The 18-th International Conference on Electrical Machines, Drives and Power Systems ELMA 2023
June 29 - July 1 2023, Varna, Bulgaria

A model based comparison on the efficiency of electric vehicles to conventional vehicles

Valentin Totev
Faculty of Electrical Engineering
Technical University – Sofia
Sofia, Bulgaria
valentintotev@tu-sofia.bg

***Abstract*— A model based comparison between an electric vehicle (EV) and a conventional vehicle with an internal combustion engine (ICEV) is presented in this paper. The study is performed by use of "Advanced Vehicle Simulator" (ADVISOR) in MATLAB environment. Both types of vehicles are subjected to a New European Driving Cycle (NEDC) procedure and to a combined "city-highway" fuel economy test procedure. As these test procedures are US based ones, it is not explicitly the case in terms of Bulgaria's conditions. Thus, in addition, a comparative fuel economy evaluation is presented. Based on obtained results from ADVISOR, it can be seen that NEDC's nature of fast and aggressive style of driving does not enhance EV's inherent advantages and the necessity of charging infrastructure is vividly exhibited. Emissions' results of simulated ICEV exceed the normative values of hydrocarbons and of particle matters set by US' Environmental Protection Agency (EPA) and Europe's EURO 6 standards. However, the simulation done by ADVISOR does not account for emissions reduction techniques. In addition, the fuel consumption and fuel economy evaluation shows that to travel by EV is less expensive. This, however, is a direct comparison of "tank-to-wheel" efficiency of EVs and ICEVs. Whenever "well-to-wheel" efficiency is considered the efficiency with which the primary source of energy to respective vehicle is produced has to be included. That is to say the "well-to-wheel" efficiency is the product of the "tank-to-wheel" efficiency and the efficiency which is known as "well-to-tank". Then, if an EV is charged with electricity generated by coal-fired power plants its "well-to-wheel" efficiency is similar to the one of ICEVs. Furthermore, albeit ICE's inherent lower efficiency, the accessibility of ICEVs is still widely needed as there are many uncertainties regarding EV's charging purely by spatial point of view at residential complexes. Thus, taking everything below into considerations a complete extinction of any type vehicle seems unlikely and it is more likely that in the future a vehicle diversification comprised of ICEVs, EVs and hybrids will be the standard.**

***Keywords*— advisor, electric vehicles.**

I. INTRODUCTION

Electric vehicles (EVs) are one of the most promising contenders to replace conventional internal combustion engine vehicles (ICEVs) as a mean of transport. Even though an electric motor is significantly more efficient than its ICE counterpart and EVs' are characterized by significantly higher "tank-to-wheel" efficiency than ICEVs, the "well-to-wheel" efficiency of EVs appear to be heavily influenced by the method of electricity's generation [1] – [4].

A model based comparison on the efficiency of EVs to ICEVs is presented in this paper. The study is done in development environment MATLAB with the help of the "Advanced Vehicle Simulator" (ADVISOR) gui. ADVISOR is a flexible but robust analysis tool allowing advanced vehicle modelling [5] – [7], [11]. Since some relations and processes are significantly complex and computationally intense to present by a model of simple description, they are simulated in an idealized nature. Comparing the efficiencies of their respective powertrains reveals each of their respective "tank-to-wheel" efficiencies. However, in a well-to-wheel efficiency is included not only the tank-to-wheel, but also the "well-to-tank" efficiency. The well-to-tank efficiency is consisted of the efficiency of producing the "primary" source of energy with respect to vehicle's point of view, i.e. electricity for EV's and fuel for ICEV's, and also the efficiency of transportation of said "primary" source [8] – [11]. Thus, the purpose of this paper is to serve as a baseline when comparing EVs' to ICEVs' efficiencies as a mean of transport.

II. MODEL BASED COMPARISON

In this study a relatively large sport utility vehicle (SUV) is considered for both types of vehicles. The considerations of a large SUV that are applied are as follows: frontal area of 2.7 to 3 m^2; vehicle's wheelbase of 2.9 – 3 m; curb mass of 1800 –3000 kg; cargo mass of 100 kg, passenger mass of 80 – 100 kg/person, etc. Further details of simulated EV and ICEV are presented in sections *A* and *B*, respectively.

