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ARE ELECTRIC CARS NOW AN ENVIRONMENTALLY FRIENDLY SOLUTION? YES AND NO.

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***Key words**: gasoline, diesel, LPG, CNG, electric car, fuel consumption, ecology, CO_2 emission.*

***Abstract:** Electric vehicles are increasingly being cited as the ideal solution to reduce environmental pollution, but all pollution factors are rarely considered. In addition to exhaust emissions, this paper also considered other most important elements. It analyzes some basic characteristics of potential fuels for internal combustion engines, as well as possible sources of electricity. Then, a comparative analysis of the driving and environmental characteristics of cars powered by fossil fuels and electricity is done. The research has shown that the use of electric vehicles in cases of obtaining electricity from coal from the environmental aspect is not justified. The research also analyzed the economic aspects of the application of electric vehicles. Within the conclusions of the research, some more radical solutions have been proposed for reducing air pollution and improving the quality of life in cities.*

1 INTRODUCTION

The modern world pays more attention to environmental protection than ever before. Efforts to protect air quality are particularly visible in large cities, but much less attention is paid to environmental protection in areas that are less visible and not under public scrutiny.

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Sulfur dioxide and soot were considered the main pollutants in the developed world until the 80s of the 20th century primarily due to the use of low-quality fossil fuels, coal, and fuel oil. With the sharp increase in the number of vehicles in the 1960s and 1970s, new risk factors appeared pollution by lead, nitrogen oxides, and unburned hydrocarbons. With the improvement of technology, the norms became stricter over time. New standards have contributed to the creation of better-quality fuel systems for internal combustion (IC) engines. Carburetors are obsolete, and controlled injection is becoming more precise. The quality of engine parts has been significantly improved as well as the quality of fuel. Now, the harmful emission of one vehicle has been reduced several times compared to older vehicles, but the increase in the number of people and their purchasing power have led to accelerated growth in the number of motor vehicles, so pollution is becoming more noticeable. Compared to 1960, the total number of registered cars 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, or 182 vehicles per 1000 inhabitants. If these trends continue, it is not difficult to conclude that critical limits will be reached soon. If we add to this the growth of air traffic (which is not the topic of this paper), the challenges become more pronounced. At the beginning of the 21st century, the focus shifted from lead (Pb), nitrogen oxides (NO_x), and unburned hydrocarbons (HC) and soot, which were reduced by exhaust catalysts, soot traps, and changes in fuel quality and fuel injection technology, to carbon dioxide.

This paper aims to consider the justification of replacing internal combustion engines with electric motors from the economic and environmental points of view. The null hypotheses are set as:

- H_{01}: Electric cars are always more environmentally friendly than cars powered by internal combustion engines in terms of CO_2 emissions.
- H_{02}: Cars powered by electric motors are always more economically advantageous than passenger cars with internal combustion engines.

Alternative hypotheses have also been set:

- H_{a1}: There are cases when electric cars are not more environmentally friendly than vehicles powered by internal combustion engines in terms of CO_2 emissions.
- H_{a2}: There are cases when electric-powered cars are not more affordable than vehicles with internal combustion engines from an economic point of view.

2 FUELS

Hydrocarbon-based fuels are still most used to power motor vehicles, primarily gasoline and diesel, but for various reasons, alternative fuels are occasionally put in focus, primarily liquefied petroleum gas (LPG), methane (CNG), methanol, ethanol, and hydrogen, as well as mixtures thereof. Each of the fuels has its advantages and disadvantages, which over time have changed in weight with the change of technology. Nowadays, the emphasis is on the impact of fuel on the environment, on CO_2 emission, and fuel consumption. Before analyzing the behavior of vehicles depending on the type of propellant, we will first look at some basic characteristics of possible fuels for the propulsion of vehicle engines.

