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Real world experience with operating electric vehicles in the Netherlands

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Abstract

Between July 2011 and March 2012 a group of eight electric vehicles have been monitored while operating either as part of a local taxi fleet or as a service vehicle for local authorities. With these vehicles a total distance of 38078 km was covered in that period. Analysis of the monitoring data gives results that are in line with these applications. These vehicles are operating mostly in urban and extra-urban traffic conditions, with average trip lengths well below their maximum driving range. Charging took place frequently, usually well before running into charge depletion conditions. Furthermore real world electric energy consumption is well above the nominal values mentioned by the manufacturers. Correspondingly, for seven out of the eight vehicles actual driving range is around half of the value mentioned by the manufacturers. This is believed to be due in part to the lower ambient temperatures in the monitoring period. A cost analysis (considering a five year operating period) shows that – in the Netherlands – these electric vehicles are clearly economically viable, but this is a result of the current subsidy levels. Without subsidies the opposite situation would exist. Finally, estimated well-to-wheel CO_2 emission levels of these vehicles are not substantially different from those of the corresponding reference conventional vehicles. This is because electric energy in the Netherlands still mainly originates from non-renewable sources.

Keywords: Battery electric vehicle, range, energy consumption, cost, emission

1 Introduction

Electric mobility is seen as an important path towards achieving a sustainable mobility in Europe. To stimulate the implementation of electric vehicles, in the Netherlands, both national and local authorities have initiated and financially supported a number of electric driving field tests. These tests have made it possible for fleet owners to gain real-world experience with the implementation of electric vehicles. At the same time it was decided that the driving and charging behaviour of these vehicles should be monitored. In combination with interviews of the drivers this monitoring was to provide all relevant stakeholders with a better understanding of the practical differences between conventional and electric vehicles.
One of these tests took place in the province of Brabant and involved real-world operation of 10 different EV's. This paper presents the monitoring results for 8 of these vehicles and covers the period between July 22nd of 2011 and March 2nd of 2012.

2 Fleet description

Results are presented for 6 OEM quality passenger car electric vehicles (Nissan Leaf) and for 2 conventional Ford Connect vehicles that were converted to electric vehicles by a local company (AGV). The latter vehicles are referred to as AGV vehicles in the rest of this paper. The most important properties of both vehicle types are summarized in Table 1.

Table 1: Principal test vehicle properties; (*) in the NEDC test.

Vehicle type		Leaf	Connect
Make		Nissan	AGV
Reference		[1]	[2]
Production year		2011	2011
Battery type		$LiMn_2O_4$	$LiFePO_4$
Slow charge duration from 230 V	[h]	8	8
Nominal battery capacity	[kWh]	24	24
Vehicle weight min/max	[kg]	1525 /1567	1520
Nominal range	[km]	175(*)	130
Tractive power	[kW]	80	75
Max speed	[km/h]	145	110
Acc. time 0→100 km/h	[s]	11,9	N.A.
ECO-mode		Yes	No

3 Instrumentation

Every vehicle was provided with a commercial “track and trace” system from Routeconnect [3]. The heart of this system is a GPS-sensor that determines the position of the vehicle with reasonable accuracy (± 10m). A GPRS antenna and wireless communication unit transfers the GPS-coordinates together with the vehicle unique ID-number and GMT-time to a central server.

Registration and communication of time/position takes place when 1 of the 4 following criteria is met: the vehicle is started (contact on), the vehicle is stopped (contact off), the vehicle has turned more than 40°, 5 kilometres have been travelled since the last communication. For this project, the time between consecutive position registration was in the order of 2 minutes. At the server this info is processed into distance travelled. Start of a trip coincides with contact on, the trip ends with contact off. the Because of its low registration frequency the Routeconnect system trip length estimate cannot be exact. A comparison with odometer registration for a selection of trips however indicated that the error made was smaller than 3,5%.

Using the same hardware, also SOC-variation was monitored, be it at fixed 5 minute intervals. For this an interface was realised between the vehicle CAN-bus and the Routeconnect On-Board unit. Finally, in order to have some indication of typical driving behaviour, for two vehicles (both Leaf) vehicle speed was also registered with a VBOX Micro 10Hz GPS data logger from Racelogic [4].

