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A Novel Method to Value the EV-fleet's Grid Balancing Capacity

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Summary

Each day, every second, imbalance occurs in our electricity grid. In Belgium, the grid operator has to solve these imbalances with the help of previously contracted Balance Responsible Party (BRP). In this study, we develop a methodology to model the behavior of a fleet of co-ordinated Vehicle to Grid (V2G) enabled EVs. This allows us to explore to what extent such a fleet could participate in an imbalance tariff and how much value is generated with this activity. To do this, we start by modelling individual V2G-EV characteristics and driving behavior. We then extrapolate to model fleet behavior to be able to assess the fleet's balancing capacity at each moment of a given time period. For our empirical setting, Belgium, our results show that the total expected value that could be generated by V2G balancing services ranges from EUR 2.35M to EUR 9.67M per year and from 906 to 664 EUR per EV in 2023.

Keywords: V2G, electric vehicle (EV), BEV (battery electric vehicle), smart charging, simulation

1 Introduction

In the Belgian context, the Transmission System Operator (TSO), Elia, constantly manages the balance between electricity supply and consumption. The total imbalance in the system is expressed by the Net Regulation Volume (NRV) which is published by Elia for each 15-minute time frame. A positive NRV means that not enough electricity is produced and negative NRV means overproduction occurred. Positive NRV causes grid frequency to fall. It can be compensated by injecting power or shedding load from the grid. The opposite is to be done when negative NRV occurs. The balancing services are performed by BRPs appointed by Elia. [1]. As the share of EVs in the fleet are expected to grow in the near future, the question arises whether a large set of connected V2G enabled EVs can serve as an additional system that provides balancing services and participate in the imbalance tariff market. Should this be the case, what would be the value of these services, i.e. which cost savings or additional revenue streams might arise from activating V2G balancing services? Many studies have studied this [2-9], and the summary of that is shown in Table 1. However, few studies have taken the EV user preferences, their satisfaction and driving behaviour into account. Moreover, most of them are focused on the primary, secondary and tertiary frequency balancing market. In this study a model is built including those missing features and objectives of the model is to uncover the value of V2G enabled vehicles participating in the imbalance tariff market in the context of Belgium.

Table 1: Previous research on the value of V2G technologies

Product	Market	Value estimate (per EV/year)	Study
Tertiary reserve power	Austria	88 – 767 EUR	[2]
Calculations based on a single RAV4 Electric vehicle	United States	2254 - 3320 USD	[3]
Secondary reserve power	Denmark	1900 EUR	[4]
Primary reserve power	France	100 - 130 EUR	[5]
Day-ahead energy market	Germany	131 - 151 EUR	[6]
Secondary and tertiary reserve power	Portugal	250 EUR	Cited by [7]
Peak load reduction	UK	360 EUR	[8]
Reserve power from truck fleet	USA	800 EUR	[9]

2 Methodology

Our model follows a bottom-up approach inspired by R. Gough *et. al* [10] and is built in Python. Our approach starts with modelling the individual EV characteristics, charging infrastructure, driving behaviour, and consumer preferences. After data acquisition, an EV model is build to receive real-time information on imbalances which allows them to respond to grid requests for balancing immediately.

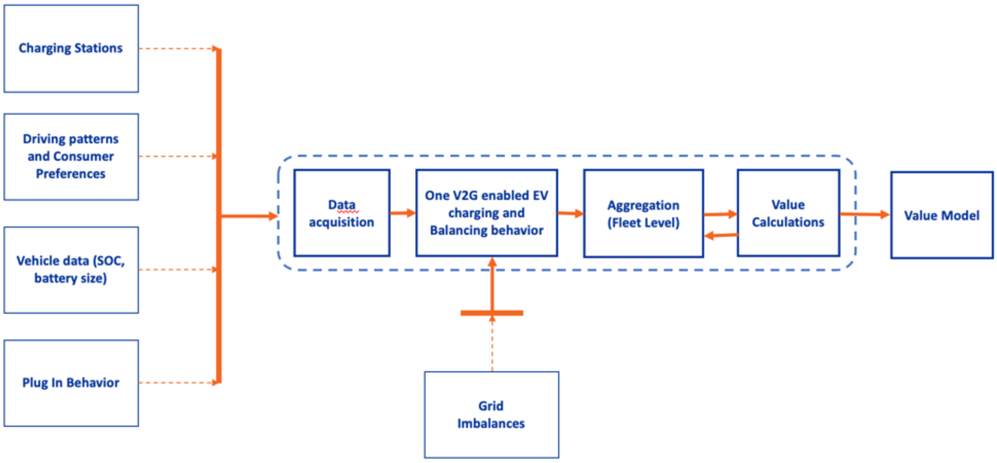

Figure 1: The methodology used in this study

Next step is to extend the model to fleet level. We then add market data. In a first step, we only look at the balancing activities: the technical Model. After this, we include the economic value (costs avoided, income lost…) in our Value Model. The model's approach is shown in Figure 1.

