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Financial Cost-benefit Analysis of Vehicle-to-Grid charging of Electric Vehicles at Schiphol Airport

Financial Cost-benefit Analysis of Vehicle-to-Grid charging of Electric Vehicles at Schiphol Airport

By

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Summary

Global warming has led to an increase in societal awareness and consequently the use of renewable energy. Electric vehicles (EVs) are gradually replacing fossil fuel driven vehicles. At the same time, consumption patterns of electricity fluctuate, leading to outages. To reduce outages, increase grid stability, and generate a small income for EV users, thus incentivizing the switch to EVs from fossil fuel cars, parked EVs can discharge electricity into the grid – a concept called Vehicle-to-Grid (V2G). Studies indicate that for such a V2G project to be feasible, transport hubs such as airports or train stations with many parking spots and long-parking durations are ideal locations. For an airport to invest in V2G it is important to know the net financial benefits and the risks. Hence, to check the financial feasibility of the V2G project, the Financial Cost Benefit Analysis (FCBA) may be used as it is one of the most widely used tools for such projects. Further, a risk analysis may be conducted.

The literature review shows that there are no specific FCBA studies or risk analyses for V2G projects at any transport hubs including airports. This study hence analyses the financial feasibility of V2G at Schiphol Airport. This airport is the largest in the Netherlands, with over 15,000 parking spots, and hence can be considered a suitable location for such a V2G project.

This study is undertaken from the perspective of the Airport. The primary research question is, "Under what set of conditions will a V2G project at Schiphol Airport, be commercially feasible?" Accordingly, the following two sub-questions are being answered: "Under what conditions is the Benefit-to-Cost ratio of the Financial Cost Benefit Analysis (FCBA) greater than one?"; and "What are the risks and their mitigation strategies associated with such a project?" The study does not include social costs such as the cost of power outages. Similarly, social benefits such as influencing owners of fossil fuel cars to switch to electric vehicles and use V2G, are not included.

The analysis uses a seven-year time-frame of January 2024 to December 2030. The objective is to help decision-making towards such a project.

The theoretical background of this study is based on the profit maximization theory which implies that Schiphol Airport will only invest in a V2G project if it is profitable for them. The key capital cost for Schiphol Airport is the cost of the V2G charger. Additionally, Schiphol Airport has to pay the EV owners a fee for their services, which is taken as a cost from the perspective of Schiphol Airport. The primary benefit is the revenue from the sale of electricity to the grid. The secondary benefit is the monetized value of carbon credits due to reduction of carbon dioxide emissions as seen in the table below.

There are four methods for generating the revenue from sale of electricity to the grid. *Firm Frequency Regulation (FFR)* is a mechanism by which the grid is made to function within a range of acceptable frequencies. An EV using V2G can be paid for offering frequency regulation on the frequency market. *Load leveling* involves charging the EV when the demand for electricity is low, and supplying when there is high demand. *Arbitrage* refers to buying electricity when it is less

expensive and selling when it is more expensive. *Peak shaving* means reducing charging when there is high demand for electricity.

The sources of data used to quantify the above costs and benefits include literature survey, and review of publicly available data on projected growth of EVs, electricity pricing, and V2G charging. Semi-structured interviews with domain experts in V2G, EVs and FCBA have been used to gain a practical perspective. For the modelling of the FCBA, two cases are defined, the Base Case, in which Schiphol Airport expands its unidirectional EV charging capacity, and the Project Case in which Schiphol Airport implements bi-directional charging to allow EV users to discharge electricity into the grid.

Based on the year-on-year growth of EVs and adoption of V2G by EVs, and Schiphol Airport's plans for decarbonization, the Base Case works with an expected increase in unidirectional chargers at Schiphol Airport, from the present 24 to 200, over a 7-year time frame. This is a very conservative number and is less than 2.5% of their existing parking slots. The Project Case, which is about adopting V2G, similarly works on the installation of 200 V2G chargers (which are bidirectional), and a conservative estimate of 30% of these being utilized by EV users. The study uses the Delta Method, i.e., modelling with the net difference between the Project Case and the Base Case.

In order to ensure that all relevant costs and benefits have been identified, an analysis of factors impacting adoption of V2G was next done. This analysis showed that indeed the relevant costs and benefits for the study had been identified. A schematic diagram was developed to show the interplay of these costs and benefits.

Assumptions for the study were listed, such as the life of a charger being ten years, the costs of V2G chargers progressively reducing by 10% of the previous year's cost every year, and no additional cabling costs in the Project Case as Schiphol Airport plans to install EV chargers at the same power capacity as per the Base Case. The study calculates the Financial Benefit-to-Cost ratio under each of the four methods for generating revenue from the sale of electricity to the grid.

The results show that frequency regulation gives a benefit-to-cost ratio greater than one. The costs, benefits, and benefit-to-cost ratio in this case is shown below. The results in the other cases are provided in Chapter 7.

Sr. No.	Item description	Value (in thousand euros)	Explanation
A	**Cost Items**		
(a)	Purchase cost (including warranty) of bi-directional chargers	409	Calculated as Euros 3000 per bidirectional charger * number of chargers installed each year @ 50 in year one and 25 in subsequent years, with an NPV at 12% for 7 years
(b)	Fee cost (to pay a monetary award to the EV user)	1,171	20% of FFR revenues are paid to the EV user as incentive
	Total cost	**1,580 ≈ 1600**	
B	**Benefits**		
(a)	FFR revenues	5,857	Euros 37,597.92 per car per year * number of chargers available each year * NPV for 7 years at 12% at 30% utilization rate

(b)	CO_2 equivalent	22	Calculated at 0.09 Euros per kg of carbon reduction, leading to -Euros 16 per car per year -Euros 3,202.11 for 200 cars per year -Euros 22,414 for 200 cars for 7 years
	Total benefit	**5,879 ≈ 5900**	
C	**Derived values**		
(a)	Net benefit (Total benefit – total cost)	4,299	
(b)	**B/C ratio**	**3.7**	**5,900/1,600**

The results of the modeling indicate that the use of FFR to calculate revenue from sale of electricity gives a Benefit-to-Cost ratio of 3.7, while the ratios are 0.4, 0.1 and 0.08 for load leveling, arbitrage and peak shaving, respectively. Further, independent of the use of FFR, the other conditions that determine commercial feasibility are: a revenue of 1.28 Euros per car per day is the threshold "make or break" value that needs to be generated to ensure the recovery of costs incurred by Schiphol Airport, and a minimum V2G utilization of 135 cars at 7.4 kilowatts each, to fulfil the statutory requirement of a minimum 1 Megawatt of power in case of use of FFR. Charger costs are a significant portion of the total costs for Schiphol Airport and hence have a high impact on the Benefit-to-Cost ratio. Given the very strong likelihood of falling costs due to technological development, and hence the Benefit-to-Cost ratio improving with time, this cost will continue to be important for Schiphol Airport to monitor but is unlikely to pose a threat in terms of financial feasibility of the project.

To answer the second sub-question about associated risks and suggest measures to mitigate the same, a risk analysis is done. The chief risks are the unwillingness of grid operators to pay for FFR services offered by Schiphol Airport, and the low adoption of V2G by EV users at Schiphol Airport. The study suggests collaboration with grid operators, awareness campaigns for EV users, incentivizing use of V2G, and working together with the government, to mitigate these risks. At the same time, given that the financial outlay for the Project Case of V2G is less than even 1% of Schiphol Airport's annual outlay for infrastructure and development, despite the risks, the project may be given the go-ahead.

The study concludes with the finding that the V2G project at Schiphol Airport is indeed financially feasible under the specific conditions of use of FFR, earning a minimum of Euro 1.28 per car per day and meeting the 1-Megawatt statutory requirement. This may be generalized to other airports outside of the Netherlands that have a similar scale, similarly profitable FFR markets and related regulations. Hence, it is recommended that Schiphol Airport may implement this V2G project. Further, to make the project successful, various suggestions are made, that Schiphol Airport can consider, such as temporary free parking to EV users using V2G as a short-term incentive – this would not be considered as a cost since it is suggested for a very short period and not for the entire seven years of the project. Similarly, the Airport may negotiate with electricity companies for favorable revenue rates, use the services of an aggregator to meet the 1-Megawatt requirement under usage of FFR, and work with the government for shaping policies of the above requirement.

Further, to address the above 1-megawatt statutory requirement under FFR Schiphol Airport can use its airport ground-vehicles under V2G. To address range anxiety concerns of EV users, it can use EV users' data to finetune the algorithms for charge and discharge of EVs at the Airport. This will improve the likelihood of V2G adoption.

Future areas of research may improve the accuracy of this study by using in-house proprietary data of Schiphol Airport, related to parking, charging patterns of EVs, patterns of occupancy through the week, etc.

Thus, this study is a small yet material value-add to the study of the V2G ecosystem, supporting its usage for transport hubs, and hopefully paving the way for future research and decision-making in real-life projects.

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List of Abbreviations and Terminology

- CBA: Cost Benefit Analysis
- FCBA: Financial Cost Benefit Analysis
- CAPEX: Capital Expenditure
- EV: Electric Vehicle
- EVSE: Electric Vehicle Supply Equipment (i.e., the EV charger)
- FFR: Firm Frequency Regulation
- G2V: Grid to Vehicle (i.e., regular unidirectional charging)
- ICE: Internal Combustion Engine (-based vehicle)
- IOT: Internet of Things
- OPEX: Operating Expenditure
- V2G: Vehicle to Grid
- V2X: Vehicle to X (any output/load)
- NPV: Net Present Value
- SLES: Smart Local Energy Systems
- L-E matrix – Likelihood – Effect matrix

- The occasional use of "Schiphol" or "the Airport" is to be taken as synonymous with "Schiphol Airport".

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Chapter I – Introduction

1.1 Background

Climate change due to anthropogenic emissions is a major issue facing humanity that needs urgent and active action to reduce or mitigate its risks. To this effect, the European Union has clearly defined one of its Climate Target 2030 goals as reducing greenhouse gas emissions to at least 55% below 1990 levels by 2030 (European Commission, 2020). Further, as a signatory to the Paris Agreement and to combat climate change, the Dutch government wants to reduce the Netherlands' greenhouse gas emissions by 95% by 2050. These goals are laid down in the Climate Act on May 28, 2019 (Government of the Netherlands, 2023).

While there are multiple approaches and solution pathways for addressing the climate change issue, renewable-energy driven transportation, and a shift away from fossil fuel vehicles form a significant part of climate-related goals (Zhang et al., 2020) and therefore the solution space. The last decade has witnessed a significant surge in the usage of electric vehicles (EVs) (IEA, 2023).

1.2 Details of the Situation and Complication leading to likely Research Gap

In the first step, i.e., identifying the current situation, it is recognized that global warming is a reality. This has, especially over the last decade, resulted in an increasing share of renewables in the energy basket. Additionally in the field of mobility, there has been an upsurge in the use of electric vehicles (EVs) over the past decade.

The combination of the intermittent and unpredictable nature of renewable energy and the increasing demands on the grid has led to fluctuating consumption and production patterns. This in turn has caused issues including fluctuations in electricity pricing and unpredictable loads on the grid (Moody's, 2023). This issue is particularly exacerbated and is expected to get worse due to an increase in the number of simultaneously charging EVs (Brigham, 2023). This is because electricity grids have been designed for average household levels of electricity consumption, while a charging EV consumes a lot of power – so much so that a fast-charging EV can take several times more power than the average house. To compensate for this, significant investments to the electricity grid are required. For example, for the US state of California alone, around 50 billion USD is expected to be required by 2035 to meet its EV targets (St John, 2023). In addition, mandates for encouraging the use of EVs have become more popular internationally, and consequently, the total number of EVs is expected to continue. Hence, the total required power for charging all EVs will increase, but so will the total stored energy in all EVs.

It is theoretically possible to turn this potential problem or challenge into an opportunity instead, and it is through a technology called V2G. However, based on research, it is found that this technology is not yet part of a commercially established ecosystem. The concept of using V2G to help energy systems in the future is certainly not new or unstudied. As noted by Dik et al. (2022) and Noel et al. (2019), V2G technology, smart grids, and better battery management systems play a key role in energy management, while simultaneously working towards decarbonization. There has been recognition of V2G at the level of energy companies as well. In its 2017 report "Future

Energy Scenarios", the National Grid Company, of the UK, describes an imminent "energy revolution" and the need for flexible energy systems, with V2G as one of the feasible solutions for addressing the rising demand for power in a decarbonizing world. Thus, V2G is as an inevitability (Interview 1). Hence it is clear that this is a topic worth researching.

In particular, long-term parking is uniquely beneficial to V2G, as the ability to use V2G requires the car to be parked, and being parked for long periods of time ensures stability and predictability of V2G service(s)' availability. Long-term parking is defined as parking for over 48 hours as per Schiphol Airport, and this definition has been used for this study. Locations like airports with a large number of cars parked for days make it ideal, as V2G services scale linearly with available capacity, which can be considered as the number of cars times the hours available.

However, based on the literature study done (described in detail in Chapter 3), it is seen that while there are many research papers on the topic of V2G, and some studies of V2G at airports, there appears to be no research done in the area of V2G for long term parking in airports. This complication leads to the likely Research Gap.

1.3 V2G, V2X, and Allied Systems: An Overview

V2G, or Vehicle to Grid, is a technology which allows transfer of power from an electric vehicle to the energy grid. This is achieved by connecting it to a V2G-enabled EV (dis)charging station via a cable, much like charging the EV. This is technically possible because the battery in an EV is capable of discharging and providing power to not just the vehicle's motors, but also to any load connected to it. Thus, in a V2G system, an EV stores energy, and can return it to the electricity grid when needed. The car uses DC (Direct Current) power while the electricity grid uses AC (Alternating Current) power. A converter is therefore required in the charger.

The broader technology is called V2X, which stands for Vehicle to X ('X' referring to any electrical load). Hence Vehicle to Grid is a subset and specific implementation of V2X. Other examples of V2X include Vehicle to Home (V2H) or Vehicle to Load (V2L), where the EV may power a home or an external load, similar to the support of a power generator. In this thesis, only V2G has exclusively been studied while the other variations of V2L have not been covered, given its potential and likely eventual necessity.

1.4 Key advantages of V2G and rising demand for this technology

1.4.1 Advantages of V2G to general society

Use of the Vehicle-to-Grid (V2G) technology in general, through the implementations mentioned above, has the following distinct and broad advantages:

1. Reduction of grid loads by allowing EVs to "put back" electricity into the grid (White et al., 2011)

2. Financial benefits for the EV users or owners who use the V2G grid (Noel et al., 2018)
3. Reducing the need for grid expansion which may be otherwise required if EV owners were to use the grid only to charge their vehicles. (Parmar et al., 2020)
4. Reduction of carbon dioxide emissions by discouraging dependence on fossil-fuel vehicles and encouraging the use of Electric Vehicles (EVs) due to the points mentioned earlier (A. Ghosh, 2020)
5. Increasing grid stability in case of natural disasters such as storms
6. Contributor as an energy buffer to smart local energy systems (SLES)

The ability of an EV to discharge to the grid provides many benefits. For example, this ability can be helpful during temporary power demand peaks. During the February 2021 Texas storm and subsequent power outage, a series of failures took significant parts of the electricity grid offline and brought it very close to a complete collapse (Laregy, 2021). At this time, EVs could have provided power to houses (The Great Texas Freeze: February 11-20, 2021, 2023). Even though the eventual power requirement was much higher, due to cascading failures it may have been possible to use V2G to avoid the grid from getting too unstable in the first place, helping avoid such outages.

SLESs are energy systems designed for standalone islands or far-flung areas unconnected to the grid. V2G can provide a unique solution for such cases. On one hand, EVs require a lot of power to charge and can be a huge energy sink for microgrids producing their own power as mentioned by Rae et al., 2020. On the other hand, with V2G these EVs also offer the possibility to discharge to the local grid and provide an energy buffer to help deal with intermittent and unpredictable renewable energy production. Additionally, for drivers who drive between their microgrid and large cities daily for work, it is possible for them to "transfer" energy by charging in the city and discharging at home.

This thesis does not study V2G in the specific context of SLES, but rather studies the more broadly applicable use cases mentioned in section 1.3.

In order to understand the context of V2G's advantages in a better way, it helps to consider the average electricity consumption in households in The Netherlands. In 2022 the Dutch household average net supply of electricity was 2,210kWh as per the Dutch Bureau of Statistics, the CBS (Statistics Netherlands, 2023). This works out to a power consumption of 252 watts of average power. A car providing power using a 7.4kW V2G charger will therefore be able to power $7400/252 \approx 29$ homes. However, this is based on an average level of power consumption and not peak power, and is aggregated across households and time of day.

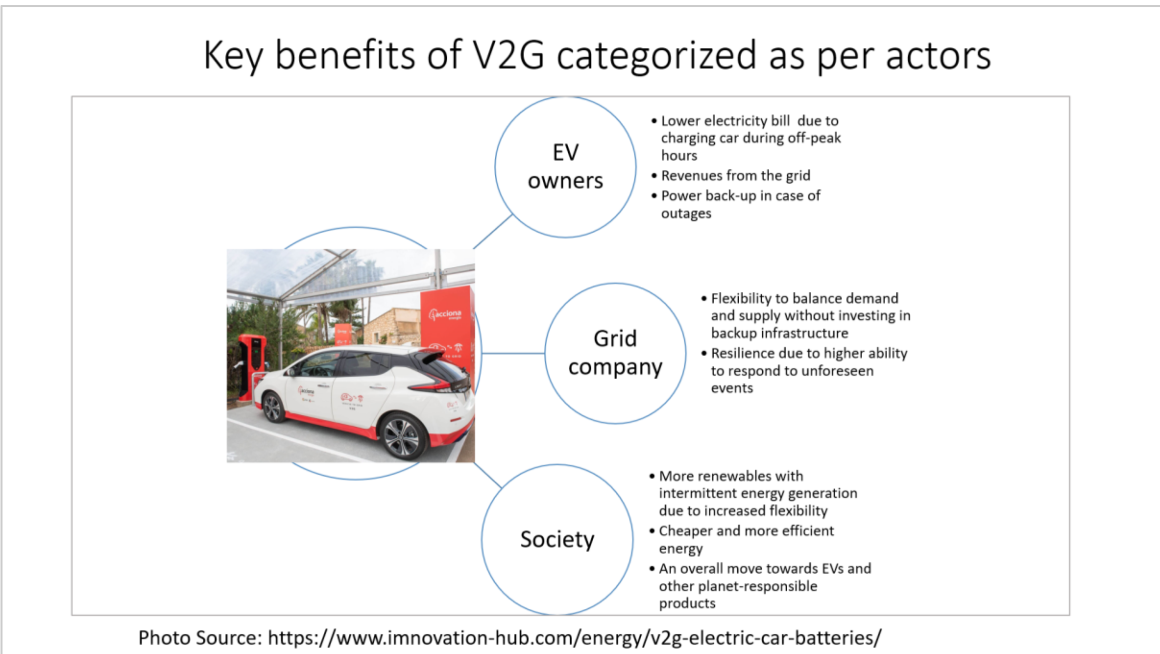
Thus, from the above, it is clear that V2G offers several benefits.

1.4.2 Analysis of Benefits of V2G through the lens of actors

As a socio-technical system, V2G involves multiple actors who can all receive different benefits. While a technical analysis to calculate financial/commercial feasibility/viability is important, it is also important to ensure that the technical system is supported by the various actors, and that they are all either favorable, or at least neutral to a new system. This is because people have a social inertia to new projects and endeavors. Social acceptance is much easier when actors individually benefit from proposed changes, as learnt in the "Managing Multi Actor Decision Making" course. Hence it is beneficial to classify the actors involved and the benefits they receive.

Key Actors in V2G: If the key benefits of V2G were to be categorized as per the actors, a representative diagram of the same would be as follows:

Figure 1 Key benefits of V2G, categorized by actors



1.4.3 Rising Demand for V2G

As shown by A Dik et al. (2022), given the growth rate of EVs combined with the stopping of ICEs, EVs are an eventuality. Thus, the growth of the V2G ecosystem is a "when", not an "if" (Interview 1). Hence studying V2G becomes more important, as the V2G technology smoothens out limitations of conventional one-way charging such as grid congestion.

Additionally, V2G is gradually being recognized as a major upcoming technology which is evident as global trends indicate greater interest in V2G technology supporting the study of this topic. The global V2G technology market size was valued at US$ 1.77 billion in 2021 and is expected to be worth around US$ 17.43 billion by 2027, recording a CAGR of 48% over the forecast period 2022 to 2027 (Precedence Research Report, 2020).

The role of V2G in decarbonization was succinctly expressed by Sovacool and Hirsch (2009), when they said:

The vehicle-to-grid (V2G) concept links two critically important technological systems–the electric power system and the petroleum-based transportation system–in ways that may address significant problems in both. By drawing on and supplying power to the power grid, electric vehicles could displace the use of petroleum and mitigate pollution and security issues related to oil extraction, importation, and combustion. It could also improve the economics and technical performance of the electric utility industry and generate revenue to owners of plug-in hybrid electric vehicles (PHEVs).

It may be mentioned that EVs and even V2G are a part of a wider set of associated systems that include car-sharing, battery-rentals, charging infrastructure, and generating electricity from renewable resources (Donada et al., 2015). While this study focuses solely on V2G, the other components of such associated systems are also expected to receive their fair share of focus as they progress in future.

1.5 The need for V2G at Airports as a part of the Identification of Research Gap

The existing research on V2G presents an interesting conundrum that leads to the research gap. V2G is a relatively well studied topic, as there are many research papers on it. However, while there is a lot of V2G research in general, and a few of V2G at airports, there are hardly any on the viability of V2G at airports. This is discussed in detail in Chapter 3. This is particularly relevant and important as airports, train stations, car parks, and such places have the potential to help cities transition towards the above climate goals, by offering V2G infrastructure for large numbers of EVs (Gordon, 2017).

Airports especially have a distinct and unique advantage when it comes to V2G implementation. An airport parking lot generally has many parked vehicles including both passenger vehicles and fleet rental vehicles, with a long "dwell time" for cars (Gordon, 2019). Additionally, the average duration of parked vehicles for travelers is high, relatively more predictable, and at all hours of the day and night, at airports compared to other places such as shopping malls or offices (Maigha, 2018).

Further, the aviation industry is classified as a key industry for tackling climate-change goals, in terms of three criteria, as per the EU Emissions Trading Systems: electricity generation, heat generation and energy-intensiveness (Alruwaili et al., 2022). Aviation is considered the second-largest source of transport Greenhouse Gas Emissions (GGE) (European Commission, 2020). By logical extrapolation hence, airports form an important part of these goals. Additionally, airports offer a higher potential towards multiple approaches in decarbonization, as they have the scope to not just implement V2G in their large car parks, but can also bring their Ground Support Equipment (GSE) into the bidirectional grid, and thereby ease grid congestion (Alruwaili et al., 2022). Hence, the capital expenditure involved in V2G can logically form part of a larger framework towards smart electrification.

This study includes the insights gathered in semi-structured interviews from domain experts from industries such as the automobile industry, consultancies and so on. One of the common forecasts of future trends in V2G-related progress is that of airports, railway stations, and large car parks emerging as "clusters" or "V2G hotspots", given the larger volumes of vehicles available for discharging energy into the grid, longer parking time, and ability of the entity (say, an airport) to invest in the capital expenditure required for such technology (Interview 1).

Hence, V2G offers many benefits but it also comes with costs. Because of the reasons explained above, airports seem favorable V2G spots. The study of V2G feasibility at airports is the identified knowledge gap, since such a study has not been done before.

1.6 V2G at Schiphol Airport

A specific focus on Schiphol Airport is taken to give practical relevance to the study, as Schiphol Airport is the largest in The Netherlands. The objective is to create a model which is potentially replicable and scalable for other such airports. The choice of Schiphol Airport, for this study is largely driven by the fact that this airport offers 15,000 parking slots (*Parking Schiphol*, n.d.). The Schiphol Airport City location has been one of the first locations in the Netherlands to test and develop novel concepts and methods in technology (Silvester et al., 2010). This combination of a high vehicular volume combined with high parking time is unique to large airports like Schiphol and gives it the above-mentioned advantage for V2G implementation.

Wider implementation of V2G at Schiphol Airport would help reduce greenhouse gases and help the country's climate control targets. Not just that, Schiphol could earn carbon credits which could potentially be monetized to reap financial benefits. So, V2G clearly represents an upside for Schiphol Airport.

1.7 The Perspective of the Study – Scoping it down to the perspective of Schiphol Airport

This study is undertaken from the perspective of Schiphol Airport, for several reasons. First, Schiphol Airport, it is an ideal location for such a V2G project, as explained above and hence the airport is the most logical actor from whose perspective an analysis of the project may be done. The airport is the only actor who can install the bidirectional chargers for the V2G project. Second, there are already two V2G chargers in Airport City (not in the Airport parking), demonstrating the intention of the Airport towards decarbonization goals, and their willingness to pilot V2G. Third, Schiphol Airport has declared their goal of being the most sustainable airport in the world by 2030 (Royal Schiphol Group, n.d.).

