Transportation Research Part D 105 (2022) 103246

Contents lists available at ScienceDirect

Transportation Research Part D

journal homepage: www.elsevier.com/locate/trd

Retrospective Total cost of ownership analysis of battery electric vehicles in Norway

Erik Figenbaum

Institute of Transport Economics, Gaustadalleen 21, Oslo, Norway

ARTICLE INFO

Keywords:
Total Cost of Ownership
Battery Electric Vehicles
Market Diffusion
Norway

ABSTRACT

A retrospective Total Cost of Ownership (TCO) analysis of battery electric vehicles (BEVs) versus gasoline vehicles (ICEVs), provided insights on the TCO effects of Norway's BEV incentives that counts the registration and value added tax exemptions, reductions/exemptions from the annual tax, parking fees, road tolls and ferry rates, and bus lane access. BEVs were according to the TCO calculation too expensive before 2001. A 2001 breakthrough failed when California revised the ZEV-mandate and the Norwegian BEV producer THINK owned by Ford had problems. The TCO has since 2012 been favorable also compared to 3-year old ICEVs. The latter enabled adoption in multi-vehicle households that effortlessly coped with BEVs limited range, through the access to another vehicle for long trips and vacations. BEVs got a good reputation. Adoption targets were revised upwards when old targets were met. The costly incentives became institutionalized and difficult to downscale without hurting the successful market.

1. Introduction

Norway is the world leader in Battery Electric Vehicle (BEV) adoption with a 2020 market share of 54% (OFVAS, 2021) and a 12% share of the total fleet (IEAHEV 2021, Figenbaum 2020a). The economy of owning a BEV compared with an Internal Combustion Engine Vehicle (ICEV), has by far been the most important reason for buying a BEV since 2014 (Figenbaum et al. 2014, Figenbaum and Kolbenstvedt 2016, Bjerkan et al. 2016, Figenbaum and Nordbakke 2019, Elbilisten 2021). The BEV growth took off after 2010 whereas the most important incentives for BEVs, such as the exemption from the registration tax, value added tax (VAT, zero rate) and annual tax, the free or reduced rates for toll roads, parking and ferries, and the bus lane access, were introduced long before, as illustrated in Fig. 1. This raises several questions. Was the economy of owning a BEV unattractive up to 2010? Were adoption barriers such as short range, lack of vehicles or infrastructure important? Why was the diffusion so fast after 2010? This article investigates the first question with a retrospective analysis of the difference in the Total Cost of Ownership (TCO) for BEVs and ICEVs between 1990 and 2020 with and without purchase and local incentives. The second and third question will be answered by identifying other factors that influenced adoption.

TCO analysis is a well-known tool to investigate current and future costs. The rationale when used retrospectively is that if the TCO was not favorable, BEVs would have been unlikely to diffuse. More factors are however involved in vehicle purchases and the extent that consumers take TCO into account is uncertain. Failure and success must therefore be investigated further by taking into account additional factors, such as vehicle characteristics and availability, and factors exogenous to Norway. A counterfactual approach is used to discuss scenarios for what could have happened if Norway had pursued other policies, i.e. less incentives for BEVs.

E-mail address: efi@toi.no.

https://doi.org/10.1016/j.trd.2022.103246

Available online 19 March 2022

The main contribution to the literature lies in the use of TCO retrospectively combined with other explanatory factors to establish a better understanding of how Norway achieved its remarkable BEV diffusion. This will aid other countries in developing efficient policies for a rapid diffusion of BEVs. Transition research approaches such as the Multi-Level-Perspective of Geels (2012), rarely analyzes such micro-level competiveness, but provide societal level insights on the Norwegian BEV diffusion as seen in Figenbaum (2017). Econometric models of observed market behavior (Fridstrøm et al. (2016) and Fridstrøm and Østli (2017) investigate mathematically how the market developed, and can also provide insights on policy changes.

The article starts with investigating the TCO research literature in Section 2, before presenting the method and data used in Section 3. The results are presented in Section 4 followed by a discussion of the results in Section 5. The conclusions are presented in Section 6.

2. Perspectives from the literature

BEVs are in 2021 still more expensive to produce than ICEVs in spite of battery costs falling from over 1000 USD/kWh in 2010 to 100–150 USD/kWh in 2020 (BloombergNEF 2020). The higher production costs of BEVs should in consumer decisions be weighed against the substantial savings in usage costs (Hagman et al. 2016, Muratori et al. 2021), such as energy and maintenance costs, while taking into account the effects of incentives (Figenbaum et al. 2019, 2020). This situation is particularly pronounced in Europe with high fossil fuel taxes, and even more for Norway having Europe's lowest electricity prices (Figenbaum et al. 2015). Furthermore, the energy consumption of a BEV (battery to wheel) is only about a third of an ICEV (tank to wheel) under Norwegian climatic conditions.

TCO calculations can provide snapshots of the historic, current or future economic competitiveness of BEVs versus ICEVs. Earlier research has shown that the economic competitiveness of BEVs is the most important element of the consumer adoption decision (Bjerkan et al 2016, Figenbaum and Nordbakke 2019), given that they have access to this information (Dumortier et al. 2015). Upfront costs weigh heavier in the decision than savings when using the vehicle (Hagman et al. 2016), but energy costs are important (Figenbaum et al. 2014, Figenbaum and Kolbenstvedt 2016, Figenbaum and Nordbakke 2019). The extent that more intangible costs such as service, repairs and insurance, are taken into account or known to buyers, is uncertain. Consumers may be reluctant to adopt if the economic advantages are not known. The relative advantage of adoption is a main driver in diffusion processes (Rogers, 1995). Yet, some studies claim that vehicle buyers are not good at taking TCO into account (Moon and Lee 2019).

Studies of the TCO of BEVs has mainly been done for individual countries (Abotalebi et al. 2019, Bubeck et al 2016, Figenbaum et al. 2020, Ouyang et al. 2021, Danielis et al. 2018, Hao et al. 2020, Rusich and Danielis 2015, Santos and Rembalski 2021, Wu et al. 2015) or for comparative assessments between countries (Levay et al. 2017), single vehicle segments (Li et al. 2021), specific vehicles (Hagman et al. 2016), fleet representative vehicles (Scorrano et al. 2020), or across multiple vehicle segments (Bubeck et al. 2016, Wu et al. 2015, Figenbaum et al. 2020). Some studies have looked at regional (Hao et al. 2020, Breetz and Salon 2018, Li et al. 2021) or local (Parker et al. 2021) variations in TCO due to electricity price differences, but should also take into account access to home charging (Scorrano et al. 2020). Some extend TCO to include external costs to society to aid policy makers (Mitropoulos et al. 2017, Rusich and Danielis 2015, Li et al. 2021), and do it for typical user groups (De Clerck et al. 2018). A TCO analysis is sensitive to annual mileage (Rusich and Danielis 2015) as energy costs savings are proportional to mileage, and to longer vehicle holding periods and high annual mileages due to the risk of battery replacement (Weldon et al. 2018). Another TCO approach is the calculate the payback period of the investment in a plug-in vehicle (Al-Alawi and Bradley 2013).

Retrospective TCO analyses of the vehicle market are uncommon. The only one found in the literature was Palmer et al. (2018) which studied the TCO and 2000–2015 market shares of hybrid and electric vehicles in the UK, US and Japan for the period. Retrospective approaches are more common in the analysis of public transport systems (Benardos et al. 2021).

The extent of details varies between studies. Some assumes that some costs are equal irrespective of technologies, while others

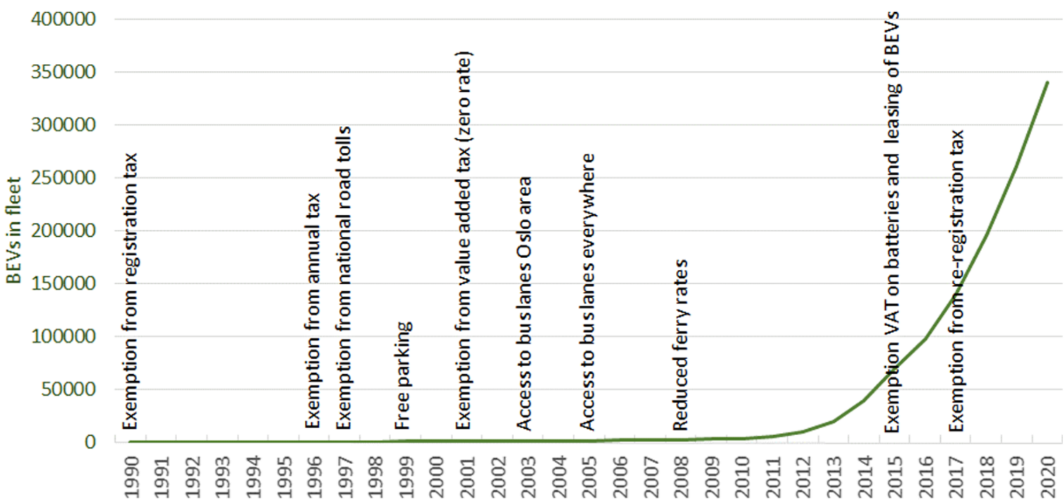

Fig. 1. BEV fleet 1990–2020 and introduction year of incentives.

develop elaborative models to calculate TCO using real market prices (Levay et al. 2017, Figenbaum et al. 2020) or bottom-up estimates (Bubeck et al. 2016, Morrison et al. 2018). This would involve understanding how BEV producers recoup investment costs, which is not straightforward (van Velzen et al. 2019).

Most early studies found that BEVs had a higher TCO than ICEVs, while newer studies show that the TCO can be lower in some countries (Moon and Lee 2019, Figenbaum et al. 2020). Most analyses of TCO includes some form of analysis of incentives to reduce the TCO disadvantage (Santos and Rembalski 2021, Palmer et al. 2018, Bubeck et al. 2016, Breetz and Salon 2018), or analyze the TCO effects of current policies (Lévay et al. 2017, Figenbaum 2018, Figenbaum et al. 2020). TCO analysis has also been used to investigate the future relative competitiveness of BEVs versus FCEVs (Morrison et al. 2018).

TCO is one side of the vehicle buying decision. It shows if and when BEVs make economic sense. Other factors, such as low range and long charge times (Hagman et al. 2016, Figenbaum and Kolbenstvedt 2015, Figenbaum 2018), insufficient availability of models and vehicles (Figenbaum 2017), lack of infrastructure (Hagman et al. 2016), lack of knowledge and uncertainty about new technology and battery life (Figenbaum et al. 2014, Hagman et al. 2016), and stability of framework conditions (Figenbaum and Kolbenstvedt 2015), are important considerations to take into account in the evaluation of the diffusion potential (Rogers 1995, Hagman et al. 2016, Figenbaum and Kolbenstvedt 2015).

Purchase incentives that modify both the purchase price and the TCO have a more profound effect on BEV diffusion than usage incentives such as exemptions from road tolls or parking fees, which only modifies the TCO. Usage incentives can go away overnight if politicians so decide, and long term political stability and early information on revisions is therefore important (Figenbaum and Kolbenstvedt 2015, Hardman et al. 2018, Hardman 2019). Lump sum support schemes favor small BEVs, while exemptions from flat taxes such as VAT favors big BEVs in absolute terms (Levay et al. 2017). Incentives that reduce the TCO disadvantage can with other incentives, such as ICEV driving bans, support future adoption (Letmathe P. Suares M. 2020).

The cost and perceived risk of buying a BEV is also modified by the general increase over time of the net household income after inflation. This factor does not seem to have been taken into account in the current TCO literature, but is very relevant for a retrospective analysis. An increase in the net real household income makes it easier to carry the additional costs of BEVs.

BEVs have developed from small special purpose short range vehicles, mainly attractive for local use (Figenbaum et al. 2014, Figenbaum and Kolbenstvedt 2015, 2016) in multi-vehicle households and fleets, to general vehicles (Muratori et al. 2021) with broad consumer appeal (Figenbaum et al. 2019, 2020), due to vast progresses in BEV technology (Muratori et al. 2021). Range limitation has been drastically reduced in all segments with the latest generation BEVs (Figenbaum et al. 2020). The fast charge speed has increased from 3 to 6 km/minute for 2011–2018 BEVs (Figenbaum 2018) to up to 20 km/minute in for instance the 2021 Hyundai Ioniq 5 (Insideevs 2021). BEVs could not be fast charged at all before 2011. These developments increase use areas and reduce adoption risks as the second hand market is larger for general purpose vehicles. Charging infrastructure was non-existent in 1990. A network of fast chargers is now available along major roads and enable travels across Norway (Figenbaum 2018, Figenbaum 2019, Figenbaum 2020b).

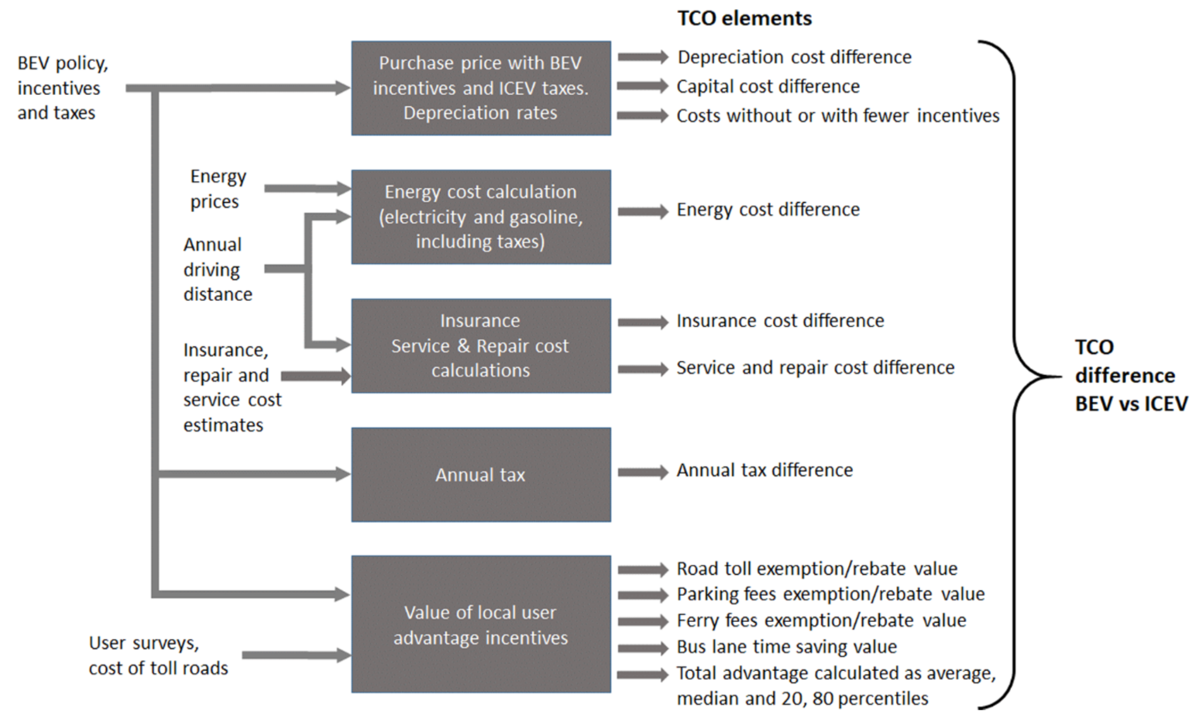

Fig. 2. Differential retrospective TCO model, cost elements.

3. Methodology and parameters

3.1. TCO model

The target of the differential retrospective TCO model is to calculate the difference in the TCO between BEVs and ICEVs, as it was likely to have been experienced by vehicle buyers. The differential TCO is calculated as the differences in the average annual cost of owning and operating the market leading Mini BEV instead of the most comparable ICEV. The full TCO is not calculated as it is not needed for the purpose of this article, and because complete datasets for the cannot be established for the 1990 s and early 2000 s. Fig. 2 provides an overview of the model. The costs included are the differences in: depreciation and capital costs, energy costs including fast charger usage and time cost, insurance, service and repairs, oil change and annual tax, as well as the value of the local BEV incentives, i.e. free/reduced rates for toll roads, parking and ferries, and time savings of using bus lanes and dedicated parking spaces. The exemption from the registration tax and the zero rate for VAT, are included in the purchase price seen by consumers.

Depreciation and interest expenses are calculated separately using the method that OFVAS (2020) uses to inform the public about the cost of owning and using new vehicles.

