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Comparative assessment of the efficiency of some car drives

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Comparative assessment of the efficiency of some car drives

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Abstract. The fundamental basis for the scientific progress is the cheaper technology. Systems analysis and engineering, decision-making systems are based on data completeness and their validation. The study aims to provide the following grounds for a systematic comparison of economic and environmental performance of vehicles with different fuel drives. The issue of logistical attractiveness and compatibility for Ukraine is especially relevant today. Thus, specific fuel consumption is calculated by determining the cost of electricity that goes to charge the traction battery from the mains and is equivalently converted into the cost of fuel. The paper presents a method of calculating the equivalent fuel consumption for electric vehicles according to European (l per 100 km) and American standards (miles per 1 gallon). According to the results of fuel efficiency studies, it is established that the equivalent fuel consumption on the territory of Ukraine of the studied electric vehicles is 8-10 times lower than the fuel consumption of cars of the same class with internal combustion engines.

1. Introduction

The increase in the world cars fleet, which exceeded 1 billion units, caused the huge emissions of flue gas into the atmosphere, which greatly worsened the environmental situation.

The imposition of increasingly stringent environmental standards on internal combustion engines (ICEs) has led world engineering to seek alternatives to the use of ICEs on vehicles that have become electric motors.

The use of electric motors in vehicles requires an electricity source. Lithium-ion batteries are the most widely used because of a number of advantages, such as high power capacity, specific power, and an enough resource compared to lead-acid, nickel-cadmium or sodium-metal-chloride batteries. At the same time, this type of energy elements is capable of igniting or even exploding in mechanical damage or recharging [1, 10].

2. Method of calculating the equivalent fuel consumption development

The undoubted advantage of electric vehicles (EV) is not only their environmental friendliness, but also their cost-effectiveness. The constant increase in the cost of petroleum products outlines the reasons why consumers choose low-fuel-efficient cars without reducing technical performance. For electric vehicles, the economic component can be described by the equivalent fuel savings.

The equivalent fuel savings will be different in different countries for one brand of electric vehicle. This is due to the different cost of electricity and fuel. Thus, calculating and estimating the equivalent fuel consumption of electric vehicles in different countries is an actual task. Methodological bases for estimating the fuel economy of electric vehicles have been developed. This will allow potential buyers, owners or economists of the trucking industry to objectively estimate the equivalent fuel consumption and to successfully select a particular brand of electric vehicle.

According to [4], as well as the most environmentally friendly electric vehicle (the lowest energy consumption per unit of distance) in 2018, Hyundai Ioniq Electric is equipped with an electric motor of 120 hp. (88 kW), which develops torque of 295 Nm, consuming combined (55% of highway, 45% of city) 25 kW / 100 miles or equivalent in the US fuel market is 136 MPGe, lithium energy capacity - ionic battery is 28 kWh. The claimed mixed cycle run on a single full charge of the battery under the EPA tests is 124 miles (198 km) [5,6].

The second place is occupied by Tesla Model 3 Long Range, equipped with an electric motor with a capacity of 283 hp. (211 kW) with a maximum torque of 510 Nm, which uses in the combined mode 26 kWh / 100 miles or 130 MPGe, the energy capacity of the lithium-ion battery is 75 kWh. The declared mileage in the mixed cycle on one full charge of the battery according to EPA tests is 325 miles (520 km) [7,8].

Closes the top three BMW i3, equipped with an electric motor with 168 hp. (125 kW) with a maximum torque of 250 Nm, which in combined mode uses 27 kWh / 100 miles or 124 MPGe, the energy capacity of the lithium-ion battery is 42 kWh. The declared mileage in the mixed cycle on one full charge of the battery according to EPA tests is 160 miles (256 km) [9-11].

According to the American Automobile Internet Resource [3], various ratings have been compiled, including the most saving electric vehicles, citing the latest trends in world automotive production. There is a difference between the European and American units. For convenience, we will hereafter indicate both dimensions of quantities. According to American standards, the mileage (1 miles = 1.609 km) that a car is capable of overcoming one gallon of fuel (1gal lig = 3.755 l) is taken per unit of fuel economy (MPG).

