

ELECTRIC OR INTERNAL COMBUSTION ENGINES FOR PASSENGER CARS? - ENVIRONMENTAL AND ECONOMIC ASPECTS

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Resume

The paper is focused on fuels, their users - engines and the end-user, the vehicles, from an environmental and economic point of view. The basic characteristics of potential fuels for internal combustion engines, as well as possible sources of electricity, are analysed. A comparative analysis of characteristics of vehicle propulsion with gasoline, diesel fuel, compressed natural gas, liquefied petroleum gas and electricity was performed. The research has shown that the application of vehicles with an electric motor is ecologically justified only in cases of obtaining electricity in an environmentally friendly way and that in other cases there is no profit in an ecological sense. From an economic point of view, if there were no subsidies to manufacturers and buyers of electric cars, they would not be competitive with internal combustion engines now. Within the research, potential solutions for reducing air pollution and improving the quality of life in cities have been proposed.

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1 Introduction

The modern world is taking more and more seriously the impact of environmental pollution on the life and survival of living people, as well as that pollution is transmitted through the atmosphere and occurs where it is not expected, in uninhabited and industrially underdeveloped areas.

Depending on current problems and technological possibilities, the focus of efforts to reduce the harmful effects of air pollution changes. In the developed world until the second half of the 20th century, the main pollutants were sulfur dioxide and soot, due to use of the low-quality fossil fuels, primarily low-quality coal and fuel oil. It is unfortunate, but even now a significant part of air pollution in many cities is a consequence of the same energy sources. The use of cleaner fuels and flue gas filters has greatly reduced the problem. In the sixties of the twentieth century, there was an increase in the number of motor vehicles, which gave rise to new risk factors. Imperfect technology of Diesel engines and carburetors of gasoline engines, with low-quality gasoline, have led to appearance of danger of pollution by lead, nitrogen oxides and unburned hydrocarbons. With improvement of technology at the leading engine manufacturers, the conditions were created for appearance of restrictions in the allowed emission of

harmful gases, so even the smaller manufacturers were forced to change their technologies and products. The norms became stricter over time. For that reason, many producers began to unite or fail. The new standards have contributed to application of better-quality fuel injection systems, controlled injection and removal of carburetors from use, improved production of parts and engines and more uniform quality, as well as to a significant improvement in fuel quality. All this has led to a reduction in fuel consumption per kilometer traveled and even to the fact that the harmful emissions of one vehicle have been reduced many times over in relation to the vehicles from the 1970s. Increase in the number of people on Earth, with the increase in the purchasing power of the population, has led to accelerated growth in the number of motor vehicles. World trends in the growth of the number of vehicles are shown in Figure 1. If one looks at the trends of vehicle registration by year, one can see that in fifty years the total number of registered vehicles has increased more than 11 times. The number of passenger motor vehicles increased 10.6 times and the number of trucks 13.6 times. It is estimated that there were 1.4 billion vehicles in the world in 2019, which means that in relation to the total number of inhabitants (7.674 billion), there were 182 vehicles per 1000 inhabitants. Given number of vehicles, it is logical to expect that over time there will



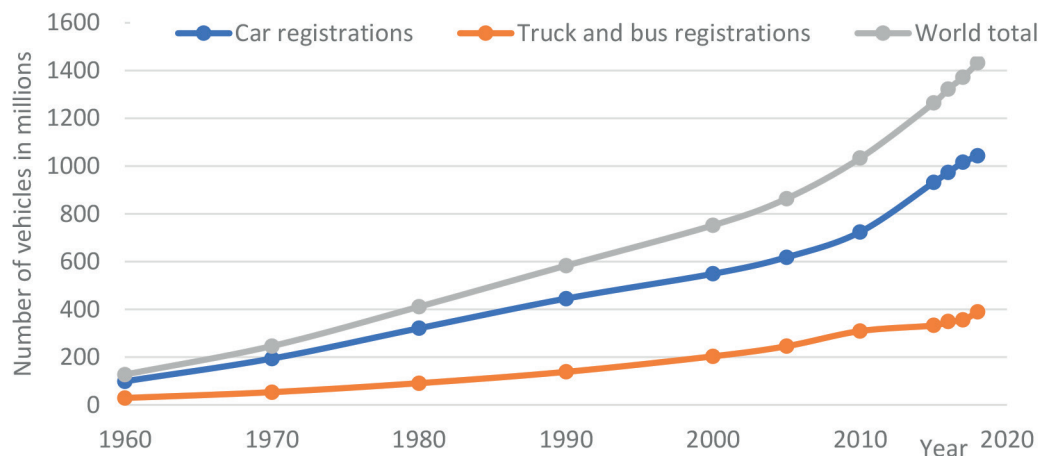


Figure 1 World vehicle registration trends [1]

