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Tools for the assessment of business models around the exploitation of bidirectional electric vehicle chargers

DISSERTATION

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Abstract

Electric vehicles can be considered as important amounts of energy stored in batteries. The possibility of taking advantage of such energy to other ends out of transport is a great opportunity for the transition from combustion engine's vehicles to electric vehicles. To do this, it is necessary to use bidirectional chargers, so the energy can flow in both directions: from the vehicle to the electrical system it is connected to and vice versa.

This project studies an optimization tool to assess the impact of exploiting the energy in electrical vehicles in buildings through bidirectional chargers and its application to two models representing two different kind of buildings: a medium office and a data center. Afterwards, business models around this idea are discussed.

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1 Introduction

Nowadays, lots of efforts are being focused in solving the environmental problematic surrounding us, from different perspectives and study fields. Between all the steps that have been carried out in order to reach the aimed sustainability, it can be remarked the improvement of electric vehicles. Such achievement has lead the population and governments of different countries to participate in vehicles' integration to society. Thereby, the transition from internal combustion engines' vehicles to electric vehicles as the main transport, is bound to become a reality during the next few years. Thus, along with it, it is needed to exploit electric vehicles' not only in transport but in others applications to achieve a full development of their potential.

The aim of this project is to take advantage from the battery in electric vehicles using it as a source of energy, aswell as developing business models around the concept. To do so, bidirectional chargers are needed, as they allow energy to flow in both directions: from the building to the vehicle and viceversa. This idea will be studied with a practical application of it concerning two kinds of buildings: An office and a data center. A model will be developed based on the idea that workers usually follow a routine, spending a few hours in the building. With smart grids and controlling each worker's routine, the company can obtain energy from the battery while the car is parked and return it before the user leaves.

To estimate the behaviour of the process, an optimization model will be created, where the main objective will be the reduction of energy costs of any person involved. Furthermore, defining the model and obtaining the needed data to define the details of the process, will be necessary for its posterior study. Afterwards, through simulating different scenarios an analyse will be carried out and business models around the results will be discussed.

Notwithstanding, the scope of the project will not include how bidirectional chargers work internally. The batteries will not be studied electronically, and the charging process control will not be considered. The project will be mainly based in all the inputs and outputs of the process, aswell as the model creation to allow its study and a generic study of the ways in which a vehicle can exchange energy with the building it is connected to.

2 State of the Art. The project's background.

The background of this project is mainly based on the ways in which is possible to connect an electric vehicle to smart grids, together with its beneffits and drawbacks. There are four principal modes of interest to establish the relation between the grid and the vehicles.

2.1 G2V: Grid to Vehicle

It is the most common use, as it consists in charging the battery directly from the grid. The scheme of the process can be seen in the next figure:

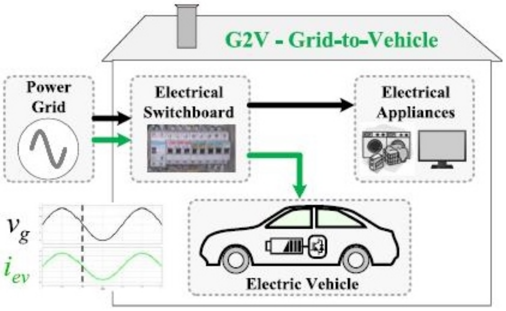


Figure 2.1 G2V scheme. Source: [18]

2.2 V2G: Vehicle to Grid

It is used to transfer electricity to the building extracting it from the electric vehicle's battery. As a conventional charger doesn't allow energy to flow from the battery to the building, bidirectional chargers are needed. Furthermore, smart grids and a communication between the vehicle and the grid are important to optimize the process.

The main use of this system is to stabilize the power grid demand, filling the valleys and shaving the peaks of load: Filling the valleys would only mean to increase the house load in those periods of time, thus to charge the battery; shaving the peaks would suppose using the battery as a power source to reduce the power demand from the grid. This advantage, acquires a huge relevance when a house has intermittent renewable energy sources, as when the system is producing in excess the surplus is used to charge the battery [14]. Following the same argument, when the renewable sources are not producing enough, the battery is used to supply electricity to the building [26].

Notwithstanding, it has to be considered the drawback of the process, as discharging the batteries shorten their lifes. Thus, the cost this fact supposes needs to be estimated and taken into account while calculating the profitability of the system. Fortunately, researchers estimate the potential net returns from V2G methods applied in domestic buildings range between 90-4000 $/year (depending on factors like the power capacity of the electrical connections, the number of electric vehicles, the battery capacity...) [25]. More information regarding the battery's degradation will be shown in subsection 2.5 and section 6. In next figure, the scheme of the G2V mode can be observed:

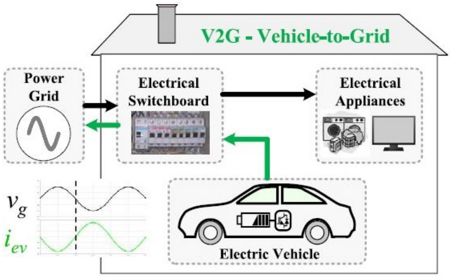


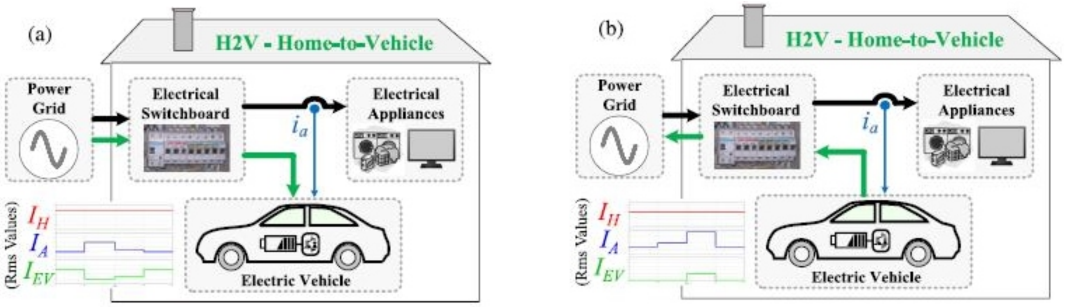
Figure 2.2 V2G scheme. Source: [18]

2.3 H2V: Home to Vehicle

The G2V and V2G operation modes are controlled to share active power with the power grid, neglecting the other electrical appliances of electrical installation where the EV is plugged in. In the H2V mode, while charging the vehicle its current regulation is function of the total current at the house, also considering the other electrical appliances, in order to prevent overloads and overcurrent trips [17]. Depending on the combination of H2V mode with G2V and V2G modes, the current of the vehicle is calculated in different ways:

Together with G2V mode, the RMS current to the EV (I_{EV}) results the difference between the home maximum current ($I_{H_{max}}$) and the one directed to the home electric appliances (I_A): $I_{EV} = I_{H_{max}} - I_A$. A drawback of the system is that the electrical appliances connected at the home electrical installation are impossible to predict. Thereby, circuit breaker trips could be caused without an smart charging strategy which, in case to be installed, would slow down the charging time of the vehicle.

Using the H2V mode together with V2G implies that the electric appliances of the house exceed the maximum current allowable. The car compensates the difference: $I_{EV} = I_A - I_{H_{MAX}}$. The scheme of the process can be seen in next figure:



(a) H2V + G2V scheme.

(b) H2V + V2G scheme.

Figure 2.3 Scheme of the H2V mode together with G2V (left) and V2G (right). Source: [18]

2.4 V4G: Vehicle for Grid

In this mode the vehicle is not used for the active power it can supply to the building, the finality is to compensate the power factor of it while producing reactive power. One of the beneffits of the process is that it doesn't cause aging to the battery and that this mode can also be used simultaneously with G2V or V2G. The scheme is shown in the following picture:

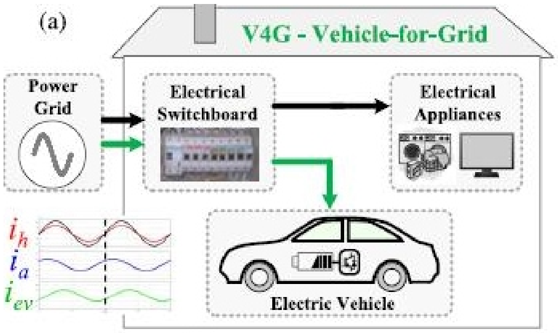


Figure 2.4 V4G scheme. Source: [18]

2.5 Basic definitions

In case it is needed, it has been thought convenient to clarify some basic concepts regarding electric vehicles as they will be used all along the project:

- **State of Charge (SOC):** Is the percentage of charge that has the battery compared to the value when it's fully charged. It can also be expressed in so much for one instead of a percentage.
- **Depth of Discharge (DOD):** Is the percentage of discharge compared to the battery's capacity. A DOD of 70% means a 30% of SOC, e.g.

- **Number of life cycles:** Number of cycles that can be developed in a battery's lifetime. A cycle supposes the discharge of the 100% of the battery, i.e. if the battery has a DOD of 33% it needs to be discharged three times until a cycle has finished [12].

The discharging process of the battery produced in mode V2G reduces the battery's lifetime, as explained in the previous subsection 2.2. Thus, it is important to specify the minimum SOC considered to be acceptable in each vehicle, as the DOD has a great effect on the number of life cycles, following the tendency represented in next figure.

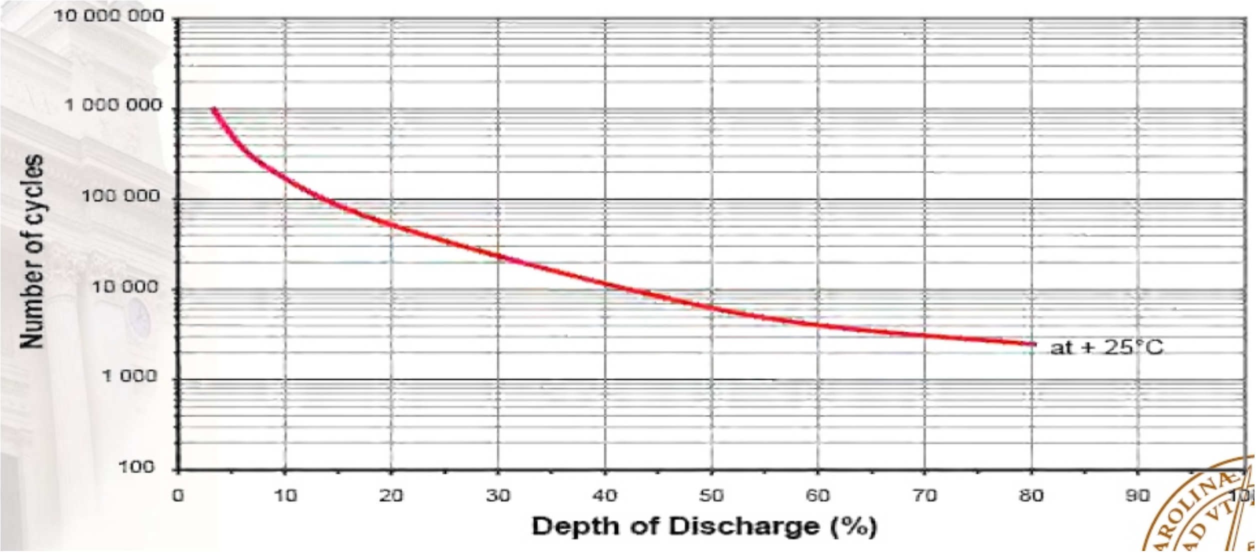


Figure 2.5 Number of life cycles in function of the DOD. Source: [2]

As it can be seen in the figure, a higher DOD produces more degradation to the battery, which leads to an increase of the price of extracting electricity from the battery. During the simulations, the cost of discharging has been estimated in order to decide the most appropriate for the people involved on the procedure (see section 6).

3 Introduction to vehicles' integration into the electric system

As the project is going to be developed in Spain, the actual situation of the energetic market, specially concerning the electricity price, aswell as the electric vehicles' implementation being carried out in the country, is important while designing the model and will be shown in next subsections.

3.1 The spanish electric system

The most important information regarding the spanish electric system related to the project is the electricity's price. Thus, all taxes and fees are going to be explained all along the section. First of all, while consuming electricity, a variable and an unvariable fee have to be considered. The variable fee is associated to each kWh consumed. This means that when a user is consuming, the final price will consider the energy price at that moment in the market plus the tax, which is a 5% [7]. The second one is related to the contracted power in the building. It is an annual fee, but paid in every bill proportionally to the facturation days. Thus, the goal of any process applied to the building should be to decrease the contracted power in order to also reduce the unvariable fee.

To the energy price and the contracted power tax, it has to be added the rent of measure equipment, which depends on the kind of network (monophasic or triphasic) and on the possession of measuring devices in the facilty. Finally, the indirect tax generally applied in Spain (VAT) has to be added to the bill [3].

When this price is calculated, there is also another concept needed to be paid: the access' fees, which are to pay the access to the network. There are three: related to energy (the consumption), to capacity and to power (the contracted power). They depend on the tariff and on the moment of the day if it has hourly discrimination. Usually, for domestic users the access fee is included in the kWh price, and only the other taxes described in the previous paragraphs need to be added [8].

