EVS32 Symposium
Lyon, France, May 19-22, 2019

The value of vehicle-to-grid (V2G) for distribution system congestion management

Sjoerd Moorman[1], Tim van ’t Wel[2], and Tim van Beek[1]

[1]*EV Consult B.V., Overtoom 60-4 Amsterdam, the Netherlands, info@evconsult.nl*

[2] *Delft University of Technology (Student), Jaffalaan 5, 2628 BX Delft, tvantwel@gmail.com*

Executive Summary

Vehicle-to-grid (V2G) technology has the ability to accelerate the transition towards a more sustainable electricity system. However, a quantification of the value of V2G services is lacking within current research. his paper aims to quantify the value created by V2G for distribution system operator (DSO) congestion management services. Using the SparkCity model, a real-life neighbourhood is modelled to investigate (dis)charging patterns of electric vehicles (EVs) combined with the introduction of solar PV and heat pumps within this neighbourhood. In addition to the previous version of the model, smart charging and V2G algorithms are developed the basis of congestion data within the grid assets of the neighbourhood. The neighbourhood modelled is Lent (Nijmegen, the Netherlands). The observed emerging charging smart charging behaviour lowers peak loads within the grid and could delay investments in grid components potentially necessary due to EV growth. Based on the results presented in this paper, utilizing V2G charging for low voltage congestion management could lower the costs for potential grid reinforcements for the DSO.

Key words: V2G (vehicle to grid), smart charging, EV (electric vehicle), simulation, case-study

1 Introduction

The Netherlands is aiming for a more sustainable energy system, which includes a larger share of electricity within the energy mix and a larger share of intermittent renewable energy sources [1]. The integration of these intermittent sources together with a larger share of electricity within the energy mix will create a greater mismatch between supply and demand and shift generation from a top-down structure to bottom-up [2]. The introduction of electric vehicles (EVs) within this system could cause potential problems, such as congestion, within the current electricity grid [3]. EVs can mitigate this problem through smart charging mechanisms (V1G) in which the charging of the EV is regulated [3]. Additionally, EVs can provide flexibility for the integration of other measures within the energy transition using vehicle-to-grid (V2G) [4]. V2G has many different applications that could provide value to different stakeholders[4]. In Table 1, the applications of V2G are presented. The greatest value for V2G could be reached by providing a combination of these services, so called ‘stacked services’. However, the value of these services remain unclear. The current body of research regarding the value of V2G services is mainly focused on national grid and national markets such as the FCR market [e.g. 5].

In order to gain better insight into the value of vehicle-to-grid applications and the value of these services, all these services and their value will need to be quantified. A valuation of V2G congestion management services is currently lacking and therefore this paper will try to answer the following question:

What is the value of V2G for DSO congestion management services?

Table 1: Services of V2G

	Level	Service
V2H/V2B	Home/building	Local storage & use
	Home/building	Peak shaving
	Home/building	Power backup
V2G	Local grid	Local storage & use of energy
	Local grid	Congestion management *(+ power quality and voltage control)*
	National grid	Balancing markets
	National grid	Wholesale energy markets

2 Methodology

A model is created to estimate the impact of V2G on the electrical loads within the distribution grid. After this estimate, the impact on electrical load will be translated to a monetary value.

First, an agent-based model (ABM) is created to estimate the impact of V2G on the loads within the distribution system. This is done through expanding the Sparkcity ABM to include different charging strategies based on driving patterns and geography [6]. While modelling EV charging impact, three main uncertainties are present: driving behaviour, electricity usage and the share of EVs [3]. For this reason, an ABM approach is selected. ABMs allow a model to have a heterogeneity between agents and allow the modeller to capture emergent behavioural patterns within a diverse group of agents [7]. In this case, a more heterogenic driving behaviour could be implemented in comparison to equation-based models. The Sparkcity model, specifically, is an ABM with the objective to study the impact of EVs on the local electricity grid balance and technological developments and will thus be used as the basis of the model [6]. This model is able to estimate the EV charging impact on the electrical load with the usage of GIS-data to make a representation of a real-life neighbourhood (figure 1). This neighbourhood can be divided in three layers: electricity grid, road network and dwellings. The GIS-data is provided by the DSO and the local municipality. To explore the value of V2G congestion management, the electrical load in the low voltage grid is modelled with a V2G congestion management charging strategy and compared to the electrical load combined with a smart charging strategy based on congestion management. In this manner, this paper contributes to the main body of research regarding the impact of V2G. Through developing an ABM and through the integration of solar PV and heat pumps in the electricity demand.

