Anna van Buerenplein 1
2595 DA Den Haag
P.O. Box 96800
2509 JE The Hague
The Netherlands

www.tno.nl

T +31 88 866 00 00

TNO report

TNO 2018 R10919v2

Inputs and considerations for estimating large scale uptake of electric vehicles in the Dutch passenger car fleet up to 2030

Date	31 August 2018
Author(s)	René van Gijlswijk, Emiel van Eijk, Elisah van Kempen, Norbert Ligterink, Evie Cox

Copy no	2018-STL-RAP-100316311v2
Number of pages	61
Number of appendices	1
Sponsor	Planbureau voor de Leefomgeving Bezuidenhoutseweg 30 2594 AV DEN HAAG
Project name	Ontwikkelingen praktijkverbruik en samenstelling personenwagenpark
Project number	060.35097

Samenvatting

Het Planbureau voor de Leefomgeving (PBL) heeft de taak om de effecten van het Nationale Klimaatakkoord te evalueren. Een belangrijk deel van de CO_2-reducerende maatregelen heeft betrekking op de verduurzaming van het personenwagenpark. Het zuiniger maken van auto's met verbrandingsmotor en de ingroei van nulemissievoertuigen, waaronder batterij-elektrische voertuigen, zouden in 2030 tot een vermindering van de (directe) CO_2-emissie moeten leiden. Een snelle ingroei van elektrische voertuigen zal niet vanzelf gaan, maar wordt in vele bronnen wel min of meer als een gegeven beschouwd. In dit rapport is zoveel mogelijk op basis van feiten nagegaan wat de randvoorwaarden zijn voor grootschalige uitrol van elektrische voertuigen (EV's), en is een bandbreedte berekend waarbinnen de grootte van de Nederlandse EV-vloot waarschijnlijk zal liggen in 2030. Dit kan als basis dienen voor schattingen of scenarioanalyses waarin het effect van CO_2-reducerende beleidsmaatregelen wordt beoordeeld.

Dit rapport bevat feitelijke achtergrondinformatie en inzichten over randvoorwaarden voor de grootschalige uitrol van elektrische voertuigen. Het dient als input voor een door PBL te maken schatting van de ontwikkeling van het elektrische wagenpark in Nederland tot 2030.

Wagenpark
De aanschaf van personenauto's wordt voor meer dan de helft gedaan door zakelijke klanten: leasemaatschappijen, bedrijven. Hierbij is ook private lease meegeteld. De meeste van deze auto's komen na enkele jaren op de tweedehandsmarkt. Er is een flinke mismatch tussen het aanbod van deze gemiddeld wat grotere voertuigen, veelal met een dieselmotor, en de vraag van particulieren naar kleinere benzinevoertuigen die een niet te hoge aanschafprijs hebben. Daarom worden op grote schaal auto's geëxporteerd en geïmporteerd. Als geen aanvullende maatregelen worden genomen, zullen mogelijk veel EV's, die vooralsnog in de hogere segmenten vallen, worden geëxporteerd bij gebrek aan vraag.

De jaarkilometrages variëren sterk van voertuig tot voertuig, verder wordt met zakelijke auto's gemiddeld meer gereden. De meeste EV's worden zakelijk gekocht, en hiermee worden op dit moment significant minder kilometers gemaakt dan met zakelijke auto's op benzine of diesel, behalve in het E-segment (Tesla). Kennelijk worden vooral voertuigen vervangen die weinig kilometers maken. Dat heeft invloed op de CO_2-winst van de vervanging.

Een analyse van de restwaardeontwikkeling van elektrische voertuigen leert dat kleine en middelgrote EV's sneller in waarde dalen dan vergelijkbare benzinevoertuigen, en grote EV's langzamer, uitgedrukt in procenten van de nieuwprijs, met correctie voor de kilometerstand. Dat kan te maken hebben met de bruikbaarheid tweedehands; grote EV's hebben meestal meer actieradius. Door de snelle ontwikkelingen in nieuwe EV's zal de bruikbaarheid van tweedehands voertuigen over een aantal jaar ook toenemen, waardoor mogelijk de restwaarde stabieler zal blijven.

De autonome vervanging van conventionele auto's door elektrische voertuigen gaat zelfs met een hoog marktaandeel niet snel. De gemiddelde levensduur van personenauto's is 18 jaar. Het is goed om te benadrukken dat ongeveer een derde van de voertuigen die in 2030 rondrijdt, al verkocht is, hier of in het buitenland.

Ontwikkelingen in de wereld en Europa

Kijkend naar de wereldmarkt, valt op dat in de top 10 landen waar de meeste EV's verkocht worden, stimuleringsmaatregelen van kracht zijn. China dwingt zelfs een percentage elektrische voertuigen af bij fabrikanten. In totaal rijden er wereldwijd ca. 3 miljoen EV's rond, waarvan ruim 800.000 in Europa (2017).
Qua laadinfrastructuur zijn we in Nederland ver: er is een publiek laadpunt voor elke 3 EV's, veel meer dan in andere landen.

De accuproductie zou een limiterende factor kunnen vormen: de kobaltwinning moet vertienvoudigen in 2030 om aan de (geprojecteerde) wereldvraag van accu's te kunnen voldoen. Dat geldt ook voor de batterijproductie zelf. Gezien de aangekondigde accufabrieken in China zal de productiecapaciteit in enkele jaren verdubbelen.

Beleid

De invloed van CO_2-beleid op Europees niveau is veelvormig. Vanuit fabrikanten geredeneerd kan de norm, die nog niet definitief is, gehaald worden met een mix van batterij-elektrische auto's, plug-in hybrides en conventionele voertuigen die zuiniger zijn gemaakt. De reductiewaarden waarover gesproken wordt variëren tussen 30% (het voorstel van de Europese Commissie) en 50% (standpunt van de ENVI-commissie van het Europees Parlement) ten opzichte van 2021. 30% kan misschien gehaald worden louter door conventionele auto's zuiniger te maken. Analyses duiden erop dat dit tegen geringe meerkosten kan die binnen ongeveer 5 jaar worden terugverdiend door de bespaarde brandstofkosten. Voor verdere reductie zijn wel elektrische voertuigen nodig. In elk geval zal een deel van de norm gehaald worden door reductie van de uitstoot van het niet-elektrische deel van de vloot. Voor de grootste effectiviteit is het belangrijk om verbeteringen aan conventionele voertuigen onderdeel te laten zijn van beleid op het gebied van CO_2-reductie van personenauto's.

De reductie-eisen gelden ten opzichte van het gemiddelde op de WLTP-testcyclus in 2021. Dat betekent dat des te hoger de WLTP-waarde op dat peilmoment, des te hoger de normwaardes zullen zijn. In dit systeem zit een motivatie om de declared WLTP-waarden zo hoog mogelijk te zetten. Of hierop wordt ingezet, en zo ja in welke mate, zal pas later zichtbaar worden.

Wat verder nog speelt, is dat er een groot verschil is tussen normverbruik en praktijkverbruik, en dus ook tussen CO_2-uitstoot volgens de test en in de praktijk. Dit verschil groeide van jaar tot jaar, maar is wel gestabiliseerd de laatste jaren. Het moet worden bezien of verdere verbeteringen aan auto's in de praktijk evenveel reductie geven als in de folder. De afstand tussen norm en praktijk is bij plug-in hybrides nog een stuk groter, waardoor ze in de praktijk nauwelijks minder CO_2 uitstoten dan een vergelijkbare diesel. Door de lage normuitstoot kunnen plug-ins wel op papier bijdragen aan de CO_2-reductie: ongeveer de helft van dat van een batterij-elektrisch voertuig (bij gelijke kilometrages).

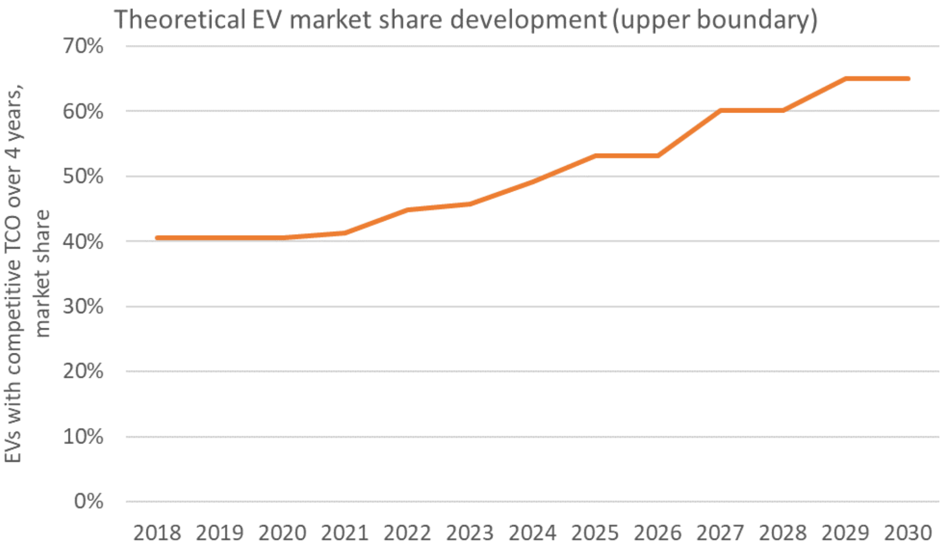
Nederland is niet het enige land dat stimuleringsbeleid voor zuinige voertuigen en nulemissievoertuigen voorbereidt als onderdeel van hun bijdrage aan het Parijsakkoord. Daardoor kan de beschikbaarheid van elektrische auto's onder druk komen te staan.

Randvoorwaarden

Als alleen rationele argumenten meetellen, zullen bedrijven de aankoopbeslissing voor EV's waarschijnlijk nemen op basis van gebruikskosten (TCO) per kilometer over een periode van enkele jaren. Particulieren die zelf nieuw kopen zullen voornamelijk letten op de aanschafprijs. Elektrische voertuigen hebben op dit moment hogere aanschafprijzen maar lagere gebruikskosten. Dat betekent dat een langere horizon de kostenberekening gunstiger uit laat vallen voor een EV. Voor hogere jaarkilometrages geldt dat ook. Verder geldt dat bij grote auto's met een hoger brandstofverbruik de extra aanschafkosten eerder zijn terugverdiend. Grootschalige marktintroductie zal beginnen bij grote zakelijke auto's, vervolgen met kleinere zakelijke auto's, grote privaat aangeschafte auto's, en tot slot kleinere privé-auto's. Naast aanschafprijs en gebruikskosten (mede bepaald door de prijs van elektriciteit) speelt ook de beschikbaarheid van laadinfrastructuur een rol.

Optimistische en pessimistische scenario's voor ingroei elektrische voertuigen

Op basis van de totale gebruikskosten is voor zakelijk en privé, voor vijf marktsegmenten en voor vier jaarkilometrage-groepen van ieder 25% van de rijders in een marktsegment bepaald op welk moment een EV voor deze groep aantrekkelijk wordt qua gebruikskosten over 4 jaar. Er wordt ervan uitgegaan dat alle EV's in de vloot blijven: geen export, geen sloop.
De verkoopcurve zou er dan, zonder extra beleid, met maximale beschikbaarheid van voertuigen, zo uitzien:



Dat betekent dat in 2030 bij geen nieuw beleid in het gunstigste geval zo'n 65% van de nieuwverkopen EV's zijn. Opgeteld over de jaren 2018-2030 zouden er dan in 2030 maximaal ca. 2,8 miljoen EV's rond zouden kunnen rijden. Het grootste deel is zakelijk, en valt in het C- en D-segment.

Voor kleine auto’s valt de rekensom niet snel gunstig uit, ook al omdat er gemiddeld relatief weinig kilometers mee gemaakt worden.

Overigens zijn plug-in hybrides niet meegenomen in deze berekening. In het algemeen maken de hogere kilometerkosten plug-ins minder gunstig dan batterij-elektrische voertuigen, en zal de rol ervan beperkt blijven bij ongewijzigd beleid.

Er liggen flink wat aannames onder de curve van het berekende maximale marktaandeel. Omdat de TCO’s van EV’s en conventionele auto’s vaak slechts enkele centen per km uit elkaar liggen, is de gevoeligheid voor een aantal aannames groot. Deze aannames zijn de prijsontwikkeling van EV’s, de vraag of de prijsdaling van accu’s ten goede komt aan de accugrootte of aan een lagere aanschafprijs, de elektriciteitsprijs en de brandstofprijs. Bijvoorbeeld, indien er niet vanuit wordt gegaan dat iedereen tegen thuistarief kan laden, maar alleen aan een publieke laadpaal, zakt het marktaandeel van 65% naar 57% in 2030.

Een conservatievere variant is berekend waarbij: 1) particulieren wachten met aanschaf tot de aanschafprijs van een EV lager is (in plaats van de TCO), en 2) zakelijk beslissers pas EV’s aanschaffen bij een 10% lagere TCO, en particulieren pas EV’s aanschaffen bij een 10% lagere aanschafprijs. Bij deze variant is het verkoopaandeel 41% in 2030, en het geschatte aantal EV’s in 2030 onder de anderhalf miljoen.

Voor een 30%-reductiedoelstelling in 2030 hebben fabrikanten waarschijnlijk geen nulemissievoertuigen of plug-in hybrides nodig. Indien we ervan uitgaan dat zij kiezen voor het verder benutten van al gedane investeringen in conventionele technologie, ervan uitgaan dat de huidige verkopen van EV’s gedreven zijn door stimuleringsmaatregelen, en ervan uitgaan dat deze verdwijnen na 2021, dan kan de aanwas van de EV-vloot in Nederland stagneren.

Scenarioanalyse met verschillende beleidsmatige stimuleringsmaatregelen kan uitwijzen welk effect kan worden bereikt met welke middelen. Het meeste potentieel zal liggen in het voorkomen van export door een betere match tussen zakelijke nieuwverkoop en privé-tweedehandsaanschaf, het stimuleren van lange-termijngedrag bij particulieren, verlagen van de financieringsdrempel, en het overbruggen van een klein kostenverschil voor een grote groep middelgrote voertuigen. Gezien de naar elkaar toe bewegende gebruikskosten van EV’s en conventionele auto’s, de verschillende groottes van de marktsegmenten en de jaarkilometrageverdeling van de personenautovloot, is het voor het bereiken van een groot vlootaandeel EV’s belangrijk om het moment van stimuleren zo te kiezen dat een grote groep met een relatief kleine investering enkele jaren eerder over de streep getrokken kan worden.

Contents

Appendices

1 Introduction

The composition of the Dutch fleet in 2030 will depend on many factors. These are the autonomous fleet development, real-world CO_2 emissions of vehicles, the international market, European targets and the necessary requirement for electric vehicles (EV) uptake. Together, these factors will determine the European influx of EV. Whether the available EV will be sold in the Netherlands may depend on Dutch policy, in the light of European and worldwide developments.

In this report, we elaborate on each of these factors to support PBL in their task to evaluate the effect of the National Climate- and Energy Agreement. Much attention in the Climate agreement negotiations goes to the sales of new vehicles and the fraction of electric vehicles in the total sales. These two elements are not enough to estimate the fleet and the reduction in CO_2 emissions. Three more elements must be taken into account in this analysis. First, combustion engine vehicles will remain dominant in the fleet well beyond 2030 and their emission performance will play an important role for many decades. Second, if the sales of new vehicles do not match the majority of the Dutch passenger car fleet, i.e., small private-owned petrol cars, these EVs will be exported rapidly, like is the case with other business vehicles. Third, the availability of electric vehicles is of importance, also in the lower market segments, for the variety of use. It is assumed that European targets will drive the uptake of EV production. However, that does not automatically imply that European targets will ensure EVs to be available in the Netherlands and so for all market segments.

This report provides the background information on the necessary conditions needed to ensure that EV uptake in the Netherlands is sustainable. Up till now, it seems mainly luxury EVs in business use are sponsored with public funds. The fact that 40% of the total Dutch EVs sold belong to a market segment that makes up 5% of the sales volume, means the current situation with EVs has very little relation with a broad uptake of EVs in the Dutch fleet, replacing conventional vehicles in many different uses and ownerships. Many people pay 10,000 Euros or less for their car, which is a small fraction of the vehicle costs often taken as example for the success of EV sales.

The study examines the current situation and the potential for change. The renewal rate and the typical fleet composition is starting position. This is set against the trends and developments, the conditions, and the driving forces to show the bandwidth of developments in the different market segments and usages. This report does not come to a single conclusion. The different chapters show the issues concerning the uptake of EV from different angles. The current situation is very uncertain and prognoses are difficult to make. There are however many constraints which will limit the change from the current situation. With less than 0.4% electric vehicles in the total fleet, it is too early to claim that the sale and use of electric vehicles will definitely take off in the next few years.

With uncertainty on the intake of electric vehicles, the conventional vehicles will play an important role in three manners: First, as a viable alternative for EV for consumers. Second, in their impact on the CO_2 emissions from transport well beyond 2030. Third, dependent on the actual stringency of the post-2020 targets on

CO_2 emission, these targets can be met by a certain ratio of EVs and (improved) conventional vehicles. Hence, the study places the uptake of EVs against the development of conventional vehicle technology.

The results of the study are accumulated in uptake scenarios in the last chapter for the different market segments, which place the current development in perspective. It will be hard to compete with the standard low-cost compact car which hinders the broad uptake and retention of EVs in the Dutch fleet.

2 Historical fleet development

2.1 Introduction

There is a large variety in vehicle types and vehicle ownership situations. Private car use is generally related to older and smaller cars, with limited resale prices. These vehicles make up a large part of the Dutch fleet. For years already there is a mismatch in composition between the new car sales and the private car fleet, which is compensated by large numbers of cars being imported and exported. Hence, the influx of new electric vehicles does not naturally result in a similar fraction of EVs in the total fleet over time. Making electric vehicles land into the second hand (private) car fleet may be the biggest challenge to achieve electrification of the Dutch fleet. This chapter provides some insight in the mismatch of fleet segments.

The current vehicle fleet was analyzed, based on RDW vehicle data of November 2017 and June 2018.[1] Only two forms of ownership are distinguished: business and private. Private-lease vehicles are included in the business sector.

2.2 Market segmentation

The consumer market for cars can be segregated in classes of vehicles with a different pricetag. These price based segments correlate partially with size and other characteristics in terms of functionality and luxury. In this chapter, trends are analysed solely from a price perspective. The distinguished segments are presented in Table 2.1. From paragraph 2.8 onwards in the report, functionality and luxury are considered as well, employing a segmentation which correlates better with the (not formally defined) market segmentation commonly used by the industry.