All vehicles were charged from standard 230V sockets, either at home or at a dedicated and reserved parking spot at work. When charging, electric power was monitored at 1 minute intervals and stored on a flash disk. This info was then manually collected (and consequently processed) at regular intervals.

4 Results

4.1 Usage pattern and driving behaviour

With the different vehicles a total distance of 38078 km was covered. As indicated in Table 2 the average distance per trip was limited and well below the nominal maximum distance that can be covered on a single charge according to the manufacturers (viz. Table 1). Furthermore the average trip length with the vehicles used by the local authorities was small and in line with their typical use: short trips to and from work and between different locations within a small city (aimed at monitoring for instance of parking spots or sport accommodations or for attending meetings at different locations). The intensity of the use of these vehicles (determined by extrapolating the data in Table 2 into expected distance covered per year) is not very different from that of the conventional vehicles that they replace. Surprisingly, even the taxi companies are using their electric vehicles for relatively short trips. Here, intensity of use is clearly below that of comparable conventional vehicles, indicating a difference in planning of the use of these vehicles (taking into account expected limitation on driving range).

Table 2: Overview of vehicles, their typical use and trip data. Unless indicated differently, owners were local authorities in the province of Brabant in the Netherlands. The L-4 and L-5 vehicles are shown on a darker background; they are the ones where also high-frequency trip info was gathered.

Vehicle type	ID nr.	Owner	Typical use	# km	# km / day	# trips	Av. trip length (km)	Max. length for 50 % of trips	Average trip speed (km/h)
Leaf	L-1	Bernheze	Staff travel	4672	36,6	424	11,02	8,93	36,56
Leaf	L-2	Bernheze	Staff travel	2571	29,6	380	6,77	5,52	30,27
Leaf	L-3	Bernheze	Staff travel	3101	35,7	709	4,37	2,17	23,98
Leaf	L-4	Oss	Staff travel	6724	58,0	609	9,11	10,96	37,23
Leaf	L-5	Van Dijk	Taxi	8690	70,1	430	20,21	15,44	46,68
Leaf	L-6	Van Driel	Taxi	2901	38,7	497	5,84	2,91	19,6
Connect-1	C-1	Oss	Staff travel	4105	28,5	1107	2,82	2,65	15,78
Connect-2	C-2	Oss	Staff travel	5313	47,0	1081	4,87	3,14	35,2

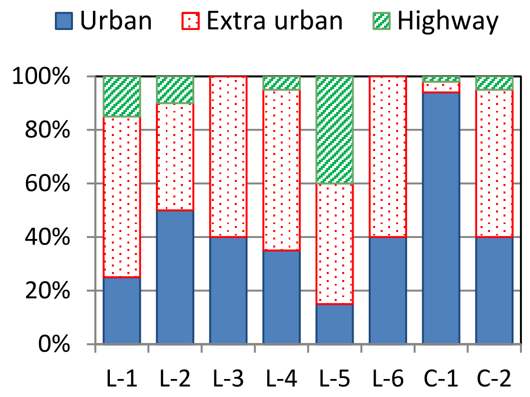

Figure 1: Percentage of distance covered in urban, extra-urban and highway conditions for the different vehicles.

Table 2 also shows average trip speed data determined from the Routeconnect data. These data are in line with the local traffic conditions: as shown in Figure 1 most vehicles were moving in an urban or extra urban environment for most of their time. The results shown in Figure 1 were obtained by correlating vehicle position with maps of the region they were operating in.

Further analysis showed that the time and location where vehicles were driving were such that they did not suffer from congestion or from excessive start-stop driving conditions.

It is worthwhile to point out that in the Routeconnect definition a trip will usually also include moments of standstill: at traffic lights, while waiting for or assisting (taxi) clients, or while leaving the vehicle for short inspection rounds. Because of this the actual average speed of the vehicle while in motion will be higher. This was evident from an analysis of the high frequency position monitoring using the V-Box data for two vehicles (L-4 and L-5). This is illustrated in Table 3; this table summarizes driving pattern characteristics for a typical set of trips of these vehicles. When the uncertainties and accuracies of the different data are taken into account the results of Routeconnect and Racelogic are found to be consistent.

