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MASTER THESIS

Examining the environmental effects of increased EV size and power

Thesis Master of Science

GRA 19703

1st of July 2022

Acknowledgements

This thesis marks the end of our two years completing our master's degree in Strategic Marketing Management at BI Norwegian Business School. The thesis was finalized the 1st of July 2022.

We both share the same interest in cars, and especially electric driven vehicles. For us to be able to write about something we have a lot of interest in, and to cultivate this in the thesis, has been a great experience and made the writing process much more facile.

We also want to give a big thanks to our supervisor, Erik Olson, for great contribution and assistance along the way.

Sincerely,

Mats Nålby
Johannes Andresen Rød

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Description of vehicle types

EV | Electric Vehicle

EV stands for electric vehicles (or electric cars). EVs are equipped with a battery-powered motor instead of a traditional internal combustion engine. Contrary to PHEVs and HEVs, EVs do not have a gasoline tank and output zero tailpipe emissions. They are associated with a lower carbon footprint than traditional vehicle types (Virta, 2021).

BEV | Battery Electric Vehicle

BEVs are a type of electric car that exclusively get their energy from rechargeable battery packs. BEVs do not have an internal combustion engine, a fuel tank, or a fuel cell (Virta, 2021).

HEV | Hybrid Electric Vehicle

HEVs use both electric batteries and gasoline. Often, the electric motor is here to assist the internal combustion engine, during the acceleration phases, for instance. Note that HEVs cannot be plugged into regular EV charging stations. Batteries replenish themselves via the energy generated by the combustion engine or via regenerative braking (Virta, 2021).

PHEV | Plug-in Hybrid Electric Vehicle

PHEVs rely on both electric batteries as well as gasoline to power an ICE. These vehicles run on electrical power until the battery is depleted and automatically switch to the ICE. Charging hybrids can also be plugged in to charge their engine (Virta, 2021).

ICEV | Internal combustion engine vehicle

Vehicles that depend entirely on the fossil fuel to power them, either gasoline or diesel (Agarwal et al., 2019).

kWh | Kilowatt-hour

kWh defines the amount of energy that is required to power an electrical appliance for one hour (Virta, 2021).

Abstract

The Norwegian vehicle fleet has evolved dramatically over the last 10 years, with electric vehicles (EVs) paving the way and being the favored option for Norwegian consumers when buying new cars. One of the major reasons causing this strong EV growth within Norway, is rooted in liberal government subsidies for EV adopters. The shift towards EVs and government policies to support it have been driven by environmental concerns. Thus, research is limited concerning the examination of potential negative environmental spillover effects of EV adoption. Our research contributes to the field by looking at the relationship between EV adoption and the potential for increased vehicle size. This research aims to provide feasible interpretations and insight with the use of archival Norwegian car sales data, along with dimension specification for vehicles, accounting for the expeditious increase in vehicle size, weight, and power. Our research show that increases in the mentioned dimensions are present, affecting the potential environmental benefit of the shift towards EV integration. The findings from this study also indicates that both size and power has increased significantly since the entrance of EVs, in line with a substantial growth to the power-to-weight ratio of vehicles. Additionally, our scenario analysis insinuates potential opportunity costs concerning prospective environmental gains that foregoes, exemplified through the change in consumer preferences with the adoption of larger, heavier, and more powerful EVs.

1.0 Introduction

Norway has a long history of government subsidizes for electric vehicles (EVs), leading to a substantial growth of both EV and hybrid electric vehicle (HEV) adoption. In fact, Norway inherits the highest number of EV owners per capita in the world (Nikel, 2019). This is heavily reflected in the priorities and objectives of the Norwegian parliament, whereas Norway is unique in that it has a nationally uniform policy that includes every major incentive category: reduced parking costs, infrastructure usage pricing benefits, point of sale pricing benefits, infrastructure access benefits, and charging access benefits (Mersky et al., 2016), in addition to implementing an initial target of all new cars sold by 2025 being zero-emission. During a convention in the Norwegian Parliament discussing the reduction of nationwide climate emissions, the prime minister at the time, Erna Solberg, stated the following:

"The government says that we will have a sustainable car tax system in the future, but right now there is a clear and distinct signal that we want people to buy electric cars. That is the most important thing you can do personally and privately to help reduce climate emissions".

Compared to internal combustion engine-based vehicles (ICEVs), EVs do not produce any form of on-road greenhouse gas (GHG) emissions or criteria air pollutants, and the upstream pollution they do produce can be considerably less severe, depending on the electricity source used for battery charging and the energy intensity of manufacturing (Holdway et al., 2010; Michalek et al., 2011; Samaras & Meisterling, 2008), reflecting some of the environmental benefits that further enhances EV adoption and integration. As with other technologies that furnishes environmental benefits, the Norwegian government has implemented various policy mechanisms to further encourage EV adoption, with the main driver being governmental subsidies in terms of financial incentives. By initiating both the 2025 zero emission goal and the 50% rule (not charging more than 50% of the initial price concerning parking, transportation etc.), as well as excluding taxes such as VAT and the one-time fee of new car purchases, this has allured extraordinary EV adoption in Norway, making it sufficient to say that government incentives and social underlying factors are altering Norwegian consumers' behavior towards EVs (Olson, 2015).

Concurrently, environmental benefits that follows with EV adoption inaugurates questions for further discussion. By questioning both the political and consumer driven glorification around EV adoption in Norway, we seek to expound prospective negative environmental impacts in relation to vehicle size, weight, and power capacity, potentially redeeming a considerable portion of the supposed environmental benefits, being a question rarely addressed in the literature of EV adoption (Olson, 2022). Thus, the amount of GHG emissions and air pollutants composed by EVs is like an equation, being both dependent of and affected by different parameters, such as the source of electricity, as well as the required energy intensity of manufacturing such vehicles. Firstly, when interpreting the source of electricity, this parameter might be preserved by the variety of conventional and renewable technologies used to produce electricity.

Reflected in a size, weight and power point of view, logical interpretation assumes that larger, heavier, and more powerful EVs would require a higher degree of both power intensity and electricity consumption concerning both manufacturing, as well as the life cycle assessment (LCA). Previous studies have shown that when comparing the life cycle GHG emissions level and human toxicity level performed in various countries, the emissions level decrease for EVs compared to ICEVs. However, there is an increase in human toxicity level for EVs, due to larger use of metals, chemicals and energy for the production of powertrain, and high voltage batteries (Verma et al., 2022). This substantiates our assumptions of vehicle size, weight, and power, as a larger EVs in terms of size dimensions is equivalent to an increase in weight, in line with requiring a bigger and more powerful battery to store more power, as well as running the vehicle and supporting acceleration. Eventually, with the initial target of expanding the driving range of EVs, heavier usage of metals, chemicals, and energy follows in the powertrain production as well as the assembling of batteries with higher voltage, resulting in a negatively correlated environmental exchange.

This paper contributes to the literature by questioning the elevation of EV adoption within the Norwegian market, as assumptions are rooted in revealing the actual residuals linked to an increase in EV size, weight, and power. By analyzing EV sales data in Norway, this paper seeks to provide a more detailed assessment of how the EV entrance has affected the market in terms of size and weight. A tendency seen with EVs is the correlational need for a bigger and more powerful battery as the size of the vehicle increases, additionally how bigger and heavier cars are reluctant on supplementary resources to retain the added size (simultaneously affecting the vehicles weight). Additionally, the paper aims to provide the field with a more sufficient understanding of the net environmental impact by calculating other severe factors considering emissions, as well as the overall damage to the environment. These are also factors that (Truelove et al., 2014) point out to be the most strident downfalls within current studies of the topic.

The results show clear tendencies of size, weight, and power capacity increase of vehicles over the last couple of years, being heavily implanted in the entrance of EVs in the market. Further, the compelling increase in all aspects (weight, HP, and power-to-weight ratio) has resulted in the development of certain prospects considered to be deleterious for the environment, e.g., how weight increase derives higher production resources, more wear of road, and normally requiring additional horsepower. Lastly, the study enlightens various rebound effects, revealing how the increase in all aspects shows rebound effects of the efficiency improvements to the CO2 emissions from cars, as well as how the power-to-weight ratio (PTW-ratio) indicates that the entrance of EVs has influenced consumer preferences towards more powerful engines. With the limited research examining the cause-and-effect relationship associated with the entrance of EVs when considering size, weight, and power increase, this research aims to fill this gap by answering the following research questions:

QUESTION	FORMULATION
1	Has the physical size of vehicles sold been influenced by the entrance of EVs in the market?
2	Has the power capacity of vehicles sold been influenced by the entrance of EVs in the market?

2.0 Theoretical framework

2.1 Bigger is better

In retrospect, there has been conducted comprehensive research with regards to EV sales, especially addressing the reasons for an extensive growth of EV adoption within Norway. With the rapid growth in the number of motor vehicles, transportation has become one of the largest contributors to CO2 and air pollutant emissions, and vehicle electrification is considered an effective measure to alleviate these environmental issues (Xia & Li, 2022). Researchers have also questioned the LCA of EVs, often compared to petrol driven ICEVs, concluding that with the adoption of EVs there is a reduction in GHG emissions, thus there is an increase in the human toxicity level due to the larger use of metals, chemicals and energy for the production of powertrain, and high voltage batteries (Verma et al., 2022). Although the research within the field of EV environmental implications is comprehensive, examining various elements considered to have a substantial impact on the environment, current research is inadequate when considering the examination of increased EV size, weight, and power, and the adverse environmental impacts that follows.

Additionally, it is often stated that EVs are only as green as their power source. Research with basis in the US market show that in 2016, the natural gas and coal stood for 64% of Americas produced energy, reflecting non-renewable sources with high amounts of emissions (Ivković, 2022). In other words, for EVs to alter the environmental benefits, renewable energy sources are highly important to help reduce emissions. Thus, power sources are not the only important parameter in the GHG equation, as emissions from manufacturing, power stations, combustion, upstream fuel production, and grid loses are all important aspects when interpreting the overall GHG emissions of EVs (Ivković, 2022). Especially concerning the raw materials, and like many other batteries, the lithium-ion (Li-ion) cells that power most electric vehicles are reluctant on raw materials like cobalt, lithium, and rare earth elements, that have been linked to grave environmental and human rights concerns. For example, mining cobalt produces hazardous tailings and slags that can leach into the environment, and extracting these metals from their ores also requires a process called smelting, which can emit Sulphur oxide and other harmful air pollution (Tabuchi & Plumer, 2021).

Correlational with the size and weight increase of vehicles, is the need for bigger and more powerful batteries, especially "considering that the battery is one of the core components of EVs, its production, use, and disposal have a great impact on the environmental efficiency of EVs" as stated by Xia & Li (2022). The most common battery types for EVs are Molten Salt, Nickel-metal hydride, Lithium-sulfur, and Lithium-ion, with the latter having the biggest market segment in equipping EVs (Iclodean et al., 2017). The disadvantage of Li-ion batteries is represented by the high developed operational temperature, which could affect energetic performances, along with lifetime and safety in exploitation (Doughty & Roth, 2012).