Table 2.1: Passenger car segmentation on the basis of catalogue prices

Segment	Price range
I	0 – 15,000
II	15,000 – 25,000
III	25,000 – 35,000
IV	35,000 – 50,000
V	50,000 +

2.3 Business cars and private cars

Figure 2.1 shows the distribution of cars over market segments, for the business car fleet as well as the private car fleet. There is a substantial difference in segment sizes between the two. The higher market segments are more prevalent in business cars and newer vehicles. Contrary, segments I and II together make up almost 70% of the vehicles in private use, but around 42% for business cars. Since more than half of the newly purchased cars are business cars, the amount of new cars in segments I and II does not suffice to supply the second hand market with vehicles aged four to ten years, later on. The lacking vehicles are imported.

---

[1] TNO 2018 R10367 Nederlandse wagenparksamenstelling 2017

Electric vehicles, however, are bought mainly by businesses at the moment, and they fit predominantly in the higher market segments, for which the second hand market is limited. The mismatch between business and private use manifests itself in age, fuel, and market segments. To retain electric vehicles in the Netherlands, it is important that EV sales in the business sector (and private sector) match well with the second hand market demands in terms of share among the segments. In the current situation the retention of electric vehicles is not obvious.

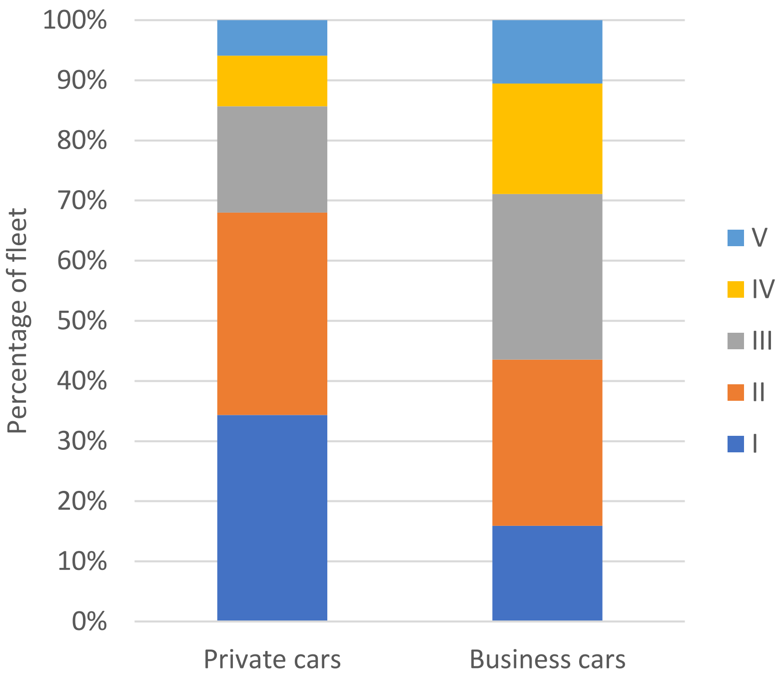


Figure 2.1: The market segment distribution based on the type of ownership as registered by RDW.

Since 2008, the surcharge on income tax for employee benefit of the private use of company cars (“bijtelling”) is lower for vehicles with low CO_2-emissions. Since this only affects business users, this regulation has increased the uptake of hybrid and electric business cars. Currently over 9% of business cars is a hybrid or (plug-in or full) electric vehicle, compared to less than 2% for privately owned cars, see Figure 2.2.

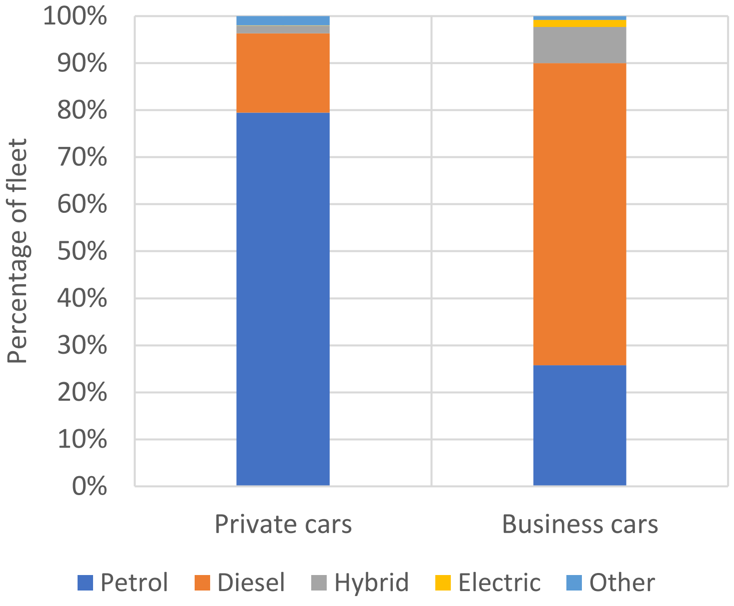


Figure 2.2: Share of drivetrain/fuel in private car and company car fleet.

The mismatch in drivetrain between the new business vehicles and the older private owner vehicles also causes the extensive import and export of passenger cars. This is related to the difference in road tax and fuel levels between petrol and diesel.

2.4 Import and export

Business cars are commonly exported within the first 4-8 years, see Figure 2.3. It is not to be expected that electric cars from the business fleet are naturally retained in the Netherlands more than diesel or hybrid cars from the business fleet, without additional measures. As long as benefits such as reduced income tax surcharge apply, the vehicles are retained. Consequently, a large incentive for business owned EVs will have an effect of about one third of the effect that stimulation of privately owned EVs will have. The latter mostly remain in the Netherlands for their entire lifespan of (on average) 18 years.

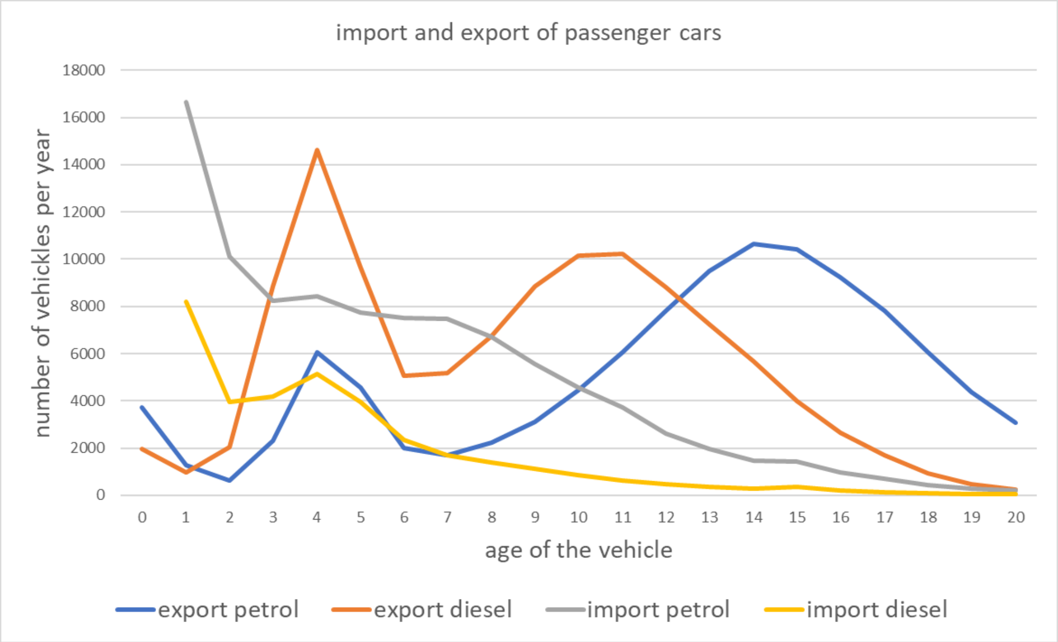


Figure 2.3: Annual import and export of vehicles in relation to their age (RDW; annual average in the period Jan. 2013 – Nov. 2017; the exported vehicles aged four years are traced back mainly from business use). Business cars are exported predominantly after four years, while private owned cars are exported from eight years till the end of the useful lifespan. Export is about 40% of the total sales, import is slightly less.

A closer look at the exported business vehicles in Figure 2.4 shows that segment III is dominant in the export. Most of these vehicles are exported after around 4 years. The number of vehicles is lower in the higher segments, but still export is significant, considering the size of the segments.

Export of company cars with a new price of below € 25,000 (segment I and II) is limited.

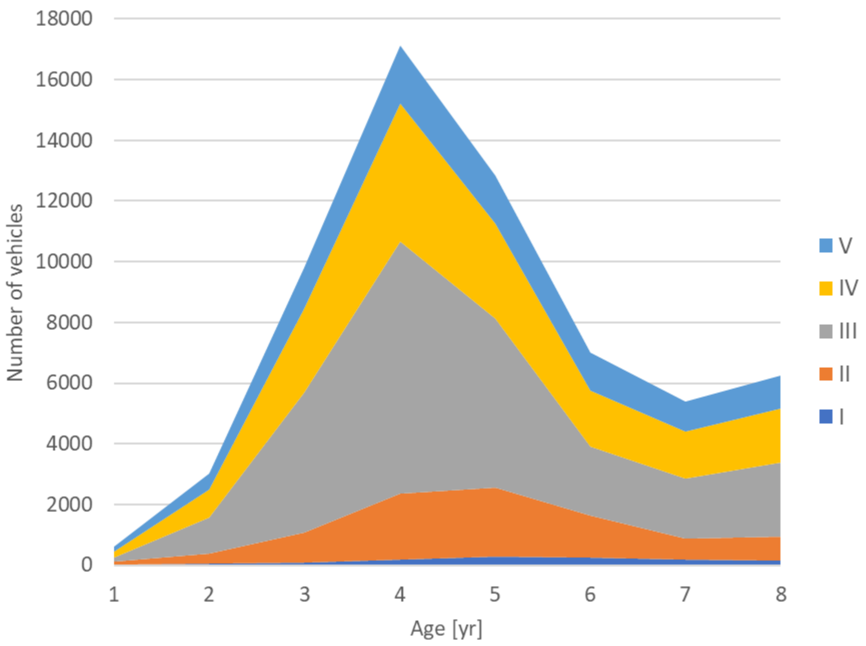


Figure 2.4: The age at export for business cars, for different segments.

The current import of electric vehicles is also limited, and the ones imported seem to be utilized as business cars. If private cars are imported at a given age, there is no market for electric cars yet that fills this share.

The market segment shares of imported private vehicles can be seen in Figure 2.5. There is a clear pattern from young cars in lower segments to older cars in the higher segments. The latter is very likely related to the avoidance of high, CO_2 emission related purchase tax (BPM). The former shows the need and lack of affordable cars in the Netherlands.

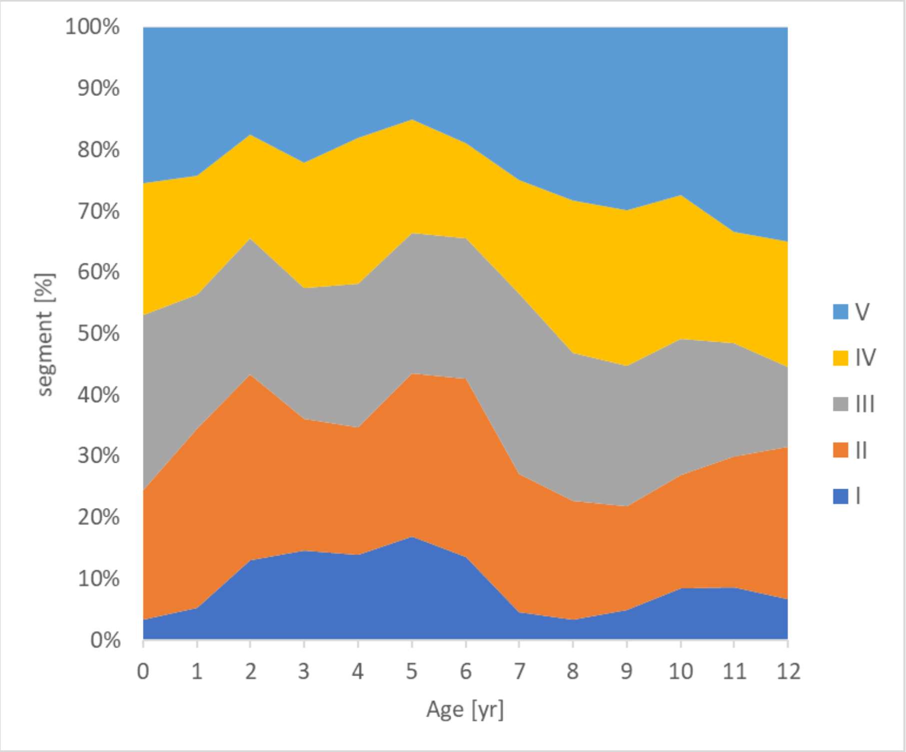


Figure 2.5: Imported vehicles for private use, across market segments and age.

Figure 2.6 shows the annual number of imported vehicles (average since 2015). The renewal by import is mainly accomplished by private cars with a wide age range.

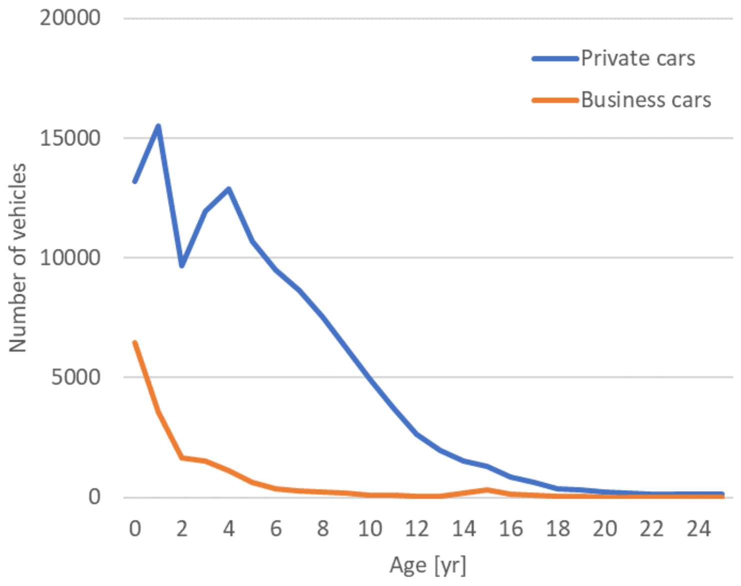


Figure 2.6: The average annual import in the period 2015-2018 for private and business use, differentiated to age.

2.5 Annual mileages and vehicle use

Due to the import and export the market segments distributions vary with age. As shown in Figure 2.7, the least expensive segments I and II make up less than 30% of the new vehicles, but double in seven years to the majority of the total Dutch fleet.

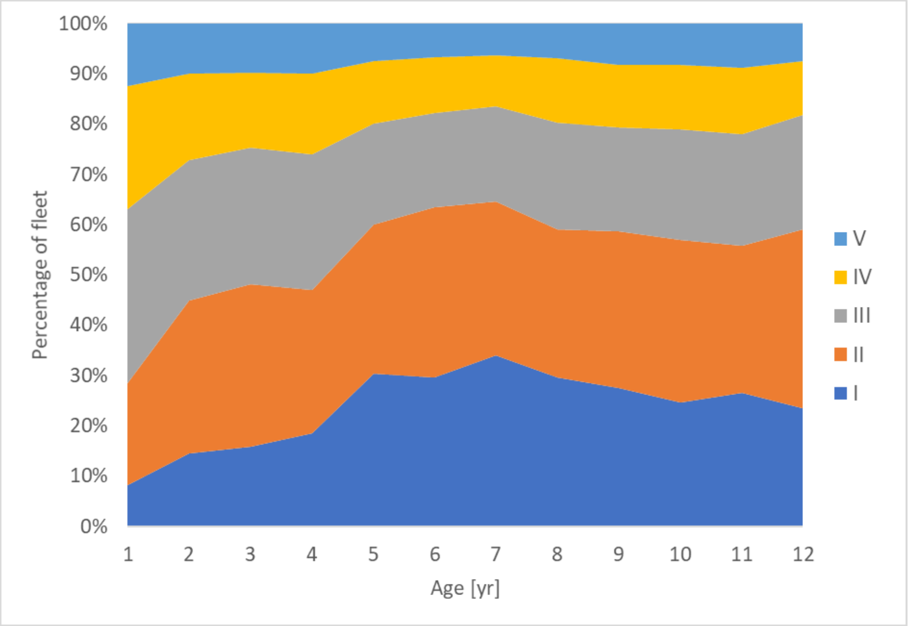


Figure 2.7: Fleet composition in market segments, for each vehicle age

Figure 2.8 shows the same data, presented as a percentage of the total fleet.

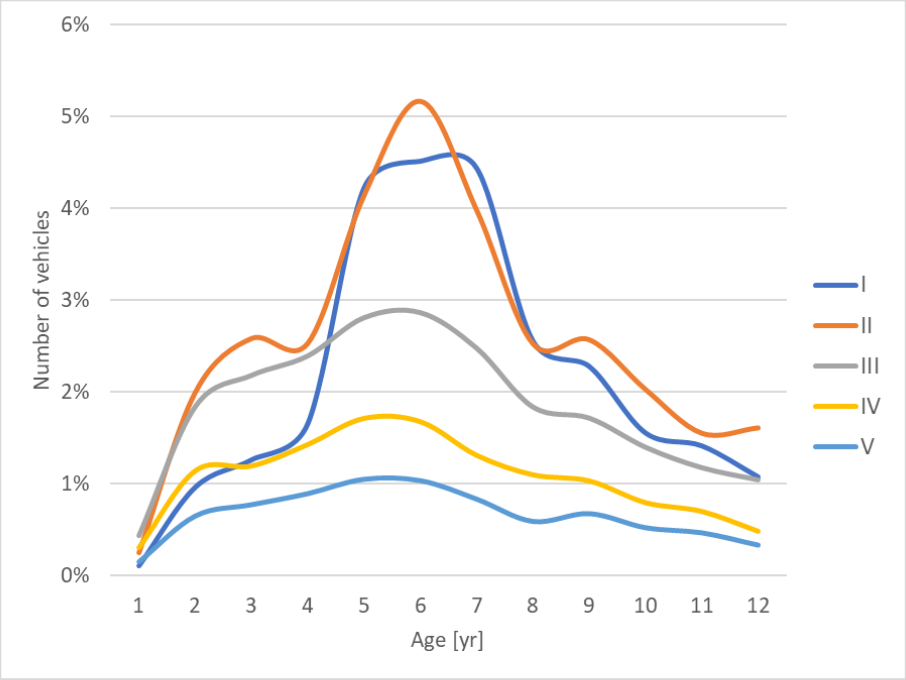


Figure 2.8: Fraction of the fleet in the different segments over the years

To establish the influence of segment distribution, import and export on the CO_2 emissions, an important factor is the mileage of these vehicles.

