Analysis of CO_2 Emissions for a Supercharged Engine and a Series–Parallel Hybrid System

Gabriel Constantin Benga(✉), Sorin Vasile Savu, Iulian Stefan, Adrian Bebe Olei, and Ionel Danut Savu

University of Craiova, 200585 Craiova, Romania
gabriel.benga@edu.ucv.ro

Abstract. The emissions of CO_2 represent an important factor for the automotive industry in the climate change at the global level. The paper aims to study the influence of driving conditions on the CO_2 emissions and fuel consumption for two different types of propulsion systems: one conventional propulsion system consisting of a supercharged engine with a low displacement of 998 cm^3 and 88 kW output power and one series–parallel hybrid propulsion system consisting of a naturally aspirated engine of 2487 cm^3 displacement, and 131 kW coupled with an electrical engine of 88 kW.

Keywords: CO_2 emissions · Supercharged engine · Hybrid system

1 Introduction

Fossil fuel dependence, as well as the surrounding environmental problems induced by greenhouse gas (GHG) emissions, have become an issue that has attracted the attention of many researchers in the automotive industry in the last decades. The worldwide oil consumption in 2020 was 88.5 million barrels/day [1]. On the other hand, the U.S. Energy Information Administration (EIA) estimates that the world consumed 92.2 million barrels per day (b/d) of petroleum and other liquid fuels in 2020 [2]. Under these circumstances, it is reasonable to assume that the transport sector has a major influence on GHG, and significant efforts have been made to reduce the CO_2 emissions in the automotive industry. The geopolitical situation with the conflict in Europe started in 2022 is another element that puts pressure on fossil fuel prices, registering spectacular increases for both gasoline and diesel.

The implementation of hybrid systems in vehicles equipped with internal combustion engines (ICE) is a promising solution to meet on the one hand the environmental requirements by reducing GHG emissions in the transport sector and on the other hand to meet consumer demand for fuel consumption as low as possible as fuel prices rise [3]. In a series–parallel hybrid system, the vehicle can be driven either by a self-propelled fossil fuel internal combustion engine or by a single electric motor, or by both the internal combustion engine and the electric motor working together. The power distribution between the thermal engine and the electric motor is developed so that the thermal engine

I. Dumitru et al. (Eds.): ICOME 2022, AHE 15, pp. 331–339, 2023.
https://doi.org/10.2991/978-94-6463-152-4_37

Table 1. Propulsion systems specifications

Type of propulsion system	ICE	ICE + HEV
Engine type	Spark-ignition, 4-stroke	Spark-ignition, 4-stroke
Electric motor [kW]	-	88
Battery pack voltage [V]	-	244.8
Charge system	Turbocharger	Naturally aspirated
Displacement [cm^3]	998	2487
Valves per cylinder	4	4
Power [kW]	88	160
Torque net [Nm]	190	221
Emission standard	Euro 6d-TEMP	Euro 6

can run in the optimum operating range as much as possible [4]. Many researchers made sustained efforts to study the effect of hybrid systems on reducing CO_2 emissions in the automotive industry [5–7].

2 Research Methodology

This paper aims to present research related to the evaluation of CO_2 emissions of two types of engines for similar driving conditions. The engines subjected to this research were turbo-engine with a displacement of 998 cm^3 providing a total of 88 kW output power and a full hybrid system one consisting of a naturally aspirated engine with 2487cm^3 displacement combined through a power split device with an electric motor of 120 kW providing a total power of 160 kW. The main technical specifications of both propulsion systems are presented in Table 1.