Finally, doing the study from the perspective of the Airport, as against, say, doing the study from the perspective of the government or society, implies using a more cautious approach, since several societal benefits such as pushing car owners from fossil fuel cars to EVs are ignored in the study. Ignoring such benefits and not quantifying them for inclusion leads to more conservative Benefit-to-Cost ratios. Hence this works as a more stringent test or filter for the project. Further, likely government incentives or subsidies for encouraging the use of V2G are not being considered.

1.8 Primary Research Question and Sub-Questions

Given the above-identified knowledge gap, the following is a vital question to answer: "To what extent is V2G implementation economically feasible at Schiphol airport?". This question can be well-answered using Financial Cost Benefit Analysis (FCBA). This knowledge gap is explained in greater detail in Chapter 3 Section 3.2.

Based on the above, the following primary research question is generated: **"Under what set of conditions will a V2G project at Schiphol Airport, be commercially feasible?"** Accordingly, this study is carried out solely from the perspective of Schiphol Airport.

To assess the commercial feasibility there are two sub-questions that need to be answered.

1. **"Under what conditions is the Benefit-to-Cost ratio of the Financial Cost Benefit Analysis (FCBA) greater than one?"**
2. **"What are the risks and their mitigation strategies associated with such a project?"**

By addressing this, the chances of success of the V2G project at Schiphol Airport are sought to be increased.

1.9 CBA in the context of Business Case analysis

Generally, when a company is considering a new project or initiative, they can conduct a business case analysis, or compare the new project with business as usual.

Typically, when a business enterprise debates over whether to implement a new project, a Business Case is prepared. Such a Business Case essentially establishes the justification for the proposed project or undertaking on the basis of its expected commercial benefits.

Alternative options are evaluated for a Business Case. Here, since the V2G initiative is not a fundamentally new project (it is only an extension of an existing project), the alternative simply is 'No action'. In other words, the alternative is the Base Case situation, wherein, till 2030, number of EVs in Schiphol's parking increases but there is no implementation of V2G. So, the test of 'comparing with an alternate project' cannot really be applied to this proposed V2G project.

Further, for a project evaluated using a Business Case, a 'Go' or 'No-Go' decision is finally taken by the Management. The chosen project, i.e., the one that finally wins the 'Go' decision from the management, becomes an eligible recipient of the company's budget. In this case, we are not looking to finalize on a 'Go' or 'No-Go' decision, rather one in which the set of conditions for financial viability of Schiphol are worked out. Schiphol Airport already has an articulated objective of aspiring to be the most sustainable airport in the world by 2030, which is a big driver for them to go for V2G implementation.

Hence, rather than doing a complete "Business Case" for this proposed project, a Financial Cost Benefit Analysis, which is a widely used assessment tool of a Business Case, is being carried out.

Figure 2 Progression of a Project Business Case

1.11 Link between this study and the CoSEM degree

EVs, and V2G by extension are socio-technical systems. V2G can be helpful in reducing carbon dioxide emissions, which is a direct societal benefit. While the core physical aspect of the system is engineering-based, V2G involves the direct involvement of public users, along with the cooperation and support of multiple actors and stakeholders - EV owners, EV manufacturers, electricity and grid operators, the government, the charging station provider, and the land owner. Additionally, to determine the feasibility/profitability of a V2G system requires an economic analysis involving social and hidden costs, and externalities; and the calculations for some of these require an engineering background. Hence such a study becomes multidisciplinary, and greatly benefits by being carried out by a CoSEM (Complex Systems Engineering and Management) student. Further, being as yet in a nascent stage, and being beneficial to the cause of climate change and society at large, V2G promotion at this early stage might require governmental support through policy decisions that encourage the usage of V2G. Policy interventions for technology promotion are a part of the CoSEM curriculum. Socioeconomics of future energy systems is a part of the CoSEM study. While CBA is socio-economic in nature, V2G is a future energy system. Hence, there is a high degree of linkage between this study and CoSEM.

1.12 Structure of this document

The outline of the following chapters of this thesis document is described below.

Figure 3 Flow of Document

As the introduction and rationale for studying this topic have been provided in Chapter 1, Chapter 2 starts with the literature study. It then shows the process of finding the knowledge gap and formulating the research question and the corresponding sub-questions. Chapter 2 frames the conceptual design of the study, describing the use of the FCBA, the linkage between V2G and economics, the four methods of calculation of electricity revenue, and studying the interplay of Schiphol Airport and the actors who would be associated with such a project in real life. Chapter 3 details the literature review, listing the various scholarly articles, as well as the semi-structured interviews used for gaining an understanding of the theme of this study. Chapter 4 describes the methodology, starting with the scope of this research, and then defining the base case and project case(s). Chapter 5 details which factors/costs/benefits are relevant and have been chosen for this study. In Chapter 6 all associated costs and benefits are first listed, then the relevant costs and benefits are quantified, the process of the financial cost benefit analysis is conducted and the assumptions are stated. Chapter 7 describes the results of the modeling, in terms of the Benefit-to-Cost ratios obtained under different methods of electricity revenue calculation. Chapter 8 discusses the possible risks that might be associated with this V2G project, along with certain specific as well as general strategies for risk mitigation. Chapter 9, the concluding chapter, explores the possible reasons as to why Schiphol Airport may not have implemented such a V2G project so far, and also enumerates multiple recommendations to the Airport, ending with the value-add that this study brings. The appendices A, B, C, and D have the details of the various factors impacting the adoption of V2G, Appendix E has interview transcripts with domain experts, and Appendix F has the details of modeling, the explanation of the choice of Nissan Leaf for determining relevant costs, and details of other costs that may be considered beyond the FCBA. This is followed by the references, with the details of scholarly papers as well as news articles related to this study.

Chapter II – Background Theory behind this study

2.0 Introduction

Building on the foundation of Chapter 1 which describes the potential for V2G, the unique positioning of Schiphol Airport for such a project, the research gap, and the research questions, this chapter develops the conceptual details of the model. This forms the basis of the rest of the study. The chapter begins with a description of the chosen framework for analysis, i.e. the Financial Cost Benefit Analysis. Following this, the linkage between V2G and economics is also briefly described. Next, the chapter studies the interplay between Schiphol Airport and the other actors who are involved in such a project. Finally, the chapter describes the four chosen methods of calculating revenue from electricity for the V2G project. Taken together, these create the conceptual model for the study.

2.1 The use of the Financial Cost Benefit Analysis (FCBA)

As mentioned in Chapter 1, the study uses the FCBA to model the Benefit-to-Cost ratio for the V2G project at Schiphol Airport. The reasons for this choice may be explained as part of the conceptualization of the study.

2.1.1 Profit Maximization Theory leading to the choice of FCBA as a tool

Profit maximization serves as a fundamental objective for commercial enterprises, aligning with the broader goal of enhancing value for shareholders. According to Carbaugh et al. (2011), one of the essential conditions for profit maximization is that marginal revenue (MR) must be at least equal to marginal cost (MC) (i.e., MR ≥ MC). By adopting a profit maximization approach, firms strategically aim to remain competitive by either increasing per-unit revenue, reducing per-unit costs, or employing a combination of both (Dey, 2009).

To achieve optimal profits, firms must simultaneously focus on revenue maximization and cost reduction. Revenue maximization involves maximizing revenue while maintaining costs at a certain level. This may involve intensifying marketing efforts, expanding services, and exploring new markets.

Historical theories suggest that profit maximization can be compatible with social goals or values (Wenders, 1972). Additionally, Cost-Benefit Analysis stands as a widely used tool for optimizing overarching values, such as company profits (van de Poel, 2009). Owing to this, there is a firm basis for considering reduced carbon emissions while modelling to conduct a Cost-Benefit Analysis for Schiphol Airport.

2.1.2 An explanation of the FCBA framework

The Financial Cost Benefit Analysis is one of the most widely used analytical frameworks globally to evaluate decisions related to public expenditure and infrastructure projects. The framework is said to have been first used in the 1930s in the western states of the United States of America, to evaluate expenditure on dams. The projects needed to be justified to taxpayers and the Congress; hence, the FCBA was used. Thus, the purpose of the tool is to help society help allocate scarce resources towards the right purpose. Two rules were used in this framework and continue to be relevant to date: If there are no constraints on inputs, then adopt projects that have net positive benefits, and, if there are projects that have constraints of any kind then choose a combination of projects by which the net benefits are maximized (J. E. de Steiguer, n.d.).

This gives a simple rule: if the Benefit-to-Cost ratio is greater than one (B/C >1) then the project may be given the go-ahead. In other words, this framework gives an indication of the economic efficiency of a project: Do the benefits outweigh the costs (Romijn and Renes, 2013)

Further, the FCBA compares the benefits and costs with the project, to the benefits and costs without the project (J. E. de Steiguer, n.d.). This allows the derivation of the Base Case and the Reference Case (Chapter 3). In other words, the framework allows a comparison of the two scenarios: what are the costs and benefits if the project is not done, i.e., Base Case, with, what are the costs and benefits if the project is done, i.e., Project Case.

2.1.3 The rationale for the use of FCBA for this study of V2G at Schiphol Airport

While there are many benefits of V2G infrastructure at an airport, policy-makers need to determine whether such implementation is economically worthwhile, in terms of the costs incurred, and the benefits gained. FCBA can be used as a tool to evaluate the economic impact of public expenditure choices, in general, by firstly helping policy-makers allocate limited resources and choose the most optimal option (Damart, 2009).

Finally, the use of the FCBA is endorsed by the domain experts interviewed for this study, who spoke about this tool being one of the most widely used methods to analyze the commercial feasibility of an infrastructure project (Interviews 2 and 3).

2.2 Theoretical Framework for V2G in Society – an Economics-based perspective

The various approaches towards decarbonatization often include a shift from easily available but polluting fossil fuels towards clean, renewable sources of energy. This therefore involves a shift from vehicles that use such fossil fuels, to those that run on cleaner sources of fuel. Since EVs and V2G represent long-term benefits to all sections of society but may not be natural choices of producers and consumers in the short run due to various factors, their pricing, taxation, and related policies would fall under the domain of public economics and the analysis of externalities, which in turn fall under the broader subject of welfare economics.

A transition from “dirty” fuels to clean fuels often needs economic incentives to push desirable behaviour on the part of consumers and producers, and economic disincentives, to discourage undesirable behaviour. This is because the earlier market models existed and thrived for decades, were based on factors such as product cost, product efficiency, etc. and did not include environmental sustainability as a key criterion for product choice. For example, a potential purchaser of a car would assess cost, speed, safety, need for maintenance etc. Emission norms would have rarely figured in the list of such a purchaser. Similarly, automobile manufacturers too would have responded with portfolios of various products based on consumer demand.

The shift from fossil fuel-driven cars to EVs has hence needed the boost of government-led initiatives including tax incentives, charging rebates, free night-time charging, etc., in many countries, in order to shift preferences of both, consumers as well as producers towards planet-responsible choices (Zheng et al., 2018). Such government-driven initiatives thus imply a change in the pricing of, say, electricity, based on who is using it and for what purpose.

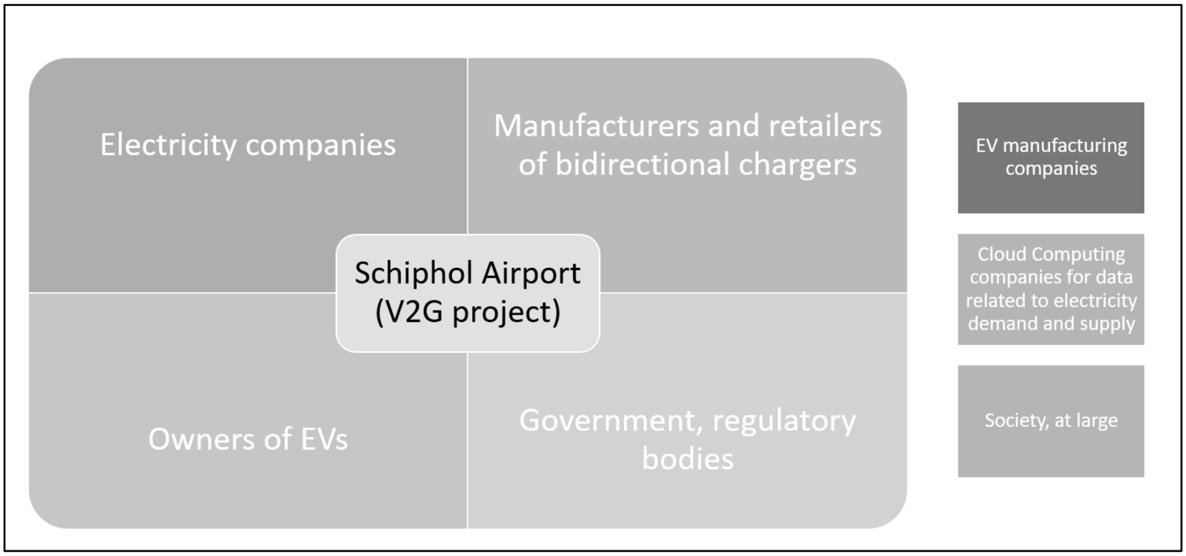
However, welfare economics states that maximum welfare for a society happens at the point of competitive equilibrium. This implies that any artificially induced reduction of costs or charges, or any incentives that are over and above market-driven prices, represent a Deadweight Loss (DWL), meaning, a net loss to society owing to trades that are not made, and also allocative inefficiency. At the same time, such initiatives are required. The government can hence use the equity-efficiency trade-off, so that there are more people who are net gainers or beneficiaries of such initiatives, and the aspect of DWL is therefore addressed. Given that EVs and V2G are a part of a wider ecosystem that benefits society as a whole, such a trade-off is necessary.

Further, it is helpful to analyze who the benefiting and losing out actors are in such a trade-off - especially at the relatively early stages of transition. For example, if an EV owner is incentivized into using V2G to ease grid congestion, and it is the government that decides to offset the bulk of incentives that are passed on to the EV owner, it would be a better choice than allowing the market equilibrium to decide how much of an incentive the grid company should pay the consumer for using V2G. While the latter would help in terms of efficiencies, the former would allow a measure of comfort to grid companies and therefore bring more such companies to the table for collaboratively working towards V2G systems. Once society has a large number of such companies as actors in the V2G domain, then market dynamics can be allowed to play a larger role as compared to government interventions.

2.3 The interplay between Schiphol Airport and other actors

This study is being undertaken from the perspective of Schiphol Airport, for reasons explained in Chapter 1. However, any V2G project involves the interplay between several actors, or entities who work in collaboration. The following are the key actors for this project, as seen in the diagram.

Figure 4 Interplay between Schiphol Airport and other actors



As seen in the diagram above, there are four chief actors, and two additional actors.

Chief Actors:

1. Manufacturers, distributors of bi-directional chargers
2. Owners of EVs
3. Electricity companies willing to buy electricity discharged by the batteries of EVs
4. The Government and regulatory bodies governing the laws of the land and current rules regarding electricity pricing, incentives for decarbonization, etc.

Secondary Actors:

1. Manufacturers of EVs
2. Cloud computing companies to real-time communication and data-sharing between the grid, Schiphol Airport, the charging system, and the EV owner

Society, at large, is the backdrop against which such a V2G project would take place. While it does not feature separately in the study, it is the very basis for the rationale of the study, as the entire V2G ecosystem is a part of decarbonization of fossil fuel vehicles, grid stability and EV owners being incentivized.

2.4 Various power discharge methods for V2G and related revenue generation

An FCBA has two aspects, namely, the benefits and the costs. These are chosen and quantified, and then the Benefit-to-Cost ratio is calculated. This V2G project has two distinct costs, which is the cost of the chargers, and the remuneration paid to the EV user – this is explained at length in Chapter 6. Benefits are primarily from the sale of electricity to the grid.

There are four ways to implement V2G. They have been explained in this section owing to their technical nature. As V2G generates revenue these coincidentally turn out to be the benefits. The following offers a detailed explanation with scientific research of these four methods, as chosen by Heilmann and Friedl (2021).

Revenue can be offered for grid services like ***frequency regulation***.

Frequency regulation of the grid is a method to ensure the balance of electrical supply and demand at all times. Frequency regulation entails the provider (in this case, an EV or a group of EVs) to absorb excess power, and provide power to compensate when it is insufficient. This is because when the produced power exceeds demands, the grid frequency increases, and similarly when the production is lower than the demand, the frequency drops (EPRI, n.d.).

While this process may sound like regular charging-discharging of an EV, frequency regulation is a grid service based on the amount of power that can be provided/absorbed and the time it is available for. The actual flow of electricity may or may not happen, depending on whether or not the grid requires it and the grid operator asks the EVs for the service. The frequency regulation provider offers bids on the European Frequency Regulation Market at a particular rate per hour per Megawatt. It is in a way a kind of guarantee or insurance, only being invoked, when necessary, but being paid for as long as it is offered, regardless of whether or not the grid uses it.

Additionally, the timescale of frequency regulation is in the order of tens of seconds to tens of minutes, unlike typical charging-discharging cycles which take hours. This also means that the EV batteries are only charged or discharged a small(er) amount, rather than to their full capacity. The bid duration is measured in hours; however, the grid almost always corrects its frequency within a few minutes.

Frequency regulation is considered to be one of the key potential contributions of V2G (Heilmann and Friedl, 2021), as the lithium-ion batteries in EVs suffer negligible degradation from being charged and discharged to a small degree when within the middle of their state of charge. (That is, charging an EV from 40% to 60% and discharging back to 40% causes several times lesser battery wear than charging from 0% to 100% and back to 0%.)

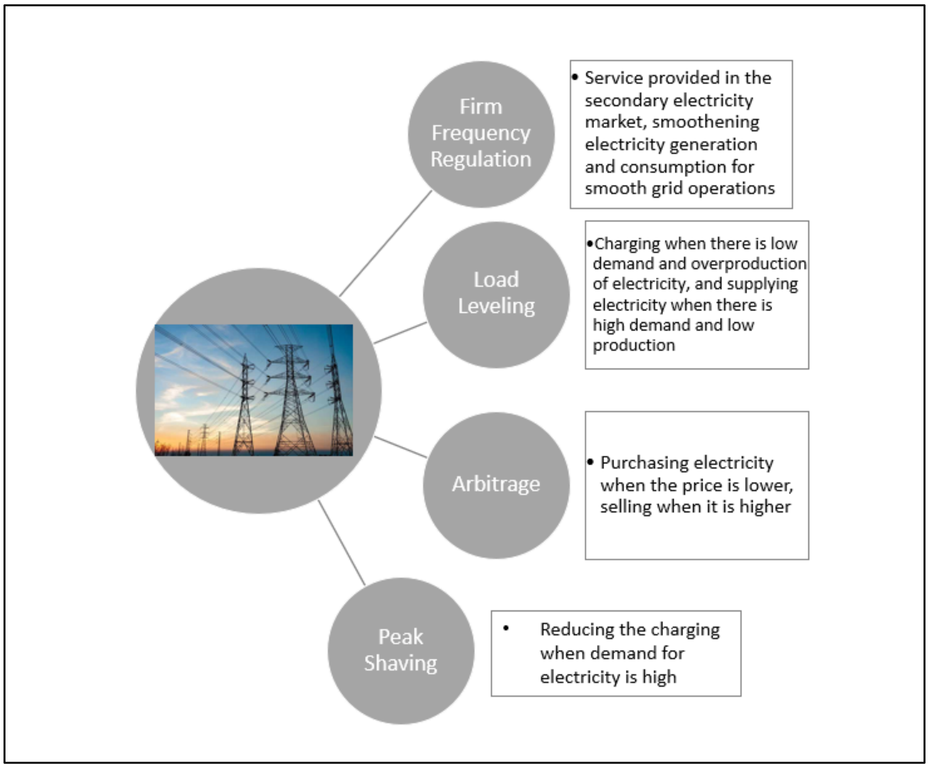
Similarly, ***load levelling*** emerges as another possible V2G application for revenue generation. It is defined as a method used to balance large fluctuations that occur in electricity demand by charging the battery during low load demand and overproduction; and discharging the battery when the grid requires it during high load demand (K. Ananda Rao et al., 2015). Unlike frequency regulation, the timescale of load levelling is longer, typically measured in minutes to hours. **Revenue is provided by the electricity grid in exchange for grid and price stability.**

Similarly, **in *peak shaving***, charging is reduced when demand for power and electricity prices are high. Such a system can provide economic benefits by mitigating the need to use expensive peak electricity generation (X. Luo et al., 2015). **Revenues are provided not by an external party, but by the reduced costs of charging.**

Another method of generating revenue is through ***arbitrage***. When the electricity is fed back to the grid and sold on the electricity market, revenue is provided by the grid company. In this case, the revenue is for the direct sale of electricity and is dependent on the amount of energy sold, measurable in kilowatt-hours. The reason energy can be bought and sold from the grid while making a profit is because electricity prices fluctuate minute-to-minute. Hence it is possible to buy electricity and charge the vehicle when it is cheap, and discharge when expensive. The timescale of arbitrage can vary but is typically measured in hours. **Revenues are provided in this case by the electricity market.**

The following diagram presents a depiction of these methods.

Figure 5 Four methods to discharge electricity back to the Grid in the V2G process



Chapter 6, 6.3.2 has the details of the actual valuations, in Euros, for the revenue from the sale of electricity.

2.5 Conclusion

This chapter thus builds the conceptual design of the study, by first examining the theory of profit maximization and the FCBA framework, next looking at the interplay between Schiphol Airport and the other key actors in this study, and then analyzing the four methods of revenue generation. The next chapter undertakes to explain the literature review based on which the study proceeds.

Chapter III – Literature survey and knowledge gap for CBA for V2G

3.0. Introduction

This section describes how existing literature was searched to find the knowledge gap. While there is significant literature for V2G and cost-benefit analyses at airports, there is no existing literature about V2G's commercial feasibility at airports, or transport hubs in general. However, a study of the literature about CBA for V2G yielded helpful results. The various terms used for search have been described.

3.1. Search Methodology

Google Scholar was primarily used with a time filter for 2019 to 2023 (the last five years), for relevance of technology-related aspects, and for manageability. The top relevant results based on Google's "Relevance" metric (which uses age of paper and number of citations) were taken. *For ensuring the validity of the research gap, a further search was conducted using Scopus which showed zero results on the identified gap.* This search was performed on the default fields of article title, abstract, and keywords.

Papers that were application agnostic were preferred since no airport-specific papers on CBA for V2G came up in the search. Papers were also taken from the references of the initial papers studied (snowballing). Additionally, a Google search for "V2G CBA" was also used for comprehensiveness to obtain whitepapers and any other media not indexed by academic search engines. Further, older papers (from 2010 onwards) that have relevant facts have been referenced in specific cases.

3.2. Findings from the literature

The following were found:

- While a search using "V2G AND CBA AND AIRPORT" gives 180 results, "Schiphol Airport and V2G implementation" gives 227 results.
- However, a search using "V2G AND CBA AND Schiphol" lead to 9 research papers, none of which specifically address the aspect of the use of CBA for V2G at the airport.
- When conducting a search for validating the research gap, zero results were found when using Scopus with the following search term: (cba OR "Cost-benefit-analysis" OR "cost benefit analysis") AND (v2g OR vtg OR ("vehicle to grid") OR ("vehicle-to-grid")) AND ((transport*) W/2 (hub* OR cluste*))

The tables below show the emergence of the research gap.

Search Number	Search Term (in Scopus)	Number of Results	Remarks
1	(V2G OR VTG) AND CBA *in all fields*	12	Literature is only vaguely related to the topic
2	(V2G OR VTG) AND CBA *in Article Title, Abstract, and Keywords*	2	Results do not include literature about any hub or aggregated parking
3	(V2G OR VTG) AND CBA AND AIRPORT* *in Article Title, Abstract, and Keywords*	0	No papers exist in this research gap

Search Number	Search Term	Number of Results	Remarks
1	(v2g OR vtg OR "vehicle to grid" OR "vehicle-to-grid") AND (cba OR "Cost-benefit-analysis" OR "cost benefit analysis") *in Article Title, Abstract, and Keywords*	225	Results do not include literature about any hub or aggregated parking
2	(v2g OR vtg OR "vehicle to grid" OR "vehicle-to-grid") AND (cba OR "Cost-benefit-analysis" OR "cost benefit analysis") AND ((transport*) W/2 (hub* OR cluste*)) *in Article Title, Abstract, and Keywords*	0	No papers exist in this research gap

The following are some of the important papers on EVs, V2G, and CBA, categorized as per the factors impacting V2G implementation. The list of papers is indicative and by no means exhaustive. Also, there clearly appears to be more research on technology-related and economic or pricing-based topics, as compared to government-related or regulatory-aspect related topics.