Diesel vehicles clearly cover higher annual mileages than petrol vehicles, but the annual mileages exhibit a rather small dependence on the market segment, see Table 2.2. Only with age the annual mileages drop.[2] For the total fleet the average annual mileage is around 13,000 km/ann. The annual mileage about halves for the group of vehicles of ten years and older.[3]

Table 2.2: Annual mileages [km/ann] of vehicles for different fuels, ownership and market segments, average for the first four years of use.

Fuel	Segment	Private	Business
Petrol [km/ann]	I	12100	18500
	II	13400	20100
	III	15400	23900
	IV	16800	24100
	V	17000	22100
Diesel [km/ann]	I	23200	23600
	II	27100	26700
	III	29700	31600
	IV	28300	30700
	V	27600	34300

---

[2] TNO 2016 R11872 Nederlandse wagenparksamenstelling 2016

[3] Source CBS

In the total cost of ownership of new vehicles the mileage plays a minor role, with these mileages. For the group where the cost per kilometre may play a larger role, i.e., private owners, the price of the vehicle is also less, both by a shift in segment as well as in age.

Another aspect to EV penetration and effectiveness of EV for CO_2 reduction is the replacement in the annual mileages by electric kilometres. It appears at the moment that in particular vehicles that are used only mildly (low mileages) seem to be replaced by EV. This limits the contribution to the total mobility, and the potential CO_2 emission benefits. The effect is illustrated for business cars and private cars in Figure 2.9 and Figure 2.10.

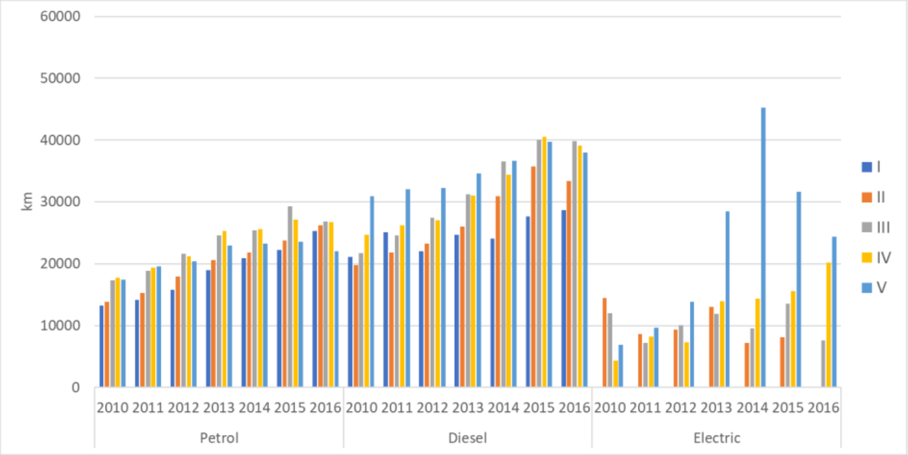


Figure 2.9: Annual mileages of business cars, per fuel and age. Note that EVs are much more expensive than ICEVs of similar size and luxury and therefore fall in higher catalogue price segments.

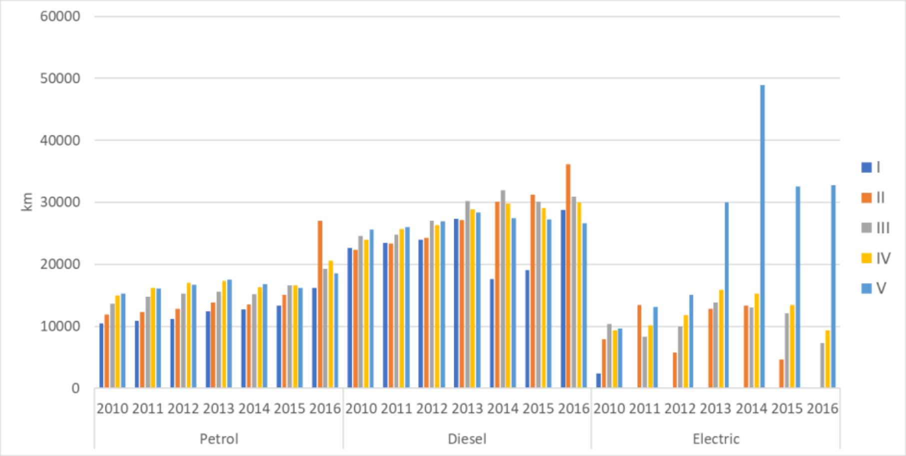


Figure 2.10: Annual mileages of private cars, per fuel and age. Note that EVs are much more expensive than ICEVs of similar size and luxury and therefore fall in higher catalogue price segments.

2.6 Vehicle lifespan and turn-over rates

It must be understood that up to 2040 and beyond the Netherlands will have a substantial fraction of combustion engine cars, contributing to the CO_2 emissions. This can already be clearly deducted by looking at the current age distribution of the vehicle fleet (Figure 2.11). The average age has been increasing steadily over the years, so the current fleet will lead to low estimates of the average age of vehicles in 2030 and beyond. The age distribution will lead to slightly different conclusions with respect to the uptake of EV in the fleet than the new sales would. With an annual influx of more than 500,000 vehicles and a total fleet of 8,000,000 vehicles, it could be concluded that the lifespan is sixteen years. In reality, EV may be follow the trend of cars in the segments III to V, and could be exported, being too expensive for private owners. The turnover rates of these vehicles will limit their impact on the average Dutch fleet. On the other hand, there are many private owners who own a vehicle for five years or longer.[4] These people may consider an EV vehicle as the next vehicle in 2025 or beyond.

Also in this respect the private owners in the segments I and II will form an inert group not easily susceptible for the current stimulation and taxation policies which seem to cater mainly for the business use in the higher market segments.

---

[4] TNO 2014 R10643 In- en uitstroom en samenstelling van het Nederlandse personenautopark

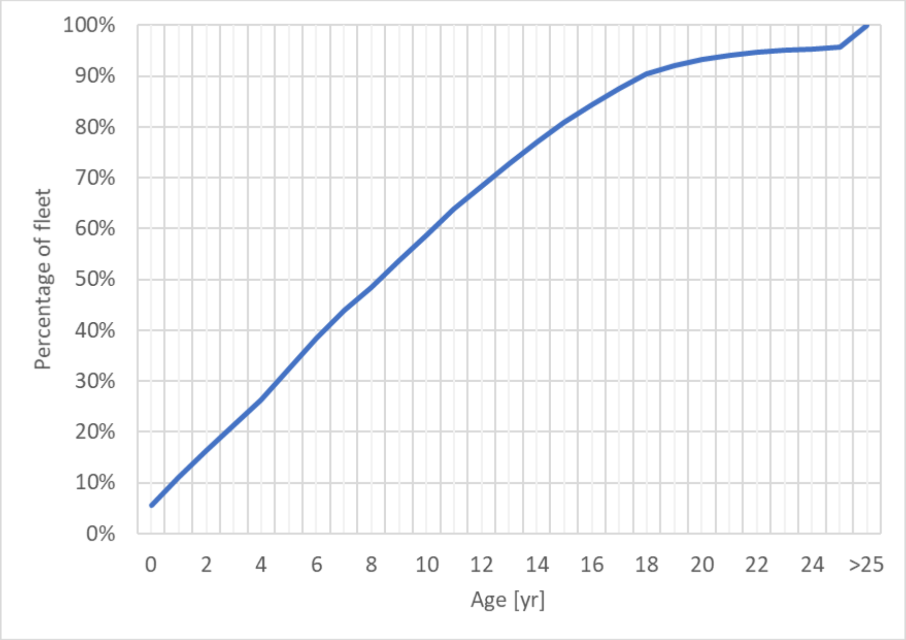


Figure 2.11: The age distribution of the Dutch fleet.

A share of 31,6% of the vehicles are older than 12 years, which means that about a third of the vehicles present in the 2030 fleet will have been sold already (in the Netherlands or abroad), as the average age increases.

2.7 EV catalogue price

As explained in paragraph 2.2, market segments are defined by the catalogue price in this report. Even compact and small EV have substantially higher prices than similarly sized conventional vehicle models. Based on catalogue prices, EVs in the Netherlands are evenly distributed over the segments III, IV, and V (see Figure 2.12). For petrol cars, for which EVs should be the main competitors given their current electric range, this is only 40% of the vehicles.

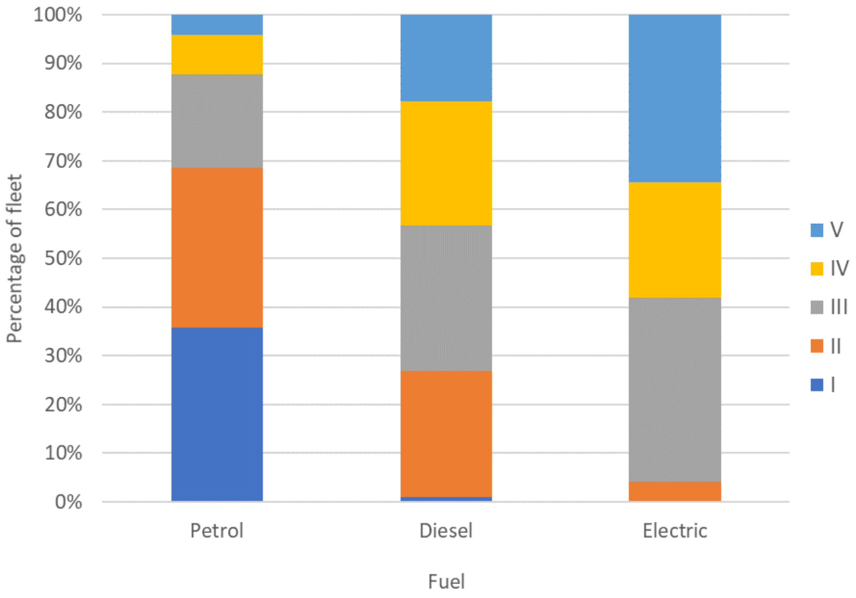


Figure 2.12: Vehicle segmentation for petrol (B), diesel (D) and EV (E) on the basis of the catalogue price. EV's are much more expensive than ICEVs of similar size and luxury and therefore fall in higher catalogue price segments. This is a nuance to the nevertheless valid observation that EV sales in the Netherlands are dominated by midsize and luxury segment vehicles and limited in the segments of compact and sub-compact vehicles.

It can be argued that the higher catalogue price of EV is compensated by lower running costs. But with a registration office of individual debts (BKR) private owners may be reluctant to paid up-front for lower running costs, to break even after four years or longer, depending on the annual mileage.

Comparing the catalogue prices of EV with the fleet average, it is clear that EV are sold in two groups: C- and D-segment and in the high end of the E-segment (see Figure 2.11). In particular these vehicles are uncommon in the Dutch fleet. This niche market is unlikely to match with private ownership. Half the normal Dutch fleet, including lease, has a catalogue price below 24,000 Euros, close to the lowest current price of any EV.

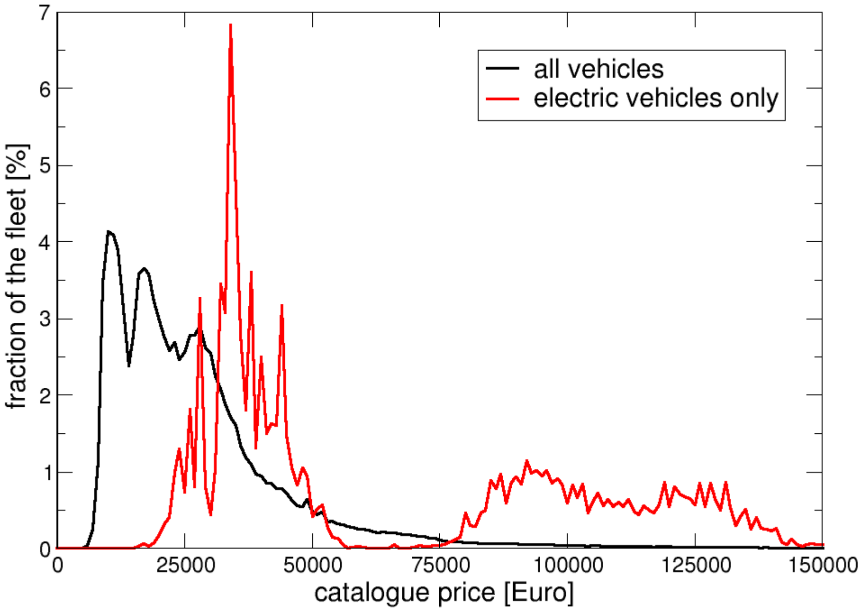


Figure 2.13: The distribution of 5.5 million known catalogue prices of all registered vehicles and all registered EVs, both normalized to 100%. About 40% of the EVs have a catalogue price above 75,000 Euros.

2.8 Second hand electric vehicles

By analysing the second hand market of electric vehicles, the residual value can be determined. For this analysis, all second hand vehicles (> 1.000 kilometres) offered on autowereld.nl (as of August 2, 2018) were analysed. In contrast to the analyses in the previous sections each model was assigned to a market segment A-E, as listed in Appendix 1. This was done in a similar way as the list published by AutoRAI[5] for ICEVs. Conventional vehicles on the list and equally classified electric vehicles in appendix 1 should have a similar size/luxury level.

In Table 2.3 it can be seen that in total 649 second hand EVs are available. The majority of vehicles available is situated in the C segment (compact family car). Outliers can be explained by luxury options.

Table 2.3: Second hand price range of EVs

Class	Minimum price	Average price	Maximum price	Number of class
A	€ 4,500	€ 15,214	€ 29,850	108
B	€ 9,450	€ 18,832	€ 35,699	154
C	€ 5,450	€ 30,086	€ 52,880	267
D	€ 16,900	€ 16,900	€ 16,900	1
E	€ 37,490	€ 63,997	€ 154,950	119

---

[5] https://autorai.nl/duidelijkheid-over-autosegmenten/

Analysis reveals that resale value of second-hand full electric vehicles can be explained by the vehicle age and the kilometres driven. Figure 2.14 and Figure 2.15 show:

- The (exponential) relation between residual value (as a factor of the original price) and the years since registration.
- The (logarithmic) relation between residual value (as a factor of the new price) and the kilometres driven. This implies that after a steep decline the line indicating the residual value flattens.
- By these variables 65% of the change in residual value can be explained (Adjusted $R^2 = 0,65$; p-value<0,001), which can be considered a reasonably good fit of the model.
    - According to this model; keeping kilometres constant will result in a 3% decrease in price when comparing vehicles of 1 year and 2 year old respectively. When comparing vehicles with a vehicle age of 4 years and 5 years, the price of the latter vehicle will on average be 9% lower.
    - According to this model; keeping the vehicle’s age constant will result in a 5% price decrease when comparing vehicles that drove 20.000 versus 40.000 kilometres. When comparing vehicles that drove 80.000 and 100.000 respectively the price decrease between the former and the latter will only be 1%.

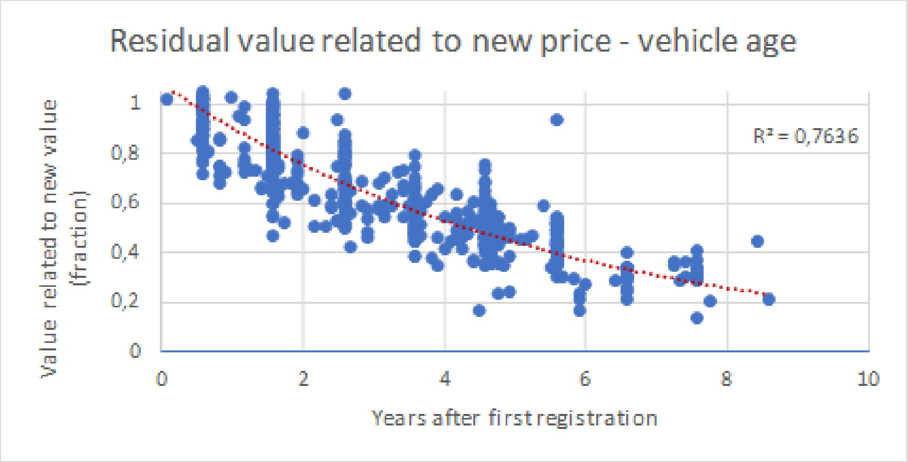


Figure 2.14: Residual value of EV as a function of its age.

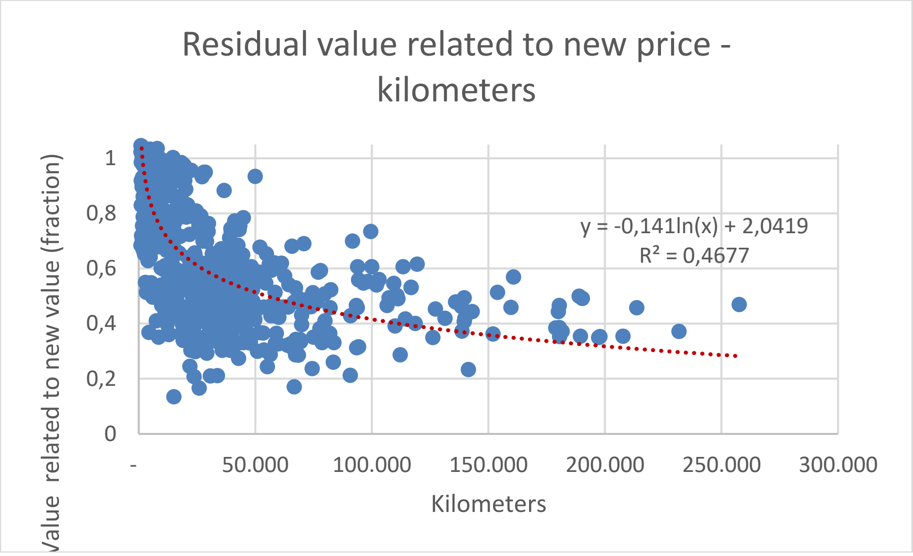


Figure 2.15: Residual value of EV as function of its mileage.

An overview of prices, compared to the catalogue prices yield a substantial reduction of the resale value of the EV, as shown in Table 2.4. Note that the data are uncertain, and can only be used as an indication of a limited market.