Instead, the economy of an electric vehicle is determined by the number of miles the vehicle can overcome using energy equivalent to that contained in a gallon of gasoline. This technique is used for plug-in hybrid electric vehicles (PHEVs) and alternative fuel vehicles (NGV-natural gas vehicles; FCV-fuel cell vehicles). That is, one gallon of gasoline equivalent indicates the number of kilowatt-hours of electricity, the volume of natural gas, or the mass of hydrogen, which is equivalent to the energy of a gallon of gasoline (1 MPGe = 33.7 kW · h = 121 MJ) at which the vehicle walks a distance in one mile. In vehicles that use two or more fuels (PHEV, NGV, FCV), they indicate the consumption of each fuel in gallons of gasoline equivalent.

3. Analysis the different between two measurement units systems

However, all vehicles in the lineup since 2013, by decision of the United States Environmental Protection Agency (EPA) and the National Highway Traffic Safety Administration (NHTSA), in addition to the equivalent fuel consumption, indicate the amount of energy required to overcome 100 miles of path.

The purpose of this work is to evaluate the efficiency of electric vehicles by developing methods for estimating their specific fuel consumption and the relative cost of 100 km mileage in different countries. The results can be used by potential consumers of electric vehicles, as well as economists of motor transport companies.

The aim of the study is to analyze the fuel economy of the above mentioned electric vehicles and determine the specific fuel consumption in different countries, taking into account electricity and fuel prices, drawing conclusions about the economical use of these electric vehicles in different countries.

Problem solving. Specific fuel consumption is calculated by determining the cost of electricity that goes to charge the traction battery from the mains and is equivalently converted into the cost of fuel.

The efficiency of transportation by car through the working process of a reciprocating internal combustion engine in terms of energy efficiency and highlighting such processes are considered. By combining the transformation of the physical process of evaporation (change in the aggregate state), the chemical process of combustion, and the physical and mechanical process of heat generation under variables in a wide range of temperatures and pressures, with a difficult-to-control variability of the working fluid state are obtained [13, 14]. Heat transfer inside the cylinder and through its walls to the cooling system is of great importance in the operation of the ICE. Extraction of heat from the working medium (gas) causes energy losses. Hence, the evaluation of the efficiency of devices with internal combustion engines as the degree of use of thermal energy determines the level of ecological impact on the environment. Internal combustion engines as part of vehicle drives, in electric energy cogeneration systems create a significant ecological pressure on the environment, burn a large volume of fuel and air with relatively low productivity [15, 16]. Among the various indicators of efficiency of internal combustion engines as fuel filling factors λpv [kg/kg)] , as air filling λpl [kg/kg)], average effective pressure pe [Pa], specific fuel consumption ge [g/(kW·h)], the effective efficiency factor ηe [J/J] are considered.

Determine the specific fuel consumption for the above mentioned electric vehicles. Taking into account the energy capacity of the battery of the electric car, as well as the efficiency of the cycle "charge-discharge" and the charger, the amount of electricity that will be consumed to fully charge the battery (subject to full discharge) will be:

$$Q = \frac{c}{\eta}; \tag{1}$$

where Q - the amount of energy consumed when charging the battery, kWh; η - total efficiency (taking into account the efficiency of the charger and the efficiency of the "charge-discharge" cycle), c - the energy capacity of the battery, kWh.

Given the maximum mileage on a fully charged battery and the cost of one kilowatt-hour of electricity, the expression for determining the specific value of 100 km of mileage will look like:

$$C_1 = \frac{c \cdot a}{\eta \cdot l} \cdot 100; \tag{2}$$

where C1 - the cost of electricity consumed to overcome 100 km of road; a - the cost of one kilowatt-hour of electricity; lkm - maximum mileage on a fully charged battery, km.

Then the equation for determining the specific fuel consumption will look like:

$$C_2 = \frac{c \cdot a}{\eta \cdot l \cdot b_l} \cdot 100; \tag{3}$$

where C2 - equivalent fuel consumption of the electric car l / 100km; bl - the cost of one liter of fuel.

Or in the case of calculating the specific fuel consumption in MGPe (miles / 1 gallon) the equation will look like:

$$C_3 = \frac{l_m \cdot b_{gal} \cdot \eta}{c \cdot a}; \tag{4}$$

where C3 is the equivalent fuel consumption of the electric vehicle in MPGe (miles / 1 gallon); bgal is the cost of one gallon of fuel; lm is the maximum mileage on a fully charged battery, miles.

It is clear that the specific fuel consumption and the specific cost of 100 km run directly depends on the cost of energy, which are different in different countries. Therefore, it is important to study these indicators.

4. Results and Discussion

Figure 1 shows the cost of a kilowatt-hour of electricity and liters of gasoline in certain countries as of the last quarter of 2019 in UAH.

