



# A Well-to-Wheel Comparative Life Cycle Assessment Between Full Electric and Traditional Petrol Engines in the European Context

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**Abstract.** Automotive sector is crucial for the economic and social system. Conversely, it also plays an important role in the global emissions balance with strong consequences on the environment. Currently the Research world is engaged in the reduction of the emissions, especially in order to contrast the Climate Change and reduce toxicity on humans and the ecosystem. This study presents a comparative Life Cycle Assessment, Well-to-Wheel, between the most common technology used in the automotive sector, i.e. the traditional petrol Internal Combustion Engine and the full Battery Electric Vehicle. The different configurations have been analysed within 17 different impact categories in terms of climate change, human health, resourced depletion and ecosystems. The Well-to-Wheel approach allows to focus the attention on the use stage of the vehicle, considering the local effects due to the direct emissions in high density urban zones and it mitigates the dependence of usage hypotheses, different scenarios and intrinsic differences between the various models of cars in circulation.

**Keywords:** Life Cycle Assessment · Electric vehicles · Green design · Climate Change

## 1 Introduction

Road transport is the third largest source of European greenhouse gases accounting for around 26% of total emissions [1]. In the UK, e.g., conventional road transport also remains the predominant source of many local emissions including nitrogen oxides (NO<sub>x</sub>) and particulates (PMs). Within urban areas, the percentage contributions due to road transport are particularly high. For example, although road transport is responsible for around a quarter of particulates on a national level, in London road transport contributes almost 60% of known primary emissions [2]. Worldwide population growth and industrialization have resulted in increases in demand for energy in the transportation sector, among other sectors. As a result, air pollution and anthropogenic greenhouse gas emissions have become key global problems. Various options are available to mitigate

the effect of the road emissions. The use of alternative fuels, mainly biodiesel, petrol–alcohol blends, natural gas and liquefied petrol gas in vehicular applications has grown in recent years in European Union countries, the United States, Japan, India, Brazil and many other markets. Legislation is also in place to encourage or effectively force further adoption of these fuel types [3]. European Union requirements regarding vehicle emissions for passenger cars and light commercial vehicles, specified as Euro 6, set strong limits for emissions of HC, CO, and NO<sub>x</sub>. Instead, CO<sub>2</sub> emissions are covered by separate legislation. The Life Cycle Assessment (LCA) is a very valid method in order to evaluate the real impact of a process or a product [4, 5]. In particular, the Well-to-Wheel approach (WTW) allows to better emphasize on the usage phase, focusing on aspects relating to emissions in urban areas and more specifically verifying aspects related to engines and the production and refining of fuels [6].

## 2 Materials and Methods

The LCA analysis has been carried out with OpenLCA software version 1.10.1 [7], integrated with the ecoinvent database version 3.6 [8]. The allocation of the environmental burden has been handled by means of the cut-off system. In this way, if a material is recycled, the primary producer does not receive any credit for the provision of any recyclable materials. As a consequence, recyclable materials are available burden-free to recycling processes, and secondary (recycled) materials bear only the impacts of the recycling processes. Recyclable materials have been selected on the European market for products, consequently they include all the upstream burdens included average transports of that product within the geography, as well as inputs of the product itself to cover losses in trade and transport [8].

The consumption is stated, depending on the propulsion concept, in litre petrol per 100 km, for the traditional Internal Combustion Engine (ICE) and in kilowatt-hours per 100 km, for the Battery Electric Vehicle (BEV). For a general comparison, the energy consumption is converted in MJ/100 km/100 installed-kW as well for tank-to-wheel and well-to-tank approach. The consumption per kilometre of a car is strongly influenced by several factors, among which the most important are speed, weight and aerodynamics. In order to make a comparison between the different powertrains, a car model was chosen, looking for those on the market, sedan-type cars (with 3 volumes), with similar, as much as possible, installed power, of the same segment (medium) and of the same year of production (2018). The choice was for a Mercedes C-Klasse with a petrol 155 kW internal combustion engine (1991 cm<sup>3</sup>) and a Tesla model S with a 193 kW electric engine.

This particularly affects the energy mix referred to in the production of electricity for recharging electric car batteries but also the emission related to the petrol production and distribution. In all cases, reference was made to urban driving in areas with high population density. The electricity market activity ends with the transport of the energy at low voltage (400 V) electricity in the transmission network over aerial lines and cables. The ecoinvent dataset includes: electricity inputs produced in this country and from imports and transformed to low voltage; the transmission network; direct emissions to air; electricity losses during transmission. The dataset is extrapolated from year 2017

to the year of the calculation (2019). The energy mix change greatly in function of the natural resources and the political choices of the country. The Well-to-Tank (WTT) stage includes fuel extraction, refining and distribution for ICE vehicles and, electrical energy production, transformation and distribution for BEVs. The Tank-to-Wheel (TTW) stage includes the fuel combustion for ICE while it has not emissions for BEVs. The Life Cycle Impact Assessment (LCIA) has been conducted according to the ILCD 2018 method [9]. In this work, the midpoint methodology has been adopted. The ILCD midpoint categories are grouped into four areas of protection: Climate Change (CC), Human Health (HH), Resources Depletion (RD) and Ecosystems (EQ). The impact categories of the endpoint method are those of IPCC for CC [10], of Posch et al. [11] for EQ, Henderson et al. [12], Frischknecht et al. [13], for HH and van Oers and Guinée [14], Milà I Canals et al. [15], van Oers et al. [16] for RD.

