Vehicle-to-Everything (V2X) in the Netherlands

Marijn Roks – Master Energy Science Internship (GEO4-2520)
Netherlands Enterprise Agency – Supervisor: Hielke Schurer
Utrecht University – Supervisor: dr. ir. Ioannis Lampropoulos
June 2019

(adapted from NewMotion, n.d.)

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1. Introduction

The sun does not always shine, and the wind does not always blow. A fact that complicates the integration of renewable energy sources in the electricity grid (Noel, Zarazua, Rubens, Kester, & Sovacool, 2019). Besides that, issues raise about the decentralized generation of renewable energy (Alanne & Saari, 2006). Some people see (a part of) the solution for these problems in the application of Vehicle-to-Everything (V2X) technology. V2X is a collective name for the following technologies (Thompson, 2018):

- Vehicle-to-Grid (V2G): Using an electric vehicle (EV) battery to interact with the electricity grid, both in charging and discharging modes, which is different than smart charging (only) approaches.
- Vehicle-to-Building (V2B): Using EV batteries to optimize local building energy consumption and generation.
- Vehicle-to-Home (V2H): Optimizing home energy consumption and generation or using EVs as emergency back-up power.
- Vehicle-to-Load (V2L): Any other instance of an EV battery providing energy to a load.

In short, V2X refers to the possibility of bi-directional charging an EV. In other words, electricity does not only flow into the EV, but could also flow back. A diagrammatic representation of V2X technology is shown in Figure 1.

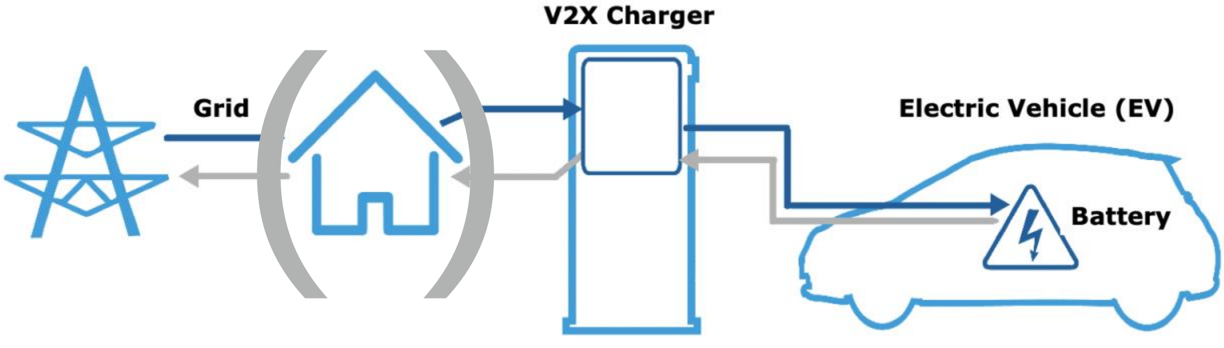


Figure 1: Diagrammatic representation of V2X (adapted from Payne & Cox, 2019)

At this moment EVs are in most cases directly charged at homecoming after a day of work, while this is already a peak moment for the electricity grid (Erden, Kisacikoglu, Kisacikoglu, & Erdogan, 2018). By charging the EV at a later moment and possibly even discharge the EV, the load of the electricity grid can be lowered (Noel et al., 2019). If the charging happens at times when renewable energy is overproduced, the share of renewables in the electricity mix is enlarged. Besides that, V2X offers the possibility to store locally generated energy from solar panels (V2H). In this way the renewable energy consumption at home-level could be increased (self-consumption) (Grant, 2018). Potentially this could even lead to houses going off the grid. V2X also makes it possible to trade with the battery capacity on the electricity market (energy arbitrage).

In conclusion, V2X seems to have a lot of potential. However, there are also aspects, e.g. battery degradation and institutional bottlenecks, that could limit the potential of V2X. The Netherlands Enterprise Agency (in Dutch Rijksdienst voor Ondernemend Nederland: RVO) is especially interested in these limiting aspects. Besides that, the Netherlands Enterprise Agency is interested in the economic aspects of V2X. In other words, what is the business case behind this relative new technology. Altogether, this report focusses on several aspects of V2X technology and in this way tries to sketch the current state of development of V2X in the Netherlands.

This report starts with an overview of the stakeholders involved in V2X and describes their point of view on the basis of a stakeholder analysis(Chapter 2). Next, the business case for V2X is examined in chapter 3. The business case of V2X is highly affected by battery degradation. Different studies are examined in order to draw a nuanced conclusion about the impact of V2X on battery degradation (chapter 4). Potential limiting legislation and policies are reviewed and discussed in chapter 5. In the conclusion (Chapter 6), the current state of development of V2X is summarized.

2. Stakeholders involved in V2X

A stakeholder analysis helps to identify different roles and relevant parties involved in the relative new technology of V2X (Varvasovszky & Brugha, 2000). Figure 2 shows a visual overview of the stakeholders involved in V2X in the Netherlands. All stakeholders and their interest are discussed in this chapter. During this research a lot of stakeholders were interviewed in order to find out more about their interest regarding V2X. A complete list of the interviewees can be found in Appendix I. The interviewees were approached by mail, with help of my supervisors at the Netherlands Enterprise Agency. The interviews were not structured and mostly started with an introduction of the company/organization the interviewee is working at. After that, their opinion about V2X was discussed. In the discussion the same topics as in this report were discussed; stakeholder involvement, business case for V2X, battery degradation, legislation/policy and other bottlenecks.