Table 3: Typical vehicle driving pattern characteristics determined from high-frequency position monitoring.

	L-4	L-5
Distance covered [km]	30,9	198,5
Average vehicle speed while driving [km/h]	47,7	47,0
Average positive acceleration [m/s2]	0,32	0,40
Standstill [% of time]	20	21
Speed < 50 km/h [% of time]	47	46
50 km/h < Speed < 80 km/h [% of time]	27	26
Speed > 80 km/h [% of time]	6	7
Average trip speed [km/h]	42	36

From interviews it was further determined that the drivers of the Leaf vehicles all used their vehicle in ECO-mode for a significant period of the operating time (on average around 65 to 70 % of the time). Under cold ambient conditions these vehicles were preheated and – while driving – the heater was put on. With the AGV-vehicles there was no ECO-mode and no possibility to preheat.

4.2 Charging behaviour

Figure 2 indicates that charging took place often, and usually considerably prior to running into charge depletion.

This is in line with the short trip lengths mentioned before and with a practice of hooking the vehicles to the grid immediately upon returning from a trip.

At the same time, on some occasions, almost all of the charge was depleted prior to discharging. This would be indicative of growing confidence as experience with the vehicles was building up. In one case (vehicle C-2) the maximum energy charged from the grid even exceeds the battery capacity. This is possible because only part of the energy supplied by the grid is turned into effective battery charge. From monitoring charging data and SOC on the C-type vehicles, it is was determined that only 90 % of the energy supplied ends up in the battery. Similar values have been suggested for the Nissan Leaf's [5]. At the same time, in practice, the energy charged to the battery is smaller than its nominal capacity because SOC-variation is usually in the 15-100 % range. In view of the above observations, the data in Figure 2 are considered to be consistent.

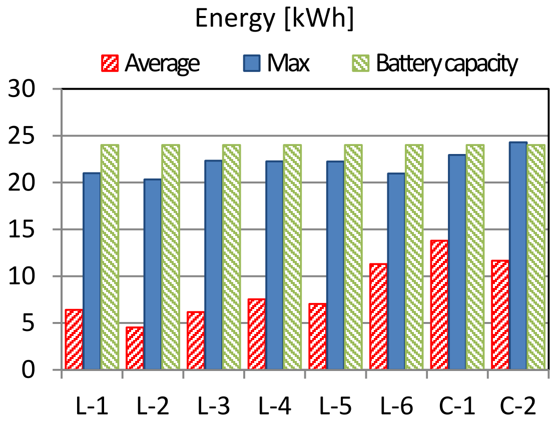

Figure 2: Energy charged from the grid compared to battery capacity

Figure 3 illustrates the timing of the charging events by separating day-time charging from charging during the night. For this, "day-time" was defined as the period between 09:00 and 21:00 hrs. This definition is consistent with data from the Dutch high-voltage electricity transport system operator TenneT. According to this info, throughout the year, the electricity demand tends to increase from a lower level to a higher level between 08:00 and 10:00 hrs., and falls back to the lower level in the period from 20:00 hrs. to 22:00 hours) **[6]**.

As shown in Figure 3 for most vehicles, charging took place during the day. Only for the L-4, C-1 and C-2 vehicles, charging was prominently during the night.

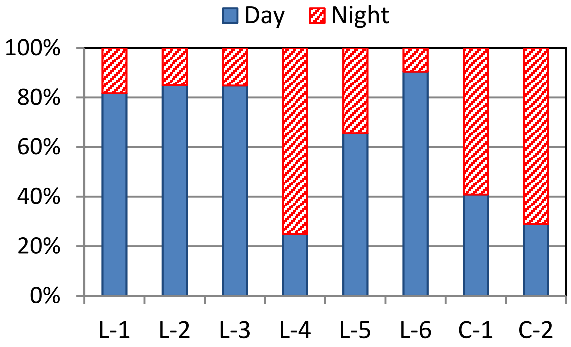

Figure 3: Percentage of electric energy that is charged during day/night.

As shown in Table 2 all three vehicles belong to the same owner and the timing reflects operational charging directives of that owner plus the fact that the vehicles could be charged by the drivers at their home from the 230V mains.