ADVISOR's setup windows for EV and ICEV are shown on Fig. 1. (a) and Fig. 1. (b), respectively. Beneath these setup windows Simulink models are generated. It has to be noted that ADVISOR takes a multitude of variables into account [5], [8]. Values of some of the variables in considerations are set in a way that describes behaviour and response that are purely theoretical and idealized. This is done with the purpose of faster and simpler simulation.

The comparative analysis on the efficiency is comprised of two parts – firstly both types of vehicles are run through a simulation on a standard New European Driving Cycle (NEDC) procedure; secondly both types of vehicles are subjected to a combined fuel economy test procedure "city-highway". Taking into account that ADVISOR has been developed by US' Department of Energy [5], the "city-highway" test procedure is primarily giving results of fuel economy in the US. Emission standards by US' Environmental Protection Agency (EPA) [12] exhibited in Table I.

Thus, as this is not explicitly the case in terms of Bulgaria's conditions and standards, a comparative fuel

979-8-3503-1127-3/23/$31.00 ©2023 IEEE

economy evaluation is done in addition (chapter III, section *C*), in accordance to Europe's Euro 6 standard (Table II) [13].

Initial conditions of NEDC are as follows. Ambient temperature, as well as ICEV's interior converter's temperature, exhaust pipe's temperature, engine's cylinders, hood, interior and exterior initial temperatures, and also EV's energy storage system's (ESS') initial temperature and motor's initial temperature are set to 20 °C. Additionally, ESS' initial state of charge (SoC) is set to 0.5.

A. *Electric vehicle's considerations.*

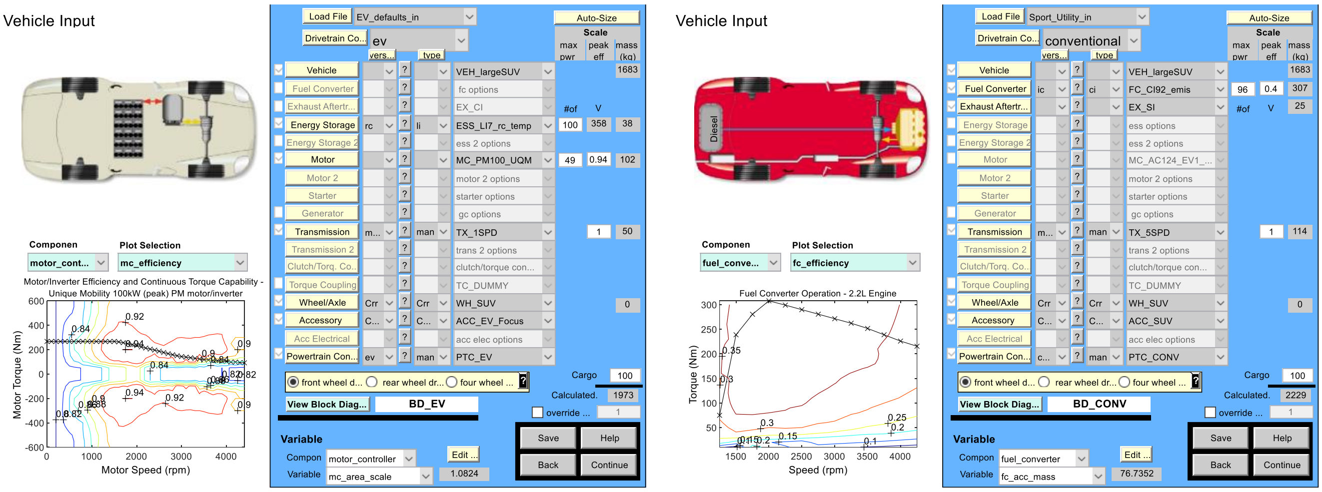
The considerations of an EV SUV in this study are the following:

- A permanent magnet synchronous motor with nominal power of 100 kW is taken as a traction motor in the electrical drivetrain system. ADVISOR's interface treats the electrical motor and its corresponding inverter as one unit. Thus, on the bottom left hand side of Fig. 1 (a) the efficiency map is noted as "motor/inverter";
- The battery pack is comprised of 100 modules. A battery module is equivalent to a single battery in ADVISOR. Each module is set to represent a Li – ion battery;
- Transmission is set as a single-speed gearbox and layout is chosen to be front-wheel drive;

B. *Considerations regarding internal combustion engine vehicle.*

Analogously to EV's considerations in section *A*, ICEV's considerations are as follows.

