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Fuel-electricity mix and efficiency in Dutch plug-in and range-extender vehicles on the road

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Abstract

For the Dutch Ministry for Infrastructure and the Environment data of plug-in vehicles was collected. Data concerning fueling and charging of plug-in vehicles is collected from lease companies, a fuel-pass company, and the charging infrastruture organisation. More than 10% of the total Dutch plug-in fleet is covered. The electricity data is insufficient to derive a real-world electricity use, e.g., kWh/100km. However, the amount of electric kilometers are determined and verified to be about 24%. A substantial group of users charge the vehicle once or twice a day. However, among the business users, there seems to be a substantial group who do not use the charging capabilities of the plug-in vehicles. The Dutch report is sent by the minister to the Dutch Parliament in June 2013. [3]

fuel consumption, plug-in vehicles, range-extender vehicles, monitoring

1 Introduction

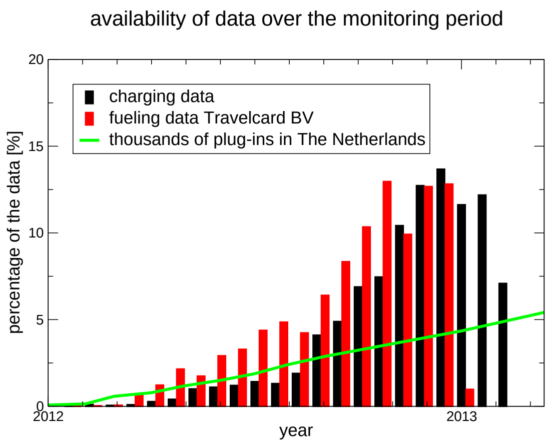

Figure 1: The data and number of vehicles available during the monitoring period in 2012. Note the increase over the year, with the sales of plug-in vehicles.

From early 2012 the number of plug-in vehicles has increased rapidly in The Netherlands. This is in part due to the favorable tax-and-grants regime in The Netherlands, which is based on the type-approval CO2 value. It was reported in the media that these vehicles use a lot of petrol. Therefore, the Dutch Ministry of Transport and the Environment asked TNO to include explicitly the plug-in vehicles in the analyses of real-world fuel consumption of passenger cars [1] they carry out intermittently since 2009. [2]
The extent of the study increased through the collaboration of several stakeholders such as vehicle importers, lease companies, and the charging infrastructure service company. The major difficulties in the data collection are the actual mileages of the vehicles and the recovering of all charging transactions. [3]

2 Dutch national trend

From 2012 the number of plug-in vehicles has increased significantly in the Netherlands. See Fig. 1. From a few vehicles, at the end of 2012 about 5000 plug-in hybrid vehicles and range-extender vehicles driving around. Three-quarter of these vehicles are owned by companies, a quarter is private ownership. With a few exceptions the three makes and models are:

the Opel Ampera, the Toyota Prius Plug-in, and the Chevrolet Volt. The Volt is technology-wise identical to the Ampera.

The popularity of these vehicles is partly due to tax incentives, both sales, income, and road taxes a reduced or exempt. The Dutch government sees a role for plug-in and hybrid vehicles for the transition to sustainable road transport. The tax scheme is based on the CO2 emission, which for the Ampera and Volt is 27 g/km and 49 g/km for the Prius. These numbers are mainly due to the electric range on the test.

The test (see Tab. 1) is a combination of an electric range test, a full battery test, and an empty battery test (test 2). Typically, only in the second test fuel is used; the first test of 11 km is usually short enough for a full electric driving. The type-approval value is based on the range and the fuel consumption in test 1 (i.e. 0) and test 2:

$$X_{type-approval} = X_{test\ 2} \frac{25}{Range + 25} \qquad (1)$$

The consequence is that the electric range plays an important role as the fuel-driving part is restricted to 25 km. Most plug-in vehicles have ranges of 25 km or more, reducing the fuel-consumption contribution by half or more. The most favourabl;e tax regime for vehicles under 50 g/km CO2 is easily met by plug-in vehicles.

Table 1: Type-approval determination of plug-in and range-extender vehicles with fuel consumption (FC[l/100km]) and CO2 ([g/km])

	range	test 2		overall	
	km	FC	CO2	FC	CO2
Prius	25	4.2	98	2.1	49
Ampera	87	5.2	119	1.2	27
Volt	87	5.2	119	1.2	27

The Tab. 1 shows the actual fuel consumption, as with an empty battery, and the type-approval value resulting from weighing with the electric range. Note, all these values are obtained on the NEDC test: a low load and velocity test compared to average European driving. Furthermore, both at high temperatures (above 25 C) and low temperature (below 10 C) the electric range will drop due to battery efficiency and auxiliaries usage. The official test is carried out between the favourable 20 and 30 C, where the laboratories even have the freedom to set the temperature within this range.