5 Discussion

5.1 Energy consumption and temperature effect

Combining the trip length data and the charge data allows to estimate the energy consumption for the different vehicles as it evolves with time. A typical result is shown in Figure 4.

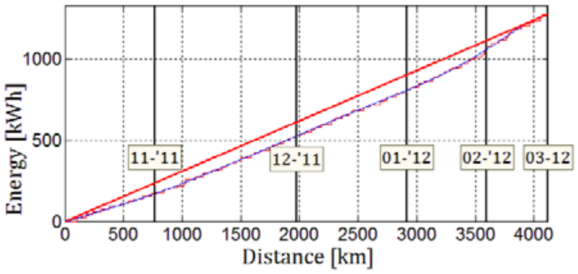

Figure 4: Evolution of (grid) energy used with distance for L-4; time indications added. The red line represents the average energy consumption as in Figure 5

This figure indicates that – on average - energy consumption seems to gradually increase with time during the project. Especially towards the end of the project a significant increase is noticed. A similar behaviour was observed for the other vehicles. This behaviour is attributed to a decreasing ambient temperature (average daily temperature dropping with 14-15 °C from August until February, with lowest values of -5°C at the start of February). This will result in additional energy needed for heating the vehicle prior to start as well as more energy needed for heating the passenger cabin while driving. The corresponding average energy consumption (for the whole project period) is shown in Figure 5. Obviously this energy consumption is well above the nominal value mentioned by the manufacturers. This difference is especially large for the Nissan Leafs. The difference between observed and nominal energy consumption is smaller for the AGV vehicles (C-1 and C-2); that is in part due to the fact that these vehicles were suffering from problems and therefore not operational during the coldest periods.

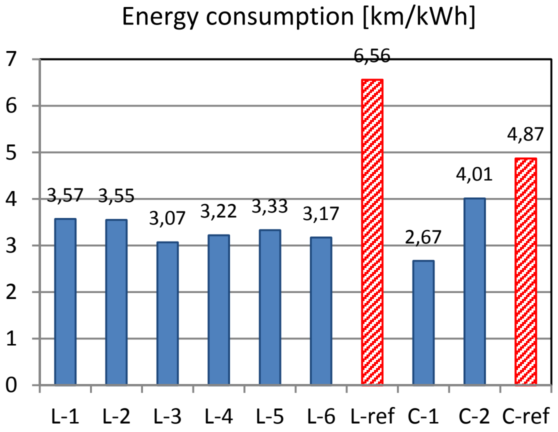

Figure 5: Real world energy consumption in km/kWh (with energy charged from the grid as input) compared to the nominal energy consumption mentioned by the manufacturer [1,2].

Considering Figure 5 it should be mentioned that the reference energy consumption values shown originate from correcting the nominal battery capacity for a 10 % energy loss during charging from the grid and dividing this with the range as claimed by the manufacturers. Because this does not take into account that only part of the battery capacity is used when demonstrating the nominal range, these reference values can be considered conservative.

Other similar studies, e.g. by TNO [7] as well as Nissan itself [5], also have mentioned real world consumption values significantly below the reference values. Nevertheless, the number of km that could be driven on 1 kWh for in this study are clearly on the lower side. For comparison: TNO [7] noticed an average of 4,25 km/kWh for a group of 12 Nissan Leaf vehicles. The higher consumption in the present study is attributed to the lower ambient temperatures in the monitoring period. These results have been checked and retained because, as shown in Figure 6, the range observations from this study are consistent with these energy consumption values.

From interviews of the drivers the following additional information was gathered: (1) the relatively sharp range indication change shortly after starting the vehicle was considered disturbing and worrying, (2) two drivers (of L-4 and L-5) deliberately tried to drive a maximum distance before recharging. This is confirmed in Figure 6.

A final detail for Figure 6: for the L-5 Leaf some charge data were missing; this explains the max trip length exceeding the max distance registered for a single charge.

