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One year monitoring of 26 electric vehicles

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Abstract

The Dutch government regards electric driving as a very promising option to make our future automobility more sustainable, to strengthen the Dutch energy position and to give our economy a structural boost. Therefore, it was decided to gain experience of electric driving through field tests with the Dutch government's Public Works department, Rijkswaterstaat (RWS), the aim being twofold: as a highways authority RWS wants to learn more about future mobility and by 2015 RWS wants to have a quarter of its vehicle fleet consisting of electric vehicles. This study has revealed that this second objective is indeed feasible.

To gain insight into the costs, environmental impact, use, deployment, maintenance and other aspects, 24 EVs and 2 PHEVs were monitored over a period of one year and the users asked to feed back on their experiences of electric driving.

One of the findings was that the actual range came to around 60% of the reported radius, but such a range is still sufficient for more than 25% of the Rijkswaterstaat fleet. User appreciation increased as the trials progressed. For example, the question "would you recommend electric driving to colleagues for work travel?" was just 4.8 out of 10 at the beginning but 7.7 at the end. Despite the lower energy costs (50% less for entrepreneur and consumer, and even 80% less for Rijkswaterstaat), electric driving is still relatively expensive. Rijkswaterstaat redeems its costs for an electric car after 7 years. For a period of four years' use, it pays €0.06 per kilometre more to drive electric.

Keywords: fleet, range , TCO, acceptance, implementation

1 Introduction

In the presentation of the Electric Driving Plan on 3 July 2009, the Dutch government expressed its view of electric driving as a highly promising option in the light of three targets:

1. To make our future automobility sustainable (climate targets of 2020 and beyond);
2. To strengthen our energy position; and
3. To give our economy a structural boost.

In that same context the government took the decision to begin electric driving field tests to gain the requisite experience (Plan for Field Tests of Electric Driving of 19 April 2010). Given the size of the fleet (some 1700 vehicles) and the diversity of vehicle use, Rijkswaterstaat was an obvious choice to carry out the field tests. These began with 26 Rijkswaterstaat vehicles, four of which are also used by other departments.

At the start of 2011 the field test began in ceremonial fashion with the delivery of 6 Mitsubishi i-MiEVs to Secretary of State for Infrastructure and the Environment, Atsma. Along with 2 Toyota Prius plug-ins, 6 Peugeot iOns and 12 Nissan Leafs, they form the fleet for the field tests. The purpose of the field tests is twofold. On the one hand RWS wants to learn more, as a highways authority, about future mobility and, on the other hand, investigate, as a fleet manager, the deployment of electric vehicles within its own vehicle fleet. The Secretary of State expressed the aim at the start of the field tests to have a quarter of the RWS vehicle fleet driving on electric power by 2015.

This paper reports of the whole trial period from week 48 in 2011 until week 26 in 2012.

1.1 Aim and research issues

The field tests at Rijkswaterstaat are part of the broader exploration being employed by Rijksoverheid to investigate the potential of electric driving in the Netherlands. In this context a study fits within the machinery of government. Given its relatively large vehicle fleet, the RWS organisation was selected.

The research issues can be divided into three focal categories: the environment, the user and the product.

1.1.1 Environment

- What are the implications for the existing facilities?
    - How much electricity will actually be used?
    - What charging patterns (demand for electrical energy) are visible?
- What is the impact on other road users?
- What level of sustainability is achieved?

1.1.2 User

- What user behaviour (and behavioural change) can be observed?
- What are the user experiences, both short and long-term, and what is the safety perception?
- What are the user costs, both fixed and variable?
    - Lease
    - Use (energy)
    - Maintenance (fixed and variable)
    - Unexpected

1.1.3 Product

- What (and how much) maintenance is needed?
- What effects of use are visible?
- Do the safety requirements still comply in the event of large-scale use of e-vehicles?

2 Vehicles and instrumentation

This section describes the vehicles that comprise the vehicle fleet along with the sensors and communication equipment (the metrics) incorporated in the vehicles.

2.1 The vehicle fleet

The following vehicles are being used in the tests (manufacturer specifications):

12x Nissan Leaf	
Type	Fully electric
Weight	1,525 kg
Battery capacity	24 kWh
Top speed	145 km/u
Size lxbxh (cm)	445x177x150 cm
Range	160 km
Acceleration 0-100 km/h	11.9 sec.

6x Mitsubishi i-MiEV and 6x Peugeot IOn	
Type	Fully electric
Weight	1,085 kg
Battery capacity	16 kWh
Top speed	130 km/h
Size lxbxh (cm)	347x147x161 cm
Range	150 km
Acceleration 0-100 km/h	15.9 sec.

2x Toyota Prius Plug-in hybrid	
Type	electric/petrol
Weight	1,420 kg
Battery capacity	4.4 kWh
Top speed	85 km/h electric, 185 km/h petrol
Size lxbxh (cm)	448x174x149 cm
Range	25 km electric, 730 km petrol
Acceleration 0-100 km/h	11.4 sec.

2.2 Instrumentation of fully electric vehicles

The 6 Mitsubishi i-MiEVs, 6 Peugeot IOns and 12 Nissan Leafs were equipped with a data logger, a GPS module and a module for wireless data transmission.