Additionally, there seems to be an abundance of papers on charging efficiency, V2G technology, cost benefit analysis of various scenarios etc. These reinforce the hypothesis that V2G holds significant merit, and provide confidence that, with proper CBA studies, it is likely to be possible to find a window of parameters within which V2G for airports, specifically Schiphol Airport, is economically viable.

The following is a brief synopsis of the conclusions of some of the important and relevant papers studied/reviewed during the literature survey study:

Table 1 Key papers impacting CBA of V2G

Factors impacting CBA of V2G	Paper	What the paper studies/conveys
Technical / Engineering	Electric Vehicle Aggregate Power Flow Prediction and Smart Charging System for Distributed Renewable Energy Self-Consumption Optimization by Franco et al. (2020)	This paper provides a methodology to predict aggregate power flows of EVs charging in positive energy districts and a smart charging system to optimize the self-consumption from distributed renewable energy sources. It studies the factors affecting the charging process, including driver behavior and the use of a charging management system.
	Assessment of charging technologies, infrastructure and charging station recommendation schemes of electric vehicles: A review by Savari et al. (2022)	The paper reviews EV charging infrastructure, technology, and issues related to charging station identification. It also looks at types of charging (DC vs AC)
	A Cost Benefit Analysis of a V2G-Capable Electric School Bus Compared to a Traditional Diesel School Bus by Lance Noel and Regina McCormack (2014)	This CBA study shows that with the inclusion of V2G capabilities, adoption of electric heavy-duty vehicles is imperative. Quantifying the benefits, the study says that choosing an electric bus with V2G capabilities over a traditional diesel bus would save \$6,070 per seat. Without V2G revenues, an electric bus would not be cost-effective, costing \$2,000 per seat.
	Cost-Benefit Analysis of Optimal Charging Strategy for Electric Vehicle with V2G – by Jiachen Fan et al. (2020)	In this paper, a Mixed Integer Linear Programming (MILP) formulation is developed to optimize the efficient charging and discharging of EVs based on the actual electric vehicle running data. It was found out that when V2G technology is used with less battery degradation, EV owners can achieve less cost and even earn a profit.

Economic / pricing related	Economic Analysis of Vehicle-to-Grid (V2G)-Enabled Fleets Participating in the Regulation Service Market by Rios et al. (2012)	This study says that the V2G revenue potential for fleets is significant. An EV/PHEV can earn $700-900 per year per vehicle performing ramp-down regulation services, resulting in a 5-7% reduction in cost. Further, an EV/PHEV can earn $1250-1400 per year per vehicle with ramp-up and ramp-down regulation services, resulting in a 9-11% reduction in cost. Flexible operations and the ability to adjust fleet operating schedules can realize notable increases in marginal V2G revenue.
	A Model for Cost–Benefit Analysis of Privately Owned Vehicle-to-Grid Solutions – by Rodríguez-Molina et al. (2020)	This paper describes a cost–benefit analysis of how consumers can make use of V2G solutions, in a way that they can use their vehicles for transport purposes and obtain revenues when injecting energy into the power grid. Further, the study says that purchasing an EV or V2G automobile and having the battery leased, instead of bought altogether with the vehicle, is economically inefficient for periods of time longer than five years, except for a comparatively brief period of time after the vehicle battery is replaced. The study concludes that V2G technology is still more economically efficient overall when compared to ICE vehicles. However, batteries are still the main bottleneck for greater profits, as they impose limits to the savings that can be done from purely maintenance costs. Also, the more a vehicle is used, the more economically efficient V2G technology becomes.
	A cost-benefit analysis of alternatively fueled buses with special considerations for V2G technology – by Shirazi et al. (2015)	This paper conveys that the marginal addition of a small CNG, or a small V2G-enabled electric bus is not cost-effective at 2015 prices, but large e-busses may be cost-effective at the right prices. The study also quantifies the detrimental effect of cold temperatures on EV operations.

	Using vehicle-to-grid technology for frequency regulation and peak-load reduction – by Corey D. White a, K. Max Zhang (2011)	While there is little financial incentive for individuals when the vehicle-to-grid (V2G) service is used exclusively for peak reduction, there is a significant potential for financial return when the V2G service is used for frequency regulation.
Government and regulatory	Electric Mobility & the Urban Environment; the Schiphol Case – by Silvester et al. (2010)	Though a 2010 paper, it clearly identifies the potential of the Schiphol area for an EV ecosystem at Schiphol, including fast charging and the potential for V2G.

From the above table which classifies important studies on V2G into three broad categories viz. Technical/Engineering, Economic/Price related and Government and Regulatory factors, the following is evident.

In the technology space, there has been a fair amount of research done on smart charging systems (aligned with driver behaviour), charging infrastructure, the benefits of heavy vehicles endowed with V2G capabilities and also charging optimization. The studies on economics/pricing convey that the benefits of V2G can be further leveraged in fleet operations through flexible operations and schedules. Lease vs buy options and economic viability of V2G over pure ICE vehicles have been studied for private vehicles. Additionally, studies have found that deploying V2G for frequency regulation is far more financially viable than using it for peak reduction. Further, Silvester et al. (2010) identifies Schiphol as an area with V2G potential.

There is one paper that exists about the use of CBA for V2G in US Military airports. However, since the paper is about a military-base airport, with a very different and smaller user profile as compared to a public airport such as Schiphol, the same is referenced but not considered to be very relevant.

It may also be noted that a relatively recent paper (Heilmann et al., 2021) conducted a meta-analysis of V2G CBA papers. Despite the paper analyzing over 300 other papers and providing recommendations to improve V2G's profitability/BC ratio, only 18 other papers have since cited the Heilmann paper. Further, none of these 18 are based on airports.

The conclusions of the above studies have been used as a guide to direct and clearly identify a space of research work which holds promise, and on which studies have so far not been done, viz. the potential for V2G in Schiphol Airport.

3.3 Resulting Knowledge Gap

While V2G technology has been relatively well-researched, and CBA is a well-understood tool for aiding decision-making in infrastructure projects, there is a clearly identified gap in the existing literature, when it comes to the use of CBA for V2G at airports, particularly at Schiphol Airport – as seen from the findings above, research papers do not exist on this topic.

It is identified that a Cost-Benefit analysis of V2G systems has not been conducted at any transport hub, despite the potential value of such an implementation and the requirement for a financial analysis to validate its feasibility.

Chapter IV – Methodology

4.0 Introduction

In Chapter 3, the research question and the two sub-questions have been clearly identified. This chapter explores the specific details of the methodology adopted for answering the primary research question, by describing the frameworks being used to answer the two sub-questions. The first sub-question involves numerical modelling and is further covered in Chapters 5-7. The second sub-question is answered in Chapter 8.

This chapter includes the research design, the descriptions and definitions of the base case and project case, and the scope of this research. There is a tabular description of the six semi-structured interviews that were conducted with various domain experts for the purpose of this study. Lastly, this chapter specifies the timeframe for this study, the number of parking slots being used in the base case and project case along with the various sources of data using which the study is being done.

4.1 Research Design

The research design is divided into two parts, qualitative and quantitative research. A literature survey was used to gather qualitative information about the V2G ecosystem, the current state and expansion potential of V2G, electricity pricing, trends in the EV ecosystem, and the various factors impacting V2G. Semi-structured interviews with domain experts were used for gaining insights and as a means for building a more accurate model. This includes executives in the domains of the following fields: Finance, Modelling, Cost Benefit Analysis, Electricity grids, Electric Cars and Vehicle to Grid. For quantitative modelling, data used was from published papers as well as publicly available data.

Qualitative judgements are used for risk analysis as described in detail in Section 4.3.

4.2 Methodology for Financial Cost Benefit Analysis (FCBA)

The steps taken in the research were as follows:

1. Determine realistic conditions to consider as the base case and the project case.
2. Use different sources of data to find values of important/relevant factors – for example, Costs of V2G chargers.
3. Calculate, or make reasonable estimates for other numerical parameters – for example, the Number of vehicles or inflation rates
4. Calculate the total benefits and costs.
5. Discount it to obtain the NPV.

4.3 Framework for Risk Analysis Using Likelihood-Effect (LE) Matrix

Schiphol Airport may use the L-E matrix to assess the risks to the V2G project. The intention of such a matrix is not to quantify the risks as there is nothing to be, say, physically measured in absolute terms. The purpose of using such a matrix is to help the decision-maker, in this case, the Airport, prioritize its actions according to the perceived risks (Colins, n.d.). For the purpose of quick evaluative decisions, qualitative risk analysis is often preferred to quantitative risk analysis. The latter is time-consuming, expensive and needs proprietary data, and is usually used for critical security issues. For regular corporate decisions, qualitative risk analysis may be chosen, in which the L-E matrix is often used (Evrin, 2021).

The L-E matrix for these risks may be mapped as below:

Figure 6 Risk assessment matrix

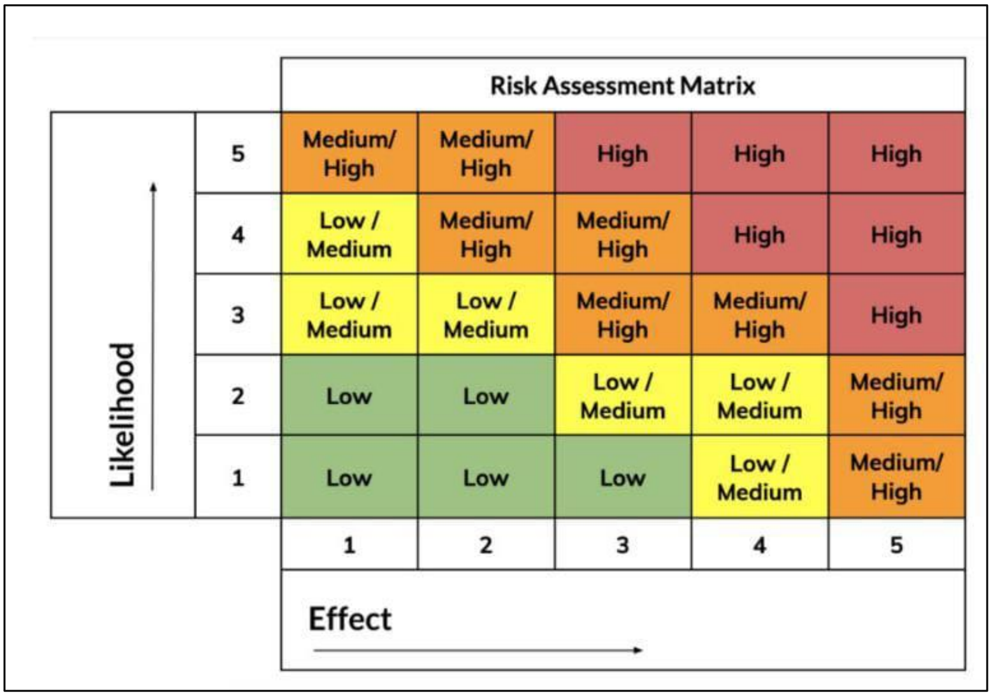


Image source: Veriforce CHAS

Effect Matrix:

Table 2 Effect Matrix

Sr. No.	Effect level	Effect Score
1	Insignificant	1
2	Minor	2
3	Moderate	3
4	Major	4
5	Critical	5

Likelihood Matrix:

Table 3 Likelihood Matrix

Sr. No.	Likelihood description	Likelihood Score
1	Remote	1
2	Low	2
3	Moderate	3
4	Likely to happen	4
5	Almost certain	5

Using the above framework, risk analysis conducted to answer the second sub-question can be seen in Chapter 8.

4.4 Scope of this research

The scope of the research was taken as follows:

- Geographical frame: within The Netherlands
- Time frame: From January 2024 to December 2030
- Perspective: Schiphol Airport using FCBA as a tool to study commercial feasibility

4.5 Base Case (or Reference Case)

As briefly mentioned in Chapter 1, this is what Schiphol Airport may be assumed to be doing, till 2030, at their current levels of action, displayed engagement and stated policies, with regular charging of EVs in their parking space. The Base Case is thus the scenario in which Schiphol Airport continues with and expands its EV charging network at a rate consistent with the estimated rate of growth of EVs in the Netherlands for a seven-year timeframe beginning January 2024 and ending December 2030. The choice of 2030 is made as several climate goals are intended for 2030, and Schiphol Airport has set a target of being the most sustainable airport by 2030 (Royal Schiphol Group, 2022).

4.5.1 Defining parameters of the Base case

Based on public domain knowledge about Schiphol Airport, and interviews the following parameters and conditions have been identified for the Base case**:**

1. It is expected that Schiphol will most likely increase its EV chargers to accommodate for the rise in EV usage/ownership. The number of EVs registered in the Netherlands was 271,000 in 2020, 382,000 in 2021 and 457,000 (till July) in 2022. (RVO, 2022). Hence, it is seen that there is a year-on-year growth of about 40% in the number of EVs in the Netherlands. Making it more conservative to 35% and rounding off the value helps us calculate the number of EV chargers for the base case.
2. Capital expenditure (Capex) cost has been considered.

3. Only 4-wheeler cars are being considered; buses or trucks are not being considered.
4. The parking is intended for long term, with long-term parking defined as parking for 48 hours or more as per Schiphol Airport.
5. As regards charger cost, while inflation increases costs, economies of scale and technological advancements reduce costs. A conservation year-on-year reduction of 10% in charger costs has been taken. (Rosamond, 2023)
6. Capitally intensive products like chargers are typically sold with warranties for two to five years as indicated by current real-life warranty terms (Tesla, n.d.). Hence for the remaining duration of the project maintenance or operational costs are not being considered separately as they are likely to be minimal.

4.5.2. Rationale

For determining the growth in the total number of unidirectional EV chargers, the past growth rate of EVs has been used. The growth rate of chargers has been assumed to match the growth rate of EVs. While this may appear to be an aggressive growth rate, it is realistic as it is based on a few factors:

1. Low current installation base
   Schiphol Airport currently only has 24 EV chargers across over 15,000 chargers. To reach parity they will need to catch up and install more chargers at a high rate. This is because the EV market is about 10% of the 4-wheeler car market (with about 119,000 public chargers in the Netherlands). Since Schiphol Airport has 15,000 parking slots, it is assumed that 10% or at least 1500 would correspond to EVs. The base case takes a far more conservative number of EV chargers as explained in Section 4.4.1.
2. Schiphol Airport's stated plans
   The airport has indicated that they intend to increase the number of EV chargers installed in their parking lot.
3. Further, news reports indicate that there is no V2G currently at Schiphol Airport. Schiphol Real Estate trailed 2 bidirectional chargers at the Outlook building in March 2019, but nothing was done in the airport. At the same time, Schiphol Airport has been trying to be more customer-centric. Hence, one may estimate the increase in EV charging spots.

4.5.3 What is not being considered in the Base case and why

The base case does not consider any sudden and massive increase in regular traffic because passenger traffic has increased by 151% in the last 3 years. It has been 52.5 million, 25.5 million and 20.9 million in 2022, 2021 and 2020. (It was 71.7 million in 2019 before Covid.). The pandemic and its subsequent effects on travel and hence revenue streams for airports may have possibly altered plans for V2G. This aspect is not being considered.

4.6 Project case

The Project case looks at the situation where Schiphol Airport implements the V2G project.

4.6.1. Defining parameters of the Project Case

In order to define the project case, three things are being considered: the number of EVs, the growth rate of EVs and assumed growth of adoption of V2G.

1. The number of V2G chargers is calculated using the same growth rate for V2G adoption as was used in the base case for EV charging growth rate as seen in Section 4.4.1.
2. Capital expenditure (Capex) cost has been considered.
3. Only 4-wheeler cars are being considered; buses or trucks are not being considered.
4. The parking is intended for long term, with long-term parking defined as parking for 48 hours or more as per Schiphol Airport.
5. As regards charger cost, while inflation increases costs, economies of scale and technological advancements reduce costs. A conservation year-on-year reduction of 10% in charger costs has been taken. (Rosamond, 2023)
6. Further, capitally intensive products like chargers are typically sold with warranties for two to five years as indicated by current real-life warranty terms (Tesla, n.d.). Hence for the remaining duration of the project maintenance or operational costs are not being considered separately as they are likely to be minimal.

4.6.2 Rationale

While it is impossible to predict V2G volumes in the future, it is highly expected to increase significantly as technology improves and costs reduce. In the Project case, Schiphol Airport installs bi-directional (V2G) chargers at the same rate as it installs unidirectional chargers in the Base case.

This assumes the same growth rate of 40% year on year, starting from the current 24 chargers, as explained in Sections 4.4.1 and 4.4.2.

4.6.3 What is not being considered

It is assumed that Schiphol Airport is adding the V2G chargers and not converting existing EV chargers as the demand for EVs is already growing and is expected to continue upwards, hence resulting anyway in an increased number of unidirectional/bidirectional chargers. (RVO, 2022)

4.7 Choice of timeframe

7 years is taken as the uncertainty grows rapidly over time and hence makes it difficult to predict. A longer timeframe gives a healthier Benefit-to-Cost ratio of V2G, as there are higher capital expenses in the initial years. Additionally, small capex investments are often considered with a payback period of 5 years. The timeline chosen is from 1st January 2024 to 31st December 2030, to make it realistic in accuracy predictions. Additionally, the chances of scaling up of V2G exists in the near future. Please see Section 4.5 for the relevance of the choice of 2030 for Schiphol Airport.

4.8 Sources of data for quantification of certain parameters

In order to build the Base and Project case, data about the number of EVs in the Netherlands was taken. Initially, news articles were considered. However, due to a lack of consistency in the numbers in different articles, the government website showing registration of Battery Electric Vehicles, Fuel Cell Electric Vehicles and Plug-in Hybrid Electric Vehicles, was finally chosen. Of these 3 categories, EVs were selected. Additionally, V2G hub (V2G Hub, 2023) is a repository of V2G projects around the world. It was used to gather information on active V2G projects in the Netherlands.

In order to build the Project case data was used from the EU website of the North Sea region as well as multiple news articles (European Union, 2023; House, 2023).

As mentioned earlier, in addition to scholarly articles, there were six semi-structured interviews with different domain experts – please refer to Table 4 below. Questions were created as per the domain of the professionals and their linkage to this study with some flexibility for raising more questions based on the answers to the initial questions.

As there are four technical topics in this study – EVs, Electricity Markets, V2G, and FCBAs, professionals were chosen from each of the domains. The interviewees were contacted through contacts of the author. For the topics of CBA and EVs, more than one person was consulted to obtain a broader and more accurate perspective. In two cases, multiple interviews were conducted. Five of the six interviewees have consented to have their names shared for the purpose of the study.

Interviews have been referenced based on their number, for example, as “Interview 1”.

Table 4 List of semi-structured interviews conducted

Interview Number	Interviewee’s Name	Position	Domain of expertise	Key topic(s) discussed in the interview
Interview 1	Dr Deb Mukherji	Managing Director, Omega Seiki Mobility Pvt. Ltd.	EVs, V2G, future trends and predictions	Evolution of EVs and the inevitability of V2G
Interview 2	Mr Sameet Pai	Chartered Accountant, General Manager, Corporate Strategy Department, Bharat Petroleum Corporation Limited	Cost Benefit Analyses, Financial Modelling and Analysis, Asset Lifecycle Costing	Differences between Capex and Opex-based modelling, remnant/terminal values and Lifecycle Analysis
Interview 3	Ms Esha Tulsiani	Manager (Finance), Retail Headquarters, Bharat Petroleum Corporation Limited	Financial Modelling and Analysis	How to source, or extrapolate, necessary data in an accurate manner

Interview 4	Mr Shubhankar Sen	Head - Electric Vehicles, General Manager. BPCL	EVs trends, electricity grids, key business and active players	Importance of cost in EV adoption in some markets, the existing and growing strain on electricity grids from EV charging, the likelihood of smaller players to take up key roles in this transition
Interview 5	Mr. Sunil Kumar	Retired Chief General Manager – Electrical, Maintenance and Projects, currently a consultant	Electricity Grid operations, stability, voltage and frequency regulation	Challenges ahead for largescale V2G implementation including difficulty predicting energy flow, risks of cyberattacks,
Interview 6	*Name not provided for privacy*	Head – Electric Vehicles and Innovations Ecosystem, Morris Garages (M. G. Car Company Limited), India	EVs and their future trends and plans	Potential barriers in V2G adoption that are likely to improve with time

4.9 Conclusion

Thus, after defining the methodology, this study begins the first and very crucial stage of answering the research question, by raising a relevant sub-question "What are the factors that impact the adoption of V2G for EVs?" This question is answered in the next chapter, that is, chapter 5.

Chapter V – Factors impacting adoption of V2G

5.0 Introduction

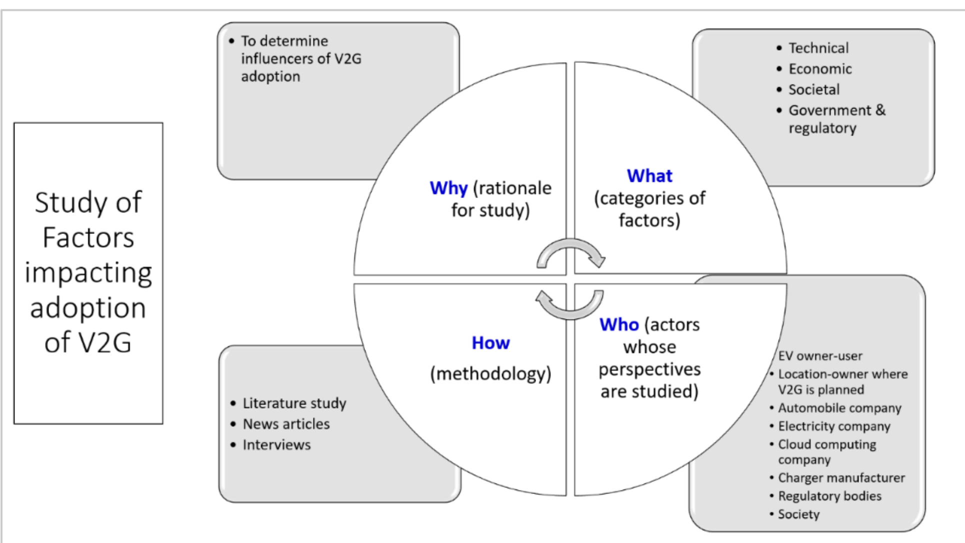
In the previous chapter, the research methodology was defined. In this chapter, the important and significant factors impacting the adoption of V2G have been identified. The modelling in this study requires only the quantitative factors. However, qualitative factors play an important part in understanding the practicalities of the V2G ecosystem at Schiphol Airport. Therefore, the scope of the study was voluntarily expanded to also include qualitative factors such as social and governmental factors, while maintaining focus on the financial modelling using quantitative factors. The quantitative factors are classified under technological and economic factors. The qualitative factors have been included in Annexure A. A schematic diagram to depict the interplay of costs and benefits for such a study has been developed and included in this chapter.

5.1 Overview

While the factors mentioned in this chapter do not have a direct bearing on the FCBA study, these factors were studied to gain a more holistic understanding of the costs in the FCBA space. The study of the factors impacting V2G started with an analysis of the following: Why is it important to determine these factors? What are the broad categories of factors? Who are the actors whose perspectives are studied? How is the study being done? While the preceding chapters have described the "Why?", "Who?" and "How?", this chapter lists the "What?" aspect of the factors.

This information has been represented in the figure below.