In the project, the domestic buildings, which have a contracted power lower than 10kW, can choose between three different tariffs: 2.0A, 2.0DHA and 2.0DHS. The first one has an established energy price "chosen" by the energetic company; the second one has hourly discrimination (cheaper price during the night but more expensive during the day); and the last one refers to electric vehicles' owners and have double schedule discrimination (even cheaper during 8 night hours but expensive during the day). In the next figure the evolution of the price in function of the tariffs of domestic buildings can be seen (the price includes the access fees).

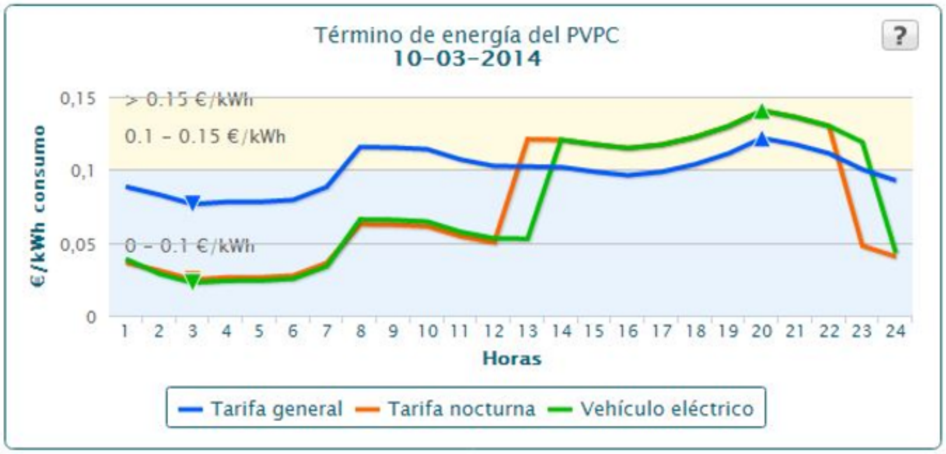


Figure 3.1 Energy price evolution depending on the tariff applied. Source: [6]. In the figure tariff 2.0A is *"Tarifa general"*, 2.0DHA is *"Tarifa nocturna"* and 2.0DHS is *"Vehículo eléctrico"*.

The tariff considered in the project has been 2.0A, without discrimination. It has the highest average price for kWh, so it is the most unfavourable case.

While talking about buildings, there are a few different tariffs chosen in function of the needs of each building. In the case studied, the tariff 3.0A is the one considered. This tariff obtains the energy price directly from the free market. Furthermore, in offices or industries, aside from all the taxes described, it also has to be added the penalisation for the power factor: if the building has a power factor lower than 0,95, there is a penalisation [23]. This fee is just applied during the day and it has the following values [1]:

Power factor value	**Penalisation fee** [€ /(kvar · h)]
$0,90 \leq cos\varphi < 0,95$	0,041554
$0,85 \leq cos\varphi < 0,90$	0,041554
$0,80 \leq cos\varphi < 0,85$	0,041554
$cos\varphi < 0,80$	0,062332

Table 3.1 Value of the penalisation in function of the power factor of a company. Source: [23]. Data from 2010.

3.2 Methodology of vehicles' integration into the grid

This project is based on an scenario where some of the workers of a company own an electric vehicle. This is not possible without the participation of the government, as the population needs to be provided by the appropriate charging stations and the law framework regarding chargers at homes. Thus, it has been considered important to understand how the catalan government is getting involved in the establishment of electric vehicles in society.

In 2010 the IVECAT was created, as a strategy to promote a technologic development regarding charging systems, aswell as the creation of the needed facilities to charge vehicles in public places fast and efficiently. In 2012 the plan PECAC (2012-2020) was created, to also promote the progress in rapid charging and to create a network of charging stations. Moreover, PECAC also contemplated the fact that in public charging stations, the energy consumed needs to be sold to the final users, the electric vehicles' owners, which wasn't possible before [13].

Furthermore, the actual law obligates all new buildings built to install the facilities needed to have charging points or, at least, execute the electric preinstallation to allow minimum the 15% of the people using the parking to charge their vehicle. In existent private or public buildings it is compulsory to install a charging station for every 40 workers [13], which is an advantage for the project as the users and the building have to be connected.

Moreover, in Spain it has been studied to install the modes V2G and V2H in domestic buildings. For example, in 2012 it was planned to install 6 bidirectional charging stations in Málaga, promoted by the company *Endesa* and *CITCEA*, an advantage for the poject as V2G stations are going to be used in the scenario contemplated [24].

3.3 The project's application regarding vehicles' integration in buildings

In the project the main goal has been to create an interaction building-users which would assure economical savings for any person involved on it. The general idea has been to use the modes G2V and V2G (see section 2) in order to shave the peaks of load in the building. The direct consequence sought is the reduction of the contracted power in the building, which would decrease the unvariable tax paid (see subsection 3.1), aswell as the energy consumption in some periods of the year. In order to achieve it, it is necessary to extract energy from the users' battery. Thus, in the design of the process, it has been guaranteed that before the user leaves the battery wouldn't be discharged, aswell as a compensation for the degradation of the battery caused during the discharging process.

As the idea could be applied to any building, it was thought to choose the ones more likely to take advantage of the system. Thus, different kinds of buildings were aggregated in four general groups:

1. Residential buildings
2. Companies owning machinery working 24 hours/day with 3 turns of workers, such as industries or data centers.
3. Companies were workers usually do an 8 hours turn every day and almost no employers are considered at night nor weekends.
4. Tertiary sector' companies, which adapt to users schedule in function of the service, such as shops, supermarkets or sport centers.

From those four groups of buildings, the last one was the most conflictive, as it has a number of users undefined and difficult to predict, aswell as extremely variable in function of the service and period of the year. Thus, the study should be based in an specific case and the conclusions would rarely be applicable to other buildings in the group. Therefore, number four was discarded for the study.

In residential buildings, as the users of the system are the same that represent the building, the only implementation that could be applied is individual: Every neighbour improving, in function of their consumption, when to extract energy from the battery in order to reduce the contracted power. An advantage is that the conclusions of the study could be applied to numerous homes, as they would share the same initial conditions. Notwithstanding, the implementation of the system would get complicated in buildings where the parking is shared by all the neighbours and it would be necessary to take into account that usually having an electric vehicle leads to an increase of contracted power [13] (before the application of the system). Contrarily, in companies, where users are the workers, the system wouldn't have this problematic, as the company doesn't own the vehicle nor have to share the network. Thus, even though residential buildings were interesting for the study, it has been decided to study companies with higher consumption and where users and buildings are represented by different persons, inasmuch as the interaction building-users entail more consequences (see section 6).

Therefore, group two and three were the ones included in the study. In group two workers follow a strict routine and in group three they usually have a predictable and stable routine. In both cases it seemed easy to control the workers' habits and their batteries' SOC, fact that is extremely important for the study. Moreover, in both kind of buildings, a study made on a particular case could be easily applied to different cases, as they would describe similar behaviours. Thus, and to specify more the model to be developed, just a representative of each group was chosen: a data center in group two and a medium office in group three.

4 Optimization model

4.1 The model hypothesis

Once the system's concept was developed, in order to design the model and establish the restrictions some hypothesis were needed:

1. Every worker in the company follows a labour routine that is known.
2. The SOC of each car's battery is known every simulation period of time, even when the workers have finished their workday.
3. During the weekend, the interaction building-workers is just considered in the data center, as in the office users are not supposed to work apart from weekdays.
4. The same workers participate in the project every day considered in the study.
5. The electrical consumption of the building is known at every period of time.
6. No holidays, sick leaves nor worktrips are considered of any of the workers during the period of study.
7. Seven hours minimum are considered for each worker to be home daily, in case it is necessary to charge the battery.
8. All the costs associated to the discharging process are covered by the company, as it is a beneffit for them.
9. When a user charges their vehicle at home it is because it is extremely necessary (not enough battery just charging at the building).
10. The users don't own a bidirectional charger at home.
11. No electricity can be provided to the network while implementing the system.
12. No energy regeneration is considered when users are driving their vehicles.
13. The energy consumption per km in each user is the same regardless of the path driven.
14. The contracted power in the building is not going to be surpassed any period of time.

Considering all the hypothesis described, to build the model it has been needed to obtain the necessary data (see section 5) and describe the equations and restrictions that represent the system [10]. Regarding the energy cost, the variable tax, the rental equipment fee, aswell as the capacity fee and VAT (see section 3.1) is included in the hourly energy price (parameter $price_t$ in the simulation). The unvariable tax plus the power access fee is considered in the parameter λ_{year}. The energy access fee is considered in the parameter λ_{energy} in the building and λ_{home} regarding the users. Everything will be shown in next subsections.

4.2 Input data

Parameter set concerning the optimization:

- t=1, ... , T Period of simulation [h]
- n=1, ... , N Electric vehicle related to a user

Parameter set concerning the building:

- $price_t$ Hourly price of energy [€/kWh] $\forall t$
- $cons_t$ Hourly energy consumption [kWh] $\forall t$
- λ_{year} Yearly contracted power tax [€/(kW · year)]
- λ_{energy} Tax per energy consumed [€/kWh]

Parameter set concerning the vehicles and their users:

- $c_{n,max}$ Maximum charging power of the n vehicle [kW] $\forall n$
- $d_{n,max}$ Maximum discharging power of the n vehicle [kW] $\forall n$
- B_n Battery capacity of the n vehicle [kWh] $\forall n$
- $SOC_{n,max}$ Maximum SOC of the battery in vehicle n $\forall n$
- $SOC_{n,min}$ Minimum SOC of the battery in vehicle n $\forall n$
- λ_{home} Tax per energy consumed at home [€/kWh]
- C_n Economic penalisation for discharging the battery in vehicle n [€/kWh] $\forall n$
- $US_{n,t}$ Vehicle n usage at time period t [kWh] $\forall n, t$

Parameter set concerning the chargers:

- η_{bc} Charging efficiency of the bidirectional charger
- η_{bd} Discharging efficiency of the bidirectional charger
- η_{uc} Charging efficiency of the unidirectional charger
- $c_{c,max}$ Maximum charging power of the bidirectional charger [kW]
- c_{c,max_h} Maximum charging power of the unidirectional charger [kW]
- $d_{c,max}$ Maximum discharging power of the bidirectional charger [kW]

Binary inputs:

- $A_{n,t}$ Availabilty. $\forall n, t \begin{cases} 1 & \text{if vehicle } n \text{ is at the building at time period } t \\ 0 & \text{otherwise} \end{cases}$
- $H_{n,t}$ Home. $\forall n, t \begin{cases} 1 & \text{if vehicle } n \text{ is at home at time period } t \\ 0 & \text{otherwise} \end{cases}$

4.3 System variables

Variables related to the building:

– $c_{n,t}$	Charging rate of vehicle n at time period t [kW]	$\forall n, t$
– $c_{tot,t}$	Total charging power (considering all vehicles) at time period t [kW]	$\forall t$
– $d_{n,t}$	Discharging rate of vehicle n at time period t [kW]	$\forall n, t$
– $d_{tot,t}$	Total discharging power (considering all vehicles) at time period t [kW]	$\forall t$
– $M_{DAM,t}$	Active power consumption from the network at time period t [kW]	$\forall t$
– E_{con}	Contracted power in the building [kW]	
– $id_{n,t}$	Charging/Discharging indicator, $\forall n,t$ $\begin{cases} 1 & \text{if vehicle } n \text{ is charging at the building at time } t \\ 0 & \text{if vehicle } n \text{ is being discharged at time t} \end{cases}$	

Variables related to the users and their homes:

– $SOC_{n,t}$	SOC of vehicle n at time period t	$\forall n, t$
– c_{n,t_h}	Charging rate of vehicle n at time period t at home [kW]	$\forall n, t$
– c_{tot,t_h}	Total charging power at all users' homes at time period t [kW]	$\forall t$

4.4 Objective function, Z

The objective function in the optimization will be minimized. The items included are:

- **The global energy cost for users:** The user cost in the system is what he/she has charged at home all along the simulation considering the price of electricity at that period of time. In users working in the office weekends aren't considered (see subsection 4.1 and 3.3). Moreover, the users' contracted power and their particular consumption is not included, as it doesn't affect the system proposed. The equation is: $\sum_{t=1}^{T} c_{tot,t_h} \cdot (price_t + \lambda_{home})$
- **The global energy cost for the building:** It consists in the consumption from the network at any period of time multiplied by the energy price at that moment in the building. The equation is: $\sum_{t=1}^{T} M_{DAM,t} \cdot (price_t + \lambda_{energy})$
- **The cost related to the contracted power in the building:** $E_{con} \cdot \lambda_{year}$
- **The cost for the battery's degradation while discharging the vehicles:** $\sum_{n=1}^{N} d_{n,t} \cdot C_n$

