ELECTRIC VS GASOLINE VEHICLES: Total Costs of Ownership and emissions

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Abstract

The automotive industry is pivotal in addressing global sustainability challenges, particularly concerning environmental impacts and energy utilization. This paper undertakes a comparative analysis of the three main propulsion technologies—Internal Combustion Engines (ICE), Plug-in Hybrid Electric Vehicles (PHEV), and Battery Electric Vehicles (BEV)—to explore their operational, financial, and environmental implications. By examining the Total Cost of Ownership (TCO) and lifecycle emissions of representative vehicle models across different European markets, specifically Austria and the Czech Republic, this study offers a comprehensive assessment tailored to differing regional regulatory and fiscal landscapes.

The methodology encompasses a systematic review and a detailed financial and emissions modeling, integrating factors such as purchase price, fuel and energy costs, subsidies, and taxation. The study contrasts TCO outcomes considering varying supercharger usage scenarios and projects lifecycle emissions from vehicle production through to disposal, highlighting the emissions trade-offs among the vehicle types.

Results indicate that BEVs generally offer a lower TCO and significantly reduced lifecycle emissions compared to ICE and PHEV models, largely due to lower operational costs and zero tailpipe emissions. However, the extent of these benefits varies between the two countries due to differences in electricity carbon intensity and governmental incentives. The study underscores the influence of national policies on the economic and environmental attractiveness of electric vehicles and suggests that supportive policies are crucial for promoting their adoption.

This paper contributes to the discourse on sustainable mobility by providing data-driven insights that can aid consumers, policymakers, and industry stakeholders in making informed decisions regarding vehicle technologies and promoting a transition towards greener transportation solutions.

Introduction

The modern automotive industry is undergoing a significant transformation, driven by escalating concerns over environmental sustainability and energy efficiency. At the heart of this transition lie the three primary propulsion technologies: Internal Combustion Engine, Plug-in Hybrid Electric Vehicles, and Battery Electric Vehicles. Each of these technologies represents a distinct approach to addressing the pressing challenges facing the automotive industry today.

Motivation

The motivation behind comparing ICE, PHEV, and BEV stems from the need to mitigate the environmental impact of transportation, particularly in terms of reducing greenhouse gas emissions and dependence on fossil fuels. Secondly, as consumers increasingly prioritize sustainability and cost-effectiveness, there is a growing demand for vehicles that offer superior fuel efficiency and lower operating costs. By comparing these three propulsion technologies, we aim to provide valuable insights into their respective strengths and limitations, thereby facilitating informed decision-making for consumers, policymakers, and industry stakeholders.

This paper seeks to address several key questions regarding ICE, PHEV, and BEV:

- What are the fundamental differences between these propulsion technologies in terms of operation, efficiency, and environmental impact?
- How do the Total Cost of Ownership over a fixed period of six years and emissions profiles of CO_2 over their life cycle of ICE, PHEV and BEV compare?
- What implications do these comparisons have for our understanding of different car propulsion technologies?

Methodology

The methodology for this study involves a systematic comparative analysis of ICE (gasoline), PHEV, and BEV regarding their TCO and emissions profiles. This involves conducting a literature review to establish a theoretical foundation, selecting representative vehicle models, collecting relevant data on technical specifications, costs, and emissions. The gathered data will be analyzed, followed by interpretation of findings and discussion of implications.

We aim to select three vehicles within each segment, ensuring they closely match in both performance and luxury across various drivetrains: Battery Electric Vehicle, Plug-in Hybrid Electric Vehicle and Internal Combustion Engine. Our approach involves calculating the Total Cost of Ownership for each vehicle in the two countries, utilizing a model derived from literature. This TCO assessment spans a six-year period and incorporates the latest data on electricity tariffs, fuel efficiency, and other operational expenses.

In addition to financial considerations, our analysis extends to environmental impact, with a comprehensive examination of emissions. This involves gathering the most up-to-date information available on production, operational, and disposal emissions. By evaluating emissions throughout the entire lifecycle of each vehicle, we aim to provide a thorough understanding of their environmental footprint.

Theoretical framework

Total Cost of Ownership

TCO is a comprehensive assessment of all direct and indirect costs associated with owning and operating a particular asset over its entire lifecycle. In the context of automotive vehicles, TCO encompasses various elements such as acquisition costs, operating costs (including fuel, maintenance, and repair), depreciation, insurance, taxes, and other fees. Understanding TCO is crucial for consumers, businesses, and policymakers in making informed decisions about vehicle purchases and fleet management.

It is important to recognize that TCO analysis can vary significantly depending on regional factors such as taxation policies, incentive structures, fuel prices, infrastructure availability, and regulatory standards. For example, in regions where there are generous subsidies or incentives for electric vehicles, the TCO of battery electric vehicles may be more favorable compared to regions with limited support for EV adoption. Similarly, differences in taxation rates on fuel and vehicle ownership can influence the relative TCO of conventional internal combustion engine vehicles versus hybrid electric vehicles or plug-in hybrid electric vehicles.