2.1 Fuels for vehicle diesel engines

From the environmental aspect, the most important for diesel fuel are the lowest possible density, the lowest final boiling point, and the lowest possible sulfur content. Burnt sulfur is converted to sulfur dioxide (SO_2) by more than 95%. Sulfur compounds cause increased corrosion, increased air pollution, and acid rain. The residue mixed with soot forms the particle mass that is considered carcinogenic. Thanks to improved fuel production processes, SO_2 emissions from diesel engines are no longer a risk to the environment. Since particles cannot be completely removed by limiting the sulfur content, additional exhaust gas treatment with appropriate filters is necessary.

Biodiesel appears as an alternative to classic diesel fuel. The idea is, not to emit more CO_2 into the atmosphere than plants take from the air for their growth. In this way, no additional amount of CO_2 would be emitted into the atmosphere. However, biodiesel brings with it new problems in the form of a small increase in NO_x emissions, an appearance of "fritting" odor from the exhaust and polycyclic aromatic hydrocarbons, insufficient stability, causing substantial deposits on the nozzles and in the combustion chambers. [1, p. 821]

The use of other fuels in diesel engines requires significant design changes, so other fuels are not used in cars.

2.2 Fuels for Otto engines

The most common fuel for Otto engines (Spark Ignition engines - SI) is gasoline. As an alternative to gasoline, they appear as fuels in SI engines [1, p. 836]:

- LPG - Liquefied Petroleum Gas. Pressurized, liquefied autogas 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), is also termed wood spirit.
- ETOH - Ethanol. Alcohol from sugar-containing plants.
- GH2 - Gaseous Hydrogen. Can be made from water and all hydrogen-containing energy carriers.
- LH2 - Liquefied Hydrogen. Hydrogen is liquid at low temperatures.

The use of liquefied gases in SI engines brings advantages in the field of fuel consumption and emissions, but only in engines that are designed for that. When adapting the engine, dual-fuel propulsion, more favorable exhaust emissions will be obtained due to a more favorable C/H ratio, but high resistance to detonation cannot be fully exploited. In addition, the storage of the second fuel requires an additional tank that significantly reduces the usable space of the trunk.

2.2.1 Gasoline

Gasoline is a mixture of reformates, crack gasoline (olefins), pyrolysis gasoline, isoparaffins, butane, alkylates, so-called replacement components such as alcohols and ethers, and slight amounts of additives. [1, p. 824] Due to more precise control of the fuel-air mixture, many of today's new engines can work with the direct fuel injection into the cylinder and in the stratified charge mode.

Gasoline tanks are exposed to a certain risk of explosion. An explosion can occur if the volumetric ratio of fuel and air is 1-8%. Under normal circumstances, the concentration of gasoline in the tank is significantly above the upper limit. In addition to the appropriate concentration, there must be a source of ignition of the mixture, so these risks are at a very acceptable level.

The octane value of gasoline, which defines the resistance to detonation combustion, by removing lead from use, is regulated by ethers in addition to the further developed high-octane, classic components, and alcohols. There is no uniform standard for the quality of gasoline in the world, so different types of gasoline appear in different, even high-developed, countries in terms of composition and octane values.

Due to the reduction of 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. Various other additives are added to gasoline to improve the characteristics, but also the color to differentiate gasoline by types, and to identify gasoline manufacturers.

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. LPG is a fuel like gasoline but with a lower density. In its gaseous form, LPG is heavier than air. LPG is not heavily toxic, but it is unbreathable with slightly toxic effects [2]

Compared to gasoline the energy content of LPG is slightly higher [3] LPG has a higher-octane number than gasoline, which allows it to work at higher degrees of compression. It can be injected into the engine cylinders in the gaseous state, but also by directly injecting fuel into the cylinder. [4].

Studies of the use of LPG as a fuel in SI engines have shown [5] that CO and HC emissions can be reduced, five and seven times respectively, but with twice the NOx emissions at higher engine speeds.

