Cost of storing energy in electric vehicles. Price of stored energy injected into the grid

Tarcísio Silva
Instituto Superior Técnico, Lisboa, Portugal

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Abstract

As result of the limits set for carbon dioxide emissions, car manufacturers have turned to electrification of the sector making the electric vehicle more competitive. On the other hand, governments have encouraged electric mobility, but it must be complemented by an increase in production from renewable sources so that the energy needed to charge these vehicles is not produced in thermal power stations. The Vehicle-to-Grid(V2G) application can help increase renewable energy penetration by storing excess energy being produced and injecting it into the grid when necessary and can also mitigate the intermittency of renewable sources. In this study, V2G will be used to do Peak-Shaving/Load Shifting by injecting energy at peak times to decrease production and charging the vehicles at off-peak times. The aim of this dissertation is to demonstrate the benefits that this technology can have in the context of the island of São Miguel, where about half of the electricity is produced in a thermal power plant using fuel oil. To this purpose, an algorithm will be developed to simulate the coordination of charging and injection into the grid, with the number of vehicles varying. And finally, a financial analysis is made based on the current tariffs available in the archipelago of Azores.
Keywords: Load Shifting, Peak Shaving, São Miguel, Vehicle-to-Grid, Electric Vehicle

1. Introduction

In the Azores archipelago each island has its own electric production system, which makes it very dependent on thermal production. To overcome this, in recent years the installed power of renewable origin has increased as a result of policies for the decarbonisation of the sector.

In order to guarantee the stability of the system, the grid operator has to match production to consumption. In order to do this, it is necessary to have at its disposal dispatchable sources in order to be able to adjust production and mitigate the intermittency of renewable sources.

The increasing number of electric vehicles (EVs) on the roads can be a problem but also a solution. A problem if their load is not controlled, which can result in higher peaks in consumption. It is a solution, using V2G technology, because this way the EV can supply power to the grid reducing energy production at peak times.

The objectives of this paper are:

- Study the tariffs for charging the EVs and injecting energy into the grid;
- Propose a recursive algorithm to make the load diagram more uniform;
- Study the economic viability of V2G technology.

In order to meet the objectives of this paper, the tariffs available to the user of the electric vehicle as well as the cost of energy production in the thermal power plant will be studied. Then a recursive algorithm for charging is explained, which has as variables the energy required, the maximum power and the values of the charge diagram.

Finally, a case study is created in which different scenarios and profiles are defined in order to calculate the revenues and also study the expenses. With these, a financial analysis is made using the Net Present Value (NPV) and the Internal Rate of Return (IRR) to study economic viability.

1.1. Structure

A description of the electrical system in the Azores is given in section 2.

In section 3 an analysis is made of the national and regional EV sales market, various types of charging and vehicle batteries.

A description of V2G technology is given in the fourth section, namely the benefits, the challenges, the necessary infrastructure and the two-way charger. A description of the main projects is also given.

Section 5 presents the conditions of the case study in which the charger to be used is described, the tariffs, the user profile and the number of vehicles to be used in the simulation.

The recursive algorithm is explained in section 6 and the results of the simulations that have been made are also presented. An estimate of revenues and expenses is made and then used in the financial analysis.

Finally, the conclusions of this paper are presented

2. Electric System of Azores

In 2019 the total electricity consumption was 743 377 303 kWh [10] and the sectors that have consumed the most energy are Commerce/Services (35%), Domestic (34%) and Industrial (17%) .[10]

The electrical system of the Azores is conditioned by the fact that each island is independent in terms of electricity which, due to its size and isolation, remains very dependent on thermal production.

About 62% of the production in the archipelago comes from fossil fuels, in the larger islands fuel oil is used and in the smaller ones is diesel fuel. Next, we have geothermal energy with about 24%, which presents a relatively stable production throughout the year. However, it is only produced on the islands with the highest consumption, namely São Miguel and Terceira. Thirdly, we have wind energy with close to 9%, characterized by its intermittent behaviour, and fourthly, with almost 4% hydroelectric energy that presents a seasonal behaviour [10].

The installed power per type of resource is: 192 050 kW for fuel oil, 24 376 kW for diesel fuel, 36 650 kW for eolic, 34 275 kW for geothermal, 8 484 kW for hydroelectric and 1 000 kW for photovoltaic [9].

3. Electric Vehicle

The first electric vehicle was built during the 19th century, but years later with the production of the internal combustion car in series, it was practically no longer used as it was considerably more expensive. Today the paradigm has changed as there is a greater concern for the environment.