2.1 Technical Model

2.1.1 Rationale

The main objective of the model is to uncover the value of V2G enabled vehicles in balancing out the grid imbalances expressed as NRV (in MW). We assume that there is no foresight possible: operators, DSOs, TSOs, EV owners can only react to imbalances at the moment they appear. As such, V2G enabled vehicles are used to balance the grid depending on their state of charge (SOC) and on their plug-in behavior. This approach means that our model is not an optimization exercise to calculate the value of V2G under perfect foresight (e.g. through optimized, smart, charging), but an attempt to model the real-world situation as it will occur.

We define nine variables related to driver behavior and consumer preferences. The daily distance traveled allows us to calculate how much of the battery's capacity is used for driving. On average, people use their vehicles for 40 to 80km per day [11]. In our model, we vary this travel distance between that range. Next, we define the plug-in profile of each vehicle in a specific cluster. Therefore, we assign twotiming profiles to each cluster of EVs. The first timing profile represents a typical weekday, the second timing profile represents the weekend profile. Each of these timing profiles consists of four time variables which are the departure time from home to the destination, the arrival time at destination, the departure time at destination (work) and finally the arrival time at home. These variables are crucial as these model the plug-in behavior. Departures time indicates that the vehicle disconnects from the grid and as such is not available to provide balancing services. Arrival time indicates the EV is connected to the grid and available for balancing.

Table 2: Variables

Variable ID	Description	Variable ID	Description
v1	Departure time from home to work	v10	Daily travel distance
v2	Arrival time to work	v11	Minimum required SOC at morning
v3	Departure time from work to home	v12	Charge power rating at home
v4	Arrival time at home	v13	Discharge power rating at home
v5	Departure time from home to a destination (weekend)	v14	Charge power rating at work
v6	Arrival time to the destination (weekend)	v15	Discharge power rating at work
v7	Departure time from the destination to home (weekend)	v16	Charging loss
v8	Arrival time at home (weekend)	v17	Battery capacity
v9	Energy usage of EV per km	v18	Minimum SOC

When V2G enabled vehicles are connected to the charging point, they can be either charged or discharged by the grid request. The power at which this can be done differs based of vehicles and charging points. To model the battery behavior, we define three variables. The first one is the battery capacity, expressed in kWh. In order to prevent a deteriorating impact on the battery's state of health and its lifetime (for instance by doing deep discharges as a result of V2G), a minimum State-of-Charge (SOC, expressed in %) is defined by the user that should be contained at all moments.On top of this, vehicle users might also want to avoid their batteries to go below a certain SOC as a result of V2G services to further deteriorate the State of Health (SOH) of the battery. On a similar note, the user of the EV will have the desired SOC level he/she wants to find their vehicle in the morning (7:00) to cover his daily commute. It is important to note that these variables could also be categorized as ‘consumer preferences’ but for clarity and the uncertainty about who will set these conditions in the future, we link them here explicitly to the battery. This choice does not affect the model outcome and is cosmetic.With regard to the EVs, we further specify two variables. Energy usage per 100 km: used to calculate the SOC evolution as a result of driving the vehicle across a distance. Charging loss: power loss as a result of charging/discharging the vehicle, e.g. due to inefficiencies in AC/DC conversion. In total 18 variables are defined for each EVs which are shown in Table 2.

In every time step t, the model will minimize the difference between NRV and aggregation of charging/discharging power of EVs,

$$\min \left| NRV_t - \sum P_{(EV_n)_t} \right| \tag{1}$$

Constrains:

$$EVSoCmin_n < EV_n < EVSoCmax_n \tag{2}$$

$$T_{in} \leq EV_t \leq T_{out} \tag{3}$$

$$EVSoC_t + R_n(T_{out} - t) > minEVSoCtravel_n \tag{4}$$

$$EV \in \begin{cases} EVSoC_m, EVSoC_{m1}, EVSoC_{m2}, \dots, EVSoC_{mk}; NRV > 0 \\ EVSoC_{mk}, EVSoC_{m(k-1)}, EVSoC_3, \dots, EVSoC_m; NRV < 0 \end{cases} \tag{5}$$

