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Identification of EV use patterns, based on large scale EV monitoring data

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Abstract

This paper presents a methodology to analyse electric vehicle (EV) monitoring data to identify use patterns. The methodology is applied to the monitored data of a fleet of electric vehicles and plug-in hybrid vehicles (PHEV). The methodology introduces a link of the travel behaviour and characterisation with the range of the electric vehicle. To identify use patterns a number of indicators are defined: reset points, extra range potential, daily distance driven, average distance between reset points and maximum distance between two reset points. These indicators are calculated on monitored data of EVs, and the first results and observations are presented.

Keywords: BEV(battery electric vehicle), mobility, range

1 Introduction

In the framework of the Flemish Living Labs Electric Vehicles, which is a large–scale field trial funded by the Flemish government [1], data monitoring of an electric vehicle fleet is performed. The Living Labs consist of multiple platforms (called EVA, IMove, EV Teclab,Olympus and Volt-Air), each with a different scope and focus within the domain of electric mobility. This paper presents first result from an analysis of mostly aggregated vehicle data of the EVA platform. This paper also introduces a new methodology to analyze the data regarding to the concept of “trips”, which has little value as a measure to describe electric vehicle (EV) use.

In the frame of the test project, the vehicles are equipped with a GPS logger. The purpose is double: the loggers offer an instrument to monitor the vehicles activity on a day-to-day basis, but the collected data even so allow further analysis in the field of individual trip behavior, driving behavior and vehicle performance.

The day-do-day monitoring is important for the Living Lab, as test vehicles are temporarily available for municipalities in order to get familiar with electric driving and to evaluate different types of vehicles. For a maximal return of the project, it is crucial that the vehicles are effectively used during the test period, and that periods of stand-still are minimized. Therefore, if a vehicle is inactive (if no trips are logged) during several consecutive days, a reminder will be sent to put the vehicle into use. On-line dashboards offer to the project partners an overview some key-indicators, in order to detect anomalies in the use of the vehicles as soon as possible. An example of the online dashboard for one of the vehicles is depicted in Figure 1.

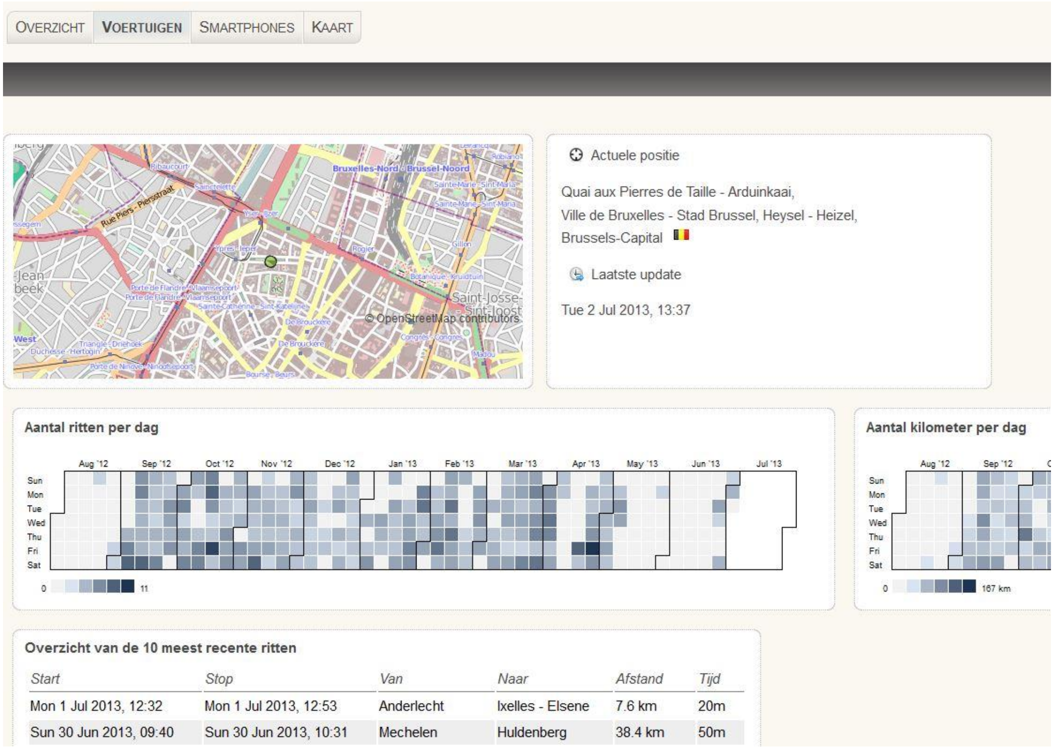

Figure 1 Snapshot of the online dashboard for one of the vehicles, as an example, with the recorded trips and distances per day and the current position.