The transport sector was responsible for around 24% of Portugal carbon dioxide emissions during the year of 2017 [2]. Given that one of the objectives of governments is to reduce these emissions, one of the solutions is to increase the penetration of renewable energies combined with a commitment to electric mobility (also reducing noise pollution, especially in large cities).

3.1. Market of sales

Although the hybrid vehicle plug-in is considered electric, it will not be taken into account for the study due to the low battery capacity (up to 15 kWh), unlike 100% electric cars (in most cases it is 40 kWh or more).

Since 2015, approximately 14 380 [8] EVs have been purchased in Portugal mainland and in Azores, the number is almost 240 [7].

In Portugal during 2019 the best selling models were Tesla Model 3, Nissan Leaf and Renault Zoe [8].

3.2. EV Charging

When it comes to chargers there are many options and we have to look at the needs of each user to choose the best solution. There is 3 levels of charging power: level 1 ($\leq$ 3.7 kW), level 2 (3.7 - 22 kW) and level 3 (>22 kW). According to Saldanã et al. (2020) [18], slow charging causes less battery degradation and also the charger is cheaper.

To use the public charging network stations (normal/fast charging and in the future ultra fast charging stations will be available) you need to have a contract with one of the Electricity Suppliers for Electric Mobility. In Portugal initially all types of charging on the public network were free, in a second phase only the normal charging was free and since the beginning of July 2019 all types of charging are paid.

With the increasing number of EVs the dependence on fossil fuels decreases, but it will increase electricity consumption.

3.3. Battery

The battery was pointed out as one of the limitations for the use of the EV because there were no solutions with high energy density and power at competitive prices. But with the development of materials and lithium-ion battery technology, the paradigm has changed and lithium-ion batteries now take up less space and allow autonomy to increase.

Batteries are characterised by ageing over time and the number of cycles set by the manufacturer. Once this limit is reached, the capacity decreases until its replacement is necessary.

According to figure 1, we can see that the cost of batteries in 2010 was around 1 000 €/kWh and almost 10 years later it has fallen to around 130 €/kWh. This difference combined with the financial incentives has led to a decrease in the price of the EVs. The other consequence of the decrease in the price of batteries is that it makes the injection of energy into the grid more interesting since the costs associated with degradation are lower.

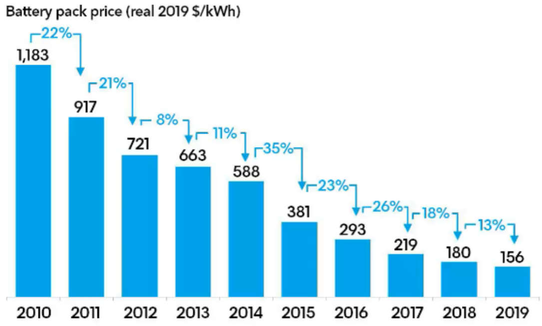


Figure 1: Battery pack price [13].

4. Vehicle-to-Grid (V2G)

This concept consists in a two-way flow of energy, this means that in addition to the normal charging, it is now possible to inject the energy that is in the EV batteries into the grid while the vehicles remain parked and connected to the electrical grid.

4.1. Benefits

According to authors Yilmaz e Krein (2013) [20] and Kumar et al. (2019)[14], we can highlight the following benefits of V2G technology.

Load Shifting and Peak Shaving

The concept of Load Shifting corresponds to the reduction of peak hour consumption and increase in off-peak hours in order to make the load diagram as flat as possible while maintaining total consumption.

As for Peak Shaving, it consists of reducing consumption at peak times in order to avoid peaks in load diagrams.

Ancilliary Services

The transmission system operator is responsible for ensuring a balance between generation and consumption in order to have a stable electricity grid. To ensure this balance, in Portugal there are mandatory system services and complementary system services.

Mandatory services are characterised by the regulation of basic system parameters (voltage and frequency), also referred to as primary regulation . This is a mandatory and unpaid service provided by generators in service and aims to automatically correct instantaneous imbalances between production and consumption.

Complementary system services covering secondary regulation of frequency and reserve regulation are remunerated on a market logic, while synchronous compensation or autonomous start-up are based on bilateral contracting. Secondary frequency regulation and regulatory reserve are used when the primary regulation is not sufficient and consist of a power variation to increase or decrease the frequency.

