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# ENERGY CONSUMPTION AND CARBON FOOTPRINT OF AN ELECTRIC VEHICLE AND A VEHICLE WITH AN INTERNAL COMBUSTION ENGINE

**Summary.** The use of electrically powered vehicles is becoming more and more established in practice and represents a promising solution in future ensuring quality mobility and reducing the pollution in the environment. Since these vehicles are high-priced, and there is still a low awareness among consumers in terms of energy consumption and pollution, vehicles with an internal combustion engine remain the norm. For this purpose, the study, here, provides an energy consumption estimate of an electric vehicle and thus its carbon footprint and compares it to the energy consumption and carbon footprint of a vehicle with an internal combustion engine. The results of this study reveal the orientation for the use of electric vehicles in future, in terms of raising awareness among the individual manufacturers, consumers and, last but not the least, the society as a whole, which is committed to sustainable developmental orientations.

## 1. INTRODUCTION

Traffic flows of heavy vehicles and passenger cars have a negative impact on the road and its structure [1]. Road transport is also a major source of air pollution, particularly in towns and cities. In urban areas road traffic accounts for more than half of the emissions of nitrogen oxides, carbon mono-oxide, and volatile organic compounds [2]. Therefore, finding an alternative to oil as a new type of vehicle fuel has become an important research project for the whole world transportation industry and environmental protection department. As a class of new energy vehicles, as well as a fusion of a variety of new technologies, pure electric vehicles, using electricity instead of oil, can effectively solve the problem of energy crisis and environmental pollution with its outstanding characteristics, such as "Zero emissions", no pollution, and low noise [3-4].

Despite the fact that the use of electrically-powered vehicles represents the future both in terms of quality mobility and reduced environmental pollution, the use of vehicles with internal combustion engine (ICEV) still prevails. This is primarily because of the high price of batteries, which prevents people from purchasing electric vehicles and the fact that electric vehicles offer less autonomy [5-6]. The problem is that the average vehicle user only takes into account the transportation costs incurred on a particular route [7], without considering the costs incurred throughout the company. In the broadest sense, the user has no clear insight into the entire chain of energy consumption factors [8] that relate to energy generation, energy consumption during the manufacturing of a vehicle, a vehicle's use and recycling at the end of the chain. Therefore, passengers' personal preferences are an important factor affecting the choice of mode of transport [9].

An important factor in assessing the social viability of electric vehicles is carbon footprint, which is defined as the total greenhouse gas emissions from direct or indirect processes caused by an activity or a product. The life cycles of physical products are divided into five phases, which are raw materials phase, production phase, distribution phase, consuming phase, and waste disposal phase [10]. A carbon footprint is an indicator that is based on an estimation of the consumption of goods. It has also become a valuable approach in understanding the role of individual countries in the consumption of goods and environmental pollution.

Therefore, the purpose of this paper is to introduce a uniform measure for the calculation of energy consumption of an electric vehicle and thus its carbon footprint, compared to the energy consumption and carbon footprint of a vehicle with an internal combustion engine. This information is not made available to Slovenian consumers before purchasing a vehicle, which is why the proposed methodology represents a scientific novelty in its clear formulation and calculation of the viability of use of an electric vehicle from the source of electricity to the final energy consumption in a real-world traffic environment. The proposed methodology aims to set new guidelines for displaying the energy consumption data of an electric vehicle and thus its carbon footprint. This information would undoubtedly contribute to raising awareness among the consumers, helping the broader social environment in understanding the importance of phasing-out internal combustion engine vehicles as a long-term perspective towards environmental protection and in the pursuit of sustainable development.

The applicability of the proposed methodology was verified based on a test drive of the delivery vehicles Piaggio Porter Electric (PPE) and Piaggio Porter 1,3 (PP1,3). The test drive took place in the suburbs and in the city centre of the municipality of Koper in a real-world traffic environment. The results of the methodology have been simulated at a distance of 30,000 km, which is the average life of the standard lead built-in batteries that are installed in PPE vehicles. The results of the study indicate a clear orientation for the use of electric vehicles in the future in terms of raising awareness among individual consumers and the society as a whole.