Where, (6)

$$k = \begin{cases} \frac{NRV}{P_{EV}}; \frac{NRV}{P_{EV}} < \sum EV_n \\ \sum EV_n ; \frac{NRV}{P_{EV}} > \sum EV_n \end{cases}$$

$$EVSoC_{mk} > EVSoC_{m1} > \cdots > EVSoC_{m(k-1)} > EVSoC_m \tag{7}$$

k is the number of EVs required in each time step. Sorted EVs according to SoC level in time step. Constraints of the model are firstly the limitation of the EV battery itself in equation 1. Each EV has a minimum and a maximum SoC value which are set by the user. When the EV in driving mode and not connected to the charger, obviously it can not participate in the balancing activity. The second constraint is derived from that fact. For simplicity, in this model, it is assumed EVs are connected to the charger as soon as they arrive at work/home and disconnected as soon as the user leaves. Therefore, in equation 2 T_{in} and T_{out} here means the time of arrival and time of departure either from work or home. Since the primary function of the EV is transportation, a constraint is set in the next equation 4 to secure that. *Rn* is the rate of the charger and minEVSoCtravel is the minimum charge needed for next transport either from home to work or work to home. So, during the balancing activity, if there isn’t enough SOC to go to work or home, then the demand to fulfil the battery charging will overwrite over balancing purposes. Sometimes, the value of NRV might be so low that, not every EV, but a limited number of EVs connected to the charger will able to respond to the grid demand. So, this will set another constraint. To select the appropriate set of EVs we included sorting system in the model as shown in equation 5. For example, when NRV is positive, in other words, when there is a shortage of energy in the grid, the model will sort all the connected EVs in descending order according to the *SOC* so that EV with highest SoC can deliver energy at that moment. On top of that, to mirror the NRV curve, the number of EVs needed will be determined by the model at each step. That number is defined as *k*. When k is larger than the total number of EVs connected, then k will be reduced to the total number of EVs which are connected.

3 Case Study:

In the first step, we model the behavior for 26 vehicles for the case study. This number is selected to have enough variation of the 18 variables we defined earlier. A detailed behavior list is given in numbers of EVs have to participate in balancing to have an impact. In this model, we consider 26 clusters of vehicles and we assume that each car in the cluster behaves in the same way. As such, our 26 vehicles represent the behavior of one cluster.

Table 3. Given the magnitude of the imbalances that might occur every 15 minutes, it is clear that 26 V2G enabled EVs are considered to be noise on the system rather than providing valuable balancing systems. Therefore, large numbers of EVs have to participate in balancing to have an impact. In this model, we consider 26 clusters of vehicles and we assume that each car in the cluster behaves in the same way. As such, our 26 vehicles represent the behavior of one cluster.

