LIFE-CYCLE AND ENERGY CONSUMPTION OF THE COMMERCIALLY AVAILABLE PASSENGER CARS

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Today, passenger vehicle emissions alone represent 15% of global greenhouse gas emissions (GHG). The automobile industry is aware of this and has taken steps towards decarbonization over the past decade. Emissions related to the six phases of the life cycle were determined from the LCA database compiled on the basis of data collected on emissions during the life cycle of different types of vehicles, units, sizes and geographical areas. Typically, Internal Combustion Engine Vehicles (ICE) constantly emit CO_2 while driving, whereas Battery Electric Vehicles (BEV) and Fuel Cell Electric Vehicles (FCEV) do not. The transition to an electric vehicle is only as clean as the energy source used to charge the vehicle. Each BEV car represents approximately 2.2 MWh/year of load on the country's electric power system, while due to the way energy is converted, the ICE car represents approximately 11.9 MWh/year of fuel-equivalent load.

KEYWORDS

ICEV, BEV, Energy, CO_2

1 INTRODUCTION

In 2019, the European Commission published the European Green Deal, a comprehensive strategy aimed at increasing the sustainability of the European Union's (EU) economy and achieving climate neutrality by 2050. The deal focuses on reducing greenhouse gas (GHG) emissions, with a minimum target of 50% reduction by 2030 compared to 1990 levels. One of its major milestones is the significant reduction of GHG emissions within the transportation sector, particularly by addressing passenger vehicles' emissions [Rimar 2020].

Today, emissions from passenger cars alone account for around 15% of global greenhouse gas (GHG) emissions. The automotive industry is aware of this and has taken steps to reduce carbon emissions over the last decade.

The industry's main objective has been and continues to be the electrification of the fleet, with a focus on significantly reducing the number of cars with internal combustion engines or their emissions. However, recent studies have pointed out that when modelling a hypothetical scenario of aggressive fleet electrification, hypothetically powered by completely fossil-free energy sources, GHG emissions are still exceeded due to supply chain emissions.

Currently, different energy sources, such as liquid fuels, fuel gases, or lithium-ion batteries, can be used to power passenger cars. Typically, Internal Combustion Engine Vehicles (ICE) constantly emit CO_2 while driving, whereas Battery Electric Vehicles (BEV) and Fuel Cell Electric Vehicles (FCEV) do not. However, consumer information brochures often only describe passenger vehicles' driving emissions, which might mislead consumers to believe that Zero-Emission Vehicles (ZEV) do not emit any CO_2 since other life-cycle emission aspects are omitted. To fairly compare the climate impact of different vehicles, a common approach is to use Life-Cycle Assessment (LCA) in terms of equivalent CO_2 emissions. LCA considers the entire life cycle of products or services, accounting for multiple environmental impact categories. It evaluates emissions from vehicle production, energy sources used to charge BEVs' batteries or produce hydrogen, and even disposal/recycling aspects. However, LCA results involving BEVs can quickly become outdated due to battery production/recycling techniques' steady improvement and local developments in green energy generation plants. Additionally, certain greenhouse gas aspects like electricity carbon intensity or carbon emissions associated with fuel transportation vary locally. As a result, directly comparing LCA results from different research papers remains challenging. An LCA comparison between an Internal Combustion Engine Vehicle (ICE) and a Battery Electric Vehicle (BEV) in China from 2018 reveals interesting insights. The study considers the impact of electricity generation mix on carbon emissions from vehicles. While BEVs are generally considered to have higher energy efficiency and better control over CO_2 emissions compared to ICEVs, the effectiveness of CO_2 emission reduction for BEVs can be weakened or even counterproductive in regions where a large amount of thermal power is still used. The study demonstrates that BEVs in regions with high penetration of thermal power produce more CO_2 emissions, whereas BEVs in regions with higher penetration of renewable energy have better environmental performance in carbon emission reduction. For instance, in a region with over 50% penetration of renewable energy, a BEV can reduce more CO_2 (18.32 t) compared to an ICE. Therefore, regions with high carbon emissions from vehicles should prioritize increasing the proportion of renewable generation rather than solely promoting BEVs.