Table 1 C/H ratio and minimum required amount of air for full fuel combustion (A/F) [2, p. 813]

Fuel	C	H	O	C/H	A/F
	% (m/m _{fuel})			-	$\frac{\text{kg}_{\text{air}}}{\text{kg}_{\text{fuel}}}$
Methane	~ 74.9	~ 25.1	-	~ 3.0	~ 17.4
Propane	~ 81.8	~ 18.2	-	~ 4.5	~ 15.8
Butane	~ 82.8	~ 17.2	-	~ 4.8	~ 15.6
Gasoline	~ 85.5	~ 14.5	-	~ 5.9	~ 14.9
Super gasoline	~ 85.1	~ 13.9	~ 1	~ 6.1	~ 14.6
SuperPlus	~ 84.7	~ 13.3	~ 2	~ 6.5	~ 14.4
Diesel fuel	~ 86.3	~ 13.7	-	~ 6.3	~ 14.8
Methanol	~ 37.5	~ 12.6	~ 49.9	~ 3.0	~ 6.5
Ethanol	~ 52.1	~ 13.2	~ 34.7	~ 4.0	~ 9.0

be increasing of air pollution, which at some point could become critical for human survival. If the impact of air traffic (which is not the topic of this paper) is added to this, it is clear what the challenge is.

At the beginning of the 21st century, the focus shifted from lead, which has been removed from gasoline and ceased to be a critical element, to nitrogen oxides and unburned hydrocarbons, which have been reduced by exhaust catalysts and fuel injection technology, to carbon dioxide. With Diesel engines, the use of carbon black catchers significantly reduced harmful emissions, but the problem of carbon dioxide remained.

The aim of this paper was to consider the justification of tendency to replace the internal combustion engines by electric motors. In this sense, the null hypotheses are set:

H₀₁: Internal combustion engines are always more environmentally unfavorable than the use of electric motors to drive passenger cars.

H₀₂: The use of internal combustion engines is always economically less favorable than the use of electric motors to drive the passenger motor vehicles.

Alternative hypotheses have also been set:

H_{a1}: Internal combustion engines are in some situations more environmentally friendly than the use of

electric motors to power passenger motor vehicles.

H_{a2}: The use of internal combustion engines is, in some situations, more favorable than the use of electric motors to drive passenger motor vehicles, from an economic point of view.

2 Fuels

Nowadays, hydrocarbon-based fuels, primarily gasoline and diesel, are still used the most to power vehicle engines. Not predominantly because of awareness of the air pollution but because of occasional oil shortages or fears and forecasts that oil deposits will be depleted, alternative fuels occasionally come into focus. Some of the most intensive such research were conducted in the 1970s when the possibilities of using various alternative fuels were investigated, primarily liquefied petroleum gas (LPG), methane (CNG), methanol, ethanol and hydrogen, as well as their mixtures. Each of the fuels had its advantages and disadvantages, which over time, with the change of technology, had a different weight. Today, the emphasis is on the impact of a fuel on environment and therefore on fuel consumption. Before analyzing the behavior of vehicles depending on the type

of propellant, some basic characteristics of possible fuels for the propulsion of vehicle engines are considered, see Table 1.

2.1 Fuels for Diesel (compression ignition) engines

From the environmental aspect, the most important for diesel fuel are the lowest density, the lowest final boiling point and the lowest sulfur content. Petroleum naturally contains sulfur which, when burned with more than 95%, is converted into sulfur dioxide (SO₂). The rest passes into the particle mass of the exhaust that contains sulfurous acids and sulfates. Sulfur compounds cause increased corrosion and increased air pollution. The residue is mixed with soot, which contains many compounds that are considered carcinogenic. Thanks to improved fuel processing processes, the SO₂ emissions of diesel engines are no longer a risk to the environment. Since the particles cannot be completely removed by limiting the sulfur content, it is necessary to further treat the exhaust gases with appropriate filters, particle traps. To improve the fuel quality, detergents and dispersant additives, corrosion inhibitors, lubricant additives, antifoaming agents and regeneration aids for particle filters are added to diesel fuels.