For research purposes, the collected GPS data gives detailed insight in the use of the electric vehicles. Possible topics include driving behavior and its impact on battery consumption, charging behavior (frequency, location and duration of charging) and individual trip behavior (e.g. the mode choice between the electric car and other transport modes). The analysis in this paper will cover the impact of the limited driving range of electric vehicles on the usage of the vehicle.

1.1 Fleet

The rolled-out fleet currently consists of over 50 monitored vehicles, of which 21 EVs (electric vehicles) and 4 PHEVs (plug-in hybrid electric vehicles) have produced sufficient data to perform some analysis. Together, the fleet has produced data for an aggregated distance of more than 100000 km. For most of the analysis, the PHEV's are analysed separately from the pure EVs because of their fundamental operational difference, i.e for the PHEVs the all-electric range (AER) is not an absolute limit for the distance that can be driven.

2 The relation between the distance driven with a vehicle and its range

2.1 Inconsistency of the concept of trips for the analysis of use patterns for EVs

In traffic models, trips are defined as a travel from an origin to a destination and are used to model the in-and out flow of traffic in area's [2, 3]. However, there is a tendency to use the concept 'trip' to describe electric vehicle use. The number of trips and average distance of a trip are used as a measure to indicate the frequency of use and, the average distance driven with an EV. There are two fundamental problems in doing so. Firstly, the definition of a trip from monitored data is arbitrary: as per convention, a trip is defined as the travel between two points where the time the vehicle is "switched off"[1] or parked is longer than a threshold value, set per convention. Or, if the

[1] The term "switched off" is preferred to "stand still" or "no-use" as a vehicle can be in "stand still" during a travel or "in-use" during parking (i.e. charging).

parked time exceeds the threshold time, a new trip starts. Since the threshold time is chosen arbitrary, the classification into a trip is arbitrary. Secondly, there is no link with the ability to charge during a parked time. There is no distinction between park times little over the threshold value or park times sufficient to fully recharge the battery. This inconsistency in the trip definition as used for the interpretation of electric vehicle use can be easily illustrated by an example. Assume 3 places A, B and C with the distance $|AB|$ = 15km $|BC|$ = 45km and $|AC|$ = 60km as illustrated in Figure 2.

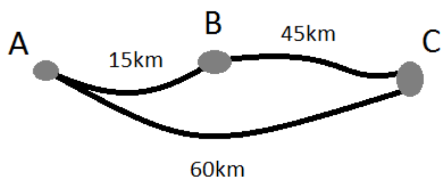

Figure 2 Example trajectory with starting point A and stop points B and C.

Assuming for this particular example that a person travels from A to C and back with stops in B and C (with switched-off times T_B and T_C) and a threshold park time of 15 min, this gives the following options:

1. T_B<15min and T_C<15min

   Considered as 1 trip (A-> B->C->A) with average trip distance 120km/trip

2. T_B< 15 min T_C>15min

   Considered as 2 trips (A->C, C-A) with an average trip distance of 60km/trip

   bis. T_B>15 min T_C<15min

   Considered as 2 trips (A->B, B->C->A) with an average trip distance of 60km/trip

3. T_B>15 min T_C>15min

   Considered as 3 trips (A->B, B->C, C->A) with an average trip distance of 40km/trip

A person doing deliveries everyday on this particular trajectory might vary in between these 4 options and so his travel categorized as 3, 2 or 1 trip(s) with an average of respectively 40, 60 or 120 km/trip, depending on his park times of that day.
To illustrate the necessity of the link with charge times we continue with the same example while introducing a number of available range scenarios:

a) Range[2] = 120km
   - Option 1, option 2, option 2bis and 3 are achievable.

b) Range = 100km
   - There's a need for at least 2 hours of charging[3]
   - Option 2, option 3 are achievable.

