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Combined vehicle to building (V2B) and vehicle to home (V2H) strategy to increase electric vehicle market share

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ABSTRACT

Buildings are one of the most important energy consumers in modern economy countries. The massive use of electrical vehicles could help decarbonizing the economy by using electricity produced using renewable energy. Combined use of Vehicle to Grid (V2G), Vehicle to Home (V2H) and Vehicle to Building (V2B) is one of the strategies to increase the number of electrical vehicles, ensure a better coupling between energy generation and consumption, reducing peak demand and increasing global energy efficiency. This research presents a novel approach of combined use of V2H and V2B that can be applied in different scenarios such as when the building workers own EVs, company shared car fleets or leasing, among others. Recharged energy at workers homes during night hours is delivered in the building during daily working hours lowering peak demand, reducing carbon intensity and energy cost savings. The results show that the methodology is feasible and can be extended to other cases and greatly contribute to better energy efficiency, reduces peak demand in buildings and increase electric vehicles penetration in transport to workplaces.

1. Introduction

The automotive world and the automotive industries are currently undergoing a transition process influenced by climate change and increasing need for independence from oil, that is the main carrier source in the transport sector nowadays. According to different publications and researches, the whole transport sector must suffer a deep transformation that also should propose a solution to the low effective use of vehicles. Nowadays the average private car, which is used privately for daily journeys, is idle for more hours than it is in operation [1–3].

EVs can also have an important role to ensure grid stability, to reduce the power outages episodes and to increase global energy efficiency [4] and provide additional grid services. EVs can be located in different locations and therefore their batteries can be used as a rolling accumulation system, that allows peak reduction, absorbing or providing energy to the grid, as required in each moment [5]. This technology is called Vehicle to Grid (V2G), and its variants are Vehicle to Home (V2H) and Vehicle to Building (V2B), being all of them a two-way system that allow energy to be injected from the electric car into the grid and vice versa [6].

The objective of this research is analyzing and presenting a novel scheme to increase EV share in the energy market by combining three key aspects for EV development: shared transport modes, V2B and V2H.

This research proposes a mixed scheme in which company workers share their cars to travel from home to the office or company building, and they use their cars as V2B agents at the company building and also as V2B at their homes [6], a flexible model that can be applied in different scenarios, for example:

- Workers are car owners and they use it to travel to workplace and also contribute in the V2B strategy
- The company or the administration owner of the building offers a shared car fleet to the workers. This modality includes own property cars or other modes such as renting or leasing.

This strategy allows benefits for both participants and to the

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Nomenclature and formulae

BEMS	Building Energy Management System
CDD	Cooling Degree Days
CHP	Combined Heat and Power
CN	Carbon Neutrality
DG	Distributed Generation
DGT	Spanish Road traffic Regulator
DHW	Domestic Hot Water
EU	European Union
EV	Electric Vehicle
GHGs	Greenhouse Gases
IEA	International Energy Agency
PS	Peak Shaving
PNIEC	National Integrated Energy and Climate Plan
RE	Renewable Energy
RP	Recharging Point
SCOP	Seasonal Coefficient of Performance
SOC	State of Charge for the Battery
TSO	Transmission System Operator
V2B	Vehicle to Building
V2G	Vehicle to Grid
V2H	Vehicle to Home

Formulae

C	Battery capacity (kWh)
C_B	Battery specific cost (€/kWh)
$L_{n,DOD}$	Life cycles before degradation for a fixed DOD
C_c	Charging Cost (€)
C_r	Specific Energy Cost (€/kWh)
C_t	Charging Time (h)
Co_2	CO_2 Emissions (kg)
Co_{2eq}	CO_2 - equivalent Emissions (kg)
Co_{2m}	Specific Emissions Ratio for the month (kg/kWh)
DOD	Depth of Discharge (%)
$DOD_{n,\max}$	Maximum Admissible DOD (%)
D_e	Battery Degradation Cost (€/kWh)
$E_{vm\ 1=4}$	Delivered Energy from Vehicles in the morning for Monday to Thursday working hours (kWh)
E_b	Energy Balance in the Building (kWh)
$E_{b\_A\ 1=4}$	Building Energy Demand in the afternoon for Monday to Thursday working hours (kWh)
$E_{b\_M\ 1=4}$	Building Energy Demand in the morning for Monday to Thursday working hours (kWh)
E_{b_S}	Building Energy Demand on Friday working hours (kWh)
E_{month}	Energy for the calculated month (kWh)
$E_{v\_A\ 1=4}$	Delivered energy from vehicles in the afternoon for Monday to Thursday working hours (kWh)
E_{v_5}	Delivered Energy from vehicles on Friday working hours (kWh)
I	Intensity (A)
L_n	Life Cycles Before Degradation
η_c	Charger Efficiency (%)
η_d	Bidirectional Charger Efficiency (%)
P	Recharging Power (W)
$\cos\phi$	Power Factor
V	Voltage (V)