As an alternative to classic diesel fuel, biodiesel appears. The idea is to emit as much CO₂ into the atmosphere as plants take from the air for their growth. In this way, no additional amount of CO₂ would be emitted into the atmosphere. However, biodiesel brings with it new problems in the form of a small increase in NO_x emissions, the appearance of “fritting” odor from the exhaust and polycyclic aromatic hydrocarbons, insufficient stability, substantial deposits on the nozzles and in the combustion chambers [2, p. 821].

Methanol and ethanol are bad fuels for Diesel engines if used alone and could eventually be used in dual-fuel propulsion. However, it is economically unprofitable.

The use of diesel and water emulsions brings lower concentrations of NO_x emissions and black smoke, however, it increases hydrocarbon (HC) and carbon monoxide (CO) emissions, as well as fuel stratification, endangering the injection system and potential freezing of water at low temperatures, so when all this is considered, these solutions are not a good choice to apply to vehicle engines.

The use of LPG and CNG in Diesel engines requires an additional classic fuel injection system for the mixture to ignite in the cylinder. Such solutions exist with some city buses, but users more often decide to rework the engines by replacing the injectors with spark plugs and the injection pumps with an electric ignition system. All this must be followed by reducing the compression ratio to the level of the SI engine, 11: 1. However, this is not widespread either.

2.2 Fuels for vehicle spark-ignition engines (SI)

The most common fuel for spark-ignition engines¹ is gasoline, which is a fuel that consists of many hydrocarbons found in basic gasoline that is obtained in refineries by various processing methods from petroleum from a wide range of origins. It is a mixture of reformates, crack gasolines (olefins), pyrolysis gasolines, isoparaffins, butane, alkylates, the so-called replacement components such as alcohols and ethers and slight amounts of additives [2, p. 824]. It has been used for a long time with the use of carburetors, but due to the better control of the fuel-air mixture, today's new engines work with fuel injection.

As an alternative to gasoline in Otto engines as fuel, appear [2, p. 836]:

- LPG - Liquefied Petroleum Gas. Pressurized, liquefied auto gas based on propane and butane.
- CNG - Compressed natural gas based on methane.
- LNG - Liquefied Natural Gas. Gas liquefied at low temperatures based on methane.
- MEOH - Methanol. Alcohol, usually from natural gas (methane), also termed wood spirit.
- ETOH - Ethanol. Alcohol from sugar-containing plants.
- GH₂ - Gaseous Hydrogen. Can be made from water and all the hydrogen-containing energy carriers.
- LH₂ - Liquefied Hydrogen. Hydrogen that is liquid at low temperature.

Use of the liquefied gases in spark-ignition engines brings a few advantages in terms of fuel consumption and emission, but only in engines designed for this. When adapting the engine, dual-fuel propulsion, more favorable exhaust emissions will be obtained due to a more favorable C/H ratio, however, the high resistance to detonation cannot be exploited. In addition, the storage of the other fuel requires an additional tank that significantly reduces the usable space of the trunk.

2.2.1 Gasoline

Gasoline is a fuel that is exposed to a certain risk of explosion while stored in a tank. An explosion can occur in the zone where the volumetric ratio of fuel and air is at the level of 1-8%. Under normal circumstances, the concentration of gasoline in the fuel tank is significantly above the upper limit of 8%. Critical situations can occur in the case of low volatility and low environmental temperature, but in addition to the appropriate concentration, there must exist the source of ignition to ignite the mixture, so these risks are at an acceptable level.

An important characteristic of gasoline is the octane value, which provides it with resistance to detonating

¹Spark-ignition engines (SI) - Otto engines known as “gasoline engines” in the USA and “petrol engines” in the UK.

combustion. With the elimination of lead from use, ethers appeared as components to increase the octane number of fuels in addition to the further developed high-octane, classic components and alcohols. There is no uniform standard for gasoline quality in the world. For example, three types of gasoline are sold in Serbia:

- Euro Premijum BMB 95 (Euro 95 Regular unleaded motor gasoline).
- Euro BMB 98 (Euro 98 Unleaded Motor Gasoline).
- Euro BMB 100 (Euro 100 Unleaded Motor Gasoline).

where the numerical values correspond to the minimum RON² value that the fuel must have.

Application of the modern fuel injection systems has brought the need to bring the fuel density to a narrow range to enable computer systems to work properly and reduce the fuel consumption and emissions.