The depreciation is calculated as a constant annual cost, i.e. the difference between the purchase price and the residual value divided by the number of years of ownership:

$$P*(1-R)/y$$

were P is the purchase price (NOK), R the residual value (share of the purchase price), y the years of ownership.

The average interest expense over the ownership period is calculated as:

$$P*(1+R)/2*r$$

where r is the interest rate.

A 15% mark-up was added to reflect dealer on-cost and profit of selling a second hand vehicle when comparing the purchase of a new BEV with a 3-year old ICEV.

BEV energy costs are calculated as:

$$EC_{BEV} = d*E_{con}*(P_{el}*(1 - FC_{share}) + FC_{share}/(C_{Power}/60)*(P_{FC} + P_{Time}))$$

Were d = annual distance (km), E_{con} = Energy consumption (kWh/km), P_{el} = Electricity cost for home charging, FC_{share} = Share of km driven with fast charge electricity, C_{Power} = average fast charge power (kW), P_{FC} = Fast charge cost (NOK/min), P_{Time} = driver and passenger time cost (NOK/min) per minute the fast charge lasts.

The time cost P_{Time} of fast charge is calculated to be 2.8 NOK/minute based on the estimated average time cost for commuting (50%) and for leisure trips (50%) with lengths of 70–200 km in Flügel et al. (2020), taking into account the number of persons in the vehicle (Vågane 2009).

For 2014–2019 BEVs it is assumed that 5% (FS) of the energy comes from fast chargers for average BEV owners, based on fast charger use data (Figenbaum 2019, 2020b), and user surveys (Figenbaum et al. 2014, Figenbaum and Kolbenstvedt 2016, Figenbaum and Nordbakke (2019). Figenbaum (2019, 2020b) estimated the average BEVs fast charge power to be 30 kW. The fast charger usage market price is 3 NOK/minute. Up to 2013 were BEVs mainly charged at home. >90% of BEV owners still charge at home (Figenbaum and Nordbakke 2019). Norway had in 2020 2.6 million dwellings (SSB 2022). Charging will be possible in most detached (49% of all dwellings) and small houses (21%), and in the 45% of multi-dwelling buildings (25%) that have installed chargers according to market actors (Spot-on 2021). They latter have low vehicle ownership rates (Christiansen et al. 2015). Charging is thus possible in 80% of households.

Wall-box has gradually become the charging norm (Figenbaum and Nordbakke 2019, Elbilisten 2020) so that an installation cost has been added for the 2018–2019 TCO calculations, written off over 10 years. The cost of the basic installation is paid for over the rent regardless of owning a BEV or not and is not an extra cost. The wall-box plugged into this installation cost about the same as a complete detached house installation. A 15% electricity price mark-up cover administrative cost, i.e. about 300 NOK/year. The cost of using municipal chargers is decided politically and does not reflect the real cost (Spot-on 2021).

The energy cost of ICEVs follows from:

$$E_{ICEV} = d*E_{Gas}*P_{Gas}$$

Were d = annual distance (km), E_{Gas} = Fuel consumption (liter/km), P_{Gas} = Gasoline price (NOK/liter).

Insurance, service and repair costs collected from insurance companies and vehicle importers by OFVAS (2020) have been adapted to the annual mileages used in this article. Large BEVs have higher and small BEVs lower costs than ICEVs. The 2020 cost difference was used backwards in time due to lack of data. BEVs should with fewer moving parts and no oil change have lower service costs than ICEVs. This was not the case for early BEVs (Figenbaum (1994) and both higher (DN 2014) and lower (Elbil.no 2014, Elbil24 2018, TV2 2021) costs have been reported for newer BEVs. Other maintenance costs, such as washing and tire wear, are assumed equal. New technology and low volumes lead to higher repair costs as seen in insurance claims (ABCnyheter 2019, Elbil24 2019, Motor 2019a, Motor 2019b, Motor 2019c). BEVs had up to 2010 a high share of driving on low speed low risk roads, and the insurance costs were lower since insurance companies lacked experience (Elbil24 2019). High power makes handling difficult. The powerful BEVs available from 2013 are more often involved in insurance claims than ICEVs (Motor 2019a, Motor 2019b, Motor 2019c, ABCnyheter 2019, Elbil24 2019) and insurance costs are higher. Small BEVs still have a lower cost. It is uncertain if these differences are transparent to users.

3.2. Vehicle assumptions

Mini BEVs have been available in the Norwegian market since 1992. Small and compact sized BEVs came after 2012 but were also limited available 1998–2002. The first large BEV came in 2013. Therefore, the TCO model compares the most popular mini BEV with the most comparable ICEV. From 2015 were BEVs better equipped than ICEVs and a higher ICEV trim level was assumed. The 1992 BEV was the very basic 2-seater Kewet with a 70 km/h, top speed and a range of 20–45 km, using lead-acid batteries needing replacement every 0,5–2 years (Figenbaum 1994). The 1999–2001 BEV was the Norwegian THINK 2-seater with a 90 km/h top speed, 60–80 km range using expensive but reliable Ni-Cd batteries that needed maintenance every 6000 km, costing 1570 2019-NOK (Akershus Amtstidende 2007). Imported second hand French BEVs and earlier produced THINKs were the only BEVs available 2003–2004, whereas the Kewet based Norwegian Buddy Quadricycle came in 2005. A new 2-seater THINK BEV with Li-Ion batteries and 100–150 km range without fast charge capability, was produced 2008–2010. From 2011 the fast charge capable 4-seater Mitsubishi I-Miev with 80–130 km range was popular and from 2015 the VW E-up with 90–140 km range. The cheapest 1992 ICEV was a Fiat Ritmo. The Daewoo (Chevrolet) Matiz was the cheapest ICEV 1999–2005, followed by the Kia Picanto 2009–2013 and the VW Up from 2014. The battery warranty was 2 years up to 2007, 3 years from 2008 to 2010, 5 years/100000 km from 2011, and 8 years/160000 km from 2014. Further technical characteristics and vehicle prices are found in Table 1 and Table 2.

3.3. Residual values

The residual value of the vehicles is estimated in Table 3 from second hand prices and buyer expectation at the time of purchase. The estimates may seem high compared to other countries, but not considering the access to local incentives and a periodically limited availability of new BEVs.

3.4. Annual driving

The annual driving distance for mini-BEVs and ICEVs is set to12000 km for 2009–2020 models, which is close to the national average of vehicles (SSB 2021), and in accordance with the BEV user surveys of Figenbaum and Kolbenstvedt (2016) and Figenbaum and Nordbakke 2019). Variations between regions for 2018 are shown in Table 4. Earlier BEVs had short range and lacked fast charging. 8000 km/year was thus assumed for the 1992 year-model and 10000 km/year for 1999–2005 year-models.

3.5. Energy prices – Gasoline and electricity, and cost of home charger.

The nominal electricity prices including all taxes, VAT and grid costs, fluctuated around 0.6 NOK/kWh for the period up to 2002 (NOU 2004:8, NOU (1998:11) as shown in Table 5. The 2004 to 2020 electricity prices are from Statistics Norway (SSB 2021), gasoline prices are from Drivkraft Norge (Drivkraft 2021). Fig. 3 shows that the relative competitiveness of electricity was highest in the 1990 s and between 2011 and 2015, and the lowest between 2003 and 2006, and 2008 to 2011. The cost of wall box installations for 2018 and newer BEVs, is 1627 NOK/year, when written off over 10 years. Gasoline price include (NOU 2007) CO_2 tax, energy tax and VAT.

The average electricity price variation between Norwegian counties is on average small as seen in Table 6 but can fluctuate substantially temporarily due to limited transfer capacity.

3.6. Other base assumptions (2019 NOK)

The median household income after tax increased substantially between 1990 and 2020 as seen in Table 7 and Table 8. It is used in the results section to calculate households economic gain or loss when choosing a BEV over an ICEV. Bank interest rate, consumer price index, inflation, and real interest rate are also shown in Table 7.

3.7. Policies and policy scenarios

The large package of incentives shown in Table 9 were introduced gradually from 1990 to reduce the price disadvantage of BEVs and provide local advantages unavailable to ICEV owners. The 1992 registration tax was on weight and vehicle value. The tax 1999–2005 was on engine power, volume and weight. The 2009–2017 tax was on CO_2– and NO_x-emissions, weight and engine power. The latter was removed in 2018. CO_2-emissions below a threshold value give a negative tax (since 2010) that is deducted from the sum of the other taxes, but the total cannot be negative. 2010 and newer mini-BEVs would not have paid registration tax had they been subject to it, but large heavy BEVs would. 1992–2005 BEVs would have paid a substantial registration tax as seen in Table 10. The annual tax (insurance tax from 2018) exemption/reduction value is also shown. When this incentive is removed in some scenarios, the ICEV rate is applied.

The use of and value of local incentives is estimated from user surveys (Figenbaum 1994, Asplan Viak 2009, Figenbaum et al. 2014, Figenbaum and Kolbenstvedt 2016, Figenbaum and Nordbakke 2019). The 2014 values are extended to 2013, the 2016 values to 2015 and the 2018 survey values to 2019. These surveys (Figenbaum et al. 2014, Figenbaum and Kolbenstvedt 2016, Figenbaum and Nordbakke 2019) indicate that the local incentive value has been fairly stable. The estimated values are for the Oslo area up to 2012

Table 1
Example mini/small BEVs and closest resembling ICEVs per electromobility period. Nominal prices unless otherwise indicated. Sources include: Figenbaum 1998, Figenbaum 1995, Elbil.no 2021, VG 2010a, VG 2010b, VG 2011, Asphjell et al. 2013, Vattenfall 2010, price lists from OFVAS (1994–2019), vehicle test articles accessed through Retriever search, old brochures etc.

Period	1990–1996	1997–2002	1997–2002	2003–2006	2003–2006	2007–2010	2007–2010	2011–2015	2011–2015	2011–2015	2011–2015	2011–2015	2016–2020	2016–2020	2016–2020
Example year	1992	1999	2001	2004	2005	2009	2010	2011	2012	2013	2014	2015	2016	2018	2019
BEVs															
Model	Kewet	THINK	THINK	Peugeot 106 s hand	Kewet Buddy Quadri-cycle	THINK	THINK	Mitsubishi I-Miev	Mitsubishi I-Miev	Mitsubishi I-Miev	VW E-Up	VW E-Up	VW E-Up	VW E-Up	VW E-Up
Seats	2	2	2	4	2	2	2	4	4	4	4	4	4	4	4
Length (meter)	2.4	2.8	2.8	3.68	2.44	2.8	2.8	3.47	3.47	3.47	3.54	3.54	3.54	3.54	3.54
Battery type	Lead-Acid	Ni-Cd	Ni-Cd	Ni-Cd	Lead-Acid	Li-Ion or Na-$NiCl_2$	Li-Ion or Na-$NiCl_2$	Li-Ion	Li-Ion	Li-Ion	Li-Ion	Li-Ion	Li-Ion	Li-Ion	Li-Ion
Battery (kWh)	9.45 (5 h dis-charge rate, unrealistic)	11.4	11.4	12 kWh	13.1 (5 h dis-charge rate, unrealistic)	18.7Li-Ion 23Li-Ion 24Na-$NiCl_2$	18.7Li-Ion 23Li-Ion 24Na-$NiCl_2$	16 kWh	16 kWh	16 kWh	18.7	18.7	18,7	18,7	37 kWh
Range nominal (km)	50 Producer estimate	85 Producer estimate. 60 WLTP (est.)	85 Producer estimate. 60 WLTP (est.)	75 km	40–80 Producer estimate.	130–180 (NEDC) 100–150 (WLTP)	130–180 (NEDC) 100–150 (WLTP)	105 (WLTP)	105 (WLTP)	105 (WLTP)	160 (NEDC) 130 (WLTP)	160 (NEDC) 130 (WLTP)	160 (NEDC) 130 (WLTP)	160 (NEDC) 130 (WLTP)	256 (WLTP)
Range real world (km)	30–45	60–80	60–80	60–80	30–60	100–150	100–150	80–130	80–130	80–130	90–140	90–140	90–140	90–140	180–280
Average real energy cons. kWh/km	0.25	0.22	0.22	0.22	0.22	0.2	0.2	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
BEV price	89,000	199,000	160,000	120,000	119,000	285,000	244,000	240,000	192,500	151,900	189,300	191,100	199,800	171,100	202,300
Price (2019 NOK)	155,500	301,000	228,000	164,400	160,650	351,300	292,800	261,200	227,150	176,204	213,909	212,000	213,786	195,840	202,300
Battery pack replacement	0.5–2 years	>100000 km	>100000 km	>100000 km	3 years	>100000 km	>100000 km	>100000 km	>100000 km	>100000 km	Likely last the vehicle life	Likely last the vehicle life	Likely last the vehicle life	Likely last the vehicle life	Likely last the vehicle life
Battery pack replace. cost	12,000 NOK	Prohibitive Module change	Prohibitive Could replace modules	Prohibitive Could replace modules	23,750 NOK	Prohibitive Can replace modules	Prohibitive Can replace modules	Prohibitive Can replace module	Prohibitive Can replace modules	Prohibitive Can replace modules	Prohibitive Can replace modules	Prohibitive Can replace modules	Prohibitive Can replace modules	Prohibitive Can replace modules	Prohibitive Can replace modules
Battery main-tenance (2019 NOK)	0	1570	1570	1570	1570	0	0	0	0	0	0	0	0	0	0
Base Km/year	8000	10,000	10,000	10,000	10,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000
Energy use	City	City	City	City	City	City	City	Mixed	Mixed	Mixed	Mixed	Mixed	Mixed	Mixed	Mixed

Table 2
Gasoline mini-vehicles. Sources: VG 1992, Autodata 2021, MotorEU 2021, Ultimatespecs 2021, Vehicle price lists (OFVAS 1994–2019), news articles accessed through Retriever research.

Period	1990–1996	1997–2002	1997–2002	2003–2006	2003–2006	2007–2010	2007–2010	2011–2015	2011–2015	2011–2015	2011–2015	2011–2015	2016–2020	2016–2020	2016–2020
Year-model	1992	1999	2001	2004	2005	2009	2010	2011	2012	2013	2014	2015	2016	2018	2019
Gasoline vehicles															
Gasoline Model	Fiat Uno	Daewoo Matiz	Daewo Matiz	Daewoo Matiz	Chevrolet Matiz	Kia Picanto	Kia Picanto	Kia Picanto	Kia Picanto	Kia Picanto	VW Up	VW Up	VW Up	VW Up	VW Up
Seats	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Average fuel consumption (liter/10 km	0.836 (city)	0.79 (city)	0.79 (city)	0.79	0.79	0.836	0.836	0.583	0.583	0.583	0.495	0.495	0.50	0.50	0.504
Price (NOK (nominal)	99,900	99,900	122,000	112,900	124,950	125,000	119,900	120,000	122,400	123,300	155,600	159,000	165,100	173,700	183,700
Price (NOK 2019)	174,600	151,200	173,800	154,700	168,682	153,900	143,880	142,400	145,956	143,028	175,828	177,000	176,657	177,174	183,700

* Gasoline car fuel consumption is for all years up to 2017, assumed to be 10% higher than the nominal value, 20% from 2018, a conservative estimate based on ICCT (2018). The electricity consumption is estimated from real world experiences and Authors assessment.

Table 3
Residual value (percentage of purchase price). Authors estimates based on typical second hand vehicle prices and tuning of the depreciation rates to match typical second hand prices.

Depreciation factor	Gasoline car	BEV 2018–2019	BEV 2015–2016	BEV 2011–2013	BEV 2009–2010	BEV 2004–2005	BEV 1999–2001	BEV 1992
First year	80%	80%	80%	78%	75%	75%	75%	70%
Subsequent years	86%	83%	80%	78%	75%	75%	75%	70%
Value after 3 years	59%	55%	51%	47%	42%	42%	42%	34%
Value after 5 years	44%	38%	33%	28%	24%	24%	24%	17%
Value after 8 years	28%	22%	17%	13%	10%	10%	10%	6%
Value of 3-year old car, when it is 5 years-older, in percent of its 3-year purchase price	47%							

were well over half the fleet was located. The road toll exemption value 1999–2005 was assumed to be the annual subscription cost, and from 2009 to 2012 based on the cost of individual passes 25 NOK (2019), i.e. 4440 NOK/year (2019 NOK), for the 82% of drivers that said they used toll roads daily (Asplan Viak 2009).