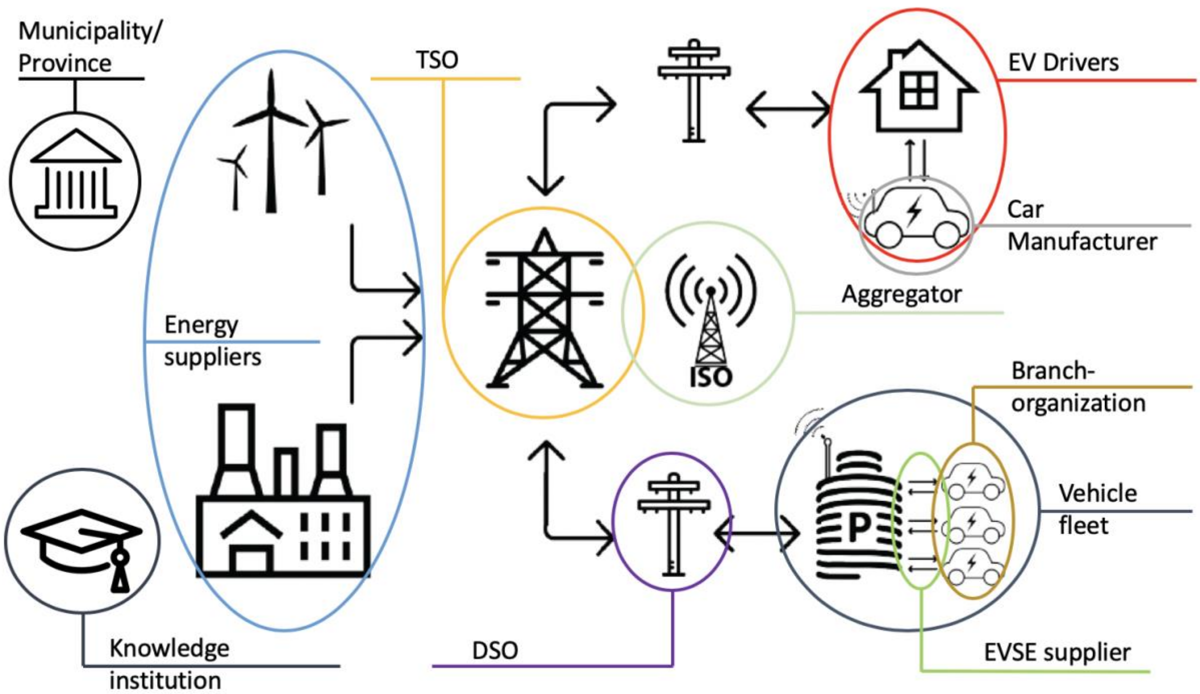
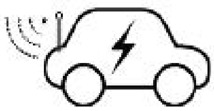


Figure 2: Stakeholder overview

EV Drivers

EV drivers are the consumers of the electric cars. For EV drivers, V2X potentially is a cheaper and more sustainable way to charge their electric car (Payne & Cox, 2019). Besides that, it potentially offers EV drivers an opportunity to get off the grid with their households (Gaton, 2018). However, V2X also brings challenges as battery degradation and extra infrastructure costs.

Car manufacturers

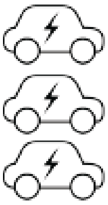


Car manufacturers are responsible for the manufacturing of EVs. Important part of an EV is the battery-based energy storage. Car manufacturers are obliged to provide guaranty on the EV and the battery. Since the effect of V2X on the battery is not proven yet, most car manufacturers have no EV able to use V2X yet (Alvarez, 2018). To be more precise, only the Nissan Leaf and Mitsubishi Outlander (Plug-in Hybrid Electric Vehicle) are currently suitable to charge bi-directional, since it requires the CHAdeMO charging protocol (Zecchino, Thingvad, Andersen, & Marinelli, 2019).

Aggregators

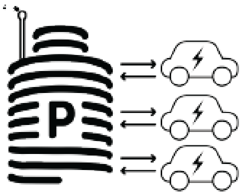
An important role in the implementation of V2X seemed to be the aggregator (ACM, 2019). In the case of V2X, an aggregator can be seen as a third-party who empowers EV owners to make their battery capacity available for V2X. The aggregator then links several EVs to the electricity grid in order to react flexibly to changing electricity prices. The aggregator predicts the amount of flexibility all EVs can deliver in advance (Han, Han, & Sezaki, 2010). This flexibility can be used to interact with several electricity markets. There is no clear aggregator in the field of V2X yet, several companies and organizations (from electricity suppliers to car manufacturers) see themselves becoming an aggregator.

Branch organizations



Branch organizations represent and lobby for several other stakeholders. Since they represent different stakeholders, branch organizations have no single vision on V2X. In common all branch organizations see potential in V2X technology. Branch organizations especially for electric transport (e.g. Vereniging Elektrische Rijders or USEF) are however more optimistic about the potential compared to other organizations who also represent stakeholders not involved in electric transport (e.g. Koninklijke RAI vereniging).

Vehicle fleet



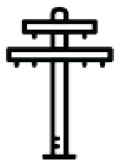
A vehicle fleet owner has numerous EVs available. By combining these EVs during a certain time (e.g. during working times), V2X could be implemented on a large scale. Using V2X to trade on the electricity market could potentially lead to a better business case for the vehicle fleet owner. Besides that, V2X can be used to flow electricity back into the building (Center for Automotive Research, 2019). Especially at peak demand this could potentially significantly lower the energy bill.

EVSE manufacturer

The electric vehicle supply equipment (EVSE) manufacturer is responsible for the production of both the hardware (charging point) and the software. Both hard- and software need adjustments in order to make it suitable for V2X (Izumi et al., 2014). At this moment, V2X charging points are still very expensive and not produced on large scale.

DSCO (Distribution System Operator)

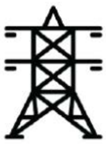
The grid operator is responsible for the regional transport and regional distribution of the electricity. V2X could lead to shifts in peak demand and therefore costs for grid reinforcements could be limited (Mwasilu, Justo, Kim, Do, & Jung, 2014). Besides that, V2X could be used to stabilize the grid, which avoids penalties for grid imbalance.



Energy supplier

Most energy producers are in a transition from energy produced from large scale power plants towards more locally produced renewable energy. Besides that, they have to deal with the electrification of the society. This brings several challenges and could lead to grid reinforcements. V2X offers a potential solution for the energy producers. Besides that, some energy producers see themselves become aggregators in the future as well.

TSO (Transmission System Operator)



One of the key tasks of a TSO (TenneT in the Netherlands) is to ensure a secure and continuous supply of electricity (TenneT, 2019b). As said before, this task is hampered by the further integration of renewables in the electricity grid. V2X could be a helpful tool to accomplish this task but is not considered as more promising than other innovative technologies at TenneT.

Knowledge institutions

Knowledge exchange is considered to be very important to make an innovation successful (Hekkert, Suurs, Negro, Kuhlmann, & Smits, 2007). By sharing knowledge and research some issues regarding V2X, e.g. battery degradation, could be resolved. Several universities (of applied sciences) are researching several aspects of V2X technology.

Municipality/province

A lot of charging points are public and installed on behalf of the local municipality. Municipalities could therefore play a major role in the fast adoption of V2X chargers. Besides that, municipalities could sometimes work around national legislation in so called 'living labs' (proeftuinen in Dutch) in order to experiment with new technologies. An example of such a project is LomboXnet in Utrecht (LomboXnet, 2019).

3. Business Case

In this chapter the business case of V2X is described. The focus will be on Vehicle-to-Grid (V2G). As said before, with V2G the battery capacity can be used to interact with the electricity grid (Noel et al., 2019). The electricity market however contains several markets that can be traded on (Lampropoulos, 2014). First, it had to be identified which market has the most potential concerning the characteristics of an EV battery. Therefore, a short description of the electricity markets is given.

3.1 Electricity Markets

Consumers and generators in the electricity system are connected through the transmission and distribution grids. In the electricity system, supply must always equal demand in order to avoid black-outs. Whenever this is not the case, the frequency of the electricity grid (50 Hz in Europe) deviates. The electricity markets are also based on this principle and thus always focused on the grid balance (Erbach, 2016).