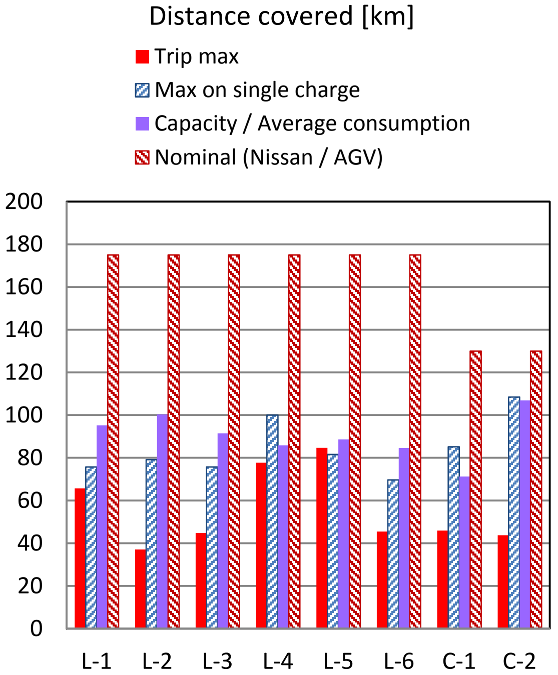

Figure 6: Observed range compared to nominal values and consistency with energy consumption data.

5.2 Vehicle costs

A short study was made of the total costs for each of these vehicles when compared to a conventional vehicle with similar performance (comparable maximum speed and similar acceleration from 0 to 100 km/h) and comfort (room for passengers and trunk space) as the electric vehicle.

Table 4: Overview of reference vehicles (built in 2012) selected for cost comparison.

EV	Reference vehicle / fuel type
L-1, L-2, L-3, L-4	VW Golf 1.2 TSI / gasoline
L-5	Seat Ibiza 1.6 TDI / diesel
L-6	Mercedes B-klasse / LPG
C-1, C-2	Ford Connect 1.8 TDCi / diesel

Table 4 gives an overview of these reference vehicles. Their fuel choice reflects the preference of the end users: gasoline for most local authorities (where annual km driven is limited) respectively diesel or LPG for taxi fleets (where more km are driven annually).

Table 5 illustrates the calculation procedure followed when performing the cost comparison. It is assumed that the vehicles are purchased by a company, hence VAT does not contribute to the net costs. Further the calculations consider a 5-year period. To purchase the vehicles, the company takes up a 5-year loan at a fixed interest rate of 5,75%; this capital is paid back in equal yearly instalments together with the interest of that year. It is assumed that no investments are to be made in charging equipment. It is also assumed that companies takes full profit of the (ordinary and extra-ordinary) possibilities of reducing their taxable income at a marginal tax rate of 25 %. The residual value of the vehicles after 5 years was set at 40 %. This is acceptable for conventional vehicles. For the electric vehicles, for lack of data, the same rule was used. Maintenance costs were estimated from experience with the partners in the project respectively from indications provided by the manufacturers of the electric vehicles. For calculating energy costs, typical fuel pump prices respectively electricity prices were used for 2012. All costs are in 2012 €. Inflation in the period 2012-2017 was assumed to be constant at 2%.

Table 5: Procedure for cost calculation

Purchasing cost (incl. of VAT)		
	-	VAT on purchase cost
	-	Subsidy B (3 % purchase cost reduction)
	-	Subsidy A (additional 36 % of purchase cost tax deduction)
	-	Regular purchase cost tax deduction
	-	Residual value after 5 years (excl. of VAT)
= Net cost		
	+	Capital cost for 5 year loan
	+	Energy cost (excl. VAT)
	+	Maintenance cost (excl. VAT)
	+	Road tax (excl. VAT)
	+	Insurance cost (excl. VAT)
= Total cost		

The outcome of such a calculation is shown in detail in Figure 7 for vehicle L-1 (and for its reference vehicle). In this figure subsidies are shown negative. The sum of their absolute values together with the net cost corresponds to the purchase cost (exclusive of VAT). Clearly, through the different subsidies and other advantages the disadvantage of a higher purchase costs is almost completely compensated. As can be seen, the EV is further subsidized by the absence of road tax. Because of these subsidies and because of the lower energy costs, total cost of ownership of the electric vehicle is significantly below that of the conventional vehicle. For additional information, in the same figure also the total VAT and excise duty have been added.