For conventional combustion technology is has been know for a long time that the NEDC fuel consumption deviates from the real-world value. However, recently the gap is increasing with years and and with low type-approval values. [2, 3, 1] The trend seems independent of technology and fuel. Also the plug-in vehicles monitored fulfill the same expectation. See Fig. 2.

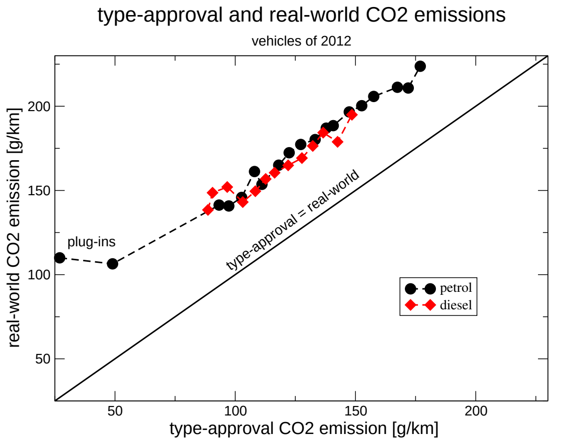

Figure 2: type-approval and real-world CO2 emissions, convential passenger cars and plug-ins (this study).

3 Data collection

The data consists of charging transactions and quantities, fuelling transactions and quantities, and mileages. The data shows a wide range in vehicle use, with a large group of consistent users charging their vehicle once or twice a day. Another group does not seem to charge the battery at all, which is confirmed by the fuel consumption data.

Before November 2012 charging at public charging stations was not regulated in The Netherlands. The costs were not considered as sales. Henve prior to this date, the business administration may not have been atuned to handle this data. Some charging data may be missing. Furthermore, several charging passes may be used: either associated with the vehicle or with the charging point. This data is coupled to the vehicles as much as possible.

Furthermore, vehicle mileages are often missing or entered incorrrectly. The study made use from maintenance data, driver data, and lease company data to achieve a full set. However, many records had to be deleted manually, as the entered mileages were deemed incorrect. This deficiency was a major drawback in determining the fuel consumption and the electricity usage of the vehicles per kilometre.

Eventually, the data, with different cross sections, in Tab. 2. For different analyses, different cross sections were used. An existing, stricter method to select correct vehicle mileages, as used in previous studies [2], removes 60% from the mileages data. This leaves not enough data, except for determining the fuel consumption.

4 Fuel consumption

Most of the fuel consumption data is from Travelcard Nederland BV, a fuel-pass company. For convential vehicles this data has been used for an accurate determination of real-world fuel con-

Table 2: Cross sections of the different data sets, leaving only a small set of complete data. In total 690 vehicles were available.

fueling	charging	mileage	samples
X	-	-	631
-	X	-	245
-	-	X	456
X	X	-	191
X	-	X	456
-	X	X	148
X	X	X	148

sumption. Using the stricter criteria, rather than the total mileage and the total registered fuel, only 183 of the 456 vehicles can be used.
The real-world fuel consumption of the plug-in vehicles correponds to CO_2 emissions of 106 g/km for the Ampera and Volt, and 106 g/km for the Prius. These numbers are in line with deviations of real-world fuel consumptions of all passenger cars. See Fig. 2.

5 Charging

Together with the introduction of the electric and plug-in vehicles also the charging infrastructure was developed. However, people occosionally have to wait for the home charge point, making it hard to charge efficiently. Despite these setbacks, a large group of vehicles charge frequently. See Fig. 3.

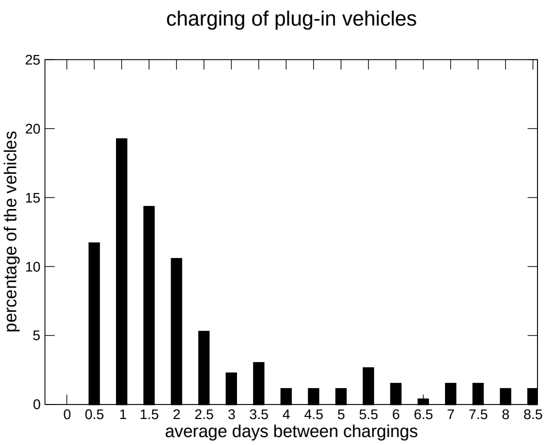

Figure 3: The charging of a large group of vehicles is once of twice a day. However, much longer periods also occur.

From the data it is clear that in many cases the battery was substantially depleted, before the charging started. Whether full charging was achieved is not a priori clear. There are several reasons for a lower that full charge: reduced battery capacity, engine control strategy which recharged the battery partially, short duration for charging, etc.