Electricity is already traded months and years ahead, on the so called 'forward' markets. One day before consumption, electricity is traded on the day-ahead market. At this day, the Balancing Responsible Party (BRP) has to make sure his portfolio of generation and demand is balanced and submit it to the TSO. On the day of delivery, electricity can be traded on the intra-day market. This is done to correct portfolios due to wind and solar forecasts but also power plant availability. With the increasing integration of renewables in the electricity mix, it is more difficult to predict supply. Imbalances could therefore occur more frequently.

So, whenever there is imbalance in the electricity system, the BRP is subject to the imbalance market. The imbalance market consists of reserves, which can be activated by the TSO (Schittekatte & Meeus, 2018). The imbalance price is based on the incremental prices that is paid in advance by the TSO in order to be able to provide the reserves all day (TenneT, 2016).

This seems to fit V2G since EVs are able to provide capacity continuously due to their fast response rate and the high availability. However, imbalances occur infrequently and, more importantly, require large amounts of energy which can drain batteries and therefore possible increase battery degradation. The overall fit for V2G to provide imbalance reserves is considered to be good, but not perfect (Noel et al., 2019).

Small changes in supply or demand could lead to deviations in the grid frequency. The restoration of the grid frequency is done via three different reserves, respectively Frequency Containment Reserves (FCR), automatic Frequency Restoration Reserves (aFRR) and manual Frequency Restoration Reserves (mFRR) (Lampropoulos, van den Broek, van der Hoofd, Hommes, & van Sark, 2018; Schittekatte & Meeus, 2018).

First, FCR are activated. These should be able to respond within 30 seconds after a deviation (TenneT, 2019a). Because the actual supply could be either too little or too much compared to the demand, reserves should be provided both from and to the grid. As a consequence, FCR is almost always needed. Besides that, FCR requires quick reactions and high-power capacity but limited energy capacities (TenneT, 2019a). All of which coincide with the advantages of EV batteries. FCR is thus considered to have the best fit for V2G.

aFRR is less optimal, since it does not require as fast reactions as FCR does (15 min compared to 30 seconds) and besides aFRR are less needed, requires higher energy capacities and have a higher bid size (Lampropoulos et al., 2018). mFRR are less suited, since they are activated manually.

3.2 Business case input

In order to calculate the potential earning from providing FCR with EVs, some estimations had to be made. First of all, three different scenarios are developed which simulate the availability of the EV battery during weekdays and during the weekend (respectively Figure 3 and 4).

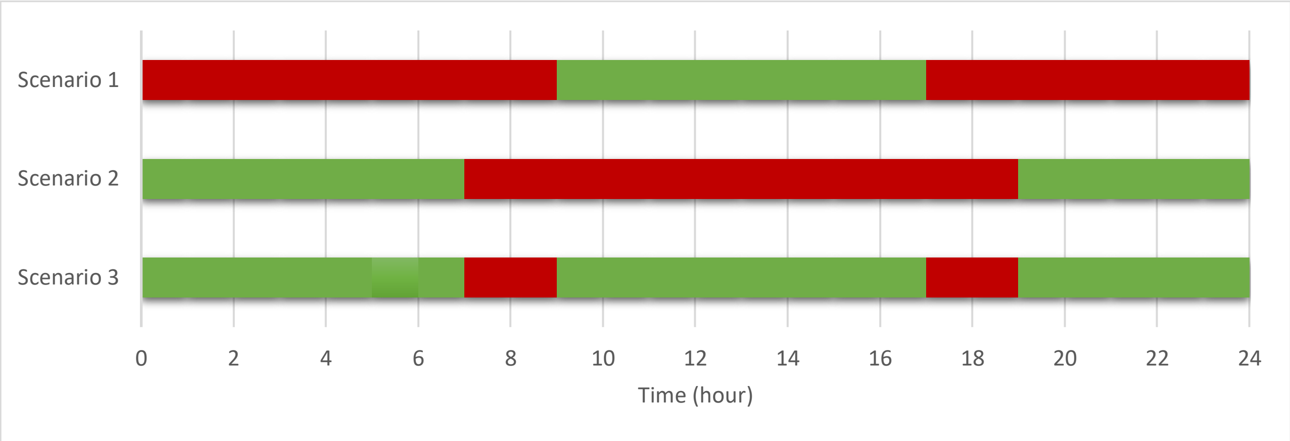


Figure 3: Car Availability during weekdays

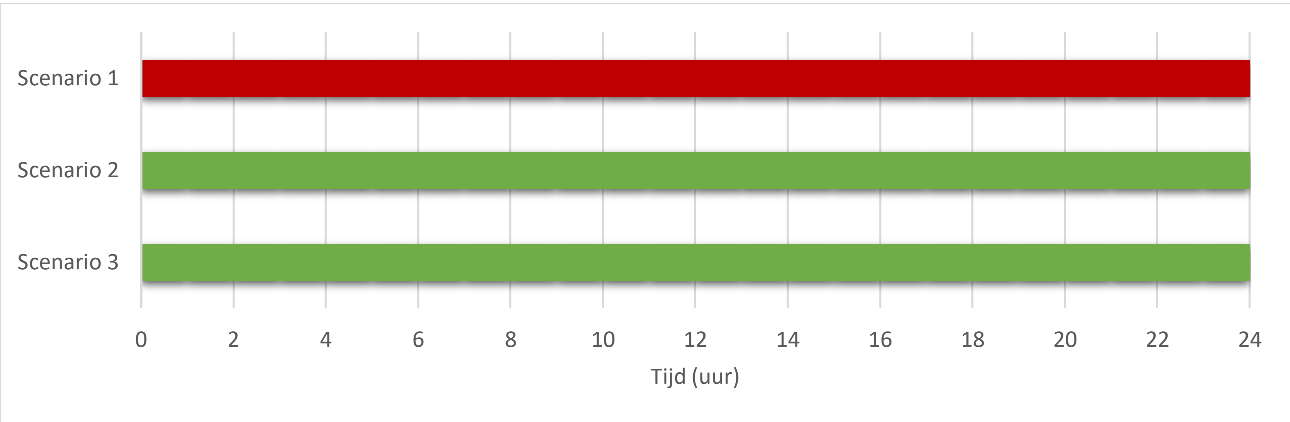


Figure 4: Car Availability during weekend

Scenario 1 refers to the case when bi-directional charging is only possible at work (destination charging), so charging could only happen during working hours (respectively 9:00 until 17:00) (Herron, 2017). In scenario 2, bi-directional charging is only possible at home (19:00 until 7:00) and scenario 3 is a combination of the other 2 scenarios, thus bi-directional charging is possible both at work and at home (Herron, 2017). Altogether, this leads to a yearly availability of 2080, 5616 and 7696 hours for respectively scenario 1, 2 and 3.