Increasing the penetration of renewable sources

With the development of the technology, renewable sources present increasingly competitive prices causing the installed power to increase year after year, bringing challenges to the electric grid. Despite policies for the decarbonisation of the sector, it must be taken into account that some renewable sources have the inconvenience of not being dispatched, that is, we cannot simply ask to increase production.

Electric vehicles will be able to store the excess energy being produced and then inject it into the electric grid when necessary. This will increase the production from renewable sources.

4.2. Challenges

According to authors Yilmaz e Krein (2013)[20] and Kumar et al. (2019)[14], the main challenges of V2G technology are the following:

Battery Degradation

One of the constraints of EVs is their battery which, unlike combustion vehicles, cannot be refuelled (charged) almost instantly. Using the battery for functions other than mobility will decrease the battery's lifespan, which may no longer be a problem if the compensation is interesting enough.

According to the report "Critical Elements of Vehicle-to-Grid (V2G) Economics" [19] , the number of life cycles, the depth of discharge of each cycle and the temperature are determinants for the degradation and lifetime of the battery. In the same report they came to the conclusion that by limiting the depth of discharge to 80% degradation reaches acceptable levels. As mentioned above, the price of batteries has been decreasing, which helps to minimize the problem of battery degradation caused by energy injection into the grid.

Investment Costs and Energy Losses

Higher power chargers are more demanding for the grid as they can overload the local distribution transformer if there is a large EV penetration.

According to Moghe et al. [16], in the scenario with a EV penetration of about 50%, the life of the transformer can decrease between 200% and 300% if there is no charging control.

Effects on Distribution Equipment

With the increase in the number of EVs it will be necessary to expand power generation, thus increasing losses in the power grid, and it may be necessary to invest in an expansion of the distribution network capacity. According to Nour et al. [17], it will be necessary to invest in improving the distribution grid if there is no control of charging.

4.3. Infrastructure

The implementation of V2G technology has two major differences from the representation of the so-called normal electrical system. One of them is that the energy flow becomes bidirectional, that is, the EV supplies or consumes energy through the needs of the network. The other difference is that there is now a new participant, an entity responsible for aggregating the various EVs spread throughout the network, with the responsibility of coordinating the charging/injection of the vehicles under its jurisdiction, bidding on the energy markets and monitoring the tariffs so that the EVs provide the most profitable service.

Bidirectional Charger

One of the fundamental elements for the use of V2G technology is the bidirectional charger that has two main components:

- a reversible AC-DC converter with the function of charging the battery or injecting power into the network;
- a reversible DC-DC converter operating as buck, charging the batteries at constant current or voltage, or as boost, discharging the batteries at constant current.

Also filters, controllers and protections must be added to ensure that the parameters set by the EV manufacturer are respected and to ensure the quality of the power injected into the network.

4.4. Projects

Currently there are many projects to investigate and build the business model for V2G technology. However, there are not many studies available yet and therefore a description of the project Parker is made, which was the first to be developed on a commercial level and serves as a basis for many of the current projects, the V2G Amsterdam project and finally, the project that is taking place on the island of São Miguel, the V2G Azores.

Parker Project

This project had a duration of approximately 2 years (August 2016 to July 2018), was composed of a fleet of 10 EVs and cost about 2 million euros. The aim of the project was to investigate the applications in which the EVs can be used, the network readiness and scale and replicability.

In this project the fleet of vehicles provided system services. According to Parker Report [5], in order to have a higher profit in the future it is necessary to improve the efficiency and power of the chargers and increase the capacity of the batteries. In that case it will become easier that the over cost of the charger and battery degradation are absorbed by the remuneration of the system services, thus making the V2G increasingly interesting for the user, since it will result in the highest possible profit (about 2 300 €).

Amsterdam Project

This project consisted in using the solar panels that were installed in the boat where a family lived, taking advantage of the batteries of a smaller complementary boat, used to move around the channels of Amsterdam. With V2G technology, these batteries are now used to reduce the electricity consumption of the grid.

The main conclusions were that electricity consumption decrease 45%, the efficiency of the process was 80% and the battery degradation after two years was 6-7 % [1].

V2G Azores Project

Since March 2020, the project has made use of 10 EVs batteries which provide a total of up to 100 kW from a Peak Shaving perspective.The following profile has been defined: charging between 2 AM and 5 AM; use of the vehicles for mobility between 10 AM and 6 PM, as these vehicles are part of the EDA fleet; injection of energy at peak hours between 8 PM and 10 PM. According to Galp's press release [3], from April to the end of July 2020 around 13.4 MWh, equivalent to the daily consumption of 15 homes, was injected into the grid.