c) Range = 60km
   - There's a need for at least 5 hours of charging
   - Option 2 and option 3 are achievable

d) Range <60km
   - This trajectory is no longer achievable

According to the available range of the vehicle, the trip characteristics of a person traveling from A to C and back can be different, independent of the equal origin and destination of the trip. Moreover, there is no differentiation between an incidental "new trip" because park time was just over threshold value or a park time of long duration where the EV is charged. So, for example can scenario a), equally as scenario b), fall under option 2 (2 trips, 60km/trip) but the duration of the park time in a) is voluntarily and can be just over the threshold value, where with scenario b) the driver is forced to stop 2 hours in option 2. As an example the exercise has been done on real-life data of the university Nissan Leaf within the EVA project, with a threshold time of 2 minutes, 5 minutes and 12 minutes. The results are listed in Table 1.

[2] Although the real range of an EV is subject to a lot of variations due to circumstances, the range is taken as a hard figure fort his theoretic exercise
[3] Assume slow charging with a rate of 12km added range, per hour charging. (This corresponds more or less with the 220V 10A single phase charge rate and an average consumption of about 0.18kwh/km)

Table 1. Trip count and average trip distance with different threshold values for the Nissan Leaf of the Vrije Universiteit Brussel over a tracked distance of more than 5000 km

Threshold time	Trip count	Avg trip distance (km)
2 min	525	10,6
5 min	423	13,2
15 min	357	15,6

The theoretic example as well as the example from the real-life data again point out that trips are not the right tool to describe the use of EVs.

2.2 Indicators for the use patterns of EV's

The objective of the analysis is to establish patterns in the EV use. The use of the EV will be analysed using a number of characteristic figures which highlight a specific part of the electric vehicle use. These indicators are divided in measures of distance and measures of duration. The measures of distance are the car reset point (CRP), the extra range potential (ERP), the daily driven distance, the average distance between two reset points and the maximum distance between two reset points while the measures of duration are the travel duration and the stop duration.

2.2.1 Measures of distance

Car reset point

EV use is limited by its range. Therefor the use of the EV must thus be described in consideration of its range. To overcome this problem, the new concept of "car reset point" was introduced in our analysis. [4] introduced the concept of trip-chain, which was defined as the distance travelled between long rests that constitute charging opportunities. In contrast with the analysis performed by [4] where the long rest was defined as 4 or 8 hour minimum for a charging opportunity, in this analysis shorter switched–off periods with a charge opportunity are take into account, and it is the travelled distance between two points in time where the battery can be fully charged that is used. Such points will be called "car reset points".

A car reset point (CRP) occurs when the vehicle is "reset" range-wise, i.e. when the time between two uses is sufficient to charge the batteries of the vehicle to the same level as prior to the use. Mathematically this translates in the following equation:

$$CRP = CD - TD > 0$$

And

$$CD = Tpark * charge\ rate$$

$$Ex.1\ hour\ park\ time\text{:}\ CD = 1h * \frac{12km}{h} 12km$$

With

T_{park} = park time
TD = travel distance
CRP = car reset point
CD = charge distance

The CRP introduces a point where the cars history prior to that point has no influence on the future use. However, the travel in between two reset points is the essence for the analysis of EV use.

Extra range potential (ERP)

There is a need to stop in between two reset points if the distance exceeds the range, extended with the potential range acquired by charging during the park time. Thus we can define the intermittent charge time (ICT) as the park time necessary to acquire sufficient range to be able to make a particular trip. Or:

$$\frac{Reset\ point\ distance - range}{charge\ rate} = T_{ict}$$

$$Ex. \frac{120km\ - 100km}{12km/h} = 1.7h = T_{ict}$$

A negative T_{ict} indicates the range of the vehicle exceeds the distance between two reset points. The condition to travel between to reset points thus becomes:

$$T_{ict} < T_{park}$$

Evidently, this condition is met for data coming from monitoring data. If a trip is planned, this condition has to be fulfilled in order to travel between two reset points. If $T_{ict} < T_{park}$, the excess in park time of the vehicle leads to a potential excess in range if charged during that time, expressing that vehicle distance potential was not fully exploited. This "extra range potential" (ERP) can be mathematically described[4] as

$$ERP = (T_{park} - T_{ict}) * charge\ rate$$

The ERP is an indicator for exploitation of the range of the EV. A high ERP indicates higher distances than with current use are achievable and the EV might be used in a broader scope.
A high ERP results from travel behaviour with small distances and long park time or from an overestimation of the realistic AER[5] in the ERP formula. This travel behaviour has multiple potential causes:

- Travel needs
- Range-anxiety
- EV inexperience
- Inaccurate range estimation / large variations on estimated range

A high ERP is therefor also an indicator for these causes.