The emissions associated with the six life cycle phases were determined from an LCA database compiled from data collected on life cycle emissions of different vehicle types, sizes, and geographical areas. Production emissions are assumed to occur in the year of sale, while use phase emissions are distributed over the lifetime of the vehicle. Fuel/electricity production and exhaust emissions are assumed to be spread over the lifetime of the vehicle. Fuel/electricity production and exhaust emissions decrease by about 3 to 4 % per year. This means that fuel/electricity production and exhaust emissions are higher than average in the first half of the lifetime, while they are lower than average in the last half of the lifetime. The front-loading captures the effect of new cars being driven more than old cars (e.g., a higher proportion of rental cars and/or taxis) [Claeys 2019, Ou 2012, Moro 2018, Zackrisson 2010, Ellingsen 2016, Polestar 2023, BEO 2023, BP 2022].

2 MATERIALS AND METHODS

The following stages of the vehicle life cycle have been taken into account in this study:

- Automobile production
- Manufacture of batteries
- Fuel consumption
- Fuel/EE production
- Maintenance
- Recycling

Based on information from the LCA database, all vehicles have been divided into three size categories based on the Euro NCAP categorization to simplify and standardize the results:

S- small vehicles

A- segment mini cars
B- segment small cars
C- segment medium cars

M- medium vehicles

D- segment large cars
Small SUV
Small MPV

L- large vehicles

E- segment executive cars
F- segment luxury cars
S- segment sports coupes
M- segment multipurpose cars (medium and large MPV)
J- segment sport utility cars (medium and large SUV).

The vehicle breakdown presented is mainly based on life-cycle energy consumption, including energy consumption for vehicle production, maintenance, recycling and manufacturing, and fuel consumption.

The analysis presented in this document focuses mainly on identifying the energy consumption over the whole life cycle of a vehicle and tracking the impact of fleet change on energy.

3 RESULTS AND DISCUSSION

The automobile sector, while presenting environmental hazards, also paves the path for sustainable development through its technological advancements. Vehicle manufacturers committed to sustainable mobility must embrace the responsibility of recycling vehicles post their operational lifespan [Kuric 2011, Bozek 2021]. Vehicle design necessitates balancing consumer demands, technical and manufacturing capabilities, safety, legal compliance, and ecological conservation [Krenicky 2018]. In the journey of crafting a new vehicle, these elements often clash, with environmental regulations, particularly emission standards, taking precedence [Claeys 2019, Ou 2012, Moro 2018].

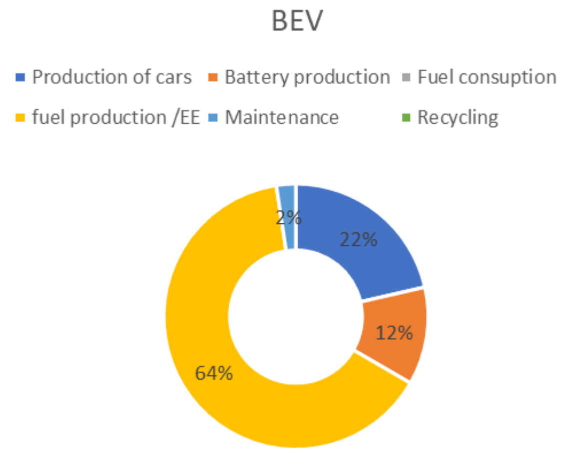

Figure 1. Tailpipe emissions of BEV

Based on Green NCAP and ICCT analyses, production, and fuel consumption account for a significant part of the lifetime emissions of internal combustion engine vehicles, while battery production is another concern for electric vehicles. Tailpipe emissions of passenger cars with an internal combustion engine and an electric account for the overwhelming majority of the car's total life cycle emissions are at the figures [Ellingsen 2016, Polestar 2023, BEO 2023, BP 2022].

As a benchmark, the term life cycle means the expected lifetime of the vehicle of 240 000 km. The charts show that the transition to EVs is only as clean as the energy source used to charge the vehicle. At a global level, applying the current global electricity generation mix to a new electric fleet will achieve emissions reductions of around 15 to 30 tCO_2e (54 to 65% lifetime emissions reduction) for an average electric vehicle compared to an internal combustion engine vehicle over its expected lifetime of 240,000 km [Ou 2012].