Second, To translate the impact of EV charging and the impact of V2G charging, an grid operator cost benefit analysis is created. The socialized value that is created is based on the load of the transformers within the modelled area. On the other hand, the costs of equipping V2G chargers is calculated. Through the addition of value created for the DSO this paper adds to the current body of research in which the value translation of V2G congestion management remains unclear.

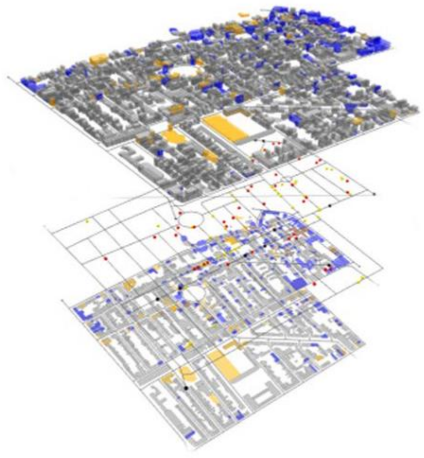

Figure1: Representation of a neighbourhood within Sparkcity [6]

3 Model description

In this section, the adaptations of the Sparkcity model created in [6] are presented. To extract the impact of V2G on the electrical load within a neighbourhood a V2G module and a V1G module for DSO congestion management are created.

3.1 Charging behaviour

Following [1], overloading issues might arise earliest at transformers within the distribution grid. Therefore, the optimization for both charging strategies are based upon the loads within the correspondent transformer. These transformer loads are based on household loads, loads of electrical appliances and EV charging loads. In order to optimize the load in the transformer, the expected load of the transformers for the hours in which the EV is available is calculated. V1G based on valley filling on the basis of expected load within the transformer. In the V2G scenario, first a smart charging optimization is performed for the EV and given this charging schedule, the potential discharge moment and amount is calculated. In order to ensure that the EV owner is not inconvenienced due to a low state of charge (SOC) of the EV, the SOC of the EV battery at the end of the charging session is the same in the V2G and V1G strategy.

3.2 Neighbourhood selection

The neighbourhood that is selected for the model is Lent (Nijmegen, the Netherlands). This neighbourhood is a residential area and is chosen because flexibility solutions are already required within this area. The local DSO and other parties already have a flexibility market for congestion and thus congestion management is recognized as potential solution in this neighbourhood. However, the current flexibility is not provided through EV charging strategies and this paper aims to quantify the potential flexibility and value created through EV charging strategies rather than the sources that are currently in place.

Expected peak loads in the system are expected to be higher than for other neighbourhoods due to the already insufficient grid infrastructure and potential overloads. This overloading allows for a V2G congestion management business case. A future energy scenario is created for 2030 for this neighbourhood. Figure 4 shows the part of Lent that is modelled. Adjusted standard Dutch load profiles are used to represent the electricity usage within the neighbourhood. Solar PV and heat pumps are added to this profile to represent a potential future electricity profile. In order to gain insights in the potential of V2G it is assumed that these loads are not controlled. For the electricity usage per year, real life data per building is used to estimate the height of the electricity demand. In Figure 5 the low voltage electricity grid of this region is described.

Using the parameter settings presented in Table 2 the following connections to the electricity grid can be identified as presented in figure 5.

Figure 4: Lent (Nijmegen, the Netherlands)

Table 2: Neighbourhood input description

Variable	Value
Households (#)	1342
Car ownership *(car/household)*	1
EV share (%)	30
Heat pump share (%)	30
Solar PV share (%)	30
Transformers (#)	11

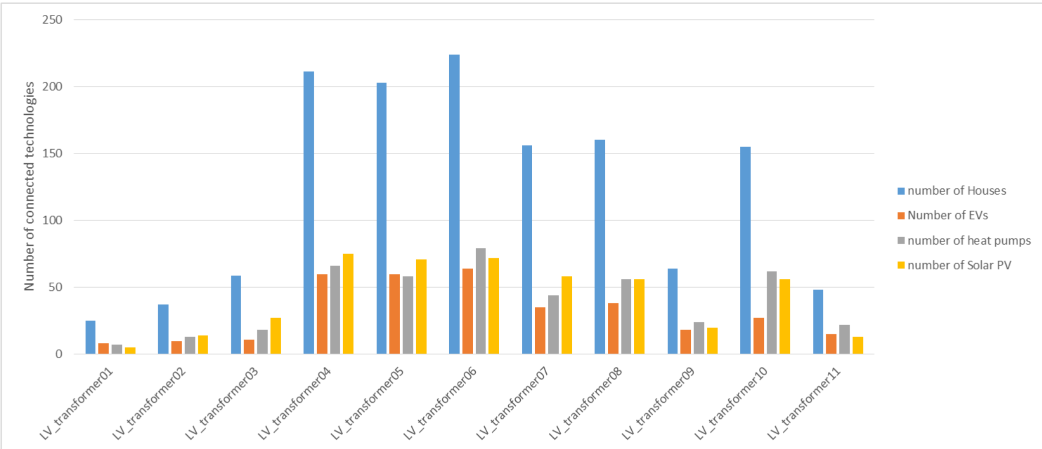

Figure 5: Lent Electricity Grid (Nijmegen, the Netherlands)