The daily driven distance
The daily driven distance is indicator for the frequency of use of an EV.

The average distance between two reset points
Similar, to the ERP, the average distance between two reset points is an indicator of averaged exploitation of the EV's range. In combination with the daily driven distance, it is an indicator for the distribution of the travels over a day.

The maximum distance between two reset points
The maximum distance between two reset points is, similar to the ERP, an indicator for the distance people (are willing to) drive before recharging the battery completely. To compare different vehicles, the ratio $\frac{maximum\ distance\ between\ reset\ points}{range}$ must be evaluated.

2.2.2 Measures of duration

The stop duration
The stop duration gives interesting insights on charging patterns, or charging time potential

The duration between two reset points
The duration of a travel between two reset points is useful in combination with the distance between two reset point as similarities or contrasts can indicate to external conditions.

[4] One should be careful using the park time without a lower limit in the ERP formula as in practice there will be a time threshold for the willingness to charge of the driver. In the data analysis below, this threshold time was set to 15 minutes.

[5] For this reason, a range closer to the reality has been used in the analysis of the data. The AER in used in the analysis is 70% of the AER range specified by the manufacturer.

3 First results

The results are presented for an averaged result per vehicle type. Four categories of vehicle types have been defined: PHEV's, large EV's, small EV's and EV vans. Table 2 lists the aggregated vehicle groups per model by a vehicle group ID, which is used to represent the vehicles in the graphs.

Table 2 Overview of the aggregated vehicle groups per vehicle model and the quantity per model.

Vehicle group ID	Vehicle type	Vehicle models	Number of vehicles
1	PHEV's	Opel Ampera /Chevrolet Volt	4
2	Small EV's	Citroën C-zero / Mitsubishi iMiev / Peugeot Ion	4
3	Large EV's	Renault Fluence, Nissan Leaf	4
4	EV vans	Renault Kangoo	14

When analysing the trip data, the PHEV category will often be used as the reference category representative for an ICE vehicle user pattern because of the absence of a the range limitation, allowing a comparison with the EV categories results, without making any conclusions on the PHEV user pattern.

3.1 Measures of distance

The **average distance between reset points** and the **average daily distance**, presented in Figure 3, show the exact same trend for the different vehicle categories. The PHEV distances are almost double all EV distances, while the differences between the EV categories are small. The distances of the "trips', as originally defined, are considerably lower than the distance between two reset points, leading to an underestimation of the vehicle's use if it is described as such. This is more visible for the EV vans, indicating they perform more stops longer than trip threshold value, but lower than the time to recharge, compared to other EV vehicles. The numbers for the average daily distance are low, compared to results from the Flemish Survey on Trip behaviour [5], which shows an average daily distance of 79 kilometres, of which 31 kilometres are travelled by car. As other means of transport have not been registered, these figures are hard to compare and further research should clarify whether this difference is due to the vehicle properties (limited range) or the user properties (use by employers from the municipality administration, implying shorter trips). Also higher mentioned aspects, such as the user's unfamiliarity with EV's and battery range anxiety, may contribute to this tendancy to shorter trips.