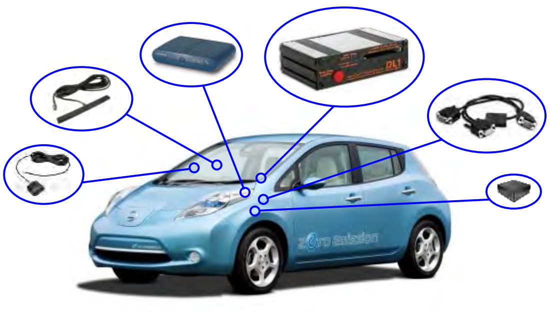


Figure 1 Metrics incorporated in each electric vehicle involved in the field test (from left to right): GPS antenna, GPRS antenna, GPRS unit, data logger, vehicle communication interface, on/off data logger module

The data were collected in a central database and the research questions were answered by interpreting different cross-sections of the data. The system components needed to describe the measurement, saving and transmission to a central database from each electric vehicle are shown in Figure 1.

- GPS sensor: the vehicle is equipped with a GPS (Global Positioning System) sensor to acquire position-related vehicle data such as location, speed and distance. The GPS sensor is connected to the data logger.
- GPRS antenna and unit: the GPRS (General Packet Radio Service) antenna and unit ensure that the saved signals are transmitted from the data logger to a central database via a mobile telephone link.
- Data logger: the main metric component is the data logger that saves the signals. These signals are GPS position and the vehicle communication system's digital messages. The data logger saves the data once every ten seconds (frequency of 0.1 Hz). When a vehicle is driving or being charged, then the data are transmitted about once every fifteen minutes to the central database via the GPRS unit that is connected.
- Vehicle communication interface: since it is not possible to read data from the vehicle communication system (the CAN bus) directly using the data logger, a separate interface (connection module) is needed.
- On/off data logger module: in order to gather as much information as possible during driving and charging of the electric vehicles, the data logger is also expected to function during these actions. This need is redundant when the vehicle is not being driven or charged. If the data logger is unnecessarily on when the vehicle is not being used, the 12V battery that powers the data logger runs empty. To prevent this, use is made of a unit that turns the data logger on only when the vehicle is running or being charged.

2.3 Monitoring Toyota Prius Plug-in hybrid

Since 2010 Toyota has run a demonstration programme worldwide with 600 Prius plug-in type vehicles that are both petrol and electric powered. Two of these vehicles were present during the Rijkswaterstaat electric driving field test. Given the nature of the demonstration programme, the manufacturer did not allow these vehicles to be monitored so these two vehicles were not equipped with the metrics described in section 2.2. However, to enable these vehicles to be compared with the fully electric vehicles, for two weeks the distance covered, energy charged and amount of refuelling in litres were recorded.

3 Data analysis

The data-processing system is geared to vehicle data analysis, enabling a selection of research questions to be answered. The MATLAB program was chosen to analyse the data since in-depth statistical calculations can be performed and presented via a "custom built GUI" (Graphical User Interface).

To be able to answer the research questions posed, different sources are used. It has been calculated that for two of these sources, the vehicle data and survey data, the quantity of information is so considerable that automated processing is the most efficient and reliable manner. The automatically processed data were saved to a database (the "TNO database") while specific interviews and logbook data were processed manually and thus not included in the TNO database.

Of the 24 fully electric vehicles in the field test, a sample was taken every ten seconds of between 16 and 18 field-test parameters (depending on the vehicle type) during driving and charging. This resulted in an average of more than 127,000 samples weekly and more than 5,.000,000 throughout the entire field test. The process of getting the vehicle data into the TNO database was therefore largely automated. This process is illustrated diagrammatically in Figure 2

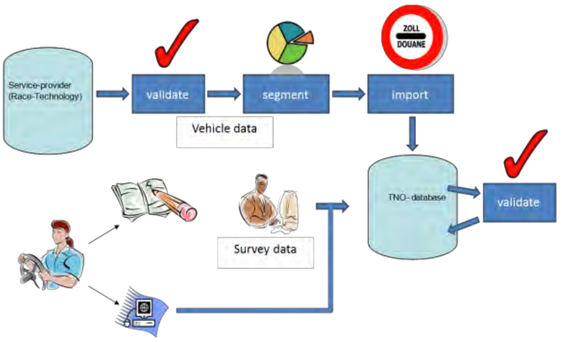


Figure 2 Processes involved in getting vehicle data and survey data into the TNO database.

Of course, the data in the TNO database must be complete and entirely compliant with the reality. To ensure this, the vehicle data were checked before being written to the TNO database. This check (external to the TNO database) mainly reviewed breaches of the limits of the measured parameters. Examples include GPS time and position, vehicle speed, battery charge, kilometrage, etc. In other words, checks on data that is not context dependent.

We took the option to translate the derived research issues in Structured Query Language (SQL) so that these could be directly executed by the database management of the MySQLTM database used. The interim results thus obtained could sometimes be used straightaway although further processing was usually needed.

To further process the vehicle data TNO used both Microsoft ExcelTM (or Excel) and the Mathworks company software MatlabTM (or Matlab). Excel was used mainly for graphical representations, sometimes in combination with simple further processing of the vehicle data. Matlab was mainly used for more complex further processing. TNO also developed a composite graphic interface within the Matlab environment for the field test to enable very common propositions to be quickly and efficiently entered and the results to be subsequently shown directly in the requisite format.