6 Electricity use

The total electricity use is substantial, however, much lower than the total petrol use of the same vehicles. This makes it difficult to derive a real-world electricity use in kWh/100km. The electricity use seemed limited by the number of times charging per day, in combination with the extensive use of the vehicles. Many drive 40 000 kilometres per year or more. This corresponds to 150 - 200 km a day, in typical business use. In that case the Ampera should charge 3 to 4 times, while the Prius should charge 10 times or more. This seems hard to combine with a business work day.

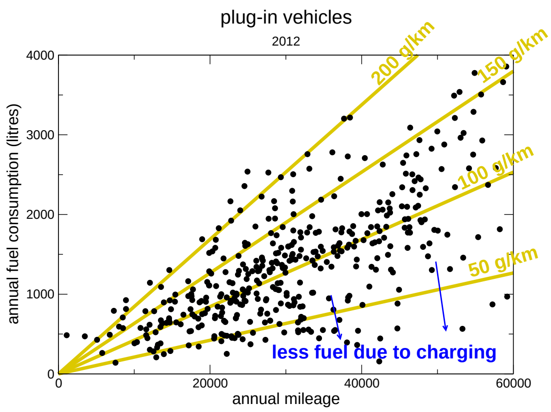

Figure 4: From the annual mileage and fuel consumption it is clear a group of vehicles use the charging facilities sunstatially, however, the scatter makes it impossible to decouple fuel efficiency from charging.

The electricity use cannot easily be recovered. Most vehicles still take a substantial amount of petrol. See also Fig. 4. Only a few vehicles do 80% or higher of the total mileage electrical. The driving style among drivers yield variations of $\pm 20\%$. Hence, a lower fuel consumption can be due, besides higher electric mileage, also to an eco-driving style.
However, there are two ways to estimate the electric part of the total mileage. First, use information of typical real-world fuel consumption of similar cars, and compare this with the average fuel consumption of the plug-ins. Secondly, estimate a typical electric efficiency at 14 kWh/100km, and compare that with the total electric charging. In both cases the electric mileage is estimated at about 24% of the total mileage.
From Fig. 5 it is clear that the assumptions underlying the type-approval fuel consumption of plug-in vehicles are met only by a few drivers. Most drivers have a much higher fraction of driving on the combustion engine, with a limited use of the charging infrastructure.

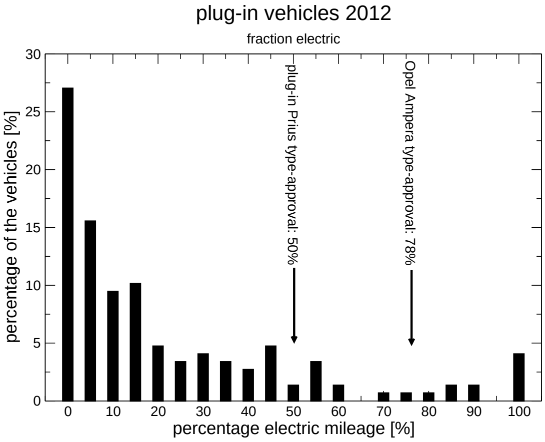

Figure 5: With a realistic, albeit slightly optimistic assumption of 14 kWh/100km (50 MJ/km), the pecentage of electric driving can be derived from the charging data.

7 Conclusions

The rapid introduction of plug-in and range-extender vehicles in The Netherlands in 2012 is monitored. The fuel consumption is higher than expected on the basis of the type-approval value, which is based on a substantial eclectric mileage, of 50% or 87%. In practice the electric mileage is typically around the 24%. However, a large spread in the data indicates there is room for improvement, by improving the charging infrastructure and the behaviour of the drivers. Some drivers can drive mainly electric, even with a high annual mileage of 40 000 km or higher.
Despite the negative publicity the electric vehicles received, based on the expectations from the type-approval value, the vehicles are the most fuel-efficient vehicles in the Dutch fleet. The combination of the technology used, with the, still limited, 24% electric driving, reduced the petrol consumption substantially. It is already a step towards reducing the transport CO2 emissions.

Acknowledgments

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Authors

Since 2007, Norbert Ligterink has been the driving force behind the Dutch national vehicle emission model, Versit+, at TNO. From that perspective, he has been involved in Euro-VI legislation, emission measurement data analyses, design of experiments, and analysing fleet composition.

At ECN, CE Delft and TNO Richard Smokers has worked on a large number of national and international projects, carrying out policy studies, consulting work and technology assessments. His focus is on future technologies, economical and political aspects of transitions towards sustainable transport.

Mark Bolech activities focus on alternative drive-trains in general and on electrical energy storage systems and recharging technology for Electric Vehicles in particular. His background in physical chemistry is put to use in the work on electrical energy storage systems that are used in such vehicles.