3.3 Scenarios

Two different scenarios will be run, starting with a base scenario. This scenario consists of 90% EVs following the V1G charging strategy with 10% of EVs that are not able/willing to charge smart. Both scenarios will be under a sensitivity analysis. Within this sensitivity analysis the share of EVs in the overall population of cars as well as the share of charging type and electricity input will be different for both scenarios.

Table 3: EV shares

	Scenario 1	Scenario 2
EV share	30%	30%
Smart charging share	90%	90%
of which V2G capable	*0%*	*30%*

4 Results

The ABM will create different outputs. The following KPIs are identified as most important to identify charging patterns and estimate the impact of EV charging on the electrical load within the neighbourhood:

- Cumulative kWh charged;
- Cumulative kWh discharged; and
- SOC per EV;
- kWh discharged per 15 minutes per EV per charging point.
- Electrical load per 15 minutes per transformer;

To cope with the variability of multiple parameters, such as the distribution of electrical appliances and EVs, the presented results are the results of multiple replications. The number of replications is related to the variability of the set parameters and the following section is based on five replications with different seed values for the random number generators.

First, the results of the smart charging scenario will be presented. Afterwards, the results of the V2G scenario will be presented and compared to the results from the first scenario. In order to understand the magnitude and behaviour of the charging sessions within the neighbourhood, first, the total kW charged will be displayed for the whole neighbourhood.

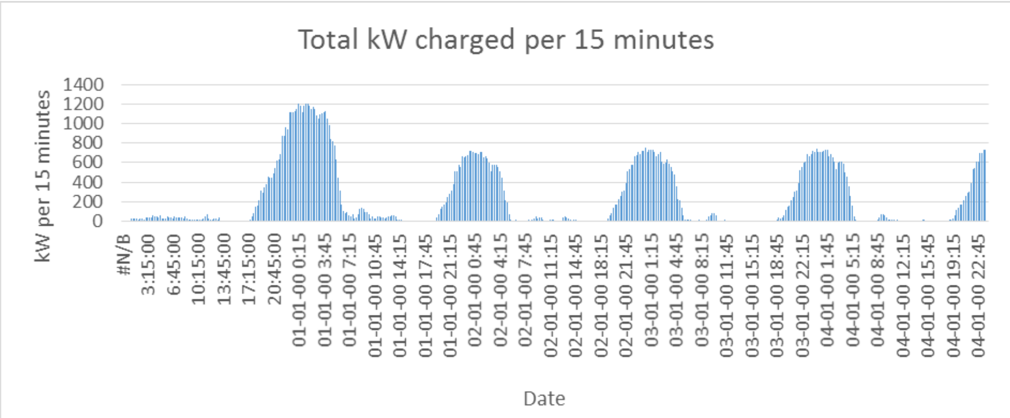

Figure 6: Total kW per 15 minutes charged in neighbourhood during winter week

Figure 6 shows the total amount of kW charged per fifteen minutes over the course of the selected simulation period. This period represents five working days in a winter week. On the x-axis the time is presented and on the y-axis the amount in kW within the fifteen-minute time frame is presented. It can be noted that the amount of kW charged varies per day and follows a day and night cycle. During the day, only a small amount of charging capacity is used while during the night the batteries of the EVs are charged. Five different peaks of electricity usage can be identified in Figure 5. Four of these five peaks are of a similar shape. The last of these peaks, during the night of the fifth day, only represents half of the shape of the previous four peaks. This is because of the ending of the simulation at midnight on the start of the sixth day. It should be noted that a peak is expected during the first hours of the simulation because EVs will be charged during the night before the start of the simulation, but due to the starting conditions of the charging strategy this electricity consumption is absent. Next to the similarity of shape between the peaks during the night, the peak consumption of electricity is around 700 kW per 15 minutes during three of the four nights in the simulation. The first night has a peak of around 1200 kW per 15 minutes. This is partly explained through the absence of charge during the first morning and is also partly explained by the starting conditions in regards to the SOC of the EVs. The effect of charging on the SOC of the EVs is presented in Figure 7.

