad (15)$$

$$\text{Specific emission target} = \text{EU vehicle fleet} - \text{wide emissions target}_{2035} + a_{2035}(\text{TM} - \text{TM}_0) \quad (16)$$

Such a distant prospect will probably see changes in EU legislation, but the current provisions on individual emission levels for passenger cars adopted in April 2023 are in force.

5. An analysis of reduction of level of CO2 emission in passenger cars

It seems that after 2035 producers may face complete ban on production of new combustion vehicles. Their future doesn't look so bleak as it would seem because adopted regulation allows to produce these vehicles provided that fuels neutral in terms of CO_2 emission will be implemented (Regulation (EU) 2023/851). Therefore, it is possible that production of combustion vehicles in Europe will be continued after 2035 provided that zero-emission fuels for such cars will be used. Electric and hydrogen vehicles are mostly regarded as zero-emission vehicles. In both cases emission in LCE (Life Cycle Emissions) should be taken into consideration. For electric vehicles, the share of renewable sources energy in production of electric energy should be considered. Therefore, treating vehicles in specific EU countries as zero-emission vehicles is a large simplification. Whereas, in the event of hydrogen, the issue of emission generated during its production is also significant. Progressing transformation of the sector of production of electric energy will largely contribute to electrification of transport. A significant aspect of this transformation is insufficiently developed infrastructure, which may curb replacing combustion cars with electric ones. Another issue is increased consumption of electric energy which will be caused by this and the problems with stabilization of electricity grid resulting from it.
According to statistics of the Polish Automotive Industry Association developed on the basis of data of Central Vehicles Register, the offices in Poland in the years 2021-2022 registered new vehicles according to the type of their drives, which is shown in table 2 (Branża Motoryzacyjna Raport 2022/2023; Branża Motoryzacyjna Raport 2023/2024). The number of registered passenger cars in the end of 2022 was 26,5 million (GUS, Transport-wyniki działalności w 2022 r.).

Table 2. New registrations of passenger cars by made of propulion (PZPM, Raport 2023/2024)

Fuel	2022	2021
Gasoline	203,1	237,5
Diesel	46,5	57,9
LPG and CNC/LNG	12,2	13,5
Battery Electric Vehicle	11,3	7,1
Plug-in Hybrid	9,7	9,3
Hybrid	136,9	122,2

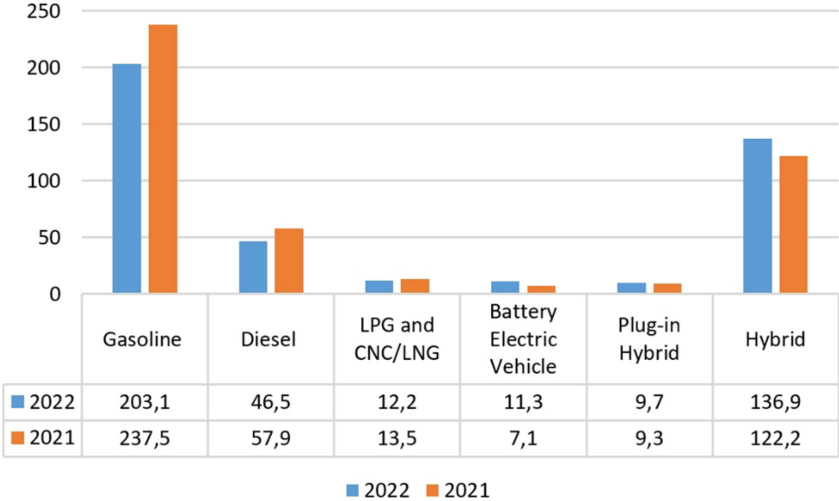
In 2023, 475 032 new passenger cars were registered in Poland, including 344 417 cars in companies, whereas 10 548 123 new passenger cars were registered in the European Union (Raport kwartalny PZPM i KPMG, 2024).
Analysing consumption of the most popular fuel in Poland for passenger cars, that is, petrol, according to data of the Polish Organisation of Petroleum Industry and Trade, estimated consumption of this fuel in the years 2021-2023 is presented on fig. 2 (Raport roczny 2022 i 2023, Przemysł i Handel Naftowy).
Taking into account that 3,1 kg of carbon dioxide is generated by total and perfect combustion of 1 kg of petrol, the amount of carbon dioxide emission based on estimated consumption of 8025 000 m^3 of petrol in 2023 may be calculated. Density of petrol $\rho = 0{,}745\ g/cm^3$ was used and calculations were made:

$$0{,}745\frac{g}{\text{cm}^3}\cdot 8\ \ 025\ \ 000\cdot 10^6\ \ \text{cm}^3\text{Gasoline} = 5\ \ 978\ \ 625\cdot 10^6 g = 5\ \ 978\ \ 625\cdot 10^3\text{kg}\ \ \text{Gasoline} \quad (17)$$

Therefore, assuming that 1kg of petrol = 3,1 kg CO_2, the result is:

$$5\ \ 978\ \ 625\cdot 10^3\text{kg}\ \ \text{Gasoline}\cdot 3{,}1\ \ \text{kg} = 18\ \ 533\ \ 737{,}5\cdot 10^3\ \ \text{kg}\ \ \text{CO2} \quad (18)$$

Fig. 1 shows graphic comparison of new vehicles registered in the years 2021-2022.



	Gasoline	Diesel	LPG and CNC/LNG	Battery Electric Vehicle	Plug-in Hybrid	Hybrid
2022	203,1	46,5	12,2	11,3	9,7	136,9
2021	237,5	57,9	13,5	7,1	9,3	122,2

Fig. 1. New vehicles registered in the years 2021-2022 with their division into type of fuels

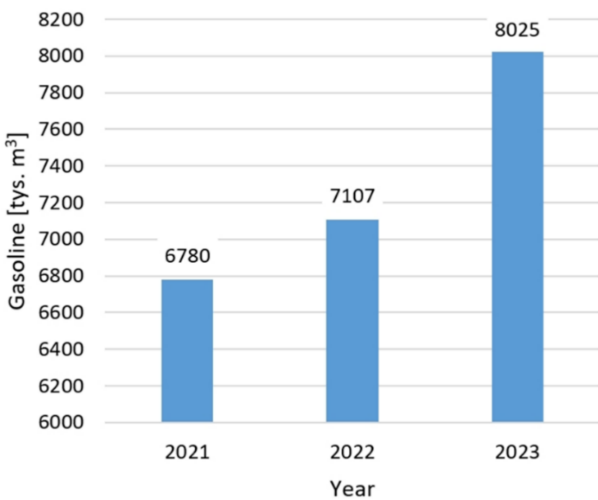


Fig.2. Estimated consumption of motor petrol in Poland in the years 2021-2023

It can't be yet assumed that only passenger cars generate specific amount of CO_2 because there are many more different devices using combustion engines powered by petrol. According to EEA (European Environment Agency), about 1/4 of total CO_2 emission in the European Union in 2019 was generated by sector of transport, including 71,7% by road transport, passenger cars as much as 60,6 %, then motor trucks - 27,1%, light delivery vans - 11,0%, motorcycles - 1,3 % (www.europarl.europa.eu, article, 20190313STO31218). In Poland, it is believed that for the amount of CO_2 emitted into atmosphere from specific types of transport is mostly responsible road transport - 65% which translates into 3,315 billion Mg CO_2. In terms of types of used fuels, the

share of cars powered by petrol engines was 51,8%, diesel engines - 31,3% and LPG - 13,0%.
Because precise methodology of calculating the level of CO_2 emission of passenger cars for the EU vehicle fleet and their individual emission will be determined in 2025, an analysis of limited reduction of level of CO_2 emission may be conducted. It should be analytically determined how much CO_2 emission should be reduced by in subsequent years and what amount of consumed fuel is needed to achieve this goal. In this article, 10 most popular makes of passenger cars in Poland powered by petrol registered for the first time in 2023 were presented in Table 3.