Other downfalls with this battery type is the recycling capacity of batteries out of use (Gaines, 2014), as well as the recharging infrastructure (Veneri et al., 2012). The major contributor to the environmental burden caused by the Li-ion battery is the supply of copper and aluminum to produce the anode and cathode, as well as the required cables or the battery management system, whereas inorganic emissions affecting the respiratory system, such as NOx, cause the highest environmental impact, followed by the use of fossil fuels and minerals (Notter et al., 2010). Understandably, bigger, and more powerful batteries designed for larger sized EVs, would require greater amounts of raw materials, which in turn penalizes the eco-friendly aspects of EV adoption.

Concerning the LCA of batteries, in the production phase, the environmental burden of batteries is relatively high because of large energy consumption and emissions of cathode material processing and electrode drying. In the use phase, increasing the share of renewable energy in power generation will help improve the environmental benefits of batteries. Lastly, in the recycling phase, retired EV batteries still have 70–80% of their remaining capacity. Direct scrapping not only wastes resources but also has a significant impact on the environment (Xia & Li, 2022). With the bigger is better heuristic stated, implementation of this in the research paper is necessary to gather insight as to whether this alters EVs, and whether the entrance of EVs has caused an increase in size and power related consumer preferences.

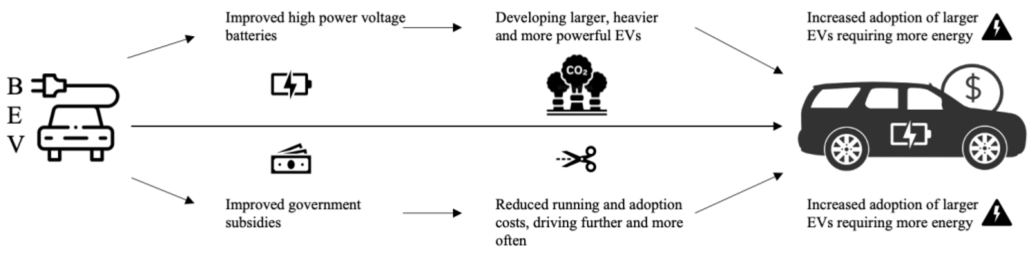

Fig. 1. Examining the potential downfalls of larger sized EVs with basis in improved batteries and Norwegian government subsidies.

Furthermore, this paper seeks to provide additional insight as to how the tradeoff between design (size) and environmental friendliness affects consumer preferences. As a confrontation to the self-proclaimed environmentally friendly consumers driving EVs with a test, examining the adoption assessment of a larger car with an appealing design, but with higher emissions, or on the contrary, a smaller car leading to a less congenial design, but with less emissions. The research clearly expedites further discussion as to how physical sizing affects consumer preferences and decisions, equivalent to the limited research done within the field of EVs environmental impact when considering its increased size, weight, and power.

These findings also advance discussion upon the idea of product specification (size) based rebound effects (Olson, 2013). The operation of EVs is cheaper than the operation of traditional petroleum-based cars, whereas this might lead to larger sized EV adoption, rather than ICEVs fueled by more expensive petroleum. From an environmental point-of-view (in which many EV owners refer to), larger EVs will require more efficient and higher voltage batteries, which in return needs a sufficient amount of resources to be produced, and as of today, there is no current process for recycling these batteries (Durden, 2021). The estimated recycling rates for Li-ion batteries are about 5%, where experts point out that spent batteries contain valuable metals and other materials that can be recovered and reused, and depending on the process used, battery recycling can also use large amounts of water, or emit air pollutants. Additionally, reusing Li-ion batteries requires extensive testing and upgrades to make sure they perform reliably (Tabuchi & Plumer, 2021).

Researchers have also flagged the need for a more sustainable circular economy approach linked to EVs, stating how a circular economy approach is, in particular, needed for electric vehicles in order to reduce their environmental impact and ensure that trade-offs are minimized in achieving the necessary climate goals (Richter, 2022). Policies has also been implemented nationwide to support a sustainable LCA, represented in the European Unions end-of-life vehicle (ELVs) directive, based on EU environmental rules that aims to ensure that ELVs are managed sustainably, seeking to eliminate hazardous substances in cars and require that most ELV parts and materials are reused or recycled (*EU*, n.d.). Thus, it is arguable that this direction should be refurbished as the entry into force was 22 years ago. Researchers assessing the directive have concluded that legislative factors and market forces have led to innovation in recycling, increased hazardous substance removal and improved information dissemination, however, by exploiting the embodied energy of high voltage batteries, an increased level of re-use and remanufacturing would be a key part of moving towards a sustainable vehicle production (Gerrard & Kandlikar, 2007).

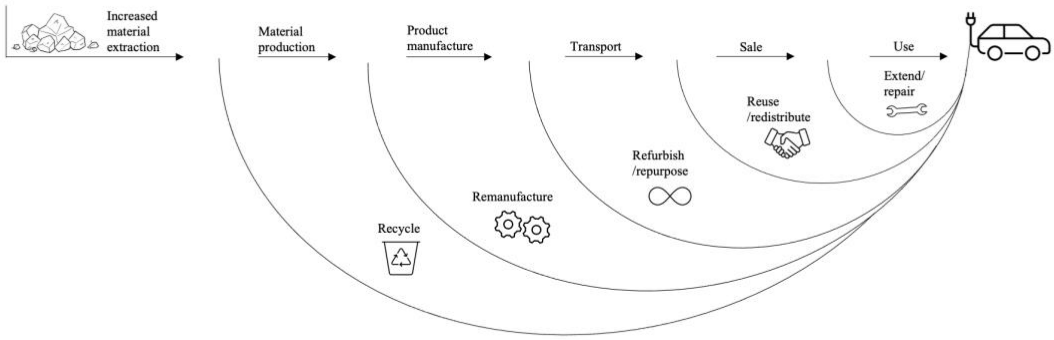

Fig. 2. Repair and reuse would strongly contribute to increasing the lifetime of EVs, in line with refurbishing and remanufacturing. Additionally, recycling materials could suppress additional mining of new primary materials (Richter, 2022).

By analyzing the mentioned research gaps, this paper contributes with compensational insight and analysis based on secondary archival sales data within the field of EV adoption, in addition to questioning the glorification of EV entrance in Norway, as additional interpretation of the underlying rationale concerning the environmental impact of EV size, weight, and power. By deliberating these elements, we seek to provide adequate answers to our research questions.

2.2 Interpreting size and power

Our assumptions are based on the significant yield of EV adoption within Norway, more specifically, how the growth of EV sales have affected the size (weight) and power increase of new vehicles. Additionally, by questioning the actual effects of this increase, this paper seeks to address the potentially detrimental impacts it has on the environment. Research done within the field of size as an influential product specification, have concluded that sizing appears better for consumer goods (Dobers & Strannegård, 2005; Meier et al., 2008; Silvera et al., 2002). Additionally, Silvera et al (2002) finds that size is one of the most important judgement cues when it comes to consumer goods. Meier (2008) finds that the appearance and physical size of marketing and fonts affects consumers, while Dobers & Strannegård (2005) states that "sustainability must ultimately be seen as intertwined with social processes such as fashion, identity and identity construction".

In year 2000, the most sold car in Norway was the Volkswagen Golf (Sørdal, 2001), a fairly small sized car with a weight just exceeding 1100 kg, inheriting a total of 115 horsepower. Ten years later, in 2020, the most sold car in Norway was the Audi e-tron, purely drifted by electricity. The e-tron weighs roughly 1500 kg more than the Golf and inherits an additional 300 horsepower. The disparity of size, weight and power when comparing these two vehicles is prominent, being further corroborated in relevant research findings, stating that as from 1992, the average car has increased by 1 m^2 (Loftås, 2021).

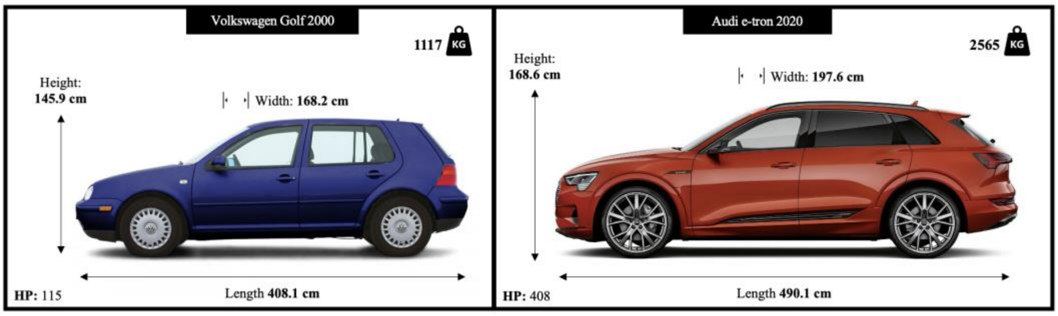

Fig. 3. Comparison of Volkswagen Golf 2000 and Audi e-tron 2020.

There are multiple elements that affects the expansion of vehicle size, where automotive design expert and professor at the Royal College of Art in London, Sam Livingstone (n.d.), have addressed certain factors of this growth, namely the major import of vehicles from other countries, e.g., with China and America representing the largest car markets in the world, designing cars based on their own environmental surroundings, where for example roads often are wider. The safety aspect also plays a big part, as crash beams, airbags, and the crumple zones need space, so cars have grown in width and length over the decades to accommodate these features. Additionally, reduced operation costs concerning production also plays a part, meaning that manufacturers can charge more for a larger car, whilst the difference in costs when comparing smaller and larger cars are almost negligible. Finally, Livingstone addresses the impact of EVs on car related size and weight, stating that "Rather than cars getting wider, we're going to see them getting slightly taller. The rise of electric vehicles will have an impact on how cars change in size in the next 10 years. The battery in an EV sits under the seats in the car, meaning cars will grow in height by around 5-10 cm" (Livingstone, n.d.), further substantiating the theory of EVs' influence on vehicle size (and weight).

To equate the performance of larger sized (and heavier) EVs comes the necessity for more powerful and high-capacity batteries. Power output of an electric vehicle can be measured in either horsepower or kilowatt-hour (kWh), whereas one horsepower equals 1.34 horsepower (George, 2011). In 2021, the average power capacity (measured in kWh) of an EV was estimated at 43 and is predicted to reach 45 within 2025. Further, EVs inherits fewer moving parts than traditional ICEVs, making it easier for them to run more efficiently, whereas efficiency does not only affect the fuel consumption, but also the speed and agility (Threewitt, 2019). In contrast to ICEVs, when switching on EVs they do not require any time to build up power and torque in terms of RPM (revolutions per minute) like ICEVs, reflecting how the peak power of an EV is always at zero RPM (George, 2011).