According to the results of EPA research and calculations, we obtain in the form of a graphical dependence of the relative mileage for Hyundai Ioniq Electric, Tesla Model 3 Long Range and BMW i3 in different countries.

The analysis of graphic dependence shows that in Ukraine the relative cost of mileage for electric cars Hyundai Ioniq Electric is 26.35 UAH / 100 km, for Tesla Model 3 Long Range 27.28 UAH // 100 km and BMW i3 28.52 UAH / 100 km, which is the lowest among all European countries. However, the lowest relative cost of 100 km is observed in Kazakhstan, as electricity prices in this country are the lowest.

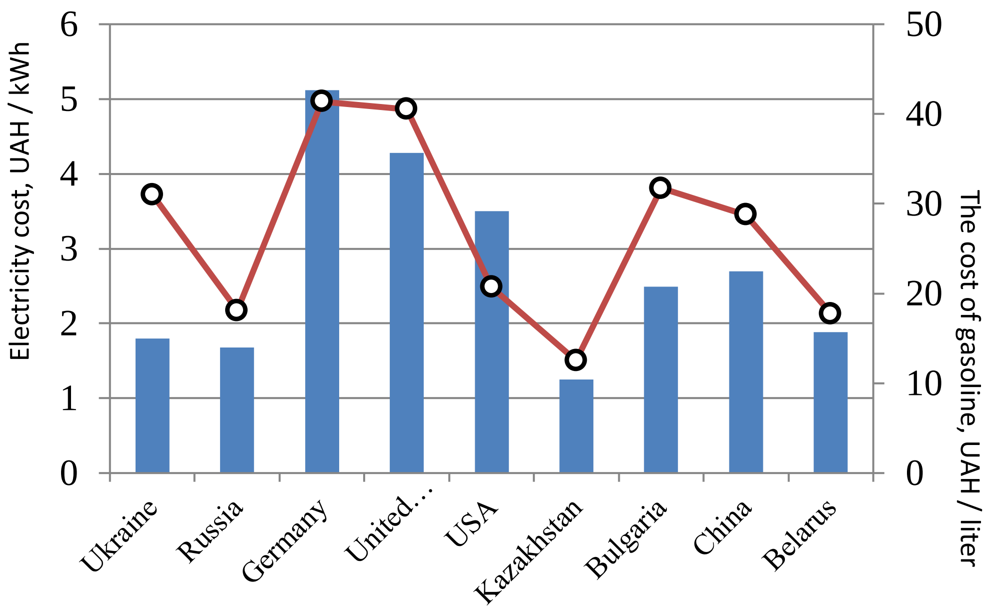

Figure 1 - The cost of a kilowatt-hour of electricity and gasoline in different countries as of 2019 in UAH

Instead, the highest equivalent fuel consumption of these vehicles in the United States, which is three times higher than the equivalent fuel consumption in Ukraine. At the same time, this creates preconditions for the expediency of using electric cars in Ukraine.