Table 2.4: Residual price of EV as function of the age, for different market segments. With the amount of available data, there is a large uncertainty in the averages reported here.

	age in years								
segment	1	2	3	4	5	6	7	8	9
A	89%	80%	52%	51%	51%	36%	33%	30%	(45%)
B	89%	84%	71%	60%	50%	48%	-	-	-
C	105%	85%	67%	56%	48%	38%	29%	34%	
D	-	-	-	-	-	-	-	-	21%
E	92%	78%	72%	57%	47%	49%	-	-	-

3 International state-of-play

3.1 World market

3.1.1 Electric vehicle sales

Today the largest electric passenger car stock is present in China: 40%. The total world stock of EVs surpassed 3 million in 2017, as shown in Figure 3.1.
Sales are over 1 million in 2017, for which China is responsible for 50%. Market shares are highest in Norway (39%), Iceland (12%) and Sweden (6%) [IEA 2018].

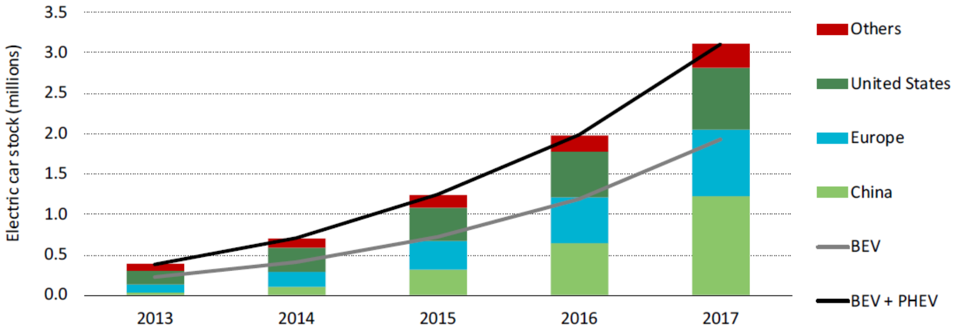


Figure 3.1: Evolution of global electric passenger car stock (source: [IEA 2018], based on country submissions, ACEA 2018 and EAFO 2018)

EV deployment has mostly driven by policy so far, as the main markets by volume (China) and sales share (Norway) have the strongest policy push [taken from IEA 2018].

3.1.2 Incentives

All countries in the top-10 of highest EV sales have a range of policies to promote the uptake of electric cars. Also, a reduction of benefits (Netherlands, Denmark) has led to an immediate decrease of uptake. It appears therefore that most uptake is incentive driven so far.

The country with the largest EV fleet (in numbers), China, mandates car manufacturers to produce a certain share of electric vehicles. A credit trading mechanism allows some exchange among manufacturers. EVs produced have to comply to minimum range (100 km for BEV, 50 km for PHEV) and efficiency standards. China targets 12% EV credits in 2020. As some EVs can get a rating of higher than one point, the actual sales may be lower than 12% [IEA 2018].

The United States is currently reviewing its greenhouse gas emission standards. The EPA determined that the standards set during the previous administration were too stringent. The 2012 standards would induce approximately 5% PHEV sales according to EPA. The state of California vows to stick with stricter rules, which are in design similar to the Chinese mandate system.

Norway is the country with the highest sales share of EVs, 39% in 2017 according to EV Norway (www.elbil.no). The incentives have been restricted somewhat in 2017 and 2018, and consist of:

- Exemption from road tax
- Exemption from 25% VAT on purchase
- Exemption from 25% VAT on lease
- Exemption on purchase/import taxes
- 40% reduced company car tax
- 50% price reduction on ferries
- Zero re-registration tax for used ZEVs
- Access to bus lanes (in Oslo requires carpooling during rush hours)
- Free municipal parking (cities can decide since 2017)

Furthermore, the Government of Norway has financed and established at least two fast charging stations on every 50 km of main road in Norway (except Finnmark and Lofoten at the moment).

3.1.3 Developments until 2030

The Model S of Tesla overtaking the luxury models of Porsche, Daimler, and BMW in sales is often taken as an example for the developments of the coming years. The suggestion is made that the traditional manufacturers are being outpaced by the “new players” on the market. But the fact is that the large volumes are in other market segments, in particular those of vehicles priced between 8,000 and 20,000 Euros (the A- and B-segments). For these market segments factories churn out vehicles at 100,000 or more per year to run a profit. The industry has matured from the days of Henry Ford, becoming more and more (cost) efficient on the way, and involves a large network of suppliers. Therefore, it is much more difficult, but not impossible, for new EV manufacturers to play a role in the lower market segments. If a new player enters this market, it may come from an unexpected direction but with large financial backing to set up the cost effective manufacturing lines.

3.2 European market

3.2.1 EV sales volumes and charging points

Figure 3.2 shows the sales numbers of full battery electric vehicles and plug-in hybrid electric vehicles in Europe, as derived from the European Alternative Fuel Observatory.

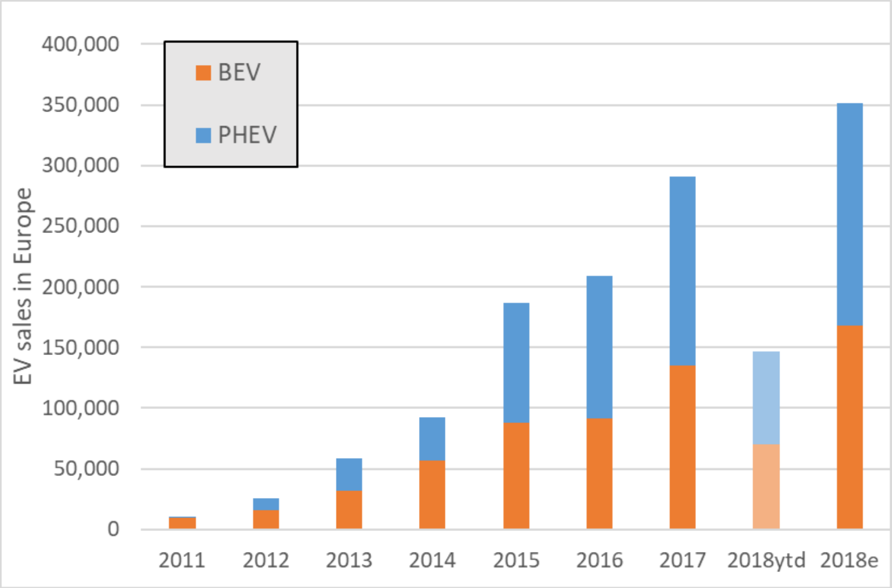


Figure 3.2: EV sales in Europe [EAFO 2018]. Data until May 2018. Ytd=year to date; e=linearly extrapolated for the entire year.

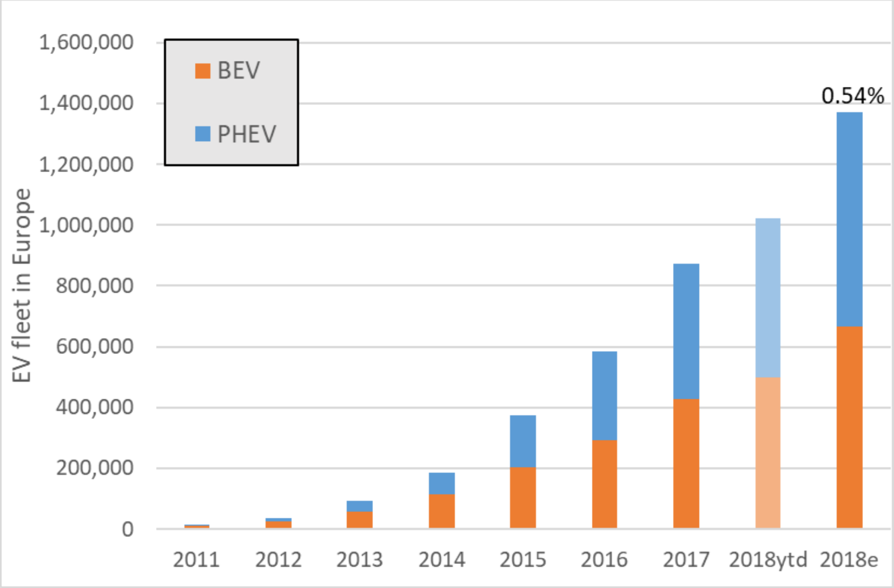


Figure 3.3: EV fleet in Europe [based on EAFO 2018]. Data until May 2018. Ytd=year to date; e=linearly extrapolated for the entire year.

The EV share in the European vehicle fleet would be just over 0.5% by the end of this year, if sales progress linearly during 2018.

Per May 2018, almost 140,000 charging positions are present in Europe, of which 15% fast chargers. A quarter of the charging positions are located in the Netherlands, although the number of fast chargers is limited to approximately 800 at the moment.

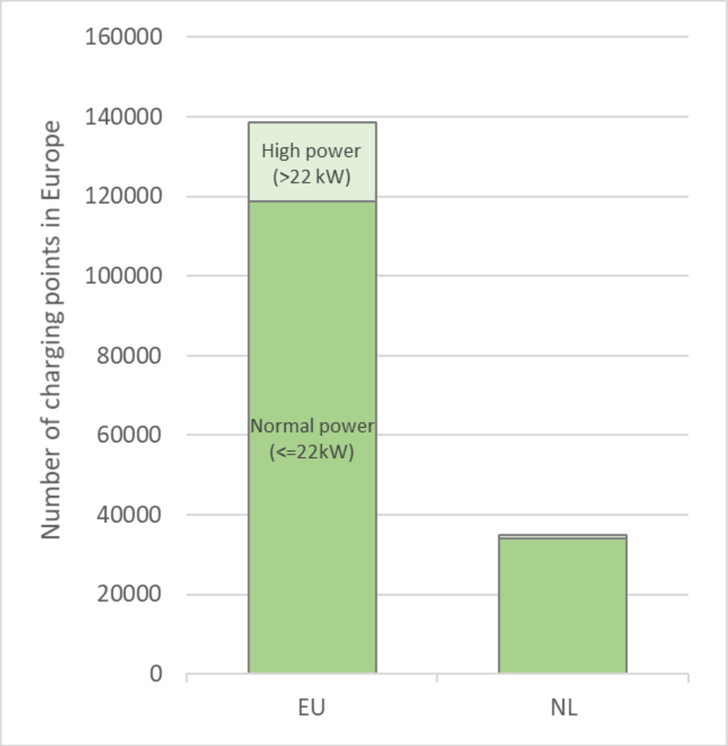


Figure 3.4: Number of charging positions in the EU28 and the Netherlands as of May 2018 [based on EAFO 2018]

Considering the number of BEVs plus PHEVs in the fleet, this corresponds to one charging position for every 7.5 EV in Europe. In the Netherlands the relative ratio of charging infrastructure is slightly better: 3 EVs for each charging position. Note that home chargers are not taken into account.

3.2.2 *Incentives in European countries*

Apart from the proposed CO_2 emission standards on a European Union level of 30% reduction in 2030, most countries in and around the EU have formulated policies to encourage EV uptake.
Table 3.1 shows the type of incentives for each country separately.

Table 3.1: Incentives for EVs in Europe [EAFO 2018]

Countries	**Purchase Subsidies**	**Registration Tax Benefits**	**Ownership Tax Benefits**	**Company Tax Benefits**	**VAT Benefits**	**Other Financial Benefits**	**Local Incentives**	**Infrastructure Incentives**
Austria	√	√	√	√	√		√	
Belgium	√	√	√	√				
Bulgaria								
Croatia		√						
Cyprus		√	√					
Czech Republic		√	√					
Denmark	√	√		√			√	√
Estonia								
Finland	√	√	√					√
France	√	√	√	√			√	
Germany	√		√	√		√	√	
Greece		√	√			√		
Hungary		√	√	√			√	
Iceland		√	√		√		√	√
Ireland	√	√	√	√			√	√
Italy	√		√					√
Latvia		√	√				√	
Liechtenstein	√							
Lithuania		√					√	
Luxembourg	√		√	√				
Malta	√	√	√	√			√	√
Netherlands		√	√	√				
Norway		√	√	√	√	√	√	√
Poland								
Portugal	√	√	√	√			√	
Romania	√	√	√					√
Slovakia	√	√					√	
Slovenia	√	√	√					
Spain	√	√	√			√	√	√
Sweden	√		√	√				
Switzerland			√			√		
Turkey					√			
United Kingdom	√	√	√	√			√	√

3.2.3 *Developments until 2030*

A number of countries have large ambitions to meet Paris Agreement targets and may upgrade the incentives to meet them. So the incentives listed above will be updated. With the increase in wind and solar energy, the need for buffering can be met partially with charging strategies for electric cars. Hence, there may be other motives to have a substantial amount of electric vehicles entering the market. The focus on biomass does not have the same issues with the need of buffering for robustness.

3.3 Announced electric vehicle models

For the coming years car manufacturers have announced to launch several new EV's. In the table below these are summarized. A few observations can be made:

- The most new models are expected to be introduced in 2019. Any introductions after 2020 are not announced yet or unknown.
- The maximum range of the announced vehicles equals 500 kilometres.
- The expected minimum resale values show that announced vehicles mainly can be categorized as higher segment vehicles. .

Tabel 3.2: - Announced EV models (Source: ev-database.nl)

Brand	**Type**	**Announced/ Concept**	**Year of introduction**	**Expected minimum resale value**	**Range**
Audi	e-tron quattro	Concept	later in 2018	€ 82.500	400
Audi	e-tron sportback	Concept	2019	€ 85.000	400
BMW	iX3	Concept	2020	€ 70.000	350
Faraday[6]	Future FF91	Announced	2018	Unknown	Unknown
Ford[7]	Several models	Announced	2020	Unknown	480
Huyndai	Kona Electric 40 kWh	Announced	2019	€ 35.000	250
Hyundai	Kona Electric 64 kwh	Announced	Later in 2018	€ 39.150	390
Jaguar[8]	I-Pace	Announced	2019	Unknown	500
Kia	Niro EV mid range	Announced	later in 2018	€ 35.000	230
Kia	Niro EV long range	Announced	later in 2018	€ 40.000	370
Lucid Motors	Air	Concept	2019	€ 75.000	375
Mercedes	EQC	Concept	2019	€ 70.000	350
Nissan	leaf E-plus	Announced	2019	€ 40.000	350
Porsche	Taycan Mission E	Concept	2019	€ 150.000	450
Tesla	Model 3	Announced	2019	€ 38.000	370
Tesla	Model 3 Long range	Announced	2019	€ 50.000	490
Tesla	Model 3 Long range dual motor	Announced	2019	€ 55.000	460
Tesla	Model 3 Long range performance	Announced	2019	€ 70.000	450
Tesla[9]	Model Y	Announced	2020	Unknown	Unknown
Volkswagen	I.D.	Concept	2019	€ 35.000	375
Volvo[10]		Announced	2019	€ 34.116	400

---

[6] Newmotion.nl
[7] Businessinsider.nl
[8] Newmotion.nl
[9] Businessinsider.nl
[10] Businessinsider.nl

3.4 International studies

3.4.1 JRC report on EV sales

JRC published some initial results of the impact that a technology transition scenario may have on the evolution of the EU passenger car fleet, and how this influences the fleet emissions and energy use. This was done by linking two models developed by JRC: 1) Powertrain technology transition market agent model (PTT-MAM) and 2) DIONE fleet impact model.

1. PTT-MAM-model

The PTT-MAM-model is a system dynamics model that studies the interaction between market agents in the automotive sector, with respect to the uptake of new powertrain technologies on passenger cars and vans, up to 2050. The agents are manufacturers, infrastructure providers and maintenance companies, authorities and end users.
With the model, key ‘levers’ can be identified that influence the adoption rate of new technologies, both on supply and demand side.

2. DIONE model

With the DIONE fleet impact model, scenarios of future European road vehicle fleet compositions can be analysed. This includes vehicle efficiency development, activity patterns, WTW greenhouse gas emissions and energy consumption up to 2050. It can be run for EU28, but also for specific countries.
It uses widely used emission factors from COPERT and it can model the energy consumption of each vehicle type separately.

The new registration composition and fleet composition from PTT-MAM are input to DIONE.

The baseline calculated assumes oil price development as in EC 2013, an EV learning rate of 10%[11], no more EV subsidies after 2015 and passenger car CO_2 targets of 70 g/km in 2025 and 41 g/km in 2050.
The technology transition scenario assumes 50% higher oil price increases, 20% EV learning rate, EV purchase subsidy of 25% of the price penalty in 2020-2025 and targets for passenger cars of 56 g CO_2/km in 2025 and 27 g CO_2/km in 2050.

New market registrations are driven by user ‘willingness to consider’ plus the relative attractiveness of a powertrain.

---

[11] The assumption that each doubling of cumulative production of EVs leads to a cost reduction of 10%.

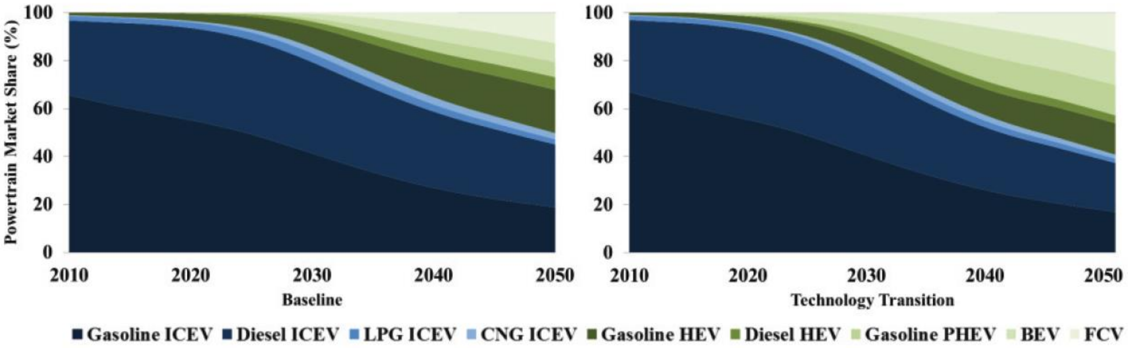


Figure 3.5: Powertrain fleet composition transition (source: [Harrison 2016])

In the baseline scenario, plug-in hybrids and BEVs have a fleet share of one third in 2050, while sales contribution is about 50% by that time. In the technology transition scenario, the conventional vehicle fleet share in 2050 is 40%, although sales has dropped to 14%. The small difference is partly related to the assumed strong increase in GDP, which induces a larger fleet and distance driven.

Because of the slow turnover speed of vehicles (long life span) and the resulting limited cumulative effect of a small sales percentage on the fleet in 2050, the timing of the uptake curve is of large importance for the fleet composition. In a similar way, the cumulative CO_2 emission is dependent on this timing [UBA 2017b].