## 2. LITERATURE REVIEW

Tian et al. [11] state that the carbon footprint per capita varies greatly across the country. They cite the example of the city of Jingjin in China’s southwest region, where the carbon footprint ranged between 2.9 and 8.4 tonnes in 2007. These fluctuations were attributed to the differences in revenue in different parts of the country. On an average, the construction industry and services accounted for approximately 70% of the regional carbon footprint in 2007. They determined that, an average, 56% of the carbon footprint is connected to investment activities, 35% of it can be attributed to household consumption, and 9% is the result of the state consumption.

An important contribution is made by Wilson [12-13], who states that the carbon footprint in electricity production depends on the degree of development in the use of a particular energy source. In countries where renewable energy production is developed, the carbon footprint of an electric vehicle (EV) on using is considerably lower than when using an internal combustion engine vehicle (ICEV). Conversely, in countries where the production of renewable energy is less developed, the carbon footprint of using an EV is significantly higher than when using an ICEV.

For the purpose of this study, a study on the use of batteries was also examined. Ishihara [14] researched the environmental burden of the manufacture and use of different types of batteries. The study deals with CO2 emissions in the acquisition of primary materials, production, transportation, recycling, disposal and the effect of recycling (no need for new primary materials).

Chang et al. [15] analyses the carbon footprint of an internal combustion engine scooter (ICE) and the four types of electric scooters, namely: a hydrogen-fuelled scooter with on-board methanol steam reforming (on-board SMR), a hydrogen scooter with methane steam reforming (SMR), a plug-in electric scooter (PEV), and a hybrid scooter. They pointed out that alternative scooters have a significantly lower carbon footprint than ICE scooters, but offer no economic benefits due to their higher costs. However, if various scooters have the same purchase price, then the main factor that will influence the use of the alternative scooters would be the price of the gasoline. Noel and McCormack [16] conducted a sensitivity analysis to determine how vehicle and diesel prices affect the costs and benefits associated with the use of electric vehicles and found that both factors affect the intention of buying such vehicles.

Zhao et al. [17] analysed the environmental impacts of various alternative delivery trucks, including battery electric, diesel, diesel-electric hybrid, and compressed natural gas trucks. They pointed out that the battery electric delivery trucks have zero tailpipe emissions, electric trucks are not expected to have lower environmental impacts compared to other alternatives. On an average, electric trucks have slightly more greenhouse emissions and energy consumption than those of other trucks. Regional analysis also suggests that the percentage of cleaner power sources in the mix of electricity plays a significant role in the impact of electric vehicles in the life cycle of greenhouse gas emissions.

Wang et al. [18] conducted an energy consumption study for electric vehicles based on real-world driving conditions in Beijing. Test cycles were made following NECC, UDDS, and HWFET standards. NEDC is the standard test cycle for China. UDDS and HWFET test cycles are suitable for calculating the energy consumption of a vehicle in the United States, where the Environmental Protection Agency measurement method is in use. The survey and tests were carried out by collecting data from 112 drivers over a period of ten months, who collectively drove approximately 10,000 kilometres on 4,892 different routes. In addition to hybrid vehicles, an ICEV marked as a CV (Convectional Vehicle), and an EV marked as a BEV (battery electric vehicle) were also successfully included in the test.

## 3. RESEARCH METHODOLOGY

The test route for the delivery vehicles Piaggio Porter Electric (PPE) and Piaggio Porter 1.3 (PP1.3) that were tested as part of the study, took place in the suburbs and in the city centre in the municipality of Koper. It was designed to include approximately the same trip length and variety in terms of roads and speed limits, as the ones that are typical for these types of vehicles in everyday conditions while doing commercial work. When delivering small consignments, the trip made by a vehicle of this type in one day of work falls within the driving range of an EV. An EV is limited to an area where speed limits are up to 60 km/h, since it cannot achieve speeds that are higher than that. When determining the route of delivery for this type of vehicle, differences in altitude must also be taken into account, as they could greatly reduce the range of the vehicle, despite the braking energy recovery systems installed in the vehicle. At the same time, the planning of the route also takes into account the scenario where the vehicle's batteries are empty and must be at least partially charged in order for the vehicle to return to its charging station at the starting location. In order to obtain a realistic picture of energy consumption on a completely identical driving pattern, the following procedure is implemented to measure energy consumption of the EV PP and PP1,3 (hereinafter referred to as "the test").