Figure 7 Factors impacting adoption of V2G – a snapshot of the direction of study



*Influencers refers to the sum of quantifiable costs and benefits as well as qualitative factors which impact V2G adoption

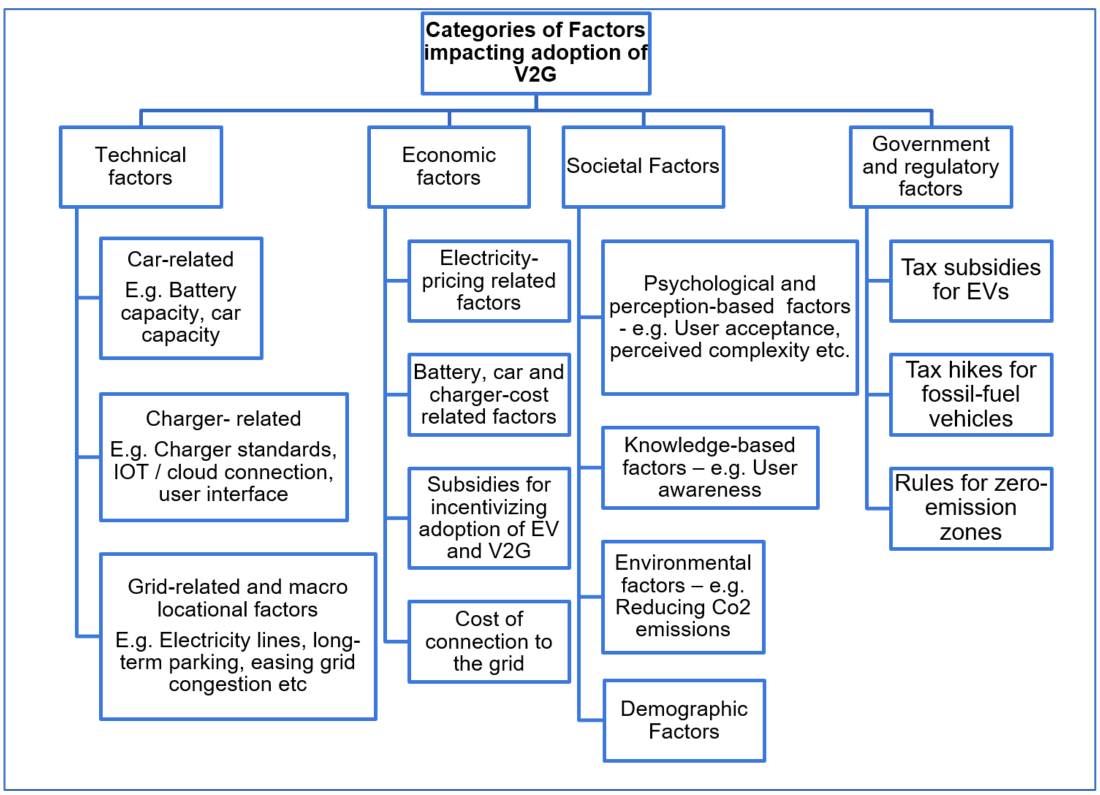
5.2 Overlapping categories

While studying and analyzing the factors, it was seen that certain factors may be categorized in more than one category. For example, battery degradation can be categorized as a technical factor. At the same time, user perception about battery degradation (which may or may not match the actual battery degradation) also plays a role in the behaviour of EV owners adopting V2G. Hence, there is also a societal aspect to it. Similarly, while charging stations may be considered a technical factor in terms of efficiency, their costs would be categorized as an economic factor.

For the purpose of this study the factors have been categorized as per the field they are most logically or closely linked to. Further, a mention is made in case the same factor also falls in another category. This way, correctness is sought to be maintained while overlaps and repetitions are minimized.

The following is a diagrammatic representation of categories of factors impacting the adoption of V2G:

Figure 8 A diagrammatic representation of categories of factors impacting the adoption of V2G



The key factors which currently allow themselves to be quantified have been selected for the CBA analysis.

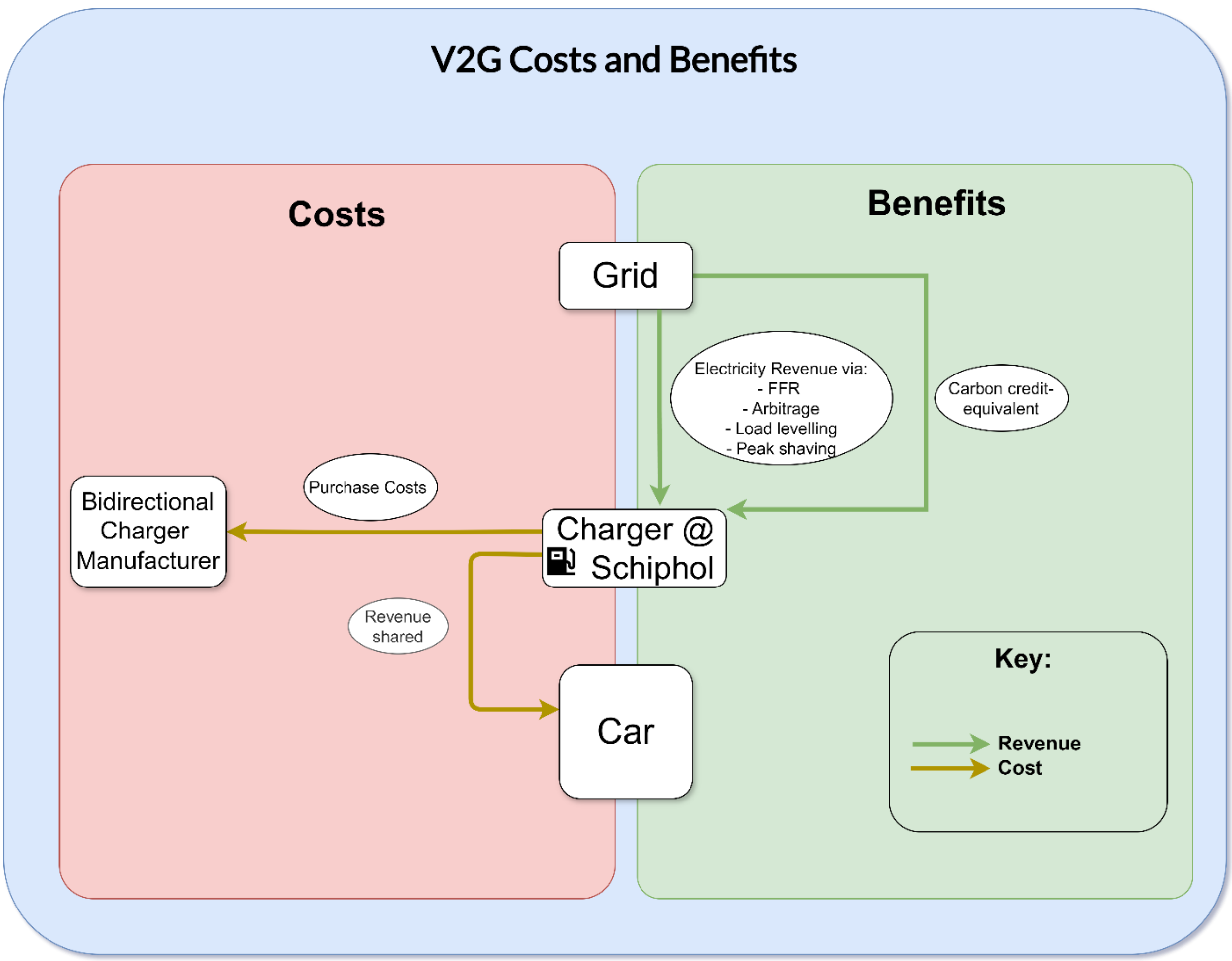
5.3 Chosen Factors Quantified as Costs and Benefits for CBA

The list of factors is meant to be fairly comprehensive. However, not all factors can be easily quantified within the practical limits of this study, and neither are all factors relevant for quantification for CBA. At the same time, the CBA is not done in a vacuum but in a wider context of decision making which may include qualitative factors. For example, demographics (age, gender, income) are a societal factor (Chen et al., 2020) that neither needs quantification for this study, nor is suitable for quantification. Similarly, certain perception-based factors of EV owners, such as the perceived complexity of technology, may certainly impact V2G adoption but are too abstract to render themselves suitable for quantification.

Therefore, this study first lists various factors and then selects a few, based on relevance, for quantification as either a cost or a benefit, for the purpose of the CBA.

Thus, the study first lists various categories of factors impacting the adoption of V2G. Key quantifiable factors are then used for modelling the CBA. These are either the direct costs and benefits of V2G, or have been converted to produce a suitable numerical value that can be used in calculations.

Figure 9 Diagram depicting chosen factors as costs and benefits



This diagram shows the interplay between the different costs and benefits, along with the connections of each element to its adjacent element. It helps highlight how these various parts of the system interact with each other.

There are various Technical, Economic, Societal and Governmental factors that impact the adoption of V2G. **Appendices A, B, C and D** contain a brief note on each of these respectively.

5.4 Conclusion

After having taken a brief look at the various factors in this chapter, the study then proceeds towards choosing and quantifying the relevant costs and benefits for the V2G project at Schiphol Airport. This can be seen in chapter 6.

Chapter VI – Calculation of Financial Cost Benefit Analysis

6.0 Introduction

Chapter 6 begins by first stating the various kinds of costs and benefits, and then proceeds to quantify the same. Given the extremely high impact of the cost of bidirectional chargers used in V2G, on the Benefit-to-Cost ratio, this chapter describes the various sources of data for the same, at some length. The process of modeling is then explained, in terms of the choice of parameters that are constant, and those that change. The choice of the Capex form of modeling is also described. The assumptions made in this study are finally listed.

6.1 The Costs and Benefits – a bird's eye view

For the purpose of doing an FCBA, all the significant costs and benefits found from the previous chapter related to it must be first determined. These have been summarized below in the table. The costs are first listed, followed by the benefits.

In the table, Primary refers to first-order effects, and Secondary refers to higher-order effects.

Table 5 Costs and Benefits from the perspective of Schiphol Airport

Nature of Cost/Benefit	***Costs***	***Benefits***
Primary	**One-time:** Charger hardware cost Fee-sharing with EV user	**Recurring:** Revenue CO_2-equivalents
Secondary - if applicable	**One-time:** Parking lot infrastructure upgrade Land Purchase	

The components of the above table are described below.

In the calculations done in this report, it is only the primary costs have been considered. The secondary costs have not been considered as the correct, accurate, and credible data would be mainly available to the implementer of the project that is Schiphol Airport. Further, if one were to analyze such a project not only from the perspective of Schiphol Airport but from a broader societal perspective, the following costs and benefits also are applicable: battery degradation as a cost, grid overload reduction, and higher EV adoption – leading to less ICE CO_2 emissions, energy security, more renewable energy utilization as benefits.

6.2 Costs

The following are the details of the charger-related costs associated with this project. To quantify the same, the process followed was that of first identifying the type of charger to be used, and then ascertaining its likely cost.

As explained in Chapter 4, Section 4.4.1, no separate maintenance costs are being considered as usually the warranty of the V2G chargers would cover the same for 2 to 5 years, based on the type of purchase contract. Hence, for this study with a 7-year time frame, the balance maintenance cost would be very minimal.

Charger hardware

Standard EV chargers are unidirectional – that is, they only can take power from the grid to charge vehicles. Vehicle to Grid implementation requires the charger to be able to supply power back to the grid, which requires specific hardware. There is therefore also a cost difference between regular (G2V) and bidirectional (V2G) chargers. In the Base case, it is assumed that Schiphol installs 200 unidirectional (G2V) chargers by 2030 assuming a growth rate of 40% year on year from the current 24 chargers, as explained earlier, while in the Project case, all of these are V2G chargers. Therefore, the costs of the two different types of chargers need to be taken.

Another factor that needs to be considered beyond the directionality and number of chargers is the charging speed or power. V2G benefits from fast charging, and as mentioned in the definitions of the base and project cases, here we compare the costs of medium-speed G2V charging with high-speed V2G. To find the cost of EV chargers at varying speeds, a search was done as per the following table. The following are the results:

Table 6 Literature Search for V2G charger hardware cost

Sr No.	Search Engine	Search term	Filter	Results	Relevant results
1	Google Scholar	"EV charger cost"	None	10	1
2	Google Scholar	"Bidirectional charger cost"	None	4	1
3	Google Scholar	"Level 2 EV Charging Station" AND "Cost" AND "Europe"	None	5	1

Additionally, Google was used as a search engine to find data about Level 2 (i.e., medium speed) charging station costs. Automobile-related websites and websites of charger manufacturing companies were also browsed to find out the possible range of costs. Finally, reports by consulting companies on clean energy were studied. While prices can be found using research papers or news articles, as the number of recent research articles is low and not indicative of real-world values, data has been selectively taken from news articles.

Cost of Wallbox bidirectional Chargers:

The Quasar 1 bidirectional charger, manufactured by the Spain-based company Wallbox, and compatible with CHAdeMO bidirectional-enabled vehicles, including the Nissan Leaf and the ENV-200, was sold in Europe for US $ 3600, while the Quasar 2, which will use the Combined Charging System (CCS) protocol, is expected to be approximately priced at US $ 1500 by the end of 2023 (Motavalli, 2023). The Quasar 1 equivalent charger is being chosen for this model.

Cost of Regular EV charger:

While households that charge their EVs may use Level 1 chargers, commercial spaces that offer charging, such as Schiphol Airport, would require at least Level 2 chargers that allow faster charging. The cost of such charging stations widely varies. It may range from US$ 650 to US$ $ 3000 including installation (Point, 2023; Penna, 2023). At the same time, it is opined that Level 1 chargers may also be useful in case of long-term parking of over 24 hours – this would reduce the capital expenditure for the airport while continuing to offer service to the customer/passenger (Richard, 2014). However, for this study, given the rate of progress of technology and likely falling costs of charging stations in future, **only Level 2 chargers are being considered**. For Europe, a cost of €2500 has been considered for Level 2 chargers (Fishbone, 2018).

Cost of Charging Stations in Europe:

The purchase and installation for commercial charge points is currently in the range of €2000 to €6000 without taking any government subsidies into account (*JustWe,* 2021). After considering the above, the modelling has been done using the following quantified values:

Table for choice of values taken for modelling:

Table 7 Explanation of various costs taken

<table>
<tr><th rowspan="2">Sr no</th><th rowspan="2" colspan="2">Item (Cost/Benefit)</th><th colspan="3">Costs/Values (EUR)</th><th rowspan="2">Assumptions & Remarks</th></tr>
<tr><th>Min</th><th>Max</th><th>Taken</th></tr>
<tr><td rowspan="2">1</td><td rowspan="2">Charger</td><td>Regular</td><td>2000</td><td>6000</td><td></td><td>Regular EV chargers range from €2000 to €6000 (JustWe, 2021)</td></tr>
<tr><td>V2G</td><td></td><td></td><td>4500</td><td>V2G Quasar charger costs 3600 USD (Motavalli, 2022)</td></tr>
<tr><td>2</td><td colspan="2">Battery</td><td>$6500</td><td>$9500</td><td>$8000</td><td>Nissan Leaf can do V2G (Find My Electric, 2023)</td></tr>
</table>

6.3 Benefits

One of the key benefits of V2G is its ability to offer grid congestion easing. Additionally, using integrating renewable and clean sources of energy implies an impact on the carbon footprint. These benefits are described as follows.

6.3.1 Grid Stability using V2G and its monetization using different methods of revenue generation

Power companies are expected to pay either EV owners, or the location-specific organization, or a combination of the two, for the energy put back into the grid using V2G technology (Shi et al., 2022). Such payment includes a component for easing grid congestion and avoiding outages. This payment represents a revenue source for the location offering V2G, in this case, Schiphol Airport. To see how much benefits are offered to the grid by use of V2G, one of the practical ways is to look at existing V2G pilot projects, and the payouts provided in them. In a UK study (OFGEM, 2021) up to GBP 30p was offered per kWh of energy.

Cost of outages – global perspectives:

Owing to humanity's massive dependence on power systems, an uninterrupted supply of power is a pre-requisite for the smooth running of all mechanized systems. Hence outages have a very high and disruptive influence on the efficiency of continuously operating systems.

A 2019 report by Bloom Energy, USA, describes an annual loss of US$150 billion, due to power outage, as based on data from the Department of Energy, USA. There are additionally unquantified but very relevant social costs of outages, such as decreased productivity, and loss of lives in critical care centres.

As this study has been done from the perspective of Schiphol Airport, outage costs have not been used for this calculation. Yet, it is undeniable would have a cost for society and hence Schiphol Airport would consider this V2G project as it reduces and minimizes outages.

6.3.2 Calculation of revenue from the sale of electricity back to the grid:

The rates of electricity revenue have been taken from V2G papers and publications. For FFR, Ryan (2019) has been taken as the data source, which gives a value of 50p GBP per kWh of frequency regulation.

Meanwhile for arbitrage, load leveling and peak shaving, values have been taken from Heilmann and Friedl (2021) of EUR120.7, EUR994.82, and EUR52.86 per car-year. Further details of calculations are included in Chapter 7, where the FCBA calculations are tabled.

Research Studies and Practical Considerations that validate the use of FFR, load levelling and arbitrage for the calculation of V2G revenue

The following studies and practical considerations and statutory requirements show the use of various grid services and a comparison of their respective revenues.

Hoogvliet et al. (2017) and Figgener et al. (2022) have analyzed FFR possibilities in EVs. It is possible to make up to 700 EUR per day. However, this is based on the concept of RRP, that is Regulating and Reserve Power. The amount of revenue generated depends on multiple factors including battery capacity and charging speed.

As per statutory guidelines, the minimum FFR capacity requirement is 1MW. Since one car provides 7.4 KW of power, 1 MW would require 135 cars to be always connected to the V2G system.

6.3.3 Sharing of revenue from the sale of electricity with EV owner-users

In order to incentivize EV owners to adopt V2G, i.e. discharge electricity back into the grid when they do not require the same, it is expected that Schiphol Airport will share some of the revenues being generated from the sale of such electricity. In the absence of transparency of data about fee-sharing for V2G projects globally, especially given that several such projects are in their pilot phases, a suitable assumption has been made about such fee-sharing.

Since the Capex model of FCBA is being used, in which Schiphol Airport has a significant initial capital expense for the cost of the bi-directional chargers, the fee-sharing may lean in favour of Schiphol Airport in the initial years. Hence a fee-sharing arrangement of 80-20 ratio, i.e., 80% of revenue to be retained by Schiphol Airport and 20% to be passed on to the EV owner. This ratio may be subsequently revisited after a reasonable period of time, such as 5 or 7 years.

6.3.4. Monetary valuation of Environmental Benefits from V2G, i.e., calculation of Carbon Credits

V2G by way of providing electric power when needed, can reduce carbon emissions. One common possible situation is when EVs charge from renewables at cheap prices, and discharge the cleanly generated energy at times of high demand, avoiding or reducing the need to use fossil (coal/gas) powered power plants. Additionally, many sectors including power generation are covered under the EU-ETS and have caps on emissions as well as the possibility to sell excess credits if they pollute less. Hence, reducing carbon emissions is also a monetization opportunity for Schiphol Airport.

EU and the Dutch government's websites were used for most data sources, along with Schiphol Airport's published reports. For the purpose of the FCBA, the reduction in carbon emissions can be quantified as a benefit. The existing ETS price can be taken as the value.

The cost of carbon was taken from the current trading price of carbon credits from the ETS. As this calculation was done in June 2023, the average prices between 1st and 31st May were taken which was close to 90 EUR per ton of CO_2. (Trading Economics, 2023). Considering the number of cars, weeks and price per ton of CO_2, the value of benefit works out to EUR 3202.11 for 52 weeks for the whole parking lot with 200 EVs. As per Cenex (July 2022), across the 38 weeks of their pilot program, each EV reduces emission of carbon dioxide by 130 kgs, per year.

6.4 Process of Excel Modelling

For modelling the CBA, individual components are identified and their interplays are modelled over the time period of the project. Hence, different costs and benefits are identified, and then the costs were summed up, and the benefits' sum was compared with it.

Microsoft Excel has been used as it is one of the most widely used tools by companies for such calculations to assess projects such as this one (Interviews 2 and 3).

6.4.1 Choice of unchanging parameters for modelling

Some common parameters were chosen and kept constant across the different individual calculations. This was done based off the values of the base case and for consistency of calculation. These include the number of V2G chargers (200), the power of G2V and V2G chargers (7kW), and time durations for costs or benefits (either per year or across the 7-year time period of the project.) In some cases where values available were on a per-week basis, 52 weeks have been taken to the year, else 365 days are considered as a calendar year.

Determining the number of chargers

The number of EVs in the Netherlands has been going up by approximately 40 to 45% each year, for the last two years (as of April 2023). Hence it may be assumed that EV-charging spots at Schiphol airport will also increase from the current value of 24 to about 200 by 2030.

6.4.2 Choice of parameters that change

Capacity factor: This refers to the rate of utilization of the V2G chargers, which indirectly accounts for the qualitative factors such as customer demographics of EV users impacting adoption of V2G.

While a project may forecast a certain number of chargers to be installed, their utilization in real life depends on factors such as the willingness of the EV user. Hence, Schiphol Airport needs to consider that out of every 100 chargers installed, only an "X" number of them may be utilized. This "X" is the capacity factor. This will impact the FCBA modelling, as revenue derived from electricity would depend on the actual utilization of the chargers. A 30% capacity factor has been taken as it is neither too conservative nor too optimistic. This value has also been chosen based on existing EV charger occupancy rates in Amsterdam (Wolbertus et al., 2016).

Inflation: The current inflation in the Netherlands is 4.9% as per the European Commission's Economic Forecast for Netherlands, and is stated to reduce to 3.3% in 2024, and 2% in 2025 (European Union, 2024). However, for the sake of this study, inflation has not been considered and the FCBA has been done at current prices.

Discount rate: A discount rate of 12%, which is higher than the inflation rate, has been used for calculation of the NPV (net present value). This is because this rate gives a more conservative calculation than that using the inflation rate. The discount rate has been applied to constant rates of costs and benefits.

6.4.3 Using the Capex Model for FCBA Modeling

A V2G setup can either be based on a model wherein the project owner owns the chargers (i.e. Capital expenditure or Capex-based) or where the chargers are rented or leased (i.e. Operating Expenditure or Opex-based). The Opex model is usually used where risks and uncertainties are high and initial investment costs are very high, for example leasing an aircraft. As EV charging and V2G are not very uncertain and capital-intensive, the capex model has been chosen. This implies, Schiphol Airport is purchasing the bi-directional chargers, and not renting them (Interviews 3 and 4).

As the technology for V2G is developing and will improve over the years, by buying bidirectional chargers, Schiphol Airport will gain over the years. A 3rd generation V2G charger, or Level 3 charger, also known as a DC fast charger, is the fastest way to charge an EV, and may be much more efficient and cost much less than a 1st generation charger. The modelling is however done with a conservative approach and does not factor in the benefit to Schiphol Airport from such technological development.

6.4.4 A comprehensive look at Costs and Benefits for V2G at Schiphol Airport for a 7-year timeframe

Before the FCBA results can be modelled, it is necessary to list the financial as well as non-financial costs for the V2G project. This would be useful to Schiphol Airport in taking a wider and more holistic view of the project. The following table hence lists the same.

Since the study has focused on the FCBA as a tool to analyze the V2G project for Schiphol Airport, only the financial costs are used for the modelling and for obtaining the FCBA ratio(s). However, the non-financial cost and the multiple non-financial benefits would, as such, play an important role if Schiphol Airport were to consider the Social Cost-benefit Analysis of this project.

Table 8 Table showing the categories of costs and benefits of both kinds, financial and non-financial

Costs		**Benefits**	
Financial	Non-financial	Financial	Non-financial
Charger costs	Opportunity cost: Loss of real estate to parking and V2G	Revenue from the sale of electricity to the grid through one or more of the four methods: FFR, Load levelling, Arbitrage, Peak-shaving	Positive publicity due to good corporate citizenship
Monetary remuneration to EV user		Carbon credits	Brand building – useful as a future differentiator for Schiphol Airport as a "hub of choice" at the global level
			Leverage with the government for good corporate citizenship

The following may be noted:

1. Parking revenue:
   Parking revenue is not being considered as a revenue source, since the Base Case and Project Case would both have similar income from parking and the modelling uses the Delta method

2. Other fees:
   Administrative fees, license fees and other contingent costs etc. are not being considered as their impact is very minimal relative to the other costs, accurate data about the same is best inputted by the implementor of the V2G project, i.e., Schiphol Airport and a discount

rate of 12% (applied to constant rates of costs and benefits) which is substantially higher than the inflation rate would accommodate contingent costs.

3. Cabling Costs:
   As the Base Case and the Project Case both include the same number of chargers being installed, with the only difference being the type of charger, cabling costs do not impact the calculation of the FCBA. This study uses the Delta Method, hence cabling costs of Base Case minus cabling costs of Project Case are zero.

4. Operational or maintenance costs:
   As mentioned in Chapter 4, Section 4.4.1, no separate maintenance costs are being considered as usually the warranty of the V2G chargers would cover the same for 2 to 5 years, based on the type of purchase contract. Hence, for this study with a 7-year time frame, the balance costs would likely be very too minimal to be considered for the modelling.

5. Installation costs:
   Installation costs, including labour and material, if any, are negligible and hence not separately considered.