Propulsion technologies

In the automotive landscape, propulsion technologies have undergone significant evolution, reflecting a shift towards more sustainable and efficient transportation solutions. At the forefront of this transformation are three primary propulsion technologies: Internal Combustion Engines, Plug-inHybrid Electric Vehicles, and Battery Electric Vehicles. Each technology offers unique advantages and challenges, shaping the way vehicles are powered and operated.

ICE

Internal Combustion Engines have long been the dominant propulsion technology in the automotive industry. These engines burn fossil fuels, such as gasoline or diesel, to generate power and propel the vehicle forward. While ICE vehicles offer familiar performance characteristics and a well-established infrastructure for fueling, they also produce emissions that contribute to air pollution and climate change. Efforts to mitigate these environmental impacts have led to the development of alternative propulsion technologies.

PHEV

Plugin Hybrid Electric Vehicles serve as a transitional phase towards electrification, blending an internal combustion engine with an electric motor and battery. PHEVs have the capability to run on electric power at lower speeds or during acceleration, while utilizing the combustion engine for high-speed cruising or increased power demand. This hybrid approach enables PHEVs to attain enhanced fuel efficiency and lower emissions compared to traditional internal combustion engine vehicles. Additionally, PHEVs can be charged, further reducing their reliance on fossil fuels for propulsion, although they still require them for certain operations, limiting their ability to achieve zero-emission operation.

BEV

Battery Electric Vehicles represent the pinnacle of electrification, relying solely on electric power stored in onboard batteries for propulsion. BEVs produce zero tailpipe emissions, offering significant environmental benefits and contributing to efforts to decarbonize the transportation sector. Additionally, BEVs benefit from lower operating costs compared to ICE vehicles, as electricity tends to be cheaper than gasoline or diesel fuel on a per-mile basis. However, BEVs face challenges related to limited driving range, longer refueling(charging) times compared to traditional refueling, and the availability of charging infrastructure. (Kumar and Jain, 2014)

Taxes and incentives

To get the full picture about the total cost of ownership it is of the utmost importance to understand national taxes and incentives. These systems are very dependent on the country and highly affect the differences of TCOs between EVs and ICEs.

Because our paper aims to compare the TCO of privately owned cars, no tax allowances or write-offs that are possible if the car is owned by a business are considered.

Austria

Incentives

In 2024, Austria will continue to support electric mobility with a funding pool of €114.5 million, €46 million of which is allocated for private individuals. This funding combines contributions from the Ministry of Climate Protection and automotive and motorcycle importers. The initiative, named "E-Mobility Offensive 2024," will run until March 31, 2025, or until funds are exhausted.

The federal government supports the purchase of new electric vehicles and fuel cell vehicles (FCEVs), including those previously used as dealer demonstrators or display models, provided they were first registered no more than 15 months before the application for funding. Funding covers both passenger vehicles (Class M1) and freight vehicles (Class N1), as well as various classes of electric two-wheelers and lightweight vehicles.

Additionally, the program subsidizes the purchase of communication-capable charging stations and smart charging cables. This can be done either in conjunction with the purchase of an electric car or separately. Eligible costs include the charging station itself and installation costs, particularly for stations directly connected to the power grid. Both individual installations in single or multi-family homes and communal setups in multi-party residences are covered.

The grant amounts are set at a fixed rate covering up to 50% of acquisition costs, with a maximum grant amount of **€5,000** for eligible vehicles, split between contributions from importers and the federal government.
Furthermore, the invoice date must be within 9 months of the application, and the vehicle's gross list price in its basic configuration (base model without extras) must not exceed €60,000.

Leased vehicles are also eligible for funding. The leasing contract must display the "E-Mobility Bonus" and show proof of a deposit or pre-payment equal to or exceeding the total expected subsidy, at least up to the amount of the federal funding.

The mandatory retention period for subsidized vehicles and charging infrastructure is 4 years, during which the vehicle must be powered by 100% renewable energy sources (electricity or hydrogen). If the vehicle is decommissioned before this period due to circumstances such as a total loss in an accident, this must be reported in writing to the KPC funding office along with relevant documents. (“Förderungen von E-Fahrzeugen für Privatpersonen in Österreich | ÖAMTC,” n.d.)

Fuel Consumption/pollution tax

The Normverbrauchausgabe (NoVA), or fuel consumption/pollution tax, is applied to the net purchase price or commercial leasing fees of new passenger cars and motorcycles, as well as those vehicles that have not yet been registered domestically. There are several exemptions to this tax, including for electric or electrohydraulic vehicles, cars used by driving schools, taxis, ambulances, diplomatic vehicles, and vehicles adapted for individuals with disabilities.