Table 3: EV behaviour

Cluster ID	v1	v2	v3	v4	v5	v6	v7	v8	v10	v11	v12	v13	v14	v15	v17	v18
EV1	08:00	09:00	17:00	18:00	10:00	12:00	17:00	19:00	40.0	80	3.0	6.0	6.0	6.0	85.0	20.0
EV2	07:30	08:00	16:00	17:00	11:00	13:00	17:00	19:00	60.0	70	3.0	6.0	8.0	6.0	60.0	20.0
EV3	09:00	10:00	18:00	19:00	10:00	12:00	18:00	20:00	20.0	80	3.0	6.0	8.0	6.0	30.0	40.0
EV4	08:00	09:00	17:00	18:00	09:00	11:00	17:00	19:00	30.0	60	3.0	6.0	6.0	6.0	85.0	20.0
EV5	07:30	08:00	16:00	17:00	10:00	12:00	15:00	17:00	60.0	70	3.0	6.0	8.0	6.0	40.0	20.0
EV6	09:00	10:00	18:00	19:00	08:00	10:00	14:00	16:00	20.0	80	3.0	6.0	8.0	6.0	33.0	40.0
EV7	08:00	09:00	17:00	18:00	07:00	09:00	19:00	21:00	45.0	70	3.0	6.0	10.0	6.0	90.0	20.0
EV8	07:30	08:00	16:00	17:00	10:00	12:00	17:00	19:00	25.0	70	3.0	6.0	8.0	6.0	40.0	20.0
EV9	09:00	10:00	18:00	19:00	10:00	12:00	17:00	19:00	55.0	80	3.0	6.0	8.0	6.0	30.0	40.0
EV10	08:00	09:00	17:00	18:00	09:00	11:00	12:00	14:00	40.0	60	3.0	6.0	6.0	6.0	85.0	20.0
EV11	07:30	08:00	16:00	17:00	10:00	12:00	17:00	19:00	20.0	70	3.0	6.0	8.0	6.0	40.0	20.0
EV12	09:00	10:00	18:00	19:00	10:00	12:00	17:00	19:00	50.0	80	3.0	6.0	8.0	6.0	30.0	40.0
EV13	08:00	09:00	17:00	18:00	10:00	12:00	17:00	19:00	15.0	80	3.0	6.0	10.0	6.0	85.0	20.0
EV14	07:30	08:00	16:00	17:00	09:00	11:00	12:00	14:00	40.0	70	3.0	6.0	8.0	6.0	40.0	20.0
EV15	09:00	10:00	18:00	19:00	10:00	12:00	17:00	19:00	40.0	80	3.0	6.0	8.0	6.0	85.0	20.0
EV16	08:00	09:00	17:00	18:00	10:00	12:00	17:00	19:00	40.0	60	3.0	6.0	6.0	6.0	85.0	20.0
EV17	07:30	08:00	16:00	17:00	10:00	12:00	17:00	19:00	20.0	70	3.0	6.0	6.0	6.0	40.0	40.0
EV18	09:00	10:00	18:00	19:00	10:00	12:00	17:00	19:00	15.0	80	3.0	6.0	8.0	6.0	33.0	40.0
EV19	08:00	09:00	17:00	18:00	09:00	11:00	12:00	14:00	40.0	60	3.0	6.0	10.0	6.0	90.0	20.0
EV20	07:30	08:00	12:00	12:30	10:00	12:00	17:00	19:00	30.0	70	3.0	6.0	8.0	6.0	40.0	30.0
EV21	09:00	10:00	18:00	19:00	10:00	12:00	17:00	19:00	20.0	80	3.0	6.0	0	0	33.0	40.0
EV22	08:00	09:00	17:00	18:00	09:00	11:00	12:00	14:00	35.0	60	3.0	6.0	0	0	95.0	20.0
EV23	07:30	08:00	16:00	17:00	10:00	12:00	17:00	19:00	15.0	70	0	0	8.0	6.0	40.0	30.0
EV24	09:00	10:00	18:00	19:00	09:00	11:00	12:00	14:00	20.0	80	0	0	6.0	6.0	33.0	40.0
EV25	12:00	13:00	17:00	18:00	10:00	12:00	17:00	19:00	15.0	90	3.0	6.0	0	0	28.0	40.0
EV26	07:00	09:00	18:00	20:00	07:00	09:00	19:00	21:00	120	90	3.0	6.0	10.0	6.0	95.0	20.0

numbers of EVs have to participate in balancing to have an impact. In this model, we consider 26 clusters of vehicles and we assume that each car in the cluster behaves in the same way. As such, our 26 vehicles represent the behavior of one cluster.

Table 4: Number of V2G enabled EVs Scenario's in 2030

Slow adoption of V2G	2600
Normal adoption of V2G	6240
Fast adoption of V2G	14560

We run the model for three scenarios' in 2023 as shown in Table 4 based on fleet composition in Belgium. A 'slow adoption' scenario where the number of V2G cars only reaches the projected 2021 level in 2023, so two years behind forecasted numbers. One 'normal' adoption scenario where we follow the projected fleet evolution and one scenario where adoption goes faster and is at the 2025 level in 2023.

3.1 Grid Imbalances

In the next step, we add the data of the NRV. The NRV is calculated for each quarter-hour using the difference between the sum of the volumes of all upward regulations and the sum of the volumes of all downward regulations requested by Elia.

This data on the NRV was downloaded from the Elia website for the full year 2017. We opted for this approach since 2017 is the true representative year, given the long downtimes of the nuclear power plants in 2018 which might distort the imbalances on the market and the prices on the imbalance market. Since the supply of and demand for electricity fluctuate through the day and over the year, a year was deemed a good level of analysis. Historical data on imbalances provides us with a solid base case to perform our analysis. After all, the NRV is the result of unpredicted mismatches between demand and supply (prediction errors).

It is expected that these prediction errors will occur more and increase in magnitude with further integration of renewables. Therefore, the analysis presented in this paper represents a conservative estimation of the value that V2G enabled vehicles can bring in balancing the grid.

Interestingly, the data from Elia also contains the prices per kWh at which the (upward or downward) regulation took place. This data will prove to be an excellent basis to calculate the potential value of V2G in balancing the grid.

3.2 Definition of the clusters

As mentioned, we model the V2G fleet by using 26 clusters of vehicles. In this section, we present how these clusters are defined. numbers of EVs have to participate in balancing to have an impact. In this model, we consider 26 clusters of vehicles and we assume that each car in the cluster behaves in the same way. As such, our 26 vehicles represent the behavior of one cluster.

Table 3 presents a detailed overview of each cluster.