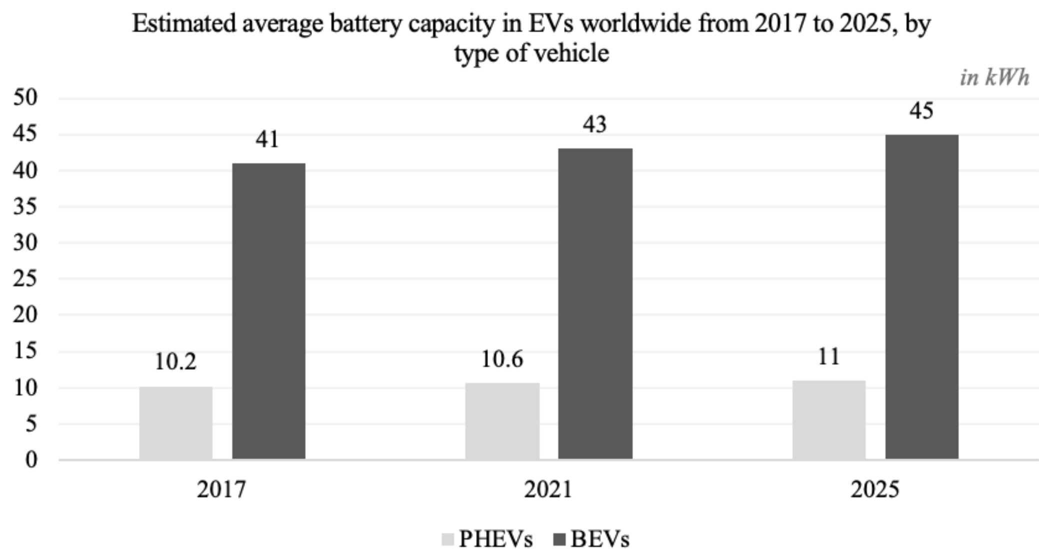

Fig. 4. Estimated average battery capacity in EVs worldwide from 2017 to 2025 (Statista, n.d.).

2.3 Spillover effects

Spillover effects are closely related to economist's concept of commons, or externalities, being the costs or benefits imposed on others (without compensation) as the result of some economic activity (Clark, 2013). In fact, spillover effects are more present in our everyday life than we aware of. Taking marketing as an example, including three parts: (1) an ad with (2) the well-known athlete that you really admire (3) uttering a new product for a specific company, resulting in increased spillovers, or the direct positive effect it has on the product and company. More specific, spillover effects are defined as an effect of an intervention on subsequent behaviors not targeted by the intervention. The intervention is in this case interpreted in a broad scene to include attempts to encourage behavioral change such as: requesting a new behavior, provision of green infrastructure, regulatory policy, or taxes (Truelove et al., 2014). These are all elements highly reflected in the Norwegian governmental subsidies for EVs, namely financial incentives, or behavioral encouragements for EV adoption.

Understandably, from the example mentioned above, spillover effects can be both positive and negative. If promotion of one pro-environmental behavior (PEB) raises the likelihood that individuals will adopt other PEBs (i.e., positive spillover), increased investments in such policies may be warranted. If, on the other hand, successful interventions induce individuals to reduce other PEBs (i.e., negative spillover), such interventions may be less desirable or may need to be redesigned (Truelove et al., 2014). It is also worth mentioning that the definition of spillover effects includes other known phenomenon such as moral licensing, gateway effects, identity effects, single action bias, and rebound effects (Truelove et al., 2014), with the latter being a theory for further discussion in the next section.

Research is limited when considering the possible spillovers linked to increased EV size, weight, and power, in relation to providing feasible answers to our research questions. Much of the environmental movement has been focused on making people feel guilty, or increasing the cost of consumption, so that people consume less (including smaller sizes), but government green subsidies (including not taxing electricity as much as petroleum) and greater efficiency of green products may allow consumers to indulge their large size preferences by reducing guilt and costs associated with larger sizes. It is believed that these subsidies are indisputable when reflecting on the causes of the significant EV growth in Norway, which is understandable when examining the diversified pricing of ICEVs compared to BEVs. Even though Norway is seen as a pioneer within EV adoption per capita, and EV sales increasing deliberately, so does the size, weight, and power of EVs.

The purpose of this paper is to provide a comprehensive, interdisciplinary review to clarify the conditions under which negative spillovers in relation to increased EV size, weight, and power, as a result of government subsidies and encouraged pro-environmental behavior. Moreover, this expedites discussion as to whether the normal consumer would be willing to buy larger and more powerful vehicles, assuming that government subsidies were abolished, and how the prominent demand for larger and more powerful EVs will affect future consumer adoption. Although the answers might be various, we still believe that there is empirical ground in our assumptions, being further interpreted in our subsequent research.

2.4 Rebound effects

Rebound effects, also known as "take-back effects", is a subcategory of the previous examined spillover effects, being a well explored phenomenon that has been assessed within multiple fields of study, such as economics and psychology (Truelove et al., 2014). The rebound effect is generally understood to mean that due to secondary effects, improvements in resource efficiency such as energy efficiency provide smaller reductions in the consumption of energy and/or material resources than are expected (Freeman, 2018). In other words, when previously limited goods become more available, the usage of that good will increase simultaneously. One example is the expanded growth of electricity usage, following the "green-shift" towards more renewable energy being produced, minimizing the actual green benefit of the improvement (Herring, 2006).

Although, what is interesting to address here, is the fact that rebound effects have been thoroughly examined in previous literature, e.g., through exemplification of the rebound effect when associated with ICEVs. Rebound effects within different scenarios are often linked to direct and indirect behaviors, e.g., the way in which fuel efficiency improvements in passenger cars have made driving cheaper, resulting in consumers driving more and buying bigger cars (direct effect), and/or spending the remaining savings on other products, such as booking flight trips resulting in increased air pollution (indirect effect) (Font Vivanco et al., 2016).

Limitations are present with the current research on EV size related rebound effects. In fact, this issue is thought to be directly transformable to EVs, whereas EV battery efficiency improvements generate an increase in both driving range and power, resulting in users buying larger sized EVs, resulting in reduced electricity and energy savings. This is also reflected in how EV suppliers will require increased recourses in terms of mining, to supply enough raw materials for larger batteries, which in return is necessary for larger, heavier, and more powerful EVs. This cultivates negative environmental impacts, embedded in an inadequately researched topic of size related rebound effects.

Today's EV market enlists certain tendencies, displaying how higher and more ecofriendly supply of electricity eventually leads to an increased market demand. Withal, debatable questions are present when considering consumer preferences, as well as vehicle size, weight, and the compulsory materials needed for manufacturing. This questions the way efficiencies, such as a more ecofriendly supply and higher market, influence the yielding of consumer preferences, as well as the evolution of vehicle size and weight, and how we respond to the recurring need for more resources.

To gain further insight into the world of rebound effects, in addition to EVs as an own field within the theory, we will provide a more concrete example. By looking into the taxing of ICEVs in Norway, this could help us determine what the tax would be on top selling EVs, assuming that they were taxed the same way as ICEVs. By using the tax calculator facilitated by OFV (Opplysningsrådet for veitrafikk), delineating the Norwegian one-time taxing, which is calculated by the tax group of the vehicle, the unladen weight, CO2 WLTP (Worldwide Harmonized Light Vehicle Test Procedure) emissions, NOx emissions, and stroke volume. Furthermore, the one-time fee is an obligational tax that must be paid when registering a motor vehicle in Norway for the first time (SSB, n.d.). Following the example, we have chosen the fully BEV BMW iX, the ICEV BMW X5, the PHEV BMW X2, and the ICEV BMW 1-series, to provide a diversified description of the inequalities in the tax system.

Vehicle	Tax group	Weight (unladen, kg)	CO2 (g/km)	NOx (mg/km)	Tax (NOK)
BMW iX M50	M1*	2510	N/A	N/A	0
BMW X5 xDrive 40i	M1	2205	205	21,3	414.828
BMW X2 xDrive 20d	M1	1675	142	19,9	154.073
BMW 1-series 118i	M1	1320	129	14,6	70.597

*M1 is the tax group for standard passenger vehicles with up to 9 seats.

Tab. 1. Examining the taxing of ICEVs and BEVs in Norway.

As shown, BEV owners do not pay any tax on new car purchases concerning the one-time fee, nor do they pay any VAT, substantiating the advantage of driving electric in Norway. The example with the BMW X5 might be a bit distortional, thus, including it provides a broader understanding of how expensive it will be with a car of an almost identical size, with the full BEV BMW iX M50. Additionally, we chose to include the BMW X2, as well as the BMW 1-series to emphasize the weighting of each variable. As the table only projects the one-time fee, an additional VAT of 25% will follow on fossil fueled cars. This reflects the theory of rebound effects, showing how the subsidized EV price is being used by customers to retrieve larger and/or more powerful vehicles that they most likely would not be able to afford if they were to pay the normal taxes of VAT and the one-time fee on BEVs.

2.5 Previous research limitations

Along with our already established research questions we have discovered some underlying questions that remain unanswered from previous literature, whereas these questions will be further elaborated in the scenario analysis. The questions are dilemmas that arise when discussing the considerable size increase that has occurred as a direct effect of the EV entrance.

SCENARIO	QUESTION
1	What are the environmental benefits of the EV entrance?
2	What if consumers changed their internal combustion engine vehicle for an EV of the same size?

3	What if EVs never entered the market? Comparing an identical evolution in size, weight, and power.
4	What are the potential losses with the increase in EV size? Examining the difference between lighter EVs, to heavier and more powerful EVs.

Tab. 2. Scenario analysis outlay.

3.0 Methodology

3.1 Norway as a lead market

The Lead Market concept (LM) is a way of addressing how different key markets (i.e., Norway with their EV ownership share) have induced the global innovation of EVs by achieving local demands, preferences, and local environmental conditions. In other words, this results in high technology diffusion when higher value is given to EVs by government incentives and social underlying factors, which in return decreases the risk of adoption (Beise, 2004). By utilizing Norway as a lead market, this provides us with an extensive database of secondary data to analyze the effects of EV adoption and subsidies on vehicle size and capability, in terms of both years as Norway has led the world in EV sales for at least the last decade, and market penetration, as no other market has seen EVs become such a large portion of the sales mix.

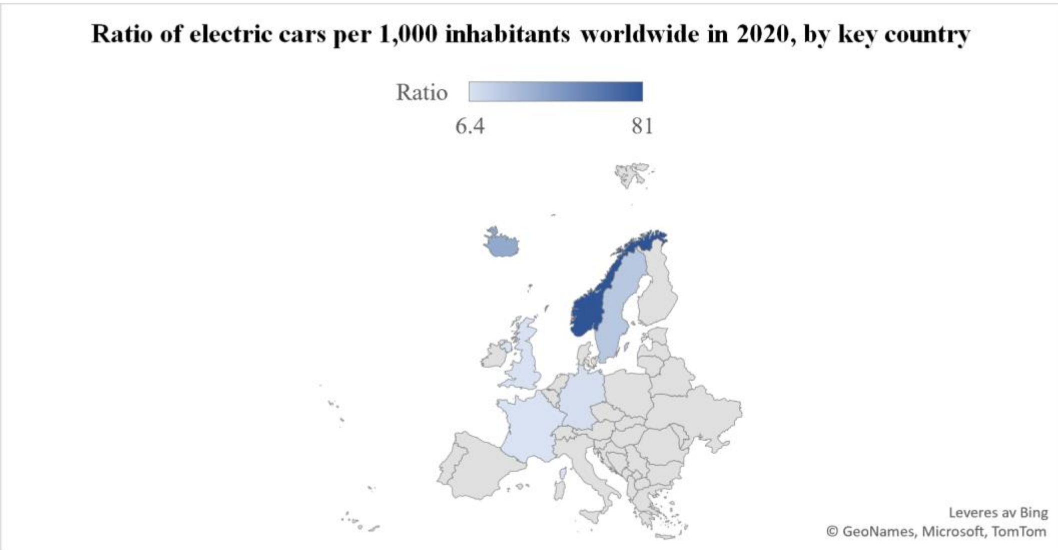

Fig. 5. Ratio of electric cars per 1000 inhabitants worldwide in 2020, by key country. Norway retaining the highest ratio of 81 (*Electric Cars per Thousand Inhabitants Worldwide 2020*, *Statista* n.d.).