4 Results

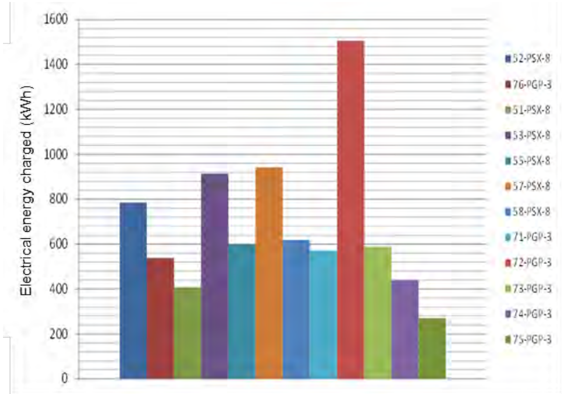
This section considers the findings per research question. Where possible the answers are put into perspective with respect to the aim of having 400 electric cars within the Rijkswaterstaat fleet by 2015. Various parties in the Netherlands have made all kinds of predictions about the number of electric cars in the Netherlands, even suggesting 1 or 2 million by 2020. More conservative estimates put the figure at 140,000 electric cars on Dutch roads by then. For this purpose, we assume 200,000 electric cars.

4.1 Environment

For the grid load, it is important for there to be a good overview of the electricity demand of the electric vehicles and the distribution of that 'extra' electricity demand over time. The total amount of electrical energy needed is, even for many electric vehicles, no problem in terms of power production.

The main question now is whether the required power can be supplied locally without overloading the grid. In time this will become important at neighbourhood, urban and regional level and the data now being gathered will provide insight into what provisionally can be expected.

4.1.1 How much electrical energy will actually be consumed?



An electric vehicle driving 15,000 km annually will tend to consume on average 4327 kWh per year. By comparison, an average Dutch household consumes 3480 kWh per year. So you can assume that an electric car will mean extra consumption equivalent to a household.

Putting this consumption in relation to the total consumption in the Netherlands of 121,815,000 MWh[1]:

- 400 electric cars (RWS target) equals 1,731 MWh, or 0.0014% of total Dutch consumption
- 200,000 electric cars (estimated number of EV's in 2020) means 865,400 MWh, or 0.7% of total Dutch consumption

4.1.2 When do users charge their electric vehicle and for how long?

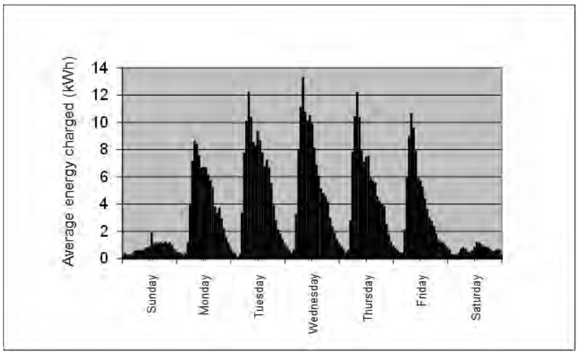


Figure 3 During the test the "peak load" on a Wednesday morning was a little over 13 kW for the whole fleet.

To put the peak load in perspective, this can be related to the entire power supply in the Netherlands of 26,636 MW[2]:

- 400 electric cars (RWS target) means 0.21 MW, or 0.0008% of the total Dutch power supply
- 200,000 electric cars (estimated number of EV's in 2020) means 108 MW, or 0.4% of the total Dutch power supply .

4.1.3 Where do users charge their electric vehicle?

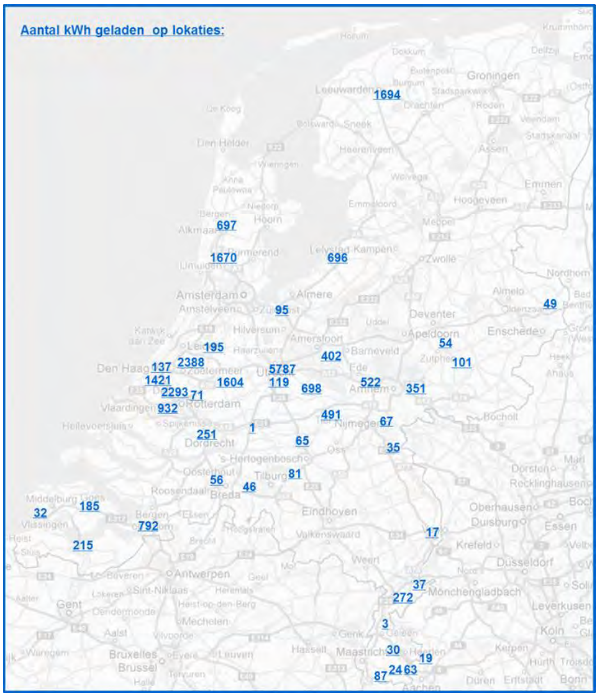


Figure 4 Overview of locations where the electric cars were charged during the field test. The amount of electrical energy charged at the location is shown in kilowatt hours (kWh).

In principle, each charging cycle can be individually traced. Some, especially very small charging cycles, are filtered out here[1] in order to gain not only a correct sum of charged energy but also the right number of charging runs.

- The data reveal that only occasionally (estimated less than 1% of the cases) is energy charged at a charging point that does not fall under the state, for instance when visiting civil authorities or when charging in transit at a 'petrol station'.
- Sporadic use is made of the fast-charge option (with higher power capacity of up to approx. 50 kW).

[1] Sometimes the metrics record one charging run as two. The total amount of energy (in sum) does not change but the charging runs are corrected by the filtering.

4.1.4 What is the impact on other road users?

The user surveys reveal that electric cars are seen as very much quieter. Other road users perhaps feel the same way but this has not been studied. At the same time the users are not of the opinion that the car will be regarded as anything other than a conventional car later on. There were no instances of accidents during the test that can be attributed to the absence of car noise.