5. Case Study

5.1. The case of Sao Miguel island

In 2019 the total electricity produced in this island was 440.42 GWh, with 53% being produced in Caldeirão Thermoelectric Power Plant, 38 % in Geothermal Power Plant, 5% in Hydroelectric Power Plant and the remaining 4% in Wind Power Plant [10].

5.2. Electricity Tariffs

In Azores the active power tariffs are defined by Energy Services Regulatory Authority (ERSE). We can exclude the single tariff, where there is no distinction of hours, as its cost is constant throughout the day, which will not bring benefits to the user in the context of Peak Shaving with V2G technology.

According to the table 1, the difference between peak and off-peak hours for the two-hour tariff is 8.43 cents per kWh and for the three-hour tariff 12.37 cents per kWh, this difference can serve as a basis for paying the energy supplied by EVs.

Table 1: Tariffs defined by ERSE [12].

Tariff		**Price (€ /kWh)**
Two-hour	**Peak Hours**	0.1827
	Off-Peak Hours	0.0934
Three-hour	**Peak Hours**	0.2236
	Off-Peak Hours	0.1573
	Super Off-Peak	0.0934

In the public charging network (table 2), the price depends on the voltage level (Low or Medium) due to the grid access tariffs.

Table 2: Tariffs defined by ERSE for electric mobility [11].

Tariff		**Price for LV (€/kWh)**	**Price for MV (€/kWh)**
Two-hour	**Peak Hours**	0.1862	0.1622
	Off-Peak Hours	0.1078	0.1007
Three-hour	**Peak Hours**	0.2875	0.2598
	Off-Peak Hours	0.1702	0.1434
	Super Off-Peak Hours	0.1078	0.1007

If we compare the two previous tables, we conclude that it is cheaper to charge the vehicle at home and that we should only use the public charging network in an urgent situation.

5.3. Profile of users of electric vehicles

The best case for using V2G technology will be one where the user drives a few kilometres a day. In this way, the vehicle is charged at night during off-peak hours and energy is injected into the grid during peak hours, thus benefiting from the biggest difference in tariffs.

According to *Google Maps*, the distance between the population hotspots:

- Ponta Delgada and Ribeira Grande is 20 km's;
- Ponta Delgada and Lagoa is 11 km's;
- Ponta Delgada and Vila Franca is 25 km's;
- Vila Franca and Lagoa is 16 km's;
- Vila Franca e Ribeira Grande is 27 km's;
- Lagoa e Ribeira Grande is 13 km's.

With the distances considered above and assuming the consumption of the Nissan Leaf (165 Wh/km [4]), we can define the following profiles:

- The optimistic profile corresponds to a user who drives up to 30 kilometres per day (plus 30 in reserve) consuming up to 10 kWh in mobility, so he can inject 30 kWh into the grid;
- The basic profile corresponds to a user who drives up to 60 kilometres per day (plus 60 in reserve) consuming up to 20 kWh in mobility, leaving 20 kWh to supply the grid. The greatest distance between the population hotspots considered is 27 kilometres, making the 60 kilometres sufficient to cover the trips between the main municipalities;
- The pessimistic profile will be a user who drives up to 80 kilometres per day (plus 80 in reserve) consuming a maximum of 30 kWh in mobility, leaving 10 kWh to inject into the grid.;

5.4. Bi-directional charger

To make the simulation we need to define the power of the charger as well as its cost. We chose the Magnum Cap charger which has a maximum power of 10 kW and an efficiency over 90% [6].

5.5. Number of Vehicles

The number of EVs considered should be significant in order to be able to replace part of the production at the Caldeirão Power Plant, resulting in environmental benefits.

That said, 3 scenarios (250 EVs; 500 EVs and 750 EVs) have been defined taking into account the number of EVs in the region and assuming the basic profile described above. Knowing that the power of each vehicle is limited to the power of the charger (10 kW) and the energy to 20 kWh:

Table 3: Variables and respective value for the simulation.

	Scenario 1 (250 EVs)	**Scenario 2 (500 EVs)**	**Scenario 3 (750 EVs)**
Max. Power (MW)	250*10 = 2.5	500*10 = 5	750*10 = 7.5
Energy Injected (MWh)	250*20 = 5	500*20 = 10	750*20 = 15
Energy Comsumption (MWh)	250*30 = 7.5	500*30 = 15	750*30 = 22.5

6. Simulation and Results

The purpose of these simulations is to make the load diagrams of the island of São Miguel more flat to demonstrate the potential of V2G technology. For this, a recursive algorithm was developed in *MATLAB* to simulate the coordination of the charging and its functioning is described in the flow chart below.