To minimize or prevent market failure, various public policies have been implemented by the Norwegian government alongside its subsidiary. The subsidies includes free toll pass, using the taxi and bus lane on the highway within certain time periods, and other policies intended to effectively encourage green technology development and generate successful diffusion (Kieckhäfer et al., 2017). Government subsidizing and effective public policies combined is what makes Norway an effective LM for EVs and has ultimately changed consumer behavior (Olson, 2018). Previously, several key studies have focused on how government incentives, social underlying factors, identification, and adoption of green technologies within a lead market have changed consumer behavior. However, there is hardly any examination of how the rise of EVs due to government substitutes and the change in consumer behavior has affected the physical size of EVs and the implications of this increase.

In a time where vast amounts of data are being collected and archived by researchers all over the world, the practicality of utilizing existing data for research is becoming more prevalent (Andrews et al., 2012). Secondary data analysis is analysis of data that was collected by someone else for another primary purpose. Being an empirical exercise that applies the same basic research principles as studies utilizing primary data and has steps to be followed just as any other research method (Johnston, 2017), in our case analyzing retrieved car sales data in Norway. We see this topic as highly deputized, being reflected in the late adoption of EVs internationally.

The data will help us gather the wanted insight by analyzing size, weight and power dimensions of new cars sold, and ultimately to provide feasible answers to our research questions. Additionally, by questioning the environmental impacts of increased EV size, weight, and power, we believe our research results can contribute with applicable insight, being highly feasible when considering worldwide governments' desire to grow the global EV fleet, further substantiated in the Sustainable Development Scenario, reaching 230 million EVs within 2030 (IEA, 2021).

3.2 Data collection

We have gathered longitudinal sales data from Opplysningsrådet for Veitrafikk (OFV), being one of Norway's largest politically independent member organizations. Thus, OFV works politically towards the government to ensure a strong and sustainable vehicle policy, producing various statistical data on roads and vehicles in Norway, and are assigned statistical sales data from all car dealers in Norway. Since our data is collected from a public record in the lead market of EVs, we perceive our data as credible, in addition to being relevant as we use the data collected for its purpose, as well as utilizing the sales data to interpret the changes in the dimensions retrieved from the manufacturer of the car.

Our aim for the data collection process was to retrieve sharable unpaid data in an electronic format, more specifically archival data of new car sales in Norway during our explicit time period (2001-2021). The dataset would have been unattainable for us in any other way if we had not been using secondary data, this along with supporting avoidance of unnecessary time consumption, seen as some of the biggest advantageous of applying secondary data (Dunn et al., 2015). Further, this data will help us distinguish market trends and evolvement of size, weight, and power, as well as sales volumes over a sufficient period, and over a wide variety of models.

Even though the dataset has the advantage of already being set up by OFV, we had to reconcile some data to obtain perceivable statistics. To make the dataset more convenient for our analysis, we designated the top six selling models for each year in the respective period, also enabling us to gain further insight within market trends. In the top six we examined the differences between each model, including to what degree they would be representative for the period. Additionally, it was an evidential difference between the 6th and 7th most sold car, and on the contrary, the difference between the 10th and 11th was minimal.

Regarding the size dimensions of each vehicle, we have used the handbook for the desired model. For the models with multiple versions within our timespan, we have chosen a model based in the following criteria: (1) When the model was most dominant in the market with basis in its market share, and (2) for how many years the specific model has been sold. Exemplifying, we have the models of Volkswagen Golf, Toyota RAV 4, and Toyota Yaris being dominant in the top six appearances for the last 20 years. To adequately include them in our analysis we had to set their dimensions to a specific year of model, thus, to further delve into the increase in size and dimensions, we have examined the best-selling vehicle of all time, the Volkswagen Golf, with all models produced within a timespan of 20 years.

3.3 Analysis approach

As we are assessing mostly numerical data, we have applied a statistical analysis approach to retrieve the data needed in assessing our research questions. When examining our sales data collected from OFV, we have made some adjustments to make them more understandable, predictable, and manageable. Firstly, we have added all the relevant data to the different car models, in addition to collecting sales data for each year and combining this with our variables gathered from the manufacturers of the respective models. We have examined the car models of the six best-selling vehicles each year for the past 20 years, meaning that we have added our dimension variables such as engine, weight, length, width, height, horsepower, and recorded CO_2 emissions. Further, with basis in Excel, we have facilitated pivot tables through modelling to extract relevant data, in addition to conducting a regression analysis. The scenario analysis has been facilitated by applying the tool of Climobil, a software designed by the Luxembourg Institute of Science and Technology, whereas the findings from the pivot table and regression analysis have been implemented.

Through our modelling approach we have calculated each of the sales-weighted average; weight, horsepower, and PTW-ratio. This has enabled us to graphically show how the increase is distributed throughout the different years, we have also divided the years into two groups, (1) before EV entrance (2001-2012), and (2) after EV entrance (2013-2021), to further enlighten how the increase has dramatically changed after the entrance of the EVs. Proceeding with the findings from the Pivot tables and modelling, we have facilitated a regression analysis using the sales-weighted average weight as the dependent variable, and EV% of top sellers, average length, and average HP as the independent variables, to further address the reasons behind vehicle weight increase and environmental impacts of EVs.

Lastly, to apprise the rebound effects of the EV entrance, we have taken use of Climobil. The software has supported us in employing comparisons between the emissions associated with EVs and ICEVs (Luxembourg Institute of Science and Technology, 2019). To accommodate our previous research considering the extensive impact size, power, and weight has on the overall LCA of EVs, we have displayed an additional comparison of different EV options with basis in the calculated emissions retrieved from Climobil. Climobil calculates the LCA based on every known environmental issue that occurs with EV production.

4.0 Data analysis

4.1 An overview: Evolution over time

Based on the collected data, we wanted to take a closer look at the evolution of EVs across different models. We have collected all top selling cars for every other year during the time from 2000 to 2021, illustrated below.

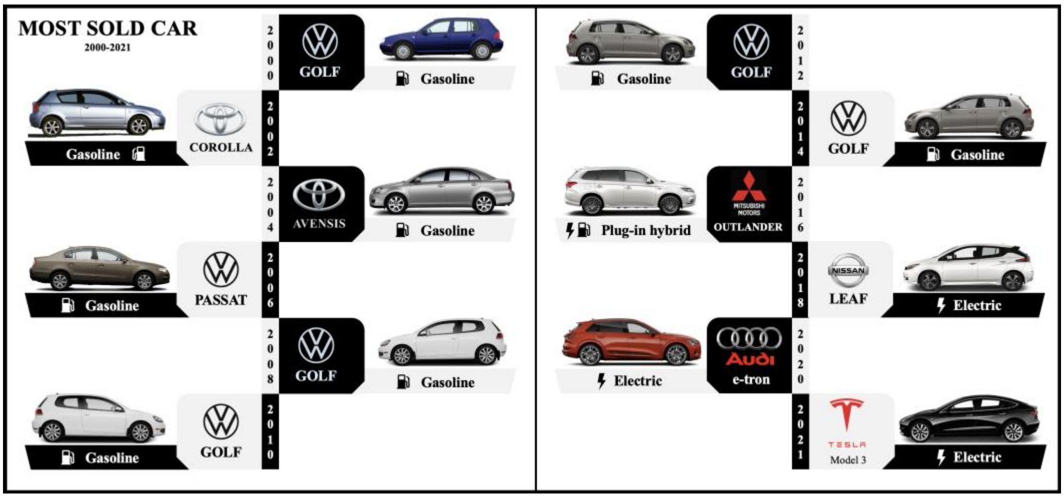

Fig. 6. Most sold car every other year from 2000-2021.

The Volkswagen Golf is recurring and is represented four times over the total 12 years period. From 2012 we can slowly see the shift from ICEVs to BEVs, in addition to the increased physical size of the various cars. For instance, the 2000 Volkswagen Golf weighs 1104 kg, compared to the 2020 Audi e-tron weighing 2565 kg, giving a weight difference of 1461 kg. Evaluating the size dimensions of each vehicle, it is clear that the length points out, displaying considerable differences, e.g., with the length of the e-tron set at just under 5 meters, whereas the Golf has a total length of just around 4 meters. Looking at the MSRP (Manufacturers Suggested Retail Price, (De los Santos et al., 2018)), the Volkswagen Golf was listed at USD 14.900 in 2000, with the Audi e-tron selling at an average list price of USD 78.210.

4.1.1 Evolution of the Golf

To provide further insight as to how the size dimensions of vehicles have changed over the last 10-20 years, we have examined the best-selling car model during this time, the Volkswagen Golf. The Golf has a long history, with the first model being introduced in 1974, and since then, six new versions of the car have been presented (Volkswagen, n.d.). The Volkswagen Golf is also an example of a model that has switched from being only offered as a fossil fuel powered vehicle to now also being offered as a BEV, and even PHEV. The example below is based on the petrol driven version of the car through time, whereas the models run from the 1997 version to the present version of the car.

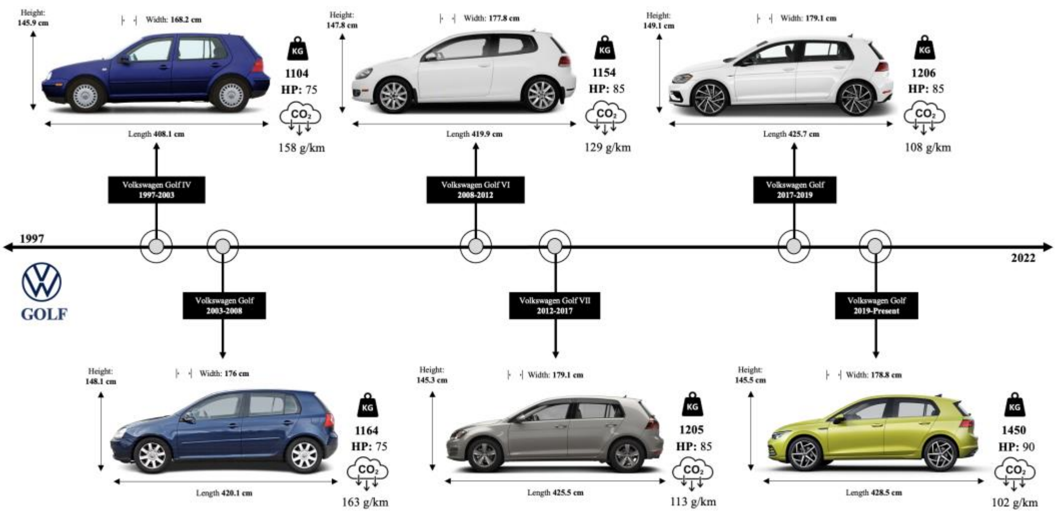

Fig. 7. Volkswagen Golf evolution 1997-2022.