For passenger vehicles, including minibuses and caravans, as well as combination cars, the NoVA calculation involves the following formula:

$$\frac{CO_2 - emissions\ in\ \frac{g}{km} - 90}{5}$$

, from which the NoVA deduction is subtracted and, if applicable, the NoVA malus fee is added. The NoVA malus fee amounts to €20 for each gram per kilometer of CO_2 emissions over 250g/km. For example, emissions of 290g/km would incur a malus fee of €800.

CO_2 emissions are determined based on the type approval under the Austrian Motor Vehicle Act (Kraftfahrgesetz) of 1967 or the EU type approval. In 2015, a NoVA deduction of €400 was available for diesel and gasoline vehicles, which was reduced to €300 for these engine types starting 1 January 2016. Environmentally friendly vehicles, such as hybrids, E85, LNG, and hydrogen cars, benefited from a NoVA deduction of €600 until the end of 2015; this was also reduced to €300 from 1 January 2016.

The maximum NoVA rate for passenger cars can reach up to 32% (excluding any applicable malus fees), and is rounded to the nearest whole number. Although NoVA is included in the basic retail price of vehicles, VAT is no longer included in this total and is now charged separately. NoVA refunds are available for rental or leasing cars that are exported from Austria, calculated based on the vehicle's standard market value.

Since 1 January 2007, NoVA refunds have also been available for vehicles exported from Austria based on their common market value. As of 1 January 2016, private individuals who sell their vehicle to a buyer abroad can also claim a NoVA refund. Car manufacturers typically incorporate the NoVA into the prices displayed on the price list. (“ACEA Tax Guide 2018,” 2018)

Taxes on ownership

Generally, there is a vehicle tax every vehicle licensed in Austria has to pay, but vehicles with a gross weight below 3,5t are exempt. They are applicable to Engine-Related Insurance Tax (Motorbezogene Versicherungssteuer) instead. This tax is calculated using a formula that takes the CO_2 emissions (measured in grams per kilometer) and the power output of the vehicle into account. Fully electric vehicles are exempt from this tax, while PHEVs are only taxed on the internal combustion engine portion of their power. (“ACEA Tax Guide 2018,” 2018) For the calculations pertaining to our vehicles, we will rely on (“Motorbezogene Versicherungssteuer | ÖAMTC,” n.d.).

Czech Republic

Unlike some countries that offer direct financial subsidies or tax benefits to incentivize the adoption of electric vehicles and plug-in hybrid electric vehicles, the Czech Republic has not implemented such measures. Consequently, EVs and PHEVs do not benefit from specific tax breaks or subsidies that could lower their initial purchase costs or ongoing operational expenses. This lack of fiscal support shapes the TCO dynamics, potentially tilting the balance in favor of ICE vehicles when considering upfront costs and long-term expenses. Furthermore, it's crucial to note that while there are no pollution taxes or ownership taxes in

Czechia, there exists a specific registration fee structure based on emission standards. Vehicles falling under Euro 2, Euro 1, and below Euro 1 norms are subject to registration fees. These fees vary depending on the emission standard: for Euro 2 vehicles, the registration fee is 3000 CZK, for Euro 1 vehicles, it amounts to 5000 CZK, and for vehicles below the Euro 1 standard, the fee increases significantly to 10,000 CZK. This fee structure aims to incentivize the adoption of vehicles meeting higher emission standards while discouraging the use of older, more polluting vehicles. ("Ekologicky zlikvidované vraky aut podpoří 50milionová dotace," n.d.)

Car choice and Rationale

The selection of appropriate vehicle models is a crucial aspect of conducting a comparative analysis of Total Cost of Ownership and emissions between Internal Combustion Engine, Plug-in Hybrid Electric Vehicles, and Battery Electric Vehicles. In this chapter, we discuss the rationale behind our choice of car models in three distinct segments: Sub-compact (B segment), Compact SUV (C segment), and Executive (E segment). Our approach involved selecting representative models that offer all three propulsion technologies or their closest equivalents within each segment, thereby ensuring that differences other than the propulsion system are minimized or negated.

Sub-compact segment

This segment represents a popular choice for urban commuters and small families seeking fuel-efficient and compact vehicles that are well-suited for navigating city streets and tight parking spaces. By selecting the B1 segment, we aim to capture the preferences and needs of a broad demographic of consumers who prioritize affordability, practicality, and environmental considerations in their vehicle purchases. We chose the Peugeot 208 as our representative model. The Peugeot 208 is a popular choice in this segment, offering a compact yet stylish design, efficient performance, and a range of engine options, including gasoline and electric variants. Fully fledged Plug-in Hybrid Electric Vehicles are quite rare in this segment due to their non-competitive costs. Consequently, we opted for the Hybrid Electric Vehicle version of the Peugeot 208, which cannot be charged via a power outlet but instead relies entirely on its internal combustion engine to charge its battery.