Since, the objective reasons prevented the test from being carried out under the conditions prescribed by the European Parliament Directive on testing vehicle emissions and emissions in transport - Directive 2004/3/EC of the European Parliament and of the Council of February 11, 2004 [19], the test was carried out following the protocol described below:

- The vehicles included in the test were PPE and PP1,3. Both are intended for the distribution of goods in urban and suburban areas.
- The PPE has built-in lead batteries based on the manufacturer's decision.
- The PPE was chosen for the test, because it is the most commonly used in its class of delivery electric vehicles in Slovenia.
- To ensure that the entry conditions in terms of vehicle temperature were the same, both vehicles were kept idle (were not driven) for 12 hours before the start of the test.
- The tires of both vehicles were inflated to 3.8 bar (according to the manufacturer's instructions).
- The EV PP entered the test with pre-charged batteries and PP1,3 entered the test with a full fuel tank.
- Both the vehicles were equipped with a GPS tracker with the function of recording information on the distance travelled (distance and geographical imaging), the speeds on the route and the average speeds on the individual sections of the route.

- Testing was carried out at a distance of 35-40 km, which represents 80% of the expected range of the batteries of the EV PP batteries on a single charge (this is also the usual average route of the EV PP in everyday use).
- The test route took place in the city centre and in the suburban area.
- The testing included cycles of acceleration, deceleration, and maintaining constant speeds for both the vehicles and free running for the vehicle PP1.3.
- The maximum speed of both the vehicles during the test was up to 55 km/h (i.e., the maximum speed reached by PPE).
- During the test, the vehicles drove one after the other - PPE went first and PP 1,3 followed right after.
- The vehicle drivers used UHF handheld stations to communicate with each other and to coordinate the performance of the test while driving.
- Upon completion of the test, the batteries of the EV PP were charged. To determine energy consumption during charging, an energy electricity cost-measuring unit was used - the Cost Control model by Technoline Ltd., which has a maximum measured power of 3600W at 220V voltage. The fuel tank of PP1,3 was filled up to the maximum capacity (i.e., like before the start of the test).

Table 1

Necessary input data for testing the proposed methodology

| | **Meaning** | **Data entry** | **Source** |
|---|---|---|---|
| **Rg** | Fuel refining (kWh/gallon) | 6 | [20] |
| **QSn** | Energy value of crude oil (kWh/l) | 10.1 | [21] |
| **Bc** | Capacity of the built-in battery (kWh) | 17.28 | [22] |
| **qE LC** | Energy consumed to manufacture the battery (on 1 kWh) | 261 | [14] |
| **$CO_2$ LC** | Burden of $CO_2$ emissions on the lifespan of the battery (kg/1kWh ) | 65 | [14] |
| **$\sum CO_2 E_{Coal}$** | Burden of $CO_2$ emissions on the environment for coal (g/kWh) | 1.001 | [12-13] |
| **$\sum CO_2 E_{Pp}$** | Burden of $CO_2$ emissions on the environment for petroleum products (g/kWh) | 840 | [12-13] |
| **$\sum CO_2 E_{Ne}$** | Burden of $CO_2$ emissions on the environment for nuclear energy (g/kWh) | 16 | [12-13] |
| **$\sum CO_2 E_{RES}$** | Burden of $CO_2$ emissions on the environment for renewable energy sources (g/kWh) | 4 | [12-13] |
| **nmi $CO_2$B** | $CO_2$ emission during the transport of batteries by boat (g/t nmi ) | 34 | [21] |
| **nmi $CO_2$F** | $CO_2$ emission during the transport of fuel by boat (g/t nmi) | 10 | [21] |
| **$Pe_{Coal}$** | Share of electricity generated by coal in Slovenia (%) | 21.5 | [24] |
| **$Pe_{Pp}$** | Share of electricity generated by petroleum products in Slovenia (%) | 2.4 | [24] |
| **$Pe_{Ne}$** | Share of electricity generated by nuclear energy in Slovenia (%) | 36.5 | [24] |
| **$Pe_{RES}$** | Share of electricity generated by renewable energy sources in Slovenia (%) | 37.9 | [24] |

Source: Authors

## 4. RESULTS

Once the test route was completed, the total amount of energy used to charge the battery of PPE was 8,022 kWh, as measured with the energy consumption meter. After the completion of the test route, the tank of the PP 1, 3 was filled once again. The vehicle's tank was filled with 2.5 litres of fuel, which is the amount of fuel consumed during the test.