3.4.2 JRC report on the possible influence of EU CO_2 car legislation on transport emissions

[Thiel 2016b] concludes that a 70 g/km target in 2030 would decrease the total EU transport emissions of CO_2 already by 5%. Assuming a learning rate of 10% in EV technology, deployment of EVs is a viable option to attain these reductions. In case of 70 g/km, more than one quarter of the passenger car transport demand is covered by EVs by 2030. Total system costs increase by less than 1%.
The learning curve has a large influence, meaning that policies should be robust to achieve reductions at lowest costs. A learning rate of 12.5% for example pushes EV deployment enough to end up below 70 g/km without additional system costs, according to the report.

3.4.3 Ricardo report on the impact of post-2020 CO_2 regulations

In the Ricardo report [Hill 2018] it is concluded that, if passenger car and van CO_2 targets would be set in both 2025 and 2030, the greenhouse gas emissions over the period until 2030 are 18% lower than in the case a target is set only in 2030. In terms of TCO, the benefits for the perspective of the first user are greater in a 30% reduction scenario than in a 40% or 50% reduction scenario. The higher scenarios are of more benefit to second users: the annual fuel cost reduction of efficient vehicles is enjoyed while only paying a fraction of the additional purchase cost that the first owner had. This means that stimulating low-emission vehicles can have a levelling effect on the automobility costs across income groups, in the long term. The stronger the increase in energy prices, the larger the levelling effect will be by 2030.

A scenario with a declining share of diesel vehicles in Europe was assessed as well. Hill concludes that even the high ambition (-50%) CO_2 targets can be achieved cost-effectively by 2030. However, the effectiveness of CO_2 reductions is estimated 18% lower, meaning that the real world emissions will not decrease as much as in the base scenario; less diesels means more petrol cars, which have, as stated in the report, a larger gap between WLTP and real world emissions. In general a potentially further increase in the gap between real world emissions and type approval emission values for petrol vehicles is a risk; it would reduce the effectiveness of the reduction policies.

3.4.4 Potsdam report on German vehicle sales composition in 2030 based on expert elicitation

[Krause 2016] assessed possible characteristics of the 2030 German new passenger fleet, based on elicitation of seven experts from six German Original Equipment Manufacturers (OEMs). The results were used to build relationships in a Bayesian Belief Network: a model to predict how future technology, economic and policy scenarios will influence model projections. The network predicts that the 2030 traditional, internal combustion engine vehicle will have lower user costs per kilometre than plug-in hybrids or battery electric vehicles for most scenarios, and that internal combustion engine vehicles (ICEVs) will remain the dominant vehicle type in the 2030 German new fleet. Further CO_2 reductions on ICEVs are not economically viable from a user point of view, but can be viable for plug-ins and battery electric vehicles.

3.4.5 AECC/LAT report on sales composition

LAT evaluated a business as usual-scenario with respect to CO2-emissions of road traffic up to 2030, and the effect of a combination of improved vehicle technology, fuel and ICT measures.

The main conclusion is that reaching future CO_2 targets for road transport does not necessarily mean more advanced vehicle technology. It might be enough to use more sustainable fuels and moderate ICT implementation, such as adaptive cruise control, green driving, variable speed limits and urban traffic control.

According to LAT, a ‘low effort’ scenario would lead to a passenger car average CO_2 emission of 92.3 g CO2/km (type approval, NEDC) in 2030. This includes mostly market driven downsizing, and a mild increase in EVs. A high effort scenario reaches 56 g CO_2/km (type approval, NEDC) in 2030 due to significant penetration of PHEVs.

3.5 Manufacturing capacities

3.5.1 Battery manufacturing

A lot of effort is put in improving battery specifications, in terms of capacity per kg and per litre, power per kg and per litre and durability, while reducing the manufacturing costs. Another challenge is to reduce the use of certain materials that have a high unit price. Cobalt is the most prevalent one. The demand of cobalt in other applications is relatively low, which means that the production has to step up to a large extent in order to keep up with projected EV sales and battery capacity increase per EV.

To have enough cobalt for 125 million light duty EVs worldwide in 2030[12] (40 times the amount of today), the cobalt production would have to grow by a factor of 10.

Price surges such as the ones that occurred over the last few years may affect the declining battery price curve and generate uncertainty around EV uptake. This works the other way as well: when EV uptake is predictable, production capacity of cobalt can be increased accordingly, avoiding strong price fluctuations.

Lithium-ion chemistry is expected to remain the chemistry of choice for EV technology for many years to come. In the longer future, other lithium- and non-lithium-based chemistries are expected to gain ground [Meeus 2018].

In 2017, about 125 GWh of EV batteries was produced [Perkowski 2017, Cleantechnica.com 2018]. The production capacity is projected to be doubled to 250 GWh in 2020. Panasonic estimates a sixfold production of battery units in 2026 compared to 2017. Its own production volume is estimated 35 GWh in 2019.

Most current EV manufacturers source cells from LG Chem, including Renault, and Nissan from 2019. Tesla uses Panasonic, and BYD produces its own batteries.

Announced battery factories in China:
- Contemporary Amperex Technology: 24 GWh in 2020 (total by then: 88 GWh)
- BYD: 24 GWh in 2019 (total by then: 60 GWh)
- Eve Energy: 1.5 GWh in 2018 (total by then: 7.5 GWh)
- Funeng Technology: 10 GWh being built now
- Guoxuan High-Tech: 4 GWh in 2018

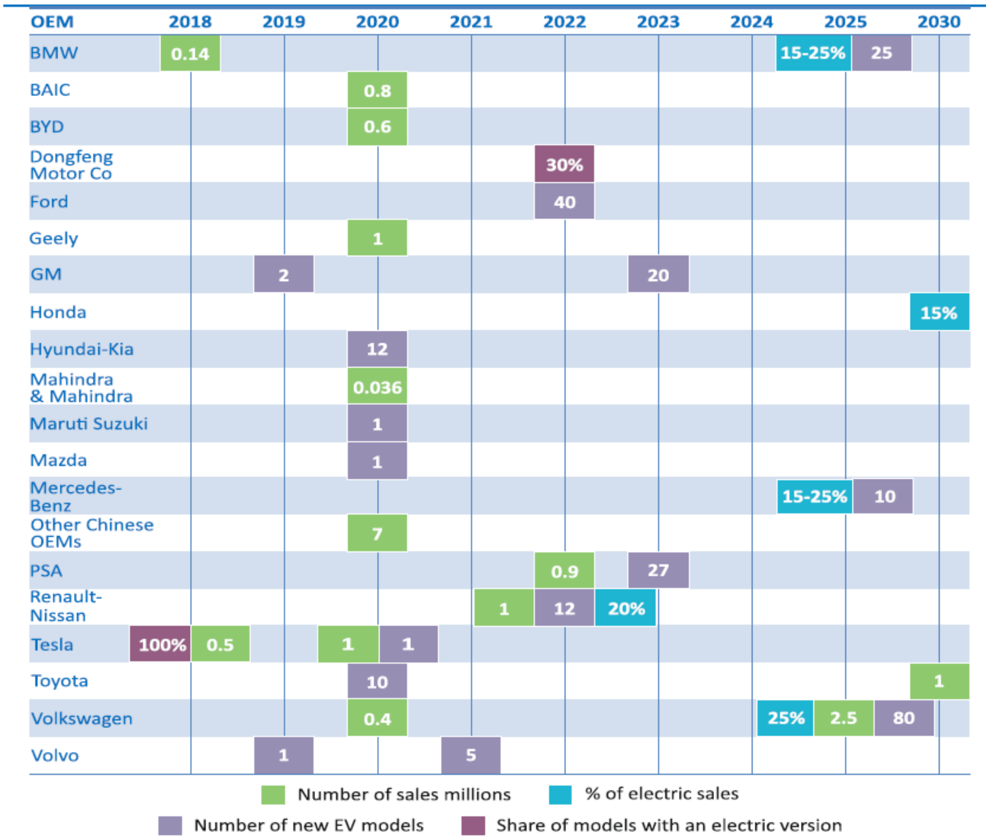
Looking at the market, for a viable electric car a battery capacity of about 40 kWh is needed. The current battery production is only sufficient for a few percent of the worldwide sales volume of passenger cars. For large scale uptake, the battery production capacity needs to increase by a factor of 10 by 2030.

3.5.2 EV manufacturing

Announcements of EV models as well as projections of EV sales have been issued by many car manufacturers. Figure 3.6 shows an overview of these, taken from the IEA Global EV Outlook 2018.

---

[12] The EV fleet size resulting from the IEA New Policies Scenario [IEA 2018], assuming existing and announced policies



OEM	2018	2019	2020	2021	2022	2023	2024	2025	2030
BMW	0.14							15-25% 25	
BAIC			0.8						
BYD			0.6						
Dongfeng Motor Co					30%				
Ford					40				
Geely			1						
GM		2				20			
Honda									15%
Hyundai-Kia			12						
Mahindra & Mahindra			0.036						
Maruti Suzuki			1						
Mazda			1						
Mercedes-Benz								15-25% 10	
Other Chinese OEMs			7						
PSA					0.9	27			
Renault-Nissan					1 12 20%				
Tesla	100% 0.5		1 1						
Toyota			10						1
Volkswagen			0.4					25% 2.5 80	
Volvo		1		5					

🟩 Number of sales millions
🟦 % of electric sales
🟪 Number of new EV models
▨ Share of models with an electric version

Figure 3.6: OEM announcements of electric cars [IEA 2018].

Reuters has analysed that global carmakers are planning to invest 90 billion dollars in electric vehicles [Reuters 2018]. This is at least 19bn in the USA, 21bn in China and 52bn in Germany. German and US automaker executives have said in interviews that the bulk of those investments are earmarked for China, where the government has enacted escalated EV quotas starting in 2019. In Europe, announcements by the industry have not always materialized in actions. Such announcements also play a role in economic affairs.

The actual increase of production capacity cannot be derived from this information.

The projected number of sales in 2020 in the graph sums up to almost 11 million EVs. The battery production capacity is estimated to be double by then, amounting to 250 GWh. 2020 EVs will predominantly be vehicles in the larger size, more luxurious segments (compact family cars and higher), as will be explained in chapter 6. Assuming an average battery size for these vehicles of 60 kWh in 2020, a simple calculation shows that the joint ambition of the manufacturers outpaces the battery production capacity growth. 650 GWh would be needed to make the announcements happen, even without the sales by manufacturers that did not quantify the 2020 sales numbers.

4 European CO_2 policies and the influence on the fleet composition

4.1 Introduction

The influence of CO_2 policies on the potential CO_2 benefits of the uptake of EVs has many facets. First of all, the real emission level of conventional, internal combustion engine vehicles (ICEVs) does not correspond to, and has no fixed relation with, the type-approval CO_2 values of the vehicles sold. This has an effect on the real world emissions that set the reference point for 2030, as explained in paragraph 4.2. Furthermore, changes in the test procedure will lead to a change in the ratio between reported emission levels and real world emission levels for conventional vehicles, while flexibilities in the new procedure introduce an additional uncertainty about the 2030 target levels. This is elucidated in paragraph 4.3. Next, manufacturers have multiple ways to reduce the CO_2 emissions of their sales fleet towards 2030, including reducing emissions from traditional, internal combustion engine vehicles (ICEVs). Furthermore, plug-in hybrid vehicles (PHEVs) can play a role in meeting the targets. The ‘mix’ of technologies employed will be dependent on the stringency of the policy target, as demonstrated in paragraph 4.4 and 4.5. Lastly, the uptake of EVs helps meeting air quality targets as well, which could generate an extra pull, which is described in paragraph 4.6.

4.2 ICE technology developments and the ‘gap’

EU CO_2 emission targets can be at least partially met by decreasing the CO_2 emissions per kilometre of gasoline and diesel powered vehicles. As widely understood, in the real-world CO_2 emission levels of passenger cars are higher than on the New European Driving Cycle (NEDC) label. Actually, the gap between real-world emissions and NEDC type-approval emissions has increased in the last fifteen years. This has a number of causes:

- Manufacturers increasingly exploit the so-called ‘test flexibilities’, i.e., bandwidths and ambiguities in the prescribed test procedures and conditions, to achieve lower CO_2 emission values on the type approval test without changing the vehicle.
- The increased use in real-world driving of energy consuming auxiliaries such as air conditioning and day-time lighting, which are not switched on during the type approval test.
- the application of CO_2-reducing technologies that yield higher reductions on the type approval test than under real-world driving conditions.

As many of the advanced technologies described above are gradually being implemented, it can be concluded from the growing gap that the last cause is true for (most of) these technologies: the real world CO_2 reduction is smaller than the effect on the type approval value.

The latest state of play is described in [Van Gijlswijk 2018]. Figure 4.1 shows that the gap is between 40 and 50 g/km for both diesel and gasoline passenger cars sold in the Netherlands in 2017 (average: 46 g/km). In other words: the average real world emissions are 46 g/km higher than the average NEDC value.

The large deviation in the gap in 2015 can be explained from the peak in plug-in hybrid electric vehicles in that year. This is further explained in paragraph 4.5. The result is that strict targets will have limited effect. The current trend deviates only little from the earlier estimates dating back to 2010 [Ligterink 2010].

Another interesting conclusion that can be drawn from the graph, is that the average absolute CO_2 emission value of cars sold in 2017 is quite a bit higher than for those sold in 2016 or 2015. The reasons can probably be found in the cutback on fiscal advantages for plug-in hybrids, the announcement of the enforcement of the WLTP test cycle (see paragraph 4.3) and a trend towards heavier and larger cars as a result of increased economic prosperity.

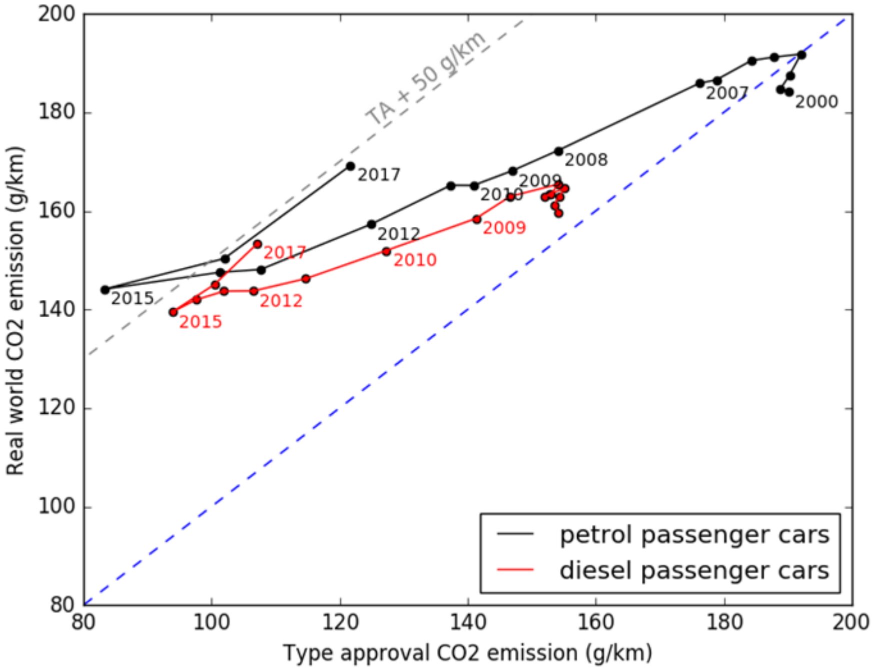


Figure 4.1: Average real-world CO_2 emissions versus the average type approval value of new petrol and diesel cars, including plug-in hybrids, differentiated by the year of introduction / registration in the Netherlands (2017 value is preliminary) [Van Gijlswijk 2018]

As can be derived from the graph as well, is that the gap does not seem to increase significantly over the last few years, besides the plug-in hybrid effect. Even though it is not known what the real world effect will be of taking further steps improvement of efficiency of the vehicle, it seems safe to say that both type approval and real world emission values will benefit. The two main ways to increase the efficiency of an internal combustion engine vehicle are to improve drivetrain efficiency or to improve vehicle parameters such as air drag (from which battery electric vehicles benefit even more).

There is a variety of technologies readily available, and applied to a part of the vehicles on the market today already. According to [ICCT 2016] the extent to which these technologies are needed by manufacturers to meet CO_2 emission targets was systematically overestimated, as have the final per-vehicle costs of meeting standards.

One reason for these overestimations is the reliance on industry surveys to estimate the costs and potential.

Technologies that are applied and can be further deployed:

- Gasoline direct injection
- Continuously variable transmission or 6+ gears
- Single stage and two-stage turbocharging plus downsizing of the engine
- Variable valve lift and timing / cam-profile switching
- 12V start stop system
- 48V belt starter-generator (mild hybrid)
- Hybrid
- (Cooled) exhaust gas recirculation
- Two-stage and fully variable compression ratio
- Miller/Atkinson cycle
- Low-friction design

And the more generic measures:

- Rolling resistance reduction
- Vehicle mass reduction
- Aerodynamic drag reduction

At a certain point, the marginal costs of producing an ICEV having more of these technologies on board may surpass those of the marginal costs of producing an electric vehicle, from a manufacturer's perspective. It is likely that manufacturers will in that case fill the remaining gap to the company's emission target with electric vehicles.

ICCT has calculated the additional costs per vehicle (2014 model) as a function of the NEDC emission target. Assumed is that first all ICEV improving technologies are applied before electric vehicles are introduced. See Figure 4.2.