Compact segment

We chose the Compact SUV segment as another focal point for comparison due to its growing popularity and significance in the automotive market. Compact SUVs represent a versatile and increasingly preferred choice for consumers seeking a balance between practicality, comfort, and style. These vehicles offer ample interior space, elevated seating positions, and often come equipped with advanced technology features and safety enhancements, making them well-suited for a wide range of driving conditions and lifestyles. We opted for the Kia Sportage as our representative model for ICE and PHEV variants, and the Kia EV6 as the BEV equivalent. The Kia Sportage is a versatile and popular choice in the compact SUV segment, offering gasoline and plug-in hybrid variants. Additionally, the inclusion of the Kia EV6 allows us to assess the impact of a fully electric propulsion system within the same segment.

Executive segment

We selected the Executive segment as our third choice for comparison due to its representation of luxury, performance, and advanced technology in the automotive market. These vehicles often feature cutting-edge technology, luxurious interiors, and powerful performance characteristics, making them a benchmark for automotive excellence. By choosing the E segment, we aim to address the preferences and considerations of luxury vehicle buyers who place a premium on quality, prestige, and innovation. Furthermore, the E segment's inclusion allows us to explore how different propulsion technologies impact the ownership experience and environmental footprint of luxury vehicles. This segment is particularly relevant for assessing the adoption of electrified propulsion systems within the luxury automotive sector, where considerations of status, performance, and sustainability converge. We chose the BMW 5 Series as our representative model. The BMW 5 Series is renowned for its luxury, performance, and advanced technology features, making it a benchmark in the executive sedan category. Importantly, the BMW 5 Series is available with all three propulsion technologies: gasoline, plug-in hybrid, and fully electric variants.

By carefully selecting representative models within each segment, we aim to provide a fair and meaningful comparison of TCO and emissions between ICE, PHEV, and BEV vehicles. This approach allows us to isolate the effects of propulsion technology on ownership costs and environmental impact while minimizing confounding variables related to vehicle size, features, and brand. Through this comparative analysis, we seek to contribute valuable insights to the ongoing discourse surrounding sustainable mobility and the transition towards electrified transportation solutions.

TCO Calculation

We will use the method of calculating TCO described in (Gil Ribeiro and Silveira, 2024) with a few adaptations.
The model is as follows:

$$TCO = VIV + ITx - GS + IM + (EC * RC * DT + ATx + AM + MC) * \frac{(1+d)^t - 1}{d * (1+d)^t} - (VFV * \frac{1}{(1+d)^t})$$

, where VIV - vehicle inital value, ITx - inital taxes, GS - government subsidies, IM - inital malus value; EC - energy cost, RC - rate of fuel consumption, DT - distance drive, ATx - annual taxes, AM - annual malus value, MC - maintenance cost; VFV - vehicle final value; d - discount rate, t - years.

The formula is divided into three segments: the initial payment at purchase, yearly payments, and the final value, which is deducted. The yearly payments are multiplied by a factor to adjust for annual expenditures and the discount rate. Additionally, the final value must also be discounted, to account for the time value of money.

Vehicle Initial value, Government subsidies, taxes and initial malus value

The initial value of a vehicle represents the cost of the car excluding taxes and subsidies. To this base price, specific taxes and the initial malus value (for example, the NoVA in Austria) are added. Conversely, government subsidies are deducted. The resulting amount constitutes the final purchase price payable at the dealership.

Fuel costs and yearly taxes

Energy costs are calculated by utilizing the manufacturers' data on fuel and electricity consumption rates, which are often measured using the Worldwide Harmonized Light Vehicles Test Procedure (WLTP). These rates are then multiplied by the annual distance and the cost of energy. For plug-in hybrid electric vehicles, this calculation also incorporates the manufacturer's estimates of the annual kilometers driven using gasoline and electricity.
It is necessary to consider two different price levels for electricity: the cost of electricity at home and at supercharging stations. There will be several scenarios included with different charging behaviors.
The yearly taxes and the annual malus value are detailed in the "Taxes and Subsidies" section of the paper. This section provides an extensive overview of the recurring financial obligations associated with vehicle ownership, as dictated by relevant fiscal policies.

Insurance cost

Insurance costs are influenced by factors such as vehicle type, the characteristics of the driver or company, previous accident history, and the location of operation (country and city). These costs also vary according to the specific commercial strategies of different insurance companies (Danielis et al., 2020). Literature reviews show mixed findings on how insurance rates differ between electric vehicles and diesel vehicles (DVs); several studies (seven, specifically) excluded insurance costs from their analyses, arguing that the price differences between propulsion systems are minimal (Scorrano et al., 2020). This paper will also omit general insurance costs, with the exception of the “Motorbezogene Versicherung” in Austria, as only ICEs have to pay them.