**The first part of the study** is focused on the calculation of energy consumption for PPE and PP 1,3 at a distance of 30,000 km, which is the average lifespan of lead-acid batteries. Where:

Pp - the distance travelled
$\bar{\upsilon}$ - average speed
Q95 - fuel consumption of 95-octane fuel
KWh - amount of energy consumed
KWh/100 km - energy consumption per 100 km
Rg - fuel refining 6 kWh/gallon [20]
QSn - energy value of crude oil 10.1 kWh/l [21]
KWh/Test - energy consumption over the life cycle of the battery (30,000 km)
ΣQb - total energy consumption for the manufacturing of the battery
qE LC - energy consumed to manufacture the battery, 261 kWh for a lead-acid battery with the capacity of 1 kWh [14]
Bc - the capacity of a built-in battery of 17.28 kWh [22]
∑Q – total energy consumption on 30,000 km

$$\text{kWh/100 km (PPE)} = 8{,}022 \text{ kWh}/36.79 \text{ km} * 100 \text{ km} = 21.80 \text{ kWh/100 km} \tag{1}$$

$$\text{l/100 km (PP 1.3)} = 2.5 \text{ l}/36.64 \text{ km} * 100 \text{ km} = 6.82 \text{ l/100 km} \tag{2}$$

$$\text{kWh/100 km (PP 1.3)} = (\text{Rg/gallon} * \text{l/100 km}) + (\text{QSn} * \text{l/100 km}) \tag{3}$$

$$\begin{aligned}\text{kWh/100 km (PP 1.3)} &= (6 \text{ kWh}/ 3.7854 \text{ l} * 6.82 \text{ l}) + (10.1 \text{ kWh} * 6.82 \text{ l}) \\ &= 10.80 \text{ kWh} + 68.882 \text{ kWh} \\ &= 79.682 \text{ kWh}\end{aligned} \tag{4}$$

$$\text{kWh/Test} = \text{kWh/100 km} / 100 \text{ km} * 30{,}000 \text{ km} \tag{5}$$

$$\text{kWh/Test (PPE)} = 21.80 \text{ kWh} / 100 \text{ km} * 30{,}000 \text{ km} = 6{,}540 \text{ kWh} \tag{6}$$

$$\text{kWh/Test (PP 1.3)} = 79.682 \text{ kWh} / 100 \text{ km} * 30{,}000 \text{ km} = 23{,}904.6 \text{ kWh} \tag{7}$$

$$\sum Qb = \text{qE LC} * \text{Bc} \tag{8}$$

$$\sum Qb = 261 \text{ kWh} * 17.28 \text{ kWh} = 4{,}510 \text{ kWh} \tag{9}$$

$$\begin{aligned}\sum Q &= \text{kWh/Test} + Qb \\ &= 6{,}540 \text{ kWh} + 4{,}510 \text{ kWh} = 11{,}050 \text{ kWh}\end{aligned} \tag{10}$$

The energy consumption calculated per 100 kilometres for PPE is 21.80 kWh, for PP1,3 it is 6.82 l of fuel. Table 2 shows that PPE consumes 11,050 kWh for a distance of 30,000 km, including the energy required for the manufacture of the batteries, while PP1,3 consumes 23,904.60 kWh for the same distance (including the energy from the pumping of crude oil for its consumption). If the results obtained are converted for a distance of 100 kilometres, the energy consumption of PPE is 36.83 kWh compared to the energy consumption of PP1,3, which is 79.24 kWh.