For calculating values, the following aspects have been taken:

1. Charger costs are taken as Euros 1500 per charger in the Base Case and Euros 4500 per charger in the Project Case. The difference, which is Euros 3000 per charger is thus used in this Delta Method
2. Carbon credits have been calculated using Cenex (2022), as detailed in Chapter 5, 5.3.4.
3. For the revenue calculations, the process used is as follows:
   a. Under the FFR method, the income is 103.0005 Euros per car, per day, based on Ryan (2019). This when calculated for the year, gives Euros 37,595 per car per year. This, when multiplied by the number of total available chargers installed every year, and aggregated to 7 years with 12% NPV, and further reduced to 30% to account for utilization factor, gives Euros 5,857,317 as an income.
   b. A similar approach has been taken for the other three methods
4. A payout of 20% of revenues earned from electricity is earmarked for the EV user. In other words, Schiphol Airport retains 80% of the revenue and passes on 20% to the EV owner. As explained in Chapter 5, 5.3.3, the payout ratio has been taken based on the high capital costs borne by Schiphol Airport in the initial years.
5. The average number of cars at any point of time is 125, derived as the statistical mean of the cumulative number of chargers, and the cars utilizing the respective chargers, across 7 years.
6. Decimal points have been rounded off to the nearest Euro for ease of calculation

While this study focuses on the FCBA from the perspective of Schiphol Airport, doing the same from the perspective of the government, would bring in an additional cost of battery degradation. Even if this were to be included in the FCBA from the perspective of Schiphol Airport, the impact on the ratios is minimal, as the cost of battery degradation would be negligibly low for the methods of FFR, as indicated by the modelling results as seen in chapter 7. While it is relatively higher for the arbitrage, load levelling and peak shaving methods, this may still be excluded from consideration, as these methods give poorer revenues and hence is unlikely to be chosen by Schiphol Airport for its calculations or its negotiations with electricity companies. Appendix F states the calculations for battery degradation, if included in a wider analysis.

6.5 Assumptions

As V2G is still very nascent and has limited data available publicly, it was necessary to use news articles and refer to expert interviews in several situations. Hence the following assumptions have been made.

1. Charger related assumptions:
    a. Charger life is taken as 10 years as the average charger today has a 10-year life. This number is not expected to decrease as technology matures (Jessicatonn, 2022). *Although the charger life is 10 years, the project duration is 7 years as climate-related laws and regulations have 2030 targets. Additionally, Schiphol Airport's target to be the most sustainable airport is set for 2030.*
    b. The costs of chargers drop uniformly at rate of 10% year-on-year – this has been taken as an assumption based on the semi-structured interviews, and news articles on market trends.
    c. The residual lifecycle value of the chargers is ignored as advised by modelling experts (Interviews 2 and 3). This has been done to make the model more conservative, and because the difference in calculated costs is not very significant.
    d. Installation costs, including labour and material, if any, are negligible and hence not separately considered.
2. Schiphol Airport is anyway planning to install EV chargers for zero cabling cost assumption (Royal Schiphol Group, November 2022)
3. No law changes in the area of Frequency Regulation, for example preventing airports from selling electricity.
4. It is expected that EVs support V2G. As more people use EVs and there is an increasing push for V2G, it is assumed that there is always an adequate number of V2G EVs.
5. There is no extra expenditure for grid infrastructure like new sub-stations.
6. Schiphol Airport consumes about 200 million kWh (200 GWh) of electricity (Royal Schiphol Group, n.d.). In comparison, the electricity transferred through V2G would be a small percentage of this. This is because each V2G charger is only 7.4kW, and an entire parking lot of 200 V2G chargers would only provide under 6.5 million kWh (6.5 GWh) or about 3% of Schiphol's power.

6.6 Conclusion

Thus, this chapter has described at some length, the method of quantification of the various costs and benefits that are to be used for the FCBA modelling, the process of modelling, and the assumptions of this study. The next chapter first describes the relevant costs and benefits, and then explains the results of the FCBA modelling, in terms of the Benefit-to-Cost ratios

Chapter VII – Results of the FCBA modelling

7.0 Introduction

This chapter calculates the results of the FCBA modelling. It first lists the various costs and benefits, both, financial and non-financial. Next, the chapter quantifies the aggregate costs and benefits for the chosen time-frame, and calculates the Benefit-to-Cost ratio under each of the four methods of calculation of electricity revenue. It is useful to compare the ratios so derived, to deduce which approach of calculation of revenue would be financially feasible for Schiphol Airport. Further, the conditions under which the V2G project is commercially feasible using FCBA, are listed. Finally, the limitations of the study are also listed in this chapter.

7.1 Financial costs and benefits for the FCBA modelling, and the results of modelling

The following is the table of results of the FCBA modelling, using the financial costs and benefits, with numerical values explained in the relevant cell of the table. The ratios have been rounded off to their nearest approximate value to accommodate the volatility of electricity pricing.

Table 9 Financial costs and benefits of using FFR for revenue generation

Sr. No.	Item description	Value (in thousand euros)	Explanation
A	**Cost Items**		
(a)	Purchase cost (including warranty) of bi-directional chargers	409	Calculated as Euros 3000 per bidirectional charger * number of chargers installed each year @ 50 in year one and 25 in subsequent years, with an NPV at 12% for 7 years
(b)	Fee cost (to pay a monetary award to the EV user)	1,171	20% of FFR revenues are paid to the EV user as an incentive
	Total cost	**1,580**	
B	**Benefits**		
(a)	FFR benefits	5,857	Euros 37,597.92 per car per year * number of chargers available each year * NPV for 7 years at 12% at 30% utilization rate *(explained below table)*
(b)	CO_2 equivalent	22	Calculated at 0.09 Euros per kg of carbon reduction, leading to -Euros 16 per car per year -Euros 3,202.11 for 200 cars per year -Euros 22,414 for 200 cars for 7 years
	Total benefit	**5,879**	
C	**Derived values**		

(a)	Net benefit (Total benefit – total cost)	4,299	
(b)	B/C ratio	3.7	5,879/1,580

*FFR Revenue per car per year calculated as 0.5 GBP/kWh * 7.4kW * 24h * 1.16EUR/GBP * 365days/year*

Table 10 Financial costs and benefits of using Load Levelling for revenue generation

Sr. No.	Item description	Value (in thousand euros)	Explanation
A	**Cost Items**		
(a)	Purchase cost of V2G chargers	409	Calculated as Euros 3000 per bidirectional charger * number of chargers installed each year @ 50 in year one and 25 in subsequent years, with an NPV at 12% for 7 years
(b)	Fee cost (to pay a remuneration to the EV user)	30	20% of Load levelling revenues are paid to the EV user
	Total cost	**440**	
B	**Benefits**		
(a)	Load levelling benefits	154	Euros 994.82 per car per year *(as per Heilmann and Friedl, 2021)* * number of chargers available each year * NPV for 7 years at 12% at 30% utilization
(b)	CO_2 equivalent	22	Calculated at 0.09 Euros per kg of carbon reduction, leading to -Euros 16 per car per year -Euros 3,202.11 for 200 cars per year -Euros 22,414 for 200 cars for 7 years
	Total benefit	**177**	
C	**Derived values**		
(a)	Net benefit (Total benefit – total cost)	(-262)	
(b)	B/C ratio	0.4	177/440

Table 11 Financial costs and benefits of using Arbitrage for revenue generation

Sr. No.	Item description	Value (in thousand euros)	Explanation
A	**Cost Items**		
(a)	Purchase cost of V2G	409	Calculated as Euros 3000 per bidirectional charger * number of chargers installed each year @ 50 in year one and 25 in subsequent years, with an NPV at 12% for 7 years
(b)	Fee cost (to pay a remuneration to the EV user)	3	20% of Arbitrage revenues are paid to the EV user
	Total cost	**413**	
B	**Benefits**		
(a)	Arbitrage benefits	18	Euros 120.7 per car per year *(as per Heilmann and Friedl, 2021)* * number of chargers available each year * NPV for 7 years at 12% at 30% utilization
(b)	CO_2 equivalent	22	Calculated at 0.09 Euros per kg of carbon reduction, leading to -Euros 16 per car per year -Euros 3,202.11 for 200 cars per year -Euros 22,414 for 200 cars for 7 years
	Total benefit	**41**	
C	**Derived values**		
(a)	Net benefit (Total benefit – total cost)	(-371)	
(b)	B/C ratio	0.099 ≈ 0.1	41/ 412

Table 12 Financial costs and benefits of using Peak Shaving for revenue generation

Sr. No.	Item description	Value (in euros)	Explanation
A	**Cost Items**		
(a)	Purchase cost of V2G chargers	409	Calculated as Euros 3000 per bidirectional charger * number of chargers installed each year @ 50 in

			year one and 25 in subsequent years, with an NPV at 12% for 7 years
(b)	Fee cost (to pay a remuneration to the EV user)	1.6	20% of peak shaving revenues are paid to the EV user
	Total cost	**410**	
B	**Benefits**		
(a)	Peak shaving benefits	8	Euros 52.86 per car per year *(as per Heilmann and Friedl, 2021)* * number of chargers available each year * NPV for 7 years at 12% at 30% utilization)
(b)	CO_2 equivalent	22	Calculated at 0.09 Euros per kg of carbon reduction, leading to -Euros 16 per car per year -Euros 3,202.11 for 200 cars per year -Euros 22,414 for 200 cars for 7 years
	Total benefit	**30**	
C	**Derived values**		
(a)	Net benefit (Total benefit – total cost)	(-380)	
(b)	B/C ratio	0.075 ≈ 0.08	30/410

7.2 Comparison of the Various approaches to Revenue calculation

The following table lists some of the advantages and disadvantages of the four methods of revenue calculation. This table provides an easy reference for a decision maker at Schiphol Airport to evaluate and compare between the different options available for generating revenue.

Table 13 Comparison of the different approaches

Method of Generation of Electricity Revenue	**Benefit-to-Cost ratio**	**Advantages**	**Restrictions**	**Conditions if any**
FFR	3.70	High revenue	Minimum 1MW capacity required	Minimum requirements may pose a problem
Arbitrage	0.40	Easier to integrate technically	Not much revenue	NA

Load levelling	0.10	Decent valuation and grid benefits	Poor revenue, potential requirements for complicated contracts	NA
Peak Shaving	0.075	Can avoid grid outages (including around Schiphol Airport)	Poor revenue, potential requirements for complicated contracts	NA

7.3 Findings of the CBA study

The following are the findings of the CBA study:

1) Overall, the Benefit-to-Cost ratio is greater than one in only one of the 4 ways of calculating electricity benefits (using the Firm Frequency Regulation method), for a 7-year project period.

2) Benefit-to-cost ratios that are greater than one, are obtained even at “low” (7.4kw) (dis)charging power.

3) Electricity revenue is the main income, potential revenue from carbon dioxide reduction is relatively not much.

4) Firm Frequency Regulation offers the best returns to Schiphol Airport. FFR revenues being high enough is a sufficient condition for feasibility. If in place of FFR, other approaches for revenue calculation are used, commercial feasibility is not guaranteed.

7.4 Impact of Volume or Scale of V2G chargers on Benefit-to-Cost ratio

It is observed that changing between 50% and 100% V2G charger conversion does not affect the Benefit-to-Cost ratio. This is not surprising given that the costs (mainly from new EVSE) and the benefits (mainly from FFR revenue) both, scale linearly with the number of chargers, keeping everything else constant (ceteris paribus). Hence Schiphol Airport’s choice to convert half or all chargers is purely up to them and may depend on other reasons such as logistical ease etc. It has no direct bearing on the Benefit-to-Cost ratio.

The Airport may hence choose to convert 50% or 100% of their EV chargers to V2G. If they are optimistic, they may convert all chargers to V2G. However, they may choose to keep and install a few G2V chargers for cost reasons. They may also phase it out such that existing chargers are gradually replaced with V2G ones, as the old ones need to be replaced.

7.5 Conditions in which the Benefit-to-Cost ratio is greater than one

We now answer the first sub-research question “Under what set of conditions will a V2G project at Schiphol Airport, be commercially feasible?” The second sub-question is answered in Chapter 8.

The necessary conditions are as follows:

1. Use of FFR to calculate electricity revenue
2. A revenue of 1.28 Euros per car per day to ensure the recovery of costs incurred by Schiphol Airport
3. A minimum V2G utilization of 135 cars at 7.4 kilowatts each, to fulfil the statutory requirement of a minimum 1 Megawatt of power, in case of use of FFR

A detailed explanation of the above is as follows:

1) Choice of FFR for generating revenue
   Condition: Firm Frequency Regulation (FFR) must be used to generate revenue.
   Explanation: Based on existing electricity market pricing and the results from the modelling, only FFR provides a Benefit-to-Cost ratio greater than one.
2) High revenue from electricity
   Condition: FFR (or any other grid service) needs to pay out a minimum of 1.28 Euros per car every day for the V2G project to be financially feasible.
   Process of determination of the condition: This value is derived by calculating the break-even point where the combined values of the revenue from the electricity service and the carbon benefits match the total costs.
   The total cost of the project, Euros 409,246 is divided by the number of years of this study, i.e., 7, to first arrive at Euro 58,463.7 as required income per year, divided by 125 cars that will use the V2G chargers, giving Euros 467.7 per car per year, divided by 365, thus deriving Euro 1.28 per car per day.
3) Minimum contract requirements
   Condition: Schiphol Airport will need to provide enough power to meet the minimum legal requirements of 1MW, in case of FFR use. At 7.4kW V2G chargers, this implies the need for at least 135 cars.
   Process of determination of the condition: 1 Megawatt divided by 7.3 kilowatt chargers needs 135 such chargers.
   Explanation: In the case of selling in the FFR market, there is a minimum bid size, measured in power available to supply/use. In the Netherlands, which is part of the common European Frequency Containment Reserves Market, this is 1 MW.
   For example, with a 1MW minimum capacity, 135 cars are required at 7.4kW a car. If more powerful V2G chargers are used, this can significantly decrease as some cars can support up to 100kW of battery load, at which level only 10 cars supplying power are required.

Charger costs are the sole cost impacting the Benefit-to-Cost ratio. However, given the strong likelihood of falling costs due to technological development, and hence the ratio improving with time, this cost does not need to be considered as a boundary condition (Bleakly, 2023).

7.6 Limitations of the modelling

1) The modelling method used for the sake of ease of calculation has taken a simpler method of calculating revenues and does not consider latent values of new chargers installed

towards the end of the project. A charger purchased in year 4 would continue to provide revenue beyond year 7, but this study ends at year 7. Hence a separate lifecycle assessment of the charger has also been carried out in the appendix.

2) Additionally, Excel has been used for calculations. However, more nuanced calculations could be done using Monte Carlo or other method.
3) Only a 30% utilization rate has been taken. Higher rates will improve feasibility while lower rates may make the project unfeasible.
4) While combining different services has improved revenues, this has not been modelled in this study. The extent to which this can improve can vary, and for some cases like load levelling, frequency regulation is necessary in addition to make it profitable (White and Zhang, 2010).

7.7 Conclusion

In this manner this chapter conclusively answers the first sub-question of the primary research question that the study began with. In the next chapter, the second sub-question is answered. However, in a real-life scenario for such a project one would also need to ask the question "What are the likely risks associated with the project? Are there ways to mitigate the same?" Answering these questions makes the study more robust. This is done in the next chapter.

Chapter VIII- Risks Management Analysis

8.0 Introduction

As mentioned in Chapter 3, this chapter analyzes the associated risks and their mitigation strategies for the V2G project at Schiphol Airport. As with every project and Business Case, a study of Risks is an important step before taking a final decision on the implementation of the project. Identifying key risks enables an understanding of the risk spectrum, which in turn, enables decision-making. Identifying risks and positioning them appropriately on a Risk matrix enables the following: Rating and prioritization of risks, proactive Risk Management, promoting a culture of safety in the workplace, reduction in insurance costs and improvement of project outcomes

Having in place a good Risk Management policy will help Schiphol Airport for the following: Identifying of risks, assessing their likelihood and effects, and determining risk mitigation strategies. Also, many risks are dynamic, and of a nature that need to be periodically monitored to ascertain whether the risk is crossing an acceptable limit at any point in time.

8.1 Identification of Key Risks

Based on the study of the model made for the FCBA analysis, the key impacting parameters on the project returns (both in terms of costs as well as revenues), have been identified. Since a change in the value of these parameters would have a disproportionate impact on the returns of the project, it is helpful to monitor these parameters more than others.

8.1.1 Risks relevant to Schiphol Airport

The following 5 risks have been identified as key risks for Schiphol Airport, which would require monitoring:

1) Lower than expected usage of EVs – a critical mass of EVs is required for V2G to be successful (Interview 4)
2) Non-adoption of V2G due to various reasons
    a. It is possible that a significant number of EVs will not support V2G, technically preventing the project from being successful.
    b. There may be users' concerns about battery degradation that result in unwillingness to use V2G.
    c. Potential users may be unhappy with the amount of remuneration provided, as the income from their share of the sale of electricity is likely to be significantly lower than the parking fees for an equal amount of time.
    Multiple technical and practical challenges need to be resolved in all likelihood by a central authority like a government for V2G to be mainstreamed (Interview 1)
3) FFR-related risks for Schiphol Airport
    a. The study takes the present FFR market rates for revenue generation. This requires similarly competitive rates to continue for the duration of the 7-year project

b. The requirement of 135 cars for V2G to fulfill 1MW requirement (as explained in 6.3.2)
c. Regulatory bodies preventing Schiphol from offering V2G as a service

4) Unwillingness of grid operators to pay well for frequency regulation services
5) Limitation of existing electricity grid infrastructure near and around Schiphol Airport to handle large amounts of back-fed electricity
6) High competition from nearby projects for V2G in Amsterdam lowering the benefits of Schiphol Airport providing V2G
7) Development of mega battery storage systems, rendering V2G unnecessary
8) Unexpected surge in cost of chargers (owing to resource crunch of raw materials)

Table 14 Risk Likelihood Matrix

Sr. No.	**Risk Title**	**Likelihood score (L)**	**Effect score (E)**	**Risk Score (L times E)**
1	Lower than expected usage of EVs	2	3	6
2	Non-adoption of V2G by EV users due to various reasons	3	4	12
3	FFR-related risks for Schiphol Airport			
4	The unwillingness of grid operators to pay well for frequency regulation services*	2	5	10
5	Limitation of existing electricity grid infrastructure near and around Schiphol Airport to handle large amounts of back-fed electricity	1	4	4
6	High competition from V2G projects in Amsterdam lowering the benefits of Schiphol providing V2G	1	3	3
7	Development of mega battery storage systems,	1	4	4

	rendering V2G unnecessary**			
8	Unexpected surge in cost of chargers (owing to resource crunch of raw materials)	2	4	8

** Since revenue is obtained from grid operators, this is the single most impactful factor in the Risk Matrix, and hence a weight of 5 has been given to its effect.*

*** This is a potential technology disrupter and (if it comes) has the possibility of rendering V2G completely unviable. However, as of date, the technology is not commercially feasible.*

8.1.2 Risks for the V2G ecosystem in general

According to some of the experts interviewed, there are risks applicable to the V2G ecosystem. These may directly impact the adoption of V2G and therefore indirectly impact Schiphol Airport.

For example, many EVs currently being used are not designed to be V2G enabled. Further, technical standardization is challenging for cars and batteries and hence the standardization of calculations of costs and benefits is also challenging. Different battery chemistries may need to be worked with (Interview 1).

8.2 Key insights from the Risk Matrix and Risk Mitigation Approaches for Schiphol Airport to consider

Table 12 shows the areas where Schiphol Airport should focus on when it comes to Risk monitoring. The following are the key insights from the above.

Specific Approaches:

1) Acceptance by EV users and V2G adoption
    - As adoption by EV owners is a key element in Schiphol Airport's success, the management could use its resources to advertise to encourage V2G adoption in its airports as much as possible. This is because increased EV adoption is the single most important factor for the success of the V2G initiative.
        - This aspect about the adoption of V2G being necessary was also mentioned in Interview 4, as a critical mass of EVs may be required for a V2G ecosystem.
    - Schiphol Airport could consider providing creative sops to encourage parking of EVs in its parking lots, like offering free parking schemes or giving monthly prizes to the owner whose car has contributed to maximum electricity transfer to the grid through V2G.

        - They may also either offer higher remuneration to the vehicle owners, or offer free parking for a limited time period.
    - On account of its leading role in The Netherlands, the Airport can influence policy-making at the governmental level for increased adoption of EVs and for incentivizing EV users to adopt V2G.
2) Unwillingness of grid operators to pay well
    - Given the volatility of electricity pricing, Schiphol Airport may consider this as a medium-to-long-term risk.
    - Due to potentially increasingly unstable/unpredictable grids due to growing renewable energy, electricity companies may be willing to pay more for frequency regulation. While it is not something for Schiphol Airport to act on, it can help as a risk mitigator for them.
        - For example, pricing trends from 2023 to 2024 in the Dutch electricity market rates show an increase in value for frequency regulation price (ENTSO-E, 2024). While future prices cannot be accurately predicted, it is likely that FFR stays profitable in the future as well.
    - An important area of focus which comes out from the table above is that Schiphol Airport should engage deeply with the grid operators to get good rates in their contracts for selling power for frequency regulation. Here, they may also have to negotiate with aggregators to ensure that whatever quantity of power it can sell is purchased by the aggregator.
3) Regulatory bodies preventing Schiphol from offering V2G as a service
    - Schiphol Airport could form a subsidiary company or LLC to conduct such business.
    - However, they would need to check with the laws to ensure such a creation of a subsidiary is allowed legally.

As the other risks have lower scores, specific risk mitigation strategies have not been developed at this point of time.

General Approaches:

1. Schiphol Airport should define acceptable levels of risk.
2. A Risk Management Committee should be formed to periodically conduct risks audits to analyze market trends in renewable energy and electricity markets and EVs and V2G. This will help ensure that Schiphol Airport's V2G project is aligned with the technical and economic developments of that time.
3. The risk matrix needs to be updated periodically (perhaps every quarter), and this will help them take corrective action from time to time.

8.3 Conclusion

This chapter has considered possible risk factors and their mitigation strategies. A practical question to ask at this point is in the worst-case scenario of this V2G project not delivering the expected Benefit-to-Cost ratios for Schiphol Airport, what would be the maximum financial loss to Schiphol Airport? As previously mentioned in Section 1.10, the total cost of the project is less than 0.2% of Schiphol Airport's 2022 Annual Investment Budget of EUR 444 million. In 2023 the airport invested EUR 678 million, an increase of 53% (Royal Schiphol Group, 2022). Evidently, the cost of the V2G project is like the proverbial "drop in the ocean" for Schiphol Airport. Therefore, considering the social benefits and the greater good of society, Schiphol Airport can easily implement the V2G project.

In the next and final chapter, the study offers suggestions and recommendations that Schiphol Airport may consider for implementing its V2G project.

Chapter IX – Conclusion of the study, Recommendations for Schiphol Airport, Future Trends and Areas for Future Research

9.0 Introduction

So far, the study has looked at modelling for Schiphol Airport. The first part of this chapter concludes the findings. Going beyond the obvious, however, it can be helpful to ask why Schiphol Airport has not already implemented such a system from a practical perspective. This chapter offers recommendations to Schiphol Airport in this context, along with potential areas for further research. Future trends that the Airport may want to consider to understand the V2G ecosystem, are also mentioned.

9.1 Conclusions of this study

Based on the research done on the potential for V2G for EVs, evaluation of the financial viability of such ventures through a study of monetization options considering the costs and benefits, study of the associated ecosystem and mindful of green benefits which can be harnessed, it is found that V2G for EVs in a captive parking lot, like an airport is viable. While the study does not include the social aspects of V2G adoption, or any government taxes or subsidies, the findings indicate that it is worthwhile to pursue V2G adoption from a financial perspective as well as sustainability perspective.

The key conclusions of the study can be summarized as follows:

The study answers the research question, and shows that under a certain set of conditions, namely, use of FFR, generating at least Euro 1.28 per car per day, and meeting the statutory requirement of 1-Megawatt for FFR, V2G is a financially feasible option with a Benefit-to-Cost ratio that is greater than one. Hence Schiphol Airport may consider implementing this V2G project.

An insight that emerges from this study is about the generalization of such V2G projects at other airports outside of the Netherlands, being financially feasible. This generalization assumes that the airport has a scale similar to that of Schiphol Airport, similarly profitable FFR markets in the country, and similar regulations related to the FFR market.

9.2 Possible reasons why Schiphol Airport may not have looked at V2G in the past:

While it appears that under the specific conditions mentioned earlier, the V2G project is a good idea for Schiphol Airport to implement, there could be some possible reasons as to why this initiative was not pursued so far. These may be:

1) As an airport, making profits from energy services is not their primary objective.

2) They may have never conducted a study to look at the feasibility of V2G as a revenue source, or perhaps the cost of such a study using a consultancy agency was comparable to the potential profits.

3) They may gain more profits from investing the money for passengers in the airport.

4) They may be restricted from selling or providing such services under governmental rules or laws.
5) To meet the statutory requirement of 1-Megawatt under FFR, the required number of EVs using V2G is 135, which is a higher number than the current usage of EV charging at the Airport.

9.3 Recommendations for Schiphol Airport

Based on the above study, several aspects of pursuing V2G at Schiphol Airport become clear. It is possible to identify a set of specific recommendations for them to adopt for pursuing V2G as both, a sustainability initiative as well as a business opportunity.

Hence the key recommendation is: Schiphol Airport may implement this V2G project.

Further, Schiphol Airport may consider various suggestions in order to increase the likelihood of success of the V2G project.