For bus lane use 2004–2012, it was assumed that the 78% that in 2009 (Asplan Viak 2009) said that bus lanes were somewhat/very important, used them daily saving 15 min/day, 220 days/year, with a 2.8 NOK/minute time cost. For parking, the 2014 survey data was used back to 1999, as Asplan Viak (2009) and Econ (2006) surveys showed that free parking was important for 56.5% and 70% of users respectively. The resulting estimated values of local incentives are shown in Table 10, together with the VAT and registration tax exemption values and the annual tax exemption/reduction. Table 11 shows the purchase price, registration taxes and calculated VAT of the comparable ICEVs. The 2016 and 2018 local incentive values per county is shown in Table 12.

3.8. Scenarios

Four policy scenarios have been investigated in the results section:

A. Policies as they have been. i.e. full incentives for BEVs and taxes as been on ICEVs
B. No national BEV incentives, i.e. full VAT, registration tax and annual tax on BEVs.
C. Full VAT applied on BEVs, other incentives/taxes as they have been.
D. “European” policy, i.e. VAT and same annual tax ICEVs and BEVs, no registration tax.

Energy taxes are included in all scenarios.

3.9. Sensitivity tests

The results robustness has been tested with the parameter variations in Table 13. Test 1 uses the bank interest rate instead of the real rate after inflation. Test 2 compares new BEVs TCO with that of 3-year old ICEVs. Test 3 varies annual mileage +/- 20%. Test 4 has shorter and longer ownership periods. Test 5 halves the residual value difference and test 6 assumes it to be the same as ICEVs (percent). These tests have not been done for the 1992, 2004 and 2005 cases.

4. Results

4.1. Vehicle purchase price development 1992–2019

The historical purchase prices of BEVs and ICEVs, the price differences between them each year, and the theoretical VAT and registration taxes that would have applied had BEVs not been exempted, is shown in Fig. 4. The only times BEVs have been cheaper than ICEVs were in in 1992 and 2005 with the Kewet/Buddy BEV, due to the high taxes on ICEVs, BEV incentives, and these BEVs being very simple compared to ICEVs. New technology is expensive as seen by the high BEV prices in 1999 and 2009, the years when industrialized Ni-Cd and Li-Ion batteries were introduced. The cost of range, i.e. the purchase price divided by the real world range was reduced 80–85% between 1992 and 2019, as seen in Fig. 5. The 2004 dip was the result of import of low cost second hand BEVs.

Table 4
2018 regional data for annual vehicle km driven Source: SSB table 12576.

	Norway	Akershus	Aust-Agder	Buskerud	Hedmark	Hordaland	Møre og Romsdal	Nordland	Oppland
Annual Km driven	12,139	12,598	13,051	12,579	12,791	11,569	11,519	11,307	12,439
	Oslo	Rogaland	Sogn og Fjordane	Telemark	Troms	Trøndelag	Vest-Agder	Vestfold	Østfold
Annual Km driven	12,119	11,173	11,890	11,941	11,904	12,326	12,552	12,267	12,920

Table 5
Nominal Electricity and Gasoline prices with taxes 1990–2020. Sources: Drivkraft Norge 2021, NOU 2004:8, NOU 1998:11, SSB Table: 08448, 09,387.

Period	1990–1996	1997–2002	1997–2002	2003–2006	2003–2006	2007–2010	2007–2010	2011–2015	2011–2015	2011–2015	2016–2020	2016–2020	2016–2020
Year	1992	1999	2001	2004	2005	2009	2010	2011	2012	2015	2016	2018	2019
Electricity price NOK/kWh Nominal	0,6	0,6	0,60	0,76	0,76	0,85	1,02	1,0	0,795	0,81	0,92	1,16	1,15
Gasoline price NOK/liter Nominal	6,72	9	9,30	9,70	9,70	11,74	12,69	13,95	14,75	13,96	13,55	15,56	15,69

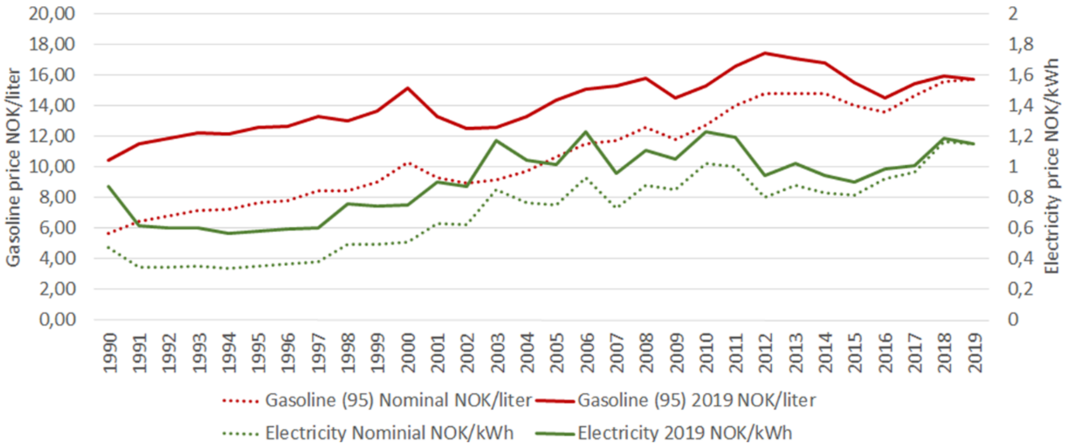

Fig. 3. Energy prices. Sources: Drivkraft Norge (2021), NOU 2004:8, NOU 1998:11, SSB Tables: 08448, 09,387.

Table 6
2018 regional data for electricity price. Source: SSB table 11011.

	Norway	Akershus	Aust-Agder	Buskerud	Hedmark	Hordaland	Møre og Romsdal	Nordland	Oppland
Electricity price per kWh	1,167	1,134	1,225	1,196	1,241	1,173	1,1245	1,013	1,196
	Oslo	Rogaland	Sogn og Fjordane	Telemark	Troms	Trøndelag	Vest-Agder	Vestfold	Østfold
Electricity price per kWh	1,18	1,19	1,348	1,223	0,934	1,238	1,233	1,189	1,164

Table 7
Interest rate, consumer price index, net consumer interest rate and median household income 1992–2019. Sources: SSB tables 08175, 03014, 04751.

	1992	1999	2001	2004	2005	2009	2010	2011	2012	2015	2016	2018	2019
Consumer price index (KPI)	1.75	1.51	1.43	1.37	1.35	1.23	1.20	1.19	1.18	1.11	1.07	1.02	1.0
Bank interest rate	13.4%	8.4%	8.8%	4.2%	3.9%	4.9%	4.5%	4.8%	4.8%	3.9%	3.5%	3.4%	3.7%
Inflation rate	2.4%	1.4%	2.9%	0.4%	1.6%	2.2%	2.4%	1.3%	0.6%	2.1%	3.6%	2.7%	2.2%
Real interest rate	11.0%	6.0%	5.9%	3.8%	2.3%	2.7%	2.1%	3.5%	4.2%	1.8%	−0.1%	0.7%	1.5%
National* median household income (1000 2019 NOK)	3220	3700	3860	4235	3834	4280	4344	4486	4626	5450	5329	5345	5400

*Regional data has been used in some of the calculations from 2005, with data from SSB table 06,944.

Table 8
2018 regional data for median household income after tax Source: SSB tables 06946.

	Norway	Akershus	Aust-Agder	Buskerud	Hedmark	Hordaland	Møre og Romsdal	Nordland	Oppland
Median house-hold income after tax	524,000	601,000	513,000	529,000	490,000	542,000	535,000	512,000	500,000
	Oslo	Rogaland	Sogn og Fjordane	Telemark	Troms	Trøndelag	Vest-Agder	Vestfold	Østfold
Median house-hold income after tax	475,000	571,000	545,000	500,000	516,000	522,000	516,000	513,000	503,000

The purchase price development for different sized BEVs, and similar sized ICEVs between 1992 and 2020 is shown in Fig. 6. Real ICEV prices have been pretty constant, apart from a rise in 2019 due to currency rates. The Quadricycle (4wheel MC) BEV price was fairly constant 1992 to 2011, apart from a reduction in 2001 when the zero VAT-rate was introduced. The price of the 1999 Ni-Cd BEVs (M1 passenger vehicles) was high. From 2001 the price dropped due to the zero rate VAT. BEVs were very expensive when they re-emerged in 2008–2010 with Li-Ion batteries. The prices had been reduced to 40% of the 2008 price by 2015. Small and compact BEVs have from 2014 had a price level comparable to ICEVs, whereas the average driving range has doubled.

4.2. Scenario A - incentives and taxes as they have been

The TCO difference between BEVs and ICEVs for the period 1992–2019 for the base scenario with incentives/taxes as they have

Table 9
BEV incentives in Norway. Authors collection and assessment.

		BEV buyers - relative advantage		
Incentives	Introduced	1990–2019	2020	Future plans
Fiscal incentives: Reduction of purchase price/yearly cost gives competitive prices				
Exemption from registration tax	1990/ 1996	Temporary in 1990 and permanent in 1996 based on value and weight, 1999–2005: Based on weight, power, engine volume. CO_2 emiss. replaced engine volume in 2007. Power was removed from 2018.	The registration tax is based on ICEV emissions and weight and is progressively increasing. Example ICEV taxes: VW Up 3,000 €. VW Golf: 6,000 €, larger vehicles even higher	To be continued unchanged at least until the end of 2021, likely also the end of 2022.
VAT exemption (zero rate)	2001	Introduced in mid-2001 when the VAT was 24%.	Vehicles competing with BEVs are levied a VAT of 25% on sales price	To be continued unchanged until at least the end of 2021, likely also the end of 2022.
Reduced annual tax (formally a tax on vehicle insurance)	1996/ 2004	1996: exemption, 2004: low rate (traffic insurance tax), 2018: full exemption	ZEVs were exempted until end of 2020.	From 2021: BEVs and hydrogen vehicles 213 €, diesel/petrol: 297–307 € (2021-figures).
Reduced company car tax	2000	Introduced 2000 when BEVs had short range and minimal private advantage	The company-car tax is 40% reduced compared to ICEVs but little impact.	Unknown.
Zero rate VAT on BEV leasing and on batteries	2015-	Introduced in 2015 to reduce owners worries about vehicle second hand value and make leasing more attractive	Only an advantage for those that replace batteries outside of warranty periods. Leasing less common for BEVs.	Continues until further notice
Exemption from change of ownership tax	2018		Change of ownership tax: ICEVs 0–3 year-old vehicles + 1200 kg: 660 Euros, 4–11 years 398 Euros.	Continues until further notice
Direct subsidies to users: Reduction of variable costs and help solving range challenges				
Reduced toll roads	1997	1997–2017: full exemption. Law revised in 2017: Rates for BEVs will be decided by local authorities, up to 50% of the ICEV rate.	In Oslo users save 60%, 360–600 €/year. Some places savings exceed 1500 €	The actual cost advantage varies from 50% and 100% of what ICEV owners pays.
Reduced fares on main road ferries	2009	2009–2017. Reduced rates, from March 2018: 50% of the ICEV rate.	Similar to toll roads, saving money for those using car ferries.	
Financial support normal chargers	2009		Reduce investors risk, reduce users range anxiety, expand usage.	National plan for charging infrastructure has been developed but is rather vague.
Financial support for fast chargers (Government, Counties Municipalities)	2011-		More fast-charging stations influences BEV distance driven & market shares. Build out of Fast chargers along major roads have been supported since 2011.	Support for fast chargers in non-commercial locations. City fast charging considered viable and left to commercial actors
User privileges: Reduction of time costs and providing users with relative advantages				
Access to bus lanes	2003/ 2005	Full access Oslo area: 2003. Nationally 2005. Minibuses no longer allowed: 2008. Local authorities have since 2017 the authority to introduce restrictions if buses are delayed	Though some limitations due to large BEV fleets, many BEV users still save time driving to work in the bus lane during rush hours.	The incentive is likely to become more and more restricted as the BEV fleet increases.
Free or reduced parking fees	1999	Fully exempted 1999–2016. Local authorities can since 2017 charge BEVs up to 50% of ICEV rates.	Users get a parking space where these are expensive and they save time as the parking is preferential to BEVs.	The actual cost advantage varies between 50% and 100% of what ICEV owners pays.

been, is shown in Fig. 7. Sensitivity variations according to Table 13 are also shown. The 1992 BEV almost matched the TCO of the ICEV and could have reached break even if the batteries had lasted longer. The Norwegian PIVCO/THINK developed a mini BEV with robust but costly Ni-Cd batteries. THINK was bought by Ford that needed a compliance BEV for the ZEV mandate in California (Think City 2000). Production started in 1999. The TCO of that BEV was only beneficial with unrealistic depreciation rates and large local incentives, such as free toll roads and free parking that had been introduced in 1997 and 1998.

Something had to be done and the EV Association that had been formed in 1995 lobbied for a VAT exemption for BEVs to aid THINK in reducing the price and thus help build a home market. During deliberations over a VAT reform in the Parliament in 2000 (Parliament 2000a, 200b) they succeeded. A zero rate VAT applied from mid-2001 (Aftenposten 2001). Prices were immediately reduced by 20% and the 2001 THINK became almost TCO competitive without local incentives and was competitive with. A potential BEV breakthrough seemed imminent but the production stopped end of 2001 to switch to a model better suited for California (Asphjell et al. 2013). It was to use Ni-MH batteries to reduce cost (Figenbaum 2021) and be prepared for EUs proposed Cadmium ban (Figenbaum 2021). The former proved wrong and Ford/THINK had to switch to Lead-Acid batteries as the remaining low cost option (Figenbaum 2021). When Ford/THINK found out in early 2002 that the range of the new model was inferior to the old (Strzeletz Ivertsen 2014) it was too late (Figenbaum 2021). No other mature battery options with acceptable costs were available (Figenbaum 2021) and the old model could not be produced because the production tools had been scrapped. Ford also had time economic problems (CNN 2002), and

Table 10
Value of BEV incentives and policies. Number in parenthesis extrapolated from other years (2019 NOK). BEV registration tax exemption value and annual tax is based on vehicle taxation schemes in the Governments Annual budget documents (Ministry of Finance 1989-2019).

	1992	1999	2001	2004	2005	2009	2010	2011	2012	2013	2014	2015	2016	2018	2019
Value of national incentives															
Annual tax	0	2000	2300	2 405	2 405	2350	2395	2400	2480	2525	2565	2600	2 690	2 820	2900
VAT rate	NA	NA	24%	24%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%
VAT exemption	NA	NA	54,912	39,465	40,163	87,638	67,200	71,400	56,788	44,051	53,477	53,030	53,447	48,960	50,575
Registration tax exemption	117,863	37,836	38,618	35,552	39,001	0	0	0	0	0	0	0	0	0	0
Value of all local incentives															
Geography	Oslo	Oslo	Oslo	Oslo	Oslo	Oslo	Oslo	Oslo	Oslo	National	National	National	National	National	National
Average	NA	8845	8289	12,430	12,366	12,267	12,164	12,130	12,096	(10166)	10,166	(12891)	12,891	15,091	(15 091)
20 percentiles	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	(2454)	2454	3519	(3519)
Median	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	(11043)	11,043	13,333	(13333)
80 percentiles	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	(25766)	25,766	25,806	(25806)
Value of individual local incentives															
Road tolls	NA	4832	4576	4384	4320	4221	4118	4084	4050	(4068)	4068	(7747)	7747	9313	(9313)
Parking	NA	(3713)	(3713)	(3713)	(3713)	(3713)	(3713)	(3713)	(3713)	(3713)	3713	(2515)	2515	2616	(2616)
Ferries	NA	NA	NA	NA	NA	NA	NA	NA	NA	(621)	(621)	(621)	621	617	(617)
Bus lane	NA	NA	NA	(4333)	(4333)	(4333)	4333	(4333)	(4333)	(2385)	2385	(2099)	2009	1889	(1889)
Park time	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	694	(694)

Table 11
ICEV price with/without tax, value of registration tax and VAT (2019 NOK) ICEV registration tax and annual tax is based on vehicle taxation schemes in the National Annual budget documents (Ministry of Finance 1989-2019, Skatteetaten 2020).