Table 2

Consumed electricity and fuel during the test

| | **PPE** | **PP1,3** |
|---|---|---|
| Pp | 36.79 km | 36.64 km |
| $\bar{\upsilon}$ | 29.48 km/h | 30.1 km/h |
| Q95 | - | 2.5 litres |
| kWh | 8,022 kWh | - |
| kWh/100 km | 21.80 kWh | 79.682 kWh |
| kWh/Test | 6,540 kWh | 23,904.6 kWh |
| | 4,510 kWh | - |
| **∑Q** | **11,050 kWh** | **23,904.6 kWh** |
| Energy consumption per 100 km | **23.83 kWh** | **79.24 kWh** |

Source: Authors

**In the second part of the study**, a comparison is made between the $CO_2$ emissions of PPE and PP1,3 at a distance of 30,000 km. $CO_2$ emissions were calculated for the sourcing of primary materials, production, transport, recycling, disposal and for the recycling effect of the lead-acid battery for the vehicle PPE used in the test. Where:

$\sum Qb\ CO_2$ - $CO_2$ emissions from battery manufacture to recycling
Bc - the capacity of a built-in battery of 17.28 kWh [22]
$CO_2$ LC - the burden of $CO_2$ emissions over the battery's lifespan, 65 kg/1kWh [14]
nmi $CO_2B$ - $CO_2$ emissions during the transport of batteries by boat, 34 g/t nmi [23]
nmi - nautical miles (shipping from Guangzhou - Luka Koper, 7847 nmi)
Bw - battery weight (0.496 t)
KWh/Test (PPE)- energy consumption over the life cycle of the battery PPE (30,000 km)
$\Sigma\ CO_2$ - total $CO_2$ emissions per 30,000 km
$\sum CO_2\ E_{Coal}$ - burden of $CO_2$ emissions on the environment for coal (1,001g/kWh) [12-13]
$\sum CO_2\ E_{Pp}$ - burden of $CO_2$ emissions on the environment for petroleum products (840 g/kWh) [12-13]
$\sum CO_2\ E_{Ne}$ - burden of CO2 emissions on the environment for nuclear energy (16 g/kWh) [12-13]
$\sum CO_2\ E_{RES}$ - burden of CO2 emissions on the environment for renewable energy sources (4 g/kWh) [12-13]
$\sum CO_2\ E$ - total $CO_2$ emissions per 30,000 km in the production of each energy product
$\sum CO_2\ E_{Total}$ - total $CO_2$ emissions per 30,000 km in the production of all energy products in Slovenia
$Pe_{Coal}$ - Share of electricity generated by coal in Slovenia (21.5%) [24]
$Pe_{Pp}$ - Share of electricity generated by petroleum products in Slovenia (2.4%) [24]
$Pe_{Ne}$ - Share of electricity generated by nuclear energy in Slovenia (36.5%) [24]
$Pe_{RES}$ - Share of electricity generated by renewable energy sources in Slovenia (37.9%) [24]

$$\sum Qb\ CO_2 = (CO_2\ LC * Bc) + (nmi\ CO_2B * nmi * Bw) \tag{11}$$

$$\sum Qb\ CO_2 = (65\ kg/1kWh * 17.28\ kWh) + (34\ g/t\ nmi * 7847\ nmi * 0.496\ t) \tag{12}$$

$$\sum Qb\ CO_2 = (1{,}132.2\ kg) + (132.33\ kg) = 1{,}264.53\ kg\ CO_2$$

The calculation of the total $CO_2$ emissions per 30,000 km takes into account data relating to the burden of $CO_2$ emissions (g/kWh) for the environment for each type of energy used by Wilson [12-13]. Since the testing of the vehicle took place in Slovenia, the share of electricity produced per type of fuel ($Pe_{Coal}$, $Pe_{Pp}$, $Pe_{Ne}$, $Pe_{RES}$) was taken into account in the calculation.

$$\Sigma CO_2 E = ((CO_2 E * kWh/Test) + \Sigma Qb\ CO_2) * Pe_{Coal} \text{ or } Pe_{Pp} \text{ or } Pe_{Ne} \text{ or } Pe_{RES})) \quad (13)$$

$$\sum CO_2 E_{Coal} = ((1{,}001 \text{ g/kWh} * 6{,}540 \text{ kWh}) + 1{,}264.53 \text{ kg } CO_2) * 0.215)) \quad (14)$$
$$\sum CO_2 E_{Coal} = 1.680{,}78$$

$$\sum CO_2 E_{Pp} = ((840 \text{ g/kWh} * 6{,}540 \text{ kWh}) + 1{,}264.53 \text{ kg } CO_2) * 0.024)) \quad (15)$$
$$\sum CO_2 E_{Pp} = 162.19$$