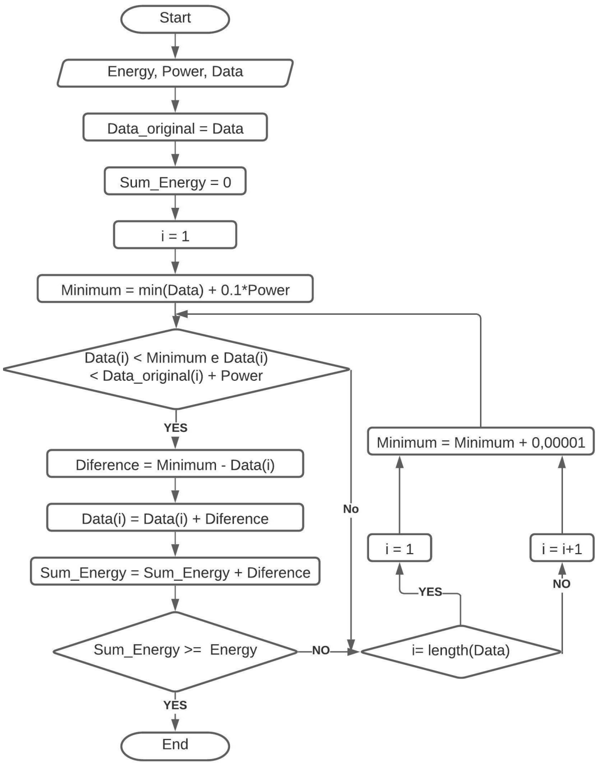


Figure 2: Flow chart for charging.

The injection into the grid can be done in a similar way but instead of calculating the minimum, we need to calculate the maximum.

To investigate the integration of V2G technology in the electrical system of the Azores, the characteristic load diagrams for each season of the year will be studied.

6.1. Winter

On 16 January the highest peak was 65.6 MW (7 PM) and the lowest was 34.4 MW (4 AM) and with the increasing integration of the EVs, the difference between these values reduces. In the figure 3.a, the maximum power injected by electric vehicles on this day would be 2.5 MW (corresponding to 250 EVs), 5 MW (corresponding to 500 EVs) and 6.47 MW in 7.5 MW (corresponding to 647 EVs), respectively in each scenario. In this case as the peaks in consumption are accentuated, the maximum power that vehicles could provide would be used.

Table 4: Highest and lowest peak for winter load diagram.

	Highest Peak (MW)	Lowest Peak (MW)	Difference (MW)
Base Case	65.58	34.42	31.16
Scenario 1	63.08	36.92	26.16
Scenario 2	60.58	39.29	21.29
Scenario 3	59.11	40.66	18.45

6.2. Spring

On 17 April the highest peak was 60.7 MW (10:30 AM and 15 PM) and the lowest was 36.7 MW (4:30 AM) and this load diagram has a more uniform behaviour than the previous one. In the figure 3.b, the maximum power injected by electric vehicles on this day would be 1.8 MW in 2.5 MW, 2.56 MW in 5 MW and 3.24 MW in 7.5 MW, respectively in each scenario. In this case as the load diagram is more uniform, the maximum power is not used.

Table 5: Highest and lowest peak for spring load diagram.

	Highest Peak (MW)	Lowest Peak (MW)	Difference (MW)
Base Case	60.90	36.71	24.19
Scenario 1	59.10	39.21	18.89
Scenario 2	58.34	41.36	16.98
Scenario 3	57.66	41.99	15.67

6.3. Summer

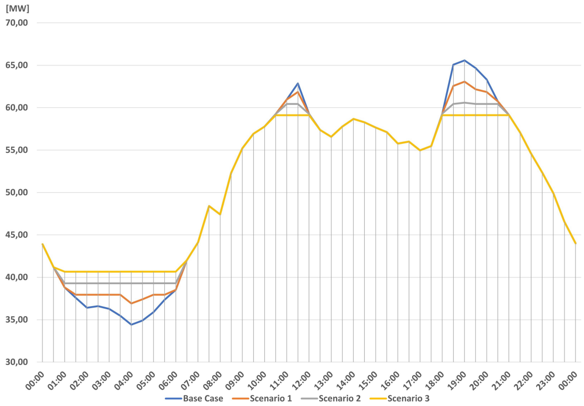
On 17 June the highest peak was 65.95 MW (11 AM) and the lowest was 38.23 MW (4:30 AM) and this load diagram his characterised by the higher consumption during regular working hours. In the figure 3.c, the maximum power injected by electric vehicles on this day would be 1.89 MW in 2.5 MW, 2.84 MW in 5 MW and 3.55 MW in 7.5 MW, respectively in each scenario. In this case the period of injection would be during the regular working hours (9 AM to 5 PM).