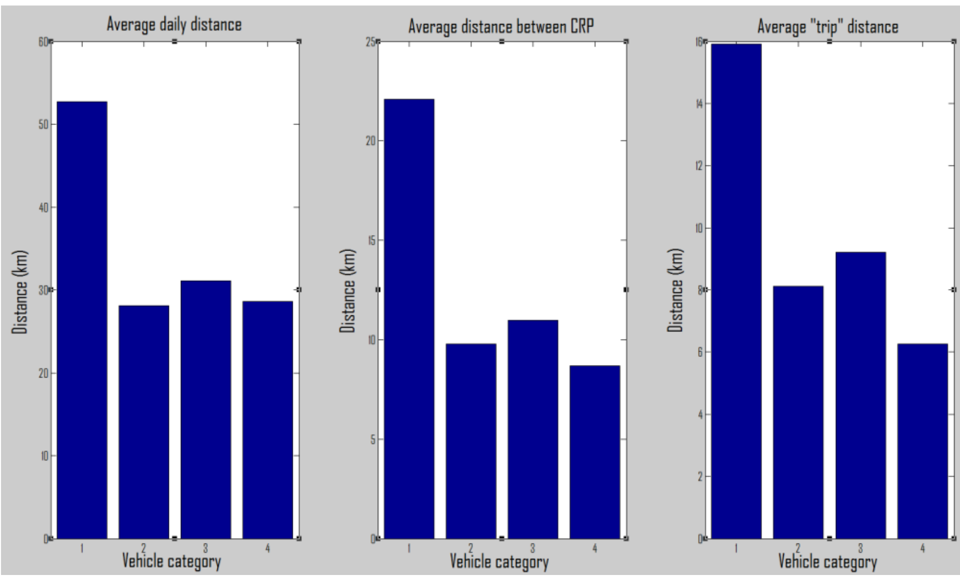

Figure 3 The average daily distance (left), average distance between two reset points (middle), average "trip" distance (right) per vehicle type

The **maximum distance between two reset points**, depicted in Figure 4**,** vary from about 80-90km for small EVs to 130km for large EVs. This is below the theoretic range of the vehicle. Whether this is caused by the vehicle limitations or the user's choice (range-anxiety, vehicle inexperience or travel demands) is to be determined by other means of observations (example: questionnaires). However, these distances are averaged over the vehicles category. Figure 5 shows a close up of each individual passenger EV. The figure shows that 5 out of 8 vehicles have a distance between 70-100km while two are around 120-130km and one over 160km. This shows the vehicle is capable of covering greater distances, although range limitations can occur according to circumstances, making it still impossible to eliminate vehicle limitation from as a cause completely. For the EV vans, the maximum distances are about 70km, while the average distance and daily distance are equal, showing a difference in the use pattern.

Figure 4 shows the **relative average ERP** between two reset points is significantly smaller for the PHEV group but shows limited variations for the EV vehicles in respect to their range. The ERP is significantly lower for the PHEVS compared to the EVs. This is expected as ERP formula is based on the AER. Extending the range using the combustion engine has a decreasing effect on the ERP. As such, the ERP as formulated in section 2.2, has no meaning for PHEVs. The average ERP is close to the range, expressed in the relative average ERP being close to 1. This indicates there are a lot of low distance travels between two reset points, leaving a value close to the range as the ERP.

The **relative average ERP** is considerably lower for the small EV's and large EV's compared to the EV vans, pointing out that the exploitation of these vehicles' ranges is greater. This fits the observation of a van use pattern, which is characterized by medium distances with frequent stops.

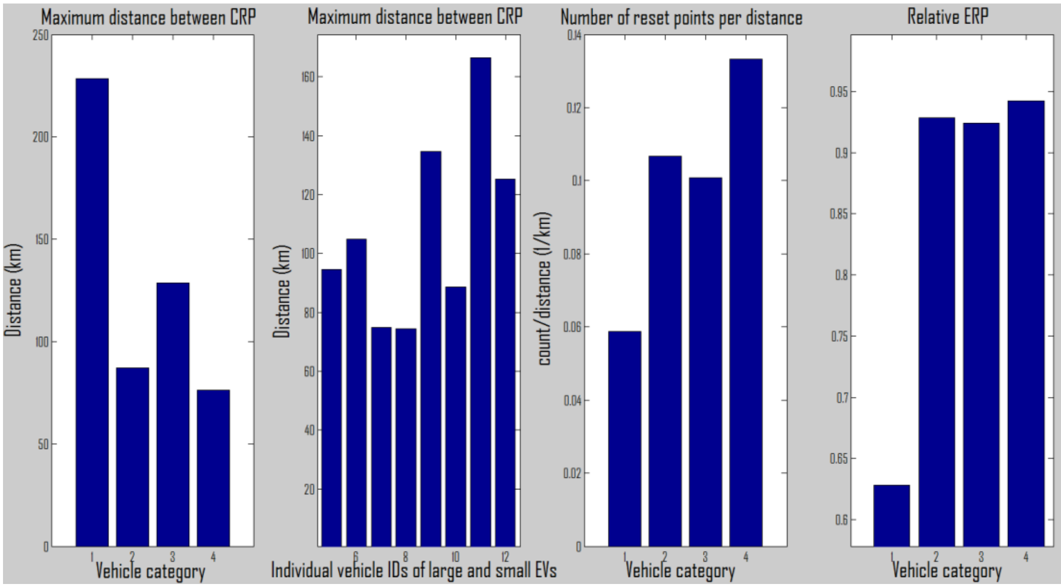

Figure 4 Maximum distance between two reset points (left), the number of reset points per distance (middle-right) and the relative ERP (right) per vehicle type. The maximum distance between two reset points for the individual vehicles of the large EV and small EV category (middle-left)