- A diesel engine with volume of 2.2 L and maximum power of 96 kW is considered. The engine is referred to as fuel converter in ADVISOR's interface as the type of ICE can be selected by the user (on Fig. 1. (b) *ci* denotes compression ignition, i.e. diesel type, while the other option – *si* denotes spark or standard ignition, i.e. gasoline fuel);
- Transmission is set as a five-speed gearbox and layout is chosen to be front-wheel drive;



(a)

Load File: EV_defaults_in
Drivetrain Co...: ev

	vers...	type		max pwr	peak eff	mass (kg)
☑ Vehicle			VEH_largeSUV			1683
☐ Fuel Converter			fc options			
☐ Exhaust Aftertr...			EX_CI	#of	V	
☑ Energy Storage	rc	li	ESS_LI7_rc_temp	100	358	38
☐ Energy Storage 2			ess 2 options			
☑ Motor			MC_PM100_UQM	49	0.94	102
Motor 2			motor 2 options			
Starter			starter options			
☐ Generator			gc options			
☑ Transmission	m...	man	TX_1SPD		1	50
Transmission 2			trans 2 options			
Clutch/Torq. Co..			clutch/torque con...			
☐ Torque Coupling			TC_DUMMY			
☑ Wheel/Axle	Crr	Crr	WH_SUV			0
☑ Accessory	C...	C...	ACC_EV_Focus			
Acc Electrical			acc elec options			
☑ Powertrain Con...	ev	man	PTC_EV			

● front wheel d... ○ rear wheel dr... ○ four wheel ...
Cargo: 100
Calculated.: 1973
☐ override ...: 1
View Block Diag...: BD_EV
Variable
Compon: motor_controller
Variable: mc_area_scale: 1.0824

(b)

Load File: Sport_Utility_in
Drivetrain Co...: conventional

	vers...	type		max pwr	peak eff	mass (kg)
☑ Vehicle			VEH_largeSUV			1683
☑ Fuel Converter	ic	ci	FC_CI92_emis	96	0.4	307
☑ Exhaust Aftertr...			EX_SI	#of	V	25
☐ Energy Storage			ess options			
☐ Energy Storage 2			ess 2 options			
☐ Motor			MC_AC124_EV1_...			
Motor 2			motor 2 options			
Starter			starter options			
☐ Generator			gc options			
☑ Transmission	m...	man	TX_5SPD		1	114
Transmission 2			trans 2 options			
Clutch/Torq. Co..			clutch/torque con...			
☐ Torque Coupling			TC_DUMMY			
☑ Wheel/Axle	Crr	Crr	WH_SUV			0
☑ Accessory	C...	C...	ACC_SUV			
Acc Electrical			acc elec options			
☑ Powertrain Con...	c...	man	PTC_CONV			

● front wheel d... ○ rear wheel dr... ○ four wheel ...
Cargo: 100
Calculated.: 2229
☐ override ...: 1
View Block Diag...: BD_CONV
Variable
Compon: fuel_converter
Variable: fc_acc_mass: 76.7352

Fig. 1. ADVISOR's setup windows – (a) EV's setup and (b) ICEV's setup.

TABLE I. Light-duty vehicle and light-duty truck exhaust emissions' standards, defined by EPA.

Unburned hydrocarbons (HC), g/mi	***Nitrogen oxides (NOx), g/mi***	***Carbon monoxide (CO), g/mi***	***Particle matters (PM), g/mi***
0.156	***0.6***	***4.2***	***0.08***
Equivalent value in metrics HC, g/km	***Equivalent value in metrics NOx, g/km***	***Equivalent value in metrics CO, g/km***	***Equivalent value in metrics PM, g/km***
0.097	***0.373***	***2.61***	***0.05***

TABLE II. Emissions' standards of passenger cars according to EURO 6.