	1992	1999	2001	2004	2005	2009	2010	2011	2012	2013	2014	2015	2016	2018	2019
Purchase price	174,825	150,849	174,460	154,673	168,683	153,750	143,880	142,800	144,432	143,028	175,828	176,490	176,657	177,174	183,700
Price without taxes	68,469	78,698	96,131	79,475	89,728	86,072	81,581	92,193	92,166	91,511	109,384	109,735	110,242	111,289	117,703
Registration tax	77,219	43,943	55,257	56,124	56,523	46,160	41,904	27,559	29,225	28,639	39,098	39,321	38,854	38,063	36,572
VAT	29,138	28,208	23,072	19,074	22,432	21,518	20,395	23,048	23,041	22,878	27,346	27,434	27,561	27,822	29,426

Table 12
2018 County differences in average value of local incentive (NOK)s, adapted from Figenbaum and Kolbenstvedt 2016 and Figenbaum and Nordbakke 2019.

	Norway	Akershus	Aust-Agder	Buskerud	Hedmark	Hordaland	Møre og Romsdal	Nordland	Oppland
Average local incentive value 2016	12,891	18,911	6125	17,694	5784	14,630	4818	9842	6865
Average local incentive value 2018	15,128	18,601	6447	11,387	10,046	16,669	8308	13,939	10,834
	Oslo	Rogaland	Sogn og Fjordane	Telemark	Troms	Trøndelag	Vest-Agder	Vestfold	Østfold
Average local incentive value 2016	18,009	9396	3796	3454	3736	7090	13,028	14,523	9535
Average local incentive value 2018	21,024	12,315	5573	10,892	4120	11,415	10,693	12,224	11,392

Table 13
Sensitivity tests.

Test	Km/year	BEV and ICEV residual values	ICEV	Ownership period	Interest rate	Local incentives
1	Base	Base	Base	Base	**Bank rate**	Base
2	Base	Base	**3-year old**	Base	Base	Base
3	**−20% / +20%**	Base	Base	Base	Base	Base
4	Base	Base	Base	**3 years / 8 years**	Base	Base
5	Base	**Half difference**	Base	Base	Base	Base
6	Base	**Same as ICEV**	Base	Base	Base	Base

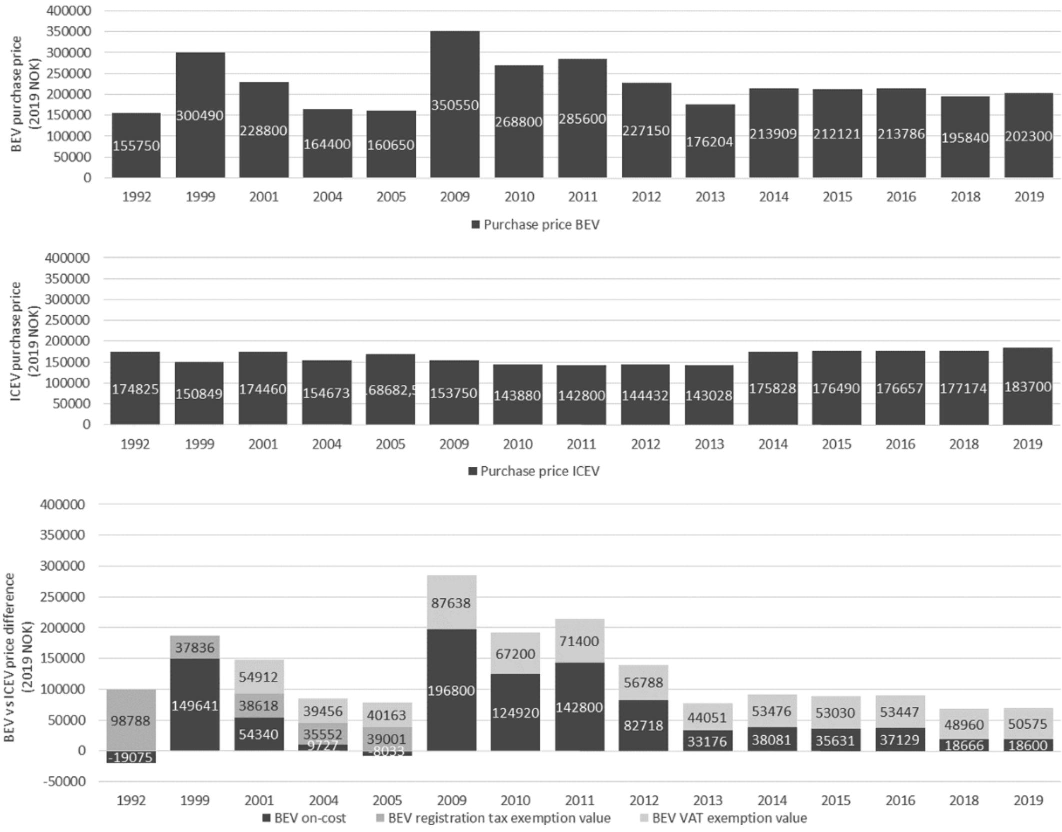

Fig. 4. BEV (top) and ICEV (middle) purchase prices and price differences (bottom) with and without incentives, in 2019 NOK.

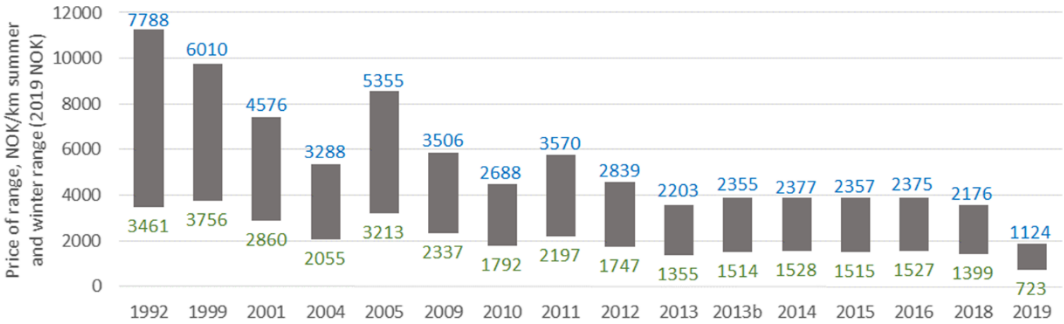

Fig. 5. Cost of summer and winter range. Calculated as nominal purchase price divided by estimated real world range (2019 NOK). Blue numbers are for winter range and green numbers are for summer range. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

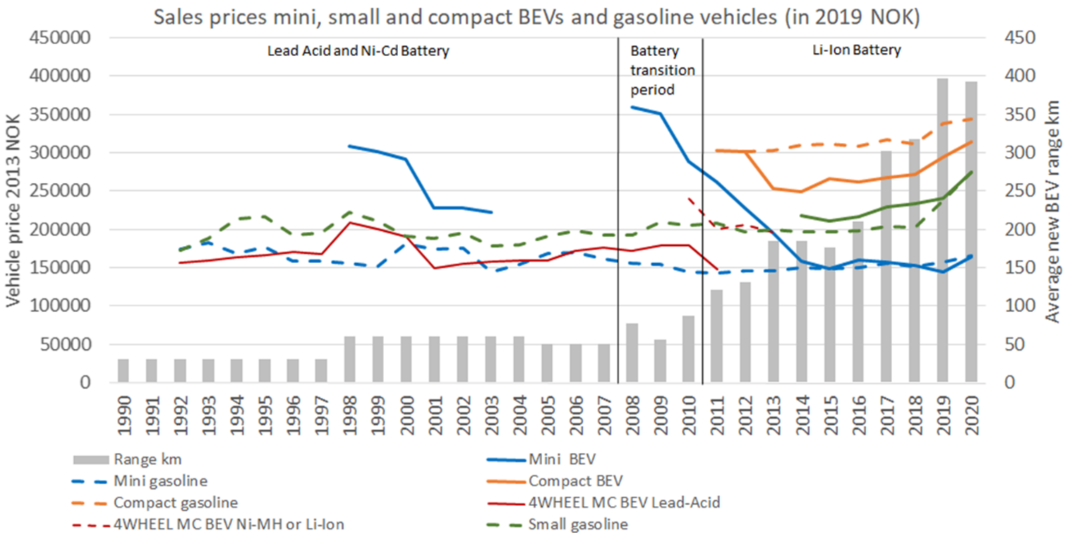

Fig. 6. BEV and Gasoline ICEV prices 1990–2020 (2019 NOK). Mini, small and compact vehicles. Estimated average WLTP range of new BEVs that entered the fleet. Sources: Old brochures, price lists from OFVAS (1994–2020), news articles (Retriever research), National Vehicle Register data.

lost interest (NYTimes 2002) and sold THINK when CARB terminated the BEV specific parts of the ZEV mandate (Wesseling et al. 2014). THINKs production never recovered and it went bankrupt a few years later. Ironically, the Ni-Cd ban was not enacted until 31.12.2005 (EU Commission 2002).

New BEVs were unavailable in Norway from 2003, but low cost second hand BEVs could be imported from France that had abandoned BEVs. The 2004 BEV therefore had a favorable TCO. The Danish BEV producer Kewet had in 1998 been bought by Norwegians that from 2005 produced the Buddy Quadricycle version of the Kewet in Norway. The TCO was advantageous with local incentives, but this vehicle was even simpler than the 1992 Kewet had been.

THINK had in 2006 been bought by Norwegian investors. The 2009 model year THINK was based on a model that had been developed under Ford, and used expensive Li-Ion batteries (BloombergNEF 2019, 2020). The TCO versus ICEVs was only favorable with unrealistic depreciation rates or 8-year ownership. A cost reduction made the 2010 TCO favorable with local incentives. THINK and the Buddy producer lost funding during the global financial crisis and the production stopped end of 2010 (Asphjell et al. 2013).

The most important incentives had been put in place to support Norwegian BEV production but they nevertheless remained in place after the industrialization setback and OEMs swiftly took over the market. The 2011 Mitsubishi I-Miev (and Peugeot and Citroën siblings) were TCO neutral with average local incentives, and became popular, especially as mini-buses no longer could use bus lanes. Nissans much larger 2012 Leaf had only a slightly higher price so Mitsubishi, Peugeot and Citroën reduced 2012 prices to stay competitive. Early i-Miev buyers thus experienced an extraordinary high and unforeseen depreciation rate. Competition and technology improvements increased BEVs TCO advantage towards 2015. The TCO has since then been advantageous while the driving range and model selection has increased rapidly. BEVs have become increasingly attractive also to single vehicle households (Figenbaum and Nordbakke 2019), and stimulated by the build out of fast chargers along major roads (Figenbaum 2018, Figenbaum et al. 2020) that enable travels across Norway. Research (Figenbaum and Nordbakke 2019, Bjerkan et al. 2016, Fearnley et al. 2016) showed that the economy of owning a BEV was the main diffusion driver.

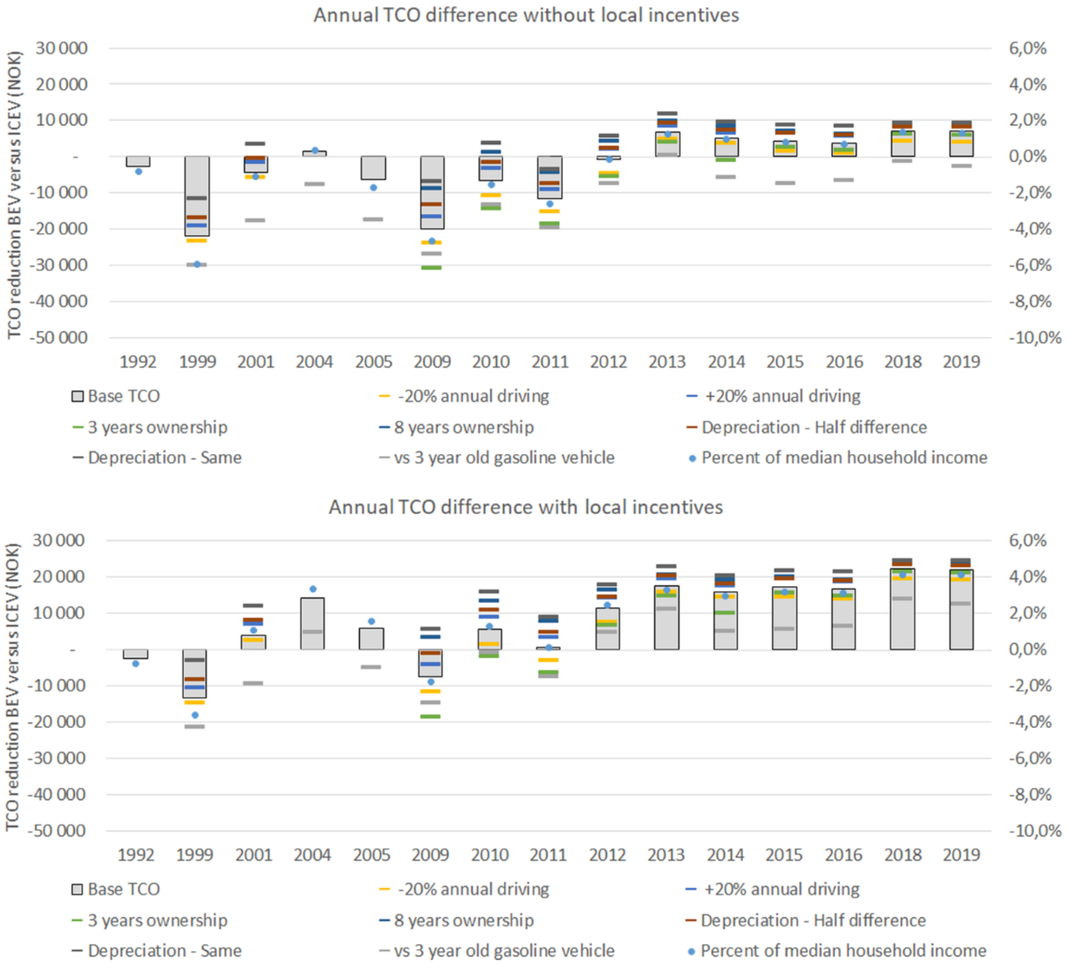

Fig. 7. Base case. All policies and incentives as they have been practiced and introduced. Local incentives estimated from user surveys (Asplan 2009, Figenbaum et al 2014, Figenbaum and Kolbenstvedt 2016, Figenbaum and Nordbakke 2019), earlier toll road fees, and own estimates.

Politicians kept the incentives in place and revised instead adoption targets when old targets were met. In 2012 the climate policy settlement (Climate Policy Settlement 2012) target was to keep incentives in place until 50,000 BEVs were in the fleet or until 2015. The year after the new Governments target was to keep incentives in place through 2017 (Sundvollen 2013), and from 2016 the parliament decided to keep them through 2020 (Parliament 2016), and then the Government extended it to 2021 (Granavolden 2019), and the Parliament decided that only BEVs should be sold from 2025 (Parliament 2017).

Local incentives tipped the scale in BEVs favor in 2001, 2005, 2010 and 2011, and has since 2015, doubled to tripled the average users TCO advantage, and supported diffusion across. BEV buyers have without local incentives had a competitive TCO compared to 3-year old ICEVs since 2018, and with local incentives since 2012. BEVs has therefore been accessible to and economic to own for multi-vehicle households that normally would have bought second hand ICEVs as their secondary vehicle. They could easily cope with and utilize BEVs limited driving range and reaped advantages from local incentives. BEVs thus got a good reputation and the vast majority of owners were so satisfied that they would buy a BEV again (Figenbaum et al. 2014, Figenbaum and Kolbenstvedt 2016, Figenbaum and Nordbakke 2019). The situation was even more favorable for compact and larger BEVs (Figenbaum et al. 2019, 2020), due to their longer range and larger annual mileages. Many BEVs introduced 2020–2021 have ranges in excess of 300 km also during the winter season (>400 km WLTP range), which 80% of BEV owners and 50% of ICEV owners in the 2016 survey said should make BEVs popular (Figenbaum and Kolbenstvedt 2016).

In 1999 and 2009, buying a BEV took 4% more of the available household income after tax than buying an ICEV. It was neutral in 2001, and from 2015 households have used 3–4% less of their household income when buying a BEV than an ICEV. Early battery life concerns (Figenbaum et al. 2014, Econ 2006) has faded as a barrier (Figenbaum and Nordbakke 2019) due to longer warranties, real life experience (E24 2015, TU 2016, TU 2018), and because BEV producers extend battery life by limiting batteries usable energy (Reiter et al. 2018, E24 2015).