To reduce CO and unburned HC, oxygen-rich compounds such as MTBE (Methyl tertiary-butyl ether), ETBE (Ethyl tertiary-butyl ether), butanol, or ethanol are added to gasoline in controlled amounts. In addition to this, various other additives are added to gasoline to improve the characteristics, as well as the color to differentiate gasoline by types and to identify gasoline manufacturer.

Sulfur appears as a regular component of oil, so it should be removed to avoid SO₂ emissions. In addition, some catalytic converters in uncontrolled conditions tend to convert sulfur into hydrogen sulfide (H₂S) that smells. As the sulfur content increases, efficiency of the catalytic converters decreases. Consequently, emissions of CO, HC and NO_x occur are increased, which can have serious consequences.

2.2.2 LPG (Liquid Petroleum Gas)

LPG (Liquid Petroleum Gas) is a blend of propane and butane compressed between 5 and 7 bars. Propane and butane mixture is liquefied by cooling to a low temperature or by compressing. When being liquefied, the mixture's volume is reduced 260 times in comparison to the gaseous phase. The LPG is a fuel like gasoline. Its density is 550 kg/m³. In its gaseous form, the LPG is heavier than air. When bearing in mind its effects on human health, the LPG is not toxic, however, it is unbreathable with slightly toxic effects [3].

The LPG has higher flame propagation speed compared to gasoline at the range of lean-to stoichiometric equivalence ratios. At the rich mixtures range, gasoline flame speed is superior. Compared to gasoline the energy content of the LPG is slightly higher, 45.7 MJ/kgK to 44 MJ/kgK of gasoline [4]. In addition, the LPG has an advantage in terms of octane number, which allows it to work at higher compression ratios.

Use of the LPG in Diesel engines is difficult to pay

²RON - Research Octane Number

off, due to the cost of investment in the adaptation of Diesel engines and research on the use of the LPG as a fuel in spark-ignition engines has shown [5] that:

- By a small increase in the pre-ignition angle, relative to the factory setting for the gasoline drive, the coefficient of variation of the indicated mean effective pressure (COVIMEP) can be reduced. At the same time, CO and HC emissions are decreasing, but NO_x emission is increasing. On the other hand, later ignition has the opposite effect followed by a reduction in engine power.
- The engine efficiency is lower at low speeds when running on gasoline and at higher speeds, the advantage is on the LPG side.
- The LPG combustion achieves significantly more favorable CO and HC emissions, five and seven times respectively, as well as twice as high NO_x emissions at higher engine speeds.

The LPG can be injected into the engine cylinders in the gaseous state, as well as by directly injecting fuel into the cylinder. This is described in detail in [6].

2.2.3 CNG (Compressed Natural Gas)

CNG (Compressed Natural Gas), is the same as the gas used to heat houses. Natural gas is a resource that is very widely available in the world. Because of its chemical composition, it is less polluting than gasoline or diesel. It consists mainly of methane and is compressed between 200 and 300 bars. It can be stored as a gas at ambient temperatures.

Compared to gasoline, natural gas has a lower burning rate, higher quenching distance and narrow flammability range. In addition, it requires a higher ignition energy [7].

The main advantages of the CNG are [8]:

- 77% less particle emission than a diesel.
- 11% reduction in CO₂ emissions (without taking the extraction method into account).
- 90% less nitrogen oxides.
- much cheaper than diesel or gasoline.

From the environmental and economic aspect, the disadvantage of the CNG application is that if it is not obtained by fermentation of plant waste, the ecologically positive impact of its application is significantly degraded, since during the extraction one part of methane always leaks and methane is a gas that has the more negative greenhouse effect impact of CO₂.

2.2.4 Hydrogen

Hydrogen could be an ideal fuel because it exists in nature in unlimited quantities. When burned hydrogen does not emit CO₂, but only water vapor and the air that remains after the combustion. Big obstacles are the price to produce hydrogen in a form suitable for use,

increased NO_x emission due to the high temperature of hydrogen combustion and the fact that hydrogen burns with a colorless flame. In the case of fire, the flame will not be visible to firefighters that can endanger their safety. High storage pressure of 350 bar (up to 700 bar) can affect the mood of users who need to drive such a vehicle. Metal hydride storage tanks provide a more cost-effective solution but can store less hydrogen. Due to the high pressure, very massive tanks are needed, which is difficult to accept for the passenger vehicles. Storing hydrogen in a liquid state requires exceptionally low temperatures (20 K), which requires a cryotank³ with efficient insulation. With all this in mind, it is hard to believe that hydrogen would emerge as a fuel for vehicle engines soon, although tests have been performed as early as the 1970s.