Thus, the main goal in the optimization will be not only to guarantee the maximum savings to the users and the building but taking into account the degradation of the battery and the achievement of the maximum reduction of contracted power possible. Altogether, the objective function results:

$$[MIN]Z = \sum_{t=1}^{T} \left[M_{DAM,t} \cdot (price_t + \lambda_{energy}) + c_{tot,t_h} \cdot (price_t + \lambda_{home}) + \sum_{n=1}^{N} d_{n,t} \cdot C_n \right] + E_{con} \cdot \lambda_{year} \tag{4.1}$$

4.5 Restrictions

Charging constraints at the building:

- The total charging power at the building is the sum of the charging power in each vehicle. It can't be negative as it would mean discharging, represented by the variable $d_{n,t}$.

$$c_{tot,t} = \sum_{n=1}^{N} c_{n,t} \qquad \forall t \tag{4.2}$$

$$c_{tot,t} \geq 0$$

- If the vehicle n is available at the building ($A_{n,t} = 1$) and being charged ($id_{n,t} = 1$), its charging power has to be between the maximum and minimum power that the vehicle can bear. Otherwise, its charging power remains 0. In case the car is not being charged nor discharged, $id_{n,t}$ could be 0 or 1 but the charging power would be set to zero.

$$0 \leq c_{n,t} \leq id_{n,t} \cdot A_{n,t} \cdot c_{n,max} \qquad \forall n, t \tag{4.3}$$

- The charging power of the n vehicle has to be between the minimum and maximum power that the bidirectional charger can provide:

$$0 \leq c_{n,t} \leq c_{c,max} \qquad \forall n, t \tag{4.4}$$

Discharging constraints at the building:

- The total discharging power at the building is the sum of the discharging power in each vehicle.

$$d_{tot,t} = \sum_{n=1}^{N} d_{n,t} \qquad \forall t \tag{4.5}$$

$$d_{tot,t} \geq 0$$

- If the vehicle n is available at the building ($A_{n,t} = 1$) and being discharged ($id_{n,t} = 0$), its charging power has to be between the maximum and minimum power that the vehicle can bear. Otherwise, its discharging power remains 0.

$$0 \leq d_{n,t} \leq (1 - id_{n,t}) \cdot A_{n,t} \cdot d_{n,max} \qquad \forall n, t \tag{4.6}$$

- The discharging power of the n vehicle has to be between the minimum and maximum power that the bidirectional charger can provide.

$$0 \leq d_{n,t} \leq d_{c,max} \qquad \forall n, t \tag{4.7}$$

Charging constraints at home:

- The total charging power at all houses is the sum of the charging power in each home.

$$c_{tot,t_h} = \sum_{n=1}^{N} c_{n,t_h} \qquad \forall t \tag{4.8}$$

$$c_{tot,t_h} \geq 0$$

- If the vehicle n is available at the house ($H_{n,t} = 1$), its charging power has to be between the maximum and minimum power that the vehicle can bear. Otherwise, its charging power remains 0.

$$0 \leq c_{n,t_h} \leq U_{n,t} \cdot c_{n,max} \qquad \forall n, t \tag{4.9}$$

- The charging power of the n vehicle has to be between the minimum and maximum power that the unidirectional charger can provide.

$$0 \leq c_{n,t_h} \leq c_{c,max_h} \qquad \forall n, t \tag{4.10}$$

Consumption:

- The active power consumption at the building is the load of the building plus the power supplied to the batteries substracting the power obtained from the vehicles. It can't be negative as in the project is not contemplated that the system provides electricity to the network.

$$M_{DAM,t} = cons_t + c_{tot,t} - d_{tot,t} \qquad \forall t \tag{4.11}$$

$$M_{DAM,t} \geq 0$$

- The power that the building is obtaining from the batteries in each period t must be lower than the power the building would consume without the system.

$$d_{tot,t} \leq cons_t \qquad \forall t \tag{4.12}$$

$$cons_t \geq 0$$

SOC of the batteries:

- The SOC of the n vehicle at time t is the SOC of the latest period plus the power that the vehicle has gained or lost, considering the capacity of the battery and the efficiency of the chargers.

$$SOC_{n,t} = SOC_{n,t-1} + \left[c_{n,t} \cdot \eta_{bc} + c_{n,t_h} \cdot \eta_{uc} - \left(\frac{d_{n,t}}{\eta_{bc}} + US_{n,t}\right)\right] \cdot \frac{1}{B_{n,v}} \qquad t = 2, ..., T; \forall n \quad (4.13)$$

- The SOC of the n vehicle at any time must remain between the minimum and the maximum SOC appropriate for the vehicle.

$$SOC_{n,min} \leq SOC_{n,t} \leq SOC_{n,max} \qquad \forall n, t \quad (4.14)$$

4.6 Model outputs

Once the model was designed, it was important to decide which outputs were more convenient to its posterior analysis. The first thing to compare was if the implementation of the system was generating profit for both the company and the workers. Thereby, some variables were created to compare the implementation with the initial state:

– $cost_{user}$	Total energy cost regarding all users [€/year]
– $cost_{building}$	Total energy cost at the building [€/year]
– $cost_{user_{noEV}}$	Total energy cost regarding all users without the implementation of the system [€/year]
– $cost_{building_{noEV}}$	Total energy cost at the building without the implementation of the system [€/year]
– $E_{con_{noEV}}$	Contracted power the building would have without the implementation of the system [kW]

The variables were added to the restrictions in order to be calculated during the simulations:

- The users' energetic cost regarding the system is the charging power at all homes considering the electricity's price.

$$cost_{user} = \sum_{t=1}^{T} \sum_{n=1}^{N} c_{n,t_h} \cdot (price_t + \lambda_{home}) \quad (4.15)$$

- The building's energetic cost regarding the system is the network's consumption considering the price of electricity in the period, plus the unvariable tax regarding the contracted power and the degradation of the battery caused to its owners.

$$cost_{building} = \sum_{t=1}^{T} \left[M_{DAM_t} \cdot (price_t + \lambda_{energy}) + \sum_{n=1}^{N} d_{n,t} \cdot C_n\right] + E_{con} \cdot \lambda_{year} \quad (4.16)$$

- The users' energetic cost without considering the implementation of the system is the consumption of the vehicle during all the simulation multiplied by the energy cost.

$$cost_{user_{noEV}} = \sum_{n=1}^{N} \sum_{t=1}^{T} US_{n,t} \cdot (price_t + \lambda_{home}) \tag{4.17}$$

- The building's energetic cost before the implementation of the system is the building's energetic load multiplied by the energy price at all periods.

$$cost_{building_{noEV}} = \sum_{t=1}^{T} \left[cons_t \cdot (price_t + \lambda energy) \right] + E_{con_{noEV}} \cdot \lambda_{year} \tag{4.18}$$

- The contracted power before the implementation of the system is higher than the power demand of the building at all periods

$$E_{con_{noEV}} \geq cons_t \qquad \forall t \tag{4.19}$$

5 Data obtaining

5.1 Routine generation

5.1.1 Routine's generation methodology

To simulate the process, it has been necessary to know, at every moment, the SOC of all users' battery. To achieve it, a programme has been created in order to randomly generate all workers' routine and how much energy is spending each vehicle at every period. The programme inputs are:

- Number of workers included in the study.
- Every worker labour's schedule. In the data center case it is specified by the turns.
- Average consumption per km for all vehicles [kWh].
- Minimum and maximum SOC for all vehicles.
- Minimum and maximum charging/discharging power available in the vehicle.
- Charging power of the domestic charger.
- Vehicles' battery capacity.

In order to facilitate the simulations it has been considered that all users own the same vehicle. Therefore, they share the same battery capacity, charging and discharging power available and the same charging power of the domestic charger. Moreover, it has also been considered that all users involved in the system would allow the building to discharge their vehicles to the same SOC. Another supposition made is that one week has different consumptions every day in the afterwork period, but this structure repeats itself all along the year, as it is common to repeat the same activities in weekdays, specially for workers with kids. These assumptions have been made in order to avoid the effects that different vehicles could cause in the simulations. Notwithstanding, it could be changed in case it was needed.

Once all inputs have been specified, the programme generates the following parameters (described in section 4): Availability ($A_{n,t}$), Home ($H_{n,t}$), Vehicle Usage ($US_{n,t}$), all parameters related to the vehicle ($c_{n,max}$, B_n, $d_{n,max}$, $SOC_{n,min}$, $SOC_{n,max}$ and c_{c,max_h}) and related to the building ($cons_t$ and $price_t$). The programme generates the Availability vector for each worker with the input information of the working schedule but Home and Vehicle Usage vectors are more complicated. First of all, for every worker, both vectors are directly generated at the hours when the user is working or commuting, as can be observed in next figure:

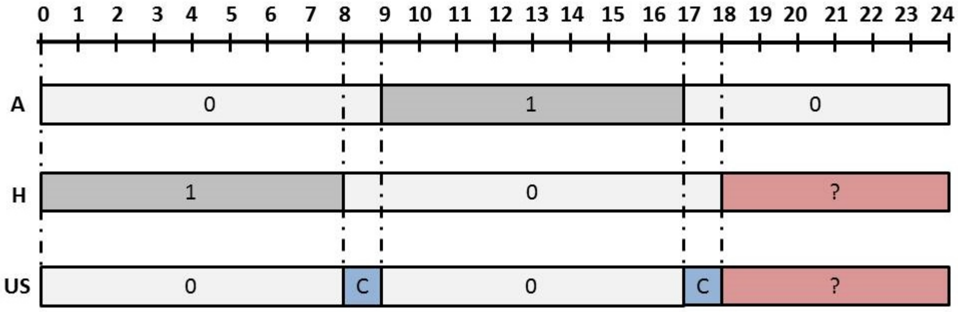


Figure 5.1 First step to generate vectors Availability (A), Home (H) and Vehicle Usage (US). C is the kWh spent by the vehicle's owner commuting. In this case the user works from 9h to 17h.

Afterwards, in the free time (afterwork usually), an empty vector is created. For every day, it is randomly chosen how many trips is the user going to do and when. It has to be made sure that it is an even number of trips, as otherwise it would mean that the user left home but didn't come back for the night. Then, Home and Vehicle Usage's vectors are simultaneously generated with the new information, as can be seen in next figure:

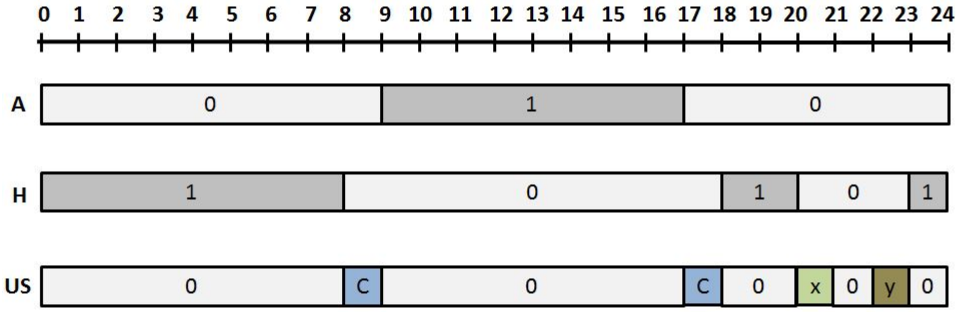


Figure 5.2 Final generation of vectors Availability, Home and Vehicle Usage. In this case, randomly, two trips are chosen for the user to do all along the afternoon. From 20h to 21h the user spends x kWh while driving and from 22h to 23h the user spends y kWh and goes back home.

Once a full week is created, the data obtained is extrapolated for the rest of the year and put together with the other workers. When this process is done, every parameter generated is exported to an excel sheet in order to be afterwards used as an input for the optimization programme.

Considering all the information above, the worker can be involved in the following activities: Working, Commuting (C in figure 5.3), at Home or at their Free time (when the Home and Vehicle Usage vectors are randomly created). In the medium office, the data generated would be in function of every user's labour schedule (as shown in the previous figure), but following approximately the same structure as turn 1 in the data center. In next figure the structure regarding the four activities in function of the turn are shown. This affects the creation of the programme outputs.

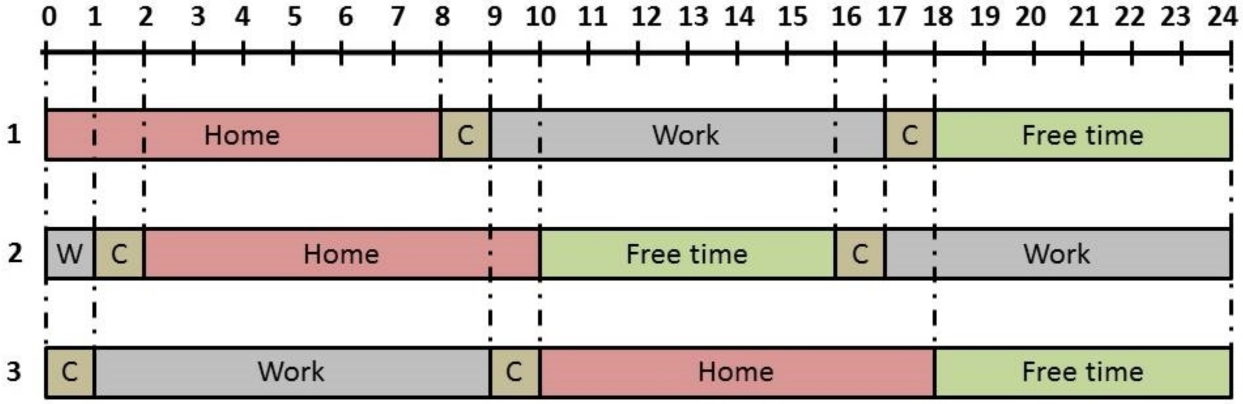


Figure 5.3 Day structure for workers in turn 1, 2 and 3. This organisation of turns have been decided for the project owing to its easy application in the programme but another organisation could be considered in case it was needed.