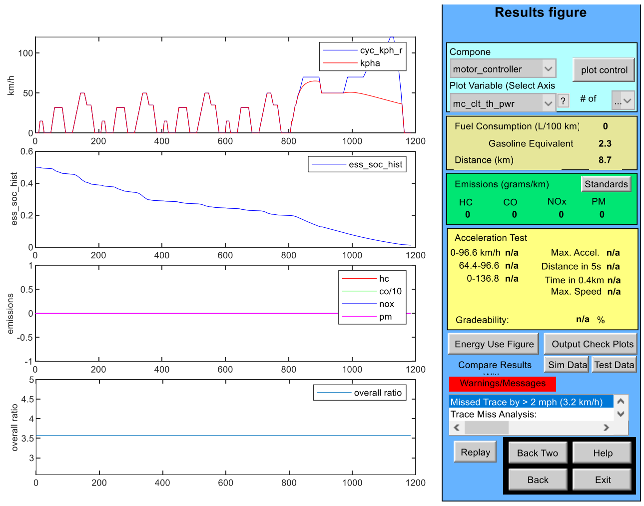
Unburned hydrocarbons (HC), g/km	***Nitrogen oxides (NOx), g/km***	***Carbon monoxide (CO), g/km***	***Particle matters (PM), g/km***
0.1	***0.06***	***1***	***0.0045***

III. SIMULATION RESULTS

Simulation is performed by ADVISOR gui in MATLAB environment. Simulation results are divided between section *A* and section *B*. Section *A* covers EV's simulation results of NEDC and "city-highway" test procedure. Analogously, ICEV's simulation results are covered in section *B*. Additionally, a fuel consumption evaluation in terms of Bulgaria is exhibited in section *C*.

A. Electric vehicle's simulation results.

EV's results panel is displayed on Fig. 2. Based on the first of the four plots it can be seen that EV has not completed the last portion of NEDC. This is due to that the last portion is characterized with flat roads with faster and more aggressive nature of driving. Thus, at that high speed portion of NEDC energy demand on ESS is significantly increased, the SoC decreases rapidly, EV cannot perform regenerative braking and at the end of simulation SoC drops to zero, i.e. EV has stopped (second plot). Nevertheless, the average efficiency of EV's driveline is 96.3352 %. The "motor/inverter" group has performed with an average efficiency during driving of 93.2083 % and an average efficiency during generating of 80.2775 %. Thus, motor/inverter's average round-trip efficiency would come up to 74.825 %. ESS' average efficiency during discharging – 93.587 %, while during charging – 95.5397 %. Thus, ESS' average round-trip efficiency is 89.4127 %. Hence, EV's tank-to-wheel efficiency would come up to 64.4514 %



Compone: motor_controller

Plot Variable (Select Axis: mc_clt_th_pwr

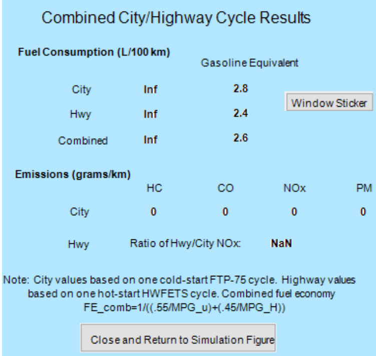
Fuel Consumption (L/100 km) 0
Gasoline Equivalent 2.3
Distance (km) 8.7

Emissions (grams/km)			
HC	CO	NOx	PM
0	0	0	0

Acceleration Test
0-96.6 km/h n/a
64.4-96.6 n/a
0-136.8 n/a
Max. Accel. n/a
Distance in 5s n/a
Time in 0.4km n/a
Max. Speed n/a
Gradeability: n/a %

Missed Trace by > 2 mph (3.2 km/h)
Trace Miss Analysis:

Fig. 2. Electric vehicle's simulation results panel.



Combined City/Highway Cycle Results

Fuel Consumption (L/100 km)		Gasoline Equivalent
City	Inf	2.8
Hwy	Inf	2.4
Combined	Inf	2.6

Emissions (grams/km)	HC	CO	NOx	PM
City	0	0	0	0

Hwy Ratio of Hwy/City NOx: NaN

Note: City values based on one cold-start FTP-75 cycle. Highway values based on one hot-start HWFETS cycle. Combined fuel economy FE_comb=1/((.55/MPG_u)+(.45/MPG_H))

Fig. 3. Electric vehicle's results on the fuel economy "city-highway" test procedure.

Fig. 3. presents EV's performance on the fuel economy "city-highway" test procedure. As expected, EV's operation there are no emissions (also shown on the third plot of Fig. 2), which is the cause that the fuel consumption values are registered as infinite by ADVISOR.