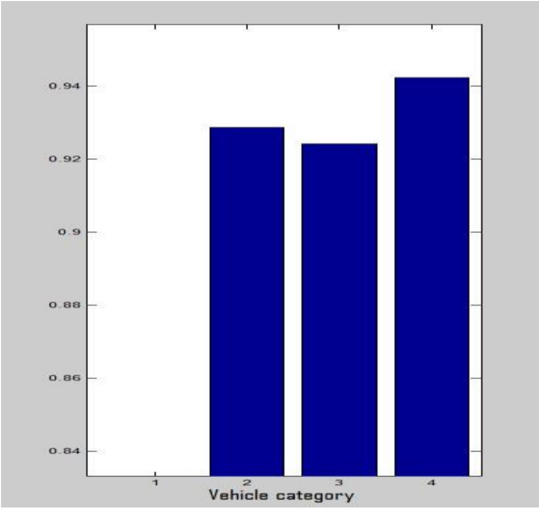

Figure 5 Zoom on the relative average ERP for the EV groups only

The distributions of **distance between reset points,** depicted in Figure 6**,** of all EV categories show similarities. The occurrences of distances larger then 40km drop very hard, while distance over 60km are rare. With the exception of a few occurrences, distances over 80km are almost non-existent for all EV categories. As mentioned earlier, further research must be conducted to determine the cause to this observation, as it may be due to a low vehicle range, by the driver's battery anxiety or to a lack of demand for longer trips. An answer to this question would be most relevant, as it demonstrate to what extent the limited range of EVs actually is a limitation to their usability. All EV types also have a high occurrence of distances smaller then 5km. The occurrences of distances < 5km are 3-4 times higher than distances between 5-10km for the case of passenger EV's and 7 times higher for the case of EV vans. This may be explained because the vehicles are mainly used by municipalities, which implies more short trips within their boundaries. Both these observations of the distance occurrence drop above 40km and the high frequency of distances <5km are valid for the PHEV category as well, although slightly less extreme. And although PHEV distance distributions show occurrences of distances greater than 100 and 120km, these occurrences are very limited, agreeing with earlier research that ICE vehicle distances unachievable for current EV's are limited [6].