Clusters EV1 through EV19 are based on our assumptions and are relatively standard clusters of users with regular daily schedules and the possibility to plug in their car at work or to another commercial building or public parking lot. To dig deeper into the value that can be drawn from V2G clusters EV20 through EV26 present 'special clusters':

- EV20: vehicles used by persons with a working schedule corresponding to a half time
- EV 21 and EV22 and EV25: vehicles only connected at home
- EV23 and EV 24: vehicles only connected at work or a commercial building
- EV26: vehicle used by an 'extreme' user with 4 hours travel time per day, 120km commutes, driving a vehicle with large battery size, exhibits long working hours and is connected at work

4 Results of the Technical Model

For each cluster, we generate the evolution of the SOC of each car in the cluster as one example shows in Figure 2. We generate this data for each cluster which means that we know which cluster has been balancing the grid at each point in time.

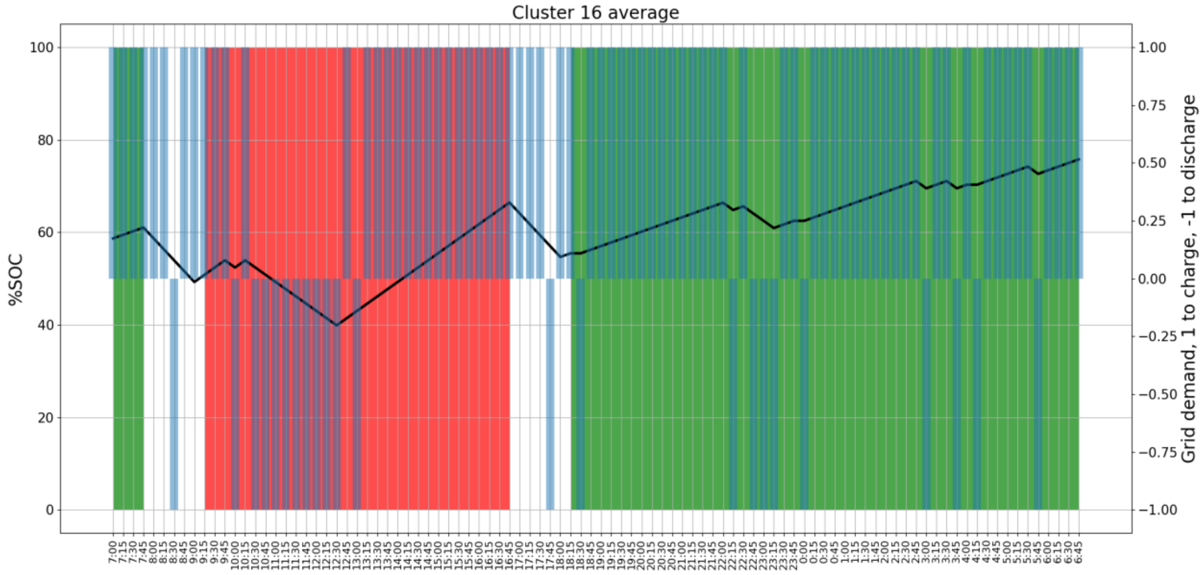

Figure 2: SOC evolution of a vehicle in cluster 17 on day 100. The time began at 7:00 am. The black curve illustrates the SOC level throughout the day. The green, white and red shade indicates the EV is at home, travel, and work respectively. The blue bar implies the V2G request from the grid. If it is 1 the grid requests EV to charge and -1 means to discharge. At 12: 30 the model detects the EV doesn't have enough charge to go back home, therefore it is charging ignoring the grid request. At night, interestingly, the EV full fills it SOC demand just by responding to the grid.

The red line in Figure 3 shows the NRV demanded by the Belgian grid on day 100 of 2017. The blue line depicts the balancing activities by the fleet of V2G enabled vehicles on that same day. The green line represents the charging of the EVs outside of balancing the grid for driving purposes.

In the year 2017, interestingly we found that in total there was more overproduction of energy than underproduction. Therefore, most of the days the vehicles got charged just by balancing the grid at night.