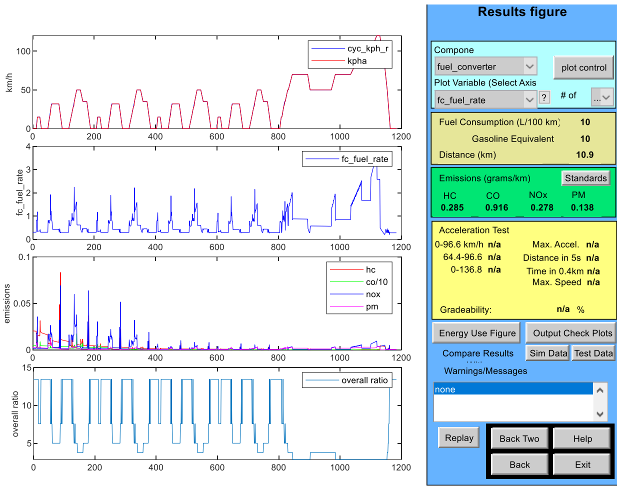
B. Internal combustion engine vehicle's simulation results.

Based on ICEV's simulation results panel on Fig. 4. it can be seen that the considered ICEV managed to complete NEDC and the emissions in g/ km are as follows – HC at 0.285 g/ km; CO at 0.916 g/ km; NOx at 0.278 g/ km and PM (PM10) at 0.136 g/ km. Based on EPA's standards (Table I) this run of ICEV on NEDC exceeds the norms of HC and PM. Based on EURO 6 standards (Table II), only CO value does not exceed its norm.

During this NEDC run the engine performed with an average efficiency of 26.2527 %. In addition, the average efficiency of the driveline is 95.7252 %. Hence, ICEV's tank-to-wheel efficiency – 25.1304 %.

Analogously to section *A*, the fuel economy "city-highway" test procedure's results are given on Fig. 5. In this procedure the simulated ICE SUV consumed 10 L/ 100 km with regards to city driving and 7.1 L/ 100 km with regards to highway driving.

Combined fuel consumption is 8.7 L/ 100 km. As the nature of this test procedure is different than the nature of NEDC, the emissions' results during this test are as follows. HC at 0.129 g/ km; CO at 0.521 g/ km; NOx at 0.218 g/ km and PM at 0.132 g/ km. Once again, the norms of HC and PM are exceeded according to EPA's standards (Table I). In terms of emissions standards of EURO 6 (Table II) during this run only CO does not exceed set norm value.



Compone: fuel_converter

Plot Variable (Select Axis: fc_fuel_rate

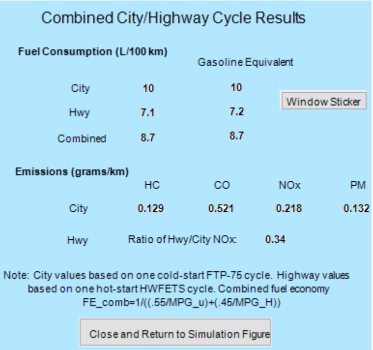
Fuel Consumption (L/100 km) 10
Gasoline Equivalent 10
Distance (km) 10.9

Emissions (grams/km)			
HC	CO	NOx	PM
0.285	0.916	0.278	0.138

Acceleration Test
0-96.6 km/h n/a
64.4-96.6 n/a
0-136.8 n/a
Max. Accel. n/a
Distance in 5s n/a
Time in 0.4km n/a
Max. Speed n/a
Gradeability: n/a %

none

Fig. 4. Internal combustion engine's vehicle simulation results panel.



Combined City/Highway Cycle Results

Fuel Consumption (L/100 km)		Gasoline Equivalent
City	10	10
Hwy	7.1	7.2
Combined	8.7	8.7

Emissions (grams/km)	HC	CO	NOx	PM
City	0.129	0.521	0.218	0.132

Hwy Ratio of Hwy/City NOx: 0.34

Note: City values based on one cold-start FTP-75 cycle. Highway values based on one hot-start HWFETS cycle. Combined fuel economy FE_comb=1/((.55/MPG_u)+(.45/MPG_H))

Fig. 5. Internal combustion engine vehicle's results on the fuel economy "city-highway" test procedure.