The following is a set of such suggestions or recommendations for the Airport. *It may be noted that some of these recommendations are also strategies for risk mitigation, as seen in Chapter 8, 8.2. However, as the following section offers a concluding list of recommendations, the overlap has been deliberately retained to maintain comprehensiveness.*

1) Recommendations related to use of FFR:
    a. Contract size negotiation: They could negotiate with the energy company as they may be able to get favorable conditions including lower minimum supply requirements.
    b. Improved revenue rates: Contract deals with electricity aggregators can significantly help, especially for frequency regulation at low scales. This would be for better FFR payback revenues.
    c. Services of an aggregator can be used essentially if Schiphol Airport alone cannot manage to provide the 1 MW which is the minimum requirement for FFR.
    d. They Airport could consider appealing to the government for changing the FFR requirements (so that even smaller loads are acceptable for FFR).
    e. In order to meet the statutory requirement of 1-Megawatt for FFR, the Airport may use their own fleet of electric ground vehicles. By doing so, the Airport may be able to provide the V2G service more easily, especially at night.
2) Recommendations related to increasing adoption of V2G by EV users
    a. Schiphol Airport can consider making parking free for an introductory period to incentivize V2G use. The ideal duration for such a "free parking" period, or the optimum sharing percentage is best worked out by Schiphol airport with the usage data (which is proprietary) that they have.
    b. In order to overcome the risk of low adoption of V2G by EV users due to concerns of range and charge, the Airport can fine-tune its service by requesting its clients to provide information on charge profiles and acceptable V2G usage. For example, a

certain EV user could potentially favor revenue and lower residual change in his car at drive-out time if say, he lives in Amsterdam. Another user who lives in say Maastricht is likely to prefer a fully charged battery even at the cost of lower revenue upon his return to Schiphol Airport to drive his car away. This would reduce concerns of EV users and hence increase adoption of V2G.

c. In order to address the aspect of low adoption of V2G due to concerns about battery degradation, the Airport could undertake construction of covered parking as a service to the customers who park their cars. This will enable longer battery life for the parked EVs especially in summer when the heat might damage car batteries in the long run. The cost of such parking has not been considered in the model as it would be part of overall airport infrastructure development for Schiphol and not just for the V2G initiative.

d. Schiphol Airport should leverage its stature and reputation, and push for enabling regulatory policies which will enable positive outcomes for both Schiphol as well as society. It could use its vast real estate and huge visible spaces for running various campaigns to increase awareness for V2G adoption.

3) Other recommendations:

a. It is more beneficial to Schiphol Airport to invest in the V2G project in a full-fleged manner rather than as a pilot project. This view is supported by two findings:

  i. A Single charger benefit-to-cost ratio using FFR provides a ratio of 3.2 (Appendix G). The benefit-to-cost ratio for the multi charger project is better than that for the single charger across the same time duration. This is because in the reference case, Schiphol Airport gains from falling charger costs across the seven-year timeframe, and the average charger cost is therefore lower for the project as a whole.

  ii. As mentioned earlier, Schiphol Airport has mentioned its target of being the world's most sustainable airport by 2030. This V2G project can form a significantly part of their sustainability goals.

b. Since the charger cost has a significantly higher impact on the Benefit-to-Cost ratio compared to other factors, it is worthwhile for Schiphol Airport could negotiate contracts with EVSE companies owing to their large scale of purchase. Even slightly lower charger costs can help a lot with commercial feasibility.

c. Currently, carbon benefits have a relatively small but steady impact. The impact may increase with time, due to social awareness and government regulations. So, Schiphol Airport should keep an active lookout for possible changes in regulations or norms in the carbon trading space, and be in readiness to act fast should a business opportunity manifest itself.

d. Schiphol Airport could include the V2G initiative in the Airport's Risk Register as an item for periodic review from the Risk management perspective. This has been detailed in Chapter 8, Section 8.2, general approaches.

9.4 Future Trends

In order to better understand the V2G ecosystem, and perhaps even consider scaling up such a project in future, Schiphol Airport may want to know the likely future trends in V2G. This will help the Airport fine-tune its strategy for interacting with the various actors in this ecosystem. Hence, based on news articles as well as interviews of experts, the likely future trends in the V2G ecosystem are described here.

Energy companies may emerge as very significant players in the V2G ecosystem (Interview 1). This is because electricity pricing has one of the largest impacts on the benefit-to-cost ratio, and the ratio decides whether V2G is financially feasible, and therefore adopted by organizations such as Schiphol Airport.

Transport companies may begin to see themselves more as technology companies. Under V2G, vehicles become a store of energy. Further, with greater adoption of V2G, the role of technology and the use of algorithms will increase to enable data sharing between the grid, entities such as Schiphol Airports, and EVs. Therefore, EV manufacturers and the transport industry in general would gain by viewing themselves as more than automobile companies; they would also play the role of technology companies. Hence, smart cars, IoT (Internet of Things) and better connectivity will further boost V2G. In other words, the faster EV manufacturers view themselves as technology companies, the faster will be the move towards V2G. (Interview 1)

Since the V2G ecosystem requires novel collaboration between different actors, startups may emerge as the key enabler or a central hub supporting the adoption of V2G. (Interview 1)
Additionally, the government will play a key role in enabling and incentivizing infrastructure development for V2G adoption (Interview 6).

In countries where EV usage is high such as Scandinavian countries, the grid is often overloaded at night when most cars are set to charge. This is an opportunity to encourage V2G adoption for grid stability. Therefore, one may expect higher adoption of V2G as EV owners become increasingly conscious of the benefits of V2G. (Interview 4)

Office clusters may be incentivized to create V2G charging capacities for office vehicles which can be charged and discharged in a pattern that is complementary to household EV charging schedules.

High charger costs impact the feasibility of V2G projects. One of the ways of reducing charger costs is to utilize local manufacturing instead of relying on imported chargers. (Interview 6)

In time it is expected that with increasing competition the costs of chargers will come down.

9.5 Limitations of this Study

As with any study, there are always things that could have been done differently or more. For this reason, this section discusses limitations of this study, and the next section is the potential areas for future research.

The key limitation of this study is that it is undertaken from the perspective of Schiphol Airport. This is helpful from the practical perspective of Schiphol Airport being the decision maker. However, if the government is the decision maker for similar V2G projects, similar such studies would need to be conducted from the perspective of other actors or stakeholders.

Further, the actual implementation of V2G at Schiphol Airport would require collaboration between the airport and other actors like the electricity company, cloud-computing company, EV users and the government.

This study uses the FCBA, which as explained in earlier chapters, is a robust and widely used decision making tool for such projects. Further, an SCBA (Social Cost Benefit Analysis) can also be conducted. Factors for the same have been identified in Appendices A-D.

There are two limitations with regard to semi structured interviews with domain experts. The first limitation is the challenge in connecting with domain experts including executives at Schiphol Airport – this has restricted the number of professionals interviewed. The second limitation is that opinions and insights are prone to subjective bias, regardless of the expertise or credibility of the interviewee.

This study has used current frameworks and has extrapolated it across the project duration. V2G has not yet been widely adopted but is likely to be significantly more popular in the future. Therefore, policies, laws, government incentives, and frameworks surrounding V2G are likely to develop and evolve over the next few years.

The aspect of generalizability of this study across different countries may be considered a limitation as the results of this study are based on assumptions that apply to economically developed countries with free market systems, large and well-developed electricity markets, and awareness about EVs and sustainability.

9.6 Potential areas for Future research

V2G still being in a relatively early stage of development and adoption, would benefit a lot from further research, whose objective would be to make V2G more cost effective, and have wider appeal and acceptance. Research is required for both – technological improvement and cost reduction; as well as desktop research; wherein some more viable Business models for V2G could be designed.

Specifically, the following areas of technical research would be beneficial for the growth of V2G:

1) R&D on fast charging batteries – these would enable parked cars to get charged faster and thereby (dis)charge more electricity to the grid more.
2) Developing lower cost chargers would be another area of research – this would give an impetus to airports like Schiphol to go in for procurement of more chargers.
3) Further developments of smart grids, which would enable the grids to be made more amenable to getting fed through the V2G route (in terms of faster rebalancing etc.).

As regards Desktop research (or literature survey), available literature could be studied in depth to ascertain how V2G or, in a more general way, V2X as an energy-redistributing concept could be used widely, across all situations where there are parked vehicles including city parking lots, shopping malls, housing complexes etc.

This study analyses V2G at an airport. Other studies could consider long-parking clusters, including train stations, large offices, large residential complexes and so on. Municipalities could also come together for such a project.

Further, such a study can be made far more accurate by using internal and proprietary data from Schiphol Airport, with respect to parking, patterns of charging of EVs, duration of parking, variation of parking and occupancy rates through the day-night cycle, the week, the year and any other such pattern.

Finally, future research in this domain may need to pay greater attention to social acceptance of V2G. This is because social acceptance plays a key role in the adoption of V2G (as described in Appendix C), thus impacting the success of such a project.

9.7 Reflection

At a macro level, this study has explored the role of V2G for Schiphol Airport, as part of sustainability-linked initiatives. Various factors impacting the adoption of V2G have been identified. At a micro-level, the analysis has focused on the use of the FCBA and risk assessment, to enable the successful implementation of such a project by decision makers at the Airport.

Going beyond the financial benefits indicated by the positive Benefits-to-Cost ratio, such a project is worthy of consideration given its potential to benefit society primarily in three ways:

a. Protecting grid stability

b. Generating income for EV users

c. Reduced CO_2 emissions

There is an allied benefit as some users may opt for EVs over fossil fuel cars due to the financial benefits accruing from V2G. Thus, there is a cascading ripple effect of positive impact, benefiting various stakeholders such as EV owners, and cloud-computing software manufacturers. Society, as a whole, stands to gain the most from such a project, given the advantages of grid stability, reduction of CO2 emissions, and indirect impetus to shift towards cleaner energy systems in general.

Further, this study may be generalized and extended to other airports in the Netherlands, airports in other countries with similar scale of parking volume and EV usage, and other transport hubs such as train stations and large bus stations. While socio-economic factors and government regulations would play a role in the adoption of such V2G projects, the increasing importance of V2G as part of the energy system is indisputable.

A brief look at the Technological Readiness Level Assessment of V2G indicates that V2G is very likely to move in the coming years from being a theme for pilot projects, to the mainstream of energy systems. As an interviewee has said, vehicles will soon be seen as energy banks and not just transport solutions (Interview 1).

Thus, this study is a small but significant contributor to the body of knowledge of the V2G ecosystem. It is hoped that this study can thus add value towards a cleaner planet, and a society with more stable and sustainable electricity systems.

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Appendix A – Key Technical Factors Impacting V2G

Technical factors play an extremely important role in the adoption of V2G. For ease of classification of technical factors, they have been divided based on the physical location and interface. Hence, they are classified as:

a) Vehicle-side – including all battery-related factors
b) Charger-related – including the vehicle-charger and charger-grid connections/interface
c) Location-related and macro technical factors – for example parking lot and grid factors

The following diagram is a schematic representation of these three categories.

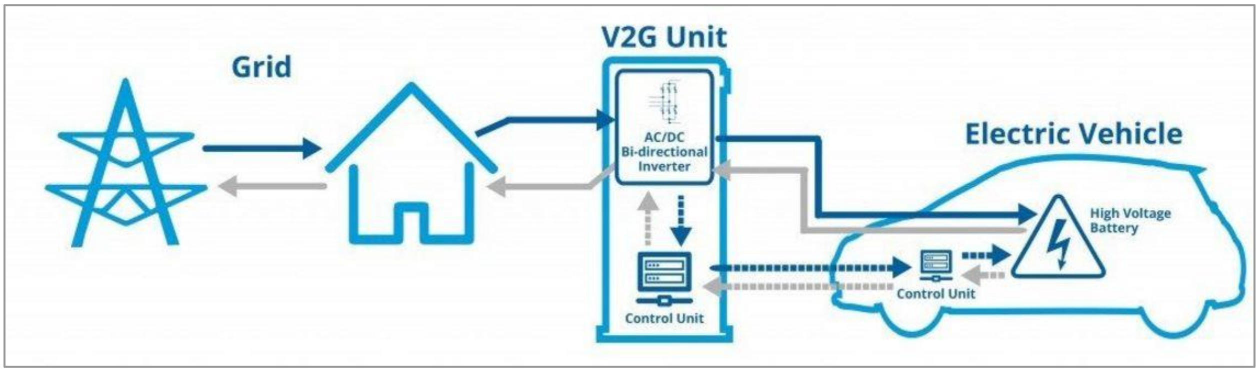


Figure 10 A schematic representation of three categories

Schematic representation of V2G (source: https://www.cleantech.com/ev-charging-software-and-grid-services/, image courtesy of CENEX)

a) Vehicle related technical factors:

Methodology:

No.	Search Engine	Search Terms	Filters	Articles
1	Google Scholar	“Battery Life” AND V2G	2019, plus sorted for relevance and citations	3,310
2	Google Scholar	“Technical factors” AND V2G	2019, plus sorted for relevance and citations	237

The following table briefly lists the key technical factors impacting adoption of V2G technology. The table is followed by an explanation of the factors.

No.	Factor	Reference Paper	Impact on adoption of V2G	Reasoning
A) Vehicle-related				
1	Battery life and battery degradation	Impact of V2G service provision on battery life – S Bhoir et al., 2021 Impact Analysis of V2G Services on EV Battery Degradation – A Review – J Guo et al., 2019 Assessing the socio-demographic, technical, economic and behavioral factors of Nordic electric vehicle adoption and the influence of vehicle-to-grid preferences by Chen et al., 2020	Harmful factor	V2G uses the battery more than regular (non V2G) EVV use, degrading it and lowering its life.
2	Battery throughput capacity	Uddin et al., 2018	Higher throughput helps, though it can also increase degradation.	Up to a point (before the grid connection becomes the weak link), more throughput helps. However rapid (dis)charging hurts battery life.
3	Battery chemistry	Miao et al., 2019	Varies	Some battery chemistries are more robust against thermal stress and degradation over a longer life.
4	Car's V2G capability	Bruinders, 2022	Necessary	Cars need to be designed with V2G in mind.
5	Charge/discharge speed and standard	Noel et al., 2019	Varies	Connector standardization is very helpful for V2G uptake/use. Different standards have different speeds, benefits, and drawbacks.
6	Connector type		Varies/no direct effect	
B) Charger-related				
7	Charger efficiency	D. Strickland et al.,2018, Heilmann et al., 2021	Variable	While fast chargers help speed up efficiency of the V2G system, these are

				likely to be heavier in terms of weight and more expensive
8	Charger connection to the grid	Letha et al., 2021	Positively linked	A larger/more powerful connection allows more power for dis/recharge which helps V2G.
C) Location-related and macro technical factors				
9	Grid congestion and load easing	Lopez et al., 2013	Positive	V2G can help supply power locally at times of high demand and hence avoid overloads and grid congestion/failure.
10	Long-term parking	Koen van Huelven et al., 2020	Positive	Long-term parking helps V2G significantly by increasing and guaranteeing available capacity.
11	Parking lot weight/size capacity	D. Strickland et al., 2018	Necessary	Higher EV size/weight necessitates a parking structure that can handle the weight.
12	Availability of public charging points	Hassler et al., 2020	Possibly necessary if not Positive/beneficial	More public V2G charger availability is necessary for adoption.
13	Time of parking per day	Maigha, 2018	Positively correlated	Longer parking time gives V2G more time to re/discharge and improves revenue and benefits.

Battery based factors include:

- **Battery life and battery degradation**: These emerge as extremely significant factors impacting adoption of V2G. Since batteries have a finite number of use cycles, the use of V2G technology leads to quicker degradation (Bhoir et al., 2021, J Guo et al., 2019, Chen et al., 2020). Hence, V2G is linked to shorter battery life. This is a known challenge for V2G adoption. However, the negative impact of V2G on battery life can be minimized, as explained here:

    - Primarily, there are two broad kinds of "Use cases" for V2G – frequency containment reserve and demand-based energy supply. Buying and selling electricity is considered a primary market activity, while services like frequency control are considered ancillary services.

- Buying and selling electricity during periods of high (or low) demand/supply generally involve longer periods for which the EV battery needs to charge/discharge, as periods of high/low demands generally last at the scale of a few hours.
- However, grid frequency varies at a much smaller timescale of minutes instead, which means that when the EV battery is (dis)charging, it does not need to (dis)charge for too long before it can again re/discharge.
- As lithium-ion battery degradation is heavily path-dependent, and increases with greater depth of discharge, very short charge/discharge cycles like in the case of frequency control are much easier on the battery.
- However, as noted by Bhoir et al.,2021, there is a power level beyond which the strain on the battery due to rapid dis/charging starts exceeds the gains. This was identified at 12kW in the paper.
- Hence 12kW is an ideal discharge power for frequency control.

- There is a moderate amount of literature on battery degradation prediction and modelling.
  - There are different kinds of models available to predict battery life. Empirical models generally are less complex but they also are less accurate as they often only test for a few variables at a time.
  - Battery degradation in V2G use also depends on battery chemistry. V2G use causes lower ageing for LFP/C li-ion batteries. (Guo et al., 2019)

- Battery throughput capacity
  - This is both the input (charging) and output (discharging) capacity of the battery. Larger batteries have larger power capacities.
  - C-rate – The C rate of a battery is a size-standardized indication of (dis)charge capacity. Higher C-rates mean the same sized battery can (dis)charge faster. (Charge and discharge speeds are generally corelated.)
    - E-rates are very similar to C-rates and are not taken separately.
- Battery chemistry
  - Different types of batteries of different chemistries can have significantly different properties. There are different types of lithium-ion batteries like Lithium Nickel Manganese Cobalt Oxide (NMC), Lithium Iron Phosphate ($LiFePO_4$) and Lithium Manganese Oxide with different energy densities, (dis)charge speeds, costs and lifecyle/degradation speeds. Miao et al. talk more about this in their 2019 paper.

Car-based factors include:

- V2G capability
  - Even though one might assume that EV growth automatically results in V2G growth, not all cars can support V2G as the OEM needs to add the necessary electronics and hardware for it. For example, the newer models of Nissan Leaf

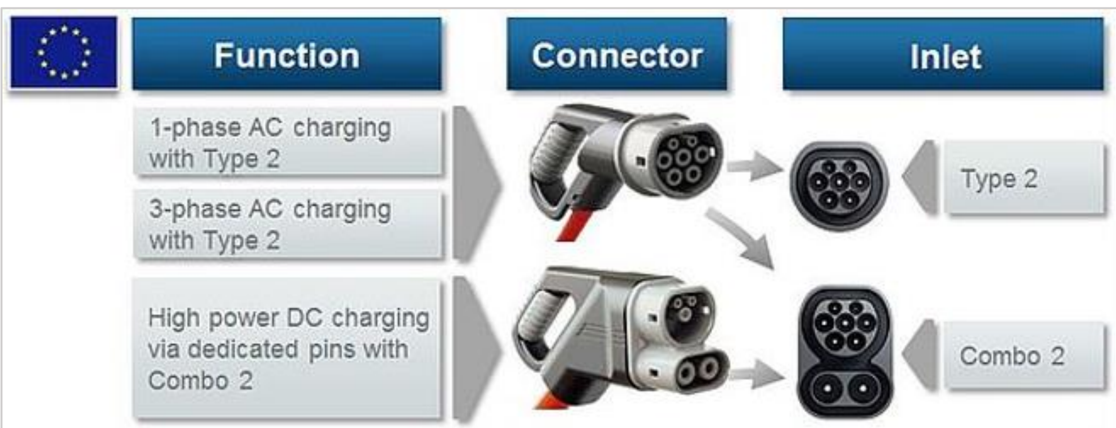
support V2G but Teslas (as of 2023) do not. Other cars like the Ford F150 EV and the Hyundai Ioniq 5 support V2Load. This is because there are only a handful of companies in the market working on V2G like Nuvve, Denso, Renault, and Honda. The lack of companies and research is a limiting factor for V2G adoption.

- Charge/discharge parameters including –
  - Speed – more expensive models generally can support faster charging speed, this however needs the battery, electronics and cooling/heating hardware to be designed appropriately.
  - Connector type – there are many different standards for EV charging. For example,

    "For the EU, the Alternative Fuels Infrastructure Directive 2019/94/EU (AFID) currently requires that all recharging points are, for interoperability purposes, equipped at least with socket outlets or vehicle connectors of Type 2, Mennekes (for AC normal and high power recharging points), and connectors of the combined charging system, CCS/Combo 2 (for DC high power recharging points)."

    (From Recharging systems, European Commission)

Figure 11 Types of charging connectors



b) Charger-based parameters include:

- The level of charger – Level 3 chargers are the fastest, while Level 1 chargers are much slower. Level 2 is in the middle. As per the AFIR proposal of the EU, these are the European classifications.

Category	Sub-category	Maximum power output	Definition
Category 1 (AC)	Slow AC recharging point, single-phase	P < 7.4 kW	Normal power recharging point

Category	Sub-category	Maximum power output	Definition
	Medium-speed AC recharging point, triple-phase	7.4 kW ≤ P ≤ 22 kW	Normal power recharging point
	Fast AC recharging point, triple-phase	P > 22 kW	High power recharging point
Category 2 (DC)	Slow DC recharging point	P < 50 kW	High power recharging point
	Fast DC recharging point	50 kW ≤ P < 150 kW	High power recharging point
	Level 1 - Ultra-fast DC recharging point	150 kW ≤ P < 350 kW	High power recharging point
	Level 2 - Ultra-fast DC recharging point	P ≥ 350 kW	High power recharging point

  - This is directly linked to the output power of the vehicle
- The connector to the vehicle and its standard
  - The earlier point and this point combined also determine if the charger outputs AC or DC power.
  - These points combined are discussed by Noel et al.,in chapter 3 “Technical Challenges to V2G” in Vehicle-to-Grid, 2019
- Connection to the electric grid
  - A high-speed charger requires a more capable grid connection. Domestic residential electricity connections cannot provide high-speed EV charging.
  - Even though EVs can supply 100kW+ of power, charging equipment and home-grid connection lines are the limiting factors. (D. Steward, 2017)
- Interfaces to the EV user and the grid
  - Some sort of interface in the form of a screen or app is necessary to communicate with the user for authentication, payment and optionally charge speed and parking time.
  - Grid information (over IoT) tells V2G and smart chargers what the current grid situation (demand/cost/frequency) is to choose to charge/discharge.
  - Khant et al.,discuss this in their 2019 paper where they talk about how wireless IEEE 802.11p standard is used for communication between vehicles and infrastructure (V2I). 2G, 3G, 4G, or WiFi may be used.
- Charger efficiency
  - About 20-30% energy is lost in V2G, which can be minimized by using higher power (dis)charging as mentioned by Noel et al.,in “Technical Challenges to V2G” in the book Vehicle-to-Grid.
  - Faster chargers help V2G efficiency but are more expensive and have higher weight, as shown by D. Strickland in 2019. This can impact retrofitting of bidirectional chargers in existing parking lots.

    - Location of power electronics
        - Putting them in the car can significantly reduce cost requirements. (D. Steward, 2017)

c) Large-scale/Location based factors include:

- Grid congestion and load easing
    - V2G can supply power to nearby locations with high demand on the grid during high demand and therefore reduce the amount of electricity that needs to be to transport that may have otherwise overloaded the grid.

- Parking lot related factors
    - There may be parameters necessary for EV charging parking lots. For example, as shown by D. Strickland in 2019, the higher weight requirements of EV parking may impact retrofitting/construction plans.
    - Amongst EV users who opt for long-term parking, consumer acceptance is a key factor impacting adoption of V2G, as shown by Koen van Huelven in 2020. Most people are amenable to V2G if they know the downsides like battery degradation and state of charge at the end, along with the environmental benefits, in addition to compensation.
    - Very short-term parking while using V2G results in an expected loss but increasing duration increases expected returns, as further indicated by Koen van Huelven.

- Availability of public charging points
    - In general, a high availability of charging points might be assumed to positively impact EV users' favourability.
    - However, Chen et al., found that the mere availability of public charging stations does not significantly affect EV adoption.
        - This is in contrast to preferences of EV drivers where 89% of participants rated it important.
        - This may be because availability is an essential factor, but is not enough of a push for adoption. It can be considered a "hygiene factor" as defined by Herzberg.
    - Adoption of EVs may be seen as a precursor of adoption of V2G.
- Lack of optimization/standardization of charging algorithms for time and prices
    - In V2G communication, charging stations calculate charging time and prices based on communication from vehicles. An EV user may find the lack of optimization/standardization of waiting time, charging price and discharging revenue (from V2G) as a factor limiting V2G adoption. The power grid by having a more optimized system can create a more predictable and transparent system for V2G which in turn help EV owners adopt V2G. (Hassler et al., 2020)
- Grid aggregator-scale factors for grid integration
    - As pointed out by Launinger et al., there are often minimum requirements for providing grid services. It may be difficult to guarantee a particular grid capacity for vehicles as they move and are unpredictable.