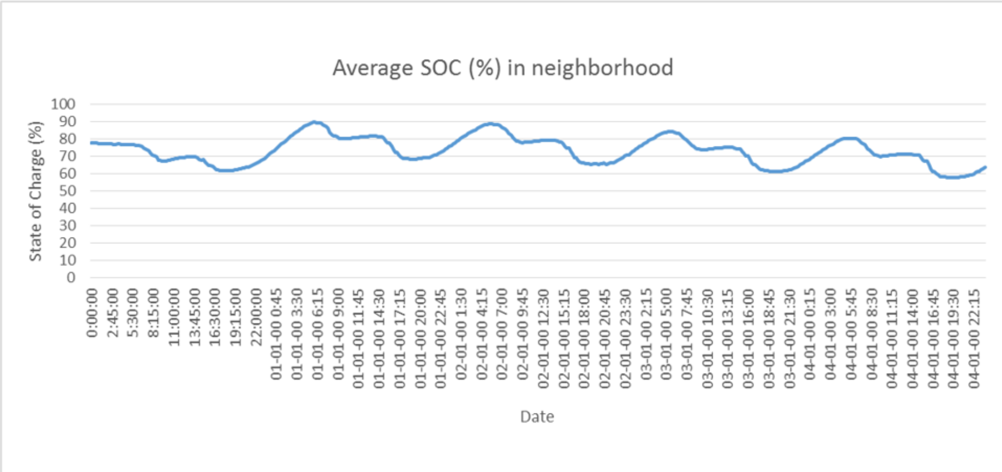

Figure 7: Average SOC of EVs within the neighbourhood

Figure 7 is a graphical representation of the average SOC of all EVs within the neighbourhood. The y-axis represents the SOC as percentage of the battery capacity and the x-axis presents the time within the simulation. The five work days can be identified separately and a similar pattern can be identified over these days. However, it can be noted that the observed behaviour on the first day is different in comparison to the next days. The lower SOC during the first day and the higher increase in SOC during the first night can be explained using Figure 5. A lack of charging during the morning on the first day and the higher total amount of kW charged during the first night cause the difference in average SOC in the neighbourhood. It can also be noted that the SOC peaks are shortly after the peaks in figure 5 which is caused by the cumulative nature of the SOC. Next to this, it can be noted that the peaks of SOC are reducing five percent in the last two nights. Overall it can be concluded that smart charging behaviour with valley filling on the basis of congestion management is highly predictable due to the inelasticity of household electricity usage pattern.

To demonstrate the impact of V2G charging with the purpose of congestion management on the low voltage transformers only transformers with potential overload are of interest. The overload of the transformer is defined as the electrical overload of the transformer. The power factor is assumed to be 1.0. A transformer is overloaded if the electricity demand is higher than the capacity of the transformer load.

For the purpose of this paper, one of the transformers within the neighbourhood is displayed. This transformer is chosen because of the present overload on the transformer. This overload is present during the evening electricity demand peak. The overload is present without the electricity demand for EVs, but additional electricity demand during this period is avoided due to the V1G charging strategy. Figure 8 is graphical representation of this transformer.