2.2.3 CNG (Compressed Natural Gas)

CNG (Compressed Natural Gas) is less polluting than petrol or diesel and consists mainly of methane. It is compressed between 200 and 300 bars and 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. Also, it requires higher ignition energy [6]

The main advantages of CNG are [7]:

- 11 % reduction in CO_2 emissions (without taking the extraction method into account)
- 90% fewer nitrogen oxides
- much cheaper than diesel or petrol.

From the ecological point of view, the disadvantage of CNG is that if it is not obtained by fermentation of plant waste, the ecologically positive impact of its application is significantly degraded, because during extraction one part of methane always leaks, and methane is a gas that has a more negative impact than CO_2.

2.2.4 Hydrogen

Hydrogen could be an ideal fuel because it is found in nature in unlimited quantities, and when burned it does not emit CO_2, but only water vapor. However, the big obstacles are the price of obtaining hydrogen in a form suitable for use, but also the increased NOx emissions due to the high temperature of hydrogen combustion in the presence of air in the engine cylinders. Because it burns with a colorless flame in case of fire, the flame will not be visible to firefighters, which can endanger their safety. Its use in automobiles (for now) is not acceptable except for experimental purposes.

2.2.5 Alcohols

Alcohols in their molecules contain the OH group which is a suitable fuel component for SI engines. Alcohol can be transported in the same way as gasoline. The characteristics of alcohol in terms of resistance to detonation combustion are better than with gasoline, so engines powered by alcohol can work with a higher compression ratio. Significantly higher heat of evaporation of alcohol compared to gasoline provides greater internal cooling of the fuel mixture, and thus the degree of the engine cylinder filling, and consequently a higher thermodynamic degree of efficiency, and even better performance. Due to the OH group, the thermal power of alcohol is significantly lower than the thermal power of gasoline, which implies significantly higher fuel consumption. In addition to higher fuel consumption, an increased risk of corrosion must be considered, and in the case of the use of pure alcohol, there may be a need to preheat the intake air in winter conditions.

Alcohol can be used in pure form or mixed with gasoline. In the case of mixing with gasoline, fuel stratification can occur when alcohol concentration higher than 15% vol. If the weather is warm and/or the mixture is stirred occasionally, neither the mixture with the methanol concentrations of 30% vol. will not stratify. (Čekerevac, 1977) The use of alcohol is not just a pure fuel change. Engine lubricating oil should also be modified. It must contain anti-corrosive additives and additives that will prevent the formation of a sticky mass in the oil-alcohol contact.

2.3 Vehicles powered by alternative fuels

2.3.1 LPG

When LPG is used as an alternative fuel on an engine designed to run on gasoline, the combustion process changes, so there appear additional problems with power regulation and exhaust composition. The advantages of one of the two criteria must be sacrificed.

The major attractions of LPG, in comparison with conventional gasoline, lie in its relatively low carbon content, causing it to burn cleanly with lower emissions of CO, CO_2, and HC. Also, higher thermal efficiency and therefore improved fuel economy can be obtained from internal combustion engines running on LPG. [5] Whether the use of LPG drives will increase or decrease depends on several factors. The main stimulus factor for consumers is the significantly lower price compared to the price of gasoline. The application of LPG also has one essential drawback. Due to the characteristics of the fuel, it is forbidden to park vehicles with LPG in closed garages due to the risk of explosion. Also, in the case of dual-fuel drive, the size of the luggage space is significantly reduced.

2.3.2 CNG (Compressed Natural Gas)

CNG-powered vehicles are usually vehicles with a two-fuel drive and a two-part tank. This allows them to switch to gasoline when they run out of CNG. Depending on the vehicle model, CNG propulsion also means a higher purchase price of the vehicle by EUR 500 to 8000, depending on the car model. It is possible to upgrade the CNG plant 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. The number of such vehicles is increasing, and it has been accelerated by increasing the number of CNG pumping stations. CNG is lighter than air, and vehicles that use this gas can access underground car parks [7].