4.1.5 What level of sustainability is achieved?

In total 233,000 fully electric kilometres were covered in the field test, with the following emissions effectively avoided:

- 333 gram particulate matter
- 5.6 kilogram NO_x
- 15.1 tonnes CO_2 net

The CO_2 figure takes account of the CO_2 chain emissions related to electricity generation. As for polluting emissions (particulate matter and NO_x), these were considered from a local perspective given that these are the most harmful to human health (especially in terms of the air quality of densely populated areas). The avoided emissions have not been corrected for the remote emissions of these substances as a consequence of electricity generation.

The net avoided emission of carbon dioxide of 15.1 tonnes is equivalent to 5187 fewer litres of combusted petroleum.

The scaled-up effects are:

- For 400 electric vehicles at 15,000 kilometres per year in the current mix of energy sources this is:
  - 6.5 kg particulate matter
  - 144 kg NO_x
  - 390 tonnes CO_2
- For 200,000 electric cars at 15,000 kilometre per year this is:
  - 3,214 kg particulate matter
  - 71,928 kg NO_x
  - 196 kilotonnes CO_2

If exclusively green energy is used for 200,000 electric cars at 15,000 kilometres per year, this would lead to a reduction of 558 kilotonnes of CO_2, or 0.33% of the total CO_2 emission in the Netherlands at the moment[3].

4.2 User

4.2.1 What user behaviour (and behavioural change) can be observed?

A striking observation is the hesitation to always use electric cars and the clear choice of a Nissan Leaf rather than a Mitsubishi i-MiEV or Peugeot iOn. Both effects taken together meant that the cars were used to a limited extent, especially evident in the winter quarter (Q3 in the field test, at the start of 2012). It may be that confidence in the cars in winter conditions played a role since the range of the other cars is less partly due to the use of heating.

The users in the test drove on average shorter journeys and used energy well below the maximum battery capacity. This could have been caused by *range anxiety* that in turn may be due to not being used to electric driving or, on the other hand, the lack of a charging infrastructure. The latter is indeed suggested by the survey among users, a view that is likely to change once more charging points are available. Earlier research in Japan suggests that not only opinion changes but actual behaviour too.

This study[4] reveals that users initially did not drive to empty and even stayed at more than 50% SOC (state Of Charge = how full the battery is). Once quick chargers had been placed in the test region, users dared to drive farther with the electric car and the SOC more frequently dipped below the 50%. This study shows that a better charging infrastructure gives users confidence to drive farther and this leads to better use of electric vehicles.

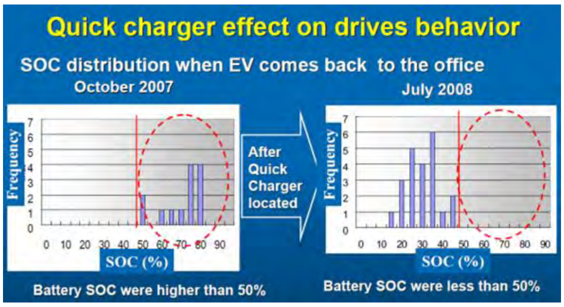


Figure 5 Willingness in a Japanese field test to drive with only a partly full battery before (left) and after (right) the introduction of quick chargers.

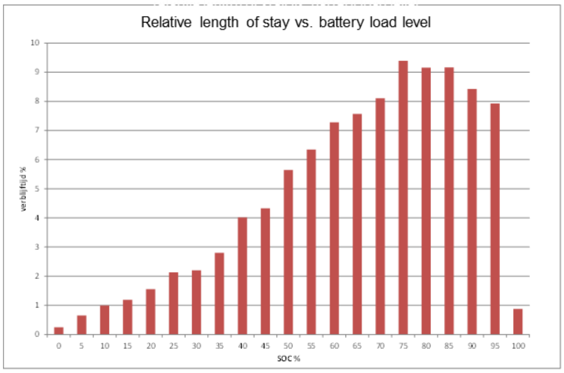


Figure 6 Distribution of charge level (percentage of maximum charge) in time throughout the monitoring period. The cars are hardly used with a low charge level.

In any case, it is striking that in the final quarter plenty of use was made of the electric vehicles (practically the same as in the two preceding quarters together). The incentives from the programme management, better weather and rising confidence in and familiarity with the vehicle properties may have helped in this respect, and such is suggested from the user survey during the final quarter.

4.2.2 What are the user experiences, both short and long-term, and what is the safety perception?

The users experience the electric car as much quieter than a conventional car. Nonetheless, the car is just as conspicuous in traffic. Braking is the same as in a normal car.

The practicability is still not fully appreciated due to the range limitations but the in-car space is adequate. Both road-holding and stability, handling and ability to overtake on the motorway are seen as more than adequate (good, smooth, good). As for charging, this is even regarded as a relatively straightforward task whereas the possibility to charge or travel without having to make preparations is seen as inadequate by the users. The overall evaluation of the electric car was satisfactory to good, and the car was recommended by the users to colleagues. The somewhat lower evaluation of the electric car in the winter quarter is noticeable but the influence of lower outside temperatures (car heating uses reduces range) is a contributing factor here, possibly more than the drawback of the wind in that quarter.

In general, however, appreciation of the electric car rose during the field test. In answer to the question: Would you recommend electric driving to colleagues for work travel, the answer in the second quarter was ‘not really’ while in the fourth quarter of the test, this was a ‘very probably’.