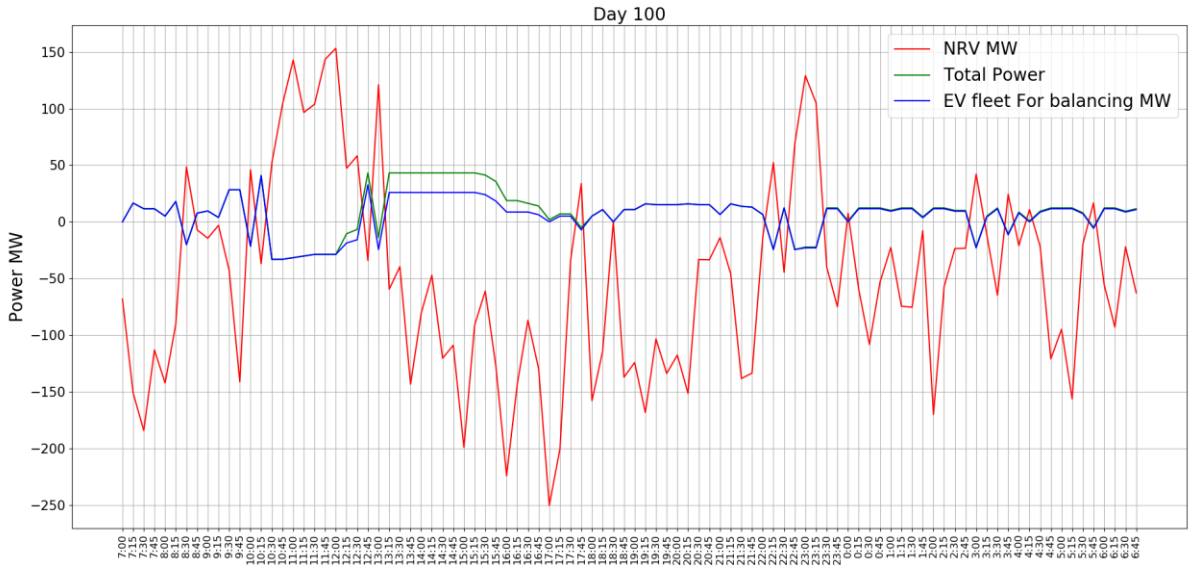

Figure 3: NRV and balancing by V2G, day 100, 6240 vehicles in the fleet.

When we extrapolate this to the one-year time frame, we know for each cluster of cars, and the fleet as a whole, the balanced volumes. The results of these calculations are used (and presented) further in the section when the results of the value calculation are presented and discussed.

5 Value Model

5.1 Rationale

In order to calculate the value V2G balancing services will yield, we look at the total regulation volumes supplied by V2G enabled EVs, throughout the year. We do this for hypothetical scenarios where large numbers of EVs (2600, 6240 and 14560 respectively) would be active on an energy market with an NRV profile identical to that of 2017.

To calculate the potential value, we consider the value to be:

$$\textit{Value} = \textit{(Total Costs Avoided at NRV+)} - \textit{(Total Income Lost at NRV-)} - \textit{(Total Cost of Energy To Replenish Activated Volume)} \tag{8}$$

5.2 Total Costs Avoided at NRV+:

Since the vehicle batteries are discharged when there is a positive NRV and as such energy can be transferred from the vehicle to the grid, there is no need to import energy from neighboring transmission grids or activate R2 services. The costs avoided can be calculated for any given time interval (15 minutes) by multiplying the kWh drawn from the vehicle batteries with the Marginal Incremental Price (MIP). The MIP is the highest price paid by TSO for upward activation for a given quarter-hour.

5.3 Total Income Lost at NRV- :

Since the vehicle batteries are charged when there is a negative NRV and as such energy can be stored on the vehicle, there is no opportunity to sell the excess energy to neighbouring transmission grids or on the R2 market. The income loss can be calculated for any given time interval (15 minutes) by multiplying the kWh put on vehicle batteries with the MDP. The MDP is the lowest price received by TSO for downward activations for a given quarter-hour.

5.4 Total Cost of Energy to replenish the Activated Volume:

At the end of the day, the vehicle used will not be willing to pay to replenish his/her battery should its SOC be lowered due to his/her vehicle being used for balancing the grid. He/she will only pay for the energy consumed while driving. As such, the battery capacity used for regulation should be replenished at the expense of the operator. We calculate the cost attached to this as follows. We calculate the difference between the SOC at the start of the day, expressed in kWh and the SOC at the end of the day (when recharging needs to start to get to the desired SOC), expressed in kWh

If this figure is greater to the total amount of kWh consumed for driving during that day, it means there was a net discharge from the vehicle to the grid as a result of the balancing activities during the day and the operator needs to charge the battery at his expense and we multiply this figure with the Levelized Cost of Energy (in our Belgian case, we assumed an LCOE of € 0.07).

5.5 Results: Total Value

Table 5 presents the results of our model. For each scenario, we first present the volume of balancing that occurs. It is clear from this that V2G enabled vehicles can play an important role in balancing the grid. Unsurprisingly, the volume increases when the fleet increases. In the most optimistic scenario, the V2G enabled fleet will receive 106.7 MWh. We observe that the volumes of energy going from the grid to the vehicle and from the vehicle to the grid are in the same order of magnitude when considering the yearly total.