5.1.2 C, x and y parameters' obtention

Parameter C refers to the km spent to commute by each user every day. The information is obtained from a probability distribution produced in a survey done in the US [19] and can be observed in next figure:

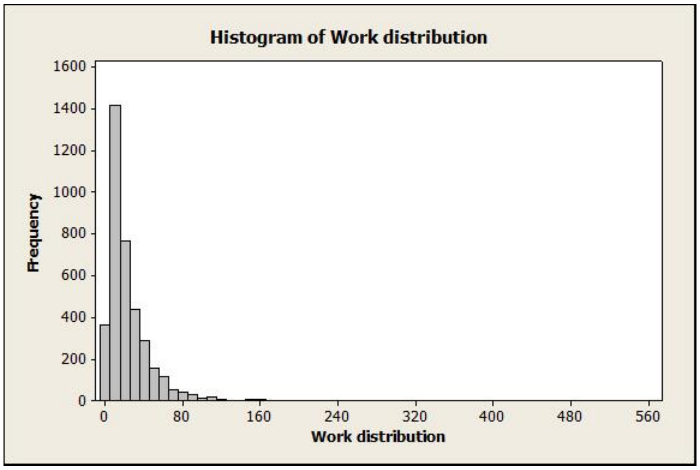


Figure 5.4 Probability distribution of the km to work. Own source.

Parameters x and y are randomly calculated following the restriction that the total energy spent in trips can't exceed the maximum established in the input. Moreover, as in the simulation the periods of time are one hour long, and in afternoons is more typical to do shorter trips, x and y values can differ.

5.2 Vehicles' data

To execute the simulations of the project it has been chosen a *Nissan Leaf* as the vehicle used for all users. Concerning the model, it has been chosen the latest version of *Visia*. It consists in an affordable electric vehicle, which its use could be easily spread among the population. It has a battery capacity of 30 kWh. Its charging power at home with the conventional charger recommended by Nissan is 3,3 kW (8 hours to be fully charged). The board charger is 3,6 kW, and its maximum charging power 50 kW. All the data has been obtained from the official Nissan Leaf catalogue.

5.3 Battery penalisation

As it has been explained in previous sections (see section 2.5) discharging the battery penalises its lifetime. Thus, the cost for discharging has been estimated as:

$$C_n = \frac{B_n \cdot C_B}{DOD_{n,max} \cdot L_n} \tag{5.1}$$

Where B_n is the battery capacity [kWh]; C_B is the battery cost for kWh [€/kWh]; $DOD_{n,max}$ is the maximum DOD admissible [in so much for one]; and L_n the life cycles that the battery can develop (extracted from figure 2.5). The cost of the battery has been considered 207 €/kWh [15]. Following the equation the penalisation factor for different DOD are:

DOD [%]	**Penalisation value** [$€/kWh$]
20	0,020700
30	0,029570
40	0,043125
50	0,063690
60	0,086250
70	0,098570
80	0,103500

Table 5.1 Value of the penalisation in function of the DOD. DOD lower than 20% haven't been considered as the system wouldn't be viable (no margin for discharging the vehicles) and higher than 80% either as it would be too harmful for the battery.

6 Simulation results' analysis

6.1 Medium Office

6.1.1 Case 0. Before implementing the system

Before implementing the system the energy cost in the building was 65.271,34 €/year with a contracted power of 176,11 kW. This value has been calculated as explained in section 4.6. The vehicle cost for the users (just concerning the charging power) was 950,39 €/year. It has to be taken into account that the vehicles' consumption in weekends is not considered and that just 20 km are allowed to do during the afternoon. Moreover, that this price includes all users, but any economical charge related to the vehicle different from charging hasn't been included. Thus, even the building's price is independent on the number of users using the system, the total cost for users increases every time a user enters the system. Thereby, this information has just been used to compare how much all persons involved in the system would save with the implementation.

Furthermore, it is important to understand the electrical building's consumption, as its tendency affects the system's behaviour all along the simulation [20]. The data is obtained from a medium office in Los Angeles, United States of America. Thus, the consumption remains more or less stable every day of the week until summer is reached, where the consumption is the maximum, and christmas, where the consumption is the minimum (holidays). In next figure, the consumption for the first and second week of January can be seen.

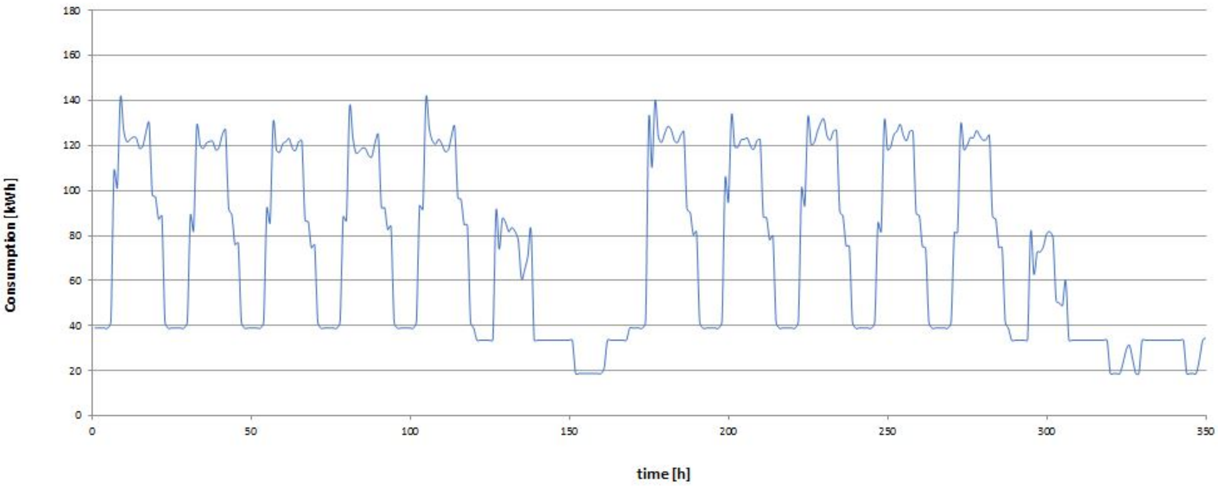


Figure 6.1 Medium office's consumption during two weeks. Own source.

6.1.2 Case 1. System's implementation. General behaviour of the process

The system was first implemented considering three workers and a DOD of 70%. All variables included in the optimization were studied.

First of all, as every user repeats the same routine, usually the system charges the vehicles at the same hour every day (or almost every day). In the case seen in next figure, user 1 gets their vehicle charged at 8h, while users 2 and 3 at 16h.

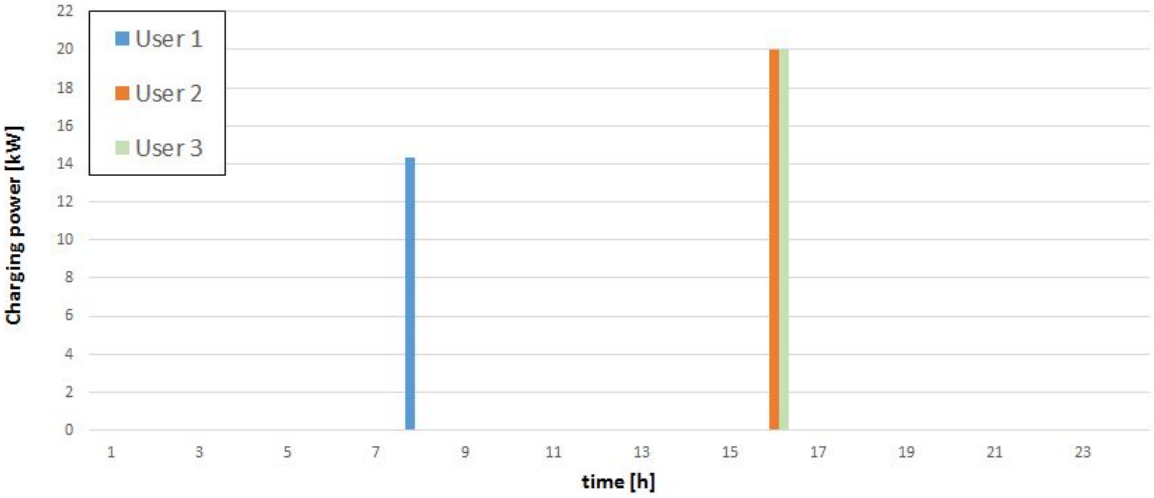


Figure 6.2 Charging periods in a day. Own source.

Concerning the discharging rate, the system behaves aiming to decrease its power consumption during the summer months, in order to accomplish its goal to reduce its contracted power. Thus, until the number of users involved in the process isn't big enough it doesn't discharge the vehicles during other seasons.

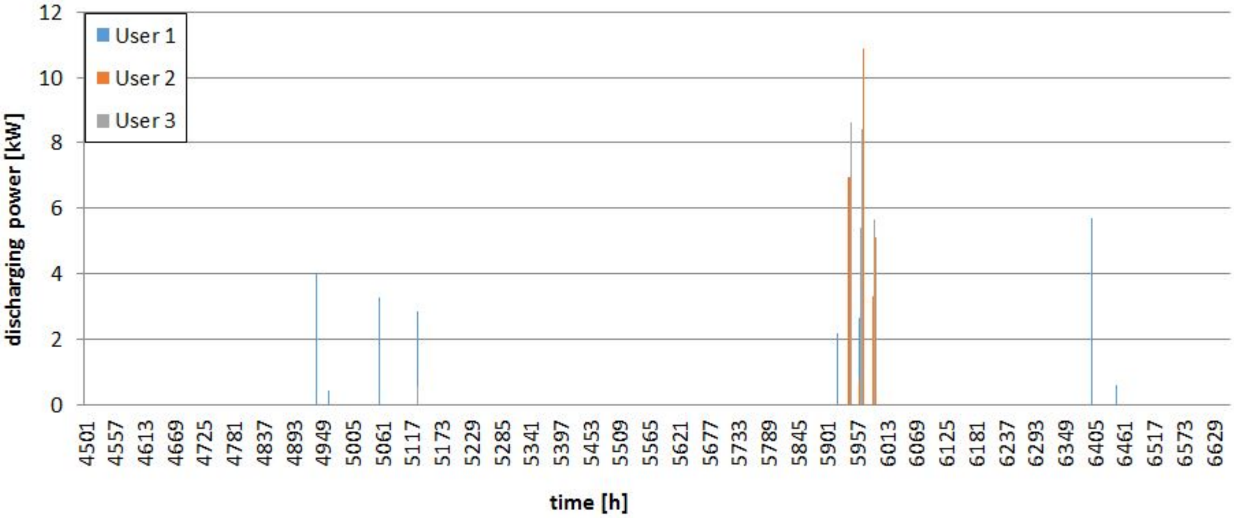


Figure 6.3 Discharging power during summer (from half june to half september). The rest of the year it remains 0. Own source.

Finally, the most characteristic feature of the system is that it literally shaves the highest consumption of the year, as it can be seen in next figure, where the line indicates the maximum consumption. When more users get involved it is easier to see the difference, which can be observed in figure 6.5.

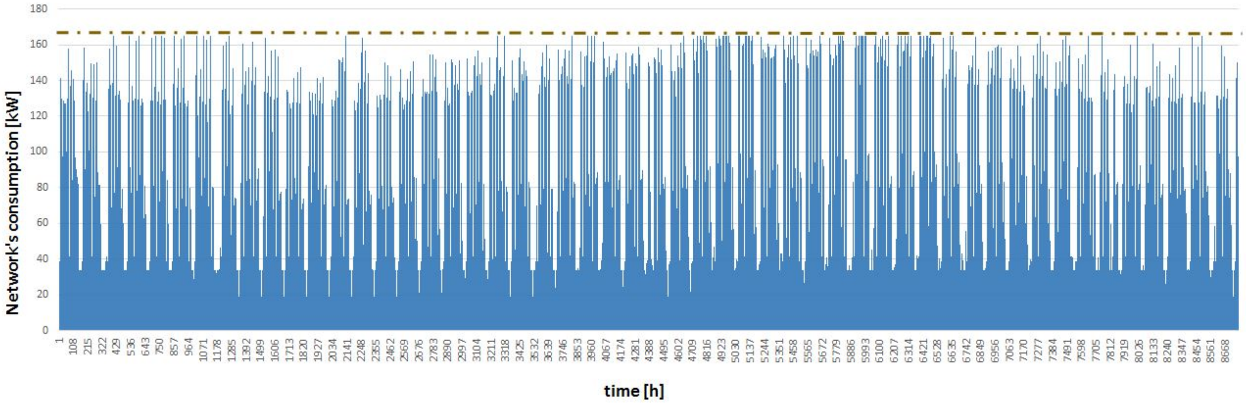


Figure 6.4 Discharging power during summer. Own source.