2.2.5 Alcohols

Alcohol contains the OH group in its molecules that is a suitable fuel component for spark-ignition engines. Producing of alcohol has been known since ancient times and is well developed. Alcohol can be transported in the same way as gasoline. Its characteristics in terms of resistance to detonation combustion are at the level of RON = 114.4, which is higher than the level that exists with gasoline, so engines powered by alcohol (primarily methanol and ethanol) can work with a higher compression ratio. Alcohols burn faster than gasoline, which means that their fuel pre-ignition map must be adjusted. Significantly higher heat of vaporization of alcohol, compared to gasoline, provides greater internal cooling of the fuel mixture and thus the degree of filling of the engine cylinder. Consequently, alcohols give a higher thermodynamic efficiency and even better performance. Due to the OH group, the calorific value of alcohol is significantly lower than the calorific value of gasoline, which implies significantly higher fuel consumption. In addition to that, an increased risk of corrosion must be considered. In the case of use of pure alcohol, there may be a need to preheat the intake air in winter conditions.

Alcohols can be used in their pure form or in combination with gasoline. In the case of mixing with gasoline, it should be borne in mind that fuel stratification can occur. Low concentrations of alcohol, of 5 to 10% Vol, in the mixture, in principle, do not represent any special problem, but the profit is small. Concentrations greater than 15% Vol. can stratify depending on external conditions, e.g., in cold weather and prolonged vehicle standstill. In the case of occasional mixing of fuel and hot weather, even the concentration of 30% Vol. of the methanol in the mixture will not stratify [11]. In the

³A cryotank or cryogenic tank is a tank that is used to store material at very low temperatures [9]. An insulated tank used for the storage of cryogenic liquids [10].

case of pure methanol, it is necessary to add a small amount of HC in the phase of cold start and engine warm-up, but also for the safety reasons. Alcohol burns with a colorless flame, which could endanger rescuers in the event of a vehicle fire. Engine lubricating oil must contain additives that will prevent formation of a sticky mass in the case of contact of the oil with alcohol, as well as anti-corrosion additives.

2.3 Vehicles powered by alternative fuels

2.3.1 LPG

If one compares the fuel supply systems, it can be seen that the LPG supply systems are generally at a much lower technological level than the corresponding gasoline systems, except when the engine was designed to use the LPG as fuel. When the LPG is an alternative fuel in the gasoline engine, this influences the combustion process and there appear additional problems with power regulation and exhaust composition. The owner can choose between power and money.

From the environmental aspect, the major attractions of the LPG, compared to the conventional gasoline, lie in its relatively low carbon content. The LPG burns cleanly with lower emissions of CO, CO₂ and HC. It provides better thermal efficiency and improved fuel economy [5]. Whether the use of the LPG drives will increase depends on several factors. One of the factors is the price of fuel. The price is significantly lower in the case of LPG compared to gasoline. It is the main stimulating factor for users because the state does not provide subsidies and tax relief for this fuel as it does for electric vehicles. If the LPG use increases, the price of fuel would also increase. Application of the LPG also has one essential drawback. Due to the fuel characteristics, drivers are forbidden to park the LPG vehicles in closed garages due to the risk of explosion.

2.3.2 CNG (Compressed Natural Gas)

The CNG-powered vehicles are usually vehicles with a dual-fuel drive and a two-part tank. Those allow them to switch to gasoline when they run out of CNG. Depending on the vehicle model, the CNG operation also implies a higher purchase price of a vehicle. The difference in prices of a new CNG vehicle and new diesel or gasoline vehicles usually ranges from EUR 500 to EUR 8000. It is possible to upgrade the CNG equipment to existing vehicles with gasoline engines, but it is a question of cost-effectiveness because the upgrade can cost 4-6000 EUR. Upgrading a Diesel engine is even more problematic and expensive, over 10,000 EUR. In all this, one should keep in mind the significant reduction of available luggage space. There are currently more than 20 million vehicles in the world running on natural gas [8]. The number of

such vehicles is increasing and it has been accelerated by increasing the number of the CNG pumping stations. The main advantages of the CNG are [8]:

- a CNG vehicle tank can be filled up as quickly as with conventional fuels, much faster than recharge batteries in electric vehicles.
- The CNG lessens the wear and tear on engines since it produces less combustion residue.
- a CNG vehicle can also run on biogas, which increases the environmental benefit.
- City buses and taxis running on the CNG offer a solution for the low-emission zones in big cities.
- Natural gas is transported via the underground transport and distribution network, which could significantly reduce the number of trucks on the roads.
- The CNG is lighter than air and vehicles that use this gas are not subjected to the ban of access to underground car parks.