C. *Fuel consumption evaluation in Bulgaria.*

Even though there are government subsidies in many countries regarding EVs' purchases, including Bulgaria, it is still unknown how electrical energy's taxing will change whenever EVs become more widely spread and utilized by the masses. Charging infrastructure is often termed as one of the biggest drawbacks of today's EVs, but it is more so their biggest necessity as it is shown by [14]. There are many uncertainties regarding charging infrastructure purely from spatial point of view concerning public parking spots in front of residential complexes and how parking spots will change for citizens living in these given complexes depending on charging stations. In terms of electrical point of view, it is shown that there are no major concerns to the state of the power grid and its potential to handle EVs as loads, especially when taking into account the implementation of a vehicle-to-grid strategy [14] and introduction of digital substations on a global scale [15]. Thus, as it stands, a fuel economy evaluation can be made by considering present electrical energy's billing and considering present prices for petrol fuels – both taken from consumer's perspective with the respective value added tax (VAT), excise for petrol fuels, etc. The presented billings and tariffs below are taken with regards that 1 BGN ≈ 0.511 € (as of February 2023).

- Domestic charging stations are billed on domestic tariff plan. Present domestic tariff plan in Bulgaria is priced at 0.21 to 0.25 BGN/ kWh ≈ 0.11 to 0.13 €/ kWh without tax for using the grid (roughly 0.07 BGN/ kWh ≈ 0.04 €/ kWh) and without VAT. Accounting for these taxes, the price range becomes 0.32 to 0.37 BGN/ kWh ≈ 0.16 to 0.19 €/ kWh;
- Industrial consumers' tariffs are billed at an average weekly stock price of 0.3 – 0.4 BGN/ kWh ≈ 0.15 to 0.2 €/ kWh. Accounting for taxes it comes up to 0.43 to 0.55 BGN/ kWh ≈ 0.22 to 0.28 €/ kWh;
- Public charging stations at present are billed at a fixed price of 1 BGN/ kWh ≈ 0.511 €/ kWh.

Considering an EV with a 40 kWh battery pack that can travel realistically 200 to 250 km on a single charge. Therefore, this results in 160 to 200 Wh/ km or 0.16 to 0.2 kWh/ km. From here, a cost per kilometer can be estimated:

- To travel a single kilometer per charge only by domestic charging would roughly result in 0.054 to 0.078 BGN/ km ≈ 0.028 to 0.04 €/ km;
- Single kilometer on an industrial billing would come up to 0.07 to 0.11 BGN/ km ≈ 0.036 to 0.057 €/ km;
- Thirdly, to travel a single kilometer only on public charging costs 0.16 to 0.2 BGN/ km ≈ 0.082 to 0.102 €/ km.

The presented petrol fuel price ranges are taken in a month's interval during February 2023 and are as follows:

- Gasoline with octane number 95 is priced between 2.44 and 2.64 BGN/L (1.25 to 1.35 €/L);
- Gasoline with octane number 98 is priced between 2.85 and 3.15 BGN/L (1.46 to 1.61 €/L);
- Gasoline with octane number 100 is priced between 2.74 and 3.48 BGN/L (1.4 to 1.78 €/L);
- Standard diesel is priced in the range of 2.69 to 2.99 BGN/L (1.37 to 1.53 €/L);
- Premium diesel is priced at 2.79 to 3.36 BGN/L (1.43 to 1.72 €/L).

Considering fuel consumption results from Fig. 5., then to travel a single kilometer via this considered SUV would cost as expressed in Table III.

Easily, it can be spotted that travelling by petrol fuelled ICEVs is more expensive due to naturally lower "tank-to-wheel" efficiency. However, the charging infrastructure in Bulgaria is scarce and insufficient in comparison to petrol stations' infrastructure. Furthermore, once EVs become widely spread throughout the masses, an additional excise on electrical energy may be incorporated towards charging.

TABLE III. Travel cost of petrol vehicle with regards to Bulgaria's circumstances.