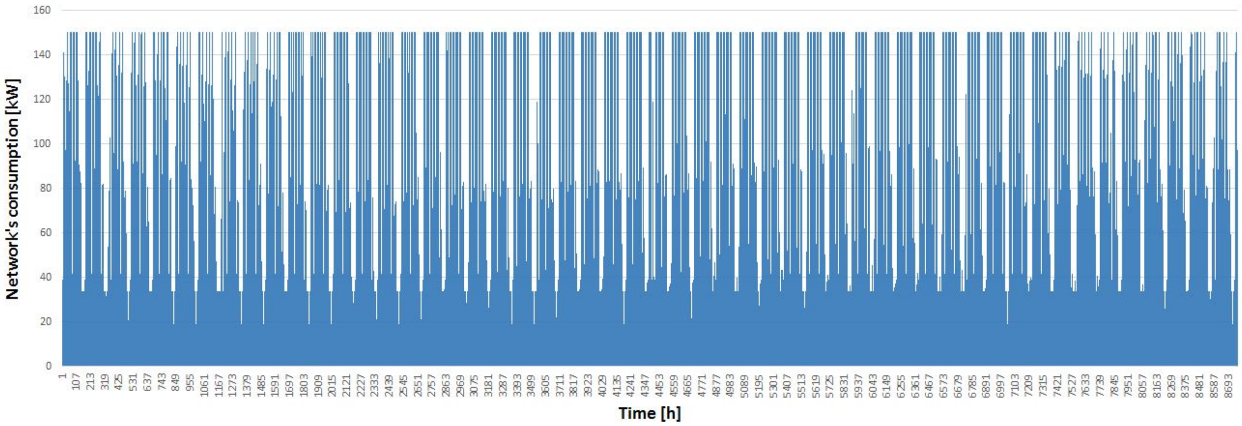


Figure 6.5 Consumption from the network when 11 workers are considered in the system. Own source.

6.1.3 Study of the appropriate DOD for both the workers and the building

Once implemented the system and considering the penalisation values for discharging the batteries in function of the DOD (see section 5.3), the savings calulated for both the building and the users have been:

DOD [%]	**Building Savings** [€/year]	**User Savings** [€/year]
60	350,65	315,49
70	445,56	315,42
80	538,44	315,34

Table 6.1 Savings for the building and the users in function of the DOD.

In the table just DOD in the range 60%-80% are included. This is because three batteries with minimum DOD allowable below 60% weren't enough to guarantee savings for both the building and the users. DOD over 80% haven't been included as they are too harmful for the battery, as mentioned in table 5.1.

Moreover, even though savings for users decrease when the DOD increases, the behaviour of the system has lead to an almost stable value. However, in the building, savings have a linearly increase. These results have been obtained for the following reason: Every time the DOD increases, the building can extract more energy from the vehicles while guaranteeing they keep their SOC in between the established limits. To compensate this effect, the system forces the building and the users to charge more the vehicles. Notwithstanding, while this charging rise multiplied by the cost of the energy makes almost no difference for users, for the building it means decreasing even more the contracted power and, thus, decreasing the unvariable fee, which causes a far more rellevant effect. In next table the total charging power at the building and at home can be seen:

DOD [%]	**Total $\mathbf{c_{n,t}}$** [kW/year]	**Total $\mathbf{c_{n,t_h}}$** [kW/year]
60	3.008,35	13,59
70	3.012,35	14,30
80	3.017,61	15,20

Table 6.2 Total charging power at the building and at home all along the simulation in function of the DOD considering three vehicles. Own source.

Considering the charging power shown in the table and an average price for energy of 0,1 €/kWh, it can be seen that the total increase of charging power in users entails approximately 0,16 €/year, which means 0,054 €/(year · user). In the building, 0,93 €/ year. Contrarily, the contracted power decrease means approximately 190 €/year in savings. Therefore, a DOD of 80% has been chosen for the rest of simulations.

6.1.4 Study of the optimal number of workers participating in the project

To develop this study different simulations have been carried out in order to compare the results with the situation before the implementation of the system. The contracted power and the savings for the users and the building are shown in next figures.

1. **Contracted power**

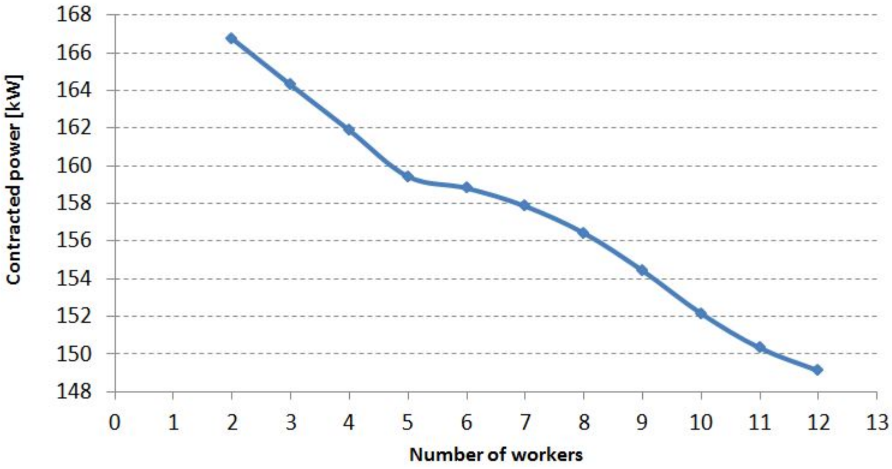


Figure 6.6 Contracted power in function of the workers considered in the system. Own source.

As it can be observed in figure 6.6, the decrease of contracted power has an almost linear behaviour. In case just one hour of consumption was considered, the energy consumption representation would be an straight line. Therefore, every car included in the system would decrease in the same proportion the contracted power. Notwithstanding, the real consumption includes a really thin peak, which facilitates the drop of contracted power at first. However, when it is wanted to be decreased approximately below 160 kW, more vehicles are needed, as the peaks are thicker and more repeated all along the year. Thus, the slope of the function is also reduced, which can be appreciated in last figure.

2. **Users' savings**

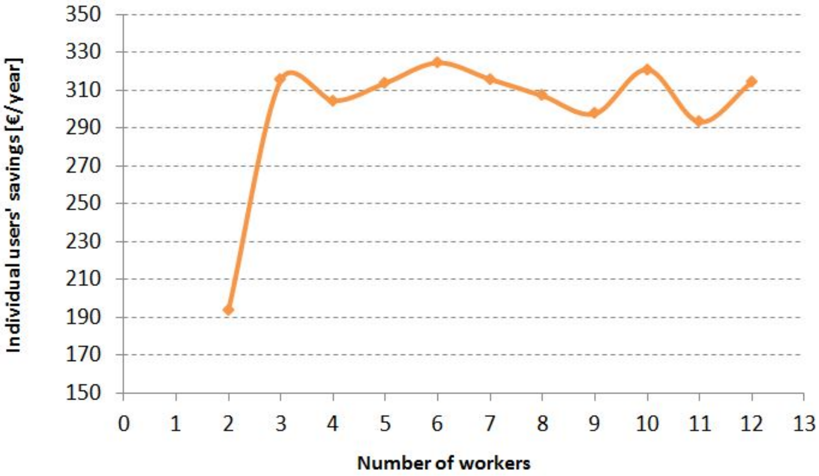


Figure 6.7 Individual users' savings in function of the workers considered in the system. Own source.

Concerning the users' savings, it can be appreciated a huge difference between the savings produced for two workers and the rest. The main reason is that two persons are not enough to develop this project and they have to charge more their vehicles at home. Furthermore, the results while considering a higher number of workers involved, depend mainly on the energy they spend to work. The maximum savings are produced when workers 6 and 10 are involved, coinciding with the persons that spend more energy commuting. Thus, every time a person spends more than the average, the savings increase. The reason is that if the building wants to guarantee their SOC to be between the limits it has to charge more the vehicles that spend more energy (in comparison with the others), as their vehicle has the same battery capacity.

3. **Building's savings**

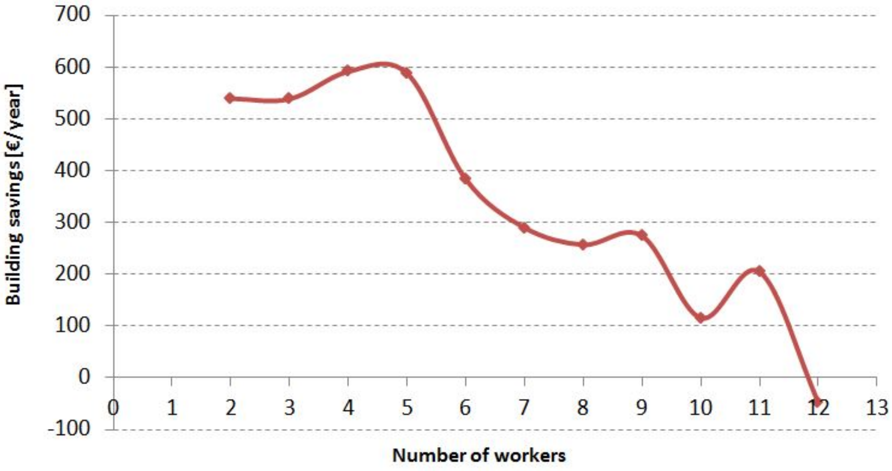


Figure 6.8 Building' savings in function of the workers considered in the system. Own source.

In this case, the savings decrease dramatically after the absolute maximum is produced. The reason is that before reaching it, the costs that suppose charging the vehicle of every new person included in the system are not rellevant in comparison with the beneffits that reducing the contracted power produces. However, afterwards, every time a person is introduced into the system, it causes the opposite effect. This fact is also promoted for the growth difficulty on decreasing the contracted power, as explained in figure 6.6. Moreover, contrarily as in the users' savings, if the new person included spends more energy commuting than the average, the building needs to charge it more than usual. This produces a local minimum, as can be seen in worker number 10 (the one who spends more energy).

In conclusion, the optimal number of workers included in the system considering the savings in both the building and the users is around five workers.

6.1.5 Study of the effect of other factors on the results

1. **Vehicle capacity**

As explained in the previous subsubsection, a person spending a lot of energy commuting can badly affect the results of the system, specially for the building. Thus, it has been studied, with one person, when the process would become infeasible, as a recommendation to the company while implementing the system. It has been found that from 68 km above, it becomes infeasible. Notwithstanding, this is the result concerning one worker. Therefore, in function of the number of users, it is likely that two workers living 40 km away from the office could also end up being problematic for the building savings.

Moreover, it has been studied what would happen if instead of owning a *Nissan Leaf*, these workers had a *Tesla S 75* (75 kWh battery capacity). The results have been that the system behaves exactly as if the vehicle spent less km commuting but had *Leaf*'s capacity. Thus, the conclusion has been that if in the building several users live far from the office, they can be included in the system if they own a car with a higher battery capacity, and it won't be damaging on the results obtained.

After realizing the effect of adapting the battery capacity to each worker needs could increase the building savings, it has been studied the effect of considering every vehicle included in the system to be a *Tesla S 75* with rear traction and one engine. The results obtained compared with the ones with a 30 kWh battery capacity can be seen in next table:

5 workers	**Nissan Leaf**	**Tesla S**	**Tesla S rapid charging**
User savings (€/year)	313,75	291,77	243,44
Building savings (€/year)	587,89	1651,21	2055,42
Contracted power [kW]	159,42	146,80	142,19

Table 6.3 Comparison between the savings produced with a higher battery capacity. Own source.

The functioning of the system observed has been the same as when all vehicles had lower capacity. However, the results are radically different, as more energy can be extracted from each battery still guaranteeing the SOC keeps in between the established limits. Thus, the contracted power is much more decreased and the building savings are tripled.

However, if the true charging velocity at home that a Tesla can bear is considered, which consists in 7,4 kW in a monophasic grid with the model chosen [5], it can be observed that in the maximum consumption period the system takes profit from these velocity and make vehicles to be charged in their homes, causing a decrease in each user savings.

2. **Discharging penalisation**

All along the project, it has been mentioned that the battery suffers a degradation while being discharged, and it has been supposed that it is the company the one paying this cost. Then, a simulation has been carried out considering the penalisation is in charge of the user, which would mean a case where the company wouldn't take into account that the user has to be paid for the energy obtention. The results have shown a decrease of the 75% in the users' savings, while the same behaviour of the system. In next table a comparison between the situation where the company is in charge of this cost (column "degradation considered") together with the case where the user pays the degradation (column "degradation not considered") can be observed.

3 workers	**Degradation not considered**	**Degradation considered**
User savings (€/year)	79,71	315,34
Building savings (€/year)	577,99	538,44
Contracted power [kW]	164,28	164,28

Table 6.4 Comparison between the savings produced in function of the one in charge of paying the penalisation for degrading the battery. Own source.