Maintenance cost

Many papers conservatively estimated that the maintenance and repair costs of Battery Electric Vehicles are 30% lower than those of Internal Combustion Engine Vehicles. This reduction is attributed to factors such as regenerative braking and the absence of oil changes, spark plugs, or transmission fluids. Despite this, there remains some uncertainty about this parameter, though increasing empirical evidence supports our assumption. PHEV cars do not have this advantage. (Scorrano et al., 2020)

This study determines that vehicle maintenance costs are influenced by how frequently the vehicle is used, particularly the distance it covers, as discussed in (Siragusa et al., 2020). This research uses the maintenance cost figures from Italy, as reported by Siragusa et al., as a benchmark. To tailor the maintenance costs for other countries, adjustments are made to the Italian figures based on the price level indices 2022, provided by (“Statistics | Eurostat,” n.d.).

Vehicle Final Value

This study constructs a model spanning a six-year period following the initial purchase of a vehicle, necessitating an estimation of each vehicle's residual value at the end of this timeframe. Several variables can influence the rate of depreciation, including the durability of the battery, maintenance expenditures, the availability of charging infrastructure, advancements in technology, and fluctuations in energy prices. While there is some short-term uncertainty, various scholars suggest that the depreciation rates of electric vehicles and diesel vehicles are likely to align over time (Danielis et al., 2020).

Nonetheless, it is imperative to determine a currently applicable value. (Schloter, 2022) conducted an extensive survey encompassing 24,000 vehicles, encompassing both electric and gasoline models, to compare their depreciation factors. This advanced model incorporates variables such as age, mileage, and purchase price. Our analysis will concentrate on the term dependent on age. By isolating the effects of other predictors, such as distance driven and initial purchase price, the findings indicate depreciation rates of 13.1% for electric vehicles and 9.9% for gasoline cars, measured using a geometric depreciation method. In the specific case of PHEVs, acquiring reliable data proved challenging; consequently, we will assume that their depreciation mirrors that of gasoline cars for the purposes of this analysis.

Currency

For better readability and uniformity, all prices will be considered in euros, using the current exchange rate.

All calculations conducted and the sources for all figures are detailed in the appendix. The relevant data can be found in the Excel file titled "TCO_calculation.xlsx".

Emissions Comparison

The emissions chapter serves as a thorough investigation into the environmental impact of internal combustion engine vehicles, plug-in hybrid electric vehicles and battery electric vehicles within the Czech Republic and Austria. Throughout this chapter, we meticulously examine the lifecycle emissions of these vehicles, spanning from production to operation and eventual disposal. By carefully analyzing each stage, our aim is to reveal insights into the comparative environmental effects of PHEVs and BEVs in contrast to traditional internal combustion engine vehicles. All the data on the cars was gathered from the manufacturers' websites to ensure our analysis is accurate and reliable.

For our analysis we will be using a slightly modified model from (Buberger et al., 2022). The basis of the model look as follows:

$Etotal = Eproduciton + Eopertaion + Edisposal$, where

E_{total} is the total lifetime emission of a vehicle

$E_{production}$ is the emission emitted during production

$E_{operation}$ is the emission emitted during vehicle operation

$E_{disposal}$ is the emission emitted during vehicle disposal

Production

In this section we examine emissions released during manufacturing, from raw material extraction to assembly. According to (Kawamoto et al., 2019) we can accurately estimate these emissions by focusing on two key variables: vehicle's curb weight and vehicle's battery weight. Utilizing a formula outlined in (Buberger et al., 2022) we can easily calculate the total production emission of each car.

$Eproduction = mbody * ebody + cbattery * ebattery$, where

$E_{production}$ is the emission emitted during production

m_{body} is the curb weight of the car(without traction battery)

e_{body} is a constant of 4,56 kg CO_2/kg

$c_{battery}$ is the traction battery capacity

$e_{battery}$ is a constant of 83,5 kg CO_2/kWh

To calculate car curb weight without the traction battery we used a battery density constant of 0,2kWh/kg to estimate the battery's weight based on the capacity. Then we subtracted the battery’s weight estimate from the car's total curb weight.

Operation

In this section, we focus on how vehicles impact the environment during their everyday use. We will split the analysis into two parts: well-to-tank(wtt) and tank-to-wheel(ttw) also sometimes referred to as local emissions. In the wtt segment, we examine the environmental impact of fuel production and distribution for internal combustion engine vehicles and plug-in hybrid electric vehicles. This stage encompasses emissions generated before the fuel reaches the vehicle's tank. For the bev this analysis considers the emissions associated with electricity production and distribution up to the charging point. The ttw analysis focuses on

emissions produced during vehicle operation, mainly combustion processes for ICE and PHEV. The operational emissions are determined as follows:
$Eoperation = wtt + ttw$, where
$E_{operation}$ is the total operation emissions
wtt is the well-to-tank emissions
ttw is the tank-to-wheel emissions

Well-to-tank

Well-to-tank emission are calculated using this formula for gas consuming vehicles:
$wtt = fconsumption * Stotal / 100 * gproduction$, where
wtt is the well-to-tank emissions
$f_{consumption}$ is the vehicle's fuel consumption
S_{total} is the total millage over lifetime
$g_{production}$ is the gasoline production carbon footprint contant: 67 g CO_2/L from (Edwards et al., 2004)
Well-to-tank emission for electricity consuming vehicles is calculated as such:
$wtt = econsumption * S\,total / 100 * eproduction$, where
wtt is the well-to-tank emissions
$e_{consumption}$ is the vehicle's electricity consumption
S_{total} is the total millage over lifetime
$e_{production}$ is the carbon footprint of electricity production, which is 432 g CO_2/kWh in Czech Republic and 76 g CO_2/kWh in Austria.("Nowtricity," n.d.)