The driver profile was as follows: gender - male, 55 years old with more than 30 years of experience in driving different types of cars. The study consisted of recording data provided by the computer unit of the cars in the period April 2021 – to April 2022. Based on the acquired data from cars' computers, the emissions of CO_2 have been calculated using the following equation:

$$CO_2 = AF \,.\, \frac{2392}{100} \tag{1}$$

where:

- CO_2 – represents the total emissions [g/km]
- AF – represents the average fuel consumption for a voyage [l/100 km]

The parameters from Eq. 1 have been determined based on the assumption that 1 L of petrol weighs 750 g. Petrol consists of 87% of carbon or 652 g of carbon per litre of petrol. In order to combust this carbon into CO_2, 1740 g of oxygen is needed. The sum

Table 2. Emissions of CO_2 from the turbocharged engine HEV in the urban cycle

Day	Distance [km]		EV Distance [km]		AF [l/100 km]		CO_2 [g/km]	
	ICE	HEV	ICE	HEV	ICE	HEV	ICE	HEV
1	1.3	5.8	0	2.9	11.2	9.3	267.9	222.5
2	4.5	10.9	0	5.1	10.3	8.2	246.4	196.7
3	13.2	19.2	0	10.3	9.7	7	232.0	167.4
4	1.4	1.3	0	0.6	12.5	6.7	299.0	160.3
5	2.3	7	0	3.1	7.1	9.1	169.0	219.5
6	1.4	6	0	2.5	12.6	7.6	301.4	181.8
7	11.6	6.1	0	2.3	10.6	8.5	252.8	203.3
8	22.1	5.3	0	1.7	11.9	7.6	285.4	182.4
9	5	2.4	0	1.2	12.5	13	297.8	311.0
10	15	6.7	0	3.5	9.6	9.5	230.1	227.2
11	1	0	0	0	15.2	0	363.6	0
12	9.8	11.3	0	5.4	11.5	8.8	274.1	210.5
13	8.6	6	0	3.1	11.7	6.9	279.9	166.2
14	10.4	12.5	0	6.7	13.2	8.8	315.7	211.7
15	16.9	3	0	0	8.7	11.3	208.1	270.3
16	37.8	2.6	0	0.01	7.5	19.6	178.8	469.6
17	22.1	5.2	0	1	8.9	13	213.5	311.0
18	17.3	1.9	0	0.05	8.5	21.3	202.5	510.3
19	2.9	10.5	0	2.8	11.9	8.1	283.6	193.8
20	1.3	0	0	0	13.5	0	322.9	0
21	4.8	5.8	0	3.1	7.1	5.5	168.6	131.6

is then $652 + 1740 = 2392$ g of CO_2/litre of petrol. The calculated CO_2 emissions using Eq. 1 for the turbocharged and hybrid propulsion system are presented in Table 2 and Table 3 covering the urban cycle and extra-urban cycle.

The values presented in the tables below represent selected data covering the last month of the study.

3 Results and Discussions

Based on the records mentioned in Table 2, the variation of CO_2 [g/km] with the travelled distance in the urban cycle is presented in Fig. 1 and Fig. 2 for both propulsion systems considered. Analysing the above figures, it can be seen that the peaks in terms of CO2 emissions for both propulsion systems happened at very low travel distances (less than 2 km). However, there are some differences in the interpretation of the results.

Table 3. Emissions of CO_2 from the turbocharged engine and HEV in the extra-urban cycle

Day	Distance [km]		EV Distance [km]		AF [l/100 km]		CO_2 [g/km]	
	ICE	HEV	ICE	HEV	ICE	HEV	ICE	HEV
1	322.1	65.4	0	23.5	6.6	5.2	156.9	123.2
2	12.1	224.7	0	69.6	6.1	5.6	145.9	132.8
3	12.1	344.9	0	98.1	6.8	5.8	162.7	138.7
4	0	175.4	0	59.6	0	5.6	0	134.0
5	49.5	0	0	0	6.5	0	155.5	0
6	24.2	0	0	0	7.0	0	167.4	0
7	0	0	0	0	0	0	0	0
8	162.9	241.8	0	72.7	6.4	5.9	153.1	140.3
9	0	0	0	0	0	0	0	0
10	372.7	18.9	0	8.3	6.3	5.9	150.1	141.1
11	228.8	11.6	0	4.9	6.4	6.1	153.1	145.9
12	0	99.8	0	52.0	0	5.3	0	126.8
13	0	0	0	0	0	0	0	0
14	0	11.9	0	6	0	5.7	0	136.3
15	506.9	62.6	0	20.3	6.7	5.2	160.9	123.2
16	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0
18	480.5	0	0	0	6.8	0	162.7	0
19	0	140.6	0	57.6	0	4.8	0	114.8
20	23.6	127.8	0	42.1	6.2	5.9	147.1	141.1
21	141.2	19.2	0	8.6	6.5	5.4	156.3	129.2