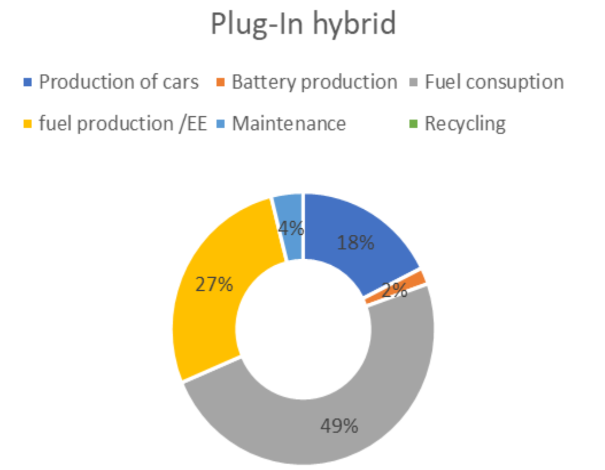

Figure 2. Tailpipe emissions of Plug-In hybrid

Within the energy mix of Slovakia, which in 2022 was 69.06% - nuclear power plants, 21.65% - fossil sources, 9.29% - RES; this means approximately 156.93 gCO_2/kWh (energy mix of sources) [Moro 2018].

Applying the current electricity generation mix to the new fleet of electric vehicles in Slovakia will lead to emission reductions of approximately 5-7 tCO_2e (74-80% reduction in lifetime emissions) for an average electric vehicle compared to an internal combustion engine vehicle over its expected lifetime of 240,000 km.

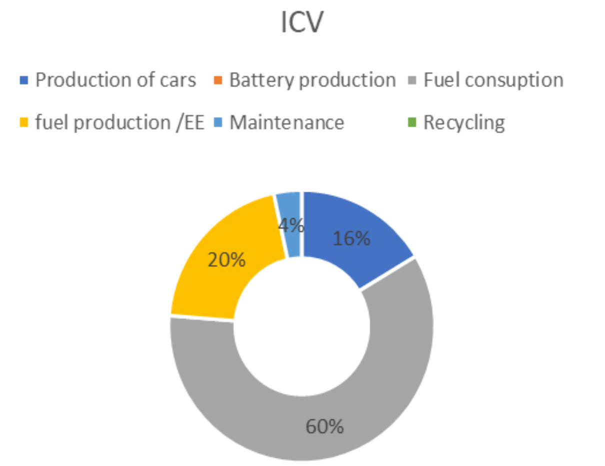

Figure 3. Tailpipe emissions of ICV

However, it must be said that BEV and plug-in hybrid production produces around 20-30% more emissions compared to ICEV production. Of course, ICE cars have more operational emissions. As part of this study, an analysis was carried out to compare the CO_2 eq. emissions production of different types of cars (Figure 4).

Based on the model developed, it was found that BEVs, Plug-In Hybrids and ICE vehicles will equal each other in CO2 eq. production in a period of about 20000-40000 km, which is a period of 1 to 2 years, then the emission production from ICE vehicles will be higher due to the fuel energy conversion method.