3. **Different Routine**

   All the reasons explaining the behaviour of the system in the simulations have been exposed in the last subsubsections. However, all results have been obtained with the same workers, so a study has been carried out in order to compare them with the results obtained with another routine. What has been observed is that the optimal number of workers is also around the same value than in the first routine. Furthermore, the contracted power has exactly the same behaviour. What changes the most is the savings for the building, as they depend on the energy spent by the workers commuting, and in routine 2 the users live closer to the office than in routine 1. Thus, the building savings are higher.

   Considering the results obtained, which can be observed in next figures, it can be concluded that the first goal exposed in section 3.3, that aimed to extrapolate the results from one simulation to other cases is accomplished with this example.

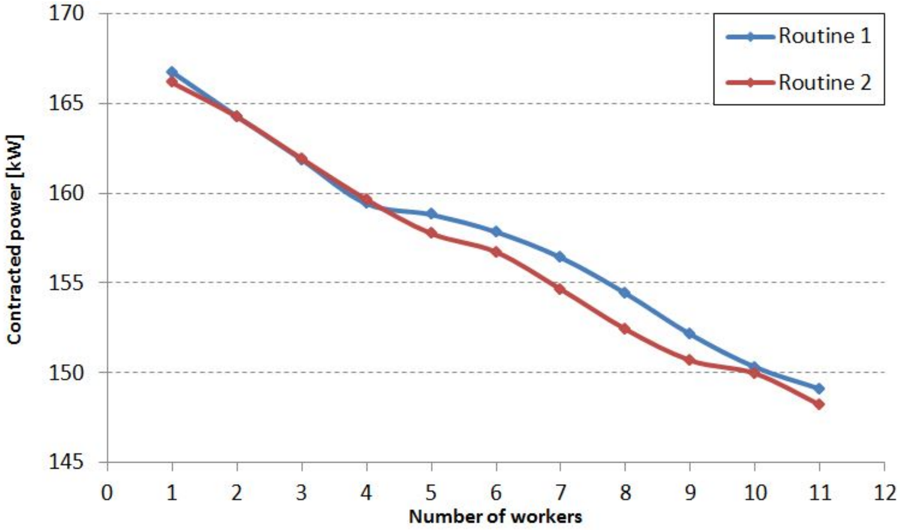


Figure 6.9 Contracted power in function of the workers considered in the system. Own source.

Figure 6.10 Individual users' savings in function of the workers considered in the system. Own source.

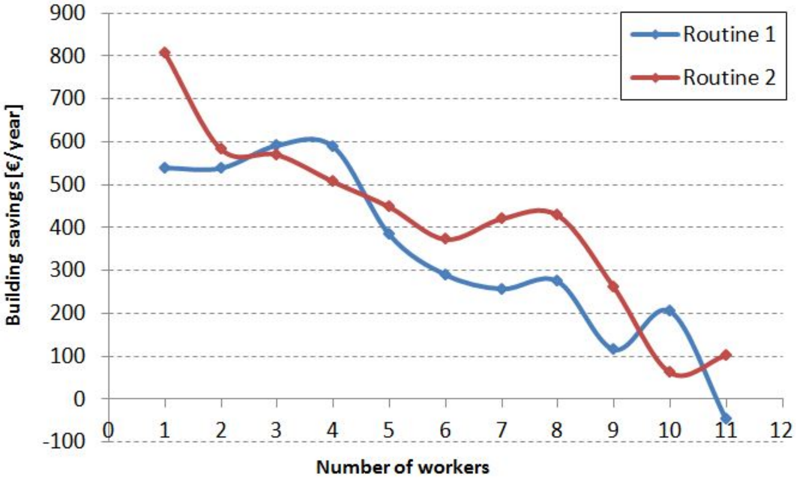


Figure 6.11 Building savings in function of the workers considered in the system. Own source.

6.2 Data center

6.2.1 Case 0. Before implementing the system

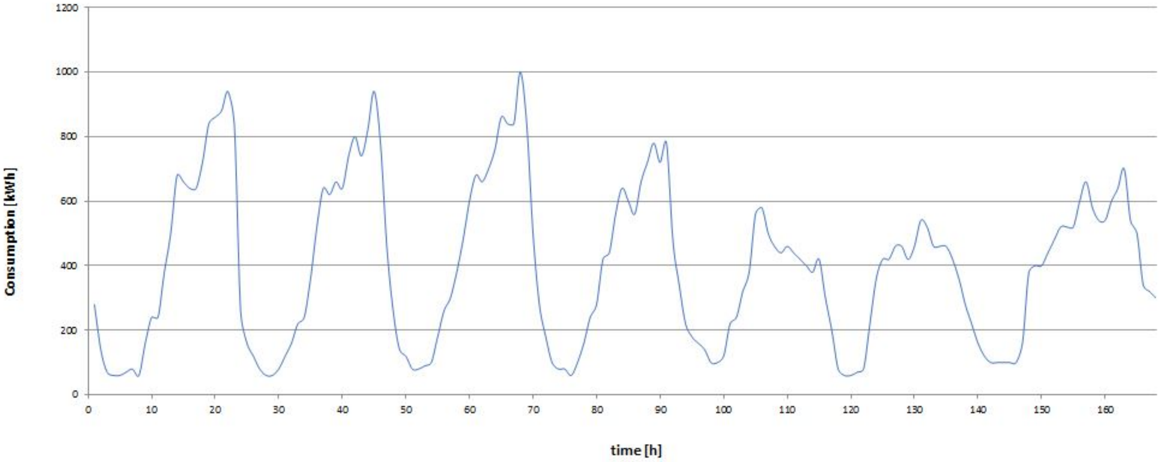


Figure 6.12 One week consumption in the data center. Own source.

In the data center, the building's load is repeated every week. Thus, the peak of energy is always produced on wednesdays, and every day during turn 2. Before the implementation of the system, the building had a contracted power of 1.000 kW [22], and the total economic amount spent on energy was 362.851,86 €/year. As in the medium office, the price calculated for users is used just to compare it and obtain the savings produced.

6.2.2 Case 1. General behaviour of the process and maximum DOD allowable

After simulating different number of workers in each turn, it has been concluded that the system just discharges vehicles from turn 2, as the peaks are always in that turn. It has been also found that the system stops being feasible (when 52 worker are included : 20 from turn 1, 16 from turn 2 and 16 from turn 3), and still is not discharging vehicles from other turns. On the other hand, the vehicles forced to be charged at home are the ones that spend more energy commuting, regardless of the turn.

While looking for the best DOD allowable, it has been found that the most appropriate is 70%. Thus, the rest of the simulations have been carried out considering this value. Its explanation is in subsection 6.3.

6.2.3 Routine 1

The results obtained with the first routine have shown that there is an ethical problematic in the company. If the workers from turns 1 and 3 are included in the system, the only vehicles discharged are from turn 2. Consequently, even though all vehicles are being charged, not all of them are contributing to the system. However, on the other hand, if just workers from turn 2 are considered, it excludes two turns from the beneffits obtained for the users.

If just the company interests are considered, then just turn 2 should be included in the system. Following this idea the results obtained are the following:

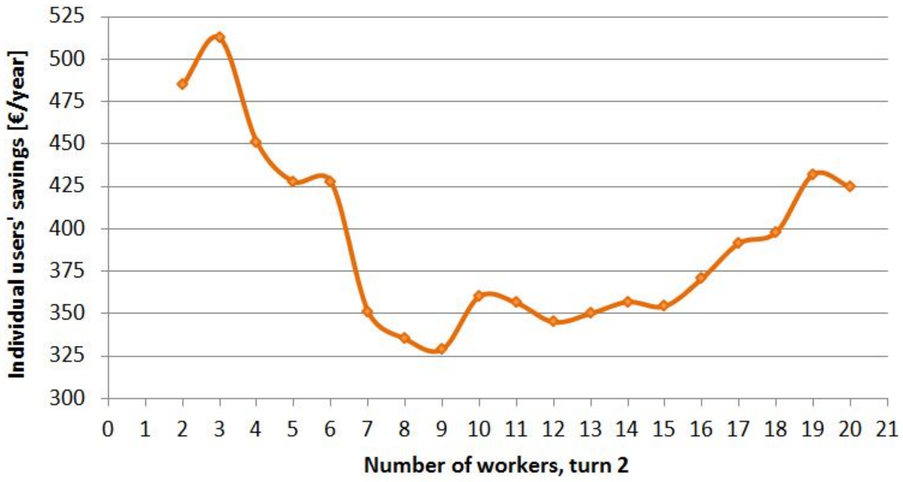


Figure 6.13 Individual users' savings in function of the workers considered in the system. Own source.

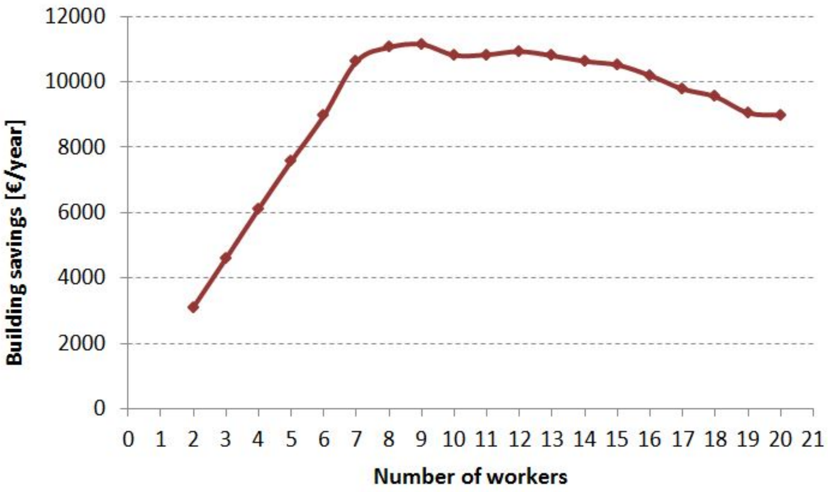


Figure 6.14 Building savings in function of the workers considered in the system. Own source.

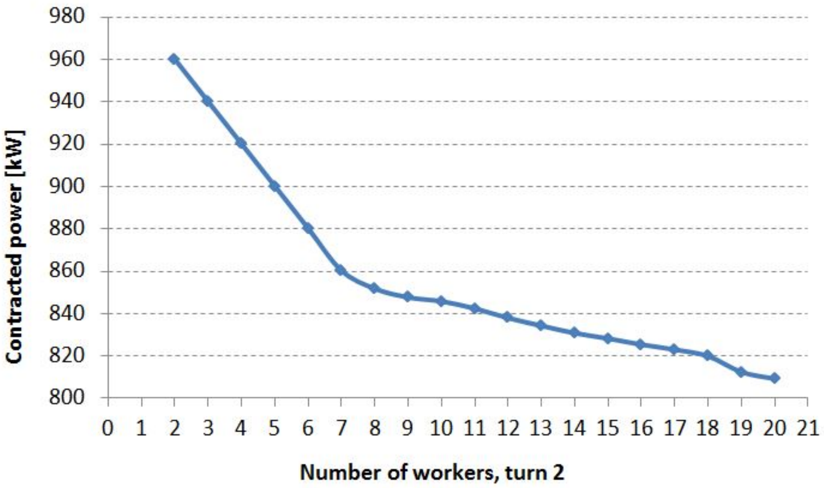


Figure 6.15 Contracted power in function of the workers considered in the system. Own source.

In the three figures, the behaviour of the process follows the same arguments than in the medium office: The users' savings depend on the energy spent commuting, the building has an absolute maximum and afterwards the savings start decreasing, and the contracted power is easier to be reduced until a concrete power is reached (850 kW in this case). Furthermore, it has also been studied the maximum km a user can do while commuting before making the system infeasible: they are 107 km.

6.2.4 Routine 2

It can be observed that the results obtained in both routines are really similar. The most different one is the users' savings, and as in the medium office, also explained by the difference in energy spent commuting.

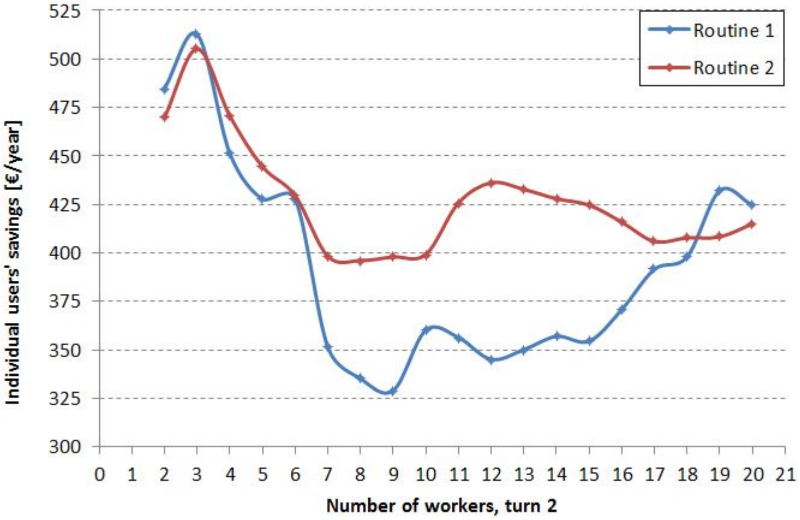


Figure 6.16 Individual users' savings in function of the workers considered in the system. Own source.