For ICE engine, the high level of CO2 emissions can be explained by the CSE (Cold Start Effect) when the engine is cold and the temperature of the aftertreatment systems does not reach the point when the catalytic reaction is initiated (approx. 350° C).

On the other hand, in the HEV case, if the battery is less than 40% charged, the internal computer of the car commands the combustion engine to start and therefore, the EV mode is not available and the overall functioning of HEV is similar to ICE behaviour during cold start.

In Fig. 3 and Fig. 4 are presented the variations of CO2 emissions with the travelled distance in the extra-urban cycle for both propulsion systems.

Analyzing the results, a significant reduction in CO_2 emissions compared to the urban cycle can be observed. In the urban cycle, the average CO_2 emissions were in the range of 250 g/km, whereas in the extra-urban cycle the average CO_2 emissions were between 130–150 g/km.

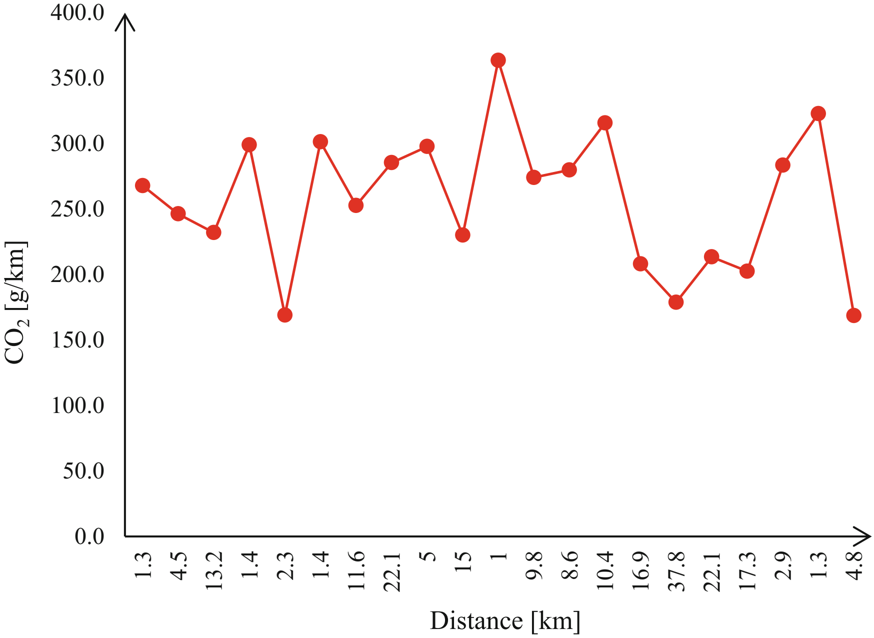

Fig. 1. CO_2 emissions in urban cycle for turbocharged engine

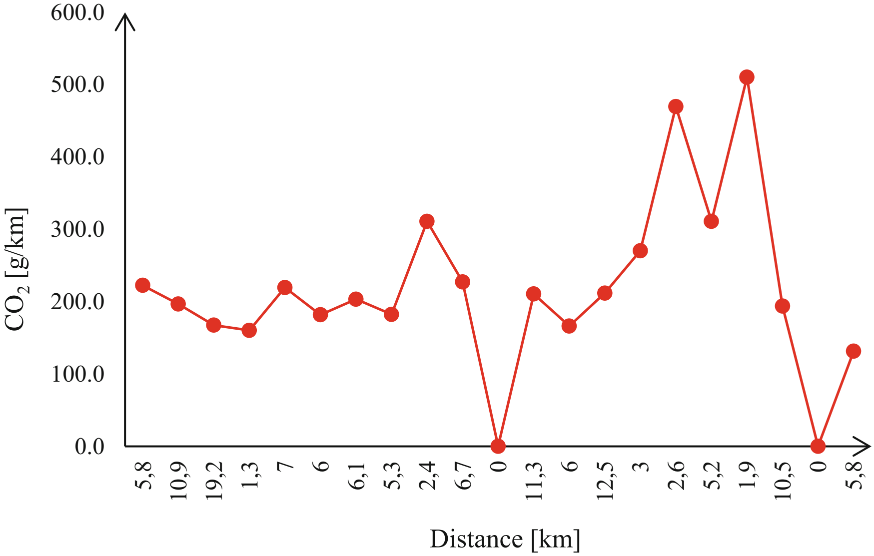

Fig. 2. CO_2 emissions in the urban cycle for the hybrid propulsion system

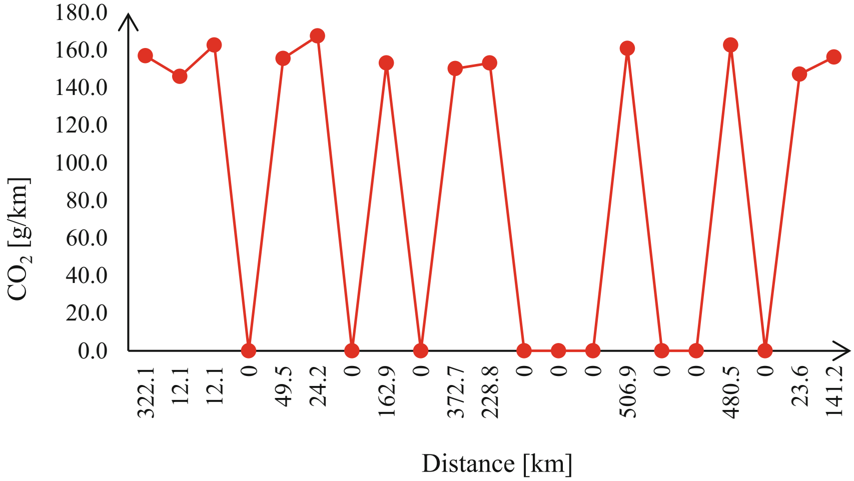

Fig. 3. CO_2 emissions in extra urban cycle for turbocharged engine

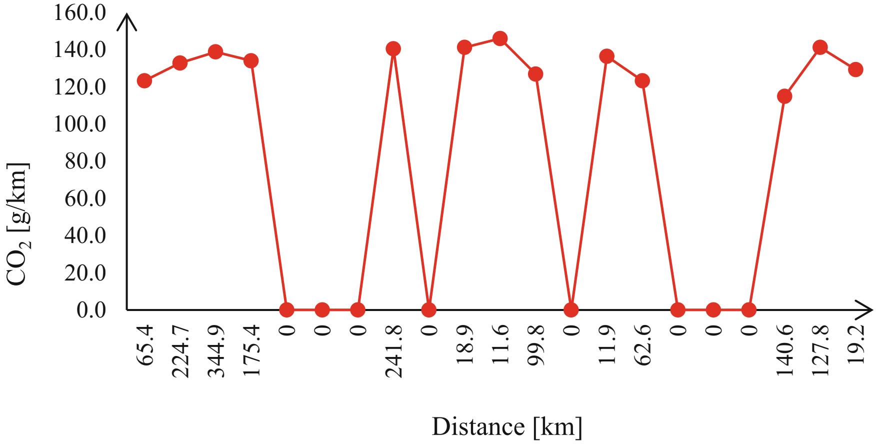

Fig. 4. CO_2 emissions in the extra urban cycle for the hybrid propulsion system

Based on recordings from car computers, have been selected records with similar distances for both types of propulsion systems. The Eco Score calculated by the internal software of the computers has been compared in order to determine to what extent the emissions of CO_2 are influenced by the driving style, gear shift, weight of the cars, etc. Figure 5 and Fig. 6 present the graphs related to Eco Score obtained for both propulsion systems.