Table 3. Fuel consumption and CO_2 emission in 10 most popular makes registered in Poland in 2023 (Sejm of the Republic of Poland, Dz. U. z 2004 r., Nr 98)

Vehicle make	Number of cars sold in 2023	Power [kW]	Fuel consumption [l/100km]	CO_2 emission [g/km]
Toyota Corolla	26 391	92	6,2	139
Škoda Octavia	15 340	180	7,1	161
		140	7,3	166
		110	5,8	132
		81	5,2	119
Toyota Yaris	13 202	92	5,4	127
Toyota Yaris Cross	13 080	92	6,1	138
Kia Sportage	12 198	110,1	6,8	155
Toyota C-HR (Hybryda)	10 451	112	4,9	117
		72	4,9	111
Hyundai Tucson	10 403	110,1	7,0	159
Dacia Duster	8757	110	6,4	145
		67 i 74	4,9	129
Toyota RAV4	8197	131	6,0	137
Volkswagen T-Roc	7371	110	6,1	137
		85	5,8	133
		70	5,7	130

Assuming that combustion of 1 kg of petrol by combustion engine generates 3,1 kg of carbon dioxide (0,322 kg of fuel per 1 kg CO_2 must be used), mass of fuel with engine of new passenger car working can be determined. Intensity of carbon dioxide emission of a combustion engine of a new passenger car under such conditions is 0,76 g/s. To assess the mass of fuel in unit of time of working engine, the following formula was used (19):

$$0{,}76\frac{g}{s}CO_2 \cdot 0{,}332\frac{\text{gGasoline}}{gCO_2} = 0{,}252\frac{g}{s}\text{Gasoline} \tag{19}$$

Density of petrol (ρ = 0,745 g/cm^3) was assumed earlier and voluminal intensity of fuel consumption was obtained (20):

$$0{,}76\frac{g}{s}CO_2 \cdot \frac{0{,}332\frac{\text{gGasoline}}{gCO_2}}{0{,}745\frac{g}{cm^3}} = 0{,}33\frac{cm^3}{s}\text{Gasoline} \tag{20}$$

It means that CO_2 emission will be limited through application of new types of combustion engines, which will result in reduction of combusted fuel or total change in applied fuels mixed with electric energy.
However, if tendency of popularity of passenger cars mentioned in table 3 was maintained in subsequent years, then fuels will have to be replaced with more ecological ones or hybrid drives will have to be used. More and more producers use this type of drive to achieve the goal of reduction of the level of CO_2 emission. Despite these actions, passenger cars has still not achieved the goal of limitation for the years 2020-2024, that is, 95 gCO_2/km. Passenger hybrid

vehicles are close to achieve the goal, but they are still far from achieving it. Fuel consumption and CO_2 emission for the most popular selected makes registered in 2023 were presented in Table 4.

Table 4. Fuel consumption and CO_2 emission for the most popular selected hybrid makes registered in Poland in 2023 (Sejm of the Republic of Poland, Dz. U. z 2004 r., Nr 98)

Vehicle make	Power [kW]	Fuel consumption [l/100km]	CO_2 emission [g/km]
Toyota Corolla	112 72	4,8 4,9	108 111
Škoda Octavia	110 81	5,3 5,1	121 116
Toyota Yaris	68	4,3	98
Toyota Yaris Cross	68	5,1	116
Kia Sportage	110,1	6,3	144
Toyota C-HR	112 72	4,9 4,9	117 111
Hyundai Tucson	110,1	5,9	135
Toyota RAV4	131	5,8	132

Graphic comparison of fuel consumption and CO_2 emission for the most popular selected hybrid makes registered in Poland in 2023 was presented in Figure 3.

In January 1, 2025, new lower goal of emission 93,6 gCO_2/km will come into force, which will be a challenge for producers of new passenger cars and they will have to achieve this goal until the end of 2029. In 2030, CO_2 emission for newly produced passenger cars must be limited to 49,5 gCO_2/km. Therefore, it can be analytically determined what amount of fuel, petrol in this case, was required to achieve the goal of emission mentioned above assuming specific emission (Sejm of the Republic of Poland, Dz. U. z 2004 r., Nr 98). Calculations to achieve the goals of emission in specific time intervals specified in the EU regulation were made for passenger cars from Table 3 and 4. Table 5 shows the results of these calculations.