- Time of parking per day
    - Some vehicles like school buses are parked a lot, while taxis/fleet vehicles very little. Higher parking time boosts benefits of V2G.
- Communication protocol
    - While there are various protocols to optimize EV charge and discharge, the IEC63110 protocol is the one of the most relevant protocols today as per Bertrand, 2020. (Add Bangladesh paper citation.)

Impact of absence of internet can be mitigated by having distributed control at the charger location, and by providing primary frequency regulation (where the provided energy is based on local frequency conditions instead of centrally provided information.)

Battery costs are a major component of profitability for V2G along with vehicle availability, as noted by Das et al., 2023.

Appendix B – Economic Factors impacting V2G

There are several economic factors impacting the adoption of V2G. These have been categorized as per the actors or stakeholders who are directly linked to that factor. Hence, the sub-categories are:

a) Electricity pricing related factors
b) EV-user incentive related factors
c) Factors related to chargers, vehicle companies and other actors-related factors

Methodology: Recent papers were taken for the literature review, however older papers have also been taken when helpful or relevant, for example, a paper with 90 citations or by the US NREL (National Renewable Energy Laboratory (NREL).

Search Engine	**Search Terms**	**Filters**	**Articles**	**Relevant Articles**
Google Scholar	"Economic factors" affecting V2G	2019, plus sorted for relevance and citations	882	5
Google Scholar	"Economic factors" AND V2G	2019, plus sorted for relevance and citations	603	2
Google Scholar	"Economic factors" "Impacting" V2G	2019, plus sorted for relevance	112	1
Google Scholar	"Cost of bidirectional charger" AND V2G	None	2	1
Google Scholar	"Charger cost" AND V2G	2019	103	2

The following table briefly lists the key economic factors impacting adoption of V2G technology. The table is followed by an explanation of the factors.

No.	Factor	Reference Paper	Impact on adoption of V2G	Reasoning
A) Electricity pricing related factors				
1	Electricity pricing and variability	Yang et al., 2021	Varies	High variability, low base prices and high peak

				prices improves V2G profitability.
2	Feed-in tariffs	Richardson 2013	Beneficial	The subsidy will make V2G less expensive for early consumers and will help the technology mature.
3	Frequency variation	Calearo, 2020	Neutral	Variation of frequency gives revenue.
B) EV user related factors				
4	Financing		Positive	Offering financing options/lower upfront costs against V2G supply could help.
5	Battery cost	Calearo, 2020	Negative	Degradation means replacing batteries is necessary.
C) Factors related to Chargers, Vehicle companies and other actors				
7	Cost of charging hardware	PWC, 2021	Negative	V2G charging hardware is moderately more expensive than V1G chargers which hurts V2G adoption.
8	Opportunity cost		Varies	V2G may not have a high ROI in the

				short term but predicted lower costs will likely change that.
9	Cost of cabling to grid	Ofgem, 2021	Negative	These costs increase the cost of V2G.
10	Cost of IoT & communication hardware and running costs	NA		
11	Grid operator costs to instruct chargers			
12	Infrastructure for identifying and payment to user			
13	Carbon cost (rebates)	NA	Positive	These benefits can be paid back as revenue to all the actors in the system by either the government or the grid company.
14	Grid stability revenue			
15	Charger efficiency	Heilmann et al., 2021	Positive	Higher charger efficiency reduces overall loses and helps improve profitability.

a) Electricity price related factors:

Electricity price & its variability, ratio of highest and lowest price, payment from grid operator for frequency changes, and operator costs for investing in V2G are all commercial/economic costs.

- Actual electricity price and its variability
    - This includes the absolute prices of peak and valley prices as well as derived values like peak-valley ratio and daily variance in price.

        - Explanation – highly fluctuating prices (for example due to high and unpredictable renewable energy production) helps boost V2G's profitability.
    - Virtual power plants can be used to model EVs for V2G.
- Feed in tariffs:
    - Feed in tariffs would be helpful to subsidize V2G before it is fully commercially profitable.
    - This is because feed-in tariffs help promote new green technology by guaranteeing an above-market price for a particular time frame.
- Frequency regulation compensation
    - This is how much the grid operator will pay for frequency regulation service.

b) Incentivizing EV users

- EV users can be incentivized by providing revenue and/or services like free nighttime charging.

c) Factors related to chargers, vehicle companies and other actors-related factors:

- Cost of charging hardware
    - It is suggested by Steward that the cost of hardware for bidirectional power is the main cost for V2G. Annual maintenance costs are about 5% of equipment cost.
- Heilmann identified that frequency regulation has the best potential for revenue. Interestingly, secondary market frequency regulation has the best revenue predictions, while primary market makes some money and tertiary market regulation makes a loss.
    - High charging power and high efficiency both help V2G outcomes.
- Large battery capacity is also helpful.
- The same paper also identified that high charging power and high efficiency both help V2G outcomes.
- Similarly large battery capacity is also helpful for higher profitability.
- MatLab can be used to simulate power usage and models for V2G, as shown by Addou in their 2021 report.

From Hoj et al., 2018, the business models of V2G need to be financially sound and sustainable for it to be a commercial possibility. Aggregators will be the central actors in the future, as they will interface between users and grid operators by providing electrical services. Minimum bid sizes (like 1MW for UK) means that individual EV owners cannot directly sell power back to the grid without resolving regulatory mechanisms, or more likely, an aggregator.

Frequency regulation market pays for availability and not actual supply of service. This may be tricky as it will require predicting EV movement.

Another paper by Rios et al. found that even though the upfront cost of BEVs and PHEVs was higher than ICE vehicles, over time the lower operating costs offset it. Particularly with V2G EVs can produce upto $1400 per year to reduce ownership costs by 10% and operating costs by 12% compared to ICEVs. Additionally, as also noted by Heilmann, faster chargers offered more V2G revenue with an almost linear correlation. However, level 3 chargers need more investment costs which can offset the benefits. The authors found 19.2kw chargers the best compromise. This is also similar to the battery recommendations that high discharge powers can hurt battery life.

Gasoline prices are a factor that drive EV adoption. Additionally fast and ultra-fast chargers also help adoption as shown by Haidar et al., 2021.

As shown in Shenzhen by Li et al., government incentives can help a lot. Subsidies are helpful instruments to equalize costs compared to ICEs. Holding manufacturers responsible is also helpful to force iterative improvements. Giving end users the least risks also helps as larger companies can absorb it better.

Appendix C- Key **Societal** Factors Impacting V2G

There are many factors that impact V2G usage and viability. While a lot of them can be quantified, some are qualitative factors. Societal and non-technical/non-economic factors include factors that affect human psychology- for example how willing a person is to use V2G. Not all humans always act rationally, predictably or in their best interests if emotions are involved, something that behavioural economics acknowledges and studies.

Categorization based on literature survey:

Factors are/can be classified as human, large-scale/emergent, information or beliefs based. Most papers studying these factors are relatively recent, most of them are after 2016. Additionally, there does not appear to be any paper quantifying the social effects of V2G.

Driver/EV owner behavioural factors can be broadly classified as psychological or perception based, and knowledge or awareness based. Additionally, factors can also be environmental in nature. A fourth category of factors that emerges, is demographic factors. This includes gender, income, and size of the family. As this category may not directly impact policy-making or policy-shaping, it has been mentioned in the following study, but not considered as a priority for the overall study.

The study of societal factors looks at:

1. Key societal factors impacting V2G in general
2. Key societal factors impacting CBA for V2G at Schiphol airport – some of the above factors (1) are chosen and quantified for this purpose (2).

Figure 12 Categories of Societal Factors

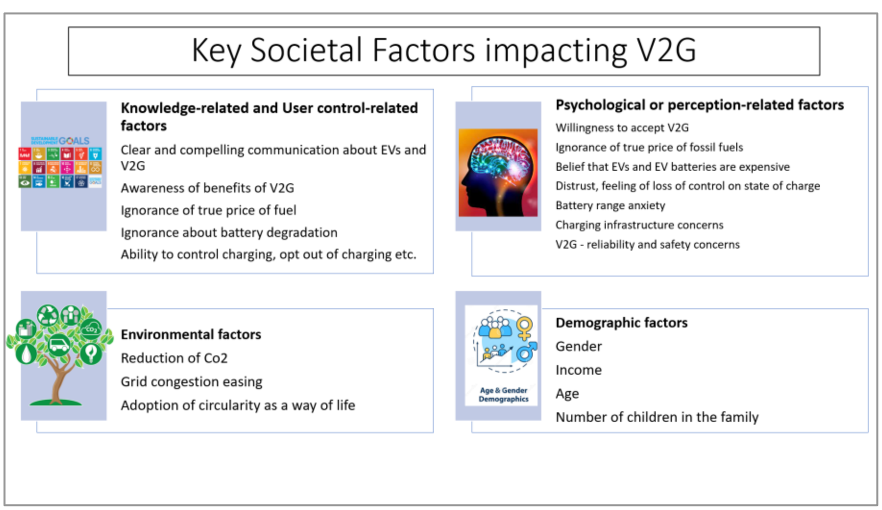


Table Summarizing Key Societal Factors impacting Adoption of V2G

No.	Factor	Paper Reference (Name, year, Authors)	Impact on adoption of V2G	Reasoning
A) Knowledge-related and user-control related factors				
1	Awareness of environmental benefits of V2G	Sovakool, 2018	Beneficial	Almost half of potential V2G users are willing to use it just because of the environmental benefits
2	Ignorance of true fuel price		Harmful	Most people don't properly calculate fuel prices, making EVs and V2G (with medium - long term benefits) look less appealing than it actually is.
3	Non-realisation of battery degradation		Neutral/beneficial	Average consumers do not always understand that V2G degrades battery capacity, leading to potentially higher interest. However consumers should not be misled.
4	Knowledge of: economic benefits for users, the effects of V2G cycling on the vehicle battery, environmental value of V2G charging, battery charging and status in real time	van Heuveln, 2020	Positive/Neutral	Informing users of the true costs and benefits/battery degradation is important. While some may feel relieved, others may choose to not use V2G.
5	Ability to set parameters on charging and to opt out of V2G charging		Postive	Giving users control over the process helps empower them.
B) Psychology or perception-based factors				
6	Willingness to accept V2G	Sovakool, 2018	Neutral/Harmful	Unfortunately the wta for people to use V2G is quite high. However proving 20% off electricity costs is more

				favourable for people on average.
7	Distrust of loss of control and battery state of charge	Sovakool, 2018, van Heuveln, 2020	Harmful	Consumers are often afraid of whether or not their EV will have enough charge or range (anxiety). There is a fear that an unknown algorithm will decide what happens to your battery.
8	Battery range anxiety	van Heuveln, 2020	Harmful	Anxiety over remaining battery percent after V2G can hurt its adoption.
9	Cost concerns	Sovacool et al., 2017	Harmful	High EV and charger cost perception hurts adoption.
10	Charging infrastructure concerns & Adequate access to V2G points	van Heuveln, 2020	Harmful	Uncertainty about availability of V2G charging points can turn away users.
11	Reliability concerns	Sovacool et al., 2017	Harmful	Concerns over battery reliability/degradation and safety hurt V2G adoption.
12	Safety concerns	Ghotge et al., 2022	Harmful	
13	Over-cautiousness	Behavioural modelling for personal and societal benefits of V2G/V2H integration on EV adoption, Kamini Singh 2022	Negative	
14	Risk Aversion			
15	Perceived relative advantage of V2G adoption	Economic, Functional, and Social Factors Influencing Electric Vehicles' Adoption: An Empirical Study Based on the Diffusion of Innovation Theory Zhengwei Xia, 2022	Positive	Users prefer products perceived as newer and hence better.
16	Perceived Complexity of V2G adoption		Harmful	Complexity turns away users.
17	Stickiness of humans to past behaviour and familiar choices	Sovacool	Variable	NA
C) Environmental Factors				

18	Reduction of CO_2 emissions	van Heuveln, 2020	Positive	Knowledge that V2G could help the environment helps V2G adoption.
D) Demographic Factors				
19	Gender (male)	Chien-fei Chen 2020, Assessing the socio-demographic, technical, economic and behavioral factors of Nordic electric vehicle adoption and the influence of vehicle-to-grid preferences	Positive	All these factors help EV adoption, and hence adoption of V2G by extrapolation
20	High income			
21	High number of children			

An elaboration of the above summarized societal factors, follows:

A. Knowledge and user control-based factors-

- Awareness of environmental benefits of V2G
    - Almost half of potential V2G users are willing to use it just because of the environmental benefits. (Sovakool et al., 2018)
    - However, they may not always be aware of this and may need to be informed.
    - Hence properly communicating this will significantly impact & help user-side adoption/agreeability. (van Heuveln 2020 Delft thesis, "Dutch electric vehicle drivers' acceptance of vehicle-to-grid at long-term parking")
- Non-realisation of battery degradation
    - Average consumers do not always understand that V2G degrades battery capacity, leading to potentially higher interest. However, consumers should not be misled.
- Ignorance of true fuel price
    - Most people do not properly calculate fuel prices, discounting the true cost of a fossil fuel vehicle.
- Belief that EVs are expensive
    - Consumers look at the upfront cost, making EVs and V2G (with medium-long term benefits) look less appealing than it is.
- Information on battery state
    - Transparent information on battery charging and status in real time is necessary to users for V2G to be acceptable. (Ghotge et al., 2022)
    - The effects of V2G cycling on battery life/degradation is also important for users to know.
- Knowledge of the financial compensation being received, particularly in context to the cost of battery degradation
- Ability to set parameters on charging and to opt out of V2G charging

- Additionally long-term parking and good trip planning integration was important at charging points for some users (van Heuveln et al., 2021).

B. Psychological or perception related factors are -

- Willingness to accept V2G
  - Unfortunately, the willingness-to-accept for people to use V2G is quite high. However, proving 20% off electricity costs is more favorable for people on average.
- Concerns about technical and economic aspects of EV use
  - Consumers have concern over factors like battery range, vehicle cost, charging infrastructure, reliability and safety of EV use. (Sovakool et al., 2018)
  - Consumers also have concerns over battery degradation and non-transparent user interface (Ghotge et al., 2022).

- Distrust of loss of control and battery state of charge
  - Consumers are often afraid of whether their EV will have enough charge or range (anxiety). There is a fear that an unknown algorithm will decide what happens to your battery. This lack of control is also noted by Ghotge et al., 2022.
  - Range anxiety in several forms can be a result of an unknown state of charge due to the EV discharging autonomously.

- Willingness (or its absence) to take risk
  - Overcautiousness & risk aversion by EV owners can reduce V2G adoption. (Singh et al., 2022)
- Stickiness of humans to past behaviour and familiar choices
  - User behaviour has been found to be "sticky" whereby people continue to have opinions and feelings biased towards their experience. Fossil vehicle owners are lesser likely than former EV owners to use EVs. Similarly, users shifting from fossil fuel cars value factors like fuel efficiency and cost more than EV users. (Chen et al., 2020)
- Adequate access to V2G points
  - An adequate number of V2G charging points with better standardisation affects consumer acceptance of V2G (van Heuveln et al., 2021).

- Perceived relative advantage
  - Defined as "the degree to which an innovation is perceived as being better than the idea it supersedes" it positively impacts EV and hence V2G adoption (Xia, 2022)
  - Perceived Complexity has a negative influence on ev adoption.

C. Environmental factors –

- Reduction of CO_2 emissions

- V2G vehicles can charge their batteries at times of high renewable energy production, and then discharge to the grid when renewable production is low, helping avoid the need to spin up coal/gas power plants.

D. Demographic factors –

For EV adoption in general, factors like gender (male), high income and high number of children positively affect EV ownership (and hence the eventual likelihood of using V2G.) (Chen et al., 2020)

Appendix D – Government and Regulatory Factors

Governments have different tools and instruments at their disposal to influence or control V2G usage and behaviour. The government can use:

1. Incentives or figurative "carrots" to encourage helpful behaviour,
2. Disincentives i.e., "sticks" to discourage unintended behaviour, or
3. Limit or restrict things.
    a. For example, governments can outright force/restrict/ban, to force actors (users, corporations etc.), or cap/limit to a value or ration/bid – for example ETS scheme for carbon trading.

Melander et al. (2022) noted policies that affect use of Electric Freight Vehicles (EFVs), suggesting that this is a topic worth studying for its impact. These can be laws and regulations that directly or indirectly put demands on firms, taxes or subsidies and environmental zones. Even though the study was specific to electric freight vehicles, the policies also apply to regular passenger vehicles.

Such policies can be targeted on different objects. It could be on:

1) Money (directly or indirectly),
2) Number of items (direct) – for example x non EVs allowed max
3) Number of items (indirect) – for example max carbon dioxide emissions per car or total of all cars is 2kg/day.

Hence, for example, some policies could be:

4) "Carrots" on item (direct) – EV rebates – as a fixed value, or percentage.
5) Stick on money – higher petrol taxes (unpolitical, though).
6) Indirect money for example tax subsidy
7) Governmental mandates, for example all school buses must be V2G

These can be formulated in a table as follows:

<table>
<tr><td colspan="2">Type of policy →</td><td rowspan="2">Incentive</td><td rowspan="2">Disincentive</td><td rowspan="2">Restriction (Partial/Absolute)</td></tr>
<tr><td colspan="2">Applied on ↓</td></tr>
<tr><td rowspan="2">Monetary values</td><td>Absolute</td><td colspan="3" rowspan="4">(Monetary amounts based on government decisions in future)</td></tr>
<tr><td>Percent</td></tr>
<tr><td rowspan="2">Number of items</td><td>Direct</td></tr>
<tr><td>Indirect</td></tr>
</table>

Policies currently in use:

Several governmental policies are already in place for climate goals and reducing emissions, including for EV use and adoption. IEA's 2021 report (Global EV Outlook 2021) shows which policies are mainly used and effective.

8) Subsidies for vehicle purchase cost and tax rebates for purchase or registration were the primary policies. This is helpful as EVs have a higher capital cost than ICE vehicles.
8.2 These subsidies were very helpful in countries like Germany, France and Italy, where despite the pandemic, the EV-based stimulus boosted EV growth.
9) Additionally, mandated electric charging points along with government funded/supported charging points have been used.
10) Low/zero emission zones in several cities have been implemented, along with preferential EV parking. While these factors may not influence a potential car buyer who is buying an ICE vehicle for cost or range reasons, it may influence someone who is on the fence.
11) On a longer timespan, several countries have pledged to ban non-electric or non-zero emission vehicles altogether. The Netherlands has banned non zero-emission vehicles post 2030.
11.2 Many countries have been continuously tightening CO_2 emission norms and standards over years.
12) Additionally, many countries have initiatives for manufacturing the EVs or their components like batteries.
13) Standardization also helps the end user.
13.2 Canada, China, the European Union, India, Japan, the United States all have hardware regulations for chargers.
13.3 All the above states except for Japan have charger hardware-based building regulations.
14) Some countries like China and states like California in the USA have emission credits, where there is a restriction on the percentage of polluting vehicles a manufacturer can make. Any manufacturer selling too many non-zero-emission vehicles needs to buy credits from EV makers.
14.2 In California, the calculation involves considering the EV range which means high-range EVs benefit much more.

Methodology:

The following search terms were used to find relevant literature.

Search Term	Search Engine	Filters	Results
“governmental factors affecting V2G”	Google	None	NA
“governmental factors affecting V2G”	Google Scholar	None	9750

Governmental Factors Table

No.	Factor	Paper Reference (Name, year, Authors)	Impact on adoption of V2G	Reasoning
1	Increased taxes on fossil fuel/ diesel vehicles	Melander et al., 2022; IEA 2021	Positive as these factors push users towards using EVs	Higher taxes on fossil fuel vehicles and lesser taxes/costs on EVs boost EV uptake and use.
2	Low taxes and subsidies on E(F)Vs			
3	Spatial restrictions like zero/low emission zones			Restrictions encourage users to take EVs instead of fossil vehicles.
4	Mandated EV charging points and government-supported/funded chargers	IEA, 2021	Positive for users	Better access to EV chargers helps users.
5	Sale-side EV quotas like ZEVs and EV credits		Positive for manufacturers	They force companies to sell a minimum number of EVs or pay other companies who make EVs.
6	Standardization of charging hardware		Positive for users	It makes it easier for consumer adoption.
7	Indirect benefits/boost like battery manufacturing subsidies/incentives		Positive for manufacturers	It incentivizes auto companies to set up manufacturing units in the country, increasing EV availability and manufacturing security.

Appendix E – Semi-structured Interviews with various Domain Experts

For the following Semi-structured interviews, appointments were sought with domain experts from the automotive, fossil-fuel-transitioning-to-clean fuel, and consultancy domains. A set of questions was prepared for each interviewee, based on their area of expertise. The topic of this study, and the objective for seeking practical insights from these industry practitioners, was explained. The interviews were conducted telephonically and permission was sought to name them in the Appendix section. Further, based on the answers given, additional or clarificatory questions were asked.

The questions, as well as the answers and insights are given in the following section. Keeping in mind the overall objective of each interview, the answers are categorized in terms of the nature of the insight, and not necessarily as per the question-answer format.

1. **Semi-structured interview with Dr Deb Mukherji (Automotive industry professional and Managing Director, Omega Seiki Mobility Pvt. Ltd., former Consultant)**

Thematic questions:

1. If V2G is a great idea, why has it yet to go mainstream?
2. What are the factors impacting the successful adoption of V2G technology? Or, what are the biggest obstacles in adoption of V2G?
3. What are some of the unique challenges in the V2G domain, due to the multiple actors or stakeholders?
    a. Who would be the central unit or actor, bringing others to the table?
    b. What are the practical approaches to finding solutions to the challenges of multiple stakeholders? Do these change for a developing country, as compared to a developed country?
4. What are the differences in V2G adoption strategies for developing and developed countries?
5. How do cars work as virtual power plants or stores of energy?

Answers and insights:

Insights into the power, automobile and V2G ecosystem:

- Tesla sees itself as a tech company; yet, it has a large share of the EV market. This is because it views transport as an industry that can gain from an IT or technological foundation.
- While V2G is a very promising technology, it is yet to take off in terms of volumes due to four primary reasons:
    - The concept is still relatively new; technology is at a nascent stage
    - Many EV automobiles currently being used were not designed to be V2G enabled

    - There are multiple technical and practical challenges that need to be sorted by a central entity, for V2G to get mainstreamed
    - There are other possible options of stationary energy storage being explored. Cars are more complex and dynamic compared to these.
- Technical and practical challenges for V2G in any country are the following:
    - Different standards exist for cars and batteries (car speeds, battery sizes and capacities, chargers, different connectors are not standardized or uniform, different voltages across different types of vehicles e.g. Output can be 48 volts for two-wheelers while trucks can use up to 350 volts).
    - Different types of lithium-ion batteries exist, and the advent of sodium batteries is expected. Hence different battery-chemistries need to be worked with.
    - Not all batteries can support V2G because of issues like thermal stress and impact on battery-life (degradation etc.).
    - The car needs to be capable of having V2G hardware and providing power to the grid. In other words, the EV needs to be designed with V2G in mind (e.g. The Hyundai is currently selling the "Ioniq 5" brand in India, with its Vehicle-to-load ability being advertised as a selling point).

      If, however, the architecture of the automobile does not have V2G systems, and an EV is retro-fitted with V2G systems, there may be compromises in safety standards and also an adverse impact on the life of the battery and the vehicle.

    - Volumes of EVs are low, hence V2G volumes are low.
    - Energy is a political commodity in many countries, developed as well as developing. Energy is closely linked to V2G, as the latter helps smoothen out grid congestion etc.
    - The energy situation of developing countries like India is very different from that of developed countries. There are a handful of government or public sector enterprises and a set of large, financially strong private sector players. The former companies are active in the B2B segment and not in the B2C or retail segment. Hence, they would find it challenging to approach potential or existing EV owners. However, the latter (i.e private companies) also invariably have front-end and backend integration of services and are much better placed to offer V2G.
    - In India, it is a seller's market for energy companies, as demand is far greater than supply.
    - While fossil fuels attract a high percentage of central and state taxes, electricity has far lower taxes. Hence, for the government, sale of petrol and diesel are more lucrative sources of revenue, while sale of electricity is not. So, in the absence of current pricing that reflects loss of tax-based revenue for the government (when people are encouraged to shift from fossil fuels to EVs using V2G), pricing of V2G incentives may be challenging.
    - A tremendous amount of coordination is required between automobile companies, manufacturers of batteries, manufacturers of battery management systems (BMS), energy companies, charger manufacturing companies, cloud-computing companies

providing real-time data on electricity pricing, the location chosen for V2G services and so on. These will require a start-up company, who helps enable the "handshake" between the various actors.

- Inertia of automobile companies has been a deterrent to V2G. Automobile companies have worked in the "silo system"; they have viewed only aspects such as engine efficiency, safety etc. Downtime (i.e. when a car is at rest) is considered as mere downtime today, whereas downtime is actually an opportunity for V2G.