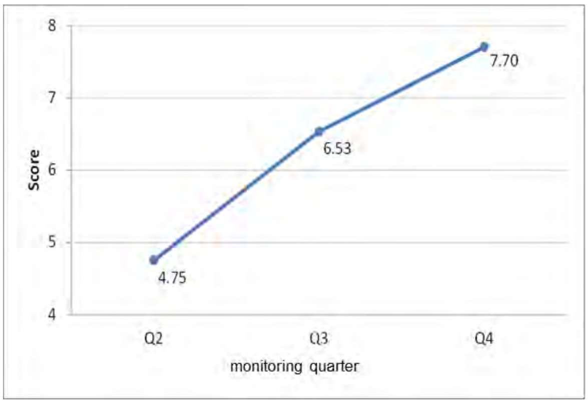


Figure 7 Trend for the score of recommendation to colleagues for work travel over the three quarters monitored.

How this higher appreciation emerged was not studied but it may be down to a more realistic and positive view of the pros and cons of the car. Where suspicion about the practicalities was initially evident, the notion grew that the electric car could be a good alternative in many places and for many purposes. A subsequent study (for Rijkswaterstaat or another party) should examine this issue

4.3 Product

4.3.1 What are the costs of use, both fixed and variable?

The section on Total Cost of Ownership (TCO) reveals that for current use, and for most categories of users, it costs significantly more to drive electric. On the other hand, it is evident that higher residual value (less uncertainty about the vehicle’s lifetime) would really help to improve the business case. Only when there is a lower purchase price over and above this will there be clear cost benefits for electric driving. And indeed that is anticipated: it is predicted that strong growth in the market for EV’s in ten to fifteen years’ time will see the same purchase price for the different powertrain technologies[5].

4.3.1.1 Residual value and lifetime

In addition to the kilometres driven, the residual value considerably affects the cost redemption moment. Currently the relative residual value (residual value divided by the new price) after 4 years is estimated by LeasePlan at roughly a factor of two lower than the residual value of a conventional car. Once the residual value of electric cars rises, and less can be written off over the period of use, in terms of TCO the electric car gets closer to the conventional car.

It is still unclear what the real lifetime of the battery will be or the second-hand value of the electric car. The analysis below is not intended, therefore, as a prediction but rather as a sample calculation to reveal the impact of assumptions in terms of depreciation and lifetime of electric cars on comparative TCO.

Figure 8 makes an assumption for the residual value trajectory of the electric and conventional car. The kink in the graph is based on LeasePlan data in which the relative residual value after four years is about 25% for an electric car (blue line) and 50% for a conventional car (red line). In Figure 8 the green line is an alternative scenario that assumes the relative residual value of an electric car after four years is 37.5%, with a lifetime set at 16 years.

For convenience a linear course has been assumed for the first 4 years and from the fourth year until the end of the vehicle's lifetime.

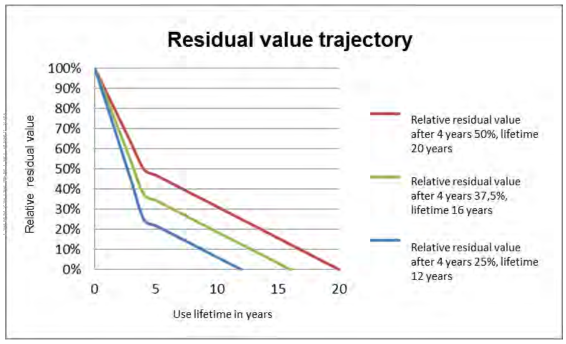


Figure 8 Assumptions for the relative residual value trajectory and lifetime for the electric and conventional car as well as an alternative scenario in which the relative residual value lies between that of the conventional car and the current electric car.

As for the lifetime of an electric car, 12 years has been assumed. The lifetime of the body and electric drive are certainly comparable with those of a conventional car but uncertainty still exists about the lifetime of the battery. This uncertainty has been translated into a shorter assumed economic lifetime for the electric vehicles.

4.3.1.2 TCO for Rijkswaterstaat at this moment

The way TCO looks depends on the perspective taken. Certain advantages do not apply for every target group. Aspects like energy prices are different for consumers, entrepreneurs or major users like RWS. This section calculates TCO per target group in the current circumstances pertaining to fuel prices and tax legislation. A Renault Clio 1.2 16V 75 Collection 5d has been used as the reference vehicle for the i-MiEV and iOn. For the Nissan Leaf the reference vehicle is a Renault Megane Energy TCe 115 Stop&Start Expression 5d. The Renault Megane is more fuel-efficient than the Clio and thus has a longer redemption time in the examples.

The costs are calculated as follows:

- Based on the assumptions a relative residual value trajectory is determined for the conventional and electric care (see 4.3.1.1)
- The absolute residual value of the vehicle at the end of its period of use is calculated according to that relative residual value and the purchase costs.
- The net investment over the period of use is calculated as the difference in the purchase price and the residual value at the end of the period of use whereby the residual value is converted using the rate of interest to the net current value.
- The cumulative variable costs are calculated as the sum of the annual variable costs converted using the rate of interest to the net current value over the period of use
- The fixed and variable costs are added up for each period of use to arrive at the total costs over the period of use.

This results in a graph that shows the cumulative costs as a function of the period of use.