	City consumption	Highway consumption	Combined consumption
Gasoline 95	0.244 – 0.264 BGN/ km or 0.125 – 0.135 €/ km	0.173 – 0.187 BGN/ km or 0.089 – 0.096 €/ km	0.212 – 0.23 BGN/ km or 0.108 – 0.118 €/ km
Gasoline 98	0.285 – 0.315 BGN/ km or 0.146 – 0.161 €/ km	0.202 – 0.224 BGN/ km or 0.103 – 0.114 €/ km	0.248 – 0.274 BGN/ km or 0.127 – 0.14 €/ km
Gasoline 100	0.274 – 0.348 BGN/ km or 0.14 – 0.178 €/ km	0.195 – 0.247 BGN/ km or 0.1 – 0.126 €/ km	0.238 – 0.303 BGN/ km or 0.122 – 0.155 €/ km
Standard diesel	0.269 – 0.299 BGN/ km or 0.137 – 0.153 €/ km	0.191 – 0.212 BGN/ km or 0.098 – 0.108 €/ km	0.234 – 0.26 BGN/ km or 0.12 – 0.133 €/ km
Premium diesel	0.279 – 0.336 BGN/ km or 0.143 – 0.172 €/ km	0.198 – 0.239 BGN/ km or 0.101 – 0.122 €/ km	0.243 – 0.292 BGN/ km or 0.124 – 0.149 €/ km

D. *Well-to-wheel efficiency*

The well-to-tank efficiency for ICEV's can be estimated in the following way [16].

- Extraction of crude oil from oil field – efficiency of 97 %;
- Transportation of crude oil to the refinery –efficiency of 99 %;
- Crude oil refining – efficiency of 91 %;
- Fuel distribution – efficiency of 98 %.

Thus, ICEV's well-to-tank efficiency is 86 %. Then, having ICEV's well-to-tank and tank-to-wheel efficiencies, the well-to-wheel efficiency can be determined as a product of the former two and comes up to, namely, 21.612 %.

With regards to EV's, well-to-tank efficiency is comprised of the efficiency of electrical power plant and efficiency of transmission. Efficiency of transmission is comprised of losses in transmission lines, losses in substation and losses in distribution, and can be considered as constant – generally around 85 % in Bulgaria. Then, the efficiencies of different power plants is the primary factor and it is as follows [17]:

- Coal based steam power plants – efficiency between 32 and 42 %;
- Nuclear power plants' efficiency is between 35 and 38 %;
- Hydro power plants' efficiency is between 85 and 90 %;
- Pumped-storage hydro power plant – efficiency between 70 and 75 %;
- Solar power plant – efficiency between 16 and 22 %;
- Wind power plant – efficiency between 20 and 40 %.

Therefore, EV's well-to-wheel efficiency ranges from 10 to 58 % depending on the type of power plant.

IV. CONCLUSIONS

A model based comparison between an EV and ICEV on NEDC and "city-highway" test procedures is presented in this paper. In addition, a fuel consumption evaluation in terms of Bulgaria and a cost to travel a single kilometer are also given.

Even though in the last part of the NEDC EV ran out of charge, it cannot be unequivocally stricken out as battery's initial SoC is set to 50%. Furthermore, due to the fact that NEDC has a lot of flat roads with more aggressive style of driving and not a lot of inclinations, regenerative braking is not utilized which in turn limits additionally battery's charging. Thus, traveling in such conditions would require charging stations to be placed more often and some vehicle-to-grid strategy to be implemented.

Based on fuel economy evaluation with regards to Bulgaria's circumstances, it is evident that by direct comparison travelling by EVs cost less. However, the travel cost becomes comparable when considering "well-to-wheel" efficiency. Thus, taking everything considered into account, it is an unlikely perspective that only one type of vehicles will be left remaining in existence, and more likely that a vehicle diversification comprised of ICEVs, EVs and hybrids, both classic HEV's and also PHEV's, will be the prospect of the future.

ACKNOWLEDGMENT

The author would like to thank the Research and Development Sector at the Technical University of Sofia for the financial support.

REFERENCES

[1] Albatayneh, A., Assaf, M., Alterman, D. & Jaradat, M. (2020). Comparison of the Overall Energy Efficiency for Internal Combustion Engine Vehicles and Electric Vehicles. Environmental and Climate Technologies, 24 (1) 669-680. https://doi.org/10.2478/rtuect-2020-0041.

[2] Faria, Ricardo & Moura, Pedro & Delgado, Joaquim & de Almeida, Aníbal. (2012). A sustainability assessment of electric vehicles as a personal mobility system. Energy Conversion and Management. 61. 19-30. 10.1016/j.enconman.2012.02.023.