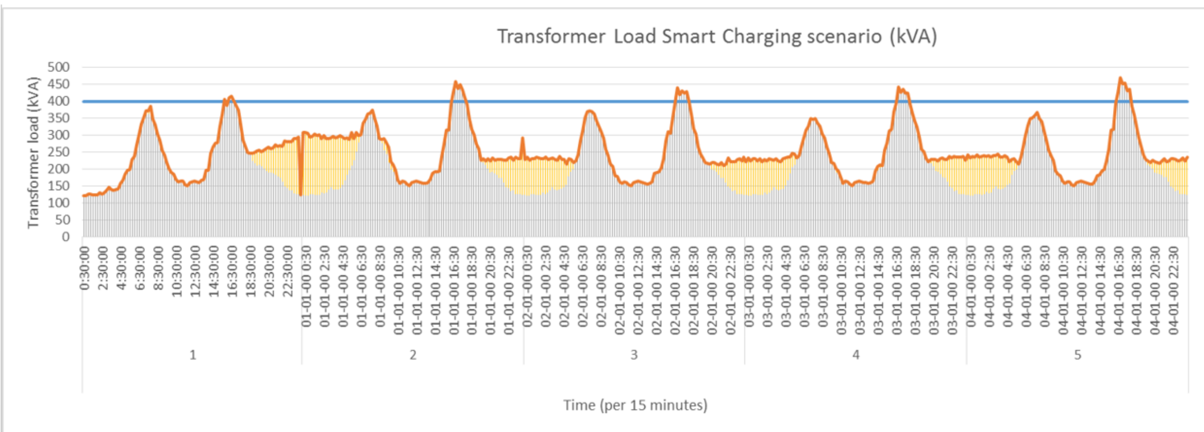

Figure 8: Electricity demand on a 400 kVA transformer with smart charging

On the x-axis, in figure 8, the time is presented. Five days can be identified. On the y-axis the transformer load is presented. The electricity demand for the houses connected to the transformer is plotted over the time. The grey area represents this base demand including non-controllable electric appliances. The yellow area is the electricity demand created by the smart charging of EVs for this transformer. The blue line represents the capacity of the transformer, which is 400 kVA and the orange line represents the total electricity demand for this transformer. The electricity demand generated by the charging of EVs can be described as valley filling. Using this method, the impact of the electricity demand is optimized to be as low as possible. This means that the EVs should not only consider household electricity demand but also electricity demand from other EVs in order to optimize the electricity demand over time below the maximum capacity. Using this smart charging technique, the expected peak demand is decreased. Without smart charging behaviour, EV charging demand would be increased during the evening peak and the total demand would increase further over the capacity of the transformer. This smart charging technique thus mitigates the problems regarding potential additional transformer overload. However, overload still occurs. In order to create additional value for the low voltage electricity grid and thus the DSO the EVs can be used to also provide electricity during peak demand hours and thus lower the electricity demand on the other side of the transformer. Figure 9 is a graphical representation of the same transformer load but with a V2G charging strategy.

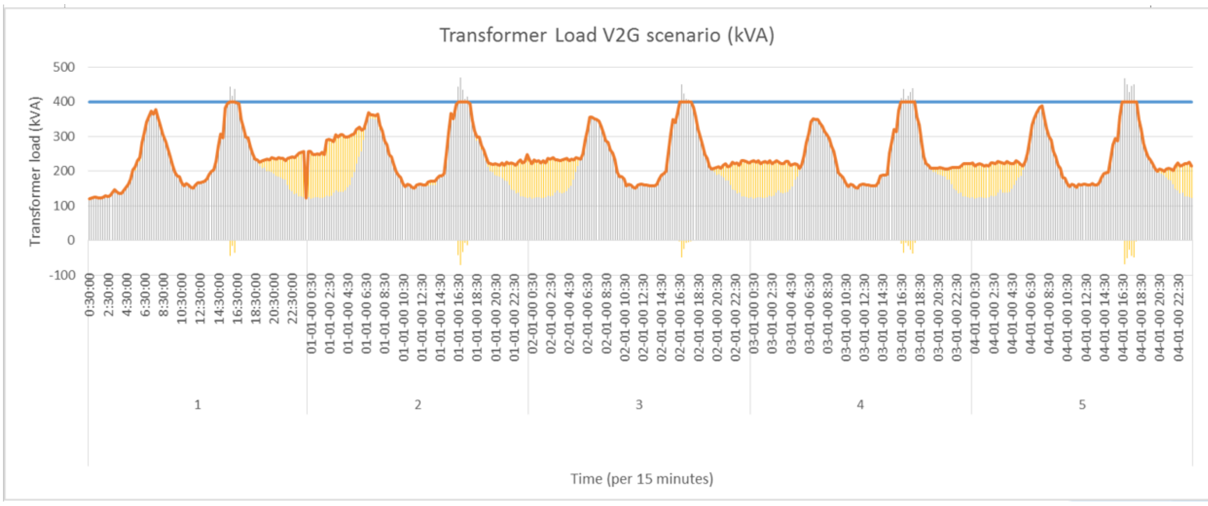

Figure9: Electricity demand on a 400 kVA transformer with V2G charging

The previous graph shows the transformer load based on both a static household demand and a variable EV charging demand with an implemented congestion management V2G charging strategy. It can be recognized that the household electricity demand is higher than the transformer capacity during the evening peak during the whole week. Through the introduction of V2G services however, this demand can be met by utilizing the battery capacity of the EVs present behind this transformer. The discharge starts when EVs are arriving home and utilize the initial SOC left in the EV. During the night, the discharge provided will be charged on top of the V1G charging strategy.