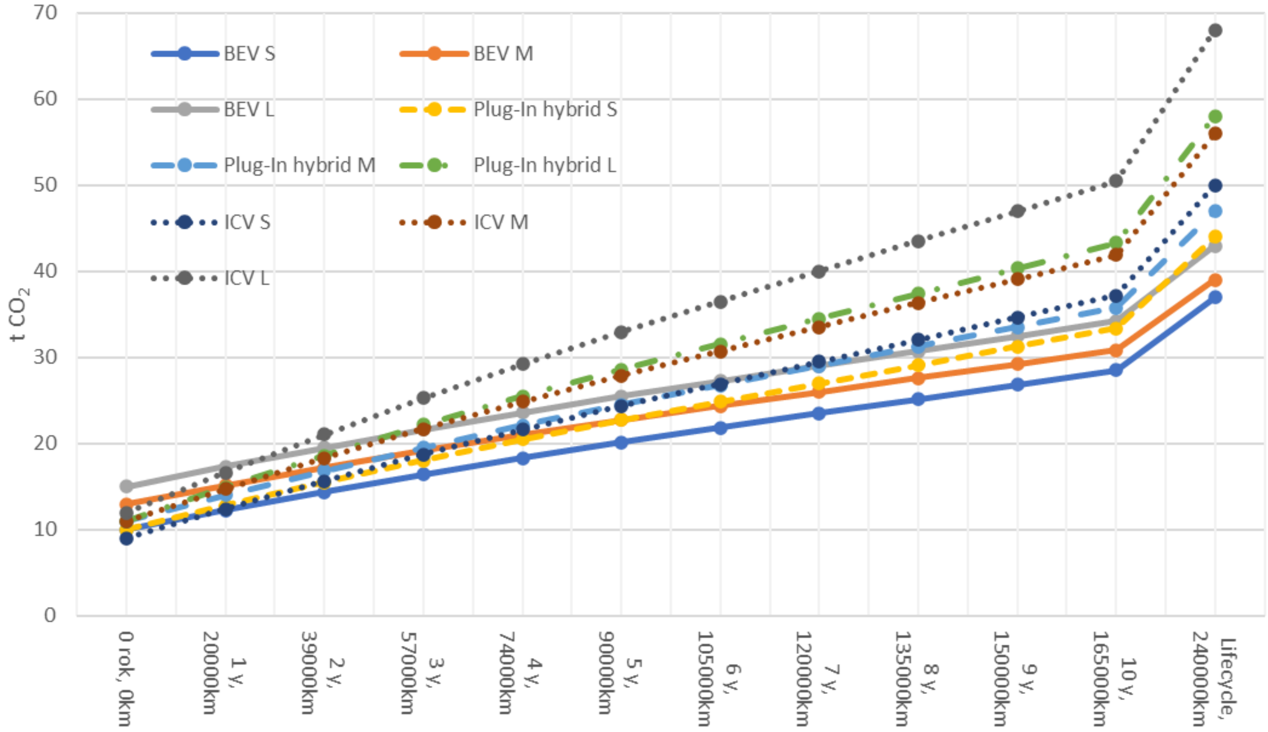

Figure 4. Lifecycle emissions of BEV, Plug-In hybrid and ICV

For example, the additional production emissions of a Tesla Model 3 SP approximately correspond to the driving emissions of a Volkswagen Passat 2.0 TSI after 18 000 km [Claeys 2019]. Similar results have been obtained for the vehicle recycling emissions, which have a positive climate change impact (emission saving). In a life cycle assessment, BEVs produce approximately 25-35% less emissions compared to ICE vehicles, depending on the type of vehicle. This means that an ICE vehicle will produce the same number of emissions over approximately 155 000 km as a BEV over 240 000 km.

The change in the fleet will also lead to a change in the fuel base. There are currently approximately 1.47 billion passenger vehicles in use in the world and the projected increase by 2030 will be approximately 1.75 billion passenger vehicles. According to BP's 2023 Energy Outlook, the projected growth in the passenger car fleet (Figure) will be up to 2.1 billion cars in 2040 and almost 2.5 billion cars in 2050. This growth will be driven mainly by electric and plug-in hybrid vehicles, whose share will increase from 11% in 2030 to 75% in 2050 [BEO 2023, BP 2022].

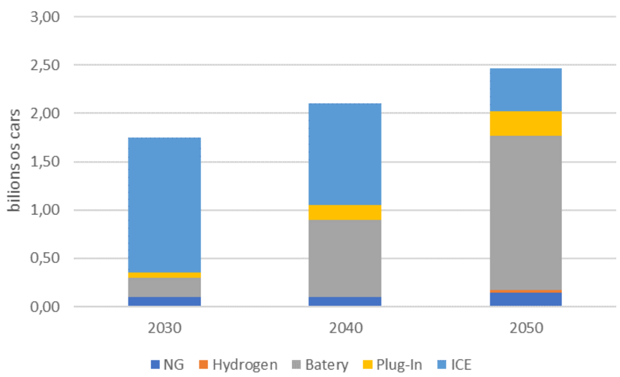

Figure 5. Forecast amount of BEV, Plug-In hybrid and ICV

Based on the scenario presented, a forecast of electricity demand growth was developed. Assuming an average battery size of 50 kWh and a range of 450 km, the average consumption will be 11.1 kWh/100 km in accordance with

$$\dot{Q}_{bev} = \frac{c_{bat}}{S_{bev}} \quad (1)$$

Where

$\dot{Q}_{bev}$ - average EE consumption, kWh/100 km

c_{bat} – BEV battery capacity, kWh

S_{bev}- BEV range, km

The average annual mileage was assessed in this study at $S_{yty} = 20\,000\ km.$

$$\dot{Q}_{EE} = \dot{Q}_{bev} S_{yty} n_{bev} \quad (2)$$

Where

$\dot{Q}_{EE}$ – Global EE BEV consumption, TWh

S_{yty} – annual mileage, km

n_{bev}- Estimated quantity of BEVs, pcs

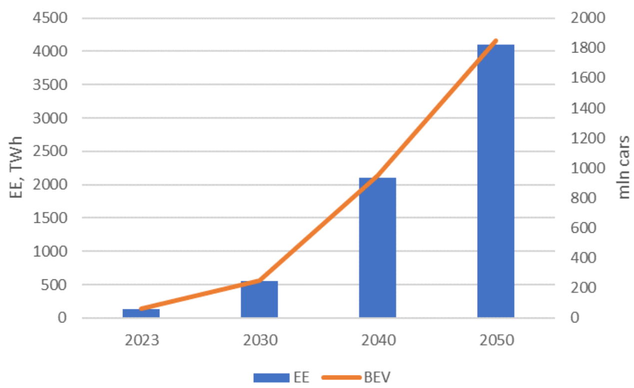

Figure 6. Forecast of EE consumption and BEV amount

According to the given assumptions, in 2023, worldwide electric vehicles would need about 130 TWh. For example, it represents about 33% of the annual production of EE in all nuclear power plants in France.