Disadvantages of the CNG application in motor vehicles are [8]:

- Insufficient number of the CNG pumping stations and very rarely these stations sell biomethane.
- Vehicles with the CNG drive are not allowed access to the Eurotunnel and some ferry lines.

2.4 DiesOtto engine

One of the possible alternative solutions to improve the characteristics of internal combustion engines is a combination of Diesel and Otto engines, DiesOtto engine (Mercedes Benz) and Skyactiv-X (Mazda). Mazda was the first to introduce such a solution into series production. This solution uses Mazda's patented technology in which an extremely poor mixture ($A/F = 40$) is compressed to high pressure and burns as in Diesel engines. The spark plug ignites a small part of the rich mixture around. The rich mixture burns and heats the remaining compressed lean mixture. A pressure and temperature increase are creating conditions for the remaining mixture to ignite as with a Diesel engine. The fuel burns faster and more completely, which has a positive effect on performance and exhaust emissions. This engine does not have a turbocharger and it uses only a small compressor. Therefore, there is no delay in responding to a change in the position of the accelerator pedal [12].

The main advantages of the Skyactiv-X engine are shown in Figure 2. More detailed information about the Skyactiv-X engine is available in [13].

Another such attempt is taking place at Mercedes Benz. The DiesOtto engine combines many technologies and combines variable compression, turbocharging and direct injection. The spark plugs fire when compression is low. They do not fire when compression is high enough to self-ignite the air-fuel mixture. The compression ratio varies with engine load [14]. This technology is more

complex than Mazda's and is still in the experimental phase for now. Due to the complicated construction, it is to expect a higher price of such engines. Such a solution can be accepted mainly by large and expensive vehicles, so it is not surprising why Mercedes chose the S class to promote this technology.

2.5 Electric vehicles

Instead of internal combustion engines, electric vehicles use one or more electric motors for propulsion. A high-capacity rechargeable battery is required to ensure a sufficient action radius. While Diesel engines without problems provide vehicle mobility of more than 1000 km, modern batteries parred with electric motors cannot offer that. Aware of these shortcomings, manufacturers of electric vehicles are constantly trying to improve the quality of used electric motors. They must pay even more attention to development and quality of batteries. Now, manufacturers encounter the need for constant compromises. By improving one feature, they endanger others. For example, to improve a vehicle journey range, the battery's charging speed, or storage capacity, a compromise may need to be made in its durability or life expectancy [15]. Lithium-ion batteries currently are considered the best technical solution, but their production is expensive and the method of obtaining lithium significantly endangers the environment.

Some companies, producers of lithium-metal batteries, claim that they have found a way to prevent fires⁴ and dendrites⁵ while still allowing ions to easily pass without degrading the battery performance. The batteries will become significantly cheaper and electric vehicles will be able to compete with gasoline-powered vehicles [16].

One of the advantages of the electric motor drive is a significantly smaller number of moving parts and parts in general, which facilitates vehicle maintenance and reduces operating costs.

Efficient recovery/regeneration of braking energy is easily achievable with electric motors, with the same machine - the drive motor, which instantly becomes a generator.

Vehicles use different variants of electric motors for their drive. For example, the Tesla Roadster uses a 214 kW asynchronous motor with a 90% efficiency.

⁴Physical damage to battery cells, pollution in the electrolyte or the poor quality of the separator may cause a fire in li-ion batteries⁴, [17].

⁵Lithium dendrites are metallic microstructures that form on the negative electrode during the charging process. Lithium dendrites are formed when extra lithium ions accumulate on the anode surface and cannot be absorbed into the anode in time. They can cause short circuits and lead to catastrophic failures and even fires⁵, [18].