$$\sum CO_2 E_{Ne} = ((16 \text{ g/kWh} * 6{,}540 \text{ kWh}) + 1{,}264.53 \text{ kg } CO_2) * 0.365)) \quad (16)$$
$$\sum CO_2 E_{Ne} = 499.74$$

$$\sum CO_2 E_{RES} = ((4 \text{ g/kWh} * 6{,}540 \text{ kWh}) + 1{,}264.53 \text{ kg } CO_2) * 0.379)) \quad (17)$$
$$\sum CO_2 E_{RES} = 489.17$$

Table 3 shows the $CO_2$ emissions over the lifespan of lead-acid batteries of the electric vehicle Piaggio Porter (PPE). Total emissions ($\sum CO_2 E_{Total}$) at 30,000 km are 2,831.88 kg.

Table 3
The $CO_2$ emissions over the lifespan of lead-acid batteries of the electric vehicle Piaggio Porter (PPE)

| **Type of energy source** | **$CO_2$ (g/kWh)** | **% Pe** | **$\sum CO_2 E$** |
|---|---|---|---|
| Coal | 1.001 | 21.5 | 1,680.78 |
| Petroleum products | 840 | 2.4 | 162.19 |
| Nuclear energy | 16 | 36.5 | 499.74 |
| RES (hydropower, wood, biofuels) | 4 | 37.9 | 489.17 |
| Other | - | 1.7 | - |
| **$\sum CO_2 E_{Total}$** | | | **2,831.88** |

Source: Authors

The calculation of $CO_2$ emissions at a distance of 30,000 km for Piaggio Porter 1.3 (PP1.3) is presented below. According to the manufacturer Piaggio [22], $CO_2$, emissions are 156g/km. At a distance of 30,000 km, the $CO_2$ emissions are as follows:

$$\sum CO_2\ PP1{,}3 = CO_2\ PP1.3 * 30{,}000 \text{ km} + \text{consumption } PP\ 1{,}3/100 \text{ km} * 30{,}000 \text{ km} * \text{nmi } CO_2Oil * \text{nmi} + Rg/\text{gallon} * \text{consumption } PP\ 1.3/100 \text{ km} * 30{,}000 \text{ km} / 100 \text{ km} * CO_{2\ Pp} \quad (18)$$

Where:

$CO_2$ PP1,3 - $CO_2$ emission is 156g/km [22]
nmi $CO_2F$ - $CO_2$ emission during the transport of fuel by boat, 10 g/t nmi [23]
nmi - nautical miles (shipping from Guangzhou to Luka Koper, 4,452 nmi)
l/100 km (PP 1,3) - consumption (PP 1.3) per 100 km

Rg - fuel refining 6 kWh/gallon [20]

$CO_{2\ Pp}$- $CO_2$ emission per kWh from petroleum products 0.840 kg/kWh (840 g/kWh) [12-13]

$\sum CO_2$ PP1.3 = (((156g/km * 30,000 km) + (6.82 l * 30,000 km * 10 g/t nmi * 4,452 nmi)) + 6 kWh/ 3.7854 l * 6.82 l * 30,000 km / 100 km * 0.840 kg/kWh $CO_2$)))

= 4.680 kg + 68,31 kg + 2.696,4 kg

= 7.444,71 kg (19)

## 5. DISCUSSION

For the purpose of analysing the actual energy consumption of PPE and PP1,3 and making a comparison of the two, the key factors affecting fuel extraction were taken into account. Crude oil has to be pumped and transferred into reservoirs at the extraction locations. The oil is then pumped out of the reservoirs at the processing sites and refined. After that, fuel has to be pumped into clean reservoirs or onto ships, shipped to its next location and unloaded from the boats with the use of pumps, transferred into smaller tanks and then transported to the sales point, where it is pumped once again by the end user. Thus, the study focuses on energy consumption from the energy source, which is a key factor in real-world economic and environmental comparisons between PPE and PP1,3.