Another input value required to calculate potential revenues is the charging power. For this input value also three scenarios are developed (Table 1). In these scenarios also a correction factor for all other input values, e.g. car availability and FCR prices, is included. In the conservative scenario, power is estimated to be 3.7 kW. The minimal power from a 1-phase charging station. In the average scenario, power is estimated to be 11 kW and the optimistic scenarios assumes a power of 22 kW. The maximum power from a 3-phase charging point.

Table 1: Input Values V2G Business Case

	Conservative	*Average*	*Optimistic*
Power (kW)	3.7	11	22
Correction Factor (%)	30	20	10

Final input required are the FCR prices. FCR prices could be downloaded from regulleistung.net. Figure 5 shows the average bid prices in 2018. The average FCR price in 2018 was 13.78 €/MWh. In this study, only the potential revenues for 2018 are calculated. When researching a bigger time horizon, the development of FCR prices should be taken into account. FCR price developments are dependent on several factors, e.g. availability of gas and coal providers. The further adaptation of V2X could have a major impact on the FCR prices and thus on the business case for V2X as well.

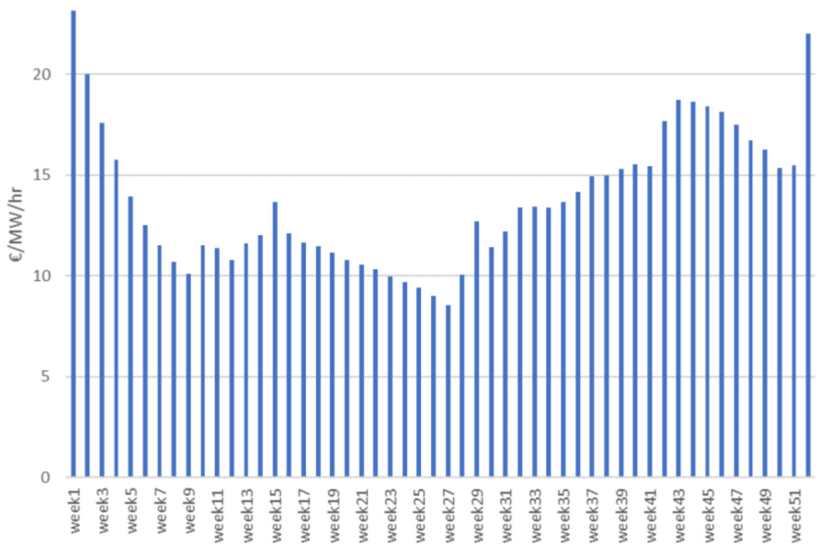


Figure 5: FCR prices (up- and downwards) in 2018 (regelleistung.net, 2019)

3.3 Business case results

When multiplying all the input variables, annual revenues from providing FCR could be calculated. Results are listed in Table 2. As can be seen, revenues vary from €75 in the most conservative situation until almost €2,100 in the most optimistic situation. Having the availability of charging with 22 kW both at work and home is however a bit unrealistic for now but is shows until what level revenues could rise in the future. Most realistic scenario for now seems to be charging with a power of 3.7 kW both at home and work. This results in a revenue of €275. If one of the two (home or work) has a 3-phase charge point, revenues could already rise up to €750. Important to consider is the fact that these are total revenue calculations. In practice revenue will be divided between all stakeholders, so revenues for the EV driver would be lower.

Table 2: Revenues from providing FCR per scenario for a single EV with V2X

	Scenario 1	*Scenario 2*	*Scenario 3*
Conservative	€ 74.24	€ 200.44	€ 274.67
Average	€ 252.23	€ 681.02	€ 933.25
Optimistic	€ 567.52	€ 1,532.29	€ 2,099.81

Another important aspect to consider is the extra cost of bi-directional charging compared to 'ordinary' charging. These costs consist of two major parts, charging point costs and battery degradation costs. As said before, costs of V2X charging points are still really high at this moment, since almost no charging points are on the market yet. Prices are however expected to decrease when the number of suppliers and demand increases. Battery degradation costs, could range from almost nothing until thousands of euros, depending on the battery degradation. This topic will be discussed in the next chapter.

4. Battery impact

4.1 Battery Studies

As described before, a lot of research is already done to the implementation of V2X. Battery degradation was however not often mentioned in this context, although it could have a large influence on the business case. The last few years battery degradation has become a more important part of V2X research. Conclusions from this research vary a lot. For this research all relevant studies of the last few years (since 2016) were analyzed. These studies were found by using scientific search engines (e.g. Google Scholar). In total 10 relevant studies were found. These studies were ranked amongst three categories, respectively 'Positive impact', 'Neutral impact' and 'Negative impact'. Were 'positive impact' indicates that V2X leads to less battery degradation compared to a situation without V2X. Neutral indicates V2X does not lead to significantly less or more battery degradation. If the studies conclude V2X leads to more battery degradation it is ranked as 'negative impact'. Result of this analysis is shown in Table 3 below. The identified studies and corresponding conclusions can be found in Appendix II.

Table 3: Summary Battery Studies

Total number of studies	*Positive impact*	*Neutral impact*	*Negative impact*
10	3	4	3

From Table 3 it can indeed be concluded that results from battery degradation research show a large variation. Some studies argue that V2X could lead up to 30% extra degradation of the EV battery during its life-time, whereas other studies argue that with a smart battery management system degradation could be limited or even decreased in an ideal situation. In order to understand this variation, it is necessary to have a simple understanding of battery degradation principles.

4.2 Battery Degradation

During operation the electrolyte in the battery is decomposed, which leads to battery degradation (more information about battery characteristics can be found in Appendix III). Battery degradation is a collective name which contains increasing resistance and decreasing battery capacity (Shi, Xu, Tan, Kirschen, & Zhang, 2017). In general, battery degradation can be split into two parts. Calendar aging, which refers to the degradation due to the time the battery is not used and cycling aging which refers to the degradation when the battery is used. In case of an EV, calendar aging occurs when the car is parked and not (dis)charged and cycling aging occurs when the EV is driven or (dis)charged.

Looking at the driver of both calendar and cycling aging, temperature and the State of Charge (SoC) have the largest impact on the State-of-Health (SoH) of the battery. SoC refers to the remaining battery capacity in percentage (0%-100%). Besides that, cycling aging is caused by the C-rate and Depth of Discharge (DoD) as well (see Figure 6). A C-rate is a measure of the rate at which the battery is (dis)charged relative to the maximum capacity of the battery (e.g. a 1C rate means that the current (dis)charges the battery in 1h). DoD is the opposite of SoC, so refers to the battery capacity that is used (0%-100%).