Table 6: Highest and lowest peak for Summer load diagram.

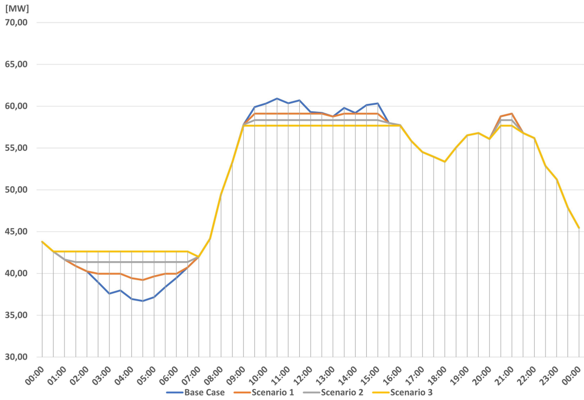
	Highest Peak (MW)	Lowest Peak (MW)	Difference (MW)
Base Case	65.95	38.23	27.72
Scenario 1	64.06	40.66	23.40
Scenario 2	63.11	42.11	21.00
Scenario 3	62.41	42.63	19.78

6.4. Autumn

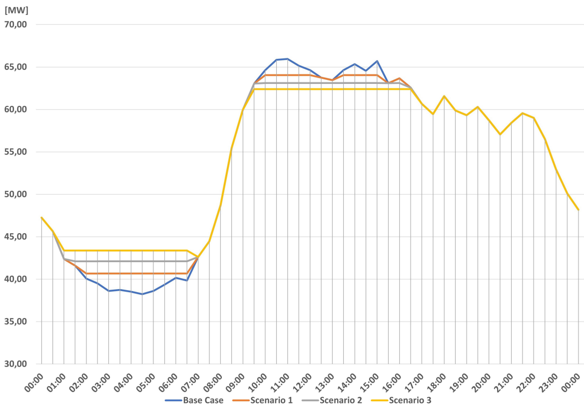
On 16 October the highest peak was 67.76 MW (11:30 AM) and the lowest was 37.81 MW (5 AM). In the figure 3.d, the maximum power injected by electric vehicles on this day would be 2.5 MW, 4.46 MW in 5 MW and 5.17 MW in 7.5 MW, respectively in each scenario. In this case the maximum power is higher as there is more variation between the various peaks in consumption.



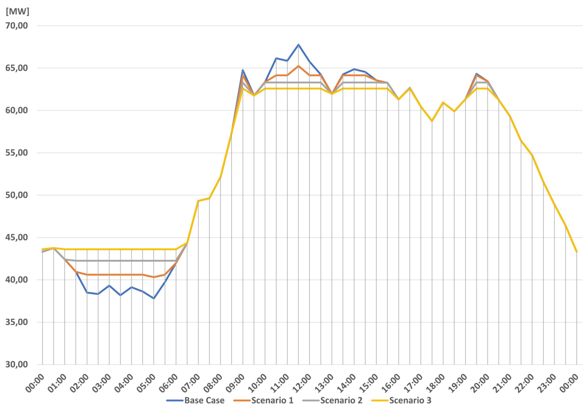
(a) Winter Load Diagram.



(b) Spring Load Diagram.



(c) Summer Load Diagram.



(d) Autumn Load Diagram.

Figure 3: Characteristic Load diagrams of the different seasons.

Table 7: Highest and lowest peak for Autumn load diagram.

	Highest Peak (MW)	**Lowest Peak (MW)**	**Difference (MW)**
Base Case	67.76	37.81	29.95
Scenario 1	65.26	40.31	24.95
Scenario 2	63.30	42.25	21.05
Scenario 3	62.59	43.34	19.25

6.5. Revenues and Expenses

In order to do a financial analysis for the various profiles, revenues and expenses were calculated, and then the viability of the V2G technology was studied.