The results presented in table 5 clearly show how much work is left for the producers of new passenger cars. Hybrid vehicles give hope of keeping production of combustion engines, provided that their structure will be developed and emission limited. Some of the analysed car makes are close to achieve the desired goal and it seems that progress in this field will allow to achieve at least the goal for the years 2025-2029. The next goal includes low-emission vehicles defined in accordance with the Regulation (EU) 2017/1151, of which CO_2 emission of exhaust pipe is between zero and 50 g CO_2/km, and after 2035, zero-emission vehicles, that is, modern fuels based on hydrogen or electric energy. The offer of cars analysed in this article includes cars of low CO_2 emission using liquefied fuels, which meet standard limits of CO_2 emission for the years 2030-2034 (Sejm of the Republic of Poland, Dz. U. z 2004 r., Nr 98). The makes were presented in Table 6.

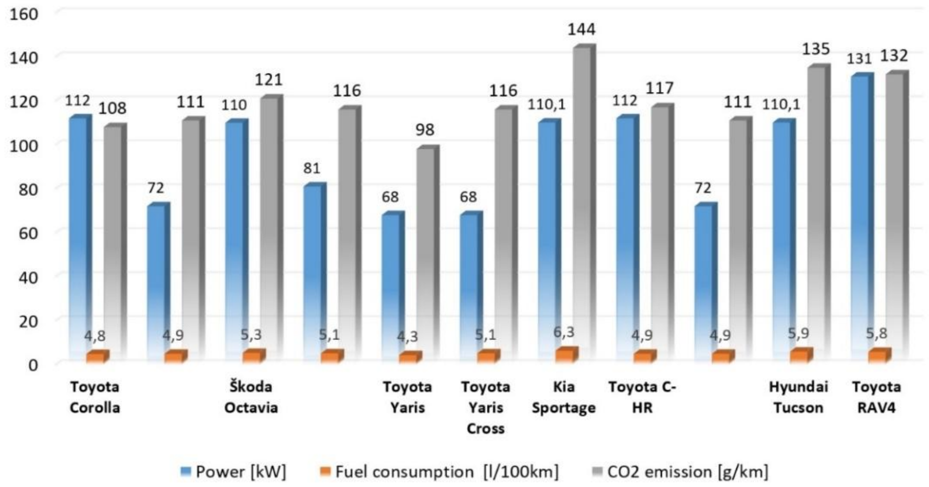


Fig. 3. Fuel consumption and CO_2 emission for the most popular hybrid makes registered in Poland in 2023

Table 5. Fuel consumption for CO_2 acc. to the EU Regulations for the most popular makes registered in Poland in 2023

Vehicle make	**Power [kW]**	**Fuel consumption [l/100km]**	**CO_2 emission [g/km] acc. to [46]**	**Fuel consumption for emission 95 gCO_2/km in 2020-2024 [l/100km]**	**Fuel consumption for emission 93,6 gCO_2/km in 2025-2029 [l/100km]**	**Fuel consumption for emission 49,5 gCO_2/km in 2030-2034 [l/100km]**
Toyota Corolla	92	6,2	139	4,23	4,17	2,30
Toyota Corolla (Hybrid)	112 72	4,8 4,9	108 111	4,22 4,19	4,16 4,13	2,20 2,18
Škoda Octavia	110 81	5,8 5,2	132 119	4,17 4,15	4,11 4,09	2,17 2,16
Škoda Octavia (Hybrid)	110 81	5,3 5,1	121 116	4,16 4,17	4,09 4,01	2,16 2,17
Toyota Yaris	92	5,4	127	4,03	3,97	2,10
Toyota Yaris (Hybrid)	68	4,3	98	4,16	4,10	2,17
Toyota Yaris Cross	92	6,1	138	4,19	4,13	2,18
Toyota Yaris Cross (Hybrid)	68	5,1	116	4,17	4,11	2,17
Kia Sportage	110,1	6,8	155	4,16	4,10	2,17
Kia Sportage (Hybrid)	110,1	6,3	144	4,15	4,09	2,16
Toyota C-HR (Hybrid)	112 72	4,9 4,9	117 111	3,97 4,19	3,92 4,13	2,07 2,18
Hyundai Tucson	110,1	7,0	159	4,18	4,12	2,17
Hyundai Tucson (Hybrid)	110,1	5,9	135	4,15	4,09	2,16
Dacia Duster	110 67 i 74	6,4 4,9	145 129	4,19 3,60	4,13 3,55	2,18 1,88
Toyota RAV4 (Hybrid)	131	6,0	137	4,16	4,09	2,16
Volkswagen T-Roc	110 70	6,1 5,7	137 130	4,22 4,16	4,16 4,10	2,20 2,17