The unladen weight of the Golf slowly increases during the years, thus most remains unchanged until examining the present version. For instance, the 1997-2003 generation had an unladen weight of 1104 kg, with the present version of the Golf weighing 1450 kg, giving a weight difference of 346 kg. The power of the Golf increases simultaneously, with a 15 HP increase when comparing the 1997-2003 generation to the present generation. Additionally, for the 1997-2003 generation, this is set at 75 horsepower / 1104 kg, resulting in a PTW-ratio of 0,068. On the contrary, the calculated PTW-ratio of the present generation is 0,068 as well, which makes sense as the power of each generation increases in line with the weight.

Furthermore, the size dimensions of the Golf have also increased. The present version has a total length of 4,285 meters, with the oldest version having a length of 4,081 meters, reflecting a difference of 0,2 meters. When evaluating the other size dimensions there are no major differences, with both width and height being almost identical for each year. Considering the total emissions of the Golf, we can see that it continually decreases with each new model, with a gap of 56 g/km when comparing the 1997-2003 generation to the present model. A possible reasoning to this decrease comes from the introduction of BlueMotion in 2006, being a start/stop system that switches off the engine automatically when the car is idling and when releasing the clutch pedal. In addition, we have taken a closer look at the BEV version of the Golf, also known as the Volkswagen e-Golf. The first full BEV version of the car was presented in 2014, and lasted until 2016 before the new version with higher kWh was presented:

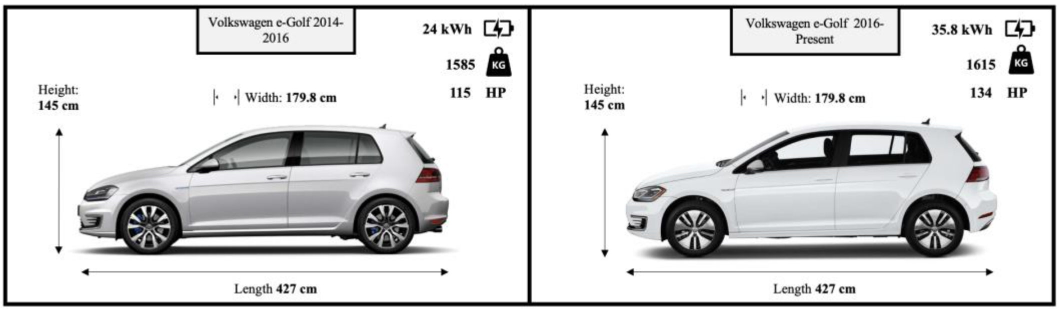

Fig. 8. Volkswagen e-Golf comparison by production year.

Firstly, the size dimensions of the car in terms of length, width and height are identical for both versions of the e-Golf. Further, the only difference to spot is the battery power, or the total kWh. The present version of the e-Golf is loaded with a bigger battery, providing an increase in horsepower, including an additional weight increase of 30 kg. Thus, when comparing the e-Golf to the standard fossil fuel driven versions, we see that the size dimensions are relatively similar. However, the weight difference is substantial, e.g., with the present version of the e-Golf weighing 165 kg more than the standard fossil fueled version. This is also reflected in power, as BEVs inherits more power than other vehicles powered by fossil fuel. In comparison, the calculated PTW-ratio for the present fossil fueled Golf is 0,068, and compared to the present e-Golf, the PTW-ratio is deliberated at 0,083.

4.1.2 BEV comparison

So far, we have looked at how the most popular car models have evolved during the last 20 years. For further analysis, and to provide more coherent answers to our research questions, we believe it would be beneficial to also determine whether there is any change in the historical development of BEVs. In this analysis, we will include the most sold BEVs each year from 2013-2022 YTD, assessing the evolvement of parameters such as the weight, power, and size dimensions, as well as the effect this has on higher capacity batteries. Below is an overview of the different best-selling models for each year (2013-2022 YTD).

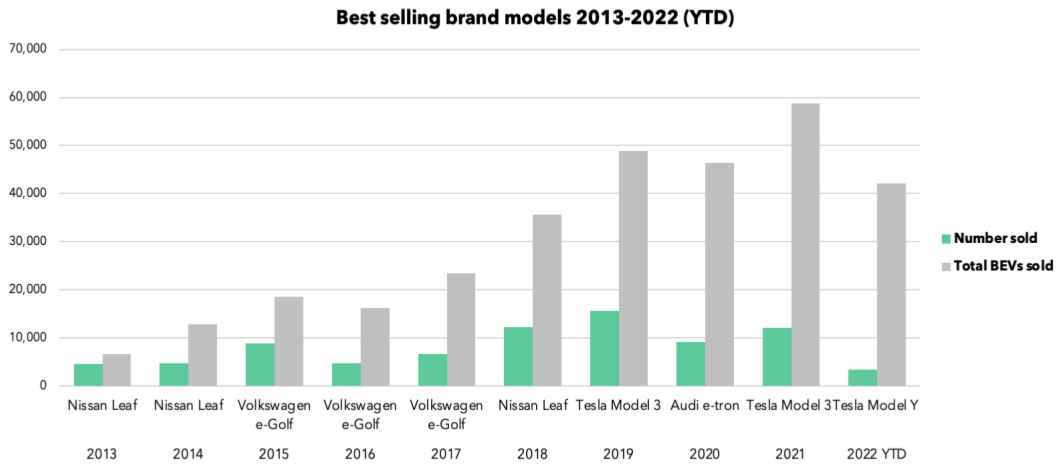

Fig. 9. Best-selling brand models 2013-2022 (YTD).

Without going into detail on each model, the first thing to note is the dominant sale of the Nissan Leaf and the Volkswagen e-Golf during the first six years of the presented timeline. We can also see a shift in size approaching in 2019 with the Tesla Model 3, but especially considering the Audi e-tron and the Tesla Model Y (Opplysningsrådet for veitrafikk, 2022). To further enlighten this, we have made the following illustration:

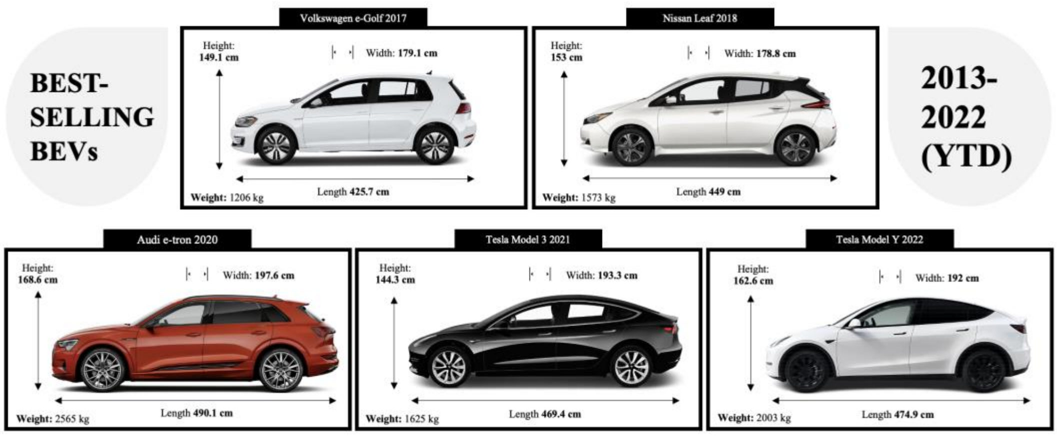

Fig. 10. Most sold BEVs during 2013-2022 (YTD).

Firstly, the size dimensions of the cars increase for each year. It is considerable, especially when examining the length, width, and weight of the cars. In general, we see tendencies in the total size maturation of BEVs, whereas we believe that there are numerous aspects involved when evaluating this trend. Firstly, the battery size and power has grown simultaneously with size. Longer driving range for bigger vehicles can explain this, as BEVs has gone from smaller vehicles with a primary purpose of shorter and more city friendly drives, to more family friendly all-wheel-drive vehicles. The continuous weight and size increase of BEVs is also represented in newer models, substantiating our personal beliefs on the EV evolution. To exemplify, we will display some of the newcomers in the BEV market, namely the Skoda Enyaq, BMW iX, Hongqi E-HS9, and the Ford Mustang Mach-E:

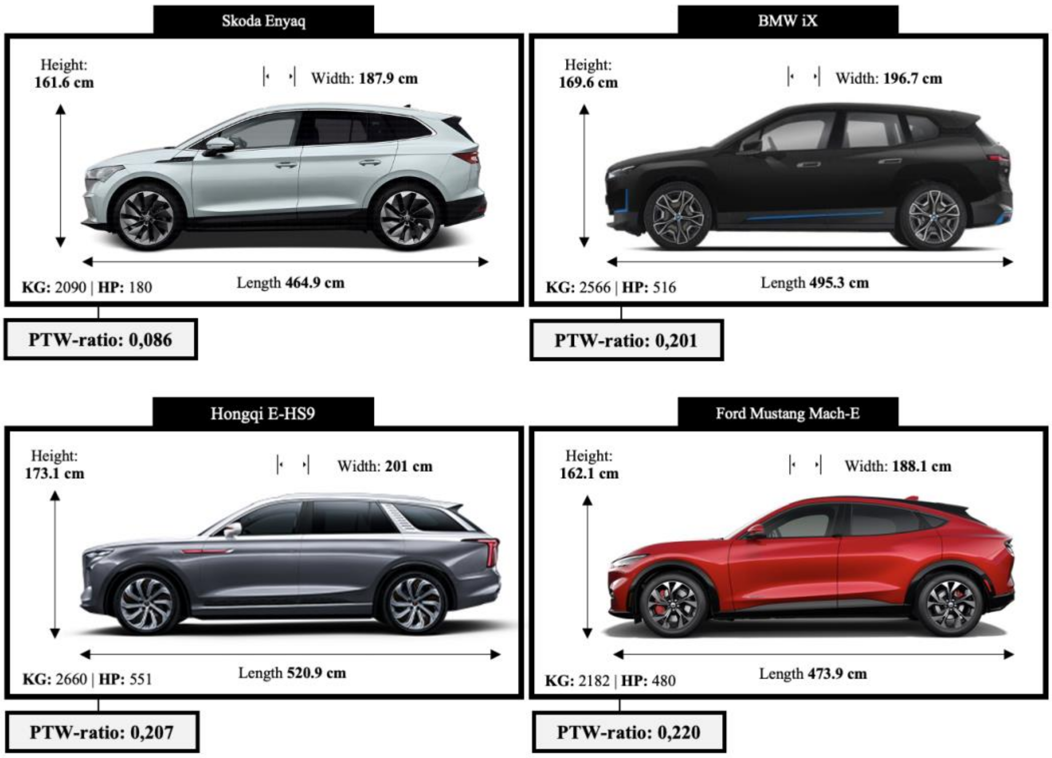

Fig. 11. New entries of BEV models in the market (2022).