An important aspect in the final analysis of the economic viability of using one type of vehicle or the other is also the selling price. In Table 4, in addition to the results obtained for electricity and fuel consumption during the test, the purchase value of the two tested vehicles is also taken into account. Despite the fact that the cost of energy consumed to drive PPE for a distance of 30, 000 km is only half the energy consumed to drive PP1,3 for the same distance, the use of the latter is economically viable. It is because the purchase price of PPE is 55% higher than the price of PP1,3. The results obtained with the comparison of $CO_2$ omissions or carbon footprint are significantly in favour of PPE, as its results show as much as a 262% reduction in $CO_2$ emissions.

Table 4

The economic viability of the use of the electric vehicle Piaggio Porter

| | **PPE** | **PP1,3** |
|---|---|---|
| Sales price | 25,055.00 € | 13,970.00 € |
| Consumption at 30,000 km | 11,050 kWh | 23,904.6 kWh |
| Consumption at 30,000 km in € | 1,436.50 € | 3,107.59 € |
| **Cost of use** | 26,491.50 € | **17,077.59 €** |
| **Carbon footprint** | **2,831.88 kg** | 7,444.71 kg |

Source: Authors

The results of the study confirm that electric vehicles are more energy efficient and shed some light on the reality of total energy consumption, taking into account more than just the energy that is required to drive an electric vehicle. Thus, this study builds upon the existing studies and provides clear guidelines for the use of electric vehicles in Slovenia, especially from the often neglected environmental aspect.

The study also represents an important analysis of the economic viability of the use of electric vehicles for international and domestic suppliers of such vehicles. Slovenian customers will not need further convincing on the benefits of using electric cars by the suppliers, which could result in increased sales in the medium term. The significant difference between PPE and PP1,3 in carbon footprint will prompt countries to subsidize purchases of electric vehicles even more, since a reduction in $CO_2$ emissions has a multiplicative effect on the quality of life and society as a whole. This means that purchasing an electric vehicle will become more and more economically viable over the years.

A sensitivity analysis was conducted, which showed a linear dependence of the final results with respect to the change in the input data (variables). The results would be significantly different, only if the value of the variables in the use of any of the energy sources in Slovenia were to change (coal, oil derivatives, nuclear energy, and renewable energy). In Table 1 (Chapter 3. Methodology) these are the following variables: $Pe_{Coal}$, $Pe_{Pp}$, $Pe_{Ne}$, $Pe_{RES}$. The fact remains that an electric vehicle is more energy efficient and more environmentally friendly if it is used in a country that has a high percentage of renewable sources of electricity

## 6. CONCLUSION

The study represents one of the first contributions that incorporate an energy consumption estimate for an electric vehicle and thus its carbon footprint and compares it to the energy consumption and carbon footprint of a vehicle with an internal combustion engine. On the basis of the results obtained, it was possible to establish that the use of an electric vehicle clearly is economically viable, if we take into account the entire process from the energy source to the final consumption of the energy in a real-world traffic environment. The results confirm that in Slovenia, the use of an electric vehicle is significantly more environment friendly than the use of a vehicle with an internal combustion engine. Such a significant difference in carbon footprint will provide a boost for the development of electric vehicles, primarily in the direction of increasing the autonomy of the vehicles, and, last but not the least, encourage countries to provide financial resources for subsidizing the purchase of vehicles that are in line with sustainable development orientations promoted by the global environment.

The fact remains that an electric vehicle is more energy efficient and more environment friendly if it is used in a country that has a high percentage of renewable sources of electricity. The difference in carbon footprint between an electric vehicle and a vehicle with an internal combustion engine is significantly smaller in countries that generate electricity mostly from the processing of fossil fuels. Despite the fact that the use of an electric vehicle in countries with a high percentage of renewable energy sources is justifiable, they remain relatively rare. It would be sensible for producers to be encouraged (obliged) to provide information on the power consumption of an electric vehicle and thus its carbon footprint. This information would undoubtedly contribute to the consumers and the broader social environment of being aware of, and thinking about the importance of phasing-out internal combustion engine vehicles as a long-term perspective towards environmental protection and in the pursuit of sustainable development.

This paper proposes a new methodology for calculating the viability of using an electric vehicle from the source of energy generation to the final energy consumption in a real-world traffic environment. For the methodology to be used globally, additional testing is required on different models of electric vehicles, as well as in different countries, depending on the interests of the individual manufacturers.

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