Even though the best values for Eco Score were obtained for the turbocharged engine in extra-urban cycle correlated with low CO2 emissions, there were some exceptions when the Eco Score was low (52.8 pts.) and this can be explained by the traffic conditions and driving style in that particular situation. In the case of the hybrid propulsion system,

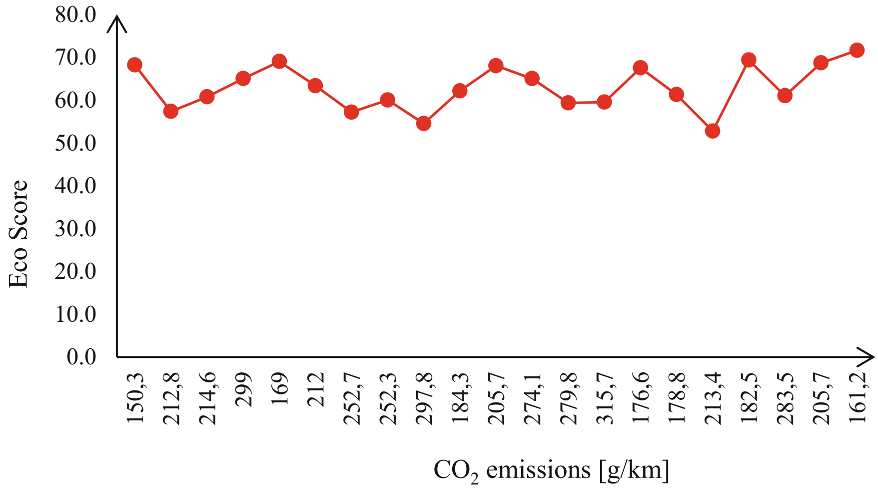

Fig. 5. Eco Score in mixed cycle for turbocharged engine

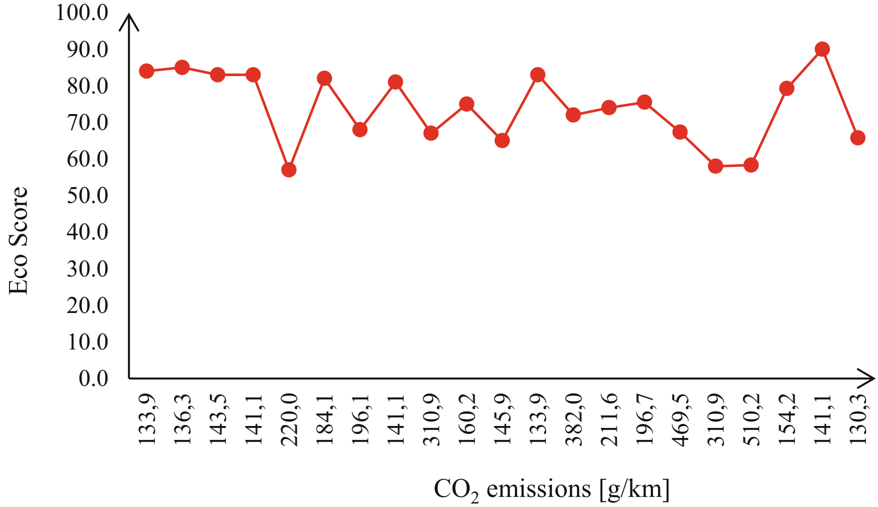

Fig. 6. Eco Score in the mixed cycle for the hybrid propulsion system

the lowest values for Eco Score (58 pts.) were obtained mainly on very short travel distances in the urban cycle (less than 1 km) which can be explained by the cold start effect of the combustion engine. As was expected, the Eco Score for the HEV reached higher values compared with the turbocharged engine for similar distances travelled. (Fig. 7).