### 3 Results and Discussion

The emission factors, expressed in g/100 km, have been taken from the specialized site <https://ecoscore.be> for the two chosen cars. These emissions are related only to the use phase of the vehicle, i.e. they are the pollutants emitted while driving. A share of these emissions depends on engine technology, another part on the fuel type and fuel consumption, and a third part is measured during the official approval tests a vehicle has to undergo before it can enter the European market. The specific TTW emissions for the ICE vehicle are 12800 g/100 km of CO<sub>2</sub>, 23.3 g/100 km of CO, 0.4 g/100 km of NO<sub>x</sub> and 2.9 g/100 km of HC. The estimated energy consumption is of 249 MJ/100 km (corresponding to a petrol consumption of 8.4 l/100 km) for the ICE vehicle, and an estimated energy consumption of 78.1 MJ/100 km for the BEV. The results are reported for 100 km and for 100 kW of installed power, according to the ILCD 2018 method. Each emission is reported in terms of equivalent unit and is categorized in the different areas of protection. Furthermore, the data are represented as a percentage comparison, making the ICE vehicle as 100, i.e.  $(BEV_{\text{emission}} - ICE_{\text{emission}})/ICE_{\text{emission}}\%$ . In this way a positive result indicates that the BEV has a higher impact on the environment and vice versa.

The global results for 100 km and for 100 kW of installed power, according to the ILCD 2018 method, are reported in Fig. 1. Each emission is reported in terms of percentage difference between the BEV and the ICE referring to the European average. The standard deviation shows a great variability of the data, especially in function of the electricity mix of the country. Focusing on some particular impact category, it is possible to see better the difference in terms of country (see Fig. 2) yellow has been attributed to a zero difference between ICE and BEVs, green to a better impact and red to a worst impact.

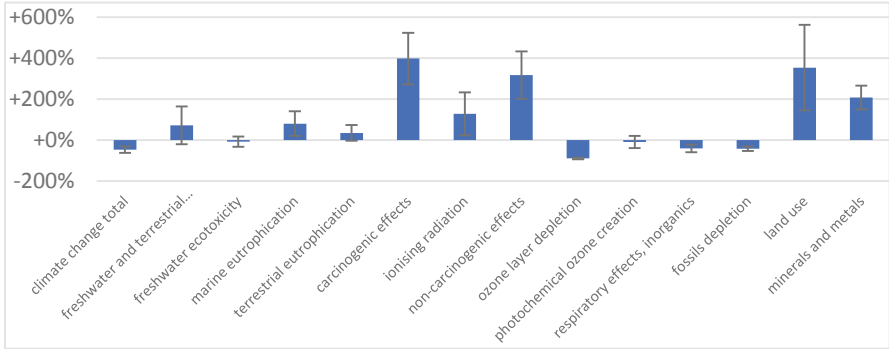


Fig. 1. Impact effect for 100 km and 100 kW of installed power

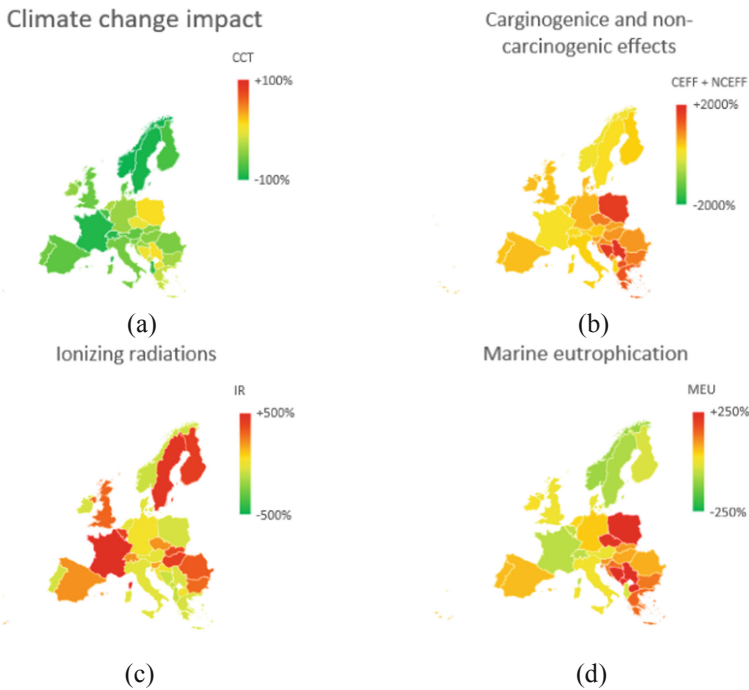


Fig. 2. Comparison of the impacts of BEV, respect to ICE, for different categories of impact

## 4 Conclusions

A comparative Well-To-Wheel Life Cycle Assessment among an ICE and a similar BEV, has been carried out in the most relevant European countries. The impact categories analysed have been based on the ILCD 2018 method with the ecoinvent database (year 2019) and the OpenLCA software.

The finding obtained are summarized as follows:

- Electric vehicles play a fundamental role in the battle against Climate Change, since they lead to a WTW reduction until 50% compared to the traditional ICE vehicles, with small exceptions in countries heavily dependent on fossil fuels;
- Conversely, BEVs have a generally higher impact on categories related to human health;
- The eutrophication of the waters (marine and fresh) and of the soil is highly dependent on the energy production methods;
- Countries with electricity produced by means of nuclear power plants have very good performance in terms of Climate Change but have major repercussions on ionizing radiation and dissipated water;
- The WTW approach allowed to focus on the fuel impact but doesn't consider construction, maintenance and dismantling of the vehicles.

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