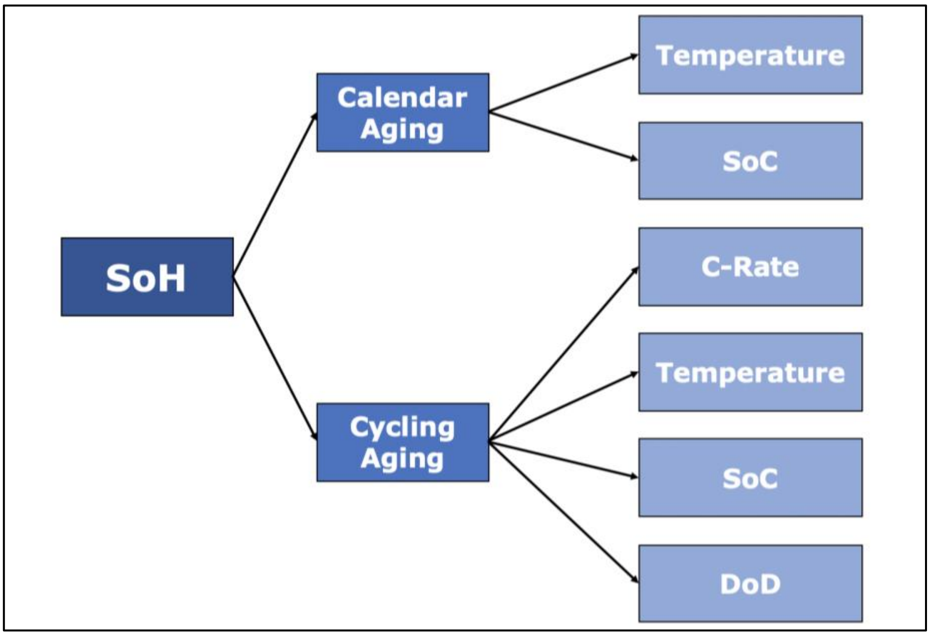


Figure 6: Diagrammatic representation of battery degradation (adapted from Thompson, 2018)

SoC is the main driver that could be influenced by V2X, since temperature is an external driver. In Figure 8 below the capacity decrease and resistance increase plotted over the SoC used for driving ($\Delta\, SoC_{Drive}$) and SoC used for V2X ($\Delta\, SoC_{V2G}$). The darker red the color is, the larger the battery degradation will be. From Figure 7 it can be noticed that at certain points the capacity fade and resistance increase could be lowered when the SoC used for V2X (($\Delta\, SoC_{V2X}$) is increased.

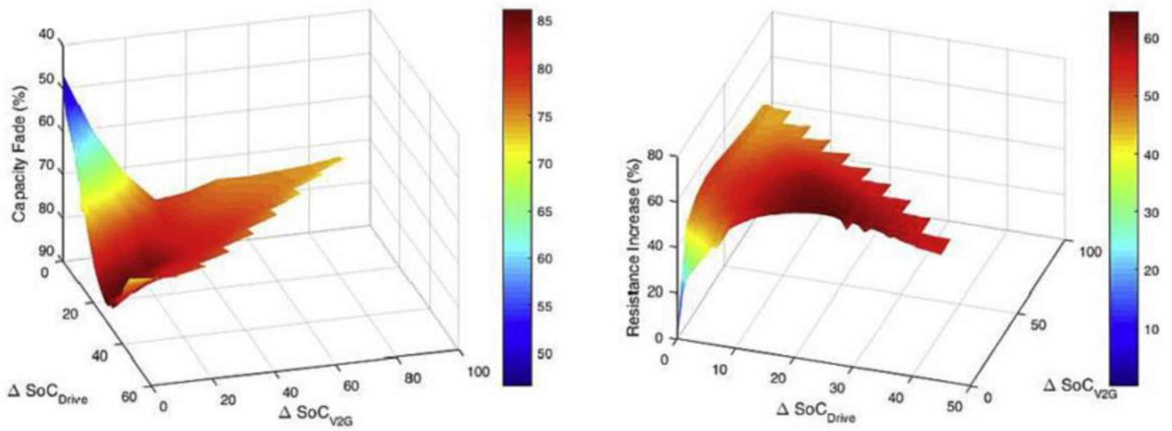


Figure 7: Impact of driving and V2X on the capacity reduction (left) and resistance increase (right) (Uddin et al., 2017)

Altogether, this provides an explanation for the variety in conclusions from the battery degradation studies. Battery degradation depends on several factors of which SoC has a main impact and can be influenced by V2X. Battery degradation occurs mostly at extreme SoC (< 20 % and > 80%). Together with a smart battery management system V2X could help to remain within these capacity limits and thus limit battery degradation and potentially even lead to less battery degradation compared to only driving an EV. Beyond these capacity limits, battery degradation increases and an extra battery cycle due to V2X could result in significant battery degradation. A smart battery management system is thus key to limit degradation, with or without V2X.

5. Legislation and policy

In 2017, PricewaterhouseCoopers (PwC) drew up a report, commissioned by the municipality of Utrecht and Stichting ElaadNL, about the legislation and the policy regarding smart charging (PWC, 2017b). Stichting ElaadNL is an initiative of the grid operators in the Netherlands and can be seen as the innovation and knowledge center in the field of smart charging infrastructure (ElaadNL, 2019). In this report the institutional bottlenecks for smart charging are described and updated to the current situation. Besides that, potential solutions are proposed. The seven most important bottleneck until 2020 are discussed below.

1. Missing incentive for using an EV to optimize electricity consumption behind the meter: EV drivers with solar panels are not financially stimulated to make optimal use of their home generated renewable electricity and the storage capacity of the EV behind the meter on behalf of their own peak demand. This results from the current netting arrangement (in Dutch: salderingsregeling). The incentive could have been created by replacing the netting arrangements by a feed-in subsidy. In April 2019, it however became clear that the current netting arrangement will be sustained until 2023 (Rijksoverheid, 2019b). The financial incentive therefore remains absent the coming years.
2. Possible double energy taxation for bi-directional charging: It seems every time an EV is discharged and recharged, energy tax should be paid over the charged kWh (PWC, 2017a). With the current netting arrangement this is not the case for private home charging. It is unclear which arrangement is in place for (semi-)public charge points. A possible solution is the adjustment of tax legislation, bi-directional charging should not be considered as a supply product anymore but should be considered as storage product for which no tax should be paid (RVO.nl, 2019).