Table 4: Neighbourhood overall transformer load

Transformer	Capacity (kVA)	Max Load (kW)	Overloaded	Load Factor (%)
Transformer 1	100	71.18	No	30
Transformer 2	100	142.21	Yes	38
Transformer 3	250	306.82	Yes	39
Transformer 4	400	528.55	Yes	37
Transformer 5	400	462.88	Yes	39
Transformer 6	400	437.71	Yes	39
Transformer 7	400	394.39	No	36
Transformer 8	400	311.41	No	40
Transformer 9	250	158.50	No	36
Transformer 10	400	363.73	No	36
Transformer 11	100	97.55	No	35

In table 4 the transformer loads of the different transformers in the simulated neighbourhood are presented. First, the capacity is presented next to the peak electricity demand of the transformer during the simulations in the smart charging scenario. If this rating is higher than the capacity this rating, overload is expected and V2G might add value to the grid. The load factor is also presented. The load factor is derived from the load profile and allows for an insight in the utilization rate of the transformers. The load factor is an indication of the usefulness for demand control mechanisms, such as the V2G as presented in the second scenario. A low load factor shows a high peak demand and a low average utilization rate. This means that the difference between the highest peak during the simulation and the average electricity consumption is relatively high. In these cases, flexibility solutions might be preferred to grid reinforcements. The simulation shows that V2G charging is able to mitigate all potential overload in Nijmegen, Lent. For the calculation of the costs of V2G in comparison to grid reinforcements only transformers with an expected overload will be taken into consideration.

In order to calculate the value of the shown flexibility solution, the framework provided by Overlegtafel Energievoorziening is used [8]. This framework is used by Dutch DSO's in order to consider flexibility solutions in comparison to reinforcements. A cost benefit approach specific to grid operators as specified in [8] is used. In order to calculate the net present value (NPV) formula 1 to 3 are used.

$$NPV_{reinforcement} = \sum_{year\ 0}^{DEPR\ period} \frac{socialized\ costs\ reinforcements_{year\ x}}{(1+discount\ rate)^{year\ x}} - \sum_{year\ z+1}^{year\ z\ +\ DEPR\ period} \frac{socialized\ costs\ reinforcements_{year\ x}}{(1+discount\ rate)^{year\ x}} \quad (1)$$

$$socialized\ costs\ reinforcements = Regulated\ Asset\ value * WACC + depreciation + operational\ costs \quad (2)$$

$$NPV_{flexibility} = \sum_{year\ 0}^{year\ z} \frac{costs\ flexible\ capacity_{year\ x}}{(1+discount\ rate)^{year\ x}} \quad (3)$$

These formulas are used to estimate the NPV of both alternatives. In order to answer for the main research question, the analyses is performed on the level of the neighbourhood and the calculations for all transformers of interest are combined. Asset value is regulated as well as the WACC, the depreciation, and the discount rate [8] [9]. Differences between operational costs between a reinforced transformer and the current transformer are deemed negligible. The costs of flexible yearly capacity required to mitigate overload is estimated through a rough estimation on the basis of the one simulated winter week. This winter week cannot just be assumed to be representative for all weeks of the year. It is assumed that overload does not occur during the summer. The winter is assumed to last 12 weeks and the amount of flexibility provided in these weeks lowered with a modifier. Next to this, 6 weeks of spring and autumn are expected to have overload. The remuneration of battery degradation to the EV owner is presented as 2.07 eurocents per kWh and the additional lump sum costs of V2G chargers compared to regular smart chargers is 500 euros per charger [10][11]. Using these values, the NPV of both scenarios are calculated. These results are presented in figure 10.

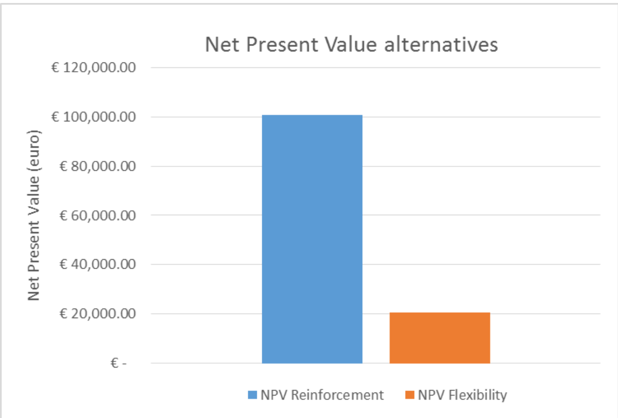

Figure 10: Net present value for 10 years

Figure 10 presents the results of the NPV calculations for both scenarios. It can be concluded from this figure that the flexibility solution has a lower NPV in comparison to the reinforcement alternative. Under the circumstances as described in this paper, the flexibility solution has a lower NPV than the reinforcement alternative. This result could be explained using the electricity load factor as presented in table 4. Average load factors for transformers within a residential area are around 50% [12]. The modelled transformers in Lent have a considerable lower load factor (38-39). Hence, these transformers are not fully utilized during most of the day and designed for relatively few peak hours. Additional high investments for these relatively scarce peak hours is expensive and a more tailored solution becomes cheaper. Because of the low amount of kWh needed to support the grid with V2G this solution seems more effective. It is expected that the load factor in other neighbourhoods are higher. Next to this, overload issues might not even be present at all in other neighbourhoods. In the latter case, V2G does not provide any additional value in comparison to a V1G scenario. However, V1G might add value in comparison to regular charging. This value is not quantified in this research.