The disadvantages of the use of CNG in motor vehicles [7] are, above all, the insufficient number of pumping stations for CNG and the fact that they rarely sell biomethane. For some users, a major drawback is that CNG-powered vehicles are not allowed access to the Eurotunnel and some ferry lines.

2.4 DiesOtto engine

In addition to alternative fuels, there are also alternative solutions for the construction and principles of engine operation. Two such solutions are a combination of diesel and Otto engines, DiesOtto engine (Mercedes Benz) and Skyactiv-X (Mazda).

Mazda was the first who introduced such a solution into series production. With the patented Skyactiv-X solution, an extremely poor mixture (A/F = 40) is compressed at high pressure, as with a diesel engine, and a small part of the rich mixture around the spark plug is ignited. This ignited part heats the remaining compressed mixture, the pressure, and temperature rise, and the conditions are created 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 emission. The engine does not have a turbocharger, but only a small compressor, so there is no delay in responding to a change in the position of the accelerator pedal. [8] The solution is favorable because it takes over low fuel consumption, High torque, and quick response from the diesel engine, and a high-power output, low heat emission, and cleaner exhaust gases from the Otto engine. [9]

Another similar attempt is taking place at Mercedes Benz. The DiesOtto engine combines many technologies including variable compression ratio, turbocharging, and direct injection. The spark plugs fire when compression is low, and do not fire when compression is high enough to self-ignite the air-fuel mixture. The compression ratio varies with engine load. [10] DiesOtto technology is more complex than Mazda's Skyactive-X and is still in the experimental phase.

2.5 Electric vehicles

One or more electric motors, asynchronous or synchronous, are used to drive electric cars. Synchronous motors provide a higher degree of efficiency, up to 97%. To ensure a sufficient action radius, a high-capacity rechargeable battery is required. Today's batteries in combination with today's electric motors are inferior in terms of action radius compared to internal combustion engines. Battery capacity is the weakest point of electric drive. Currently, the best technical solution is lithium-ion batteries, although their main challenge is how to prevent fires and dendrites while still allowing ions to easily pass through, without degrading the battery performance. Many manufacturers are working to solve these problems, and only their successes can enable competition with IC engines. For now, the production of batteries is expensive, and the way of obtaining lithium greatly endangers the environment.

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

In addition, with electric motors, efficient recuperation/regeneration of braking energy is easily achievable, using the same machine - a drive motor that instantly becomes a generator.

3 A COMPARATIVE ANALYSIS

Converting fuel energy into mechanical energy in IC engines involves combustion and providing optimal combustion conditions, but also many moving parts, which makes the driving complex. Therefore, the maximum efficiency of new vehicle engines is around 0.4 for diesel engines and around 0.35 for Otto engines. It is even lower with used engines. In the case of electric motor drive, the efficiency is up to 0.97, depending on the type of motor, power, and energy efficiency class. When the power transmission elements are added to the drive units, the efficiency is further reduced. With electric propulsion, the situation is more favorable due to the shorter power transmission chain to the vehicle wheel and possible energy regeneration, which makes electric propulsion more energy-efficient, and, consequently, more environmentally friendly. However, this conclusion may prove to be incorrect or at least more uncertain when observing the complete cycle from the beginning of mining of raw materials for the production and operation of vehicles to the movement of vehicles on the road, including the method of obtaining electricity.

When talking about the environmental aspect of the application of electric cars, one should keep in mind the annual number of kilometers traveled by one vehicle. Due to the current limitations regarding battery life, those electric vehicles that drive a lot of kilometers are more environmentally friendly.