The TCO calculation is based on 95% home charging as almost all BEV owners can charge at home and>80% of all households have or can likely get access to home charging. Vehicle owners among the last 20% must also get access to charging for Norway to reach the target of only selling BEVs from 2025. The most extreme situation would be to only charge at fast chargers costing 3 NOK/min, which with 30 kW average power equals 6 NOK/kWh. The 2019 BEV would then have had a TCO disadvantage of 3045 NOK without local incentives, and an advantage of 12,046 NOK with. The 2013–2019 TCO break-even point for the electricity price varies from 2.5 – 4.5 NOK/kWh without local incentives. Flat owners using chargers in common parking facilities typically pay 2–3.0 NOK/kWh with all costs included. Buying a BEV would for most of them be beneficial even without local incentives.

Sensitivity tests show that the 1999 BEV was too expensive in all sensitivities tested with and without local incentives. The 2001 zero rate VAT and a higher ICEV price made BEVs competitive. The TCO advantage varied around zero for the 2011 BEV in the sensitivity tests, but has been favorable for all sensitivities with local incentives included since 2012. Using bank interest rates instead of the real interest rate does not change conclusions.

4.3. Scenario B – Without national incentives

Removing the exemption from the registration tax and introducing full VAT and annual tax on BEVs results in a calculated TCO disadvantage that local incentives could not have compensated for until 2013, as seen in Fig. 8. It was however close in 2004 and 2012. TCO neutrality without local incentives would not have been possible before 2018. The pre 2018 diffusion rate would have been low and like that of other countries with few incentives, as seen by the registration statistics for other European markets (ACEA 2015–2018). Low diffusion rates are also found in the market models of Fearnley et al. (2015) and Fridstrøm and Østli (2018), when testing such policy changes. Fridstrøm and Østli (2018) predicted for instance a 74% fall in the BEV demand if the registration tax exemption was removed and VAT was applied to BEVs. New BEVs would not have had a favorable TCO compared to 3-year old ICEVs with local incentives included until 2018, but would have been beneficial from 2013 for other sensitivities. Before 2012, BEVs would in general not have been viable.

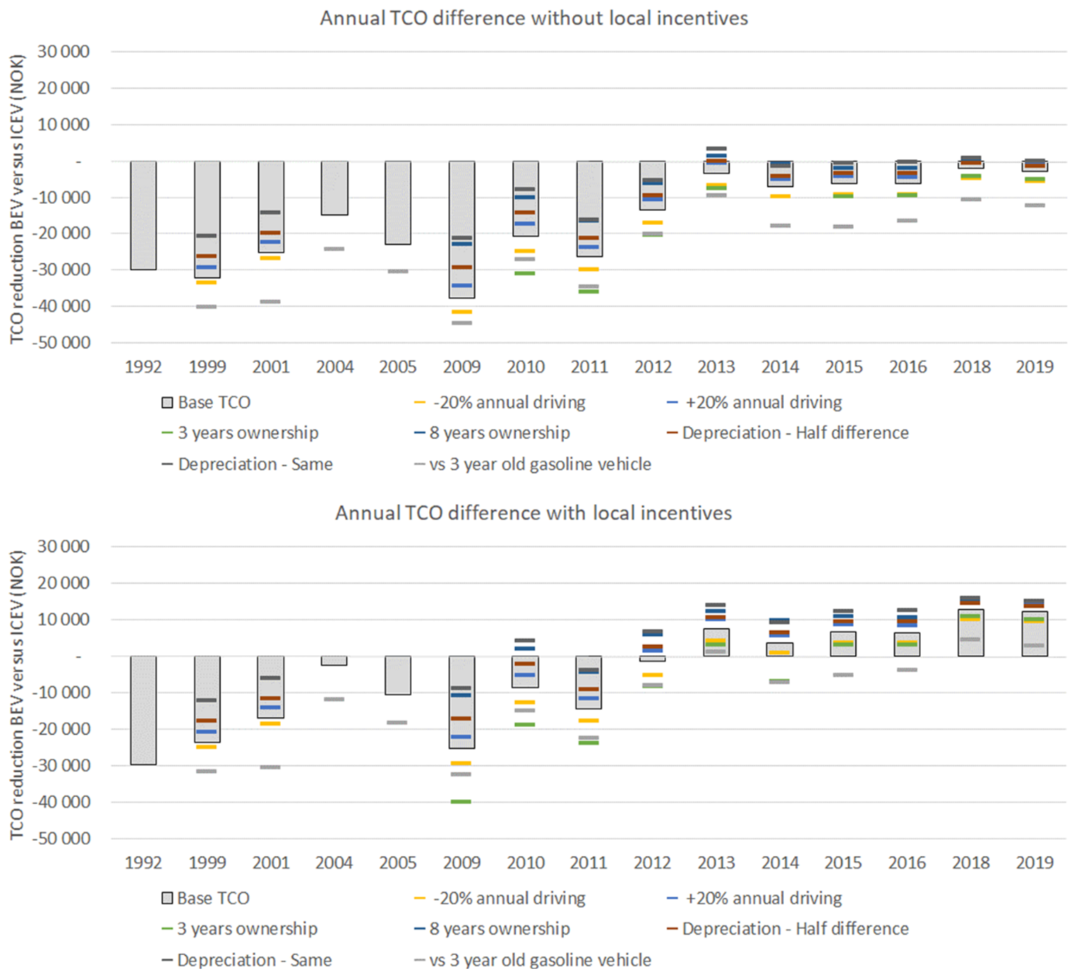

Fig. 8. No national incentives, i.e. full VAT, registration tax and annual tax on BEVs without local incentives (top) and with local incentives (bottom).

4.4. Scenario C – Without zero-rate VAT, other policies and taxes as has been

The zero rate VAT is the most controversial BEV incentive (VAT Expert Committee 2019). VAT applies to all purchased goods and services. Critics have questioned (Holtsmark and Skonhoft 2014) why BEVs are exempted while for instance bikes are not. Applying VAT to BEVs while keeping the annual tax exemption/reduction and registration tax exemption results in the situation seen in Fig. 9.

The 2001 THINKs TCO advantage would have been lost other than with an unrealistic depreciation rate and full local incentives. Too Ford, that bought THINK to get a compliance vehicle for California (THINK 2001), this might not have been a showstopper, but the production could without a local market in Norway easily been moved to a Ford facility.

A business case for importing the 2011 Mitsubishi I-Miev is difficult to see in this scenario. The TCO would have been unfavorable even with average local incentives. Yet, the price reduction between 2011 and 2012 was comparable to the value of the zero rate VAT, so the introduction might have been delayed only by a year. This is however uncertain as the price reduction was the result of market dynamics. The TCO with local incentives became advantageous from 2013, although 5000–10000 NOK less than in the original scenario. The TCO would have been marginally competitive compared to a 3-year old ICEVs from 2016 with local incentives, and from 2013 for other sensitivities. The diffusion among multi-vehicle households would have been much slower as second hand ICEVs would have had a lower TCO than new BEVs up to 2015. Users would then likely have been less enthusiastic about BEVs and diffusion more focused to areas with the highest local incentives.

4.5. Scenario D – No registration tax, full VAT and annual tax for BEVs and ICEVs

This scenario resembles the situation in EU countries without BEV incentives and has full VAT on the purchase of both ICEVs and BEVs, no registration tax, and the same annual tax for both. New BEVs would up to 2019 in this scenario not have reached TCO parity with new ICEVs without local incentives, as seen in Fig. 10. They would have been marginally competitive 2013–2016 with local incentives. The situation would have improved from 2018. When comparing with 3-year old ICEVs, new BEVs would not have been

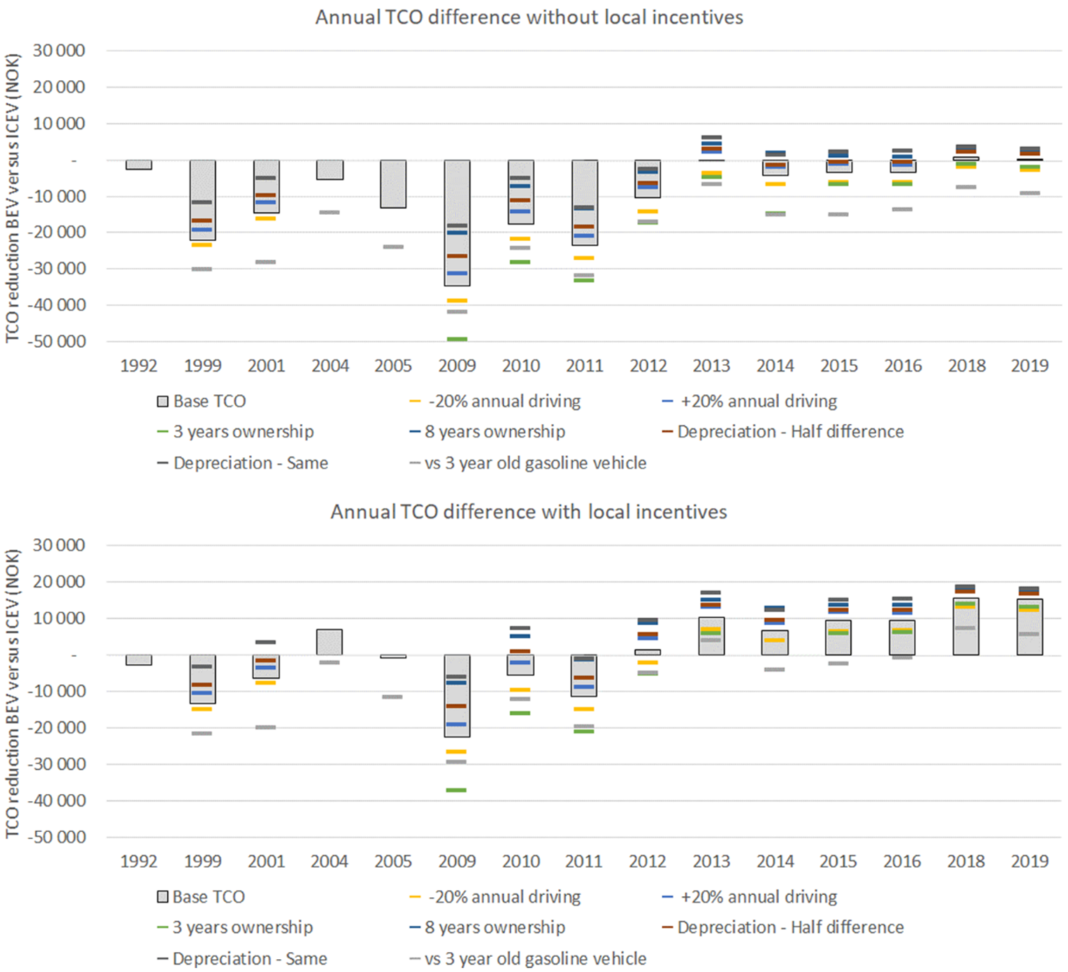

Fig. 9. Full VAT on BEVs but exemption from the registration tax and annual tax, without local incentives (top) and with local incentives (bottom).

favorable until 2018 with local incentives included. Shorter annual driving lengths or ownership periods would have made the BEV TCO unfavorable until 2016. BEV diffusion would therefore likely not have picked up speed until after 2016 in this scenario, and been similar to the diffusion in EU countries (ACEA 2015–2018) without significant BEV incentives.

4.6. TCO advantage for BEVs over ICEVs per county in 2016–2018

The 2018 TCO variation between counties has been calculated for the situation with all incentives as has been, with no national incentives, and without the zero-rate VAT respectively, as seen in Fig. 11. BEVs had a favorable TCO compared with new ICEVs in all Counties with national incentives and with and without local incentives, but also for the case even when VAT is applied to BEVs. Without any national incentives, the TCO would have been slightly worse than for new ICEVs in all Counties. The TCO was comparable to 3-year old ICEVs in most Counties with national incentives included and local incentives excluded, and beneficial with local incentives.

New BEVs TCO was advantageous in all counties regardless of local incentives compared to used ICEVs. The share of 2016 and 2018 BEV buyers that also had a TCO advantage over 3-year old ICEVs, is shown in Fig. 12 for each county together with the share of BEVs in the fleets. The fleet share of BEVs was the highest in the three urban counties were the highest share of users would have had a TCO benefit over 3-year old ICEVs with local incentives included, i.e. Oslo, Akershus and Hordaland. The fleet share was lowest in the counties with the lowest share of users with a TCO benefit, i.e. Sogn og Fjordane and Troms, and two rural counties with a higher value of incentives, but very cold winters and low population densities, i.e. Hedmark and Oppland. Between 2016 and 2018 the share with a TCO advantage over 3-year old ICEVs increased rapidly and passed 90% for the counties (Akershus/Oslo, Hordaland, Rogaland, Trøndelag, Vest-Agder, Østfold), with the largest cities (Oslo, Bergen, Trondheim, Stavanger, Kristiansand), populations and vehicle and BEV fleets.

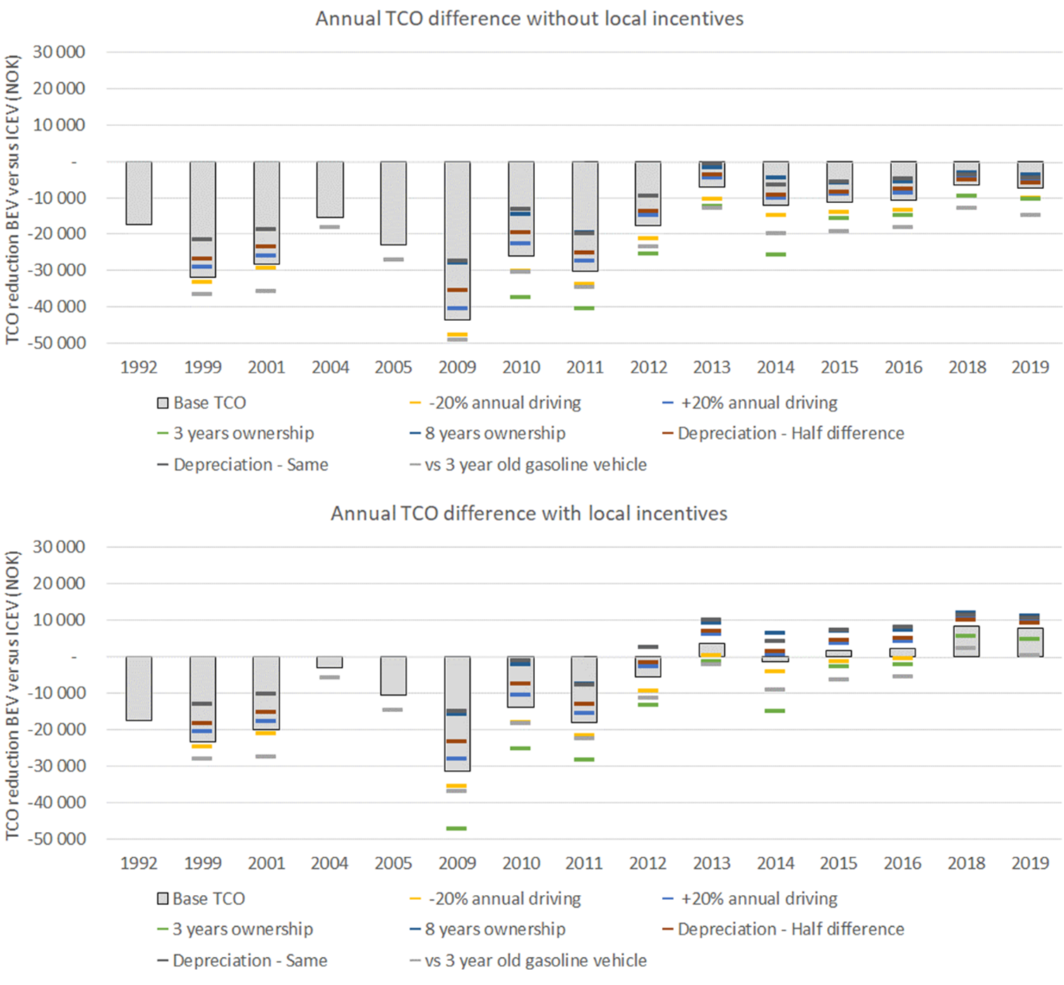

Fig. 10. Theoretical no BEV policy scenario without purchase incentives/taxes apart from a general VAT rate applied to all vehicles. BEVs and ICEVs have the same annual tax. Local incentives are estimated from user surveys (Asplan 2009, Figenbaum et al 2014, Figenbaum and Kolbenstvedt 2016, Figenbaum and Nordbakke 2019), earlier toll road fees, and own estimates.