As in the test, it is assumed that RWS purchases the vehicles itself and these are administered by LeasePlan. The TCO is calculated on the basis of these assumptions:

- 15,000 km per year
- Including 21% VAT
- Car tax exemption
- Road tax exemption (assuming this continues after 2015)

- No further tax benefits
- Interest rate of 4%
- Residual value after 4 years: conventional car 50%, electric car 25% (for residual value assumptions see 4.3.1.1)
- Purchase discount of 20% for both the electric and conventional car.
- Energy costs (excl. VAT) € 0.071 per kWh (RWS pays no duties and is a major consumer)
- Fuel costs (excl. VAT) € 1.59 per litre (petrol)

Figure 9 and Figure 10 show the trajectory of the cumulative costs of i-MiEV, iOn and Leaf as a function of the period of use for Rijkswaterstaat including the purchase and fuel costs at the time of writing. The i-MiEV, iOn and Leaf have a higher purchase price and initially higher depreciation but the lower costs of use mean that the cumulative costs rise less quickly than for a conventional Renault Clio. These assumptions mean a redemption time for Rijkswaterstaat of about 7 years after purchase for the i-MiEV and iOn and about 11 years for the Leaf.

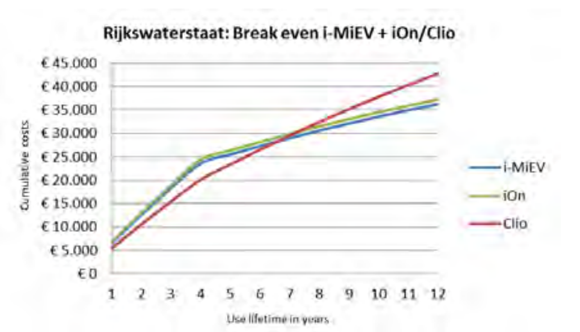


Figure 9 TCO comparison for i-MiEV, Peugeot iOn and Renault Clio for Rijkswaterstaat, with the redemption period for the stated assumptions 7 years.

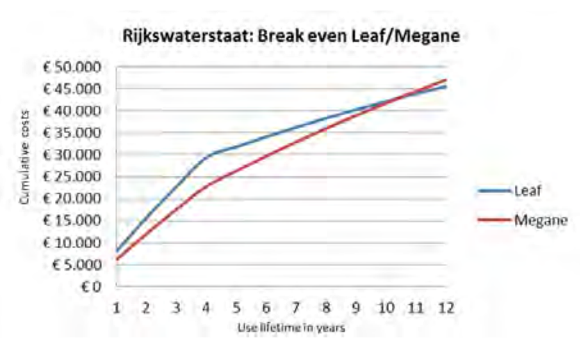


Figure 10 TCO comparison for Nissan Leaf and Renault Megane for Rijkswaterstaat, with the redemption period for the stated assumptions 11 years.

In the case of Rijkswaterstaat it is not yet feasible to redeem the costs for the electric car within the 4-year period of use.

Determining the cost redemption moment is one way of considering whether electric driving is an attractive proposition. The consumer, organisation or company can also look at the extra costs of electric driving despite the extended redemption period. At the moment of the decision by Rijkswaterstaat to purchase the electric cars for a four-year period of use, the extra annual costs currently stand at around € 870 for an i-MiEV against a Clio, or € 0.06 per kilometre. For the Leaf the extra costs are around € 1,650 per year, or € 0.11 per kilometre, on the basis of 15,000 kilometre per year.

The entrepreneur can take advantage of tax breaks and subsidies, and so redeem the costs of an electric car from the first year.

A consumer does not have these benefits and will not currently redeem the electric car costs within the foreseeable future as things stand.

4.3.2 What (and how much) maintenance is needed?

There were quite a lot of garage and service visits but these were largely due to teething troubles (inadequate charging cable) and unaccustomed users (forgetting to charge, ignoring warnings, etc). This could be improved if a group of more 'experienced' users drove the vehicles. Furthermore, there were no specific maintenance needs noted for the electric vehicles. Sporadic use of an electric car (from the pool) was regarded as not the ideal way to combine the new technology.

4.3.3 What effects of use are visible?

The effects on energy use are visible. Once the user has become accustomed to the situation, he tends to drive in a more relaxed or lively way. In addition, a few random checks reveal that there are no significant pre and post-use differences, although such would not really be expected given the limited monitoring period of some nine months.

The data provide the basis to see whether there is evidence of a decline in the available battery capacity over time. This was not the case. Any very slight decline there may have been in the batteries was not feasible without measuring the exposed batteries (with a view to safety and warranty stipulations) but the apparent charge capacity shows no evidence of such a decline. Aside from the fact that a slight decline was assumed in the limited monitoring period, the battery management system compensated this assumed, minor capacity reduction.

Subsequent research is needed to shed more light on the long-term effects on the batteries, all the more since uncertainties about battery ageing are currently proving to be an obstacle to the broad rollout of electric cars.

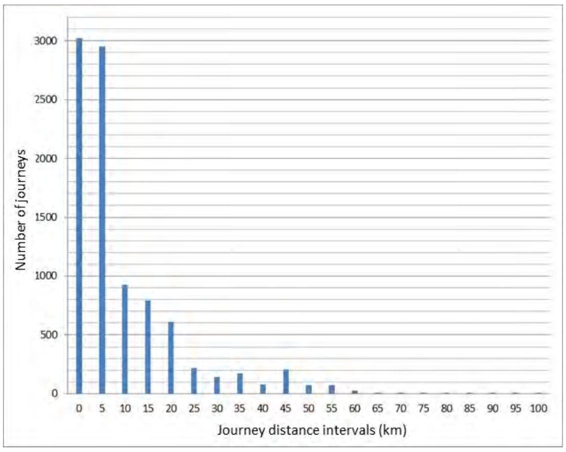


Figure 11 Distribution of registered journey distances (single journey). The intervals in kilometres run from the figure x to (x + 5).