When we translate this to the Total Value generated by these balancing activities, we see that in the pessimistic scenario (slow adoption of V2G), EUR 2.35M of value is generated. In the most optimistic scenario, this grows to EUR 9.67M of value generated. Importantly, this generated value represents the total value generated by V2G services on the market for balancing. This value will have to be shared between the different players in the value chain: the operators, the transmission companies, the EV owners and so on.

Table 5: Outcome of the model

Scenario	V2G (in MWh)	G2V (in MWh)	Total Value (in EUR)	Value per EV (in EUR)
2600 V2G EVs	21.6	22.9	2. 35 million	906
6240 V2G EVs	47.51	52.17	5.15 million	826
14560 V2G EVs	90.8	106.7	9.67 million	664

Therefore, it is interesting to investigate the value that one V2G enabled vehicle can generate. In our model, the value generated by a V2G enabled vehicle when balancing the grid lies between EUR 664 and EUR 906 per year.

However, the fleet is not composed of vehicles that all behave similarly. Therefore, in the next section, we inspect the value generated by the different clusters in our model. This allows us to get a much more fine-grained view on which types of vehicle/user combinations generate the most value.

6 Results and Conclusions: Clusters

6.1 Volumes

Figure 4 shows the total volume of balancing that occurs in the separate clusters over one year. Of course, the value is to a large extent linked to this volume. However, since prices fluctuate during the day, also the time at which the balancing service is activated, and at which power the (dis)charging takes place has an impact on the total value. A detailed description of the different clusters and their contribution to the value generated by balancing services can be found in the next section.

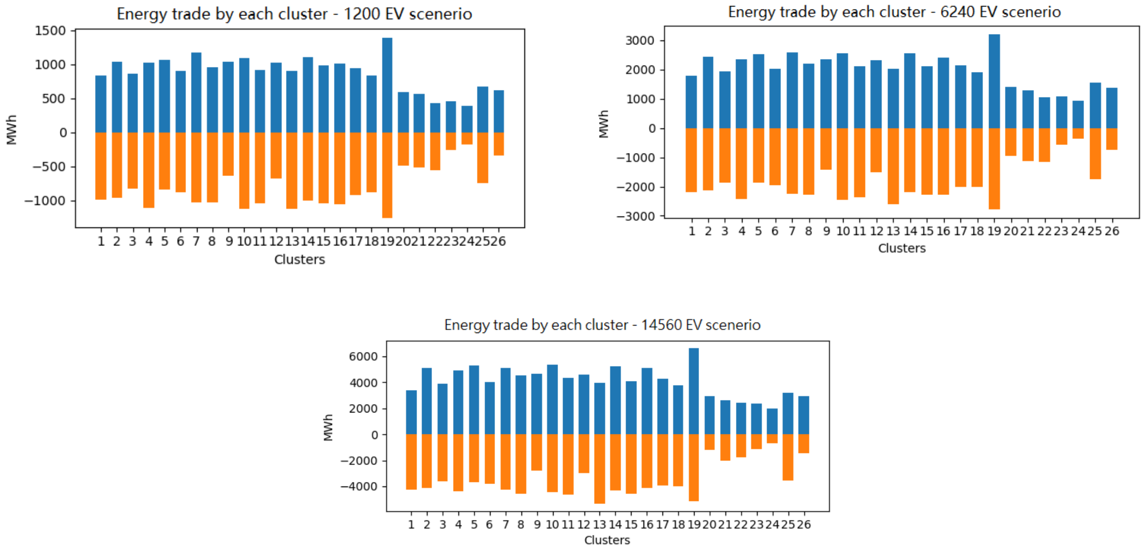

Figure 4: Energy trading in each scenario throughout the year. The blue line represents upward, and orange means downward energy regulation by EVs.

6.2 Value

Table 6 presents, for each scenario, the value generated per V2G enabled EV when used to balance the grid. We immediately observe that the average value per EV calculated in the previous section was negatively impacted by adding the ‘special clusters’. Therefore, we calculate the average value of a vehicle in the ‘standardized clusters’. Further in this section, we inspect those clusters that generate the most value, those that generate little value. We do this both for the standard and for the special clusters. Within the boundaries of this project, we take a qualitative approach towards this scrutinization. It is clear that a more structured and full-fledged sensitivity analysis would generate valuable results. By looking at the clusters that pop out in terms of (not) generating value, we aim to prioritize those variables that should be investigated first.