Tank-to-wheel

Tank-to-wheel emission are calculated using this formula for gas cars:
$ttw = cemission * Stotal$, where
$c_{emissions}$ is the vehicle's WLTP emissions in g CO_2/km
S_{total} is the total millage over lifetime
Since electric vehicles don't produce any local emission while moving their tank-to-wheel emissions are 0.

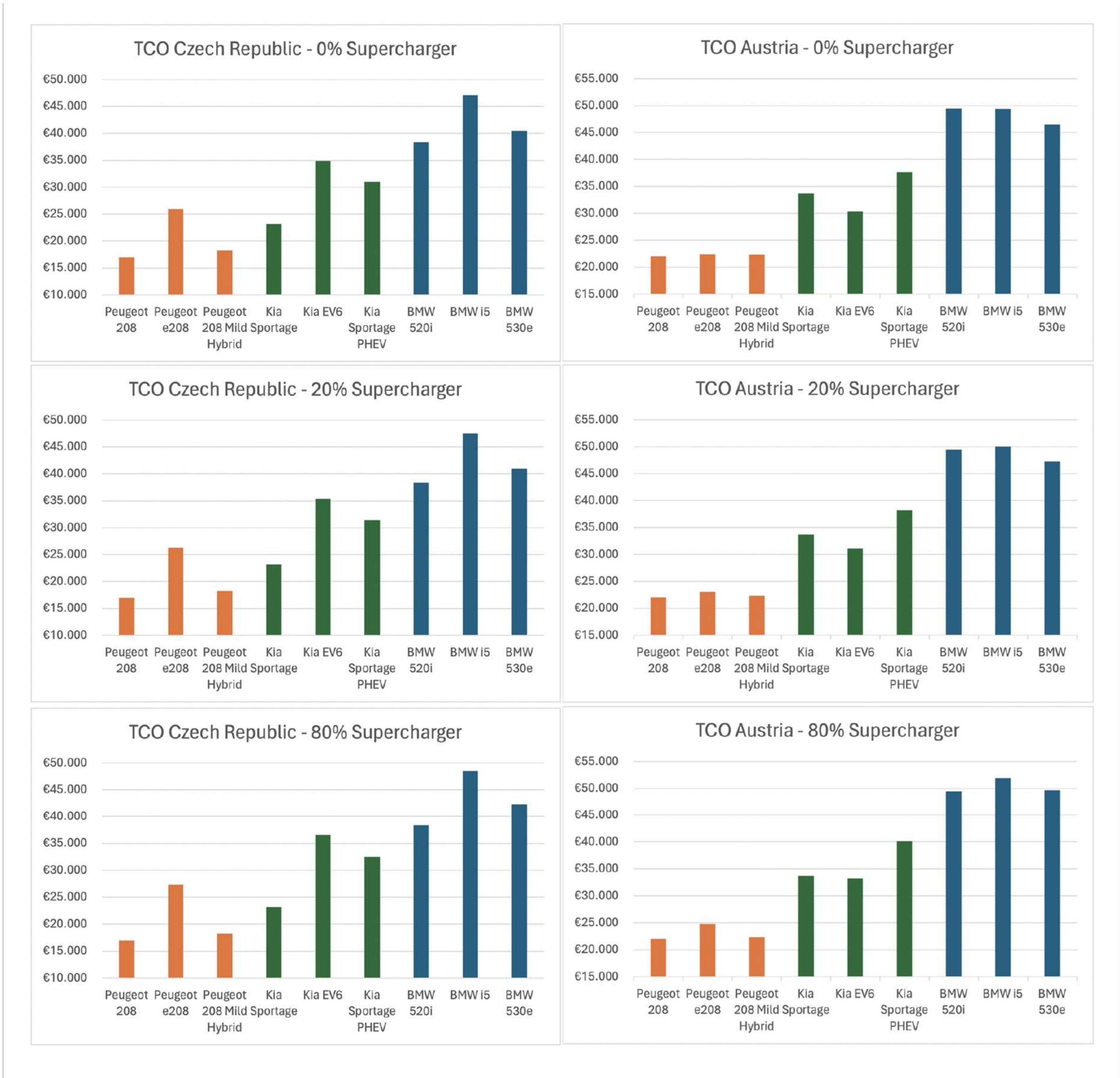
Disposal

According to (Buberger et al., 2022) when cars are properly recycled during dispolar, their carbon footprint actually decreases. This is because when recycled materials are used later in production, fewer emissions are generated compared to mining or extracting materials anew. In the aforementioned paper two variables and constants are being used in a similar manner to production emission. The formula is as such:
$Edisposal = mbody * rbody + cbattery * rbattery$, where
$E_{production}$ is the emission emitted during production
m_{body} is the curb weight of the car(without traction battery)
r_{body} is a constant of -2,93 kg CO_2/kg
$c_{battery}$ is the traction battery capacity
$r_{battery}$ is a constant of -48,4 kg CO_2/kWh
All computations carried out and the origins of all data are elaborated in the appendix. The pertinent information is available in the Excel document named "Emissions_calculation.xlsx".