The data clearly reveal that the electric vehicles were used for relatively short journeys. We do not know whether these journeys were the same for conventional cars because the electric cars were provided as additional to the conventional pool vehicles available. The user was free to choose whether he drove electric. These results do clearly show, however, how the electric car was being used.

The current use of the conventional vehicles in the Rijkswaterstaat fleet could also be examined, with the daily distance distribution being determined (see Figure 12) on the basis of some 11,000 day reports of cars that are person-centric or pool vehicles (in total some thousand cars).

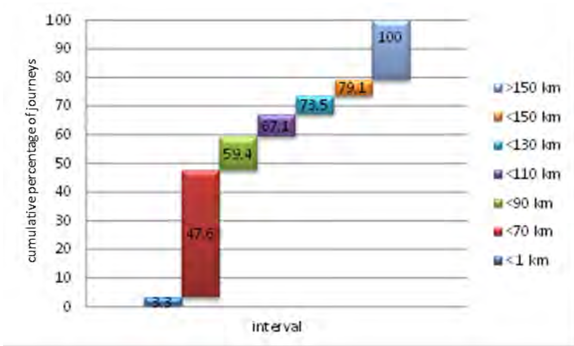


Figure 12 Cumulative percentages of daily totals driven in cars of the current (conventional) Rijkswaterstaat fleet.

In total Rijkswaterstaat has 1634 vehicles. Figure 12 shows the distribution of journey distances within 857 person-centric vehicles used exclusively for work. Of these 59.4% drive less than 90 kilometres and could be replaced by an electric car, which is 509 electric cars and thus easily achieving the target of 400 electric cars.

4.3.4 Do the safety requirements still comply in the event of large-scale use of electric vehicles?

At this moment in the field test nothing is evident that would suggest anything other than the validity of the safety requirements, also for large-scale use.

4.3.5 How dependent are range and energy consumption on circumstances of use?

The energy consumption of electric vehicles is determined by the technology applied, the vehicle mass (heavily influenced by the size of the battery), driving patterns (incl. combination of urban, non-urban and motorway roads), the driving style (incl. effective use of regenerative braking), weather conditions and other factors. The energy consumption subsequently determines the range, energy costs and much of the impact of (PH)EVs on the environment as well as on the frequency of charging and the amount of energy charged. In the period in which the field test was monitored, the fully electric vehicles drove 113,965 km on a total charge of 24.6 MWh of electrical energy. Average consumption in that monitoring period was 216 Wh/km (or 21.6 kWh per 100 km).

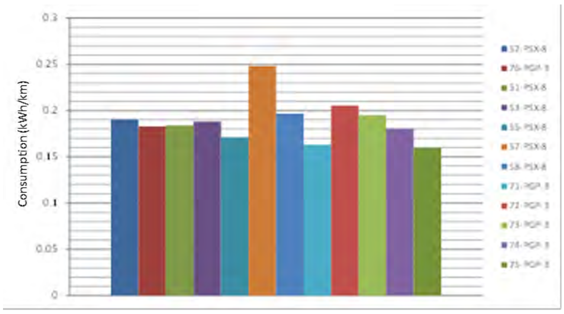


Figure 13 Mitsubishi i-MiEV and Peugeot iOn: average consumption in kWh/km in the monitoring period. The average for the 6 Peugeots is 197 Wh/km, and for the 6 Mitsubishis 177 Wh/km (together 187 Wh/km average). The difference is largely coincidental and could be attributed to driving behaviour.

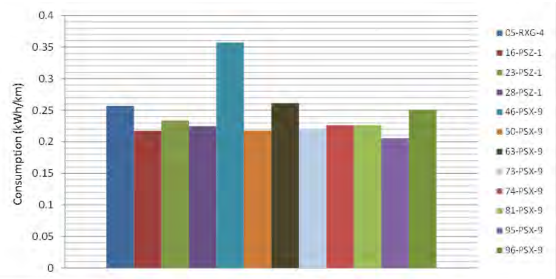


Figure 14 Average consumption for the Nissan Leafs in kWh/km over the entire monitoring period (9 months). The average for the 12 Nissans together is 235 Wh/km.

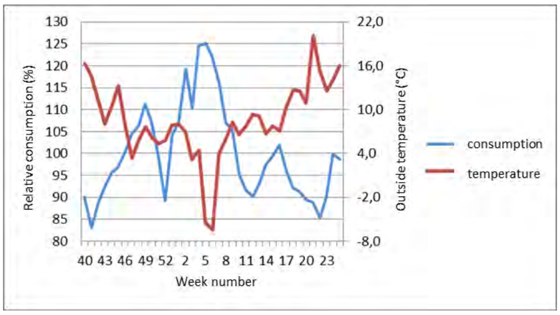


Figure 15 Seasonal influence of relative consumption in the field test (100% reference is the average over all kilometres driven, regardless of car type) as a function of week number. The influence of the seasons is in clear evidence in this graph. The average consumption was 219 Wh/km; in the most unfavourable week, the consumption was a good 1.5 times higher than in the most favourable week.

Measuring the actual consumption makes it possible to determine the actual range. It comes as no surprise that the real-life range is less than the manufacturers' specifications. However, we have measured the real consumption for a specific application over three quarters of a year, including the influence of wind an temperature. With an average actual consumption of 187 Wh/km at a battery capacity of 16 kWh the actual range of the i-MiEV and iOn is 85 kilometres rather than 150 kilometres, or 57% of the specifications provided. The Nissan Leaf has an average real consumption of 235 Wh/km, or a range of 102 kilometres rather than 160 kilometres, 64% of the specified range. In deviating, higher actual consumption, the manufacturer should really use a method of measurement that is legally compulsory. The method actually used does not properly reflect the consumption measured in this field test.