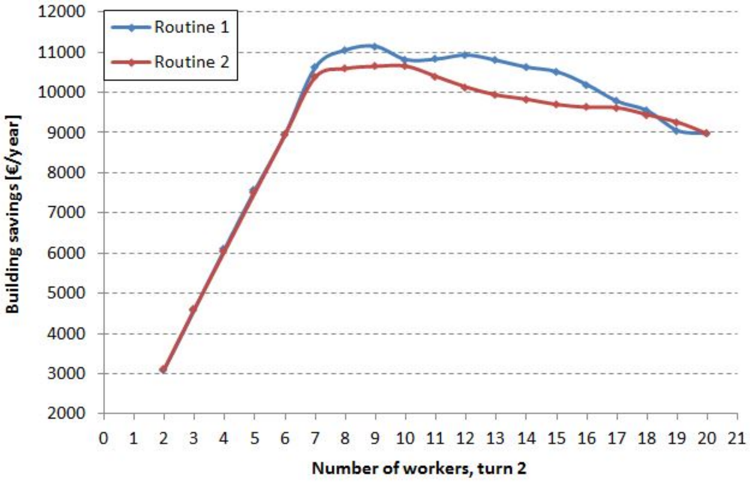


Figure 6.17 Building savings in function of the workers considered in the system. Own source.

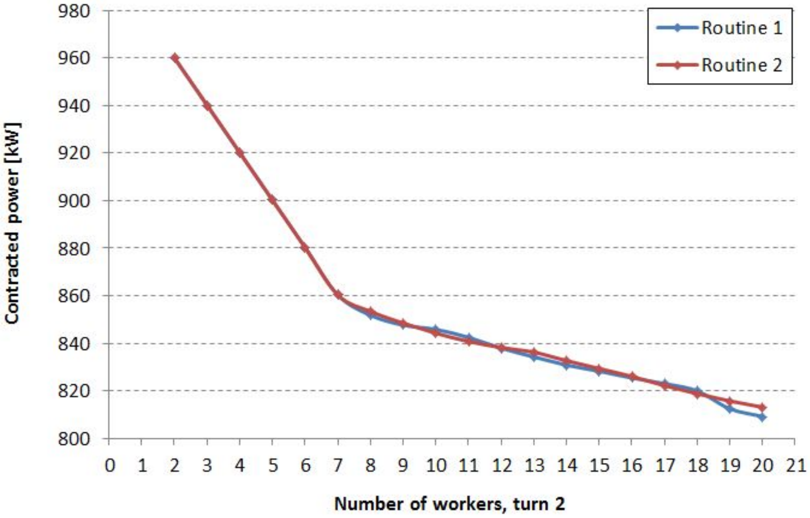


Figure 6.18 Contracted power in function of the workers considered in the system. Own source.

6.3 Comparison between the medium office and the data center

First of all, it has been observed that workers beneffit from the process saving approximately the same amount of money regardless of the building studied, which is favourable for users, as a guarantee of the behaviour of the process. Moreover, even though both processes depart from extremely different situations, the reasoning surrounding the basic ideas around how the process reacts is the same in the office and the data center.

However, in the office, the appropriate DOD chosen is 80% and in the data center 70%. This can be explained by each building's capacity to absorbe vehicles which spend more energy commuting than the average. When a car spends too much energy, the data center is able to charge it and loses money with it. Contrarily, if the DOD is 70% the system forces those vehicles to be more charged at home. Notwithstanding, in the medium office, the system is not able to charge these kind of vehicles, so this problem disappears. Furthermore, if a DOD less than 80% is chosen, the system can't guarantee them to save money.

Concerning the number or workers considered in each case, it can be seen that a lower contracted power and consumption leads to less workers in the building. Thus, it can be understood that in the office, the maximum building savings are around 5 workers, while in the data center around 10. However, it needs to be clarified that in the data center 10 workers of turn 2 could mean more than 30 workers in total, and that in the study not all the workers in the company are contemplated to participate in the project. Furthermore, it has been known that the number of workers in a data center is extremely variable [16]. This has been a problem while simulating, but as the savings' peak is caused around 10 workers in turn 2, in different internally structured data centers that have the same contracted power and a similar consumption the peak would also be around 10 users.

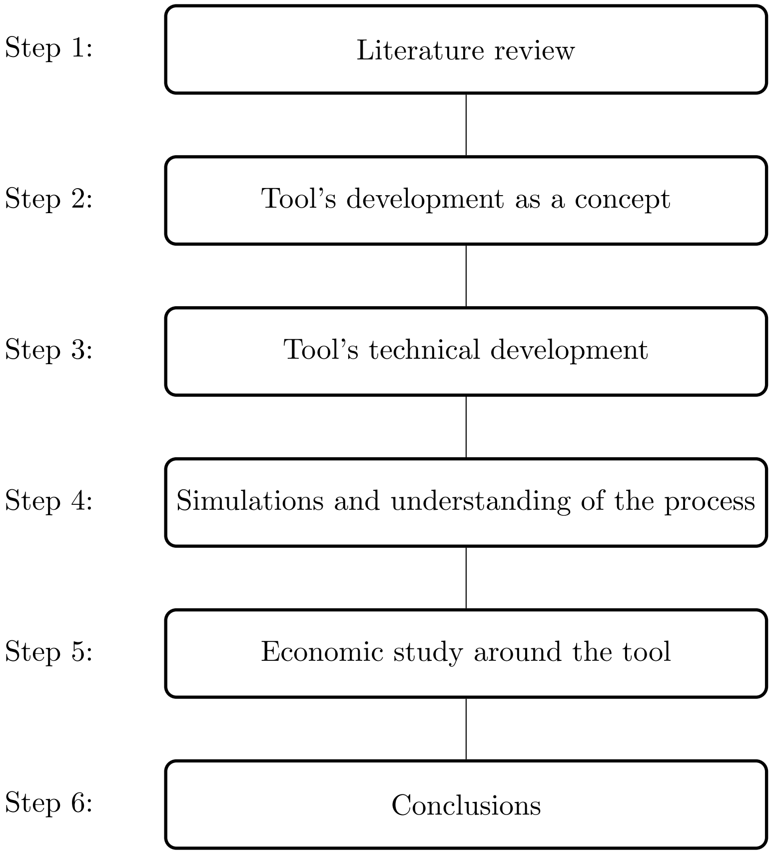
6.4 Other considerations

First of all, it has to be considered that in the medium office, as weekends are not considered in the process, the SOC at 1 AM on monday is the same than on 11 PM on friday. This supposition is false, as the user is going to spend energy during the weekend. Moreover, it is unlikely that the battery arrives fully charged on monday if the worker knows that their vehicle is going to be charged for free. Thus, it has been considered that this variation wouldn't badly affect the results.

Secondly, the optimization program doesn't make a difference between different workers. Consequently, it can guarantee a high SOC for a certain user all along the simulation and a lower one for another. In reality, the charge would be divided equally, as if the system has guaranteed every worker can be within the limits established the energy can just be redistributed.

By last, if users drive within a city, every time they break they are regenerating energy, which would increase their SOC. As the consumption commuting and during the afternoons has been estimated randomly, it is considered that the regeneration is included in the parameters.

7 Methodology



1. **Literature review**: Based on the understanding of the modes in which a vehicle can be connected to a building.
2. **Tool's development as a concept**: Based on the decisions related on how the process could be developed and all the tools needed to be created or adapted.
3. **Tool's technical development**: Creation of the generation data program and adaptation of the model to the needs of the process. Development of the outputs needed in order to study the tool generated.
4. **Simulations and understanding of the process**: Different studies carried out in order to fully understand the behaviour of the process and its applicabilities. The simulations have been done with *GAMS* and the solver *CPLEX*.
5. **Economic study around the tool**: The results obtained during the simulations have been verified for its real applicability.

8 Budget

8.1 Project's budget

As all the project has been developed by simulation, to calculate the budget they have been considered the staff and the licences used. The wages have been obtained from [21] and [9].

Engineers	**Hours worked**	**Wage** [€/h]	**Total** [€]
Project director	30	39	1.170
Undergraduate	270	8	2.160
Licenses	-	-	1000

Table 8.1 Engineering budget in the project. Own source.

The total cost is **4.371,67 €**.

8.2 Budget regarding the implementation of the process

In this subsection it has been considered that the company already owns the facilities to charge vehicles and just has to change their chargers for bidirectional chargers. Consequently, the cost of the implementation of the program has been the price of each bidirectional charger, estimated as 4.000 €/charger including all ancillary systems (wires, protections, ...) multiplied by the number of workers included in the system.

To study the viability of the process the NPV and IRR have been calculated for each building. To calculate the NPV it has been supposed a simple interest rate equivalent to the one in the spanish bond up to 10 years (1,26%) [11], as the IRR has been also calculated to an extent of 10 years. Moreover, as the users are not investing in the process, their beneffits haven't been included in the balances.

1. **Data center**

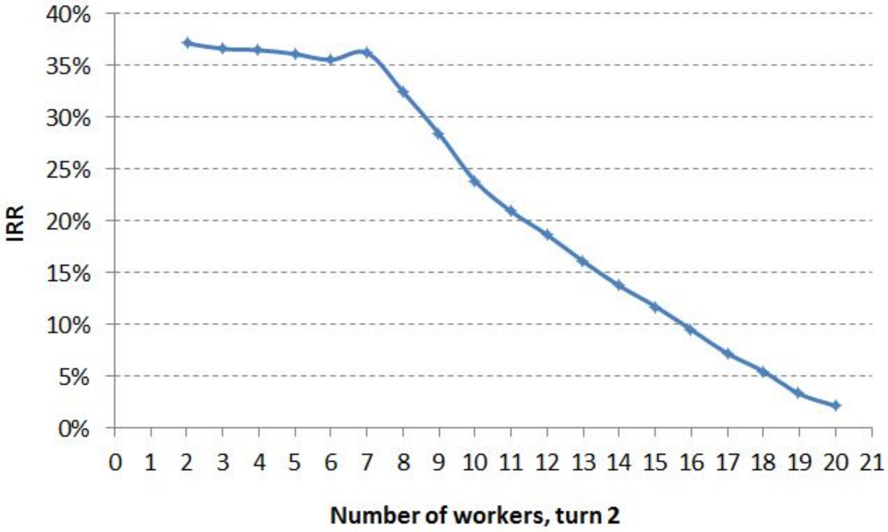


Figure 8.1 IRR in the data center in function of the number of workers. Own source.

In this figure it can be seen that the process is feasible, as its interest rate is higher than the one offered by the banks and bonds (maximum 1,26%). The NPV of the data center has been represented in next figure:

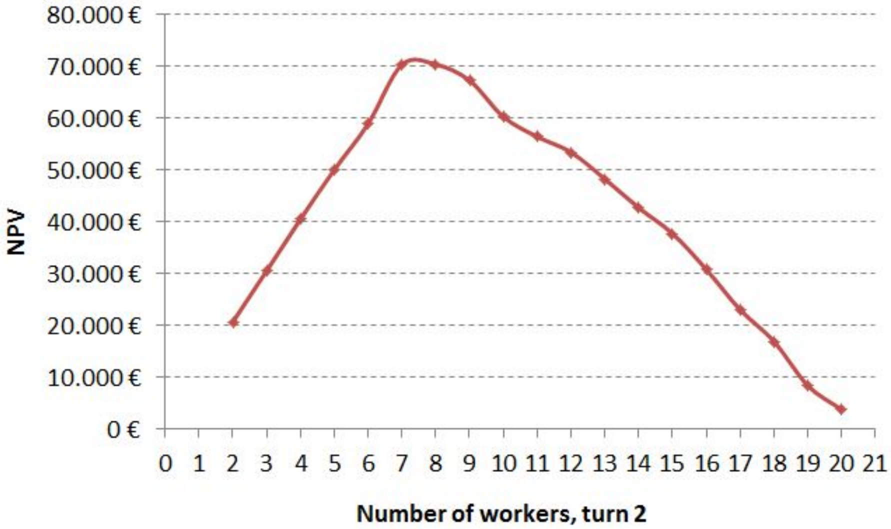


Figure 8.2 NPV in the data center. Own source.

It can be concluded that the optimal number of workers considering the price of bidirectional chargers is 7 workers in turn 2. It has to be considered that in last subsections it was mentioned that the highest savings in the process were around 10 users. That value didn't include the price of the implementation of the project, as now it can be noted that considering the high price of the bidirectional chargers it is more profitable to include less workers.