In this scenario, electric vehicles consume 2 000 TWh in 2040, which is approximately the annual EE production of all low-emission nuclear sources in the five largest countries, and a second multiple of this value in 2050.

Each BEV represents a load of approximately 2.2 MWh/year on the country's electric system and given the energy conversion methods of an ICE-powered vehicle, represents a load of approximately 11.9 MWh/year in fuel equivalent. However, the methods of generation, consumption and distribution are diametrically opposed, which may have a negative impact on the use of BEVs in areas with a poorly developed distribution network.

4 CONCLUSIONS

This article deals with the analysis of energy consumption in the case of a change in the primary energy of the fleet. Studies and reports point to a global increase in the number of electric vehicles over the next 20 30 years with a slight decrease in the number of internal combustion engine vehicles after 2040. The global increase in the number of vehicles over this period is expected to be around 60%.

In 2023, EVs will need around 130 TWh globally and in 2040, under the given scenario, EVs will consume 2,000 TWh. The transition to EVs is only as clean as the energy source used to charge the vehicle. Based on the model developed, it was found that BEVs, plug-in hybrids and ICEVs will equal each other in CO_2 eq. production at around 20,000 - 40,000 km, a period of 1 to 2 years, after which ICEV emissions will be greater due to the way the fuel energy is converted.

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REFERENCES

[BEO 2023] BP Energy Outlook. [Downloaded 5/7/2023] Available from: https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/energy-outlook/bp-energy-outlook-2023.pdf

[Bozek 2021] Bozek, P., Nikitin, Y., Krenicky, T. The Basics Characteristics of Elements Reliability. In: Diagnostics of Mechatronic Systems. Series: Studies in Systems, Decision and Control, 2021, Vol. 345, pp. 1-15. ISBN 978-3-030-67055-9.

[BP 2021] BP Statistical Review of World Energy. 2022, 71st edition. Available from: https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2022-full-report.pdf

[Claeys 2019] Claeys, G., et al. How to make the European Green Deal work. JSTOR, 2019. Available from https://www.bruegel.org/policy-brief/how-make-european-green-deal-work

[Ellingsen 2016] Ellingsen, A.-W.L., Singh, B., Stromman A.H. The size and range effect: lifecycle greenhouse gas emissions of electric vehicles. Environ Res Lett, 2016, Vol. 11, No. 5, 054010.

[Krenicky 2018] Krenicky, T. and Ruzbarsky, J. Alternative Concept of the Virtual Car Display Design Reflecting Onset of the Industry 4.0 into Automotive. In: IEEE 22nd Int. Conf. on Intelligent Engineering Systems (INES), 2018, pp. 407-412. DOI: 10.1109/INES.2018.8523962.

[Kuric 2011] Kuric, I. New methods and trends in product development and planning. Quality and Innovation in Engineering and Management, 2011, pp. 453-456.

[Moro 2018] Moro, A., Lonza, L. Electricity carbon intensity in European Member States: Impacts on GHG emissions of electric vehicles. Transp Res D, 2018, Vol. 64, pp. 5-14.

[Ou 2012] Ou, X., Yan, X., Zhang, X., Liu, Z. Life-cycle analysis on energy consumption and GHG emission intensities of alternative vehicle fuels in China. Appl Energy, 2012, Vol. 90, No. 1, pp. 218-224.

[Polestar 2023] Polestar and Rivian pathway report. [Downloaded 12/11/2023] https://www.kearney.com/documents/291362523/295334577/Polestar+and+Rivian+pathway+report-+supported+by+Kearney.pdf

[Rimar 2020] Rimar, M., et al. Performance Evaluation of Elimination of Stagnation of Solar Thermal Systems. Processes, 2020, Vol. 8, No. 5. DOI: 10.3390/pr8050621.

[Zackrisson 2010] Zackrisson, M., Avellan, L., Orlenius, J. Life cycle assessment of lithium-ion batteries for plug-in hybrid electric vehicles–Critical issues. J Cleaner Prod, 2010, Vol. 18, No. 15, pp. 1519-1529.

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