Table 1 Comparison of the number of kilometers traveled and the values of used Volkswagen Golf 7 from 2018 and new the 2021 Golf 8 cars in different versions

Volkswagen Golf 7 the year 2018	Gasoline		Diesel		Hybrid		Mild Hybrid	Electric	
	km	EUR	km	EUR	km	EUR	EUR	km	EUR
Average	54681	15797	109588	14417	30833	24070	-	28980	19370
Median	53677	15900	103623	14725	31800	22999	-	28011	19495
Golf 8 new 2021	1	18146	1	24610	1	36499	24700	0	36075

Source: [11]

Table 1 shows the results of comparing the values of used Volkswagen Golf 7 vehicles from 2018 with each other and with the new Golf 8 vehicles from 2021. The results cannot be completely comparable, because these are different generations of vehicles, but they are still indicative enough for analysis. For used vehicles, the data for the 30 cheapest vehicles from the "Top Angebot" group was considered, except in the case of hybrid vehicles, where only 9 vehicles from 2018 were on offer on May 28th. For new vehicles, data were taken for the cheapest models with a power of 100 to 110 kW. In vehicles with petrol engines, half of the vehicles were 110 kW, and the other half had 92 kW engines. In diesel engines and hybrids, all units were 110 kW. In electric propulsion, the motors had a power of 110 kW.

If we compare the mileage, we can see that vehicles with diesel engines traveled on average twice as much as vehicles with gasoline engines, 3.57 times more than vehicles with hybrid drive, and even 3.79 times more than vehicles with electric drive. Also, the corresponding ratio of the median of the diesel drive with the medians for petrol (1.93), hybrid (3.25) and electric drive (3.7) is like the mean values, which indicates that there were no extremes in the vehicle groups. Mileage indicates the fact that vehicle owners thought about their needs when buying a car. Those with the greatest needs opted for diesel engines, and those who opted for electric propulsion generally used their vehicles much shorter. The reasons probably lie in the capacity of the batteries because someone who travels fifty thousand kilometers a year has no desire to charge the batteries every two or three hours of driving. The value of the hybrid vehicle is at the level of about 66% of the purchase price after three years of operation. From the aspect of comfort, it is more favorable to use vehicles with hybrid drive, than electric vehicles. In the case of vehicles with hybrid drive, there is also a variant of the so-called "Mild hybrid", but in such vehicles, the electric motor is used only to assist the basic engine in acceleration and cruising, because such an electric motor cannot start the vehicle independently. The real benefit for the vehicle buyer is most often that hybrid vehicles (no matter how large the electric motor they have) are taxed more favorably in some countries than vehicles with IC engines.

If we assume that the prices of new Golf 8 vehicles are approximately equal, or at least in the same proportion, to the prices of new Golf 7 vehicles at the time of purchase, and if we compare the prices of new vehicles with the lowest level of equipment, we see that electric vehicles and hybrid vehicles are significantly more expensive than vehicles powered by Otto and diesel engines, almost twice as expensive as vehicles with gasoline engines and 50% more expensive than vehicles with diesel engines. After three years of operation, the average value of vehicles with gasoline engines is at the level of approximately 87% of the purchase price, and electric vehicles, which have covered half the mileage, about 54% of the purchase price. In the case of diesel engines, the corresponding value was 58.6%, but it should be borne in mind that vehicles with diesel engines covered significantly more kilometers than others.

Although today's automotive industry is shifting towards electric propulsion, without a globally conducted, comprehensive analysis that would cover all critical points, from the start of vehicle production to vehicle destruction, it cannot be said with certainty that electric cars are the best environmentally friendly solution. [12] Moreover, if we consider the vehicles in Table 1 in the analysis and calculate fuel consumption and CO_2 emissions for the median kilometers of electric vehicles, in the case when electricity is obtained by burning coal, significantly higher CO_2 emissions are obtained with electric propulsion (Table 2).