2. **Medium office**

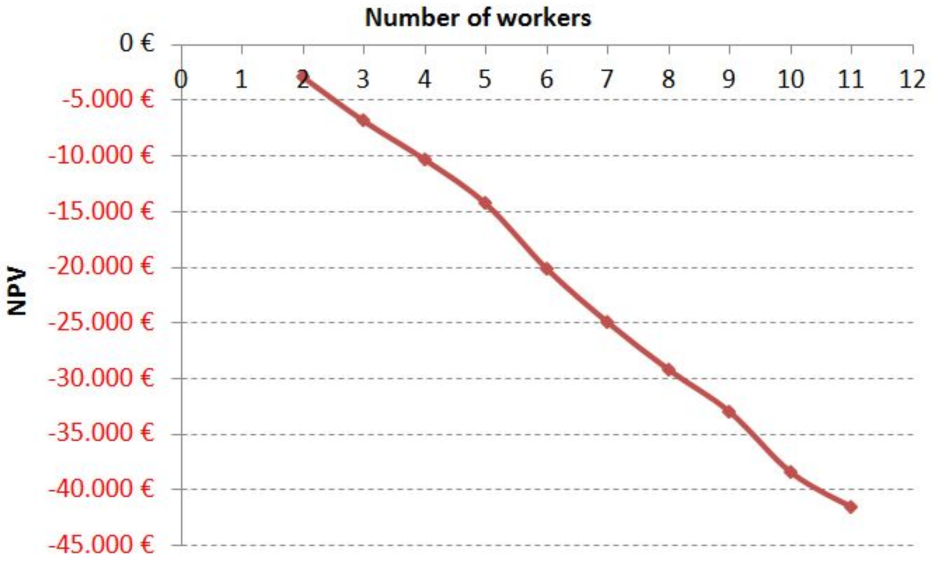


Figure 8.3 NPV in the medium office. Own source.

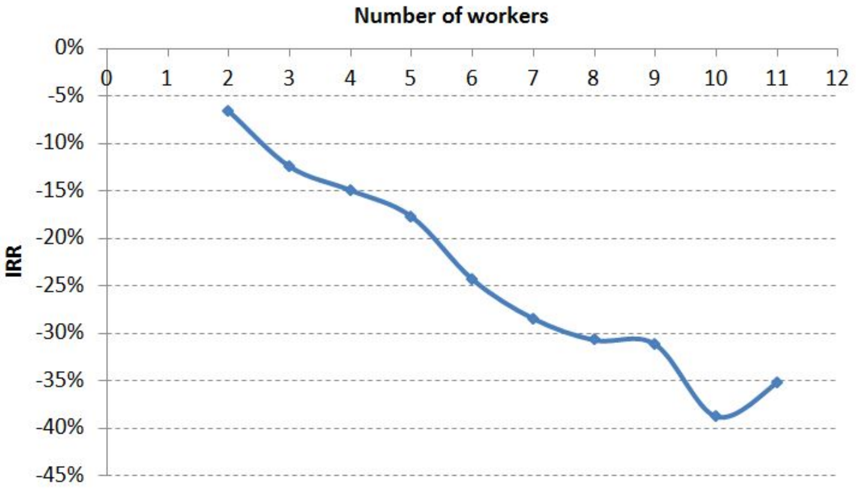


Figure 8.4 IRR in the medium office. Own source.

In the office it can be observed that the price of the bidirectional chargers is too high compared to the beneffits it causes to the building, as the IRR and the NPV are negative. Thus, it can be concluded that a consumption profile similar to the medium office is nowadays not profitable. However, if the price of bidirectional charger decreased the situation could be varied. Consequently, it has been studied which value should the bidirectional chargers have in order to make the process feasible.

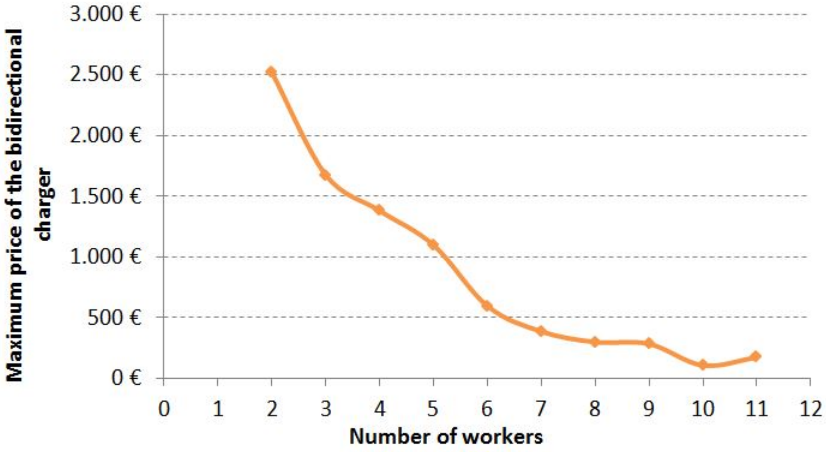


Figure 8.5 Maximum value of a bidirectional charger in order to guarantee the profitability is the system. Own source.

As the office has a lower consumption, the most appropriate number of workers is the one that supposes less investment the first year, which would need the price of bidirectional chargers to be 2.500 €.

9 Environmental study

As this project has been based on simulations, the only environmental impact caused has been related to the electricity spent by the computer. Furthermore, in case the project was implemented, the only environmental impact caused would be owing to the installation and elaboration of the chargers. This can be explained because once implemented, the electricity consumption wouldn't change, as the system just redistributes its obtention (battery and network).

The main computer used to develop this project consumes 44,45 W [4]. As the total hours estimated for the project (including the project's director and the engineer) have been 300 hours, the total consumption has been 13,34 kWh.

10 Conclusions

This report has sought to prove that it is possible to exploit electric vehicles in more ways than just in the transport field. The finality has been accomplished through an optimization where a practical application of the idea was simulated. Its basic functioning included a company, where the relation between the workers and the company was emphasized, as they were exchanging electricity all along a year. It has also been shown how this strategy should be developed and the behaviour that the process would adopt in every case.

Furthermore, some suggestions have been made in order to advice the company in case the process was aimed to be implemented. The suggestions included what would beneffit the users and the company considering different factors: the vehicles' capacity, their commuting distance, the number of workers included in the simulation...

As a general conclusion, this report has shown a way where the relation between the worker and the company could be reinforced while guaranteeing savings for every person involved on the project. The mentioned savings have been justified in detal within an economic study, in order to appreciate the profitabily of the process if the real price of the implementation was considered.

Notwithstanding, the project could be understood as a first step in the development of a stronger application. First of all, in the report, it hasn't been considered the production of renewable energies in the building. However, the electric batteries could acquire more rellevance in these cases, as they could supply energy when the sources aren't supplying enough and storage the surplus in case not all the energy produced was being consumed. Secondly, the reactive power could also take a high importance in the application, as the batteries could compensate the power factor of the company and avoid the penalisation it can suppose.

Finally, all the ideas exposed in the project could be expanded to new scenarios and implemented in a real case to see the effects it truly could cause concerning the people involved with the project. It would be interesting to understand how the practical application of it would really affect the behaviour of the workers in a company.

11 Acknowledgements

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References

[1] ABB. Penalización por energía reactiva. *http://new.abb.com/drives/es/eficiencia-energetica/penalizacion-energia-reactiva*, Data from 2010. [online] Site visited the 22-05-2017.

[2] M. Alaküla. The use of batteries in transportation. Technical report, Lund University, April 2017.

[3] CNMC. Simulador de la factura de la luz. *https://facturaluz.cnmc.es/facturaluz1.html#datos*, 2017. [online] Site visited the 21-05-2017.

[4] H.-P. Company. The eco declaration. *http://h22235.www2.hp.com/hpinfo/globalcitizenship/environment/productdata/Countries/_MultiCountry/iteco_deskto_2014623234553704.pdf*, February 2017. [online] Site visited the 23-06-2017.

[5] T. Company. Encargue un tesla model s — tesla. *https://www.tesla.com/es_ES/models/design*, 2017. [online] Site visited the 14-05-2017.

[6] Comparatarifasenergia.es. ¿qué es el precio voluntario para el pequeño consumidor (antes tur)? *www.comparatarifasenergia.es/info-energia/mi-factura/pvpc.* [online] Site visited the 21-05-2017.

[7] Comparatarifasenergia.es. La factura eléctrica. *http://www.comparatarifasenergia.es/info-energia/mi-factura/electricidad*, 2014. [online] Site visited the 20-02-2017.

[8] Comparatarifasenergia.es. Tipos de tarifas aplicables para la electricidad. *http://www.comparatarifasenergia.es/info-energia/mi-factura/electricidad/tipos-de-tarifas*, 2014. [online] Site visited the 20-02-2017.

[9] C. de Docència i Estudiantat. Aprovació de la modificació de la normativa de pràctiques. *https://etseib.upc.edu/ca/lescola/estructura-i-organitzacio/documents%20normatives/practiques-academiques-externes/normativa_practiques_upc.pdf*, january 2015. [online] Site visited the 23-06-2017.

[10] F. Diaz-Gonzalez, A. Baldauf, and R. De la Torre. Energy management optimization in buildings through electric vehicles. Technical report, International Joint Conference ICIEOM-ADINGOR-AIM-AJEM (IJC 2017). Valencia, Spain, July 6-7, 2017, 2017.

[11] elEconomista.es. Bono espaÑol 10 aÑos. *http://www.eleconomista.es/bono/bono-espana-10-years*, June 2017. [online] Site visited the 23-06-2017.

[12] L. ev. ¿cómo podemos saber la vida útil de la batería? *http://www.lemev.com/es_ES/index/comunidadver/id/73*, May 2014. [online] Site visited the 17-05-2017.

[13] A. Farran i Poca, P. Palacín i Farré, X. Amores Bravo, L. Morer, J. Castells, M. n. Escobar, R. Vilafáfila, P. Lloret, R. Ramírez, O. Sánchez i Regueras, and N. Cardellach Ramírez. Instal·lació d'infraestructura de recàrrega del vehicle elèctric. Technical report, CEEC (Clúster d'Eficiència Energètica de Catalunya) and CITCEA-UPC and AFME and Voult-Tour and CIRCUTOR SA and COMSA EMTE and ENDESA ..., June 2016.

[14] S. Gao, K. T. Chau, C. Liu, D. Wu, and C. C. Chan. Integrated energy management of plug-in electric vehicles in power grid with renewables. Technical Report 7, IEEE, September 2014. V. 63.

[15] F. Lambert. Electric vehicle battery cost dropped 80% in 6 years down to 207€/kwh. *https://electrek.co/2017/01/30/electric-vehicle-battery-cost-dropped-80-6-years-227kwh-tesla-190kwh/*, January 2017. [online] Site visited the 15-05-2017.

[16] R. Miller. The economics of data center staffing. *http://www.datacenterknowledge.com/archives/2008/01/18/the-economics-of-data-center-staffing/*, January 2008. [online] Site visited the 12-05-2017.

[17] V. Monteiro, J. Pinto, B. Exposto, J. Ferreira, and J. Afonso. Smart charging management for electric vehicle battery chargers. Technical report, ALGORITMI, Research Centre - University of Minho, Guimarães, October 2014.

[18] V. Monteiro, J. Pinto, and J. Luiz Afonso. Operation modes for the electric vehicles in smart grids and smart homes: Present and proposed modes. Technical Report 3, IEEE, March 2016. V. 65.

[19] N. H. T. S. NHTS. Our nation's travel. *http://nhts.ornl.gov/download.shtml*, 2009. [online] Site visited the 24-03-2017.

[20] OpenEI. Commercial and residential hourly load profiles for all tmy3 locations in the united states. *http://en.openei.org/datasets/dataset/commercial-and-residential-hourly-load-profiles-for-all-tmy3-locations-in-the-united-states*, July 2013. [online] Site visited the 13-03-2017.

[21] M. Page. El salario medio de un directivo en el sector técnico es de 54.000 euros. *http://www.michaelpage.es/prensa-estudios/articulos/salario-medio-directivo-ingenieria*, 2011. [online] Site visited the 23-06-2017.

[22] RenewIT. Use the renewit tool to evaluate the energy and economic behaviour of the implementation of energy efficiency strategies and renewable energy sources in your data centre. *http://www.renewit-tool.eu/*, 2017. [online] Site visited the 10-03-2017.

[23] E. spanish ministry. Real decreto 1164/2001, tarifas de acceso a las redes de transporte y distribución de energía eléctrica. (268), November 2001. Reference: BOE-A-2001-20850. Last modified october 2015.

[24] S. d. p. UPC. El citcea i endesa creen el primer punt de recàrrega per retornar l'energia del vehicle elèctric a la xarxa. *http://www.upc.edu/saladepremsa/al-dia/mes-noticies/el-citcea-i-endesa-creen-el-primer-punt-de-recarrega-per-retornar-lenergia-del-vehicle-electric-a-la-xarxa?set_language=ca*, June 2012. [online] Site visited the 7-06-2017.

[25] M. Yilmaz and P. T. Krein. Review of the impact of vehicle-to-grid technologies on distribution systems and utility interfaces. Technical Report 12, IEEE, December 2013. V. 28.

[26] R. Zgheib, K. Al-Haddad, and I. Kamwa. Assesment of the functions achieved by a bidirectional charger of electric vehicles in smart grids. Technical report, GRÉPCI (Electrical Engineering Department in École de Technologie Supérieure de Montreal) and IREQ (Institut de Recherche d'Hydro-Québec de Varennes), 2016. 3rd International Conference on Renewable Energies for Developing Countries (REDEC).