As seen in the illustration, some of the newest models to enter the BEV market are strong representatives for the striking size increase trend that we have displayed. With exception of the Skoda Enyaq, the PTW-ratios for these cars are significantly higher than with the ones of other models presented earlier. All the models illustrated above are some of the best-selling cars so far in 2022: (1) BMW iX: 1779 cars sold, (2) Skoda Enyaq: 1409 cars sold, (3) Ford Mustang Mach-E 1348: cars sold, and (4) Hongqi E-HS9: 739 cars sold (Opplysningsrådet for veitrafikk, 2022).

As seen in the table below, we have calculated the total kWh for two groups: large and small sized BEVs (with the large sized BEVs exceeding a weight of two tons), to pertain a clear picture of exactly how big the differences are in terms of battery capacity for larger and smaller sized BEVs (best battery capacity model). The total difference between the two groups in terms of battery capacity is 195,5 kWh, reflecting a considerable difference between the two groups. Thus, it is also worth mentioning that smaller sized EVs are starting to retain larger and more powerful batteries as well, reflected in the Nissan Leaf and Renault Zoe.

LARGE BEVs			**SMALL BEVs**		
Brand and model	**Battery type**	**Gross kWh capacity**	**Brand and model**	**Battery type**	**Gross kWh capacity**
Hongqi E-HS9	Li-ion	99	Volkswagen e-Golf	Li-ion	35.8
BMW iX xDrive50	Li-ion	111.5	BMW i3	Li-ion	42.2
Ford M. Mach-E	Li-ion	95	Nissan Leaf	Li-ion	62
Skoda Enyaq iV80	Li-ion	82	Renault Zoe	Li-ion	52
	Total kWh	**387.5**		**Total kWh**	**192**

Tab. 3. Comparing larger and smaller sized BEVs with basis in battery capacity.

The table also shows a reoccurrence of Li-ion battery possession by all vehicles, which is not ideal. As discussed in our theoretical framework, there are numerous environmental burdens linked to the manufacturing of Li-ion batteries, such as the mining for raw materials like cobalt, the supply of copper and aluminum causing increased inorganic emissions affecting the respiratory system, as well as the use of fossil fuels and other minerals. Accommodating the demand for higher capacity (as well as power and efficiency), Li-ion batteries for larger sized vehicles will in turn penalize the eco-friendly aspects of BEVs, expanding the environmental degradation through manufacturing and the lack of recycling options.

4.2 Variable trends

In this section, we will take use of our retrieved data to further examine the trends of our different variables, namely within the area of new car sales. Over time, numerous variables have affected the automotive industry, e.g., with digitalization. The world has witnessed a technological revolution during the last 20 years, cultivating new areas for disruptive technology-driven trends within the industry of automotives, especially considering electrification. As reflected in our research questions, not only has the technological advancement been a key player in the car market, but it has also been a heavy influencer on both vehicle size, and power. Emphasizing this, we have chosen to exploit an examination of average development of vehicle weight, horsepower, and the power-to-weight ratio. Furthermore, we seek to get a better understanding of these trends, meaning the interpretation of whether these trends are implied as intermediate, or whether more longitudinal time frames are present.

4.2.1 Average weight of cars sold

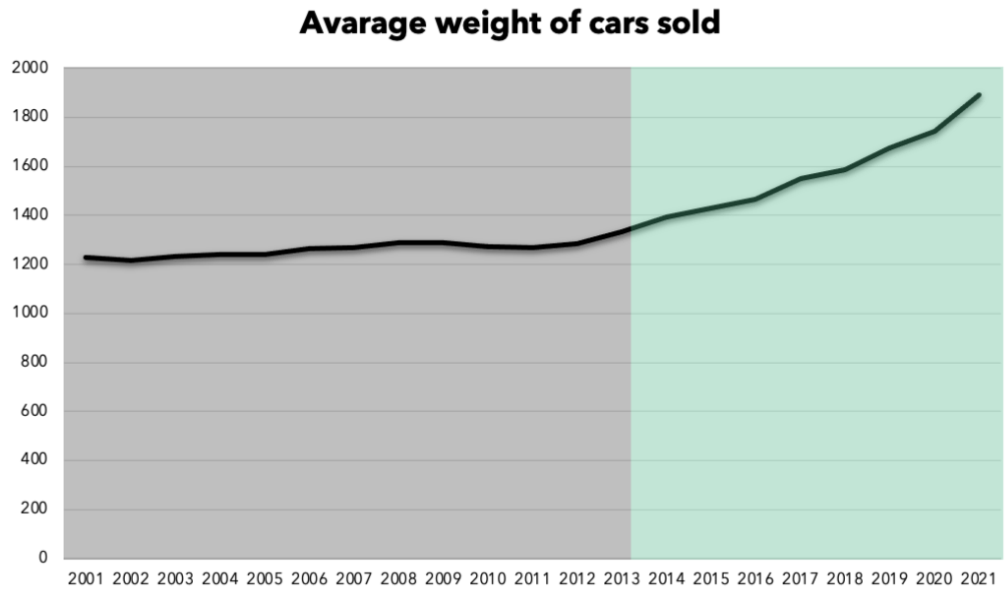

Fig. 12. Average weight of cars sold.

As we can see from the graph above, the average weight of cars sold has increased after the entrance of the EVs in Norway's top 6 best-sellers. In 2013, the revolutionary Nissan Leaf entered the Norwegian top 6 best-selling models, becoming a regular in the top-sellers list in Norway, and has surely been a pioneer paving the way for other BEV models, simultaneously increasing the share of EVs in the overall Norwegian vehicle fleet.

In 2012 (seen as the final year before EVs took ownership of the list) the average weight of a sold car was 1286 kg, in 2021 the average weight of a sold car was calculated at 1892 kg, more than 600 kg heavier when compared to the previous year. Before the EV entrance the average yearly weight increase was 5,085kg (2001-2012), after the entrance of EVs (2013-YTD) the average yearly weight increase was 69,971 kg. This massive difference in yearly weight increase equals an increase of 1276,03% from the times before EVs, to the time after. Furthermore, this increase has shown an even higher yield during the last two years, as all six best-sellers YTD are 100% electric, anticipating this growth to reach even higher peaks in the coming years, assuming that the BEV growth remains unchanged.

To calculate the yearly increase of the average weight. We have used the formula,

$$\frac{\textit{Avg weight in 2012} - \textit{Avg Weight in 2001}}{2012 - 2001} = \frac{1285{,}99 - 1230{,}05}{2012 - 2001} = 5{,}085\ kg$$

to retrieve the average yearly weight increase before the entrance of EVs.

And the formula,

$$\frac{\textit{Avg Weight in 2021} - \textit{Avg Weight in 2013}}{2021 - 2013} = \frac{1892{,}29 - 1332{,}52}{2021 - 2013} = 69{,}971\ kg$$

to calculate the average yearly weight increase after the entrance of EVs.

4.2.2 Average horsepower of cars sold

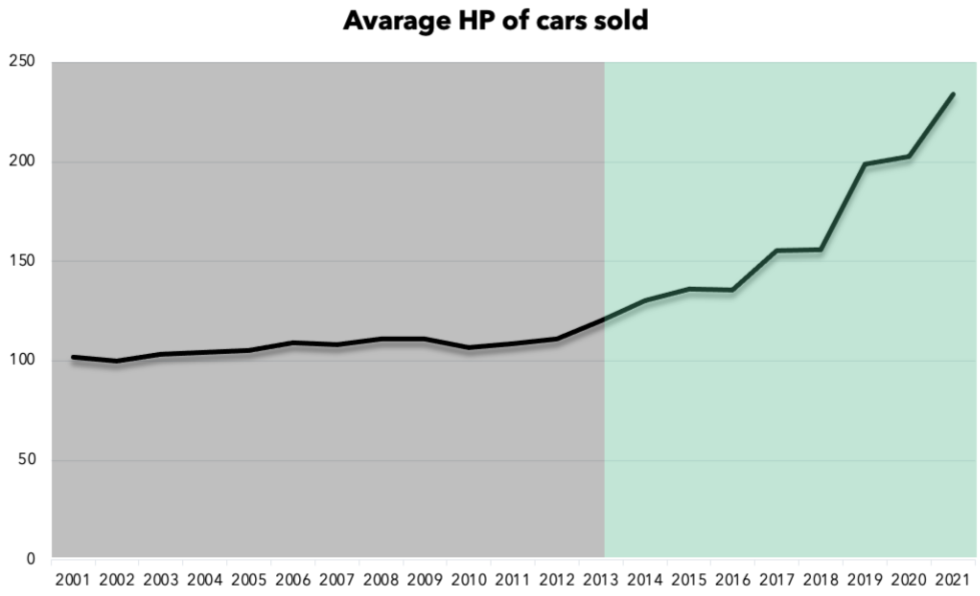

Fig. 13. Average horsepower of cars sold.

The average horsepower has an analogous increase as compared to the average weight, reflected in a substantial growth since the entrance of the EVs in Norway's top 6 best-sellers. In 2012, the average HP of new cars sold in Norway was 110,91.

Nine years later, in 2021, the average horsepower has grown rapidly, rising to 234,2, reflecting a two times growth as compared to 2012. In addition, the average yearly HP increase was 0,812 before the entrance of EVs, whereas after the EV entrance this has increased to 14,255, reflecting an immense increase of 1655,54%.

The following formula has been used to address the average yearly HP increase before the entrance of EVs,

$$\frac{Avg\ HP\ in\ 2012 - Avg\ HP\ in\ 2001}{2012 - 2001} = \frac{110{,}91 - 101{,}98}{2012 - 2001} = 0{,}812\ HP$$

Further, the following formula calculates the average yearly HP increase after the entrance of EVs,

$$\frac{Avg\ HP\ in\ 2021 - Avg\ HP\ in\ 2013}{2021 - 2013} = \frac{234{,}20 - 120{,}16}{2021 - 2013} = 14{,}255\ HP$$

4.2.3 Development of Power-to-Weight ratio

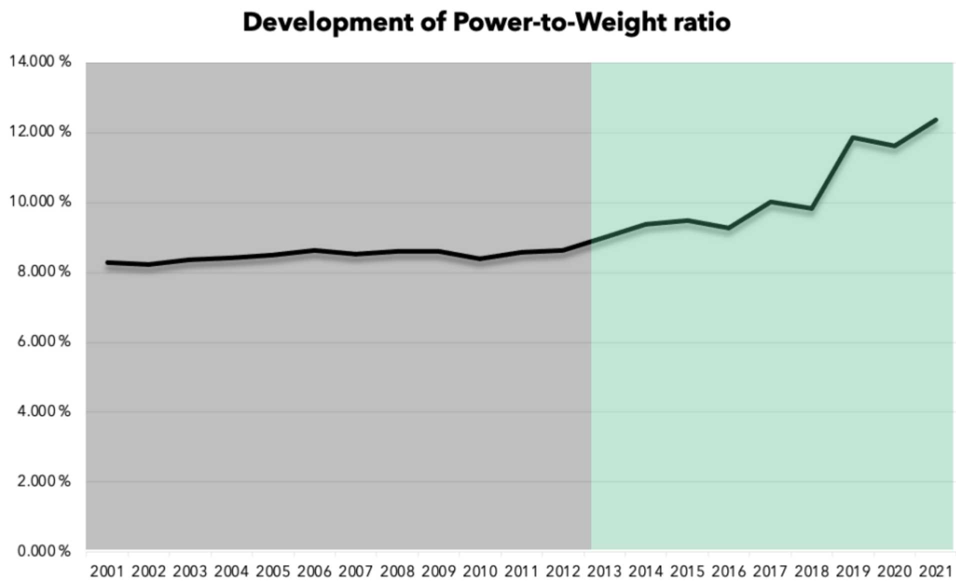

Fig. 14. Development of the Power-to-Weight ratio.