5 Discussion

V2G-charging has shown potential to aid the transition towards a more sustainable energy sector. V2G charging could be used for many different purposes. Currently, the value of these different services are explored. However, the value of V2G charging for low voltage congestion management is yet unclear. Understanding of the value of V2G charging for low voltage congestion management will help stakeholders to make better regarding grid operations and the value of flexibility in order to have a more socialized cost effective transition. The impact of EV charging in a V1G and a V2G setting is modelled in the Sparkcity ABM. The results of this simulations are then translated into a monetary value using the standard cost-benefit analysis for Dutch grid operators in regards to flexibility solutions.

To answer the main research question of this paper: V2G could be a cost effective solution for congestion management in Lent in comparison to grid reinforcements on the LV grid. Comparing these two alternatives, V2G could be up to five times more cost effective. This would create value to the DSO and thus social value. The results in this paper are compared to the results to other another study performed in the Netherlands in regards to the cost effectiveness of flexibility alternatives. The presented cost effectiveness of flexibility as presented in above is high compared to this benchmark study [13]. In [13] only a reduction of 47% is presented. This could be explained due to the low costs for flexibility. In this paper overloading is only expected during the winter period which drastically lowers the amount of flexibility that is needed to be provided. Furthermore, this research focusses on a specific low voltage whereas the benchmark study takes into account all voltage levels with the whole Netherlands as geographical area.

Although V2G charging has different benefits including the aid of the transition towards a more sustainable energy system, multiple barriers for the implementation of V2G exist until this day. Social and cultural barriers towards, implementation of V2G exist [14] as well as business and institutional barriers. One of the challenges for the V2G technology is battery degradation. EV batteries will deteriorate due to the amount of charging and discharging cycles depending on the services provided. The flexible usage of bidirectional charging options will cause the battery to start ageing faster. Another challenge are the high investment costs for V2G charging hardware. Currently, V2G charging equipment is still in the development phase and upfront costs are thus still high. Next to the technical challenges, social challenges are present for V2G charging. The main social challenge for V2G is the range anxiety as perceived by the EV owner. This is a concern among car owners with regards to EVs in general, but the introduction of V2G and sharing energy from the battery of the EV will create new concerns regarding this anxiety [14].

Following these results a number of recommendations for further research are suggested in regards to the implementation of a V2G charging strategy. If overload in grid assets is expected every day a source of flexibility as provided by EVs might not be desirable due to lower predictability and thus reliability in comparison to other more consistent measures such as a stationary battery. The actual willingness of EV owners to participate in the execution of V2G charging is not considered and might become an issue. The remuneration of EV owner is assumed to be high enough for the EV owner to participate, but this might accumulate to such an extent for which it becomes non-desirable for the DSO to use V2G as a flexible resource. Electricity household demand is assumed to be perfectly forecasted by the DSO and aggregator. Fluctuations in patterns for electricity usage are not accounted for. This may result in a suboptimal scheduling of EVs and might even cause issues regarding security of supply. Actual realization and implementation of high penetrations of solar PV, heat pumps, EVs, smart charging strategies or V2G strategies have many boundaries and are highly uncertain. Next to this, no institutional framework currently exists for the DSO to use flexible resources to balance local LV grid demand. Different pilots are conducted in order to estimate the value of this flexibility, but legal boundaries are currently in place to prevent the actualization of these practices. Furthermore, all electrical loads within the residential neighbourhood are assumed to be static except for EV charging loads. This means that it is assumed that all electrical appliances in the neighbourhood except for EVs are uncontrolled. However, demand response could be provided by, for example, heat pumps [15]. The Sparkcity model could be expanded by including the ability of heat demand or other electrical demand to be responsive and provide a more dynamic environment.

6 Conclusion

Within the neighbourhood of Nijmegen Lent future electricity demand will most likely exceed the installed capacity within the low voltage grid due to the introduction of electric appliances. A smart charging strategy based on valley filling and congestion management will avoid an increase in peak demand during the evening due to the charging of EVs. However, the smart charging strategy cannot prevent peak electricity demand to be higher than the installed low voltage grid capacity. The proposed V2G charging strategy is able to prevent overloading of low voltage grid transformers and is thus able to delay initial investments in grid reinforcements. Within the area of Nijmegen, Lent V2G congestion management is a viable strategy to avoid overloading of grid assets and the necessity to reinforce transformers in the area. The deployment of a V2G strategy in comparison to a smart charging strategy allows for avoidance of grid reinforcements which account for almost five times the costs in comparison to the V2G charging scenario. This research shows that there is inherent value created for the DSO through V2G charging, and could thus be considered as an alternative to grid reinforcements by the DSO. However, implementation of this strategy is not taken into account in this research and should be further researched.