Table 2 Fuel or electricity consumption and CO_2 emissions for different types of Volkswagen Golf vehicle propulsion (2021)

Drive type			Electro*	CNG	Gasoline	Diesel
Liter of fuel or kWh			2515 kWh	848	994	760
kg CO_2 for 19495 km	Coal	0,94 kg/kWh	2364[I]			
	Fuel oil	0,8 kg/kWh	2012[II]			
	Natural gas	0,5 kg/kWh	1006[II]			
	Solar, wind, hydro, nuclear	0,05 kg/kWh	101[II]			
	USA average	0,709 kg/kWh	1426[III]	1920	2261	1988

Sources: I [13] II [14] III [15]

With obtaining electricity by using natural gas, electric vehicles become more competitive in terms of CO_2 emissions, but only with the use of nuclear, solar, hydro and wind energy does a real reduction in CO_2 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.

The analysis performed in this paper showed that the expectations were not justified in all cases and the set null hypotheses are rejected in favor of alternative hypotheses:

H_{a1}: There are cases when electric cars are not more environmentally friendly than vehicles powered by internal combustion engines in terms of CO_2 emissions.

H_{a2}: There are cases when electric-powered cars are not more affordable than vehicles with internal combustion engines from an economic point of view.

In addition, to produce new "greener" cars, we must look for solutions that would in principle enable the reduction of pollution. We believe that one of the best solutions in urban conditions would be to improve public city transport and replace the ownership of the vehicle with shared use of vehicles, car sharing, on a subscription basis. Car-sharing enables the same as classic car rental, but in a more flexible way. [16] Thus, while maintaining the existing quality of life, the number of cars on the streets and the required number of cars in general, as well as the number of required garage spaces and the required area of paved streets and the required production of materials for making cars, would be significantly reduced. In intercity traffic, additional improvement can be achieved by applying the ride-sharing model. [17]

One of the positive solutions in terms of air pollution and pollution, in general, could be to limit the growth of cities, or, better said, to improve the dispersion of the population on the territory. Several smaller cities are in every respect more favorable than one large city. [12]

4 CONCLUSIONS

Internal combustion engines have been used to power vehicles for more than a century and have been constantly improved so that they have reached a remarkably high level of quality. Given the ever-growing number of vehicles and people and the limited resources of the Earth's atmosphere, development must continue while seeking alternative solutions. One of the ideas, which was spread over the past decade and is still receiving the most attention with financial incentives to both vehicle manufacturers and car buyers is the application of electric drives. It is certain that this cannot go on indefinitely, and that it must stop once because the states will be left without the significant revenues, they now generate from every liter of fuel sold. Therefore, development must continue to reduce the cost of production. This causes problems with pollution by other components. That is why much more radical measures than before should be taken. It is necessary to reduce the number of vehicles moving around the globe, and the total number of vehicles.

In addition to the search for environmentally friendly car propulsion, it is necessary to consider new conceptions of the organization of cities and the organization of traffic in those cities and between them.

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ЕЛЕКТРИЧЕСКИТЕ АВТОМОБИЛИ ДНЕС ПРИРОДОСЪОБРАЗНО РЕШЕНИЕ ЛИ СА? ДА И НЕ.

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Ключови думи: *бензин, дизел, пропан-бутан (LPG), компресиран природен газ (CNG), електрически автомобил, разход на гориво, екология, емисии на* CO_2.

Резюме: *Електрическите превозни средства все повече се признават за идеалното решение за намаляване на замърсяването на околната среда, но всички фактори на замърсяване рядко се вземат предвид. Освен емисиите на отработени газове настоящият доклад разглежда и други много важни елементи. Той анализира някои основни характеристики на потенциалните горива за двигатели с вътрешно горене, както и възможните източници на електричество. След това се прави сравнителен анализ на шофирането и на екологичните характеристики на автомобили, задвижвани от изкопаеми горива и електричество. Изследването показва, че използването на електрически превозни средства при получаване на електроенергия от въглища не е оправдано от екологична гледна точка. Изследването анализира и икономическите аспекти на прилагането на електрически превозни средства. В заключението на изследването са предложени някои по-радикални решения за намаляване на замърсяването на въздуха и подобряване на качеството на живот в градовете.*