Lastly, we have the development of the PTW-ratio, being dependent on weight and HP parameters, showing an expected increase. Starting with a PTW-ratio in 2001 of 8,291%, reaching 8,567% in 2012. This gives us an average yearly increase of 0,03% before the entrance of EVs. In 2013 the average PTW-ratio was 9,018%, in 2021 this has grown to 12,377%, reflecting an average yearly increase of 0,420%.

4.2.4 Development of Norway's top 6 best-selling models

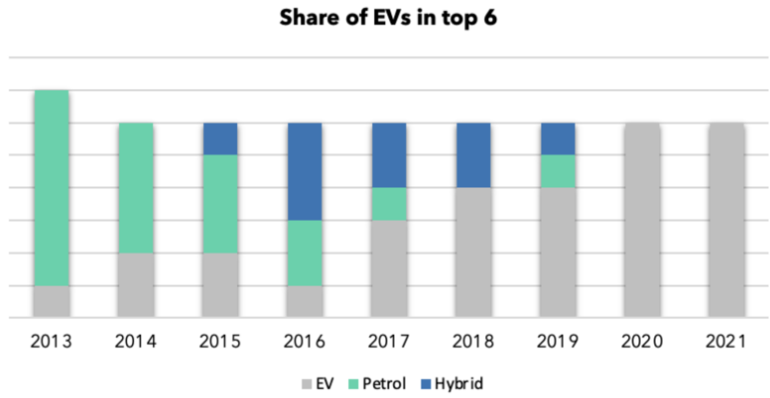

Fig. 15. Share of EVs in top 6.

As mentioned previously, the EV growth in Norway is quite substantial, being a lead market within the field of vehicle electrification. For the last 2 years, EVs account for every model in the top 6 list of best-selling models in Norway. The figure above shows how this evolution has planned out for the last couple of years, where we can see the rise of greener options, and the fall of ICEVs.

4.3 Regression analysis

By facilitating a regression analysis where average weight is dependent on; EV% of the sales amongst the top 6 best-selling models, average length, and average horsepower, we found that the average weight can be quite precisely predicted with these variables as seen in the calculated R square. From the coefficients, we find that the most influential variable on average weight is the proportion of EVs.

REGRESSION ANALYSIS | SUMMARY OUTPUT

REGRESSION STATISTICS	
Multiple R	0.995
R Square	0.989
Adjusted R Square	0.987
Standard Error	21.894
Observations	21

ANOVA	Coefficients	Std. error	t Stat	P-value
Intercept	1608.5389	1045.5437	1.5385	0.1423
EV % of top sellers	235.4271	114.1069	2.0632	0.0547
Average length	-0.1641	0.2538	-0.6466	0.5265
Average HP	3.5032	0.8954	3.9123	0.0011

ANOVA	df	SS	MS	F	Significance F
Regression	3	741732.788	247244.263	515.775	6.93E-17
Residual	17	8149.198	479.365		
Total	20	749881.987			

*EV% of top sellers account for how much of the total sales in the top 6, is caused by EV models.

Fig. 16. Regression analysis output.

We also find that:

$$\widehat{Avg\ Weight} = 1608{,}54 + EV\ \%\ of\ sales \cdot 235{,}43 + Avg\ length \cdot (-0{,}16) + Avg\ HP \cdot 3{,}50$$

From this formula we can calculate the average weight of cars in the top 6. Therefore, we find that when the goal of 100% EV adoption stated by former PM Erna Solberg is reached, along with the average length of an EV, with the average HP of EVs, the predicted weight of a top 6 car will be:

$$\widehat{Avg\ Weight} = 1608{,}54 + 100\% \cdot 235{,}43 + 4557 \cdot (-0{,}16) + 252{,}62 \cdot 3{,}50 = 1984{,}43\ kg$$

Whereas this is lower than the average EV of 2010 kg. Looking into what the predicted average weight will be if the EVs did not impact size and power, we see the necessity of making some adjustments to the variables, namely where EV% goes to 0, and both length and HP will be set to the average of all the other engine types. By this we get,

$$\widehat{Avg\ Weight} = 1608{,}54 + 0\% \cdot 235{,}43 + 4328{,}82 \cdot (-0{,}16) + 143{,}43 \cdot 3{,}50 = 1400{,}45\ kg$$

When calculating the assumed emissions with these two scenarios (via Climobil) we get that the 1984,43 kg EV will have lifetime emissions of 18,28 t C02 eq/vehicle. The other option where EVs did not impact size or power (1400,45kg), gives us 13,36 t CO2 eq/vehicle. This is a 26,91% decrease per vehicle, having a huge impact when accounting for an entire vehicle fleet.

4.4 Scenario analysis

4.4.1 Possible outcomes of changes in EV entrance

In this section, we will explore possible outcomes if the entrance of EVs had seen different paths by performing a scenario analysis. Originally, a scenario analysis is a method for predicting the possible occurrence of an object or the consequences of a situation, assuming that a phenomenon or a trend will be continued in the future (Yuan et al., 2017). In other words, scenario analyses are usually performed when dealing with possible future scenarios, thus, we want to conduct a different kind of analysis by examining the possible outcomes when adjusting its historical direction.

The reasoning for this is that we want to exhibit possible scenarios related to rebound effects. In order to execute such an analysis, we have taken use of the annual average driving distance of private cars in Norway, calculated at 11.228 km/year (SSB, 2022a). The lifetime of each vehicle is set at 18 years, being the average life expectancy of a car (SSB, 2022b). For the carbon content of the electricity mix we have used Norway's average at 31g CO2 eq./. kWh (Luxembourg Institute of Science and Technology, 2019).

4.4.2 Scenario #1

For the first scenario we will examen the real time development, comparing the best-selling car before the entrance of EVs in Golf (2013), to the current best seller in 2022, namely Tesla Model Y (Opplysningsrådet for veitrafikk, 2022). This enables an examination of the prospective environmental benefit of electrifying the fleet, with the increase in size.

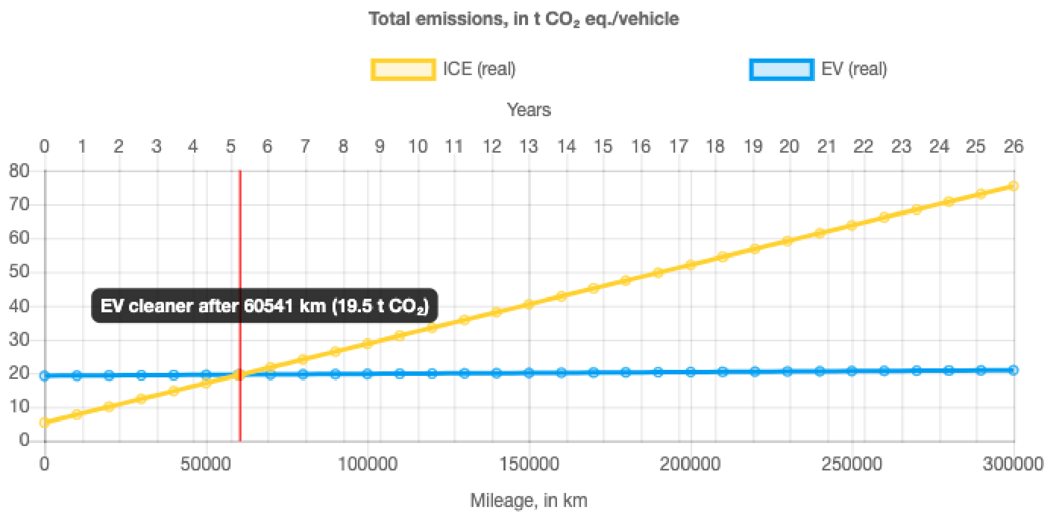

Fig. 17. Total emissions, in t CO_2 eq./vehicle

In this scenario the EV becomes the "cleaner" and more environmentally friendly option after approximately 5,5 years. With the condition of 18 years life expectancy (SSB, 2022b), we find that the Golf will produce 54,44 tons CO2 emissions over a lifetime, with the larger EV coming in at 20,37 tons, resulting in a decrease in the "average car" emissions of 62,58%.

4.4.3 Scenario #2

In the second scenario, we look at the development that could occur if the vehicle fleet was electrified, excluding the immense increase in size. To do so, we compared the best-selling car before the entrance of EVs with the Golf (2013) to the Nissan Leaf (2013), being similar cars in terms of size, power, and weight.

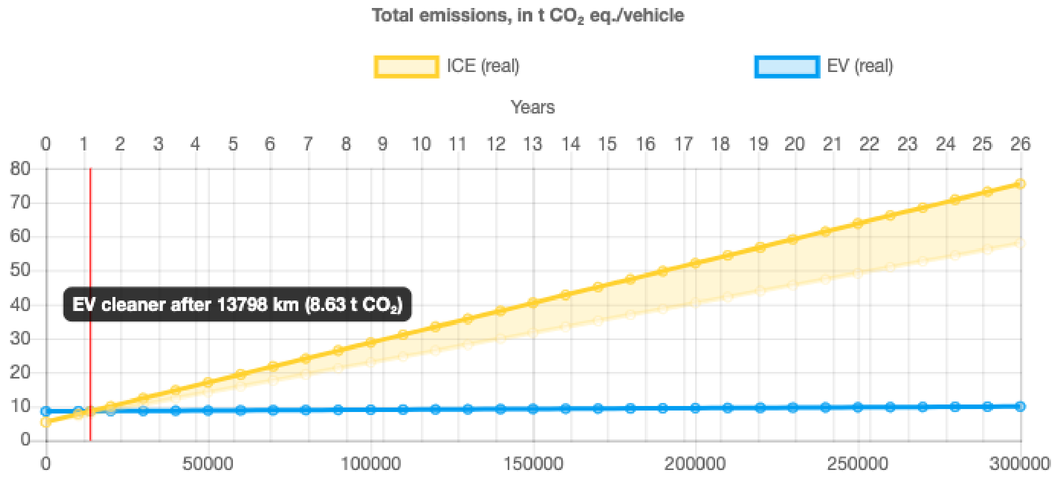

Fig. 18. Total emissions, in t CO_2 eq./vehicle

In this scenario, the EV becomes the "cleaner" and more environmentally friendly option after less than 2 years. Considering the total CO2 emissions, we see that the Golf still produces 54,44 tons of CO2 in total lifetime emissions. The smaller EV now have 9,59 tons of CO2 in total lifetime emissions, indicating an 82,38% decrease of lifetime emissions of the "average car".