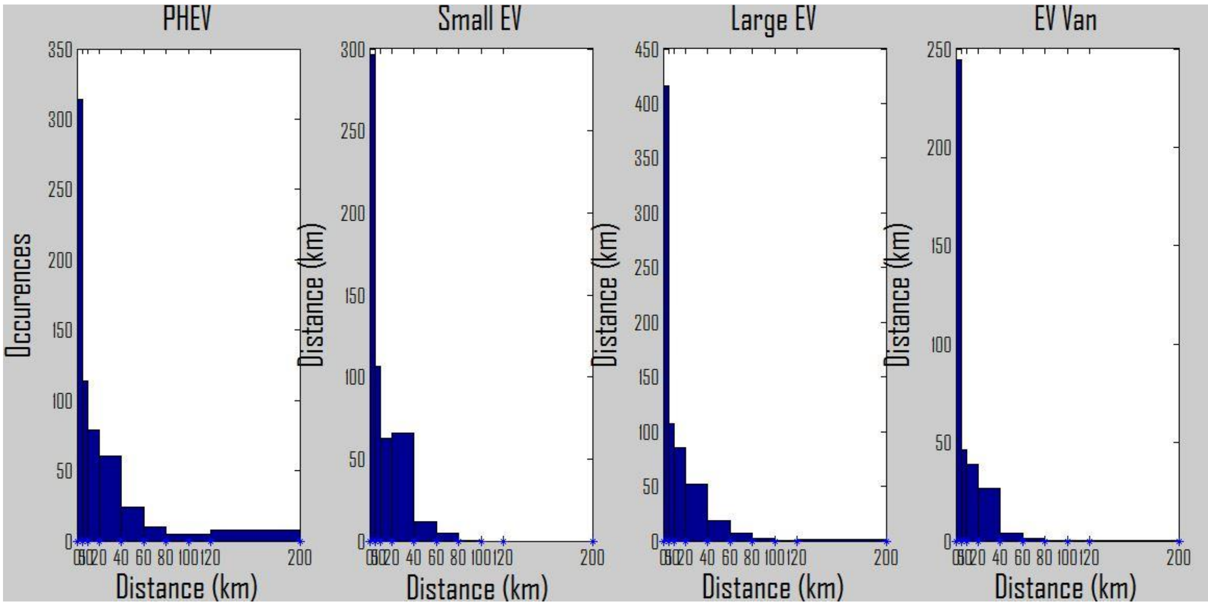

Figure 6 Distance between reset points distribution for the PHEV, small EV, large EV and EV vans categories from left to right respectively.

3.2 Measures of duration

The distributions of **stop duration,** depicted in Figure 7**,** of the PHEV's, large EV's and small EV's are very similar. A high frequency of very short stops between 15-30min, equally distributed stops between 30min and 4h, equally distributed stops between 4h and 10h but significantly lower frequency than stops <4h, and most of the stops being >10h . The stop distribution for the EV vans does not show the same pattern. The EV vans have 50% less stops between 2h and 4h than stops below 2h. Moreover, there is an almost complete absence of stop occurrences between 4h-10h. This again indicates the use throughout the day of the EV vans instead of the commuting use.

The travel **duration between two reset points**, depicted in Figure 8, has the same shape as the distance distributions between two reset points. The frequency drop of distances over 40km coincides with a frequency drop for travels over 1h. This brings an extra argument to the limited exploitation of the EV range observed earlier. The hour threshold on itself can be a limiting factor as well, i.e. users avoiding travels longer than one hour for reasons other than the vehicle itself. This observation is supported by the duration distribution of the PHEV's, where a similar drop occurs at a 1h value, although the frequency of >1h travels is somewhat higher as for the EV categories. This trip duration of maximum 1 hour seems to be realistic, compared to the Flemish survey on travel behavior [5], which reports an average trip duration of 23 minutes and an average number of 2.78 trip per day per person. This results in an average total daily travel time of 64 minutes, which corresponds with international research [7]. This number illustrates that travels longer than 60 minutes are expected to be rare in the Flemish region.

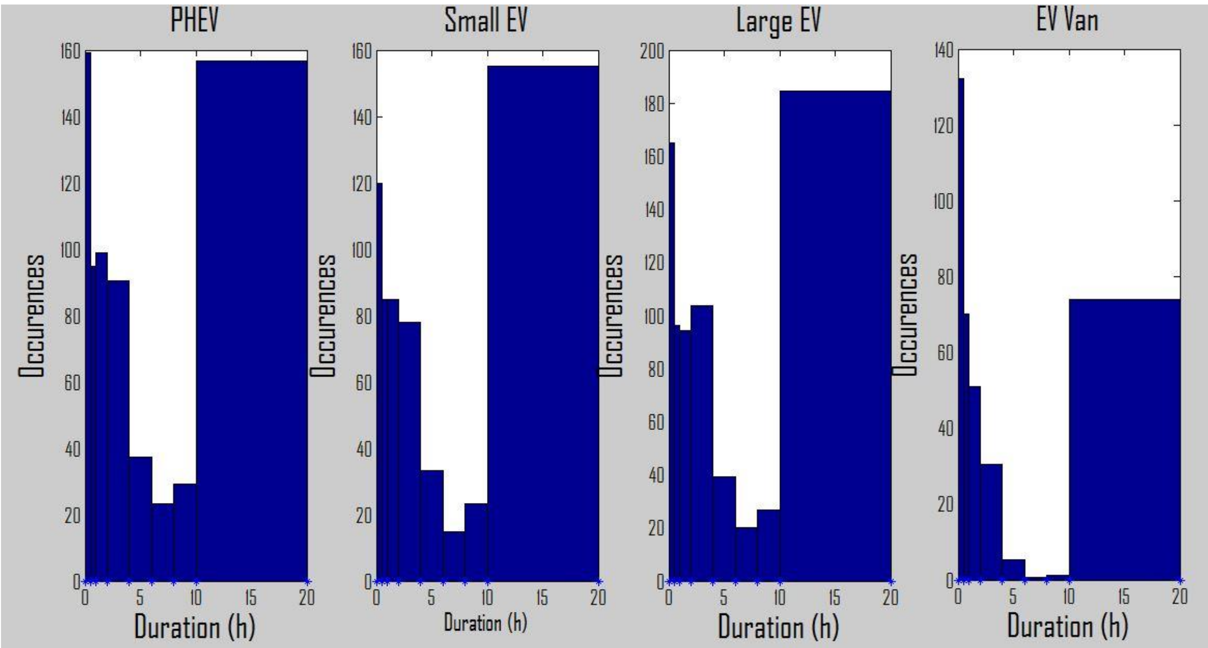

Figure 7 Stop duration distribution for the PHEV, small EV, large EV and EV vans categories from left to right respectively.