Acknowledgments

The researchers would like to thank the local DSO, Alliander, for providing information regarding the local electricity grid and the municipality of Nijmegen for providing information regarding demographics and GIS-data.

References

[1] J. Sijm et. Al., *Demand and supply of flexibility in the power system of the Netherlands, 2015-2050*, November 2017

[2] S. Weitemeyer, D. Kleinhans, T. Vogt & C. Agert, *Integration of Renewable Energy Sources in future power systems: The role of storage*, Renewable Energy, ISSN 0960-1481, 75(2015), 14-20

[3] D. Richardson, *Electric vehicles and the electric grid: A review of modeling approaches, Impacts, and renewable energy integration*, Renewable and Sustainable Energy Reviews, 19 (2013), ISSN 1364-0321, 247-254

[4] W. Kempton, J. Tomic, *Vehicle-to-grid power fundamentals: Calculating capacity and net revenue*, Journal of Power Sources, ISSN 0378-7753, 144(2005), 268-279

[5] T. van Beek, et. Al., *The Business Case of Vehicle-to-Grid (V2G) Charging within the current Dutch Frequency Containment Reserve Market*, EVS31 Kobe Japan, October 2018

[6] A. Hoekstra, P. Hogeveen, *Agent-based Model for the Adoption and Impact of Electric Vehicles in Real Neighbourhoods*, EVS30 Stuttgart, October 2017.

[7] K. van Dam, I. Nikolic & Z. Lukszo, *Agent-based modelling of socio-technical systems*, ISBN 978-94-007-4932-0, Dordrecht, Springer, 2013

[8] Overlegtafel Energievoorziening, *Afwegingskader verzwaren tenzij*, May 2018.

[9] Autoriteit Consument en Markt, *Uitwerking van de methode voor de WACC*, 2016, ACM/DE/2016/201586.

[10] T. van Beek, S. Moorman, K. Andriosopoulos, *The Business Case of Vehicle-to-Grid (V2G) Charging within the current Dutch Frequency Containment Reserve Market*, EVS 31 & EVTeC 2018, Kobe, Japan, October, 2018.

[11] T. Lehtola, A. Zahedi, *Cost of EV battery wear due to vehicle to grid application*, Australasian Universities Power Engineering Conference (AUPEC), Wollongong, Australia, September 2015.

[12] V. Montsinger, *Effect of Load Factor on Operation of Power Transformers by Temperature*, AIEE transactions, Bd. 49, 1930, p. 776-792.

[13] Ecofys, *Waarde van Congestiemanagement*, April 2016.

[14] B. Savocool, R. Hirsch, *Beyond batteries: An examination of the benefits and barriers to plug-in hybrid electric vehicles (PHEVs) and a vehicle-to-grid (V2G) transition*, Energy Policy, 37 (2009), 1095-1103.

[15] N. Voulis, M. van Etten, E. Chappin, M. Warnier, F. Brazier. *Rethinking European energy taxation to incentivize consumer demand response participation*. Energy Policy, 124 (2019), 156-168

Authors

Sjoerd Moorman holds a MSc degree in Sustainable Energy Technology from Delft University of Technology. He has multiple years experience in sustainable energy and mobility projects, ranging from strategic advice to project management and innovation. Sjoerd brings technical know-how, excellent analytical skills and a good dose of optimism. He is an expert in smart charging & Vehicle-to-grid (V2G) projects, and is involved in multiple projects in the Netherlands, UK and Belgium. Sjoerd is a former member of the world-champion Delft university solar car team, and has coordinated the development of the world's first online course on electric mobility.

Tim van ‘t Wel is a graduate student at Delft University of Technology at the faculty of Technology, Policy and Management. The results following his master thesis have been used as input of this paper. With a specialization in Transport & Logistics as well as Energy & Industry Tim has gained insight in both the transport and energy sector. Tim has also been involved in the creation of sustainability goals for the fleet of the Veiligheidsregio Rotterdam Rijnmond through his bachelor thesis.

Tim van Beek has a Masters Degree in Urban Design from the Delft University of Technology. As the founder of EVConsult he has been active as a project lead and senior consultant in various international projects. He has cooperated in devising the EV programs of the city region of Rotterdam and municipalities of Amsterdam, Utrecht, The Hague and others. Tim regularly gives workshops and presentations for national and international EV specialists at various conferences.