4.4.4 Scenario #3

For the third scenario, we investigate what could have happened if the vehicle fleet was not electrified, with a simultaneous omission of size increase. To do so, we compare the emissions of the best-selling car before the entrance of EVs in Golf (2013), modified with the average weight and size of the "average ICEV" (1290 kg), to the emissions of a RAV 4, again modified with the average weight and size of the "average EV" (2010 kg).

With the emission numbers of the Golf (2013), and the average weight of ICEVs sold before the EVs entrance (1290 kg), we find that the car would have produced 55,02 tons of CO2 emissions over the lifetime. On the contrary, the simulated petrol car with EV dimensions would have produced 60,99 tons of CO2 emissions over its lifetime, resulting in an increase of 10,85% in CO2 emissions for each car.

4.4.5 Scenario #4

In the final scenario, we investigate what is lost because of the increased weight and HP of newer top selling EVs. This comparison will show the difference between what is possible with electrification that do not increase the size and power of the vehicles, against electrification that does increase both size and power. To do so we have taken the best-selling ICEV from 2013 in the VW Golf and set it up towards the best-selling EV of 2021 in the Tesla model 3. The VW Golf will be set to an electric engine with the same HP and weight as the 2013 Golf.

When calculating this through the Climobil software, we get that the 2013 VW Golf with an electric engine will have total lifetime emissions of 10,06 t CO_2. Whereas the Tesla Model 3 (2021) have calculated lifetime emissions of 16,90 t CO_2. This indicates that the newer, heavier, and more powerful vehicle has 67,99% more emissions over its lifetime than the lighter and less powerful best-seller from 2013. To better illustrate how much this increase will impact the total emissions in Norway, we can generalize and calculate the total emissions for the entire vehicle fleet, given that we link it to certain models. According to a report from SSB (2022) there is in total 2.893.987 personal vehicles in Norway. With the emissions of the lighter EV with dimensions from the 2013 Golf we get total emissions of all vehicles at 29.113.509,2 t CO_2. With the dimensions and emissions of the Model 3 we get total emissions of all vehicles at 48.908.380,3 t CO_2.

4.4.6. Battery disposal

We find it important to note that when the disposal of batteries is highly uncertain and hard to calculate, this could have resulted in overly optimistic estimates of both price and emissions regarding the battery of the EV. This could heavily affect how environmentally friendly the larger and more powerful EVs are. One of the biggest challenges regarding the EV evolution of the vehicle fleet, are the batteries essential for the vehicles to operate, whereas these batteries possess large amounts of hazardous gasses and minerals. Considering the disposal of these batteries, some uncertainty is present with regards to whether there is, or is not, a disposal system in place for these batteries. While Durden (2021) claims that there is not any sufficient system in place, Hydrovolt (2022) on the other hand, states that they have a system in order, being abundant to renew everything from 50-80% of the battery's black matter.

The confusion continues when looking at the renewal of these batteries on a global scale. An article from BBC claims that from an international perspective, only 5% of EV batteries are being recycled or reused (Woollacott, 2021). The remaining 95% is unknown and are assumed buried in various locations. If this is the case, this is not only an environmental hazard, but a huge risk for people in the area as the batteries can explode when heated or under pressure (Durden, 2021).

4.4.7 Evaluation of scenarios

As we can see from the scenarios, the EVs comes out as the overall better option for the environment in every scenario. However, there are massive differences within the EV category. The subsidies from the Norwegian government now accounts for all EVs (NAF, 2022), but should it? As seen from our scenarios, the emissions increase from the smaller EV towards the larger best-seller. Further, findings from the scenarios clearly indicates that horsepower and weight are highly influential with regards to the total emissions of a vehicle. This leads to further discussion, questioning whether this factor have been overlooked when evaluating the "green evolution" of the Norwegian vehicle fleet, in addition to possibly being a rebound effect of the electrification of the fleet, explaining how we lose around 10 tons of CO_2 per vehicle.

From scenario #4 we find the real answer as to what is lost due to the increasing weight and size of the average vehicles sold. The findings from this analysis should be used as a base when conducting new tests as to how "eco-friendly" a vehicle in Norway is. As of today, we compare EVs to traditional ICEVs when stating how eco-friendly the new car presented is. However, when EVs account for so much of the Norwegian market, new EVs should be compared to the smaller and most Eco-friendly options to give a better picture of how environmentally friendly each model is. This will give the consumers a better understanding of how eco-friendly their car is compared to other options on the market today.

5.0 Discussion

Throughout this study we have found that the overall size of vehicles has increased during the last couple of years, along with the power capacity of the vehicles. The findings clearly indicates that the immense increase in both weight and power is a result of the EV entrance in the market. The significant increase in all aspects (weight, HP, and PTW-ratio) reflects that the entrance of EVs in the market has resulted in certain aspects considered to be environmentally adverse. The heavier the car, the more resources it takes to produce, the more wear of road, and normally more horsepower needed. The increase in horsepower shows that the larger sized (and heavier) cars require more powerful engines, but it also exhibits a trend in the market that are leaning towards more powerful cars, which in turn addresses environmental degradations.

This is also shown with BEVs, as an increase in vehicle size provides the need for batteries with expanded capacity, efficiency, and power. To accommodate this need, BEV suppliers will have to upscale their mining operations required to supply sufficient amounts of raw materials for larger batteries, which has proven to have negative environmental impacts in terms of air pollutants, as well as producing hazardous tailings and slags that can leach into the environment.

From the data, we can see that horsepower has dramatically increased since the entrance of EVs, which could be a natural effect of the size increase, since larger cars tend to need more horsepower. Thus, the PTW-ratio indicates that the entrance of EVs has led to a preference for more powerful engines, indicating that rebound effects linked to the entrance of EVs are present. With the discovery of both size and horsepower increase, we can further scrutinize the potential rebound effects of the trend.

We have earlier in the paper stated rebound effects as "The increase in energy usage that sometimes follows the efficiency improvements". To be clear, the entrance of EVs in the market is a huge breakthrough for the environmental cost of personal vehicles. However, the increase in size, HP and PTW-ratio shows rebound effects of the efficiency improvements to the CO2 emissions from cars. The scenario analysis examines what could have been the case if EVs entered the market, but without the increase in size and HP, in addition to possible outcomes if EVs never entered the market.

From the scenarios, we see that the environmental benefit of the EV entrance in the market has been huge, however, we also find that we are losing out on potential environmental gain from the EV shift when the size and horsepower has increased in line with its adoption. The analysis of the VW Golfs evolution over time indicates that the increase in size and power do not only occur as new models and brands are capturing the market with improved vehicles. It shows that the models have increased both in size and power over the last 20 years, when the needs for vehicles have remained rather consistent during this period. There is no reasoning behind this increase, other than consumer preferences and the assumption that bigger is better, as stated in the theoretical framework.

Further results show how the size and power of electric vehicles affect their environmental benefit when compared to an ICEV, whereas the Norwegian government recently decided to change their subsidized policies towards EVs. From 2023 EVs will be imposed with a 25% VTA on vehicles with the value exceeding NOK 500.000 (Buggeland, 2022). The Minister of Finance, Trygve Slagsvold Vedum, stated that "there is no reason why the person who buys a Polo should pay more in taxes than the person who buys a Porsche" (Røsvik & Fjellanger, 2022). This also substantiates the assumptions claimed in our thesis, as more expensive BEVs tends to be bigger than the cheaper ones. Moreover, findings from this research points out the implications weight and power have on emissions, questioning whether it could be a better arrangement to subsidize EVs under a certain weight limit, e.g., with EVs under 1800 kg, forcing manufacturers to develop vehicles with curtailed weight, in line with lowered power leading to less powerful and more environmentally friendly batteries.

5.1 Other relevant findings

5.1.1 Battery manufacturing implications

Although the environmental implications of EV battery manufacturing have been thoroughly addressed in our paper, we find it important to substantiate the environmental burdens that will occur if other countries follow the footsteps of Norwegian EV adoption. For the rather small Norwegian market, the mining and production of EV batteries can easily be handled. Thus, if other countries decide to implement a subsidized policy like Norway to support EV integration, we may face some grievous issues. According to Cambridge University Emeritus Professor Michael Kelly, replacing all the 32 million light duty vehicles in the UK with EVs would require huge quantities of materials to manufacture the 32 million EV batteries (Stein, 2021). According to Stein (2021) producing 32 million EV batteries would require:

- More than 50% of the worlds annual production of copper
- 200 % of annual cobalt
- 75% yearly lithium carbonate output
- Almost 100% of its entire annual production of neodymium

As the allegations stated by Stein (2021) presumes, we can see that the possibility of a global electrification of the worlds veichle fleet is close to zero, being further substantied in the limited possibility to even electrify the entire UKs vehicle fleet with todays batteries.

5.1.2 New subsidy policy

As previously mentioned, when writing this paper the Norwegian government stated that they are implementing a new subsidy policy for electric veichles (NAF, 2022). To cope with the increasing power and size of EVs, all EVs over NOK 500.000 will be charged with 25% VAT on the ammount exceeding 500.000. To better illustrate how this will affect the prices of EVs, a comparison has been facilitated to illustrate the cost increase EV owners are facing.

BRAND	MODEL	PRICE BEFORE	NEW TAX PRICE	CHANGE
AUDI	e-Tron	760.300	825.375	65.075
VOLKSWAGEN	e-Golf	334.000	334.000	-
TESLA	Model 3	494.000	494.000	-
BMW	iX	770.000	837.500	67.500

Tab. 4. Outlayed new subsidy policies (all figures in NOK).

As seen from the table above, it will only affect the salesprice of the more exclusive and expensive EVs, in order to suppress the trend of consumers choosing the more exclusive models when purchasing EVs. To state the Minister of Fiance, "*Its not climate fight to drive around in a porsche!*" (Røsvik & Fjellanger, 2022).

5.2 Study limitations

We note that our findings should be interpreted with caution, as our research has basis in the Norwegian market with a Norwegian energy mix for electricity, resulting in the possibility of making some of our scenario findings inaccurate for other countries and markets. Further research extending our efforts into other markets will offer additional external validity. Additionally, our research includes a limited number of models, to account for the change within the most popular car models. Further studies with broader sample size could help providing a broader picture of how the synergies in the market works. In addition, we only include small selections of relevant year models, in which have had several different models during this period.

5.3 Areas for further research

For further research upon the topic, we find the need to address the spillover effects from the Norwegian EV subsidy policy. More precisely, how the government incentives have affected consumer preferences regarding size, power, and weight. Are people willing to buy the large powerful vehicles without the government subsidies? Has the demand for larger electric vehicles become so prominent that consumers will choose them over other ICEV alternatives, even if the EVs become more expensive? We encourage further elaboration on such aspects of our thesis, as well as deliberate quantitative research reflecting future EV integration.

Further research extending our efforts into other markets will also offer additional external validity, as well as how conducting a similar experiment in other countries and markets will offer added external validity. Prominent markets could be the Great Britain, with basis in former statements in the paper concerning the hastening of EV integration, rooted in prospective discussions within the parliament to accommodate subsidized arrangements to push forward the entrance of EVs in the country (Stein, 2021).

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