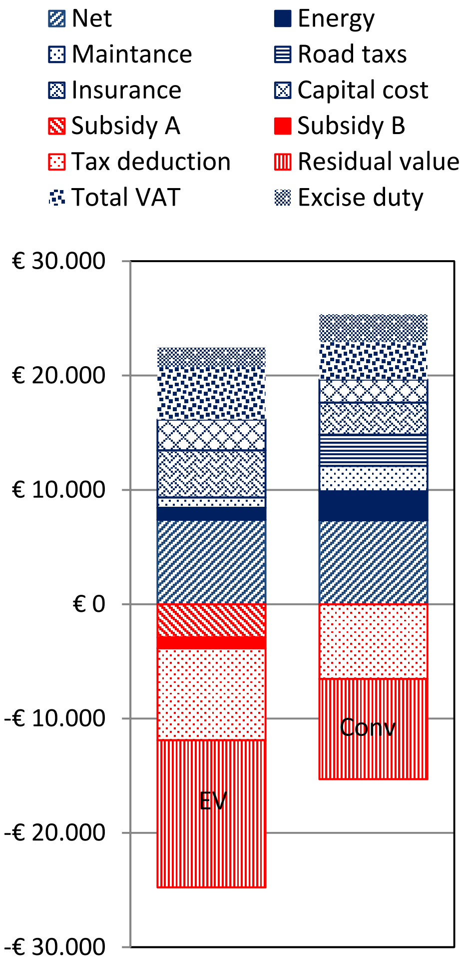

Figure 7: Detailed cost comparison for the L-1 Nissan Leaf vehicle and its conventional counterpart as mentioned in Table 4.

Similar calculations were performed for all vehicles. The outcome is shown in Figure 8. Obviously, with the tax incentives that were valid in that period, the total cost for the electric vehicles are below that of the different conventional counterparts. At the same time, this study shows that – without subsidies – electric vehicles are economically not viable.

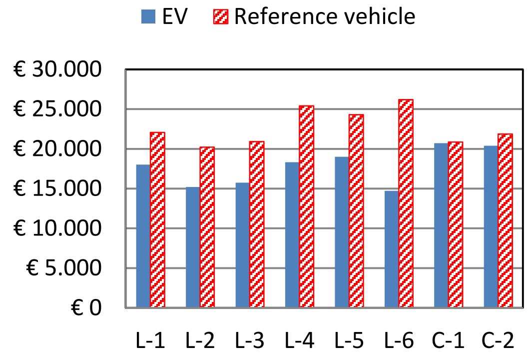

Figure 8: Actual total costs after 5 years of operation (excl. of VAT and excise duty) for the electric vehicles and for their reference vehicle; results apply to the situation in the Netherlands in 2012.

Some final remarks to the above results:

- Energy consumption of the electric vehicles was measured in a period with lower temperatures; year-average energy consumption may be somewhat lower.
- Fuel consumption of the conventional vehicles was estimated (correcting NEDC consumption for differences with real-world operation [8]).
- Costs were compared for the same amount of km driven by an EV and its conventional counterpart. In reality, especially with the application in the taxi fleets, range limitations were limiting the use of the EV. For these (and similar) applications where range limitations are an issue, costs per km driven are in practice considerably higher than those of conventional vehicles (that allow a more intensive use). This confirms the need to increase the range of electric vehicles.

5.3 Estimated CO2 emissions

Of course, electric vehicles do not produce climate gases while driving. And they are a blessing to local air quality. However, in most cases, climate gases are produced when generating electricity. Therefore, an estimate was made of the CO_2 emission (per year) for the different electric vehicles as well as that of the reference vehicles.

The (well-to-plug) CO_2 emission resulting from the generation of electricity was calculated using an (average) CO2-emission of 0,66 kg/kWh for electricity production during the night, respectively 0,58 kg/kWh during the day. These numbers are in line with year-average emission levels used in the Netherlands [9]. They furthermore reflect the practice to shut down more efficient gas-fired power stations during the night. For estimating CO_2-emission of the conventional vehicles, well-to-tank and well-to-wheel values were used as identified in the JRCreport [10]. In these values there is no impact of blending in renewable fuel components (ethanol or biodiesel).