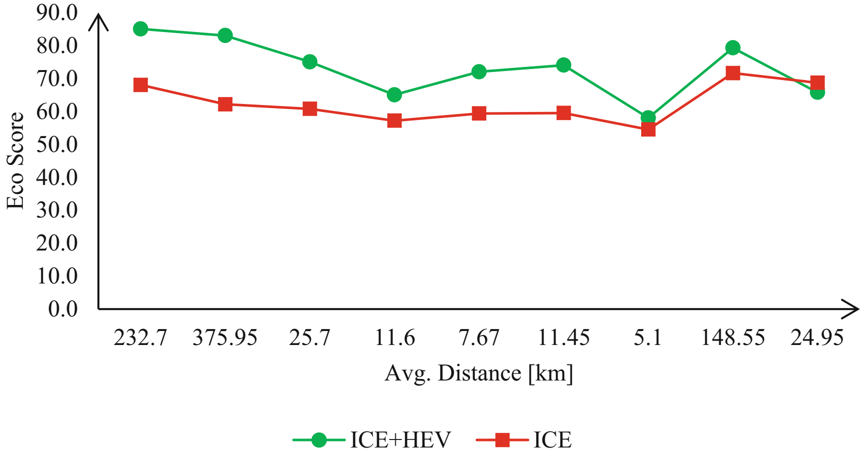

Fig. 7. Influence of the propulsion system and average distance on Eco Score

4 Conclusions

The research study covered two different propulsion systems for a period of 1 year and the data presented were selected for 21 days due to the extensive amount of data. The average total distance travelled for both cars was approximately 16,000 km. Based on the data presented, the main conclusions are as follows:

- On a very short travelled distance (less than 1 km), the calculated CO_2 emissions were in the range of 250 g/km for the urban cycle whereas, in the extra-urban cycle, the CO_2 emissions ranged between 130-150 g/km.
- The driving style and traffic conditions have a significant influence on Eco Score irrespective of the urban or extra-urban cycle.
- The results for CO_2 emissions and subsequently Eco Score for both propulsion systems, were close with the slightly better performance in favour of the hybrid propulsion system. It has to be outlined that the displacement of HEV is 2.5 higher than the turbocharged engine and the output power is almost double. Under these circumstances, the benefits of using hybrid propulsion systems compared with turbocharged engines, in terms of CO_2 emissions, are obvious taking into account that the driver profile was the same.

References

1. https://www.statista.com/statistics/265239/global-oil-consumption-in-barrels-per-day/#:~:text=Worldwide%20oil%20consumption%20reached%20approximately,decline%20in%20transportation%20fuel%20demand.
2. https://www.eia.gov/todayinenergy/detail.php?id=46596
3. Y. Oh, J. Park, J.T. Lee, J. Seo, S. Park Estimation of CO_2 reduction by parallel hard-type power hybridization for gasoline and diesel vehicles Sci Total Environ, 595, pp. 2–12, (2017)

4. http://autocaat.org/Technologies/Hybrid_and_Battery_Electric_Vehicles/HEV_Types/
5. I. López, E. Ibarra, A. Matallana, J. Andreu, I. Kortabarria Next generation electric drives for HEV/EV propulsion systems: technology, trends and challenges Renew Sustain Energy Rev, 114 (2019)
6. Y. Mishina, Y. Muromachi Are potential reductions in CO_2 emissions via hybrid electric vehicles actualized in real traffic? The case of Japan Transportation Research Part D: Transport and Environment, 50, pp. 372–384, (2017)
7. O. Balci, Y. Karagoz, O. Gezer, S. Kale, H. Koten Numerical and experimental investigation of fuel consumption and CO_2 emission performance for a parallel hybrid vehicle Alexandria Eng J, 60 (4), pp. 3649–3667, (2021)