[3] Ricardo Faria, Pedro Marques, Pedro Moura, Fausto Freire, Joaquim Delgado, Aníbal T. de Almeida, Impact of the electricity mix and use profile in the life-cycle assessment of electric vehicles, Renewable and Sustainable Energy Reviews, Volume 24, 2013, Pages 271-287, ISSN 1364-0321, https://doi.org/10.1016/j.rser.2013.03.063.

[4] Kong Deyang, Ma Dan, Wang Minmin, A Simulation Study of Upgrading Urban Gasoline Taxis to Electric Taxis, Energy Procedia, Volume 104, 2016, Pages 390-395, ISSN 1876-6102, https://doi.org/10.1016/j.egypro.2016.12.066.

[5] T Markel, A Brooker, T Hendricks, V Johnson, K Kelly, B Kramer, M O'Keefe, S Sprik, K Wipke, ADVISOR: a systems analysis tool for advanced vehicle modeling, Journal of Power Sources, Volume 110, Issue 2, 2002, Pages 255-266, ISSN 0378-7753, https://doi.org/10.1016/S0378-7753(02)00189-1.

[6] Tianlong Han, Biao Zeng, Yijie Tong, Theoretical study on energy recovery rate of regenerative braking for hybrid mining trucks with different parameters, Journal of Energy Storage, Volume 42, 2021, 103127, ISSN 2352-152X, https://doi.org/10.1016/j.est.2021.103127.

[7] Tahoori, A. & Mashad, B.. (2019). DESIGN OF A HYBRID ELECTRIC MOTORCYCLE FOR OPTIMUM FUEL CONSUMPTION AND PERFORMANCE. Latin American Applied Research - An international journal. 49. 31-39. 10.52292/j.laar.2019.282.

[8] L. Athanasopoulou, H. Bikas, P. Stavropoulos, Comparative Well-to-Wheel Emissions Assessment of Internal Combustion Engine and Battery Electric Vehicles, Procedia CIRP, Volume 78, 2018, Pages 25-30, ISSN 2212-8271, https://doi.org/10.1016/j.procir.2018.08.169.

[9] Odd André Hjelkrem, Petter Arnesen, Torstein Aarseth Bø, Rebecka Snefuglli Sondell, Estimation of tank-to-wheel efficiency functions based on type approval data, Applied Energy, Volume 276, 2020, 115463, ISSN 0306-2619, https://doi.org/10.1016/j.apenergy.2020.115463.

[10] H. Moghbelli, A. H. Niasar and R. Langari, "New Generation of Passenger Vehicles: FCV or HEV?," 2006 IEEE International Conference on Industrial Technology, Mumbai, India, 2006, pp. 452-459, doi: 10.1109/ICIT.2006.372392.

[11] Antoniou, A. & Komyathy, J. & Bench, J. & Emadi, A. (2005). Modeling and Simulation of Various Hybrid Electric Configurations of the High-Mobility Multipurpose Wheeled Vehicle (HMMWV). 2005. 507 - 514. 10.1109/VPPC.2005.1554525.

[12] EPA Emission Standards for Light-Duty Vehicles and Trucks and Motorcycles – Light-Duty Vehicle and Light-Duty Truck -- Clean Fuel Fleet Exhaust Emission Standards (PDF) (1 pg, 92 K, March 2016, EPA-420-B-16-006)

[13] Commission Regulation (EU) No 459/2012 of 29 May 2012 amending Regulation (EC) No 715/2007 of the European Parliament and of the Council and Commission Regulation (EC) No 692/2008 as regards emissions from light passenger and commercial vehicles (Euro 6)

[14] N. Matanov, A. Zahov and I. Angelov, "Modeling of the Electric Vehicle Charging Process - Part 1," 2021 13th Electrical Engineering Faculty Conference (BulEF), Varna, Bulgaria, 2021, pp. 1-4, doi: 10.1109/BulEF53491.2021.9690836.

[15] N. Matanov and P. Nankinsky, "Digital substations - the backbone of smart grids," 2022 14th Electrical Engineering Faculty Conference (BulEF), Varna, Bulgaria, 2022, pp. 1-6, doi: 10.1109/BulEF56479.2022.10021197.

[16] M. Sura, "Smart mobility – well-to-wheels efficiency of internal combustion engine vehicles" 2021.

[17] S. Etarski, "Electrical part of power plants", 2010, Tekhnika (in bulgarian – С. Етърски „Електрическа част на електрически централи", 2010, Техника).