The results are shown in Figure 9. They show that the L-1, L-2 and L-3 vehicles produce as much or slightly less CO_2 than their gasoline fuelled counterpart. The fact that L-4 CO_2-emission exceeds that of a comparable gasoline vehicle reflects the impact of almost exclusive night-time charging. The other Leaf's (L-5 and L-6) have higher emissions than the reference vehicles, but these vehicles were running on LPG respectively on an efficient diesel engine.

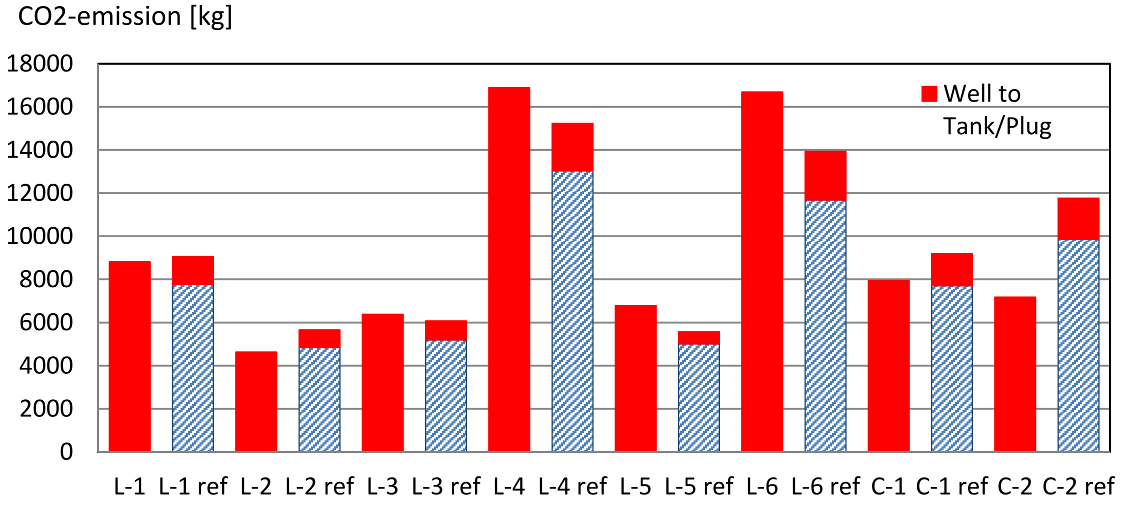

Figure 9: Yearly emission of CO_2 for EV and reference conventional vehicles.

The C-1 and C-2 vehicles score better than their reference vehicle, but as pointed out in section 5.1 the fuel consumption of these EV is somewhat flattered because they were not operating in the periods with lowest temperature. Since the energy consumption of the reference vehicles was estimated, the main conclusion of Figure 9 is that shifting from conventional to electric vehicles does not necessarily result in a strong reduction of CO2 emissions. This also emphasizes the need to make progress with the production of electricity from renewable sources.

6 Conclusion

1. Usage pattern of electric vehicles with local authorities is not different from that of the conventional vehicles that were previously used. This is because in these applications range limitations are not relevant. With taxi fleets implementation of EV is more difficult. Because of their range limitations, EV are used less intensively. This means that either they are no full replacement of a conventional vehicle or they imply a need for fleet planning modifications.
2. Charging took place often and usually considerably prior to running into charge depletion. This behaviour is an indication of range anxiety. Vehicles were connected to the grid immediately upon return to their base and staid connected until the next trip.
3. With all of the electric vehicles that were monitored, practical energy consumption is significantly lower than would be expected from the nominal vehicle characteristics mentioned by the manufacturers. Also, with all vehicles, energy consumption significantly increases as temperatures drop below 10°C.
4. With the current tax incentives and other subsidies, in the Netherlands, electric vehicles that are operated as mentioned above have lower total costs than comparable conventional vehicles. Without such subsidies electric vehicles are not economically viable. Even with subsidies, for some applications such as taxi fleets, electric vehicles are still more costly when costs are compared on a €/km driven basis.
5. Well-to-wheel CO2 emissions of electric vehicles are not significantly different from conventional vehicles when this electricity is produced with the current production infrastructure.

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