3. No incentive to roll out EVSE with maximum charging capacity for smart charging: The higher the charging capacity, the faster an EV can be charged and the more flexibility can be generated for smart charging. A high capacity connection is however significantly more expensive. This results in primarily low capacity connections are installed for (semi-)public charge points (Koen, Afman, & Van, 2017).
4. Uncertain if smart charging could be used on behalf of the regional grid operator: the group ban in the electricity legislation does not allow regional grid operators to own storage capacity (Rijksoverheid, 2019a). Therefore, it is unclear if they are allowed to use the flexibility that is offered by EV battery capacity.
5. Possible incentive for the CPO to block smart charging from third parties: the main interest of the CPO (maximal occupation of charge points) in some cases derogates from the interest of other stakeholders. There is a risk that the CPO intervenes in the planned smart charging session in order to maximize the charge point occupation.
6. Uncertainty about who is able to enable the EV for smart charging: At this moment it is unclear who determines if the EV battery is enabled for smart charging (EVConsult, 2017). Besides that, it is unclear who is in charge, in the case that the customer is associated with multiple initiatives.
7. Risk of congestion[1] at the regional grid operator due to smart charging from third parties: usage of the battery capacity of EVs for smart charging could lead to congestion on the regional electricity grid (e.g. when all available cars simultaneously start (dis)charging).

[1] Congestion on the electricity grid occurs when the electricity supply exceeds the capacity of grid assets such as cables and transformers.

6. Conclusion

This research aimed at unraveling the potential and limitations of Vehicle-to-Everything (V2X) in the Netherlands. V2X refers to bi-directional charging of an electric vehicle (EV). Through bi-directionally charging an EV the share of renewable energy source in the mix can be enlarged, e.g. by peak shaving or renewable frequency reserves (Noel et al., 2019). Besides that, it could limit the need for grid reinforcements and support market optimization by trading with battery capacity on the electricity market, thus generating profits for the involved stakeholders (Grant, 2018). However, there are also some limiting aspects of this technology. This report sketches the current state of development of V2X in the Netherlands.

A stakeholder analysis was performed in order to identify all parties involved in this technology. It turned out that, there is a wide variety of stakeholders involved (car manufacturers until local governments and EV drivers until energy producers). During this research many of these stakeholders were interviewed in order to find out their view on V2X and how they see their role. It became clear several roles have to be development further in the coming years. Most important roles in the near future are expected to be the EV drivers, car manufacturers and aggregators.

This research also investigated the business case of V2X. As stated before, by trading with the battery capacity on the electricity market profits could be made. It turned out, the frequency containment reserves (FCR) market has a good fit for V2X. It is always almost needed, requires quick reactions and requires high powers but limited amounts of energy (TenneT, 2019a). In order to calculated annual earnings, three availability- and three power scenarios were developed. This resulted in annual profits varying from just €75 in the most conservative scenario up to just over €2000 in the most optimistic scenario. At this moment of time, annual profits between €250 and €700 seem to be a realistic estimation. Important to consider is that these are total earnings, so they would have to be shared amongst all stakeholders involved. This would result in lower earnings for the EV drivers.

Battery degradation seems to be a major factor limiting the potential of V2X technology. Recently, V2X became a hot topic in scientific literature. In this research ten different studies were analyzed (Appendix II). Conclusions showed a wide variety. It turned out that battery degradation could be split into calendar aging and cycling aging (Thompson, 2018). Both types of aging are influenced by State-of-Charge (SoC) and temperature. Literature shows that in some scenarios an extra decrease in SoC due to V2X could lead to less calendar aging and thus less battery degradation, while in some situation this extra decrease could increase battery degradation (Uddin et al., 2017). However, it seems fair to assume that with a smart battery management system (BMS) the extra degradation due to V2X could be limited.

Finally, the current policies are examined in order to identify institutional bottlenecks. In total seven bottlenecks were identified (PWC, 2017b). Many of these result from a lack of incentives. At this moment there is no incentive for using an EV to optimize electricity consumption behind the meter at household. In other words, it is not profitable to store energy from solar panels in order to use it during peak hours. This is due to the current netting agreement (in Dutch: salderingsregeling) (Rijksoverheid, 2019b). Besides that, an incentive is missing to roll out electric vehicle supply equipment (EVSE) with maximum charging capacity.

Altogether, it can be concluded that V2X has a lot of potential. Due to current institutional bottlenecks, Vehicle-to-Home will not be adopted on a large scale the coming years. Vehicle-to-Building behind the meter is expected to be the first commercial application of V2X, since it is not limited by these bottlenecks. Furthermore, Vehicle-to-Grid is currently in the pilot phase, with several pilot projects around the Netherlands. These projects could proof the potential of V2X in a real-world situation. A larger supply of V2X enabled EVs is however expected to be crucial in order to apply V2G on a larger scale. In order to convince car manufacturers, the impact of V2X on battery degradation should be investigated extensively in realistic situations.

Bibliography

ACM. (2019). *Verkenning naar belemmeringen voor de rol van aggregator*.

Ahmadian, A., Sedghi, M., Mohammadi-ivatloo, B., Elkamel, A., Aliakbar Golkar, M., & Fowler, M. (2018). Cost-Benefit Analysis of V2G Implementation in Distribution Networks Considering PEVs Battery Degradation. *IEEE Transactions on Sustainable Energy*, *9*(2), 961–970. https://doi.org/10.1109/TSTE.2017.2768437

Alanne, K., & Saari, A. (2006). Distributed energy generation and sustainable development. *Renewable & Sustainable Energy Reviews*, *10*(6), 539–558. https://doi.org/10.1016/j.rser.2004.11.004

Alvarez, S. (2018). Tesla may revisit vehicle-to-grid (V2G) bi-directional charging solution. Retrieved 12 June 2019, from https://www.teslarati.com/tesla-may-revisit-vehicle-to-grid-v2g-bi-directional-charging-solution/

Baloglu, U. B., & Demir, Y. (2017). Economic Analysis of Hybrid Renewable Energy Systems with V2G Integration Considering Battery Life. *Energy Procedia*, *107*, 242–247. https://doi.org/10.1016/J.EGYPRO.2016.12.140

BYJU'S. (2019). Types of batteries - Primary & Secondary cells. Retrieved 23 May 2019, from https://byjus.com/chemistry/battery-types/

Center for Automotive Research. (2019). Vehicle to Building Interaction. Retrieved 12 June 2019, from https://car.osu.edu/research/v2b

Dubarry, M., Baure, G., & Devie, A. (2018). Durability and Reliability of EV Batteries under Electric Utility Grid Operations: Path Dependence of Battery Degradation. *Journal of The Electrochemical Society*, *165*(5), A773–A783. https://doi.org/10.1149/2.0421805jes

Dubarry, M., Devie, A., & McKenzie, K. (2017). Durability and reliability of electric vehicle batteries under electric utility grid operations: Bidirectional charging impact analysis. *Journal of Power Sources*, *358*, 39–49. https://doi.org/10.1016/J.JPOWSOUR.2017.05.015

ElaadNL. (2019). Home - Elaad NL. Retrieved 14 June 2019, from https://www.elaad.nl/

Erbach, G. (2016). *Understanding electricity markets in the EU*. *European Parlimentary Research Service*. https://doi.org/10.1186/1477-7525-8-144

Erden, F., Kisacikoglu, M., Kisacikoglu, M. C., & Erdogan, N. (2018). Adaptive V2G Peak Shaving and Smart Charging Control for Grid Integration of PEVs. https://doi.org/10.13140/RG.2.2.22736.97280