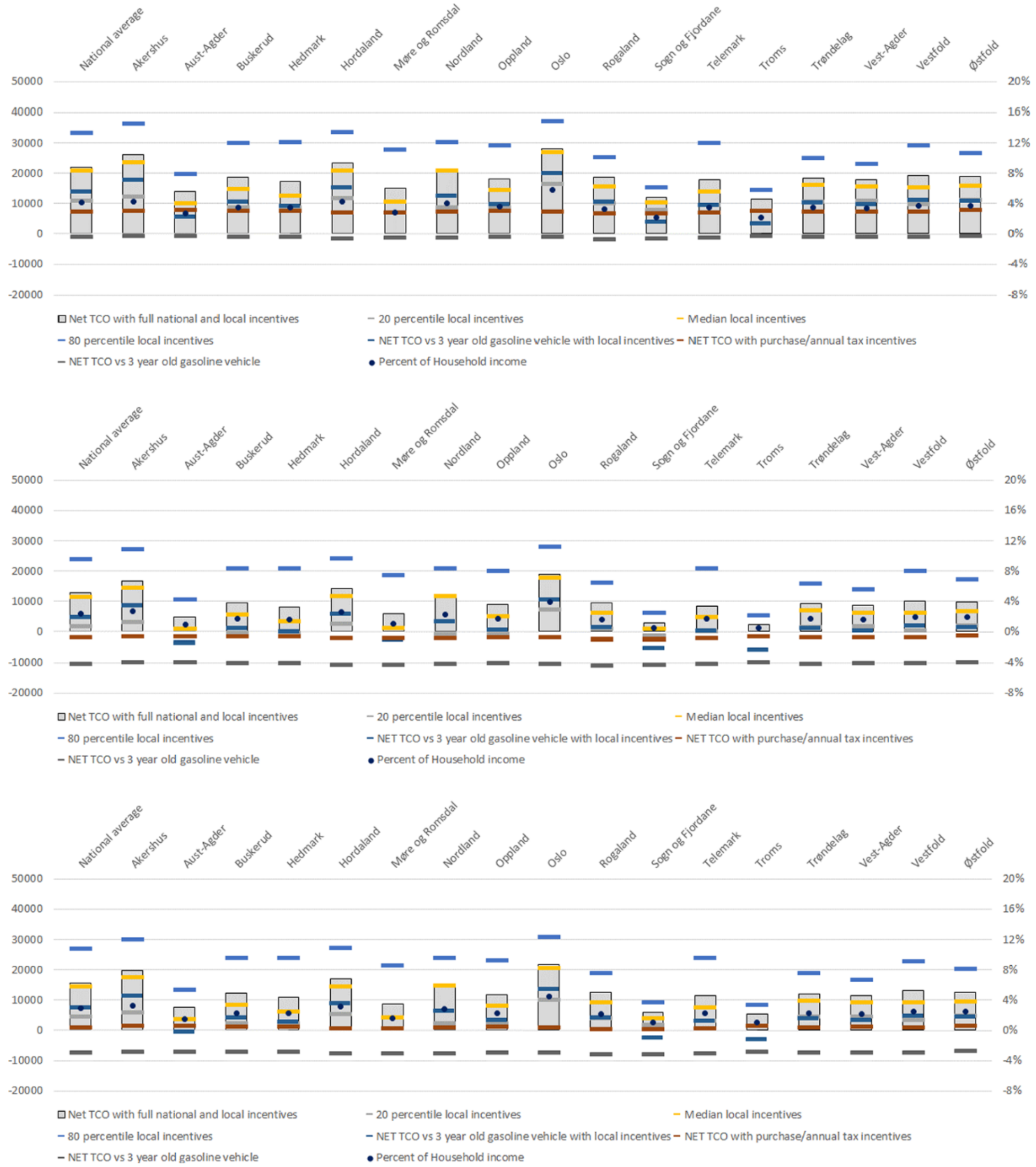

Fig. 11. 2018 TCO advantage of BEVs over ICEVs with all incentives (top), with no national incentives (middle), with all incentives apart from VAT exemption (Bottom).

4.7. TCO variation between users

For 2016 and 2018, the TCO advantage of new BEVs compared to new and 3-year old ICEVs was calculated, and in Fig. 13 arranged in increasing order of user value of local incentives derived from the surveys of Figenbaum and Kolbenstvedt (2016) and Figenbaum and Nordbakke (2018).

All national incentives are included. Buyers of new BEVs had in 2016 an advantage over buyers of new ICEVs of at least 3700 NOK/year, with an average and median value of respectively 17,100 NOK and 13,600 NOK per year. About two thirds also had a TCO advantage over 3 year-old ICEVs. From 2018 have all buyers had an advantage compared with 3 year-old ICEVs, and an advantage of at least 9600 NOK/year compared to new ICEVs with an average value of 24,800 NOK and a median value of 22,000 NOK.

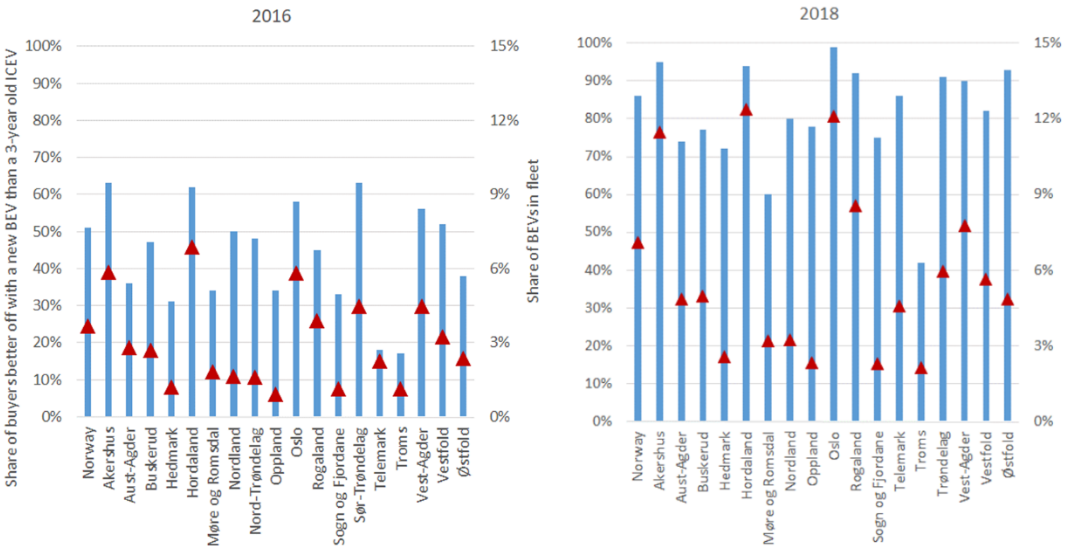

Fig. 12. The share of buyers per County with a lower TCO when buying a new BEV than a 3-year old ICEV (Blue bars), and the share of BEVs in the fleet (Red triangles) for 2016 and 2018. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

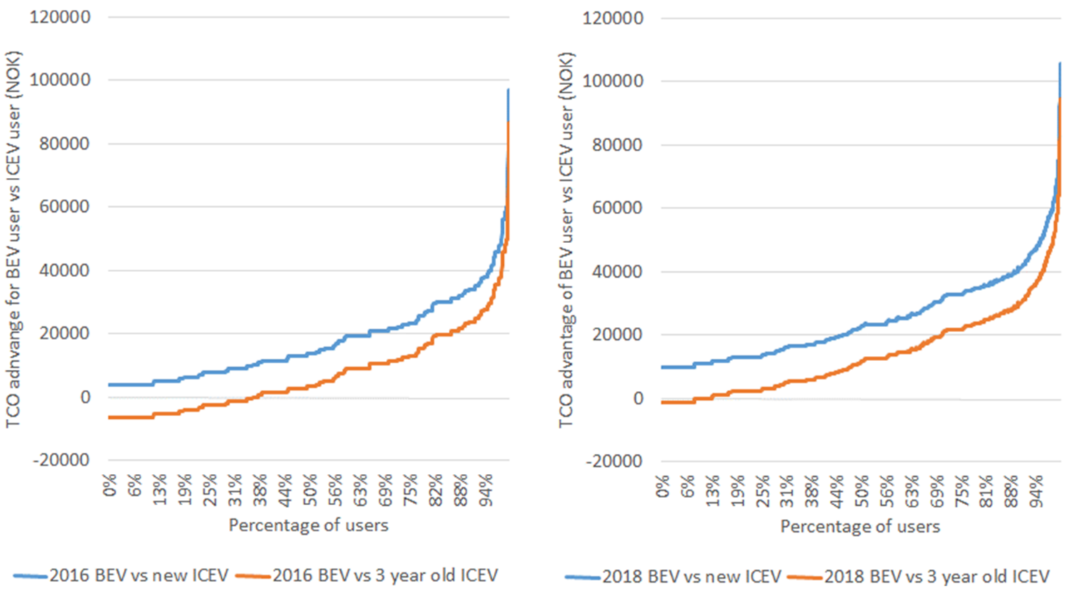

Fig. 13. Spread of BEV user TCO advantage due to variations in local incentive values between BEV owners, versus owners of new and 3 year-old ICEVs for 2016 (left) and 2018 (right). Local incentive values have been adapted from user surveys reported in Figenbaum and Kolbenstvedt (2016), Figenbaum and Nordbakke (2019). Time saving has been calculated as a cost saving using cost of time.

5. Discussion

5.1. *The development of the Norwegian BEV market*

The TCO difference was in 1992 low between the small and very basic BEV 2-seater with a range of only 20–45 km using lead-acid batteries, and the cheapest ICEV. The registration tax exemption reduced BEV prices from prohibitive to acceptable. There were no local incentives. The battery needed costly replacement every 0.5–2 years after the 2-year warranty period. The utility of this vehicle was however too low, and the battery life to uncertain to establish a real market, a situation that continued until 1999.

THINK/Ford came in 1999 with a longer range robust Ni-Cd battery 2-seater BEV. Economic conditions were favorable. Ford needed a BEV for California's ZEV-mandate, and expected only recovery of the variable production cost. THINK got access to Ford parts, production system, and technical standards. Quality improved, but the price was higher than the incentives that included toll road and parking fee exemptions from 1997 and 1999, could compensate for in the TCO. A positive TCO was only achievable with unrealistic mileages and residual values (Figenbaum 2021). The introduction of the 2001 zero rate VAT reduced prices by 20% and made the TCO almost competitive without local incentives and competitive with. BEVs could thus from 2001 have achieved a breakthrough had the Californian ZEV mandate not been changed in 2002, while THINK was switching production to a new model and had scrapped the tools for the old. Fords economic problems and technical issues with the new model, made Ford sell THINK. The buyer had by 2006 used up the dowry Ford had provided when selling THINK and went bankrupt without producing BEVs. The BEV breakthrough was potentially delayed by a decade.

Second hand import of BEVs from France and other countries that abandoned BEVs kept the market alive. Buyers were users of toll roads and bus lanes that had opened for BEVs from 2003. A small Norwegian production of the Kewet/Buddy Quadricycle supported this market from 2005. The BEV fleet, interest and competences grew slowly in this period when other countries interest in BEVs had vanished.

Norwegian investors restarted THINK in 2006. The 2008–2010 THINK model had Li-Ion batteries, double range of the previous model, but no fast charge capability. The price had to reflect all costs including development, and was high as Li-Ion batteries before 2010 cost over 1000 USD/kWh (2019 USD), compared to only 100–150 USD in 2020. The battery warranty covered only 3 years, so battery life was an issue for consumers. THINK was mainly attractive to extreme bus lane and toll road users. A new Buddy Quadricycle was also available from 2009. The 2009 financial crisis led to funding issues and frequent production halts, and the production ended for both actors in late 2010. They could both with continued funding have benefitted from later Li-Ion battery cost reductions and a Norwegian BEV industry could have existed today. OEMs that had developed BEVs in-house took over the market instead.

The 2011–2012 Mitsubishi I-Miev and Peugeot/Citroën siblings became popular, having four seats, 80–130 km range, fast charge capability, 5 years/100000 km battery warranty, and access to all existing incentives. They were marginally TCO competitive with ICEVs when all incentives were included. The prices were reduced 2012–2013 to remain competitive with the larger Nissan Leaf, which led to unexpected high depreciation rates for 2011 buyers. They could however at the time of purchase reasonably have expected an 8-year life but with a very low residual value. The TCO has been fully competitive since 2012.

By 2015 the prices had fallen so much that BEVs had the lowest TCO with and without local incentives in all sizes. A 160000 km/8-year battery warranty removed remaining battery life concerns. Fast chargers around major cities reduced range anxiety and supported local and regional driving. This situation was reinforced up to 2019. BEV prices decreased and the energy cost saving increased with higher gasoline prices. Depreciation rates became closer to ICEV rates and were higher than in other countries as buyers of used BEVs got immediate access to all local incentives. The 2019 VW E-up got double range and was more of a general purpose vehicle.

BEVs TCO was beneficial compared both to new and 3-year old ICEVs from 2012, and thus available to multi vehicle owning families that previously bought used ICEVs as secondary vehicles. They easily coped with and utilized the limited range, and had an ICEV available for long distance driving. Local incentives spread BEVs across Norway. BEVs had from 2014 a positive image in the population. The share of BEV owning single vehicle households increased when long range reasonably priced BEVs became available and a fast charger network had been built along all major roads. Households have since 2015 used 3–4% less of their disposable income when buying a BEV than an ICEV. The extent to which consumers take TCO fully into account when buying vehicles is however uncertain. Norwegian user surveys points to costs being the most important adoption parameter, and thus TCO to be a relevant indicator of BEVs market potential.

Home charging access has not been a big issue in Norway but may be more important elsewhere. In the early years BEVs were charged from existing outdoor domestic sockets. It is estimated that over 80% of households already have such sockets available or can establish charging access. The remaining, of which vehicle ownership in general is rarer, must use public chargers, workplace chargers or fast chargers. User surveys shows that over 90% of current owners can charge at home, and they increasingly invest in stable charging solutions with wall-boxes with built in safety features.

Coming back to the research questions it can be concluded that the TCO was not sufficiently attractive up to 2010. The limited vehicle supply and the short range combined with no fast charge capability were other large barriers. Poor quality was an additional barrier up to 1998. Exogenous factors such as the revision of the Californian ZEV mandate in 2001, and Fords economic problems and technical issues at THINK, ruined a potential breakthrough from 2001. The rapid diffusion of BEVs after 2011 has been due to the large package of incentives that has led to a beneficial TCO compared with new ICEVs, and from 2012 to 2013 also compared to 3-year old ICEVs. The latter unlocked a huge potential in multi-vehicle households that could easily cope with the limited range when buying new BEV as their secondary vehicle instead of a used ICEV. BEVs thus got a good reputation as a transport solution. The TCO advantage and market shares scaled with decreasing production costs. BEV adoption for primary vehicle use increased from 2017 to 2018 when reasonable long range BEVs emerged and was supported by a coherent network of fast chargers.

5.2. Policy insights

The Norwegian BEV policy has provided a stable platform for market experimentation and knowledge accumulation over time. The interest was kept up and the fleet expanded also in periods when other countries abandoned BEVs. A larger rollout was however not possible until the technology met basic user needs, vehicles became available in larger volumes, and the TCO became favorable aided by purchase incentives and local user privileges. Incentive costs were low when they were introduced and the following years so it cost little to leave them in place. They were gradually institutionalized and the reasoning behind them shifted from market experimentation, via industrialization and job creation to becoming an integral part of the climate policy.

A robust policy framework was in place when the OEMs launched their BEVs from 2011 with immediate and enduring success.

BEVs TCO advantage and market shares scaled with decreasing BEV production costs. The Government tax income loss increased but this was not critical as oil production income balances the national budgets. The national budget for 2020 was for instance balanced with 243 billion NOK oil income (Ministry of Finance 2019) whereas the tax exemptions for BEVs were estimated to have a value of 11.6 Billion NOK plus about 8 billion NOK loss from the zero rate VAT.

A form of policy lock-in developed, were the BEV incentives are difficult to change because they are vital for the market, has become institutionalized, and are an integral part of meeting Norway's Paris climate agreement obligations. The incentives are also vigorously fought for by auto sector actors in liaison with NGOs such as the EVA. Another pitfall that other countries should be aware of is "policy creep", i.e. that targets are revised upwards when old targets are met instead of incentives being reduced. These issues are not necessarily a problem. The climate crisis requires urgent actions and electrification of the transport sector will be very important for Norway.