	Otto engine	Skyactiv-X	Diesel engine
Small fuel consumption	○	✓	✓
High torque	○	✓	✓
Quick response	○	✓	✓
High power output	✓	✓	○
Low heat emission	✓	✓	○
Cleaner exhaust gases	✓	✓	○

Figure 2 What Skyactiv took from Otto - and what from the Diesel engine, [12]

Table 2 Comparison of the number of kilometers traveled and the price of ZOE and Clio vehicles from 2016

	Renault ZOE Experience R110 Z.E. 50		Renault Clio (gasoline) Experience TCe 100		Clio V Experience (diesel) 1.5 BLUE dCi 85 EU6d-T	
	km	EUR	km	EUR	km	EUR
Average	42837	7267	46707	7586	57206	6213
Median	40337	7000	45707	7500	70100	7990
New_2021	0	20490	0	15789	0	16590

Source: [19]

The Rimac Concept one uses four water-cooled synchronous motors with permanent magnets with a total power of 913 kW and an efficiency of 97%. One of Nissan LEAF's best-selling electric cars uses a synchronous power motor like its competitor Renault ZOE.

3 A comparative analysis

The propulsion by internal combustion engines is complex. In addition to mechanical, it also involves many thermal processes. Converting fuel energy into mechanical energy involves combustion and providing optimal conditions for fuel combustion. There are also many moving parts. Therefore, the maximum degree of fuel energy utilization of vehicle engines is about 0.4 for Diesel engines and about 0.35 for Otto engines. With electric motor drive, the efficiency is up to 0.97, depending on the type of motor, power and energy efficiency class. When adding appropriate power transmissions (differentials, gearboxes and reducers) to the drive units, the efficiency is further reduced, with the situation being more favorable with electric drives. That would mean that the electric drive is more energy-efficient and even more environmentally friendly. But is it true? All this refers to the period from bringing energy or fuel into the vehicle up to the road on that the wheel moves. The situation becomes more complicated and unclear when we observe the complete cycle from the beginning of mining raw materials for the vehicle production and operation, including the method of obtaining electricity, up to the movement of vehicles on the road. There is a big difference whether the electricity is produced in the coal-fired power plants or some other, more environmentally friendly way. The situation is different in this respect in different countries. When

one take the time factor into account and that the technologies are improved daily, it is easy to understand that it is impossible to give an unambiguous general conclusion.

In addition, when the analysis talks about the environmental aspect of the electric cars application, one should keep in mind the annual number of kilometers traveled by one vehicle. Due to the current limitations regarding the battery life, those electric vehicles that exceed many kilometers are more environmentally friendly. If one compares electric propulsion with gasoline and diesel propulsions, on the example of Renault car models ZOE and Clio, as shown in Table 2, one can notice that owners of ZOE cars had covered, on average, fewer kilometers than Clio owners with gasoline propulsion about 9.03% (or, comparing medians 13.3%). The difference is much bigger when comparing electro to diesel. Average the ZOE driver passed 33.5% (or comparing medians 73.7%) less than the owner of the diesel-powered Clio. The mileage of the average and median of offered ZOE vehicles were taken as a reference value, respectively. The analysis we performed on the first 30 vehicles from 2016 from the category used cars "Top Angebot" on May 7, 2021.

On average, the owners of ZOE vehicles lost the most in the value of their cars, which after less than five years were worth only 35% of the current purchase price of a new vehicle. In the case of the gasoline- and diesel-powered Clios, the corresponding values were 48% or 37.4%. Although it looks similar numerically, the difference between prices of electric- and diesel-driven cars is significantly unfavorable, because analyzed diesel cars have covered much more mileage and they are notably cheaper. If one looks at the median values of used vehicles, it can be seen that the vehicle values after less than five years are 34% for ZOE, 47.5% for Clio

Table 3 Fuel consumption or kWh for different types of vehicle propulsion Renault Clio (2021)

Drive type		Electro*	CNG	LPG	Gasoline	Diesel
Liter of fuel or kWh		6575 kWh	1371	2299	1977	1573
kg CO ₂ for 40337km	Coal	0.94 kg/kWh	6180 ^I			
	Fuel oil	0.8 kg/kWh	5260 ^{II}			
	Natural gas	0.5 kg/kWh	3287 ^{II}	3751	3792	4840
	Solar, wind, hydro, nuclear	0.05 kg/kWh	328 ^{II}			3792
	USA average	0.709 kg/kWh	4662 ^{III}			

Sources: ^I [20], ^{II} [21], ^{III} [22]

gasoline and 48.2% for Clio diesel.