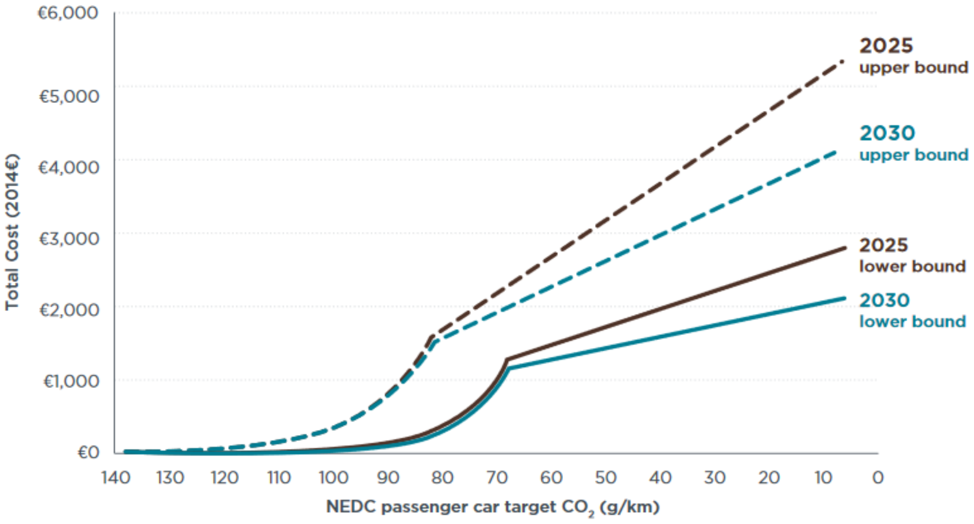


Figure 4.2: Total incremental cost of reducing the CO_2 emissions of an average passenger car in the EU (assuming full deployment of combustion engine technologies before transitioning to electric vehicles); taken from [ICCT 2016]

4.3 Transition to WLTP and the CO_2 targets

From September 2017 onwards newly introduced models have to comply to the Worldwide Harmonised Light Vehicle Test Procedure (WLTP), which replaces the New European Driving Cycle (NEDC) as a type approval procedure. From September 2018, all newly sold vehicles have to comply. Until 2021, the CO_2 emission will be communicated as calculated NEDC values. These may not be equal or related to the present NEDC values. The test cycle was replaced to be more representative for real driving conditions, and should allow for less flexibilities. As a consequence, the gap between WLTP and real world emissions should be reduced, compared to the gap between NEDC and real world.

The current target is 95 g CO_2/km on the NEDC cycle. To move towards WLTP and still be able to establish whether the sold vehicle fleet complies with the 2021 target, the European WLTP regulations contain procedures to convert WLTP CO_2 test values into ‘old’ NEDC values, using calculated, or partially measured, values. In 2021 every car will thus have a declared WLTP CO_2 value as well as a calculated or measured NEDC CO_2 value. For all new vehicles that are sold in the EU in 2021, the average WLTP and NEDC values are determined. On the basis of the average NEDC value the compliance to the 95 g/km-target is determined. The EC has proposed to determine the CO2 targets in 2025 and 2030 based on the ratio between the average WLTP and NEDC values. This means that the higher the WLTP value in 2021, the higher the future targets will be. With this system, there is a motivation for car manufacturers to set the declared WLTP values as high as possible, while in the meantime maintaining NEDC values, on average (calculated or measured) that do comply to the 2021 CO_2 standards.

The CO2MPAS calculation tool to convert NEDC values to WLTP, also contains a motivation to present high WLTP-values as well as high calculated NEDC values. The tool is under regular evaluation. If NEDC values are higher than expected, it may be decided to adjust the effect of the tool to correct this, leading to an increased difference between WLTP and calculated NEDC values, which reduces the required effort to meet the future CO_2 targets.

Without any control mechanism in place the manufacturers may increase the gap between the NEDC value and the WLTP value of the same car. The Commission has recently noted inflated WLTP values. It is doubtful if this was intentional from manufacturers, years ahead of the transition in 2021. But the fact that WLTP values are fluid is reason for concern. The possibility of flexibilities on the WLTP was already raised [Ligterink 2015]. Still there is little knowledge on the nature and the magnitude of the flexibilities on the WLTP. But given the fact that only a fraction of the current gap is explained, it is safe to assume there is an arsenal of flexibilities not covered in the WLTP [Ligterink 2016].

4.4 Impact of 30% or 40% reduction target on European EV sales

The simplest assumption is that 95 g/km is the ultimate target for conventional vehicles, and further reductions have to be filled in with electrification. Consequently, 30% electric vehicles in the new sales are often assumed for 2030 to meet CO_2 targets for 2030. The underlying reasoning seems rather limited.

In the Netherlands diesel cars in higher market segments with CO_2 values of 90 g/km have been on sale since 2013. It may be safely assumed that energy efficiency of the combustion engine has not stopped since 2013. Furthermore, according to calculations of TNO as well as of the ICCT, 70 g CO_2/km should be possible for ICEVs, using technologies as the ones described in paragraph 4.2, with low additional net costs. This would mean that a target in the range of 30% (see WLTP considerations in the previous paragraph) might be achieved without EV influx at all. To the extent EVs are part of the mix in Europe towards 2030, the distribution among countries has implications for the Netherlands as well. The Netherlands has a relatively large share of small cars. This market may be used by manufacturers to sell compact cars to meet overall targets.

All in all, manufacturers' strategies to meet the 2030 targets can be divided roughly in five elements:

1. Have a high starting value for the WLTP in 2021, i.e., maximize the NEDC-WLTP gap
2. Exploit the flexibilities on the WLTP after 2021 to reduce CO_2 values with limited real-world consequences
3. Apply fuel efficient technologies further on conventional and hybrid cars
4. Use a fraction of PHEVs to balance traditional vehicle sales
5. Use a fraction of EVs to balance traditional vehicle sales

Any car maker will make its own choices here. For high-end manufacturers it has already been observed that the PHEV plays a role in balancing the average CO_2 figure. For the manufacturer active in the A- and B-segment, the 95 g/km has been less urgent, in particular with the NEDC test.
Only EVs to balance seems rather limited as strategy. So only in the best case 30% EV in the total European sales may be expected (if policy is the driver). More likely half of that fraction is used to meet European targets for 2025 (15%) and 2030 (30%). It is expected that on all of the five parts of the strategy the manufacturers may aim for at least 5% room for the 30% target, leaving 10% EVs as a low end value.

A shift towards 40% and higher targets

European member states who have large ambitions on reducing CO_2 emissions are generally more vocal than countries with other agendas and issues. The 30% target for the reduction from 2021 to 2030, proposed by the Commission, was met with an opposition from the more vocal countries, as it was not helping their ambitions, as they considered them in line with the Paris Agreement. Moreover, technical feasibility and costs were no longer seen as insurmountable hurdles post-2020 for a broad roll-out of electric vehicles across Europe, replacing the sales of conventional cars to a large extent. In this atmosphere, targets of 40% and even 50% CO_2 reduction from 2021 to 2030 were proposed. This would increase the need for electrification, and push the electric vehicles in all market segments and for all manufacturers. It may lead to some difficulties for manufacturers now planning to meet the 95 g/km target with mainly fuel efficient technologies on conventional cars, as they will have to change their strategy quickly. Some manufacturers may be wary from earlier, unsuccessful excursions in the field of electric cars as well. The European Commission has in the past been sensitive to arguments of manufacturers concerning the long lead time of developments in the industry making it difficult to change strategy in short term.

The minimum effect on EV uptake of targets beyond 30% reduction is illustrated in Figure 4.3. If the maximum reduction potential of ICEVs is indeed 30%, the minimum share of EVs is 0% if the target is -30%. In the case of a 50% reduction target, almost 30% EVs will be needed (vertical dashed line). Of course, if more EVs are sold, the space can be filled by higher emissions of ICEVs. The blue upward line indicates this: the target remains the same, and additional EVs are swapped for a lesser reduction on ICEVs (or, less reduction is necessary on ICEVs if additional EVs are sold).

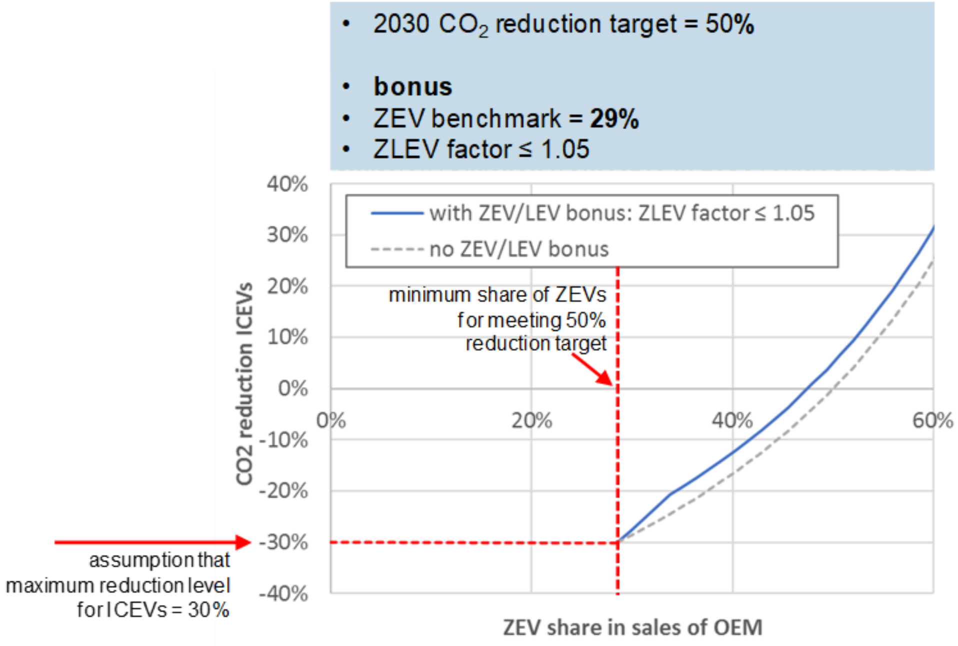


Figure 4.3: Relation between European CO_2 reduction target in 2030 and minimum EV share (LEV ~ plug-in hybrid, ZEV = battery electric vehicle or fuel cell electric vehicle)

4.5 Possible role of PHEV

The NEDC CO_2 emission of most of the plug-in hybrid vehicles on the market at the moment is 49 g/km. This means that a plug-in hybrid is 'worth' 0.5 battery electric vehicles in terms of CO_2 reduction (all else equal, such as annual mileage). The 30% EV in case of a 50% reduction target, as described in 4.4, can be fulfilled by about 60% PHEVs.

The real world emissions of plug-in hybrids in the Netherlands are much higher than shown on the label. The CO_2 emissions per kilometre are determined by the share of kilometres that the vehicle is running with an empty battery (hybrid mode), and its fuel consumption in these conditions. In [Van Gijlswijk 2018] plug-in hybrids were analysed separately, on the basis of the tank pass data set. From the frequency distribution of real-world fuel consumption, the electric distance as well as the fuel consumption on the engine was determined.

For most plug-in hybrid models, the fuel consumption is around 7.5 l per 100 km when running in hybrid, e.g., charge sustaining, mode. The percentage of kilometres in electric mode is mostly around 25%.

That leads to an average fuel consumption of 7.5*0.75 = 5.6 l per 100 km (obviously, on top of this electricity is consumed). This corresponds to approximately 140 g/km.

On the NEDC type approval, the share of electric kilometres is much higher than in the Dutch reality. Therefore also the gap between type approval and real world is larger than for engine-only vehicles: 90 g/km. The legislation favours PHEVs in CO_2 values, by the procedure of determining the weighed CO_2 emissions. Consequently, the real-world emissions are about a factor three higher than the official numbers.

The main reason for the gap being this large, is the fact that the evaluation of PHEVs in the NEDC was based on 25 km driving on the combustion engine combined with the electric range on the NEDC test. Consequently with an electric range on the NEDC of 25 km the CO_2 emission from driving on the combustion engine can be halved for the type-approval value CO_2 value. Therefore for 50 g/km CO_2 emission factory values of a high-end vehicle with about 150 g/km CO_2 on the combustion engine (i.e., charge sustaining driving), an electric range on the NEDC of less than 50 km was needed. This turned out to be the characteristics of the common PHEV model for many manufacturers. In real world the range is more likely in the order of 30 km, due to motorway velocities where the air drag, and the work demand per kilometer, is higher and due to the power consumption of the auxiliaries such as lights, heating and cooling which are turned off in the NEDC test. This range is hardly suitable for full electric driving between cities, even in a densely populated country like the Netherlands.

With the WLTP the situation it is more complex, but in practice hardly more stringent. Auxiliaries are still turned off in the WLTP. On the basis of some driving data a utility factor is derived, which does not reflect the PHEV use in the Netherlands. It is based on a combination of longer and shorter trips with weighing factors. It is claimed the range determined in the WLTP is a better representation of the real-world range than the NEDC. Indeed, the average velocity increases from 33 km/h on the NEDC to 47 km/h on the WLTP. The additional work for a brake energy regenerating vehicle like an PHEV is only the associated additional air-drag, which is 40% higher on the WLTP than the NEDC. This is expected to reduce the electric range for a heavy vehicle, with battery, like a PHEV by about 25%. This will not significantly change the gap in CO_2 emissions between the type-approval value and the normal use of PHEVs in the Netherlands, which is a factor of 3. Hence, little real-world CO_2 reduction is expected from the transition to PHEVs with unchanged use pattern, although the type-approval values suggest a large effect.

4.6 Pull on BEV’s for air-quality and national targets from Paris Agreement

All across the world electric vehicles are put forward as the sustainable solution to reduce CO_2 emissions and improve air-quality, with a growing demand for mobility. Hence, the available EV may not reach the Netherlands with a stronger pull from other countries. Emerging economies may want to skip the combustion technology. Moreover, the consequences of European air-quality standards, with a number of countries having been declared incompliant by the European Commission, may be even more drastic. Electrification is not a simple solution for air-quality problems, but with an associated positive image and positive side effects in terms of CO_2 reduction, it may emerge as a measure across Europe.

The Netherlands, with a limited fraction of diesel vehicles, does not need to take such measures for air-quality.

4.7 Conclusions: contribution of BEV and PHEV to meet CO_2 targets

The European CO_2 policies and test procedure designs have a large influence on the potential of battery electric vehicles. In case of a 30% reduction target, the influx of EVs on a European level may be somewhere between 0% and 30%, dependent on the measures taken on ICEVs to reduce the CO_2 emissions. From a technical point of view, the entire reduction of 30% could be achieved with ICEVs, meaning that manufacturers do not need EVs to reach the targets. There are indications that at least a part of these measures are cost effective for manufacturers, and therefore at this point likely to be taken. In the case of more stringent targets, e.g. 40%, (partly) zero emission vehicles are indispensible. The change from NEDC to WLTP as test programme for new cars, adds uncertainty about the target in 2030. Manufacturers may exploit room in the new procedure to slightly relax the improvement needed between 2021 and 2030. This may lead to less necessity for EVs.

Instead of full electric vehicles, plug-in hybrids may be utilized to reduce type approval CO_2 emission levels. Two PHEVs have a similar effect to one EV on the reported emissions (2018). In reality, the CO_2 emission of plug-ins is hardly lower than that of comparable ICEVs, due to the use pattern and the large gap between test and real world.

Among European Member States there is competition for zero emission vehicles, not only to meet CO_2 targets, but also to comply to air quality standards.
The availability of EVs in the Netherlands is therefore dependent on the effort made by other countries.

In this chapter solely the influence of policies was assessed. It is challengeable though that the EV fleet development would remain policy driven until 2030.
In the next chapter it is demonstrated that this may change, driven by market developments.

5 Necessary requirements for EV uptake

5.1 Introduction

A car owner who has to rely on on-street parking, needs a charging station nearby to ensure a sufficient electric range in the morning. This is one of the many considerations on which people base their decision whether to buy an electric car or one with a combustion engine. The initial purchase costs, offset by a lower cost of use will also yield a barrier for the switch from conventional to electric. In this chapter, a number of constraints on the uptake of electric vehicles are discussed that need to be taken away to achieve broad uptake of electric vehicles.

5.2 Purchase costs and total cost of ownership

If a purchase decision is to be made for a new passenger car, a private person will reason differently than a fleet owner or a person that drives a company car, even if costs were the only criterion. A fleet owner will probably look at the total costs of ownership for a fixed period of time. This includes sales price, costs of financing, projected revenue after use, fuel costs, and costs of maintenance, road tax, insurance. Electric vehicles of today are known to have higher sales prices than functionally comparable ICEVs, but lower costs per kilometre. This way, electric vehicles may be attractive financially despite a higher sales price.

Most private buyers will not know in advance how long the car will be owned and used by them, or how many kilometres will be driven in that time. Moreover, not everyone feels the need, or has the skills, to compare cars on costs of ownership, and even if they do, some information such as residual value when selling it after a number of years is more difficult to predict for a private person. Moreover, for EVs the residual value is yet more uncertain than for ICEVs. Once the technology is mature, in due course a stable second hand EV market will be established, which gives more certainty over the residual value. For now, technological improvements and improving charging capabilities and services of newer vehicles put the residual value of second hand EVs under pressure.

The results of the second hand resale value analysis in Chapter 2 suggest that vehicles in the E segment depreciate slightly slower than vehicles in the A segment. For ICEV, large vehicles depreciate quickest. There are many possible reasons for this effect, but one possibility is that large EVs (Tesla Model S and Tesla Model X) have a battery size that is suitable for a larger group of (second-hand) users, even in case the capacity drops a bit, boosting its value on the second hand market.

Another factor of importance for private buyers is that the purchase requires a large transaction at once. A more economical car during use may cost more to buy. If the money is not available (as savings money or a loan), it still cannot be bought. It is likely that private buyers tend to weigh the purchase price more, where businesses tend to give more weight to the total cost of ownership. Private lease, which is gaining market share quickly at the moment, can reduce these barriers, especially when fuel / electricity costs are included (operational private lease).

Electric cars become economically viable if the purchase price premium can be compensated by lower costs of use, compared to conventional cars. Considering

TCO for a fixed number of years (say 4 years), driving high mileages improves the business case. The ones that drive the largest distances are the first ones to reach break-even. On a side note, this is obviously easier with vehicles with a large battery, which have a larger price premium. It is a matter of balance between the two.

The fixed costs and variable costs ratio is different per market segment. Therefore, it can be expected that, taking financial attractiveness as the sole criterion, the order in which EVs become of interest for buyers will be: see Figure 5.1.

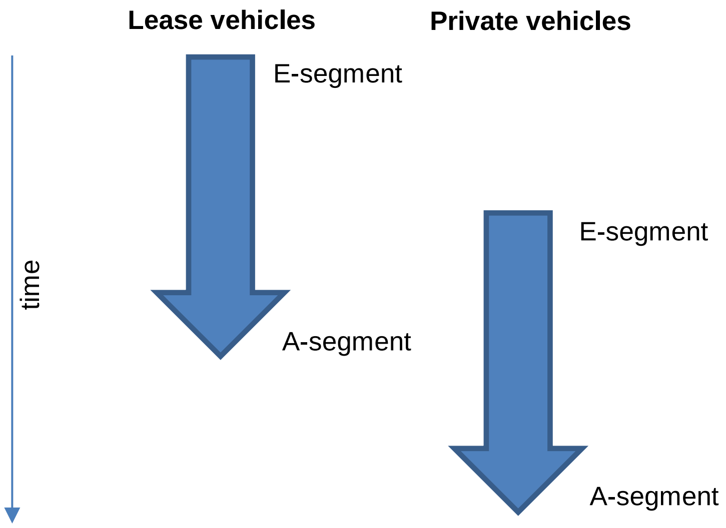


Figure 5.1: Indication of the order in which EVs become economically attractive compared to ICEVs (lease: based on TCO; private: based on sales price)

If no financial policies were influencing the costs, the uptake would be gradual, starting with the segments in which the new sales are limited.