global country energy system reducing energy cost, improving EV profitability and reducing Greenhouse Gases (GHGs) emissions associated to company, with the corporative, economic and social benefits associated [7–9]. This proposal provides a reliable option for companies, that worldwide, are increasing their efforts to become climate neutral by means of implementing RE systems, using green electricity or zero emissions transport, among others, so that both car users and companies would benefit by the adoption of shared EVs policies.

To validate the model, a detailed case study is presented for a building located in Madrid city (Spain) showing that the proposal is feasible under different schemes and could be replicable and extended to many other locations. A sensibility study for different vehicle battery parameters in presented to analyze the most important factors and their influence.

The structure of the paper is presented as follows: in Section 2 the model is presented, in Section 3 Section 2.4 describes the recharging strategy and the associated costs and finally, Section 2.5 analyzes the travelling strategy.

Section 3 studies the whole V2B model used in the research and in Section 4 the results are shown and analyzed and based on the main findings, Section 5 describes the main findings and conclusions in the research.

2. Methodology and V2B model

In this section the proposed V2B strategy is presented and analyzed. Section 2.1 analyzes the V2B strategy and Section 2.2 its benefits and applications. In following sections EV and associated battery models are presented (Section 2.3), and Sections 2.4 and 2.5 analyze the building model and the economic and environmental aspects, respectively.

2.1. Vehicle to building (V2B)

V2H and V2B support home and building energy use, respectively whereas Vehicle to Grid (V2G) responds to grid conditions and thus supports the grid. For the present research, company buildings (offices, warehouses etc.) are considered as the V2B case study. In this scenario and application field, the main advantages that can produce V2B can be shortened as follows:

- Cost reduction associated with a reduction of the electricity bill, taking advantage of the energy stored in the batteries, charged at night hours and that was bought at cheaper periods (in the presented case study for the Spanish scenario, generally during the night price energy is up to 10 times cheaper that on daily hours) to inject it into the network during peak hours, where electricity price is higher [10], reducing the building's peak energy demand and associated cost and, in this mode, the EV and its battery transfer energy consumption from the most expensive hours to the cheapest ones.
- Peak Shaving (PS) that reduces the grid peak generation power requirement and also benefiting the associated electricity cost for the building, as it reduces the maximum power requirement for the billing period and, therefore, the associated access costs [11]. This cost increase aims to promote changing consumption patterns and, therefore, reduce peak power in the grid system [12].
- Increases RE share for the electrical system, because the batteries can be used as storage of energy from renewable energies. Also, Distributed Generation (DG) systems, located in the building, can be used, for example, solar or wind installations in the building that can be used both for building supply and charging the EVs [17].

- Back-Up system: the EVs can act as a backup in the event of a power outage. During those situations, the fleet could continue to supply the building with the most important services until it returns to normal and, if required, the energy could also be delivered to the grid.
- Reduction of associated CO_2 emissions. By average, transportation and buildings represent about 75% of the total CO_2 emissions in a service provider company and, therefore, V2B technology can play a key role in reducing greenhouse gas emissions worldwide [13]. Moreover, during night hours the specific CO_2 emission factor (gCO_2/kWh) is lower in comparison with peak hours, increasing CO_2 reduction potential.

The combination of previous factors can contribute to improve the global grid performance, reduce emissions factor and improve energy performance of buildings. Moreover, the required increase in renewable energy share in the grid, to accomplish the environmental and energy objectives, requires a strong consumption pattern modification that must increase energy consumption during low demand periods. This technology can contribute to make buildings energy neutral, for this purpose both electric vehicles, renewable energies and Building Energy Management Systems (BEMS) must be unified and work together to ensure the maximum energy efficiency, ensuring the use of renewable energy if available and allowing a real time cost reduction strategy, among others [14].