Revenues

In this study, as the function of vehicles is to supply energy to the grid, revenue will depend on the efficiency for charging and injecting, the energy supplied and the difference between the Peak and the Off-Peak Tariffs, resulting in the equation defined below:

$$Revenue = 0.9 * 0.9 * Energy* \\ (Tariff_{Peak} - Tariff_{Off-Peak}) * Days \tag{1}$$

The lowest tariffs were chosen for the charging and the highest tariffs were chosen for the injection as well as the cost of the thermal power plant. The results are presented in the table below:

Table 8: Revenues for the differents profiles.

Charging Tariff (€/kWh)	0.0984		
Injection Tariff (€/kWh)	0.1573	0.1827	0.2236
Pessimistic Profile Revenue (€/year)	130.43	182.28	265.97
Base Profile Revenue (€/year)	260.87	364.56	531.94
Optimistic Profile Revenue (€/year)	391.30	546.84	797.91

Expenses

One of the major concerns of the users of these vehicles is battery degradation. In order to calculate this cost, the percentage of this degradation has been multiplied by the cost of a new battery of approximately 40 kW, approximately 8 000 €[15], leading to a cost of:

- 80 €, assuming a degradation of 1%;
- 160 €, assuming a degradation of 2%;
- 240 €, assuming a degradation of 3%.

The other component to be considered is the charger. For this purpose two options have been studied, one considering the difference between a DC and AC charger and the other the difference between a bidirectional and a unidirectional charger, both DC.

According to information obtained from the Magnum Cap, the price of a bidirectional charger with a maximum power of 10 kW is around 10 000 €, while an identical unidirectional charger will be around 8 000 €. These chargers have an advantage over AC chargers in that they require an internal charger in the vehicle that receives the power in AC and converts it to DC, thus charging the battery. The price of AC chargers of 11 kW or 22 kW can be as low as 500 € or as high as 3 000 €.

Therefore, if you consider that users will buy a DC charger to be installed in their home, the extra cost of the charger is about 2 000 €, which is the difference between a bidirectional and a unidirectional charger. When the difference between a bidirectional DC charger and an 11kW AC charger was considered (as it has the power similar to the DC type considered) it resulted in an additional cost of 9 500 €.

The investment made in purchasing the EV was not considered, since the vehicle is acquired for the purpose of mobility and not for injecting energy into the grid.

6.6. Financial Analysis

To analyse economic feasibility we will consider 2 investment evaluation indicators which are the Net Present Value (NPV) and the Internal Rate of Return (IRR). The NPV is the difference between cash inflows and outflows, duly updated during the analysis period. While IRR is the discount rate at wich the NPV of an investment equals zero.

To calculate these financial indicators, *Excel* was used with a 10% discount rate and the project duration was 10 years. Three situations were chosen according to revenue:

Situation 1

In this situation the charging is made at home during super off-peak hours, with a cost of 0.0934 €/kWh, and that the injection in the grid is remunerated at the price of the energy consumed at off peak hours that is 0.1573 €/kWh. Resulting in a difference between tariffs of only 0.0589 €/kWh.

According to the table 9 , only for the optimistic profile when the investment is 2 000€that the investment is viable since the IRR and NPV are positive.

Table 9: Situation 1 without battery degradation.

	Revenue (€/year)	**Investment (€)**	**NPV (€)**	**IRR (%)**
Pessimist Profile	130.43	2 000	-1 198.56	-7.10
		9 500	-8 698.56	-25.81
Base Profile	260.87	2 000	-397.07	5.15
		9 500	-7 897.07	-18.50
Optimistic Profile	391.30	2 000	404.37	14.52
		9 500	-8 880.20	-28.23

When we consider battery degradation (table 10), NPV and IRR are always negative, which indicates that the investment is not viable.

Table 10: Situation 1 with battery degradation.

	Revenue (€/year)	**Investment (€)**	**NPV (€)**	**IRR (%)**
Pessimist Profile	50.43	2 000	-1 690.13	-19.48
		9 500	-9 190.13	-34.16
Base Profile	100.87	2 000	-1 380.20	-10.84
		9 500	-8 880.20	-28.23
Optimistic Profile	151.30	2 000	-1 070.33	-4.78
		9 500	-8 570.33	-24.35

Situation 2

In this situation the charging is made at home at the price of super off-peak hours, with a cost of 0.0934 €/kWh, and the injection is compensated at the price of peak hours for the two-hour tariff, 0.1827 €/kWh. Resulting in a difference between tariffs of 0.0843 €/kWh.

According to the table 11 when the investment is 2 000 € for the base and optimistic profile, the project is viable because the NPV is positive and the IRR is 12.73% and 24.22%, respectively.