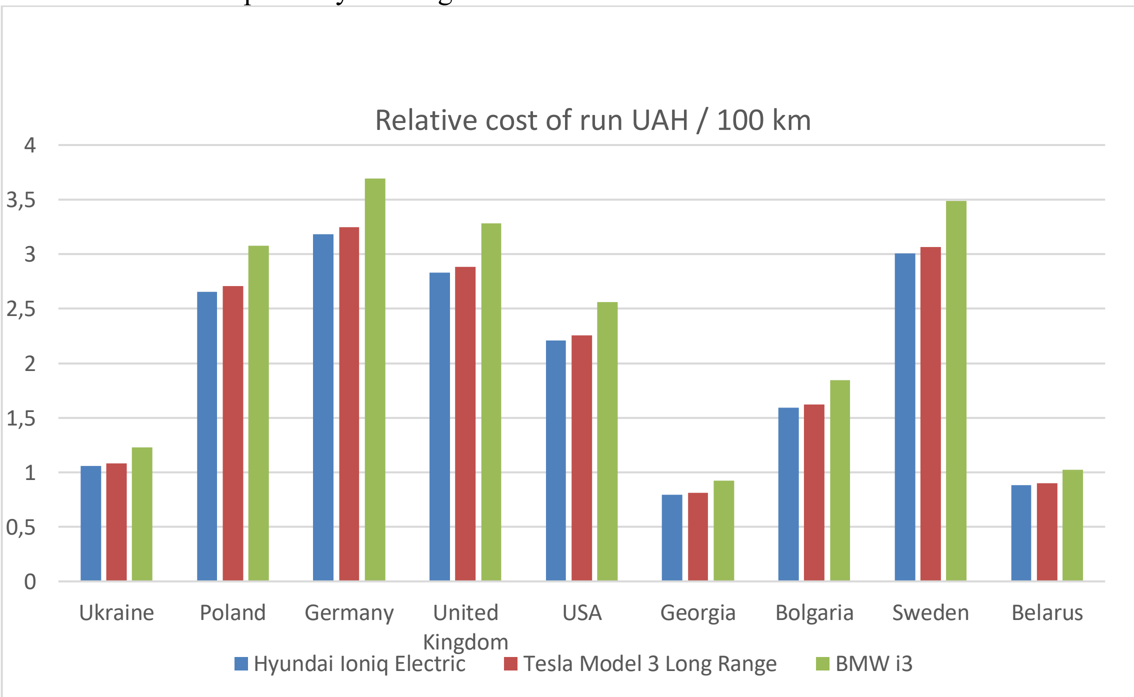

Figure 2 - Relative mileage of Hyundai Ioniq Electric, Tesla Model 3 Long Range and BMW i3 in different countries

Taking into account fuel prices, the specific fuel consumption of these electric vehicles is shown in Figure 3. The average cost of electricity in the United States as of August 2019 is $ 0.14 per 1 kWh, and the cost of a gallon of gasoline - $ 3.1. In Ukraine, the cost of electricity is 1.68 UAH / kWh, and gasoline A-95 - 31 UAH / liter. The results are shown in table 1.

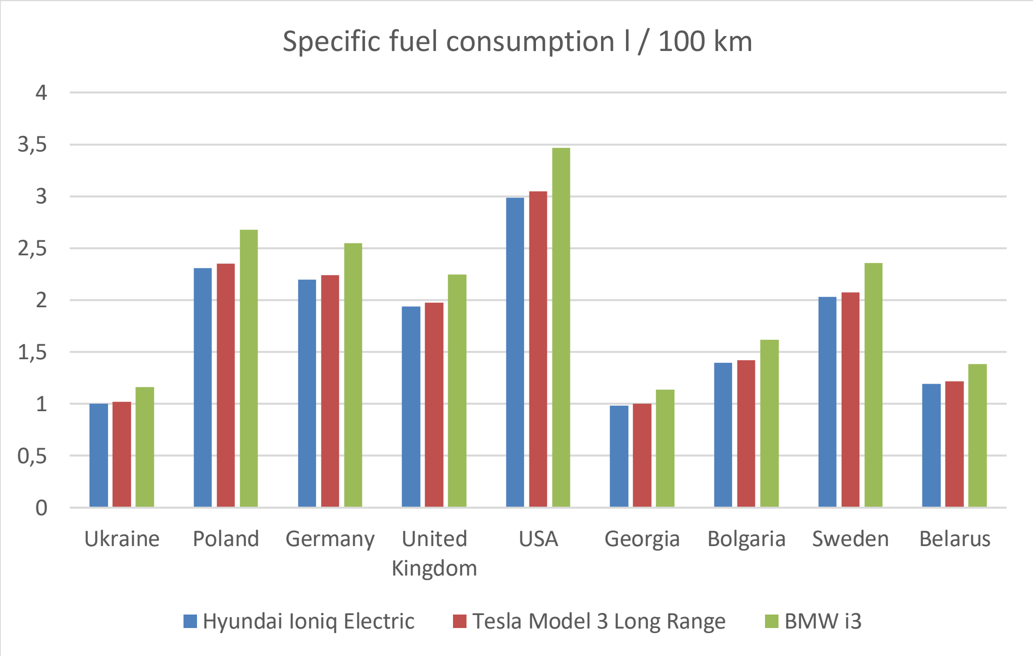

Figure 3 - Specific fuel consumption of Hyundai Ioniq Electric, Tesla Model 3 Long Range and BMW i3 in different countries

Taking into account the equivalent fuel consumption, it can be argued that in Ukraine the use of these electric vehicles is 8-10 times more economical than cars with internal combustion engines. Overall goal of any activity is gaining success, which often be estimated by economy values. Thus, fuel and costs saving are important not only for consumer and producer by direct impact in the price of production, including its modern very advanced electronic part, but also delayed effects on the environment and operational safety in general.