Table 6. Selected passenger cars meeting limit standard of CO_2 emission for the years 2025-2029 and 2030-2034 powered by hybrid drive offered by producers in 2024

Vehicle make	**Power [kW]**	**Fuel consumption [l/100km]**	**CO_2 emission [g/km]**
Škoda Octavia	110	1,0	23
Kia Sportage	132,4	1,1	25
Toyota C-HR	111	0,9	20
Hyundai Tucsonix35	132,2	1,4	31
Toyota RAV4	136	1,0	22

Comparison of fuel consumption and CO_2 emission of selected passenger cars meeting limit standards of CO_2 emission for the years 2025-2029 and 2030-2034 powered by hybrid drive was presented on Figure 4.

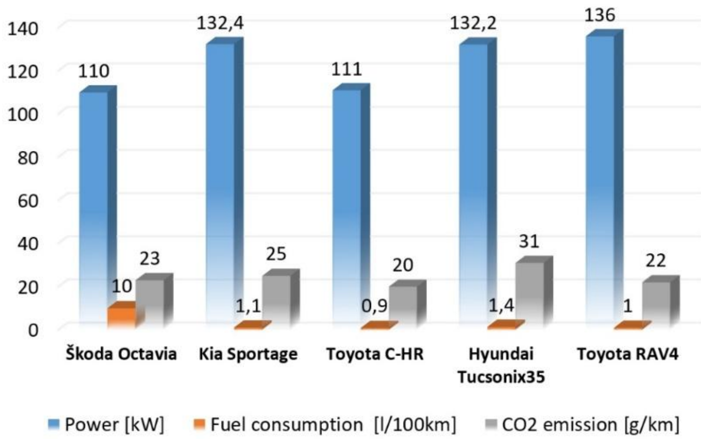


Fig.4. Fuel consumption and CO_2 emission of selected passenger cars meeting limit standards of CO_2 emission for the years 2025-2029 and 2030-2034

Strategy of the producers includes adjustment of their offers to the needs of European clients and proposing many zero-emission solutions concerning electric cars powered by batteries and fuel cells and hybrid vehicles and plug-in hybrid vehicles. An example can be Toyota Mirai with 134 kW hydrogen-electric drive and consumption of hydrogen of 0,9 H2 kg/100km and CO_2 emission of 0 g/km. Another example is Toyota Prius, 111 kW hybrid car, combustion of 0,6 l/100 km and CO_2 emission of 14 g/km.

6. Conclusions

An analysis of greenness of combustion cars shows that although there are modern technologies that can reduce their negative impact on environment, these solutions still generate large CO_2 emission and other harmful substances. The progress in the automotive engineering such as better combustion systems, filtering and hybridization allows to reduce emission, however, the basic limitation remains the same, that is, dependence on fossil fuels. Therefore, a response to the question whether diesel or petrol engine are ecological is not explicit. For combustion cars to be really ecological, they need to be replaced or their drive systems need to be thoroughly modified to use more renewable sources of energy. Conditions that vehicles are manufactured in and method of getting construction materials are also of significance.
One of the key aspects is, above all, characteristics of manufacturing plants that vehicles are manufactured in. In this case the aspect such as carbon footprint is of particular significance. A recurring question in the discussion on electromobility is whether electric cars are really more ecological than their combustion equivalents. It seems to be obvious for enthusiast of zero-emission automotive industry. The sceptics of electromobility often raise the argument that during production of batteries, large amount of greenhouse gases is emitted, what makes electric vehicles less greener. Moreover, rare-earth elements are used during production of batteries, and the process of their extraction is quite difficult. The knowledge of CO_2 in the first phase of life of electric vehicles is not enough to assess actual impact of electric cars on natural environment.

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