The VAT exemption scales with different vehicle sizes and is more neutral than the exemption from the registration tax which value increase progressively with the taxed ICEVs weight and CO_2-emission. Norway has demonstrated that local incentives can be efficient market drivers without impacting Governmental tax income. The bus lane access allocated available road capacity to BEV owners at no cost to others initially. Access restrictions had later to be introduced in the rush hours to avoid delaying buses. The exemption/ reduction from road tolls lead to longer collection periods or higher ICEVs fees to pay down the toll road companies loans. It is thus a cross-subsidy between ICEV and BEV owners that can be difficult to keep in place when the BEV share of the fleet increases.

Policies that are introduced now and make the TCO competitive, will have an immediate market impact due to the unlimited supply of attractive BEVs for a variety of users. Incentives should therefore be designed to scale well with increasing volumes, such as the bonus/malus systems in France and Sweden, were ICEV buyer's malus subsidized BEV buyer's bonus without influencing the Governments tax income.

Technology bans like EUs 2005 ban on Cadmium can have unintended consequences. That ban combined with other factors delayed the BEV breakthrough potentially by a decade as no other battery alternative was available with acceptable cost and quality in the early 2000 s. This had environmental implication for polluted cities that had to wait longer for ZEVs to make an impact on local air pollution. California's 2002 ZEV mandate revision had repercussions across the globe as the mandate had been the main driver for OEMs BEV development.

5.3. TCO as a retrospective method

Using the TCO method retrospectively brought new insights into how the Norwegian BEV market evolved. The point of the retrospective analysis was to find out what users could have expected the TCO to be when buying the vehicle. Defining the right level of residual values and interest rates was a particular challenge. Should the revealed achieved values be used or the values reasonably assumed when buying the vehicle? This article has attempted the latter. The article uses for the same reason the interest rate of the year the vehicle was purchased for the whole ownership period. The real achieved TCO of users could thus have deviated from what was calculated in this article.

A TCO advantage is in itself not enough to get the diffusion going. Barriers such as a lack of home charging, user disadvantages in terms of range or charge speed, lack of model variety, and residual value uncertainty are not captured in the TCO. These additional factors must to be taken into account to fully understand how the market developed and when it failed in spite of an advantageous TCO. The average range of new BEVs has doubled to tripled since 2011, unlocking new use areas without impacting the TCO. Uncertainty about second hand value and battery life has been reduced through experience, which again led to higher residual values. The calculations pinpoints windows of opportunities in 2001 and 2010 with almost neutral TCO. Specific external factors, such as policy changes in other countries, explains why they could not be exploited.

5.4. Uncertainties

The nominal vehicle prices have been used in the calculation and it does not take into account variations in the level of equipment. The cheapest ICEV in the lowest trim level which was most comparable to a BEV may not have been a version that dealers sold many of. If the registration tax had applied to BEVs the peak power or the continuous power could have been used. In this article, peak power is used. Savings in service and repair costs and insurance will only influence purchase behavior if consumers know about them. The difference in these costs calculated for 2020 has been used backwards in time due to lack of data, as it is known from news articles that lower costs for these items for BEVs have been discussed before 2019, although little information is available. In 2019, the first indications of a higher insurance price for BEVs emerged, but data collected by OFV AS shows that this issue is related to large BEVs, not the mini BEVs used in the calculations in this article. The regional calculation does not include differentiation of insurance costs. Regional insurance cost differences would likely have affected BEVs and ICEVs the same, with low impact on the TCO difference.

6. Conclusion

The retrospective TCO analysis provided new insights into the functioning of the BEV market, but the TCO can only be an indicator of the economic viability of adoption. Factors outside Norway halted BEV adoption periodically even when the TCO was marginally favorable. BEVs were limited available up to 2010. The exemption from the registration tax from 1990 reduced the TCO disadvantage of BEVs enough to enable market experiments. Further incentives and the zero rate for VAT from 2001 made the TCO marginally competitive when Ford owned THINK. A breakthrough seemed possible with Fords vast resources available to THINK. The opportunity was lost when negative internal and external factors aligned to make Ford sell THINK in 2002, which ended THINKs production endevour. A global BEV downturn enabled import of second hand BEVs to users of the bus lanes from 2003, and kept the Norwegian market alive. In 2009, THINK was back but with an unfavorable TCO due to the high cost of Li-Ion batteries. THINK lost funding due to the 2009/2010 financial crisis and production ended for good end of 2010.

The earlier BEV supply constraints were lifted when OEMs took over from 2011. The TCO has been favorable compared to new and 3-year old ICEVs since 2012, and made BEVs available to multi-vehicle households that used to buy second hand ICEVs as secondary vehicles. They could easily cope with the limited range, enjoyed large local incentives, and BEVs got a good reputation. The market became very competitive and grew rapidly with vehicles finally matching user needs and ability at acceptable prices and an advantageous TCO due to the incentives.

Norway has been able to balance loss of tax income from BEV incentives with income from the oil sector. Other countries can establish incentives that are cost neutral to national finances, for instance bonus/malus systems and similar local incentives as in Norway. A competitive TCO will not make new technologies succeed unless basic needs are met, and sufficient supply is available. Policy makers should adapt targets and policies, as markets and technologies develop and external conditions change.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This article has been written as part of the ELAN project with funding from the Research Council of Norway (grant number 267848).

References

Abotalebi, E., Scott, M.D., Ferguson, M.R., 2019. Can Canadian households benefit economically from purchasing battery electric vehicles? Transp. Res. Part D 77 (2019), 292–302. https://doi.org/10.1016/j.trd.2019.10.014.

ABCnyheter 2019 (news article, in Norwegian). Elbiler krasjer langt oftere enn andre elbiler. ABCnyheter.no 19. Mar. 2019. https://www.abcnyheter.no/motor/bil/2019/03/19/195562517/elbiler-krasjer-langt-oftere-enn-andre-biler.

ACEA 2015-2018. BEV registration statistics for Europe 2015-2018. Downloaded from: https://www.acea.auto/fuel-pc/fuel-types-of-new-cars-battery-electric-5-7-hybrid-18-4-petrol-42-2-market-share-in-q1-2021/.

Aftenposten 2001 (news article, in Norwegian). Kl. 24.00 natt til søndag innføres den store momsreformen i Norge. Den vil gi 24 prosent moms på tjenester. Og halv matmoms. Tiden vil vise om moms-bråket fortsetter for finansminister Karl Eirik Schjøtt-Pedersen. Momsfri gøy på fire hjul. Aftenposten 28.06.2001. Accessed through the Retriever news archive service 18. Aug. 2021.

Akershus Amtstidende 2007 (news article, in Norwegian). Forbi Strømmen med El-bil. Akershus Amtstidende 24.05.2007. Accessed through the Retriever News archive service 21.06.2021.

Al-Alawi, B.M., Bradley, T.H., 2013. Total cost of ownership, payback, and consumer preference modeling of plug-in hybrid electric vehicles. Appl. Energy 103, 488–506. https://doi.org/10.1016/j.apenergy.2012.10.009.

Asphjell, A., Asphjell, Ø., Kvisle, H. H. 2013. Elbil på norsk. Book (in Norwegian). ISBN 978-82-7704-142-1. Transnova.

Asplan Viak 2009 (in Norwegian). SPØRREUNDERSØKELSE OM BRUK AV OG HOLDNINGER TIL ELBILER I NORSKE STORBYER. Asplan Viak NOTAT, 2009-12-14.

Autodata 2021. Technical data for gasoline vehicles. Retrieved 03.06.2021. 1989 Fiat UNO (146A) 1.1 (57 Hp) | Technical specs, data, fuel consumption, Dimensions (auto-data.net), 2004 Kia Picanto I 1.1i 12V (64 Hp) | Technical specs, data, fuel consumption, Dimensions (auto-data.net), 2011 Kia Picanto II 5D 1.2 16V (85 Hp) automatic | Technical specs, data, fuel consumption, Dimensions (auto-data.net), 2012 Volkswagen Up! 1.0 (60 Hp) | Technical specs, data, fuel consumption, Dimensions (auto-data.net).

Benardos, A., Sourouvali, N., Mavrikos, A., 2021. Measuring and benchmarking the benefits of Athens metro extension using an ex-post cost benefit analysis. Tunn. Undergr. Space Technol. 111 (2021), 103859 https://doi.org/10.1016/j.tust.2021.103859.

Bjerkan, K.Y., Nørbech, T.E., Nordtømme, M.E., 2016. Incentives for promoting Battery Electric Vehicle (BEV) adoption in Norway. Transp. Res. Part D 43, 169–180.

BloombergNEF 2020. https://about.bnef.com/blog/battery-pack-prices-cited-below-100-kwh-for-the-first-time-in-2020-while-market-average-sits-at-137-kwh/.

Breetz, H.L., Salon, D., 2018. Do electric vehicles need subsidies? Ownership costs for conventional, hybrid, and electric vehicles in 14 U.S. cities. Energy Policy 120, 238–249.

Bubeck, S., Tomaschek, J., Fahl, U., 2016. Perspectives of electric mobility: Total cost of ownership of electric vehicles in Germany. Transp. Policy 50 (2016), 63–77. https://doi.org/10.1016/j.tranpol.2016.05.012.

Christiansen P., Engebretsen Ø., Hanssen J. U. 2015. Parkeringstilbud ved bolig og arbeidsplass. Fordelingsffekter på bilbruk og bilhold i byer og bydeler. TØI rapport 1425/2015. Accessed 10. Jan. 2022 from: https://www.toi.no/publikasjoner/parkeringstilbud-ved-bolig-og-arbeidsplass-fordelingsffekter-pa-bilbruk-og-bilhold-i-byer-og-bydeler-article33506-8.html.

Climate policy settlement 2012. Stortinget. Innst. 390 S (2011–2012) Innstilling til Stortinget fra energi- og miljøkomiteen Meld. St. 21 (2011–2012).

CNN 2002. Ford cutting 35,000 jobs. CNN news article January 11 2002. Accessed 23. August 2021. https://money.cnn.com/2002/01/11/companies/ford /.

Danielis, R., Giansoldati, M., Rotaris, L., 2018. A probabilistic total cost of ownership model to evaluate the current and future prospects of electric cars uptake in Italy. Energy Policy 119 (2018), 268–281. https://doi.org/10.1016/j.enpol.2018.04.024.

De Clerck, Q., van Lier, T., Messagie, M., Macharis, C., Van Mierlo, J., Vanhaverbeke, L., 2018. Total Cost for Society: A persona-based analysis of electric and conventional vehicles. Transp. Res. Part D 4 (2018), 90–110.

DN 2014 (news article, in Norwegian). Elbilister klager på service utgiftene. DN 19.08.2014. https://www.dn.no/motor/bmw/renault/ford/elbilister-klager-pa-service-utgiftene/1-1-5173354.

Drivkraft Norge. Statistics on fossil fuel prices and taxes downloaded 27.10.2021. from: https://www.drivkraftnorge.no/Tall-og-fakta/prisstatistikk/.

Dumortier, J., Siddiki, S., Carley, S., Cisney, J., Krause, R.M., Lane, B.W., Rupp, J.A., Graham, J.D., 2015. Effects of providing total cost of ownership information on consumers' intent to purchase a hybrid or plug-in electric vehicle. Transp. Res. Part A 72, 71–86. https://doi.org/10.1016/j.tra.2014.12.005.

E24 2015 (news article, in Norwegian). Slik får du batteriet i elbilen til å vare. E24. 15. May 2015. https://www.tu.no/artikler/slik-far-du-batteriet-i-elbilen-til-a-vare/196965.

ECON 2006 (in Norwegian). Elbileiernes reisevaner. ECON Analyse. Rapport 2006-040.