Results

TCO

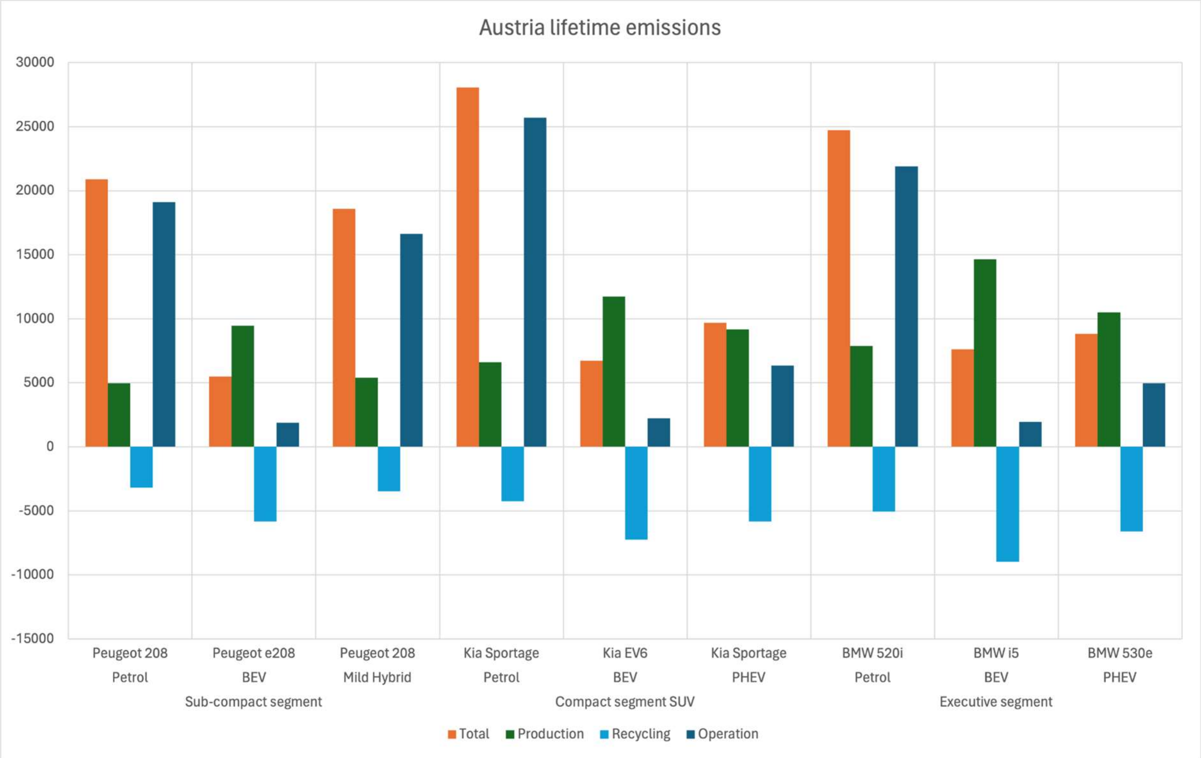
This section presents the findings from the total cost of ownership analysis for nine different vehicles categorized into internal combustion engine, battery electric vehicles, and plug-in hybrid electric vehicles. The analysis was conducted across two markets: Austria and the Czech Republic, using a consistent ownership period of six years and a discount rate of 2%. The analysis also includes different scenarios concerning charging patterns, specifically how much charging is done using superchargers. These variations are crucial for understanding the impact of charging behavior on overall vehicle costs.