Today's automotive industry is shifting to electric-driven cars without a globally conducted, comprehensive analysis that would cover all the critical points, from the start of vehicle production to vehicle destruction. No one can say with certainty that electric cars are the best environmentally friendly solution. Next are compared the vehicles from Table 2 and an additional electric vehicle of similar power and the fuel consumption and CO₂ emissions were calculated, for the median kilometers covered by analyzed electric cars. One can see that when electricity is obtained by burning coal, one would get significantly higher CO₂ emissions from electric-driven cars. Such a comparison is shown in Table 3. For the calculation results shown in Table 3, the reference value is the mileage corresponding to the median mileage achieved by the offered electric vehicles, as determined in Table 2. In the second table row are shown the energy consumption in the case of an electric vehicle and fuel consumption in liters for the reference mileage and different engine types. In the third row, CO₂ emissions for the observed vehicles are shown, with more detailed results being given in the case of electric vehicles, where they depend on the method of obtaining electricity. Thus, e.g. 1 kWh of electricity, when produced from a coal-burning power plant, will generate 0.94 kg of CO₂ emissions to the atmosphere according to CNCF.

In the case of obtaining electricity using the natural gas, electric vehicles become more competitive in terms of CO₂ emissions, but only using nuclear, solar, hydro and wind energy significant reduction in CO₂ emissions come to the fore. However, even in this case, other parameters of pollution caused by the construction of power plants and the production of electric vehicle batteries should not be neglected. If we analyze data on CO₂ emission for electricity production in the United States, we can see no practical benefit from producing and using electric vehicles. one can expect benefits only there where it is possible to produce electricity without fossil fuels.

The analysis performed in this research showed that the expectations were not justified in all the cases and refuted the set null hypotheses at the expense of alternative ones:

H_{a1}: Internal combustion engines are in some situations

more environmentally friendly than the use of electric motors to power passenger motor vehicles.

H_{a2}: The use of internal combustion engines is, in some situations, more favorable than the use of electric motors to drive passenger motor vehicles, from an economic point of view.

4 Conclusions

Otto and Diesel engines are used to power vehicles for more than a century and were constantly improved. The enormous progress of technology, primarily information technology, has enabled a significant increase in the quality of engines and vehicles. The technology also helped the rise of the fuels' quality level and the management of engine work processes. Regardless of the type of engine and the fuel used, modern engines have a long service life. They are economical and environmentally more acceptable than engines from the last century. Given the ever-growing number of vehicles and people and the limited resources of the Earth's atmosphere, development continues exploring new ways to avoid the negative impact of motorization. One of the old ideas that went into focus again over the past decade and are still receiving the most attention with financial incentives from vehicle manufacturers and car buyers is electric propulsion in passenger vehicles and much less in buses.

To promote the production and sale of electric vehicles, the governments of many countries provide subsidies to both manufacturers and buyers of these vehicles. That cannot go on indefinitely because it is logical that it must stop once. After all, the countries will lose the significant revenues they now generate from every liter of fuel sold.

In addition to continuous improvements of powertrains that could reduce the negative impact of vehicles on the environment, it is necessary to take much more radical measures than these. It is to reduce the number of cars moving around the globe and even the total number of vehicles. No matter how small the impact of an individual vehicle is, they all together have a crushing influence on the climate change. Any energy used to power vehicles causes an increased thermal load on the atmosphere, especially in large cities. No matter

how the raw materials for the vehicle production were obtained, they will affect the amount of waste needed to be dealt with.

Authors believe that one of the best solutions that would protect the environment and would not lower the level of quality of human life, is the replacement of ownership of vehicles by shared use of cars, car-sharing, on the principle of subscription. Car-sharing enables the same as classic car rental, but in a more flexible way [23]. That would significantly reduce the number of cars on the streets and the required number of vehicles in general, the number of necessary garage spaces, the required asphalted area intended for motor vehicles and

the required production of materials for car production. That is the win-win solution in every way. Applying the ride-sharing model in the intercity traffic can obtain an additional improvement [24].

In addition to this solution, it is necessary to improve the mass transportation. Massive use of the environmentally friendly metro, tram and trolleybus will reduce air pollution to acceptable limits.

One of the positive solutions in terms of pollution could be to limit the growth of cities, or, better said, to improve the dispersion of the population of the territory. Several smaller cities are in every respect more favorable than one large city.

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