Elbil24 2018 (in Norwegian). Er elbilen dyrere i drift enn fossilbilen? Elbil24 03.12.2018. https://www.elbil24.no/nyheter/er-elbilen-dyrere-i-drift-enn-fossilbilen/70452432.
Elbil24 2019 (newsarticle, in Norwegian). Derfor setter forsikringsselskapene opp elbil-prisene. Elbil24.no 20. Jul. 2019. https://www.elbil24.no/nyheter/derfor-setter-forsikringsselskapene-opp-elbil-prisene/71386655.
Elbil.no 2021. Characteristics, technical data and Norwegian battery warranties of available and older BEV models. www.elbil.no. https://elbil.no/om-elbil/elbiler-idag/.
Elbil.no 2014 (news article, in Norwegian). Dette mener importørene om servicepris på elbil. www.elbil.no. https://elbil.no/dette-mener-importorene-om-servicepris-pa-elbil/.
Elbilisten 2020. File received from the EV Assocation with 2020 results from the annual EV Association user survey: "Elbilisten".
Elbilisten 2021. Data from the annual EV Association user survey as reported in (newsarticle in Norwegian): Elbilisten 2021: De fleste av oss velger elbil av økonomiske årsaker. https://elbil.no/elbilisten-2021-de-fleste-av-oss-velger-elbil-av-okonomiske-arsaker/.
EU Commission 2002. Commission decision of 27 June 2002, mending Annex II of Directive 2000/53/EC of the European Parliament and of the Council on end-of-life vehicles (Text with EEA relevance) (notified under document number C(2002) 2238). (2002/525/EC). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32002D0525.
Fearnley, N., Pfaffenbichler, P., Figenbaum, E., Jellinek, R. (2015). E-vehicle policies and incentives - assessment and recommendations. TØI-rapport 1421/2015. Oslo: Transportøkonomisk institutt. https://www.toi.no/publications/e-vehicle-policies-and-incentives-assessment-and-recommendations-article33367-29.html.
Figenbaum 2021. Personal information obtained as an employee of Think Nordic 1998-2003.
Figenbaum E., Thorne, R. J., Amundsen A. H., Pinchasik D. R., Fridstrøm L, 2020. From Market Penetration to Vehicle Scrappage. The Movement of Li-Ion Batteries through the Norwegian Transport Sector. TOI report 1756/2020 forthcoming. Institute of Transport Economics.
Figenbaum E., Ydersbond I.M., Amundsen A. H., Pinchasik D. R., Thorne, R. J., Fridstrøm L., Kolbenstvedt M. 2019. 360 graders analyse av potensialet for nullutslippskjøretøy (in Norwegian). TØI report 1744/2019. https://www.toi.no/publikasjoner/360-graders-analyse-av-potensialet-for-nullutslippskjoretoy-article35999-8.html.
Figenbaum E. 2020a. Norway the world leader in BEV adoption. Book chapter in „Who's driving electric cars. Understanding Consumer Adoption and Use of Plug-in Electric Cars". Springer Nature 2020. https://link.springer.com/book/10.1007/978-3-030-38382-4#about.
Figenbaum E. 2019. Charging into the future. Analysis of fast charger usage. TØI report 1682/2019. Institute of Transport Economics. https://www.toi.no/publications/charging-into-the-future-analysis-of-fast-charger-usage-article35355-29.html.
Figenbaum E. 2020b. Fast Charging – Evidence from the Norwegian Market. World Electric Vehicle Journal 2020, 11(2), 38; https://doi.org/10.3390/wevj11020038.
Figenbaum, E., 2017. Perspectives on Norway's supercharged electric vehicle policy. Environm. Innov. Societal Trans. 25, 14–34.
Figenbaum, E., Kolbenstvedt, M. (2016). Learning from Norwegian Battery Electric and Plug-in Hybrid Vehicle users. Results from a survey of vehicle owners. TØI report 1492/2016. Institute of Transport Economics. https://www.toi.no/publications/learning-from-norwegian-battery-electric-and-plug-in-hybrid-vehicle-users-results-from-a-survey-of-vehicle-owners-article33869-29.html.
Figenbaum, E. 2018. Electromobility status in Norway: Mastering long distances – the last hurdle to mass adoption. TØI-rapport 1627/2018. Oslo: Transportøkonomisk institutt.
Figenbaum, E., Kolbenstvedt, M. (2015). Competitive Electric Town Transport. Main results from COMPETT – an Electromobility+ project. Institute of Transport Economics. Report 1422/2015. https://www.toi.no/publications/competitive-electric-town-transport-main-results-from-compett-and-electromobility-project-article33368-29.html https://www.toi.no/publikasjoner/competitive-electric-town-transport-hovedresultater-fra-compett-et-electromobility-prosjektt-article33366-8.html.
Figenbaum, E., Assum, T., Kolbenstvedt, M., 2015. Electromobility in Norway: Experiences and Opportunities. Res. Transport. Econom. 50, 29–38.
Figenbaum, E., Kolbenstvedt, M., Elvebakk, B. 2014. Electric vehicles – environmental, economic and practical aspects. As seen by current and potential users. Institute of Transport Economics. Report 1329/2014. https://www.toi.no/publications/electric-vehicles-environmental-economic-and-practical-aspects-as-seen-by-current-and-potential-users-article32644-29.html.
Figenbaum E., Nordbakke S. 2019. Battery electric vehicle user experiences in Norway's maturing market. TØI report 1719/2019. https://www.toi.no/publications/battery-electric-vehicle-user-experiences-in-norway-s-maturing-market-article35709-29.html?deviceAdjustmentDone=1.
Figenbaum, E. 1998. TH!NK, a Unique Citycar. Electric & Hybrid Vehicle Technology 98. UK & International Press 1998.
Figenbaum, E. 1995. Norwegian Experience. Electric & Hybrid Vehicle Technology 95. UK & International Press 1995.Figenbaum, E. 1994. Testprogram for elbiler – Elbiler i Norge – Brukererfaringer. Rapport. Teknologisk Institutt.
Flügel S., Halse A. H., Hulleberg N., Jordbakke G. N., Veisten K., Sundfør H. B., Kouwenhoven M. 2020 (in Norwegian). Verdsetting av reisetid og tidsavhengige faktorer. TØI rapport 1762/2020. https://www.toi.no/publikasjoner/verdsetting-av-reisetid-og-tidsavhengige-faktorer-dokumentasjonsrapport-til-verdsettingsstudien-2018-2019-article36266-8.html.
Fridstrøm, L., Østli, V., Johansen, K.W., 2016. A stock-flow cohort model of the national car fleet. European Transport Research Review 8 (3), 22.
Fridstrøm, L., & Østli, V. (2018). Etterspørselen etter nye personbiler analysert ved hjelp av modellen BIG (in Norwegian). TØI-rapport 1665/2018. Oslo: Transportøkonomisk institutt. Available from: https://www.toi.no/publikasjoner/ettersporselen-etter-nye-personbiler-analysert-ved-hjelp-av-modellen-big-article35208-8.html.
Fridstrøm, L., Østli, V., 2017. The vehicle purchase tax as a climate policy instrument. Transp. Res. Part A 96 (2017), 168–189. https://doi.org/10.1016/j.tra.2016.12.011.
Geels, F.W., 2012. A socio-technical analysis of low-carbon transitions: introducing the multi-level perspective into transport studies. J. Trans. Geogr. 24 (2012), 471–482.
Hagman, J., Ritzén, S., Janhager, S.J., Susilo, Y., 2016. Total cost of ownership and its potential implications for battery electric vehicle diffusion. Res. Transport. Bus. Manage. 18 (2016), 11–17. https://doi.org/10.1016/j.rtbm.2016.01.003.
Hao, X., Lin, Z., Wang, H., Ou, S., Ouang, M., 2020. Range cost-effectiveness of plug-in electric vehicle for heterogeneous consumers: An expanded total ownership cost approach. Appl. Energy 275 (2020), 115394.
Hardman, S., 2019. Understanding the impact of reoccurring and non-financial incentives on plug-in electric vehicle adoption – A review. Transport. Res. Part A Policy Pract. 119, 1–14.
Hardman, S., Turrentine, T., Daina, N., Figenbaum, E., Garas, D., Jochem, P., Karlsson, S., Naberezhnykh, D., Pontes, J., Refa, N., Sovacool, B., Sprei, F. & Tal, G. (2018). Driving the Market for Plug-in Vehicles – Understanding Reoccuring Incentives. UC Davis/International EV Policy Council. Policy Guide. March 2018. https://phev.ucdavis.edu/wp-content/uploads/2017/10/Reocurring-Incentives-Policy-Guide-No-CW-Logo.pdf.
Holtsmark, B., Skonhoft, A., 2014. The Norwegian support and subsidy policy of electric cars. Should it be adopted by other countries? Environ. Sci. Policy 42, 160–168.
ICCT 2018. From Laboratory to Road. A 2018 update of official and "real-world" fuel consumption and CO2 values for passenger cars in Europe. The International Council on Clean Transportation (ICCT). White Paper January 2011.
IEAHEV 2021. Annual report 2021. www.ieahev.org. Forthcoming.
Insidevs 2021. Article. Hyundai Ioniq 5 Amazes: Real Fast Charging Session Data Analyzed. Insidevs 26.04.2021. https://insideevs.com/news/503522/hyundai-ioniq5-fast-charging-analysis/.
Letmathe, P., Suares, M., 2020. Understanding the impact that potential driving bans on conventional vehicles and the total cost of ownership have on electric vehicle choice in Germany. Sustain. Futures 2 (2020), 100018. https://doi.org/10.1016/j.sftr.2020.100018.
Levay, P.Z., Drossinos, Y., Thiel, C., 2017. The effect of fiscal incentives on market penetration of electric vehicles: A pairwise comparison of total cost of ownership. Energy Policy 105 (2017), 524–533. https://doi.org/10.1016/j.enpol.2017.02.054.
Li, J., Liang, M., Cheng, W., Wang, S., 2021. Life cycle cost of conventional, battery electric, and fuel cell electric vehicles considering traffic and environmental policies in China. Int. J. Hydrogen Energy 46 (2021), 9553–9566. https://doi.org/10.1016/j.ijhydene.2020.12.100.

Muratori, M., Alexander, M., Arent, D., Bazilian, M., Cazzola, P., Dede, E.M., Farrell, J., Gearhart, C., Greene, D., Jenn, A., Keyser, M., Lipman, T., Narumanchi, S., Pesaran, A., Sioshansi, R., Suomalainen, E., Tal, G., Walkowicz, K., Ward, J., 2021. The rise of electric vehicles—2020 status and future expectations. Prog. Energy 3 (2), 022002. https://doi.org/10.1088/2516-1083/abe0ad.
Ministry of Finance 1989-2019 (in Norwegian). Norwegian Ministry of Finance: National annual budget documents (in Norwegian) for 1989, 1992, 1999, 2001, 2004-2005, 2009-2016, 2018-2019.
Mitropoulos, L.K., Prevedouros, P.D., Kopelias, P., 2017. Total cost of ownership and externalities of conventional, hybrid and electric vehicle. Transp. Res. Procedia 24, 267–274.
Moon, S., Lee, D.-J., 2019. An optimal electric vehicle investment model for consumers using total cost of ownership: A real option approach. Appl. Energy 253 (2019), 113494.
Morrison, G., Stevens, J., Joseck, F., 2018. Relative economic competitiveness of light-duty battery electric and fuel cell electric vehicles. Transp. Res. Part C 87 (2018), 183–196. https://doi.org/10.1016/j.trc.2018.01.005.
Motor 2019a (in Norwegian). Så mye koster de verste elbilskadene. Motor 12.07.2019. https://motor.no/bilhold-forsikring/sa-mye-koster-de-verste-elbilskadene/112439.
Motor 2019b (in Norwegian). Dobler forsikringsprisene på elbiler. Motor 10.07.2019. https://motor.no/bilhold-elbil-forsikring/dobler-forsikringsprisene-pa-elbiler/112400.
Motor 2019c (in Norwegian). Så mye oftere krasjer elbilsjåfører. Motor 11.07.2019. https://motor.no/bilhold-forsikring/sa-mye-oftere-krasjer-elbil-sjaforer/112428.
MotorEU 2021. Retrieved 03.06.2021. Kia Picanto 1.1 (65 hp) 2009-2011 MPG, WLTP, Fuel consumption (motoreu.com).
NOU 2004:8 (Official Norwegian Report, in Norwegian). Differensiert el-avgift for husholdninger. Utredning fra et utvalg oppnevnt av Finansdepartementet 26. september 2003. Avgitt 30. mars 2004.
NOU 1998:11 (Official Norwegian Report, in Norwegian). Energi- og kraftbalansen mot 2020. Utredning fra et utvalg oppnevnt ved kongelig resolusjon 16. april 1997. Avgitt til Olje. og energidepartementet 3. juli 1998.
NYtimes 2002. Ford abandons venture in making electric cars. New York Times Aug. 31. 2002. Accessed 17.08.2021. https://www.nytimes.com/2002/08/31/business/ford-abandons-venture-in-making-electric-cars.html.
OFVAS 2021 (in Norwegian. Bilsalget i desember 2020. OFVAS. https://ofv.no/bilsalget/bilsalget-i-desember-2020.
OFVAS 2020 (in Norwegian). Kostnader ved bilhold - eksempler på beregning 2020 (Cost of owning and using vehicles – examples for 2020). Opplysningsrådet for Vegtrafikken January 2020. www.ofvas.no.
OFVAS 1994-2020. Vehicle price lists downloaded from: https://www.skatteetaten.no/satser/bilpriser-listepris-som-ny/.
Ouyang, D., Zhou, S., Ou, X., 2021. The total cost of electric vehicle ownership: A consumer-oriented study of China's post-subsidy era. Energy Policy 149 (2021), 112023. https://doi.org/10.1016/j.enpol.2020.112023.
Palmer, K., Tate, J.E., Wadud, Z., Nellthorp, J., 2018. Total cost of ownership and market share for hybrid and electric vehicles in the UK US and Japan. Appl. Energy 209 (2018), 108–119. https://doi.org/10.1016/j.apenergy.2017.10.089.
Parker, N., Breetz, H.L., Salon, D., Wiggington, C.M., Williams, J., Patterson, M., 2021. Who saves money buying electric vehicles? Heterogeneity in total cost of ownership. Transp. Res. Part D 96 (2021), 102893. https://doi.org/10.1016/j.trd.2021.102893.
Parliament 2017. Innst. 460 S (2016-2017). Nasjonal Transport Plan (2018-2029). Stortinget 12. Juni 2017.
Parliament 2016. Account of the debate and decision over the national budget for 2017, during the 5. of Dec. 2016.
Parliament 2000a (in Norwegian). 2001 National Budget agreement. BUDSJETTAVTALE FORSTATSBUDSJETTET FOR 2001MELLOM ARBEIDERPARTIET, KRISTELIG FOLKEPARTI,SENTERPARTIET OG VENSTRE Inngått 18. November 2001. Stortinget . Publisert av Finansdepartementet.
Parliament 2000b (in Norwegian). Zero VAT-rate decision in the Parliament. Innstilling fra finanskomiteen om lov om endringer i l ov 19.juni 1969 nr. 66 om merverdiavgift (merverdiavgiftsloven) m.v. (Merverdiavgiftsreformen 2001). Stortinget Innst. O. nr. 24 – 2000-2001. https://www.stortinget.no/globalassets/pdf/innstillinger/odelstinget/2000-2001/inno-200001-024.pdf.
Reiter C., Wassiliadis N., Wildfeuer L., Wurster T., Lienkamp M. 2018. Range Extension of Electric Vehicles through Improved Battery Capacity Utilization: Potentials, Risks and Strategies. 2018 21st International Conference on Intelligent Transportation Systems (ITSC), 2018, pp. 321-326, doi:10.1109/ITSC.2018.8569455.
Rogers, E., 1995. Diffusion of innovations. Fifth edition. Free press 1995, 2003.
Rusich, A., Danielis, R., 2015. Total cost of ownership, social lifecycle cost and energy consumption of various automotive technologies in Italy. Res. Transport. Econom. 50 (2015), 3–16. https://doi.org/10.1016/j.retrec.2015.06.002.
Santos, G., Rembalski, S., 2021. Do electric vehicles need subsidies in the UK? Energy Policy 149 (2021), 111890. https://doi.org/10.1016/j.enpol.2020.111890.
Scorrano, M., Daielis, R., Giansoldati, M., 2020. Dissecting the total cost of ownership of fully electric cars in Italy: The impact of annual distance travelled, home charging and urban driving. Res. Transport. Econom. 80 (2020), 100799 https://doi.org/10.1016/j.retrec.2019.100799.
Skatteetaten 2020. Avgiftshistorie 2020 (in Norwegian). Skattedirektoratet. Ajour pr. 1. Januar 2020.
Spot-on 2021. Interviews with Norwegian charging infrastructure actors in the Spot-on research project in the fall of 2021.
SSB 2021. Statistics Norway. Table 08448, Table 09387, Table 11011. Available at www.ssb.no.
SSB 2022. Statistics Norway. Table 06265. Available at www.ssb.no.
Strzeletz Ivertsen, K. (2014). Partnership Drift in Innovation Processes: A study of the Think City electric car development, PhD Series, No. 2.2014, ISBN 9788793155053, Copenhagen Business School (CBS), Frederiksberg. http://hdl.handle.net/10398/8870.
Sundvollen 2013 (in Norwegian). Government declaration for 2013-2016.
Think City 2000. Think City business plan (version 2.0). 12. June 2000.
TV2 2021 (news article, in Norwegian). Servicepriser: Kan være mye billigere å eie elbil. TV2 07.03.2021. https://www.tv2.no/a/11977222/.
TU 2016. (news article in Norwegian). Så lenge kan du forvente at batteriet I elbilen varer. TU 30 Apr. 2016. https://www.tu.no/artikler/sa-lenge-kan-du-forvente-at-batteriet-i-elbilen-varer/346750.
TU 2018. (news article in Norwegian). Nissan: Leaf-batteriene varer og varer. TU 19. Dec. 2018. https://www.tu.no/artikler/nissan-leaf-batteriene-varer-og-varer/453921.
Ultimatespecs 2021. Daewoo Matiz 0.8 Technical Specs, Dimensions https://www.ultimatespecs.com/car-specs/Daewoo/4879/Daewoo-Matiz-08.html.
van Velzen, A., Annema, J.A., van de Kaa, G., van Wee, B., 2019. Proposing a more comprehensive future total cost of ownership estimation framework for electric vehicles. Energy Policy 129 (2019), 1034–1046. https://doi.org/10.1016/j.enpol.2019.02.071.
VG 1992 (news article, in Norwegian). Fransk vinner. Billigbiltest. VG 23. Desember 1992.
VAT Expert Committee 2019 (in Norwegian). Enklere merverdiavgift med én sats. Utredning fra et ekspertutvalg oppnevnt av Finansdepartementet 18. Januar 2019. NOU 2019:11.
Vattenfall 2010 (in Swedish). Downloaded 21.06.2020. ELBILAR som kommer till Sverige 2010 –2011. 16 elbilsmodeller som är på väg till Sverige (publicwebsites.se).
VG 2011. (news article, in Norwegian) Vi kårer Folkets favorittbil - du bestemmer!. https://www.vg.no/forbruker/bil-baat-og-motor/i/agGRd/vi-kaarer-folkets-favorittbil-du-bestemmer.
VG 2010a (news article, in Norwegian). Test av Buddy: Trivelig tass. https://www.vg.no/forbruker/bil-baat-og-motor/i/1KVMM/test-av-buddy-trivelig-tass.
VG 2010b (news article, in Norwegian). Test av THINK: Elegant og tøff. https://www.vg.no/forbruker/bil-baat-og-motor/i/L2jM4/test-av-think-elegant-og-toeff.
Vågane L. 2009 (in Norwegian language with English summary). Flere i hver bil? Status og potensial for endring av bilbelegget i Norge. TØI rapport 1050/2009. Extracted from: https://www.toi.no/publikasjoner/flere-i-hver-bil-status-og-potensial-for-endring-av-bilbelegget-i-norge-article28244-8.html.

Wesseling J. H, Farla J. C. M., Sperling D., Hekkert M. P. 2014. Car manufacturers' changing political strategies on the ZEV mandate. Transportation Research Part D. 33 (2014), 196-209. https://www.sciencedirect.com/science/article/pii/S1361920914000716?via%3Dihub.

Weldon, P., Morrissey, P., O'Mahony, M., 2018. Long-term cost of ownership comparative analysis between electric vehicles and internal combustion engine vehicles. Sustain. Cities Soc. 39 (2018), 578–591. https://doi.org/10.1016/j.scs.2018.02.024.

Wu, G., Inderbitzin, A., Bening, C., 2015. Total cost of ownership of electric vehicles compared to conventional vehicles: A probabilistic analysis and projection across market segments. Energy Policy 80 (2015), 196–214. https://doi.org/10.1016/j.enpol.2015.02.004.