EVConsult. (2017). *Laadinfrastructuur in de private gebouwde omgeving*. Retrieved from https://www.evconsult.nl/wp-content/uploads/2018/01/Laadinfrastructuur_in_de_private_gebouwde_omgeving.pdf

Gaton, B. (2018). V2G: What’s the state of play with vehicle-to-grid, vehicle-to-home technology? Retrieved 12 June 2019, from https://thedriven.io/2018/10/19/v2g-whats-the-state-of-play-with-vehicle-to-grid-vehicle-to-home-technology/

Grant, T. C. S. (2018). 5 Ways Electric Vehicles Can Help The Grid. Retrieved 12 June 2019, from http://electricschoolbuscampaign.org/5-ways-electric-vehicles-can-help-grid/

Han, S., Han, S., & Sezaki, K. (2010). Development of an Optimal Vehicle-to-Grid Aggregator for Frequency Regulation. *IEEE TRANSACTIONS ON SMART GRID*, *1*(1), 65. https://doi.org/10.1109/TSG.2010.2045163

Hekkert, M. P., Suurs, R. A. A., Negro, S. O., Kuhlmann, S., & Smits, R. E. H. M. (2007). Functions of innovation systems: A new approach for analysing technological change. *Technological Forecasting and Social Change*, *74*(4), 413–432. https://doi.org/10.1016/J.TECHFORE.2006.03.002

Herron, D. (2017). Electric vehicle charging scenarios. Retrieved 14 June 2019, from https://greentransportation.info/ev-charging/range-confidence/chap3/3-ev-charging-scenarios.html

Hesse, H., Schimpe, M., Kucevic, D., & Jossen, A. (2017). Lithium-Ion Battery Storage for the Grid—A Review of Stationary Battery Storage System Design Tailored for Applications in Modern Power Grids. *Energies*, *10*(12), 2107. https://doi.org/10.3390/en10122107

Izumi, T., Hirota, M., Hatanaka, K., Isoyama, Y., Sano, K., & Takayama, K. (2014). Bidirectional charging unit for vehicle-to-X (V2X) power flow. *SEI Technical Review*, (79), 39–42. Retrieved from https://pdfs.semanticscholar.org/8e52/933dd2a0d63d0850287ceba0c22ba34144db.pdf

Jafari, M., Gauchia, A., Zhao, S., Zhang, K., & Gauchia, L. (2018). Electric Vehicle Battery Cycle Aging Evaluation in Real-World Daily Driving and Vehicle-to-Grid Services. *IEEE Transactions on Transportation Electrification*, *4*(1), 122–134. https://doi.org/10.1109/TTE.2017.2764320

Koen, A., Afman, M., & Van, A. G. (2017). Uitbreiding publieke laadinfrastructuur tot 2020.

Lampropoulos, I. (2014). *Energy management of distributed resources in power systems operations*. *2014 IEEE 5th Colombian Workshop on Circuits and Systems (CWCAS)*. https://doi.org/10.1109/CWCAS.2014.6994607

Lampropoulos, I., van den Broek, M., van der Hoofd, E., Hommes, K., & van Sark, W. (2018). A system perspective to the deployment of flexibility through aggregator companies in the Netherlands. *Energy Policy*, *118*, 534–551. https://doi.org/10.1016/j.enpol.2018.03.073

Liu, L., Liu, T., Zhang, T., & Liu, J. (2016). *Orderly charging and discharging strategy optimization for electric vehicles considering dynamic battery-wear model* (Vol. 40). https://doi.org/10.7500/AEPS20150324001

LomboXnet. (2019). Primeur in Utrecht: eerste stad ter wereld met stadsbreed netwerk van publieke laadpalen die kunnen laden én ontladen. Retrieved 27 May 2019, from http://www.lomboxnet.nl/smart-solar-charging/primeur-in-utrecht-eerste-stad-ter-wereld-met-stadsbreed-netwerk-van-publieke-laadpalen-die-kunnen-laden-en-ontladen

Mwasilu, F., Justo, J. J., Kim, E. K., Do, T. D., & Jung, J. W. (2014). Electric vehicles and smart grid interaction: A review on vehicle to grid and renewable energy sources integration. *Renewable and Sustainable Energy Reviews*, *34*, 501–516. https://doi.org/10.1016/j.rser.2014.03.031

NewMotion. (n.d.). V2G maakt plaats voor V2X. Retrieved 12 June 2019, from https://newmotion.com/nl_NL/v2g-maakt-plaats-voor-v2x

Noel, L., Zarazua, G., Rubens, D. E., Kester, J., & Sovacool, B. K. (2019). *Vehicle-to-Grid A Sociotechnical Transition Beyond Electric Mobility*. Retrieved from http://www.palgrave.com/gp/series/14966

Payne, G., & Cox, C. (2019). *Understanding the True Value of V2G*. Retrieved from https://www.cenex.co.uk/wp-content/uploads/2019/05/True-Value-of-V2G-Report.pdf

PWC. (2017a). *Fiscale barrières voor Smart Charging*. Retrieved from https://www.elaad.nl/uploads/files/Fiscale_barrieres_voor_Smart_Charging_PWC_voor_ElaadNL.pdf

PWC. (2017b). *Smart charging van elektrische voertuigen: Institutionele knelpunten en mogelijke oplossingen*.

regelleistung.net. (2019). Ausschreibungsübersicht. Retrieved 14 June 2019, from https://www.regelleistung.net/ext/tender/

Rijksoverheid. Elektriciteitswet 1998 (2019). Retrieved from https://wetten.overheid.nl/BWBR0009755/2019-01-01

Rijksoverheid. (2019b). Salderingsregeling verlengd tot 2023. Retrieved from https://www.rijksoverheid.nl/actueel/nieuws/2019/04/26/salderingsregeling-verlengd-tot-2023

RVO.nl. (2019). Nationale Agenda Laadinfrastructuur, 47. Retrieved from https://www.klimaatakkoord.nl/documenten/publicaties/2019/01/08/achtergrondnotitie-mobiliteit-laadinfrastructuur

Schittekatte, T., & Meeus, L. (2018). *INTRODUCTION TO NETWORK TARIFFS AND NETWORK CODES FOR CONSUMERS, PROSUMERS, AND ENERGY COMMUNITIES*. https://doi.org/10.2870/934379

Shi, Y., Xu, B., Tan, Y., Kirschen, D., & Zhang, B. (2017). Optimal Battery Control Under Cycle Aging Mechanisms in Pay for Performance Settings. Retrieved from http://arxiv.org/abs/1709.05715

TenneT. (2016). *The Imbalance Pricing System*. Retrieved from https://www.tennet.eu/fileadmin/user_upload/Company/Publications/Technical_Publications/Dutch/imbalanceprice_3.6_clean_.doc.pdf