Table 11: Situation 2 without battery degradation.

	Revenue (€/year)	**Investment (€)**	**NPV (€)**	**IRR (%)**
Pessimist Profile	182.28	2 000	-1 198.56	-7.10
		9 500	-8 698.56	-25.81
Base Profile	364.56	2 000	240.06	12.73
		9 500	-7 259.94	-11.47
Optimistic Profile	546.84	2 000	1 360.10	24.22
		9 500	-6 139.90	-8.96

When the battery degradation is considered (table 12), this difference between tariffs only results in a viable project for the optimistic profile when the investment is 2 000 €. For the rest, the investment is not recovered and/or the remuneration does not reach the value required by the investor.

Table 12: Situation 2 with battery degradation.

	Revenue (€/year)	Investment (€)	NPV (€)	IRR (%)
Pessimist Profile	102.28	2 000	-1 371.53	-10.64
		9 500	-8 871.53	-28.11
Base Profile	204.56	2 000	-743.07	0.41
		9 500	-8 243.07	-21.21
Optimistic Profile	446.45	2 000	743.24	18.09
		9 500	-7 614.60	-16.59

Situation 3

This is the most favourable situation since the difference between tariffs is 0.1253 €/kWh. The charging is made at home during super off-peak hours at a cost of 0.0934 €/kWh and the injection into the grid is paid at the same price as the peak hour tariff for the three-hourly regime, 0.2236 €/kWh.

As might be expected, this is the best situation due to the higher difference between tariffs that results in the highest values for NPV and IRR. The project is viable for base and optimistic profile when the investment is 2 000 €.

Table 13: Situation 3 without battery degradation.

	Revenue (€/year)	Investment (€)	NPV (€)	IRR (%)
Pessimist Profile	265.97	2 000	-365.72	5.55
		9 500	-7 865.73	-18.28
Base Profile	531.94	2 000	1 265.54	23.33
		9 500	-6 231.46	-9.36
Optimistic Profile	797.91	2 000	2 902.81	38.34
		9 500	-4 597.19	-3.05

When battery degradation is considered (table 14), the project is viable for the base profile and optimistic when the investment is 2 000 € but the investment indicators are lower than those in the previous table.

Table 14: Situation 3 with battery degradation.

	Revenue (€/year)	Investment (€)	NPV (€)	IRR (%)
Pessimist Profile	185.97	2 000	-857.23	-1.30
		9 500	-8 357.29	-22.23
Base Profile	371.94	2 000	285.41	13.23
		9 500	-7 214.59	-14.21
Optimistic Profile	557.91	2 000	1 428.12	24.87
		9 500	-6 071.88	-8.67

Investment in the model with a 62 kWh battery

We can think in another possibility, it is viable buy a EV with 62 kWh instead of the version with 40 kWh. According to the information available on the Nissan website, the difference in price between these two versions is 5 500 €. So we will add this difference to the investment and we will assume the base profile (20 kWh for mobility).

Table 15: Investment in a model with 62 kWh.

	Investment (€)	NPV (€)	IRR (%)
Situation 1	7 500	-4 294.20	-6.11
	15 000	-11 794.20	-15.69
Situation 2	7 500	-3 019.87	-0.51
	15 000	-10 519.87	-11.35
Situation 3	7 500	-962.98	6.92
	15 000	-8 462.98	-5.80

For the situation 3 without battery degradation when the investment is:

- 2 000€, NPV is 1 265.54 € and IRR is 23.33%;
- 7 500€, NPV is -962.98 € and IRR is -5.80%.

If we compare the indicators for the base profile we conclude that it is not viable to invest in the 62 kWh version instead of the 40 kWh version.

7. Conclusions

The proposed algorithm distributes the charging and injection to make the loading diagram as flat as possible but for this the network operator has to know the availability of the EVs in advance.

The cost of storing energy in the EVs corresponds to the lowest available tariff, i.e. 0.0934 €/kWh that corresponds to charging the vehicle at home during super off-peak hours. The public charging network should only be used in the case of an urgency as the tariffs are higher.

For the injection into the grid, the tariffs will be necessarily higher than those of the charging so that it is possible to generate revenue to recover the investment and generate profit. According to the results obtained, even using peak hour tariffs, the revenue may not be sufficient to encourage users. The difference between the tariffs must be greater.

According to the obtained information , the major obstacle in the greater integration of this technology is the cost of the bidirectional charger, which can be overcomed by equipping the public network with this equipment.

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