Future Trends:

- V2G is a "when" and not an "if" for most countries in the future.
    - Battery capacity will increase and hence boost V2G
    - Rapid growth is expected shortly as we have reached the inflection point of growth
- In 5 to 10 years, the demand-supply gap in developing countries may reduce and the market may no longer be a seller's market.
- Energy companies may emerge as the most significant players in the V2G ecosystem
- Start-up companies will emerge as the enabler or central hub for V2G to be adopted on a large scale.
- Vehicles will be viewed as energy storage devices and not only mobility solutions. Thus, they will help provide circularity. The car will be virtually a power plant. Hence power sector regulations may partially apply to vehicles in the V2G ecosystem.
- "Car as a service" may emerge.
    - Private sector players may rent cars and other services as part of a package. Electricity and battery-swapping arrangements may be included.
    - A conglomerate of companies may offer a potential vehicle owner a single mobile application through which he or she can first, buy an EV, second, use V2G, third receive payment for the same, and so on.
- Battery costs will decrease.
- Battery charging time will decrease.
- Battery capacity will increase, leading to popularity of V2G.
    - With time, the battery capacity is likely to exponentially increase.
    - Recently, the battery manufacturer CATL announced a breakthrough – an ultra-high density battery of 500 WH per kg (April 2023). This will lead to greater battery capacity for the same battery-weight.
- V2G will eventually earn money.
    - As battery-technology improves and cost declines, batteries will store much more energy than what they need on a daily basis (E.g. a battery may have the capacity to run for 800 kms and may require to run only 200 kms), and hence they will be able to put back energy into the grid. Hence, V2G will become the norm.
    - Additionally, 80% of cars will be EVs by 2040 – this will also give a major boost to the technology needed for V2G.

    - Scalability will reduce battery costs, which will further attract more consumers, which will increase sales and improve margins for companies.
- Currently most cars are low-margin products in countries like India; hence there is low incentive to increase volumes of cars sold. V2G or V2L(Vehicle to Load) capacities may emerge as potential value-adds, allowing for higher pricing, and better margins.
- There may be clusters of V2G services at airports, large train stations and large bus stations. These would function as "hot spots" or hubs for V2G services.
- Smart cars, IOT and connectivity will further boost V2G.
    - Car may raise a red flag against V2G even when the car-owner wishes to use V2G, in case there is a safety or other technical concern.
    - Cars will communicate with the grid, and this communication will be integrated into V2G decisions, in addition to their owners' decisions.

2. **Semi-structured Interview with Mr Sameet Pai, Chartered Accountant, General Manager, Corporate Strategy department, Bharat Petroleum Corporation Limited**

    Thematic questions:

    a. As a senior professional in the petroleum industry, how do you deconstruct the various steps for a project, while making a base case and a project case (as distinct from a purely academic perspective)?
    b. What is the solution when relevant data is lacking? In what way do you use assumptions and extrapolations?
    c. When faced with a short-term capital expenditure project, how do you decide the timeline for which you will do a Cost-Benefit Analysis? For example, if you choose 5 years, and the ratio is unfavourable, do you also then check for 6 years or take similar approaches?
    d. What software do you prefer to use for CBA modelling?

Answers and insights:

- The first thing is to decide whether the model would be a capex (i.e. capital expenditure based) model or an opex (i.e. operating expenditure only based) model. This will then determine the steps for building the base case and project case.
- In order to choose between the capex and opex models, one may consider the following:
    - The Capex model is more conservative and comprehensive.
    - It is useful when the organization would like to own the assets (as opposed to leasing them out for a short duration).
    - It is also useful when the organization is fairly sure that it would like to continue with the project in the medium to long-term, for various reasons (not restricted to financial reasons, but including social benefit reasons).
    - It also implies that the organization is willing to accept the risk of low benefits in future, while incurring the initial cost outlay in the present.

    - The Opex model, on the other hand, is more appropriate when an organization is considering a project in an experimental way, in the short-run, is unwilling to take the risk of owning assets without assured benefits, and the project does not have non-financial benefits. It is a less conservative model.
    - An Opex model may also be useful when land procurement is a factor, since this is a time-consuming process. The organization may choose to initially begin a project with leased land, and therefore use the Opex model.
    - For long-term projects, the Capex model is better than the Opex model.
- In the case of V2G, given its strong social benefit, a Capex model would be more suitable.
- For an Opex model for V2G, however, while drawing up agreements with companies that provide charging equipment, one may estimate and use either cars per month or hours per day of charging as a metric to calculate the expected costs and revenues.
- After the appropriate model is chosen, one would choose either the Net Present Value (NPV) method, or the Project Payback method, or the Internal Rate of Return (IRR) method, to take a decision on the project.
- Fossil fuel companies transitioning into clean energy, are now increasingly using Business-to-Customer (B2C) along with Business-to-Business (B2B) models.
- In the absence of scientific data, one may use the most recent publications from credible and authentic sources, and then extrapolate from that to arrive at one's numbers.
- For deciding on a suitable timeline, while 5 years is appropriate for a short-term capex project, a very important aspect to consider is the life cycle of the asset. For example, if an organization decides to buy (and therefore own) the electric chargers for V2G, then the life-cycle of the charger will play a role in deciding the timeline for the Base case and the Project case. It is also possible that the life-cycle of the first line of chargers bought in the first year are 'wasted', i.e. the CBA has a negative ratio. With changes in technology and lower charging costs, the subsequent cycles may have a positive ratio. Hence it may help to take a 1.5 or 2-times period of the charger, as the timeline for the project. For example, if a charger's life is 4 years, one may consider 6 or 8 years to be the timeline.
- One would also need to consider the Terminal Value (TV) of the assets. Their resale value, if any, at the end of their lifecycle needs to be factored in. In case there are waste disposal fees, these may either be assumed to be nil (in case the fees are likely to be negligible) or extrapolated from present rates.
- MS Excel is possibly one of the most robust and useful tools for such calculations. While many other software programs exist, this one is usually enough to indicate the numbers for various scenarios, and therefore sufficient for decision-making.

3. **<u>Semi-structured Interview with Ms Esha Tulsiani, Manager (Finance), Retail Headquarters, Bharat Petroleum Corporation Limited</u>**

<u>Thematic questions:</u>

a. As a mid-management level professional in the petroleum industry, how do you deconstruct the various steps for a project, while making a base case and a project case (as distinct from a purely academic perspective)?
b. What is the solution when relevant data is lacking? In what way do use assumptions and extrapolations?
c. When faced with a short-term capital expenditure project, how do you decide the timeline for which you will do a Cost-Benefit Analysis? For example, if you choose 5 years, and the ratio is unfavourable, do you also then check for 6 years or take similar approaches?
d. What software do you prefer to use for CBA modelling?

Answers:

- To do a CBA for a project, from the practitioner's perspective, one would consider the following:
    - The cash inflows and cash outflows
    - The choice of Capex model or Opex model, based on the considerations of the organization
    - Expected growth or de-growth forecasts for that domain, like, increase in EVs
    - The costs would be held firm and unchanging while the revenues would be forecast in three scenarios – Optimistic, Pessimistic and middle-ground.
- For required data, it helps to find reports from a credible source, such as an international and reputed agency, and then build more numbers from such data. In case such reports are unavailable, one may simply use the "population" metric to build data. For example, one may compare the number of existing EVs in a country to its population to arrive at a percentage, then look at a city's population and use the earlier percentage to forecast how many city-dwellers would use EVs, and then finally add one's assumptions to fine-tune the forecasts.
- The timeline of choice would depend upon the specific assets of the project. For example, for an EV charging station-based project, the life of an EV charger may be a good criterion – the timeline can match such a life of an asset.
- Excel may be used for most calculations barring very complex scenario forecasts. Most "go" or "no-go" decisions for projects can be made using Excel.

4. **<u>Semi-structured interview with Mr Shubhankar Sen, Head- Electric Vehicles, General Manager. BPCL</u>**

<u>Questions:</u>

1. What do you think of V2G and what are the main barriers to its adoption?
2. Who would be the most important player in the V2G ecosystem?
3. What would be the role of the government in driving V2G adoption?

Answers:

- A critical mass of EVs is required for V2G to be successful.
- In countries like India and Vietnam, 2 and 3-wheeler vehicles are much more common than 4 wheelers, making up over 95% of the vehicle base. Only 50,000 EVs were sold in 2022.
    - The high battery cost is a deterrent in such price sensitive markets.
        - Two wheelers need smaller batteries, of 2.5 to 4 kWh, compared to say a 50 kWh battery for a 4 wheeler.
        - New car models like by the company MG are 2 doored, as smaller cars have smaller batteries and hence are cheaper.
        - The 1 million (10 lakh) rupee ceiling is an important one for manufacturers to keep their vehicle costs below, to be considered price-effective and not luxury.
    - In developing countries like India, purchase of EVs would be primarily driven due to lower running costs.
    - V2G needs many 4-wheelers with sufficient battery capacity to offer to the grid, and hence the absence of enough 4-wheelers due to price sensitivity is a barrier.
    - In the case of V2G, EVs need a separate grid connection with data communication for smart charging. Even within the same grid, EVs have to be viewed differently.
- In countries (such as Scandinavian countries) where EVs are relatively common, the grid is nearing an overloaded condition at night when most cars are set to charge. In India too, one-way EV charging exacerbates grid overloading and can cause outages. This is because the grid is configured for steady power consumption and not for night-time peaks. V2G can help address this challenge by easing the load.
- Notwithstanding the above challenges, given the advancements of technology, in the long-term, Vehicle-to-load or Vehicle-to-grid is very likely to become popular.
    - While the concept of V2G is good and there is interest this field, the evolution of V2G, implying mainstreaming, will take time.
    - In the initial stages, V2G may not be broad-based but may begin with either particular locations, or specific “use cases”. For example, fleet rental cars in developing countries, may not be a suitable “use case”, because of the reluctance of the owner / driver to discharge energy to the grid given that they are often constrained by the battery charge capacity.
    - V2G may be a part of small and self-reliant micro grids, allied with solar power.

- The use of renewable energy such as solar power, for V2G will be essential to avoid grid overloads, as the 2030 climate-control goals relate to a large percent of vehicles needing to be EVs and not fossil-fuel cars.
- Further, in developing countries like India, the increasing use of electric appliances like air-conditioners is already putting a strain on the grid. The agricultural sector is already struggling for power to run water pumps. The hinterlands have single-phase and poor capacity rural feeder cables. Incidentally, poor grid connectivity is true for certain areas of Europe too. This is a challenge for V2G.
- The energy providing company is the most important stakeholder in the V2G ecosystem and will have to drive the V2G initiatives. This is because their challenges with increasing distribution costs, and grid congestion are addressed by V2G. However, currently distribution companies in India are not actively considering or working on V2G, as they are busy dealing with the existing challenges faced by the grid. The linemen working on the grid are the only ones who are directly involved with the day-to-day grid challenges but they are ignorant about V2G and hence unable to influence decision-making in the management of their organizations.
- Interestingly, globally, the government may not wish to be a key or active stakeholder in this system. They may want to restrict their role to only giving subsidies or sops, which are also decreasing with time. In the case of India, it may be too early for government intervention.
- Most players in this field are start-ups, as they are willing to experiment.
- V2G requires stakeholders to have alignment of thinking.

5. **Semi-structured interview with Mr. Sunil Kumar (Retired Chief General Manager – Electrical, Maintenance and Projects, currently a consultant)**

Questions:

a. What does a grid operator/engineer think of the concept of V2G, and its potential benefits and drawbacks?
b. What are the challenges in the V2G domain from the perspective of the grid and IOT?
c. Why are power companies not taking the initiative to be the key player in the V2G sector?
d. What could be some of the ways in which these challenges are addressed?

Answers:

- There are several reasons as to why power companies have not been taking a key role in initiating V2G projects, especially in developing countries like India. these sometimes overlap with other challenges related to the adoption of V2G. The reasons include the following:

- There is loss of efficiency in discharging energy back to the grid.
- The batteries in cars are typically smaller than what is ideal in terms of storage of energy. For example, batteries with larger capacities that may be kept in residences are more suitable for discharging energy back to the grid. Smaller batteries may not be feasible in terms of the economics of the process.
- Grids, especially in India and in the African continent, already have existing issues related to reliability and maintenance. Grids may already be overloaded. Further, in these countries, there may be seasonal issues related to maintenance, for overhead grids (as compared to underground cabling systems), due to extremes of climates over the various seasons. Hence it would be challenging to introduce V2G in this scenario.
- The number of EVs that are charging from or discharging energy into the grid is variable at any point of time. Hence the grid cannot make accurate predictions about how much energy it will either need to supply, or will receive.
- V2G can make grids susceptible to malware or software virus attacks. It is a way in which grids can be vulnerable to ransomware.

- On the other hand, battery cycling can reduce battery degradation, thus addressing to some extent one of the challenges of V2G.
- Similarly, pre-determined cutoffs for energy discharge from batteries can address safety related issues as well as reassure EV owners who may otherwise be concerned about not having sufficient charge in the battery.
- Thus, there are several issues that need to be addressed before grid companies can begin taking the lead for V2G.

6. **<u>Semi-structured interview with Interviewee 6, Head – Electric Vehicles and Innovations Ecosystem, Morris Garages (M. G. Car Company Limited), India</u>**

<u>Questions:</u>

a. What is the present level of acceptance of V2G, with respect to an automobile company that manufactures EVs?
b. What is the key challenge for the mainstreaming of V2G?
c. Charger costs seem to play a significant role in the acceptance of V2G projects. Could you share your opinion on this?
d. What is the future of V2G, in general?
e. What are some of the possible future trends in this domain?

Answers:

- V2G falls under the overall umbrella of V2X. This is a relatively new and important area for automobile companies that are either manufacturing EVs, or plan to manufacture EVs. While at present V2G has not yet been widely adopted (in India, and in most countries of the world), this is likely to be an area of opportunity in future. Hence, there is acceptance for the idea, but the implementation of V2G projects can only happen in future.
- There are multiple factors that are challenges for the mainstreaming of V2G. Foremost is grid readiness. This is especially true in developing countries. Further, other technology-related challenges, including EV-readiness, battery and charger-related issues, also play a significant role.
- Charger costs indeed play a very significant role in the acceptance of V2G projects. The cost of bi-directional chargers is still very high.
- However, with increasing competition in the market, the costs of chargers are likely to decrease with time. In India, for example, there are an increasing number of start-up companies who are planning to manufacture chargers. 90% of L1 and L2 chargers used in India for EVs, are made in India.
- However, the market in India and other such developing countries, can be challenging, and market-developments can be very fast. Original Equipment Manufacturers (OEM) will have to move quickly to adapt to such markets. Countries will have to use locally-made chargers and rely less on imported chargers, in order to bring down costs, for V2G projects to become more financially feasible.
- The power grids are far more advanced in developed countries, as compared to developing countries. These grids are more suited for enabling V2G projects. However, government support may still be required in for some years, for financial feasibility reasons.
- At present, V2G is still a “niche” area. This is why there are numerous pilot projects for V2G globally; however, there are very few large-scale or mainstreamed projects. As the technological challenges for V2G get addressed with time, this will begin to change.
- Battery capacities will increase with time and technological advancements. In general, battery technology is evolving very fast. For example, lithium-ion cells may become obsolete, while Hydrogen Fuel Cells become more popular.
- V2G projects will need several “players” to collaborate. Manufacturers of EVs have to work in tandem with places such as airports or other large-parking area locations which also can offer fleet vehicles, and power distribution companies. Further, the government of the country will play a key role in enabling infrastructure development for V2G.

Appendix F – Details of FCBA modeling and additional costs beyond the FCBA

1. Modelling Values

Charger costs:

Real yr	Year no.	Cost per V2G charger	Number of chargers	If 200	Charger cost (i.e. Cost	If 200
2024	1	€ 4,500	50	50	€ 2,25,000	150000
2025	2	€ 4,500	15	25	€ 67,500	75000
2026	3	€ 4,500	15	25	€ 67,500	75000
2027	4	€ 4,500	15	25	€ 67,500	75000
2028	5	€ 4,500	15	25	€ 67,500	75000
2029	6	€ 4,500	15	25	€ 67,500	75000
2030	7	€ 4,500	15	25	€ 67,500	75000
					Nominal sum	
					€ 6,30,000	600000
					NPV ->	€ 4,09,246.03
				Charger costs	Per yr value:	€ 58,463.72
					Per month:	€ 4,871.98

The NPV value of EUR 409,246 has been taken.

Revenue from FFR:

				For FFR				
Year	Chargers	Cumulative	(If 200 total)	Rate	Unit	For breakeven	For all chargers	For 200
1	50	50	50	37597.92	EUR per car-year	35732.5	1879896	1879896
2	15	65	75			53598.75	2443865	2819844
3	15	80	100	714.65		71465	3007834	3759792
4	15	95	125			89331.25	3571802	4699740
5	15	110	150			107197.5	4135771	5639688
6	15	125	175			125063.75	4699740	6579636
7	15	140	200			142930	5263709	7519584
					Cumulative			
					$2,13,65,889.02	$3,71,113.81		$1,95,24,393.07
						371113.8419	(-> is cost-CO2)	
	With	Capacity Factor set at		30%				
					$64,09,766.71			€ 58,57,317.92
				1.687883922		1.000000074		€ 3,28,98,180.00
				EUR per car-day				€ 98,69,454.00

The NPV benefit is EUR 5,857,317 across the period of the project.

Revenue for load leveling, arbitrage, and peak-shaving:

For Load Levelling			Arbitrage			Peak Shaving		
Rate	For all char	If 200	Rate	For all char	200	Rate	For all	200
994.82	49741	49741	120.7	6035	6035	52.86	2643	2643
	64663.3	74611.5		7845.5	9052.5		3435.9	3964.5
	79585.6	99482		9656	12070		4228.8	5286
	94507.9	124352.5		11466.5	15087.5		5021.7	6607.5
	109430.2	149223		13277	18105		5814.6	7929
	124352.5	174093.5		15087.5	21122.5		6607.5	9250.5
	139274.8	198964		16898	24140		7400.4	10572
Cumulative			Cumulative			Cumulative		
$5,65,330		$5,16,604.55	$68,591		$62,678.85	$30,039		$27,449.91
$1,69,598.85		154981.3664	$20,577.2		18803.65385	$9,011.7		8234.972184

2. **Installation of EV chargers, year on year:**

The installation of EV chargers has been assumed in a realistic staggered manner over the duration of the project. For the first year 50 chargers are installed, with 25 more chargers being installed every year subsequently. This provides the following table.

Number of chargers every year

Year	Chargers	Cumulative
1	50	50
2	25	75
3	25	100
4	25	125
5	25	150
6	25	175
7	25	200

3. **Impact of inclusion of battery degradation, in the FCBA:**

Although the study is done from the perspective of Schiphol Airport and hence does not need to include the cost of battery degradation in the FCBA modeling, this aspect is significant, given the unwillingness of EV users in using V2G due to their concerns of battery degradation. Hence, the following is an additional analysis, including battery degradation as a cost. For FFR, the ratios do not change significantly, as battery degradation is minimal.

The details for battery degradation through arbitrage are shown below. Arbitrage results in the highest load or degradation on the battery.

After Yr	Degradation, arbitrage		Battery capacity at Beginning of year	Degradation during the year	Battery capacity at End of year	Value after yr n
1	96.00%		96.0%	4%	92.2%	€ 7,680.00
2	99.84%		92.2%	4%	88.5%	€ 7,372.80
3	99.99%		88.5%	4%	84.9%	€ 7,077.89
4	100.00%		84.9%	4%	81.5%	€ 6,794.77
5	100.00%		81.5%	4%	78.3%	€ 6,522.98
6	100.00%		78.3%	4%	75.1%	€ 6,262.06

These values result in a per car cost of 95.62EUR when using FFR. This works out to a value of 19,123.30EUR for all vehicles in the parking lot.

4. **Suggestion to use the Nissan Leaf, and its collaborators, for using as prototypes for calculating costs beyond those from the perspective of Schiphol Airport:**

A lot of automobile companies have made pilots and efforts for V2G. *After studying various options for choice of quantification of costs, the technological ecosystem of the car Nissan Leaf have been chosen.*

Reason for choice of Nissan Leaf, and its collaborators, for using as protype costs:

There are multiple reasons for choosing the Nissan Leaf as the "base" or prototype for determining costs of various factors, in the course of this study. Some of the reasons are:

1. It has been one of the pioneers of EVs, since 2010, with the Nissan leaf as the first mass-produced EV (Motor Trend, 2023).
2. It is one of the highest selling EV brands (Hilson, 2019).
3. It has one of the highest "owner retention rate" indicating loyalty (Motor Trend, 2023)
4. Back in 2012 the company showed its EV owners how to power their households using V2H.
5. The company addressed rising consumer needs across countries by setting up manufacturing plants in Japan, the USA and the UK (Motor Trend, 2023).
6. Nissan has the largest network of high-speed EV chargers at dealerships in the USA (Nissan website, 2023).
7. In Australia, Nissan is promoting V2G by collaborating with Power Utility company Simply Energy, San-Fransisco based intelligent energy management platform provider Sunverge, and Spain-based producer of bidirectional charging devices Wallbox, to offer the Nissan Leaf by branding the cars as "batteries on wheels" (Costello, 2021)
8. Japan has faced several natural disasters, such as the Tohuku earthquake in 2011, that have made their energy management systems vulnerable. Companies like Nissan have responded to this by taking a more holistic approach, as opposed to the approach taken by automobile manufacturers in other countries, towards the manufacturing of cars, and treating them as energy storage solutions in the event of natural calamities (Costello, 2019).

5. Impact of cabling costs on the FCBA:

The study does not include the costs of cabling as the Base Case, involving unidirectional chargers, would also involve cabling and hence no separate or additional cabling is required for the Project Case. However, in case Schiphol Airport were to not install such unidirectional chargers, then cabling costs would be a requirement for the V2G project

When cabling costs are included, results are as follows:

FFR	6.69
Load Levelling	0.2
Arbitrage	0.04
Peak Shaving	0.03

6. Coverage of Schiphol Airport under the EU-ETS

The EU Emissions Trading System (EU-ETS) is a system under which organizations need to limit their carbon dioxide emissions, or purchase credits from other companies who have spare credits. However, Schiphol Airport itself is not covered under the ETS scheme, and may need to sell carbon credits on the free market against the CO_2 reduced from V2G use. The EU Emissions Trading System is only for specific industries that are covered under it including electricity, metal, petroleum production and chemical industries (NEA, 2015). While flights within Europe are also covered under ETS, these flights are the responsibility of the airline and not the airport. As CE Delft notes about KLM (in 2019): KLM only has a duty to report on the emissions of intra-EEA flights, as stipulated by the provisions of the EU ETS. Since airports potentially have many avenues for CO_2 mitigation, including V2G, policy makers could possibly consider authorizing airports as entities for trading in ETS credits.

Appendix G – Single charger analysis

Charger costs are the most significant, and they are so by a large margin. Hence, it is worthwhile to analyze the life cycle of a single charger being installed at Schiphol Airport. Further, doing so gives the study a practical and corporate perspective of V2G, since the residual cost of the charger is included in such modeling. Additionally, single-charger modeling can aid Schiphol Airport in deciding whether to buy chargers or to lease the same.

As guided by two domain experts, the modeling was done with the following parameters: A single charger was purchased in year 0, revenues from year 1 to 7 were calculated using net present value at a rate of 3.5%, a 5% yearly maintenance cost was taken for years 1 to 7, and no fee-sharing is included here.

Financial costs and benefits for a single charger using FFR for revenue generation

Sr. No.	Item description	Value (in thousand euros)	Explanation
A	**Cost Items**		
(a)	Purchase cost of V2G chargers	3	Calculated as Euros 3000 per bidirectional charger
(b)	Fee cost (to pay a remuneration to the EV user)	11.2	20% of FFR revenues are paid to the EV user
	Total cost	**14.2**	
B	**Benefits**		
(a)	FFR benefits	44.8	Euros 994.82 per car per year * number of chargers available each year * NPV for 7 years at 12% at 30% utilization
(b)	CO_2 equivalent	0.073	Calculated at 0.09 Euros per kg of carbon reduction, leading to -Euros 16 per car per year -Euros 3,202.11 for 200 cars per year -Euros 22,414 for 200 cars for 7 years
	Total benefit	**44.9**	
C	**Derived values**		
(a)	Net benefit (Total benefit – total cost)	30.7	
(b)	B/C ratio	3.2	44.9/14.2

As the above table indicates, the Benefit-to-Cost ratios for the single charger shows that the use of FFR is recommended for obtaining a ratio that is greater than one. The values obtained are different from that of the combined model, as the latter involves a staggered installation of chargers with falling costs and discounting, leading to a difference in the net present value of charger costs.