5.3 Electric vehicles in Dutch usage

5.3.1 Electric coverage of Dutch vehicle usage

For large scale uptake of EVs in the Netherlands, the properties should suit the use cases of a large share of the Dutch vehicles. Although Dutch cars cover only 36 kilometres per day on average[13], the variation from day to day and among the vehicles is very large. The range of an EV should cater for every day, also for the longer trips. Therefore it is important to consider outliers, since these impact the decision whether to buy an electric car or not. Several factors related to vehicle usage are important to consider:

- **High mileage use**
  Although the average mileage and typical trips suggests many vehicles can be replaced with electric variants for most use without range restrictions.

---

[13] CBS, 2016

However, the typical spread in mileages in every group of vehicles is in the order of 100%. Hence a large number of people have high mileages which may be prohibitive for EV use.

- **Holidays abroad -** cars are the main transport mode (54.2% of holidays abroad, corresponding to approximately 9.7 million car movements) for travelling abroad according to the mobility survey[14]. Currently, EVs have a range of 90 (e.g. Citroen C-Zero) - 500 kilometres (Tesla Model S). This implies that for long distance travels, such as for holidays, the final destination might not be reached without charging on the go. This can be experienced as a barrier for purchasing an electric car.
    - Car lease companies offer services for temporary alternate transportation (for example for holidays). Large scale adoption of EVs could put pressure on this measure.
- **Caravans –** People who are in the possession of a caravan will experience this as an extra hurdle for purchasing an electric car; pulling a caravan requires additional power at the expense of the range. Approximately 800.000-900.000 people will probably experience this barrier. Apart from caravans, about 80% of the passenger cars, have a towing hook, or towing hook capabilities, for caravans and trailers weighing 500 kg or more. The question is if owners would consider EVs without towing capabilities.

Next to that, the overview in 6.1 shows that the vehicles available and future models (which are already announced) do not show fully coverage across the various price segments (only segments C-E) and do not improve significantly on range compared to the current models.

5.4 Charging infrastructure and network capacity

The EU Alternative Fuels Infrastructure (AFI) Directive recommends a ratio of one publicly accessible charger for ten electric cars. The amount of chargers actually needed might be lower: in Norway, there are 19 EVs (including PHEV) per public charging position [EAFO 2018]. 8% of the passenger car fleet in Norway is electric.

Whether additional overnight charging at a private charger is required, depends on the vehicle usage. Furthermore, as the fleet grows, it can be expected that also more people in denser populated areas will want to drive an EV. It is not always possible or desirable to install private chargers there.

As more energy companies, automakers, utilities and grid service providers form alliances to develop EV support infrastructure, government funding could be gradually withdrawn from the buildout of public charging, moving towards self-sustaining and business-driven solutions [IEA 2018]. Ensuring higher occupancy for publicly accessible chargers is crucial to enable this transition [IEA 2018].
The reason for this is that the investment costs of the charging infrastructure can then be spread over a larger amount of charged electricity. At the present Dutch (fast) charger stations electricity is sold for around 30 cents per kWh, while the real cost is around € 1 / kWh. With a higher occupancy the economic viability will be improved. More information can be found in [Verbeek 2018] and http://nklnederland.nl. Figure 5.2 gives an estimation of the relation between occupancy and kWh costs.

---

[14] Vakanties; kerncijfers 2016 (2017)

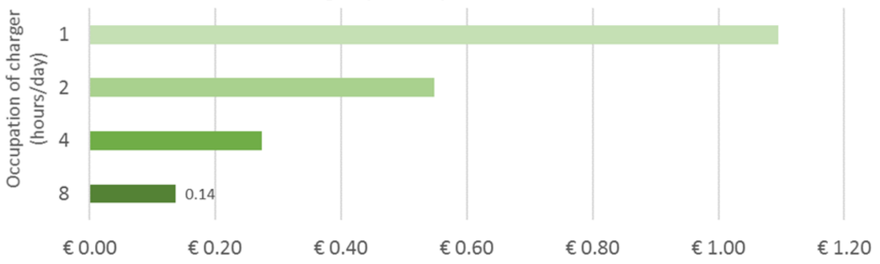


Figure 5.2: Costs per kWh of fast charging (50 kW) as function of the occupancy of the charger (exclusive of electricity costs)

In Figure 5.3, adapted from [Verbeek 2018], the CAPEX costs of the charger itself have a fair share in the total costs of providing electricity at a fast charger, even at an occupancy of 8 hours per day. (Assumptions for electricity price are taken from EU reference scenario [EU 2015]). The tariff at a charger is not necessarily close to the values displayed in the graph.

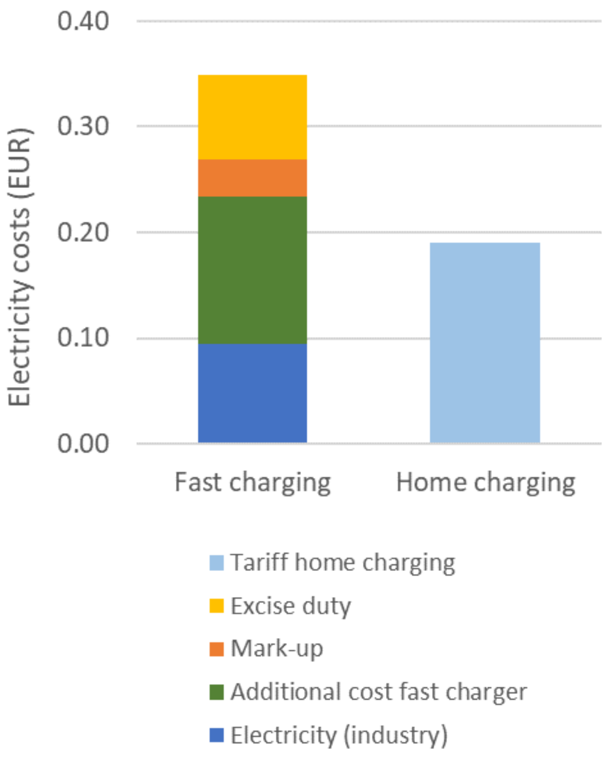


Figure 5.3: Costs of electricity at fast charger compared to home charging

The occupancy level has a trade-off with the charger’s availability over the day.

5.5 Tax effects

The current Dutch road tax system is based on fuel and vehicle weight. Consequently, electric vehicles in a given market segment may have higher road tax than comparable petrol cars.

This is due to the fact that electric vehicles have a weight penalty due to the battery weight and the vehicle structure to support this weight safely. If the road tax scheme is not adjusted for this additional weight of EVs, this will substantially increase the road tax. Therefore, it is a negative incentive for EVs.

Uptake of alternative fuels, like CNG, despite the favourable costs have been limited. The uncertainty of the future trends and policies, combined with the fuelling and maintenance infrastructure, have often been cited as reasons not to change. The line of reasoning is that, once a transition is achieved, the stimulation will end and the tax and levees will increase to an unfavourable level.

5.6 Other considerations: pushing, not pulling

The Algemene Rekenkamer concluded in 2017 that the stimulation measures of the government have not been very effective in reducing CO_2 emissions of passenger cars. Instead, effective policies should be comprehensive and should aim to bridge a small gap for many people. In that respect, it could be argued that the stimulation of electric vehicles was too early in the Netherlands. Moreover, with very limited policy on high emitting vehicles and on reducing fuel consumption and CO_2 emission in normal use, the electric vehicles should not have been the main effect of the policy. The push on removing the vehicles, and vehicle usages, with high CO_2 emission is needed as well for a broader uptake, beyond the forerunners. Counteracting measures such as increasing the speed limit to 130 km/h make a real-world reduction in CO_2 emissions more challenging as well. In that respect, CO_2 emissions reduction measures solely based on electrification of new passenger cars are longsighted and miss the broad perspective to reflect the sense of urgency expressed in the Paris Climate agreement. In practice, without incorporating CO_2 emitting cars in the policies, there is no “push” to assist the “pull” towards electrification. The pull towards electrification so far has not moved the majority of the fleet in the right direction, and has created opportunities for only a small group of owners/users. Apart from pushing out high emission vehicles and habits, towards electrification, such policies on conventional vehicles can have the benefit to achieve reductions in CO_2 emissions before 2030.

As shown in chapter 2, a large share of the Dutch fleet consists of A- and B-segment vehicles. These vehicles do play a significant role in the total mileages and therefore the total CO_2 emissions. A large group of private car owners has a limited budget. Electrification of this part of the fleet may prove difficult, because of the hurdle of purchase prices of EVs. It seems that, for this group, a car should cost less half in Euros than the annual mileage in kilometres, which makes new A- and B-segment cars unpopular. Instead, reliable vehicles of five to ten years old in the A- and B-segment are desired. The recurring problem with the uptake of EV lies in this large group of petrol vehicles of eight years and older in the A and B segments which make up almost half of the fleet. The resale price of conventional vehicles is limited and do not present a large hurdle for private ownership, unlike the newer vehicles. Taking a loan to finance a car is another hurdle for such owners.

On the other hand, private owners with older cars have a total cost of ownership which is more tuned towards the use, and the fuel cost. In the second 100,000 kilometres of driving, depending on the annual mileage, albeit lower, fuel bill of 1200 Euros a year will present the majority of the costs.

Consequently, private owners with older cars may consider the lower running costs an important argument to switch to EV.

As regards plug-in hybrid vehicles, given the fact that even with the normal share of 25%-30% electric driving a PHEV hardly has a lower real-world CO_2 emission of a fuel efficient diesel car, in the same market segment, it is clear these vehicles bring little benefit in terms of real CO_2 reduction. In part this lies in the additional weight of the battery pack, and in part in the charging behaviour and vehicle usage. For energy efficiency, the use of heavy cars, such as most BEVs, in particular in urban use, is low. The current BEV fleet has an average weight of 1700 kg. In part this is the weight of the battery, but in part this is the weight of the structure to carry this battery. Lowering the weight will bring double benefit, but may make the vehicle unsuitable for motorway driving. Since in the Netherlands, in particular the densely populated western part, the motorways are the only proper intercity routes, most people will find an intermediate between an electric bicycle and a passenger car, such as the Renault Twizy, too restrictive, as it cannot enter the motorway with a maximum speed of 80 km/h.

Eventually, in the case of a large EV fleet, the electric power consumption may be restrictive. It is therefore already important to consider energy efficiency. The average electric power consumption of a Dutch house is around 3500 kWh. With 0.7 MJ/km, the total electrification of the Dutch passenger car fleet will be in the same order of magnitude. Weight reduction and fit-for-purpose should be taken in consideration. The current D- and E-segment cars are not the right example for energy efficiency. The question is if the electric VW UP!, Fiat 500E, or the Smart ForTwo Electric Drive with an average catalogue price of 29,000 Euro will be filling the important gap in energy efficient vehicles.

6 Estimate of upper and lower bounds of EV influx based on mileage, segmentation and TCO

6.1 Dutch influx of EV according segmentation and ownership

In the previous chapters, constraints were given which may limit the uptake of electric passenger cars in the Netherlands. If the necessary requirements are met, the uptake of EVs is still limited by the fleet composition, renewal rate and vehicle usage as given in the chapters above. This is input in a (simplified) total cost of ownership model, that was developed by TNO for the present study, and deals with the affordability of electric vehicles across the vehicle segmentation in the Netherlands.

The total cost of ownership was calculated for the first owner, over a period of 4 years, for electric vehicles as well as conventional vehicles, in five market segments A-E. Because there is no general agreement on the classification of specific vehicle models, the segmentation was done on the basis of a list published by AutoRAI[15]. For electric vehicles not in this list, the table in appendix 1 was used. Current sales prices were used as a basis for the costs calculation, as well as a depreciation curve to determine the second hand resale value. New EVs are expected to further decrease in price over time, which was modelled with battery price drop curves.

One of the main differences in cost structure between EV and ICEV is the focus on purchasing costs (EV) and use costs (ICEV). This ratio changes with mileage. If one drives more kilometres in the period of four years, the EV benefits better from the fact that electricity is cheaper than fuel, per kilometre. Therefore, for each market segment the distribution of annual mileages was analysed. Each segment was cut in four pieces: the 25% with lowest annual mileage, and so on. This was done for private and business owners. The average mileage of each of the four 25%-groups was taken as an input, and the total cost of ownership was calculated accordingly.

Combining all TCOs for EV and ICEV, for private and business owners, for five market segments with four 25%-groups with different mileages, one can calculate in which year it becomes cheaper for a particular segment/group to run an EV instead of an ICEV (‘tipping point’). Combined with the market segment sizes in new sales, a potential uptake curve was drawn.

It has to be stressed that the model does not calculate the effect of policy measures, and that the uptake is purely based on rational, TCO-based decisions. The present policies are assumed to remain effective (“no-policy”), i.e. road tax is zero until 2021 for EVs, and the income tax surcharge for company cars (‘bijtelling’) will be at the same level as for conventional cars in 2021 as well. The absolute surcharge level (at a given wage) is set as an additional purchase criterion: the surcharge has to be lower for the EV than for an equivalent ICEV as well, for the EV to be attractive.

Additional stimulation and new developments can improve the uptake and expedite large scale introduction of EVs.

---

[15] https://autorai.nl/duidelijkheid-over-autosegmenten/

6.2 Inputs

The total cost of ownership (TCO) of a vehicle is, in the present calculation, the sum of depreciation costs and running costs, divided by the number of kilometers driven. The TCOs of new EVs are decreasing over the years as a result of battery price drops and EV drivetrain and electronics cost reductions, leading to a drop in vehicle prices. At a certain point in time, the TCO for a given use case (market segment – annual mileage combination) becomes lower for an EV than for a comparable ICEV. This is called the “tipping point” in the present work.

Prices of new vehicles were taken from catalog prices (see chapter 2). ICEVs are assumed to increase in price to meet emission targets (€1500 per vehicle until 2030). BEV prices were taken from current catalog prices as well. A price was assumed for the battery and the electronics and motor, which are subject to price decrease (Bloomberg curve for battery, -8%/y for motor and electronics).
80% of the battery price decrease is assumed to be utilized for extra battery capacity, 20% to decrease the vehicle price. Once the battery size reaches 60 kWh, these percentages are swapped (20% into extra capacity, 80% to price decrease). The initial battery sizes in 2018 were derived from the VW e-Up!, Renault Zoë, Nissan Leaf, Tesla model 3 and Tesla model S for segments A-E.

The depreciation of vehicles after 4 years was assumed as follows: see Table 6.1.

Table 6.1: Depreciation of vehicles after 4 years (mileage influence disregarded)

Segment	ICEV (estimation)	BEV (see Table 2.4)
A	31% (remaining value 69%)	49%
B	35%	40%
C	38%	44%
D	36%	43%
E	50%	43%

This means that large EVs currently depreciate slower than comparable ICEVs.

The financing costs are assumed 6% per year.

Running costs were calculated from the annual mileage and the km-price.
For annual mileages the actual mileage distribution was assumed for private and business owners separately (see chapter 2).
Fuel consumption was derived from the Travelcard database. An additional -1% was assumed per year. Fuel prices were taken from NEV 2017 (assumed constant after 2030) and corrected to 2018 price levels. EV electricity consumption was estimated using www.spritmonitor.de. An additional 2% efficiency gain was assumed per year.
Electricity prices and their development until 2030 were taken from NEV 2017, and corrected to real prices (2018 level). The EVs are assumed to be charged at home, for a household tariff.
Road tax is calculated based on a 1200 kg vehicle (1500 for EV). Road tax for EVs becomes normal tariff from 2021 onwards.

6.3 Limitations

To calculate the potential EV fleet growth, it was assumed that all buyers make their purchase decision only on the basis of the TCO over 4 years, even private buyers. This cannot be considered realistic, because many other factors play a role. Furthermore, export of ex-lease vehicles is not accounted for in the numbers: all EVs sold are assumed stay in the fleet until 2030.
What was also not considered is whether the EVs are suitable for the function. The high end of the mileage distribution can most likely not been done with vehicles with a limited battery size, especially in the C-segment. It depends on the variability of the daily kilometers desired by the driver.

No subsidy on purchase or use is assumed, other than a zero road tax tariff in the high scenario. Reduction of tax surcharge for private use of company cars was not assumed either.

6.4 TCO “tipping point” per segment: no-policy upper boundary

For each year until 2030, the market share of EVs was calculated, based on the tipping points per segment. A maximum curve and a minimum curve were drawn. The curve that describes the upper boundary is based on the assumptions in paragraph 6.3, and is shown in Figure 6.1**Error! Reference source not found.**.

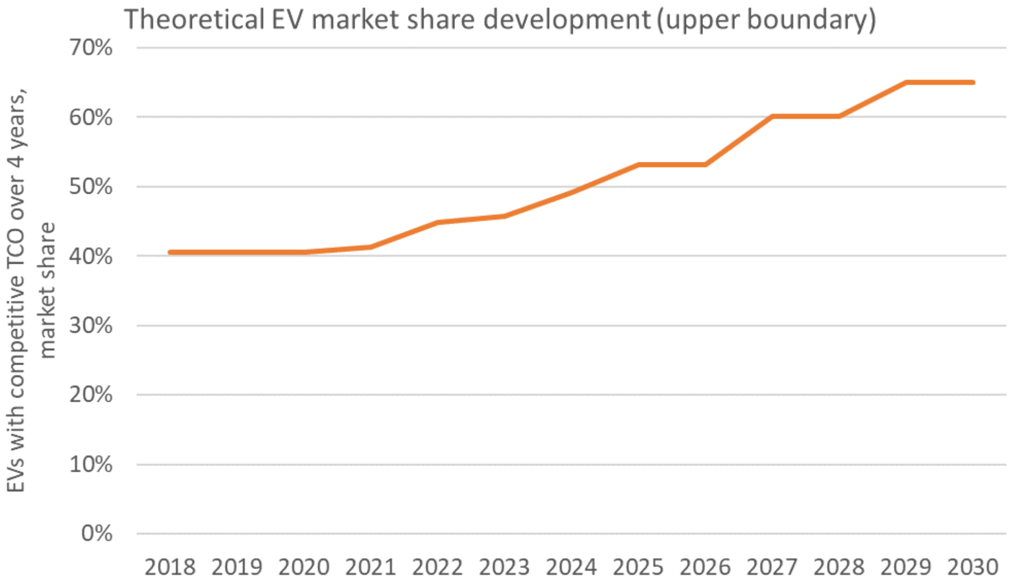


Figure 6.1: Theoretical EV market share development; estimated no-policy upper boundary

According to the rough calculations, the EV sales may reach 65%, with no additional policy, in case the 4-year TCO is the only purchase criterion. It would correspond to an EV fleet of approximately 2.8 million EVs in 2030.