TenneT. (2019a). *FCR Manual for BSPs*. Retrieved from https://www.tennet.eu/fileadmin/user_upload/SO_NL/FCR_-_Handbook-FCR-voor-BSPs.pdf

TenneT. (2019b). Security of supply. Retrieved 23 May 2019, from https://www.tennet.eu/our-key-tasks/security-of-supply/security-of-supply/

Thingvad, A., & Marinelli, M. (2018). Influence of V2G Frequency Services and Driving on Electric Vehicles Battery Degradation in the Nordic Countries. In *Evs31 & EVTeC 2018*. Retrieved from http://orbit.dtu.dk/en/publications/influence-of-v2g-frequency-services-and-driving-on-electric-vehicles-battery-degradation-in-the-nordic-countries(d5c40721-639d-4bdf-8559-a51f505cedea).html

Thompson, A. W. (2018, August 31). Economic implications of lithium ion battery degradation for Vehicle-to-Grid (V2X) services. *Journal of Power Sources*. Elsevier. https://doi.org/10.1016/j.jpowsour.2018.06.053

Uddin, K., Jackson, T., Widanage, W. D., Chouchelamane, G., Jennings, P. A., & Marco, J. (2017). On the possibility of extending the lifetime of lithium-ion batteries through optimal V2G facilitated by an integrated vehicle and smart-grid system. *Energy*, *133*, 710–722. https://doi.org/10.1016/J.ENERGY.2017.04.116

Varvasovszky, Z., & Brugha, R. (2000). A stakeholder analysis. *Health Policy and Planning*, *15*(3), 338–345. https://doi.org/10.1093/heapol/15.3.338

Wang, D., Coignard, J., Zeng, T., Zhang, C., & Saxena, S. (2016). Quantifying electric vehicle battery degradation from driving vs. vehicle-to-grid services. *Journal of Power Sources*, *332*, 193–203. https://doi.org/10.1016/J.JPOWSOUR.2016.09.116

Zecchino, A., Thingvad, A., Andersen, P. B., & Marinelli, M. (2019). Test and Modelling of Commercial V2G CHAdeMO Chargers to Assess the Suitability for Grid Services. *World Electric Vehicle Journal*, *10*(2), 21. https://doi.org/10.3390/wevj10020021

Appendix I: List of interviewees

Company/organization	Name	Function
Vereniging Elektrische Rijders (VER)	Maarten van Biezen	Boardmember
Nissan BeNeLux	Renke Barendrecht	EV Network Specialist
Renault Nederland N.V.	Jaap van Tiggelen	Manager Public Affairs
Jedlix B.V.	Jorg van Heesbeen	Head of New Energy Business
Engie Infra & Mobility B.V.	Arjan van Velzen	EV Consultant
Koninklijke RAI Vereniging	Wout Benning	Policy Adviser Sustainability & Technology
ElaadNL	Bram van Eijsden	Innovation and Development
Dutch Organisation for Electric Transport (DOET)	Michel van Lindert	Managing Director
Picnic	Amy Klein	Fulfilment Analyst
Alfen B.V.	Wouter de Ridder	Business Unit Manager Alfen Charging Equipment
TenneT	Emma van der Veen	Policy Advisor System Operations – System Services
Municipality Utrecht	Matthijs Kok	Developer New Energy and Electric Transport

Appendix II: Battery studies

Article	Author	Impact on battery SoH
Cost-Benefit Analysis of V2G Implementation in Distribution Networks Considering PEVs Battery Degradation	(Ahmadian et al., 2018)	Positive
Economic implications of lithium ion battery degradation for Vehicle-to-Grid (V2X) services	(Thompson, 2018)	Positive
Influence of V2G Frequency Services and Driving on Electric Vehicle Battery Degradation in the Nordic Countries	(Thingvad & Marinelli, 2018)	Neutral
Durability and reliability of electric vehicle batteries under electric utility grid operations: Bidirectional charging impact analysis	(Dubarry, Devie, & McKenzie, 2017)	Negative
On the possibility of extending the lifetime of lithium-ion batteries through optimal V2G facilitated by an integrated vehicle and smart-grid system	(Uddin et al., 2017)	Positive
Electric Vehicle Battery Cycle Aging Evaluation in Real-World Daily Driving and Vehicle-to-Grid Services	(Jafari, Gauchia, Zhao, Zhang, & Gauchia, 2018)	Negative
Durability and Reliability of EV Batteries under Electric Utility Grid Operations: Path Dependence of Battery Degradation	(Dubarry, Baure, & Devie, 2018)	Negative
Economic Analysis of Hybrid Renewable Energy Systems with V2G Integration Considering Battery Life	(Baloglu & Demir, 2017)	Negative
Quantifying electric vehicle battery degradation from driving vs. Vehicle-to-grid services	(Wang, Coignard, Zeng, Zhang, & Saxena, 2016)	Neutral
Orderly Charging and Discharging Strategy Optimization for Electric Vehicles Considering Dynamic Battery-wear Model	(Liu, Liu, Zhang, & Liu, 2016)	Neutral

Appendix III: EV Battery Characteristics

An EV battery consists of several electrochemical battery cells that are connected in parallel or series. By linking the battery cells in series, the batteries total voltage could be increases to desired levels, while linking battery cells in parallel results in higher capacities (Hesse, Schimpe, Kucevic, & Jossen, 2017). A battery cell consists of two electrodes, a positive and negative (respectively the cathode and anode) with an electrolyte between the two. Contact between the two electrodes is impossible due to a separator. In the case of EV batteries the electrolyte contains lithium. During (dis)charging ions flow from the cathode during the electrolyte to the anode and vice versa, while electrons flow externally in the other direction. Figure 8 gives an example of a simple battery cell.

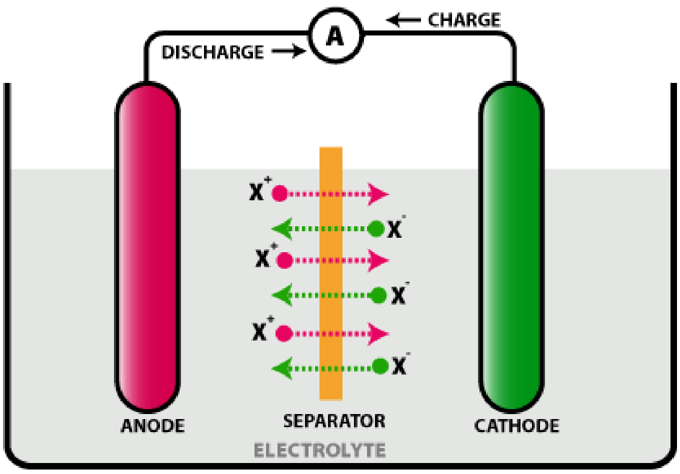


Figure 8: Simple electrochemical battery cell (BYJU'S, 2019)