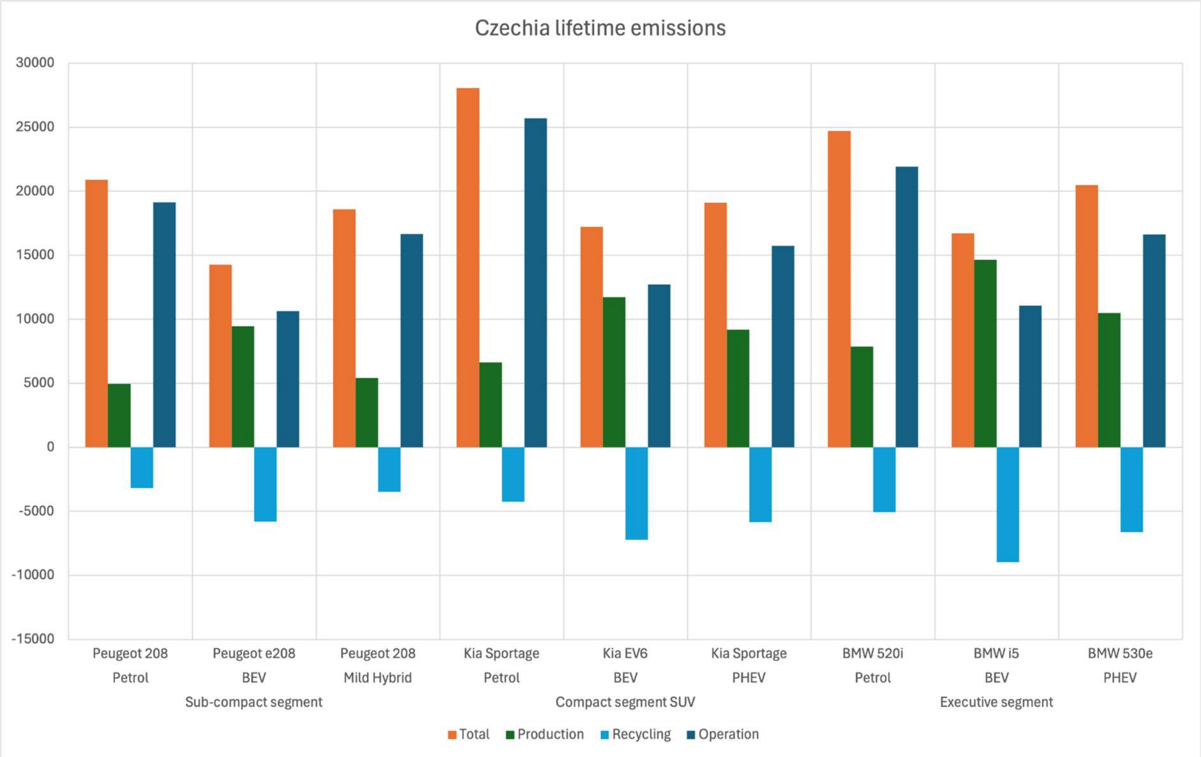


Results of TCO calculations with different Supercharger usage: orange - subcompact segment; green - compact segment; blue - executive segment

Emissions

This section reveals the outcomes of the emissions modeling for nine diverse vehicles, categorized into internal combustion engine, battery electric vehicles, and plug-in hybrid electric vehicles. The assessment encompassed two markets: Austria and the Czech Republic, modeling emissions across the entire lifespan of each vehicle.





Results of emission calculations for each country. Graph is segmented per car category and propulsion technology. Different colors signify different aspects of emissions.

Discussion

It is evident that the TCO differences between EVs and ICE vehicles are significantly influenced by the specific country, along with the associated taxes and incentives. Additionally, the use of superchargers, which are considerably more expensive than regular charging options, markedly affects the TCO. Consequently, the location where individuals choose to charge their electric cars plays a crucial role in determining overall costs.

The direct comparison between the Czech Republic and Austria suggests that policy decisions have significant implications. When conventional internal combustion engine vehicles are taxed, and this tax is eliminated for electric vehicles, it substantially impacts the overall pricing advantage of EVs. This demonstrates the influence of governmental policies on the market dynamics of vehicle costs.

The total cost of ownership calculations presented in this study have several notable limitations. Firstly, the prices listed on manufacturers' websites do not accurately reflect the average price customers pay, as these often include discounts. Secondly, maintenance costs are assumed to be uniform across different car brands and price points, which does not align with real-world observations where such costs vary significantly. Thirdly, the fuel and electricity consumption rates are derived from the WLTP, which does not faithfully represent real-world averages. Additionally, certain costs that do not vary between ICE and BEVs, such as insurance costs, were omitted from the calculations, limiting the absolute value's relevance.

The analysis of car lifetime emissions in Austria and the Czech Republic clearly favors electric vehicles as the top choice for emissions reduction. Despite their higher production emissions compared to traditional internal combustion engine vehicles, battery electric vehicles showed significantly lower operational emissions over their lifespan. This substantial reduction in operational emissions effectively balanced out the initial production emissions associated with electric vehicle manufacturing. Additionally, the integration of battery recycling practices played a crucial role in cutting emissions further.

Plug-in hybrid vehicles were also considered, showing better emissions performance than internal combustion engine vehicles but not matching the emissions performance of battery electric vehicles. The data highlights the environmental advantages of fully electric vehicles, confirming their preference for emissions reduction. Notably, the emission gap between vehicle types was narrower in the Czech Republic compared to Austria, attributed to the significantly larger carbon footprint of electricity production in the Czech Republic. The substantial decrease in operational emissions position BEVS as significant players in curbing transportation-related emissions and moving towards a more sustainable future in both Austria and the Czech Republic.

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