The market segment size in combination with the high average annual mileages and relatively high fuel consumption (costs) expedite the tipping point for larger lease vehicles.

For private owners, in the first few years only few EVs pass the tipping point. This can be attributed to the low average mileages.

All considered, the growth of the EV fleet is mainly dependent on the higher market segments. For the large group of A- and B-segment vehicles that stay below 20.000 km per year, even in 2030 the TCO of a BEV looks to be higher than for an ICEV.

6.5 TCO “tipping point” per segment: sensitivity analysis

The previous paragraph showed an upper boundary of the EV market share, if purchase decisions were all taken on the basis of TCO. A lower boundary is then determined by conditions, such as availability of EVs and charging infrastructure. But whether EVs will be made available in large scale on the market is determined by the will of manufacturers to invest in new technology, and reducing their return on investment on existing technology, considering the likelihood that they need limited or even zero EVs to meet the European 2030 CO_2 targets (if the European Commission proposal of 30% will be the target decided upon). Furthermore, low uptake will probably slow EV manufacturing developments as well, even though Europe is not the largest EV market in the world. Then, if we would link the current EV sales in the Netherlands solely to the stimulation policies in place, and assume that these disappear after 2021, the lowest uptake in 2030 should be zero EVs.

More interesting is to evaluate to which extent the calculated TCO-based uptake is affected by changes in the starting points. The growth of the EV fleet in 2030 is sensitive to some of the inputs, among other things because for a large group of vehicles the TCO is relatively close between ICEV and EV. If as a result of e.g. price changes the tipping point moves a few years, EV sales are advanced or delayed in time, affecting the market share at a given point in time.

The sensitivity of the EV market share until 2030 for some of these assumptions has been shown in Figure 6.2. These are:

- Public charging instead of home charging. Assuming an electricity price of 30 cents per kWh, the tipping point moves to a later year for some segment/mileage combinations.
- Private sales are likely to be influenced (also) by the purchase price and the financing costs, not as much by the TCO.
- An equal TCO or purchase price may or may not be enough to induce EV sales. If a 10% margin (to the advantage of EVs) is attained, the speed of growth of the EV fleet decreases.

The last two changes are combined, as shown in the graph’s legend.

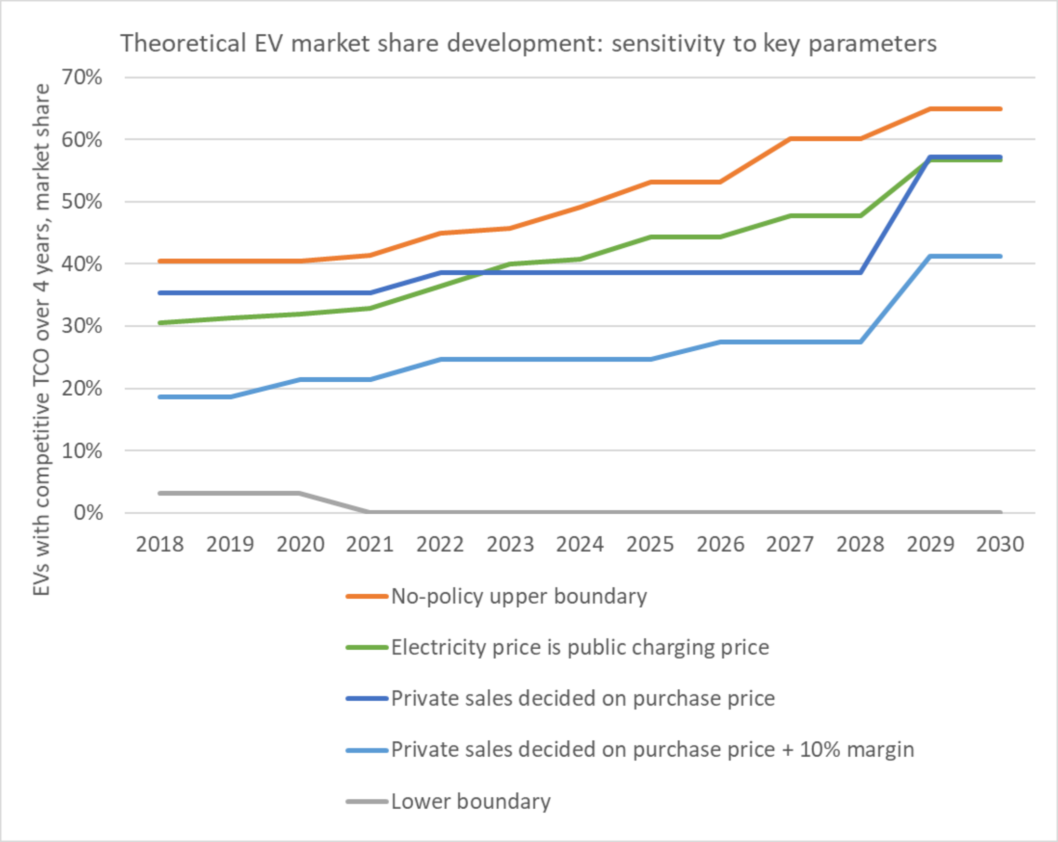


Figure 6.2: Theoretical EV market share development (baseline: 4y TCO as single purchase criterion, no export).

The sales in 2030 are expected to drop to just over 40% in the last scenario (light blue line), as the purchase price of EVs and ICEVs will be break-even later than the TCOs, and the 10% extra ‘incentive’ decreases the number of competitive cases for EVs.

For a CO_2 reduction of 30% on the fleet level, manufacturers are likely to not need any zero emission vehicles or plug-in hybrids. If we assume that they choose for better utilization of past investments in conventional technology, and furthermore that current sales are driven by government incentives and that these disappear in 2021, the growth of the EV fleet in the Netherlands can stagnate. The grey line in the graph indicates that scenario.

So far, only the sales percentages were considered. The sales lead to an increased EV fleet in the Netherlands. In due course, the vehicles will leave the fleet again at the end of service life. Given the average life span, it is likely that the 2018 EVs are generally still in the fleet in 2030. That is, if export would not play a role. EVs bought by businesses are likely to be exported after four years in case of no additional policies, because of the second-hand market mismatch. The net growth of the EV fleet is then lower than the sales percentages in Figure 6.2 suggest. If a 50% export rate is assumed after 4 years (the current diesel export rate), the net influx in case of the ‘no-policy upper boundary’ would be about 20%-point lower, starting from 2021. This means that in 2030 the EV fleet would grow with 65%-20% = 45% of the 2030 car sales, instead of 65%.

Other important factors are: (not shown)

- Whether manufacturers choose to decrease the price of the EV once the battery price drops, or whether they will increase the battery's capacity instead;
- Fuel price
- Battery price development

Policy related factors such as tax levels can have a large influence as well. These are not quantified in the present report.

6.6 Conclusions

The TCO exercise in this chapter shows that:

- The first EVs to become economically attractive over 4 years, are large vehicles that do high annual mileages. In the fleet, these vehicles are predominantly company cars.
- Combined with the fleet size per segment, the EV fleet towards 2030 can be expected to consist mainly of C-segment cars.
- This is the category of ex-lease vehicles for which the second-hand market demand is too small. It can be expected that part of these vehicles will be exported at the end of the lease term (in case of no additional measures).
- For smaller vehicles it can be beyond 2030 before a healthy TCO case is reached, with the exception of >20.000 km/year use cases.
- The difference in TCO is relatively small already for vehicles with high mileage. This means that the following factors have a large influence:
  - Electricity price
  - Fuel price
  - EV price decrease (as opposed to expanding battery capacity)
  - Road tax level for EVs
- While the model enables us to show the dependency of the EV influx of some parameters, the size of the EV fleet in 2030 cannot really be predicted. The model calculations depend to a large extent on the exact moment that the tipping point is reached for a certain market segment/mileage-combination. Combined with the fact that manufacturers may reach the European CO_2 emission targets for 2030 by improving conventional technology alone, the EV fleet size in 2030 may be somewhere between 0 and three million vehicles.

7 Conclusions

The uptake of electric vehicles until 2030 is beset with uncertainties. For this report a lot of information was collected and analysed, and combined with insights gained in previous work, to describe, and where possible quantify, the factors that influence the EV uptake in the Netherlands.

This report contains factual background information and insights on boundary conditions for the large-scale uptake of electric vehicles. It serves as input for estimates to be made by PBL with respect to the development of the electric vehicle fleet in the Netherlands up to 2030.

The current mismatch on the second hand car market between larger diesel fuelled cars released from businesses and the domestic demand for smaller petrol fuelled cars, has led to import and export on a large scale. If no additional measures are taken, possibly many ex-business EVs will be exported due to a lack of demand.

At the moment it seems that mainly low-mileage vehicles are replaced by EVs. This reduces the CO_2 benefits.

The current 3 million EVs in the world were at least for the larger part subsidized in one form or another. Due to the decreasing price premiums of EVs compared to petrol or diesel vehicles, it can be expected that the market takes over at a certain point. However, it is good to realize that even if the sales share can increase quickly, the turnover speed of cars in the fleet is low. About one third of the vehicles in the Dutch fleet in 2030 has already been sold.

The European CO_2 reduction targets for 2030 have not been established, but are likely to become in the range of 30%-50%, as a reduction from the average WLTP value in 2021. This reference point is still unknown, moreover it is possible that the real reduction will be slightly lower. In the case of a target of 30%, manufacturers may not need electric vehicles at all, because a 30% reduction may be possible using combustion engine cars with advanced fuel saving technologies. If the target is higher, EVs should be needed, but still conventional cars can deliver a contribution. It is important to stress that the reduction in emissions are related to type approval emission values. The real world emissions are higher, and there is not guarantee that the type approval-based reduction measures are 100% effective on the real world emissions.

If at a certain point EVs become cheaper to run (total cost of ownership) or even cheaper to buy, which dependent on the EV price drop rate may be as soon as 2025, policy targets no longer have influence on the EV influx. At that point, having more than 30% EVs in the mix creates room within the targets for the emissions from conventional vehicles to actually increase instead of decrease.

If only rational arguments count, companies will base their purchase decision of EV or ICEV at least partially on the total costs of ownership. Private buyers will consider purchase price as more important.

Electric vehicles are characterized by a relatively high purchase cost and a lower running cost per kilometer, which means that driving high annual mileages makes the total cost of ownership case more in favour of the EV. This means also, that even if the price of an EV is higher than that of an ICEV, it can still be financially attractive from a TCO point of view.

For the A and B segment (small cars), which make up almost 50% of the fleet in the Netherlands, EVs seem less favourable. The total cost of ownership remains higher to comparable with conventional vehicles for the years to come, because of relatively low energy consumption, and low average annual mileages. Furthermore, the purchase price premium is large, relatively speaking.

An optimistic influx scenario for EVs was calculated, based on TCO alone. In the case of no additional policies, and a drop of the current benefits for EVs in 2021, the EV sales can amount to 65% of the Dutch passenger car market in 2030. The larger part is business cars. It is expected that the C segment (compact family cars) will be the largest group of electric vehicles. In case of no export, and no additional policies, the maximum total EV fleet size would be 2.8 million vehicles in 2030.

Note that the fleet development calculated is theoretical: it was assumed that everybody for whom the TCO of an EV is lower than that of an ICEV, actually buys an EV. In reality there are many more factors other than TCO that companies and private people consider when making a purchase decision, which can all decrease the numbers presented. Furthermore, additional policies incentivising EVs can increase these numbers.

A conservative calculation was made, based on: 1) private people decide on purchase costs, not on TCO, and 3) a TCO or purchase price benefit of 10% is needed for people to decide to buy an EV. The resulting 2030 market share is around 40%.

An analysis of the effects of several policy measures can complement the present work. If a large EV fleet is desirable, most potential can be found in avoiding export of EVs, stimulating long-term decision making among private buyers, reducing financing barriers, and bridging the small cost gap for a large group of owners of midsize vehicles.

8 References

UBA 2017a Günther, J., Lehmann, H., Lorenz, U., Purr, K., A resource efficient pathway towards a greenhouse gas neutral Germany, Umwelt Bundesamt, October 2017.

UBA 2017b Bergk, F., Knörr, W., Lambrecht, U., Climate Protection in Transport: Need for Action in the Wake of the Paris Climate Agreement, IFEU on behalf of Umwelt Bundesamt, Texte 97/2017, November 2017.

2014/94/EU Richtlijn 2014/94/EU van het Europees Parlement en de Raad van 22 oktober 2014 betreffende de uitrol van infrastructuur voor alternatieve brandstoffen

Thiel 2016a Thiel, C., Drossinos, Y., Krause, J., Harrison, G., Gkatzoflias, D., Donati, A., Modelling electro-mobility: an integrated modelling platform for assessing European policies, JRC, TRA 2016.

Thiel 2016b Thiel, C., Nijs, W., Simoes, S., Schmidt, J., Zyl, A. van, Schmid, E., The impact of the EU car CO2 regulation on the energy system and the role of electro-mobility to achieve transport decarbonisation, JRC-IET, Energy Policy 96, 2016.

Harrison 2016 Harrison, G., Krause, J., Thiel, C., Transitions and impacts of passenger car powertrain technologies in European member states, JRC-IET, TRA 2016.

Ligterink 2010 Ligterink, N.E., Bos, B., CO2 uitstoot van personenwagens in norm en praktijk – analyse van gegevens van zakelijke rijders, TNO report MON-RPT-2010-00114, 2010.

Ligterink 2015 Ligterink, N.E., Zyl, S. van, Verbeek, M., Spreen, J., Potential CO_2 reduction technologies and their costs for Dutch passenger car fleet, TNO report 2015 R10730, 2015.

Ligterink 2016 Ligterink, N.E., Mensch, P. van, Cuelenaere, R.F.A., NEDC-WLTP comparative testing, TNO report 2016 R11285, 2016.

Krause 2016 Krause, J., Small, M., Haas, A., Jaeger, C., An expert-based bayesian assessment of 2030 German new vehicle CO2 emissions and related costs, Transport Policy 52, 2016.

Ntziachristos 2016 Ntziachristos, L., Samaras, Z., Papdimitriou, G., Markaki, V., Potential of combined vehicle technology, fuel and ICT measures in reducing CO_2 emissions from road transport by 2030, EARPA FORMForum future of road mobility, LAT/Emisia, 2016.

Hill 2016 Hill, N., Windisch, E., Kirsch, F., Horton, G., Dun, C., Hausberger, S., Matzer, C., Skinner, I., Donati, A., Krause, J., Thiel, C., Wells, P., Improving understanding of technology and costs for CO2 reductions from cars and LCVs in the period to 2030 and development of cost curves, Ricardo Energy & Environment, TU Graz, TEPR, EC JRC, Cardiff Business School, CLIMA C.2, February 2016.

Hill 2018 Hill, N., Skinner, I., Zazias, G., Siskos, P., Petropoulos, A., Fragkiadakis, K., Paroussos, L., Assessing the impacts of selected options for regulating CO_2 emissions from new passenger cars and vans after 2020, Ricardo Energy & Environment, TEPR, TU Graz, and E3M Lab, CLIMA C.4 (2016), February 2018.

EAFO 2018 European Alternative Fuel Observatory, www.eafo.eu, data up to May 2018 inclusive, retrieved July 31, 2018.

Verbeek 2018 Verbeek, M., Gijlswijk, R. van, Zyl, S. van, Eijk, E. van, Vermeulen, R., Huismans, H., Smokers, R., Assessments with respect to the EU HDV CO2 legislation - work in support of the Dutch position on EU regulation on the CO2 emissions of Heavy-Duty vehicles, TNO 2018 P10214, March 2018.

IEA 2018 Global EV Outlook 2018, International Energy Agency, 2018

Meeus 2018 Meeus, M., Review of status of the main chemistries for the EV market, EMIRI, IEA workshop March 2018.

Reuters 2018 https://www.reuters.com/article/us-autoshow-detroit-electric/global-carmakers-to-invest-at-least-90-billion-in-electric-vehicles-idUSKBN1F42NW

Van Gijlswijk 2018 Gijlswijk, R. van, Ligterink, N., Real-world fuel consumption of passenger cars based on monitoring of Dutch fuel pass data 2017, TNO 2018 R10371, 2018.

Van Essen 2017 Essen, H. van, Verbeek, M., Aarnink, S., Smokers, R., Assessment of the Modalities for LDV CO_2 regulations beyond 2020, CE Delft / TNO, 2017.

ICCT 2016 Mock, P., 2020–2030 CO_2 standards for new cars and light-commercial vehicles in the European Union, the ICCT, briefing, November 2016.

9 Signature

The Hague, 31 August 2018

TNO

Evie Cox
Project Leader

René van Gijlswijk
Author

A FEV's per class

Brand	**Class**
BMW I3	C
CHEVROLET SPARK EV	B
CHEVROLET VOLT	C
CITROEN C-ZERO	A
CITROEN CITROEN C1	A
FIAT 500 ELECTRIC	A
FORD FOCUS	C
HYUNDAI IONIQ ELECTRIC	C
HYUNDAI IX35 FCEV	C
HYUNDAI TUCSON	D
JAGUAR JAGUAR I-PACE	E
KIA SOUL	C
MERCEDES-AMG SLS AMG ELECTRIC DRIVE	E
MERCEDES-BENZ B 250 E	C
MERCEDES-BENZ E-CELL	C
MERCEDES-BENZ ELECTRIC DRIVE	C
MIA MIA	------
MITSUBISHI MITSUBISHI I-MIEV	A
NISSAN LEAF	C
OPEL AGILA	B
OPEL AMPERA E	C
PEUGEOT ION	A
RENAULT FLUENCE Z.E.	C
RENAULT ZOE	B
SMART FORTWO ELECTRIC DRIVE	A
TESLA MODEL 3	D
TESLA MODEL S	E
TESLA MODEL X	E
TESLA ROADSTER	E
THINK TH!NK CITY	A
TOYOTA RAV4 EV	C
TOYOTA TOYOTA MIRAI	D
VOLKSWAGEN E-GOLF	C
VOLKSWAGEN UP	A
VOLVO C30	C
VOLVO V50	D