Table 1.Fuel economy of Hyundai Ioniq Electric, Tesla Model 3 Long Range and BMW i3 electric cars

Parameter	Dimensionality	Hyundai Ioniq Electric	Tesla Model 3 Long Range	BMW i3
Fuel economy (according to EPA)	MPGe (mpg)	136	130	124
Electricity consumption	kWh / 100 miles	25	26	27
Specific fuel consumption	l / 100 km	0,85	0,88	0,92
Relative mileage 100 km (mixed mode)	UAH / 100 km	26,25	27,3	28,35

5. Conclusion

The paper presents a method of calculating the equivalent fuel consumption for electric vehicles according to European (l / 100 km) and American standards (miles / 1 gallon).

It is established that the equivalent fuel consumption in different countries may vary and depends on the cost of energy.

It is investigated that in Ukraine the specific fuel consumption for electric cars Tesla Model 3 Long Range is 0.88 l / 100 km, for Hyundai Ioniq Electric 0.82 l / 100 km and for BMW i3 0.92 l / 100 km, which is the lowest among all European and other countries that have been studied, thus creating the preconditions for the development of electric vehicles in Ukraine.

According to the results of fuel efficiency studies, it is established that the equivalent fuel consumption on the territory of Ukraine of the studied electric vehicles is 8-10 times lower than the fuel consumption of cars of the same class with internal combustion engines.

References

[1] Gavrilyuk A and Lin S 2017 Protipozhezhnij zahist kolisnih transportnih zasobiv ta shlyahi jogo pidvishchennya *Pozhezhna bezpeka* **31** pp. 11-17
[2] Maxwell J. Clerk 1892A Treatise on Electricity and Magnetism, 3rd ed., vol. 2. Oxford: Clarendon, pp.68–73.
[3] Ramchandani M and Whitehouse N 1976 Heat transfer in a piston of a four stroke diesel engine *SAE Prepr.* **760007** 9 p.
[4] Kelley Blue Book [Online resource] / The Trusted Resource - Access Mode: https://www.kbb.com
[5] United States Environmental Protection Agency and U.S. Department of Energy (2016-11-18). "Compare Side-by-Side: 2017 Hyundai Ioniq Electric." fueleconomy.gov. Retrieved 2016-11-19.
[6] Szostech, M Hyundai IONIQ Electric Specifications. *My Electric Car Forums*. Retrieved 2016-11-25.
[7] Kane, Mark (2016-03-02). "Hyundai IONIQ Electric & IONIQ Plug-in At The Geneva Motor Show (Gallery, New Stats)." InsideEVs.com. Retrieved 2016-03-02.See more details in the official press release.
[8] Rteslamotors - FW 2019.8.3 actually increased Model 3 AWD peak power by 8% above 45 mph (70 km / h) ". Reddit. Retrieved July 14, 2019.
[9] Powell, Derek (May 22, 2019). "Tesla Model 3 vs. BMW 330I vs. Genesis G70 Comparison Test." MotorTrend. US Retrieved May 25, 2019.
[10] U. S. Environmental Protection Agency and U.S. Department of Energy (July 25, 2014). "Most Efficient EPA Certified Vehicles." fueleconomy.gov. Retrieved 13 June 2015.Current Model Year excludes all-electric vehicles
[11] Gavriluk A, Rudyk Y, Kuts V and Naumchuk R 2020 Required safety component of automotive cyber-physical systems PiCS&T IEEE Conference Proc.
[12] U. S. Environmental Protection Agency and U.S. Department of Energy (November 16, 2016). "Top Fuel Sippers (EPA Ratings, 2017 Model Year)." fueleconomy.gov. Retrieved November 21, 2016. The 2014–16 BMW i3 BEV (60 Amp-hour battery) was the most efficient EPA-certified vehicles considering all fuels and of all years until November 2016, when it was surpassed by the 2017 Hyundai Ioniq Electric
[13] Haschuk P and Nikipchuk S 2018 Peculiarities of heat generation in an internal combustion engine *Automotive Transport* **42** P. 12-21. DOI: 10.30977/AT.2219-8342.2018.42.0.12
[14] Decan G, Broekaert S, Lucchini T, D'Errico G, Vierendeels I and Verhelst S 2018 Evaluation of wall heat flux calculation methods for CFD simulations of an internal combustion engine under both motored and HCCI operation *Applied Energy* **232** P. 451-461. DOI: 10.1016/j.apenergy.2018.09.214
[15] Hashchuk P 1992 *Car energy efficiency* (Lviv: Svit) 208 p
[16] Yatsuk V and Klinkovska O 2017 Peculiarities of quality assurance in the European automotive industry. *8th International science and technology conf. in memory of Professor Ihor Kisil* November 14-15