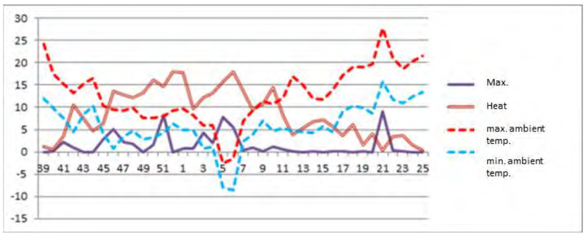


Figure 16 Seasonal influence. Supplementary to Figure 44 a graph of heat demand ("heat"), ventilator speed ("max") and ambient temperature.

5 Conclusions and recommendations

The electric driving field test for the government has provided a wealth of practical data.

The experiences of the users of electric vehicles and others involved in the field test were extensively inventoried via surveys. A striking result of this is the generally positive appreciation of electric driving and the gradual increase in that appreciation over time. But there are also aspects of user dissatisfaction due to the limitations of this relatively recent technology: the range of the cars is experienced as insufficient and that weighs heavily given the lack of charging facilities in the opinion of the users. In practice, the range is a third lower than the manufacturer specifications. This is due to the factory measurements, although performed in a legally compulsory manner, are less dynamic than normal real traffic and take no account of the added use of heating or air-conditioning. In this test the average energy used in less favourable weather conditions was 50% higher than in good conditions during the measurement period.

As for the environmental impact of electric transport, the emissions avoided during this field test period were calculated for a total of 233,000 electric driven kilometres (of which a little more than half were registered with on-board equipment) and revealed 333 grams of particulate matter, 5.6 kilograms of NOx (locally) and 15.1 tonnes of CO_2 (global). In the CO_2 figure account is taken of the chain emissions related to electricity generation. The more the vehicles are deployed, the much higher the level of avoided emissions.

In summary, there is significant and growing appreciation for electric driving and the users see good opportunities for the cars, despite the limitations of this still emerging technology (like range and charging points). The challenge in the field test was to make more use of the cars and this aim succeeded. The total distance driven in the final monitoring quarter (63,281 km) was more than in the two preceding quarters together (49,318 km). These figures reveal in the best conceivable way that there is a growing appreciation for electric driving among the participants in the field test.

5.1 Implementation and scaling up at Rijkswaterstaat

A key conclusion from the field test is that the large-scale application of electric vehicles is feasible within the Rijkswaterstaat fleet and the target for 2015 achievable. Account will have to be taken of the purpose for which the electric vehicles can be used in relation to the properties of the comparable electric cars now. Still, the desired proportion appears feasible without much difficulty.

5.2 Further conclusions and recommendations

Another conclusion is that further investment needs to be made in the purchase of the cars and in the charging infrastructure. At this point in time this generates significantly more costs in relation to conventional transport. Rising fuel prices, cheaper future EV models and more intensive use of electric cars could make electric transport more appealing even in the short term. For Rijkswaterstaat, in the current circumstances and at 15,000 km per car per year, it would take about seven years to redeem the extra costs against the conventional reference. So for a period of use of four years, there are extra costs. Based on the assumptions made in section 5 this is around € 870 per year per car, or 6 additional cents per kilometre to drive electric at present.

Entrepreneurs, by contrast, can already start to redeem these costs on the same use of the same vehicle in the first year due to a variety of benefits and deductions. It does not pay a consumer to drive electric at present from a TCO perspective (redemption more than 12 years).

Non-economic effects are also important. Like the government acting as an example, especially in terms of reducing the impact on the environment.

Below are the main recommendations for the possible implementation of a large-scale electric vehicle fleet:

Ensure an adequate, proper charging infrastructure
The absence of an adequate charging infrastructure is one of the issues clearly raised by the survey. When scaling up. it is important for there to be enough charging points with the right plug available. Smartphone apps already exist showing where the charging points are and even if they are available at that moment.

Use the electric car in the right place
Look at the entire existing fleet. Which users only cover short distances? Which users sporadically cover longer distances? For these users a pool of electric cars and a few conventional cars is sufficient.

Measures for more deployment of the electric car
The field test revealed that the addition of electric cars to a pool of conventional cars does not lead to intensive use. When in doubt or as a matter of course, people tend to opt for the petrol-powered car while electric driving would have been a suitable option. To maximise the number of electric kilometres and make electric driving a success, it is important to provide both stimuli and guidelines.

Information
There is still a lack of clarity about electric driving for many people. Does the plug fit? How far can I really drive? How long does it take to charge? Wher can I charge? Is it dangerous? Good communication is essential here. Bring people up to date with facts and supervise them in the deployment of electric cars. This helps create

confidence in the possibilities of electric driving and you manage expectations.

Make electric driving a positive experience
Let people try out and experience electric driving, organise an internal competition, for instance, to see who can drive the most electric kilometres or dares to drive the furthest. Stimulate storytelling so that colleagues share experiences.

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7 References

[1] CBS.nl – Elektriciteitsbalans: aanbod and verbruik in Nederland in 2011
[2] CBS.nl Opgesteld electric vermogen in Nederland in 2010
[3] Compendium voor the leefomgeving – 168 Mton CO_2 emissie in 2011 in Nederland
[4] T. Anegawa TEPCO 2009
[5] McKinsey, "A portfolio of drivelines for Europe"

The complete report in Dutch can be downloaded from www.tno.nl/

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