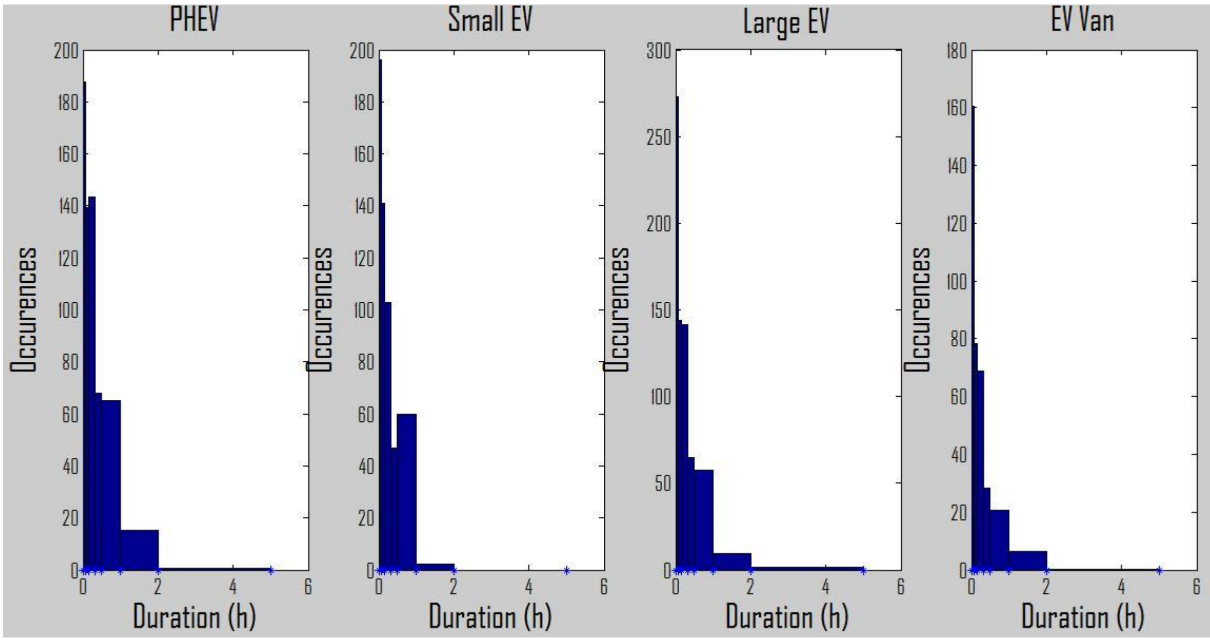

Figure 8 Travel duration between reset points distribution for the PHEV, small EV, large EV and EV vans categories from left to right respectively.

4 Conclusion

The methodology provides a set of indicators to analyse the use of an electric vehicle. The first analysis is performed on an aggregated result of 4 specified categories: PHEV, large EV's, small EV's and EV vans. PHEVs are used as a reference category, representative for ICE vehicle use to compare with the EV categories. The indicators show that the range of the EV is not fully exploited, but it is hard to pinpoint the causes to this observation. The differences between the small EV group results and large EV results are small, and do not allow us to draw any conclusions on the difference of use of these two types. It is clear however, that the EV vans are being used in a different way. A higher frequency of very short stops, a lower frequency of midlong stops and shorter distances occur for the vans compared to the other EVs indicate a more continuous use of the vehicle during the day. Other differences occur mostly in the frequency of travels and their durations and distances, as the average daily distance is similar. The causes behind the differences between EV groups, and the limited exploitation of the range, should be further investigated. The PHEV have only a limited amount of travels with longer distances and durations than the EV type vehicles. All categories show a limited amount of travels over 40km, coinciding with 1h duration.

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