6.3 Standard Clusters

We observe that the vehicles in Clusters EV19, EV4, EV 13 and EV8 generate the most value and do this consistently across the different scenarios. Clusters EV9 and EV12 consistently generate the least value.

With regard to those standard clusters contributing most to the value generated by balancing services, we draw the following conclusions:

- There are no big difference compared to other clusters in terms of plug-in behavior, of course, this is to be expected since all plug-in behavior in the standard clusters is quite comparable across clusters
- Vehicles in these high-value clusters travel less than average kilometres per day (= less than 40km)
- We observe no big differences on the variable coding for the minimal required SOC in the morning, compared to the other standard clusters.
- Two of the high-value clusters discharge at a higher power rate at work than the other two clusters, but we cannot say this has a huge influence on the value generated.
- The common denominator between the high-value clusters seems to be that the vehicles possess large batteries and the users allow for deep discharges (low minimal required SOC).

With regard to those standard clusters contributing least to the value generated by balancing services (EV9 and EV12), we draw the following conclusions:

Table 6: Value generated while balancing the grid per V2G enabled EV for one year, per cluster.

		2600 V2G EVs	6240 V2G EVs	14560 V2G EVs
		Value per EV (in EUR)	Value per EV (in EUR)	Value per EV (in EUR)
Standard Clusters	EV1	1113	1015	848
	EV2	1166	1052	840
	EV3	914	846	708
	EV4	1239	1142	887
	EV5	991	894	711
	EV6	988	912	766
	EV7	1112	1019	832
	EV8	1193	1101	921
	EV9	601	553	466
	EV10	1229	1113	849
	EV11	1185	1105	933
	EV12	673	612	512
	EV13	1221	1172	1016
	EV14	1176	1050	856
	EV15	1130	1032	866
	EV16	1186	1069	809
	EV17	1013	924	756
	EV18	983	929	797
	EV19	1336	1218	956
	Avg.	1076	987	807
Special Clusters	EV20	485	361	153
	EV21	499	437	307
	EV22	668	590	375
	EV23	232	206	175
	EV24	121	100	67
	EV25	700	664	581
	EV26	395	348	288

- Both clusters consist of drivers that could be considered ‘late starters’, they plug in their vehicle at work at 10:00 AM which prevents them from being active on the balancing market in crucial morning and evening times. This finding highlights the need to further investigate how shifts in working (plugin) hours impact the value generated by balancing services since a number of trends will increase flexible working schemes.
- The vehicles in both clusters drive longer distances than the average driver
- The vehicles in both clusters possess small batteries and while they even allow for deep discharges (SOC = 30), this does not make up for the limited battery capacity.

6.4 Special clusters

In our special clusters, Clusters EV25 and EV22 generate relatively high values, although they are consistently below the average value generated by vehicles in the standard clusters. These clusters represent vehicles that are only connected at home. As such, these vehicles are not connected during working hours or afternoons in the weekend. Importantly, the value of these vehicles can further decrease when the share of solar increases in the production mix as this production method will increase the demand for balancing services during the daytime. The vehicles in clusters EV24 and EV23 hardly generate any value. These are the vehicles only connected at work or commercial buildings and are not plugged in at home. This is an interesting finding since leasing companies and employers are experimenting with providing electric vehicles and charging infrastructure to their employees. This might entail that some consumers will consistently only plugin at work to charge their vehicle (maybe even at the employer's expense). The value generated by these users on the market for balancing is negligible, at least compared with the other users in our model. Interestingly, the results for Cluster EV26 show that the value generated by a vehicle used by an 'extreme' user (long travel time and distance, large battery size, long working hours and connected at work and home) is relatively limited. As such, companies wishing to tap into the value generated by V2G on the balancing market should not address these heavy users (directors).

7 Conclusion

This study sets out the determine the worth of the EV fleet participating in an imbalance tariff in a smart and coordinated way. From the model we developed that includes the detail driving behavior and smart fleet selection, we found out this service's total worth ranges from 2.35 to 9.67 million Euro based on the number of EV participating. Higher participating number of EV results higher total worth but less for each EV and vice versa. Another finding is, the selection of maximum and minimum SOC by the user have a major influence as it determines the selection of the EV for balancing purpose. Moreover, this SOC selection limits the battery from deep discharge and overcharging and keeps the SOC within a range. This translates to longer battery longevity even when EV participates in V2G. A further study could assess realistic driving behavior from different geographical locations and find out the results based on that. Furthermore, in future research other services would be interesting to investigate like primary, secondary and tertiary reserve markets.

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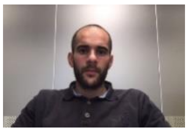

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