2.2. Vehicle to home (V2H) and vehicle to building (V2B) applications and benefits

Interest in V2B technology has been growing in recent years, and the strategy could be extensively used during next years. This concept is a combination of V2H and V2G and provides important advantages for electric vehicle owners and building owners, in this case, company buildings. Both involved actors can achieve savings in energy bills, especially in the case of office buildings as the arrival and departure times of workers are generally known and their vehicles are usually parked the whole working period. The strategy consists on the use of EVs as rolling storage, allowing introducing a high quantity of electrical storage into the grid network but without any additional investment and with the great advantage of providing both flexibility and mobility. The EV owners or users, because the EVs can be part of a company shared vehicles, charge their batteries in cheaper periods, while the car is parked at their homes (generally speaking at night), and later, this energy is used in the building during working hours, or transferred to the grid. This ensures many advantages, being one of the most important ones the feasibility of increasing RE production at night, where energy consumption is lower, and reduce peak demand during the day, using these strategies is associated with a significant reduction in CO_2 emissions [15].

From an economic point of view, energy consumption is moved from low-cost hours to more expensive ones, lowering costs. Hospitals, universities, hotels, office buildings, shopping centers, sports centers, among others, can benefit from this technology and in addition, the V2B can support critical loads of buildings such as data servers, computers, emergency lights, water pumps, elevators, etc. In emergency situations such as power outages, or transfer the energy to the grid, increasing resilience of both the building and the whole grid system [16].

For a better understanding of the proposal Fig. 1 is presented, which consists of a simplified flow diagram of the process for supplying energy to the building. To perform the V2B strategy the energy demand for the building is calculated, later the battery charging and discharging model is used considering the fixed parameters. State of Charge (SOC) of the battery is calculated in order to guarantee the maximum DOD that ensures remaining energy for the travel and not damaging the battery.

For the location the energy emissions factors, cost and generation structure is considered to calculate the economic and environmental parameters.

2.3. EV and battery model

For a specific EV and associated battery, the required power for charging is calculated as follows, for a one phase supply, Eq. (1) to Eq. (2):

$$P = V \cdot I \cdot cos\phi \tag{1}$$

where P is required power (W) for recharge, V and I are both voltage (230 V for domestic supplies in Spain, where the case study is presented) and Intensity Charge (A) and $cos\phi$ is the power factor. Based on the vehicle specifications and the selected model, charging time C_t can be calculated as follows, Eq. (2):

$$C_t = \frac{C}{P \cdot \eta_c} \tag{2}$$

Considering C as the battery capacity (kWh), η_c is the charger efficiency (%), and P, calculated as shown in Eq. (1), in kW, result is obtained in hours (h) [17,18]. An average charger efficiency of 90% is considered in the research.

Yunkun Xie et al. [19] carried out a mathematical analysis and accompanied a microsimulation of the energy consumption for electric vehicles as a function of the driving range and the results show substantial improvements in which the battery is a key element. Yangyang Li et al. [20]

presents a study on multi-objective energy management between an Atkinson cycle engine and a series hybrid electric vehicle based on the evolutionary NSGA-II algorithm using digital twins. It provides a theoretical foundation and digital model support for the development of energy efficient and energy saving new energy electric vehicles. MW Tian [21] carried out a recent investigation where the cost and energy efficiency of the resilience of buildings against energy limitations is analyzed, the solution is given by the use of the energy of electric vehicles and a demand response program. In their recent research Li Yiding et al. [22] carries out a model for estimating the safety performance of lithium ion batteries for electric vehicles under dynamic compression, implying greater autonomy and greater opportunities for EV penetration in cities with irregular geographies.

For the case study are used data from manufacturers, for which standard values have been assumed. However, given the scientific methodology of the study, it could be replicable for other battery degradation values, geographic locations or specific case studies.

The depreciation costs associated to increased battery usage is calculated and considered for the total cost calculation. Degradation of the battery depends mainly on temperature, Deep of Discharge (DOD), refrigeration system and recharging velocity [23]. The use of fast chargers, which use direct current, increases the degradation that is considered to be 10% in six years a higher value in comparison with a slow recharge with alternating current with a nominal voltage between 120 V or 240 V [24]. Latest research, such as the one carried out by Dr. Kotub Uddin, along with his team from WMG's Energy and Electrical Systems group and Jaguar Land Rover, has shown that is possible to use battery power in buildings without damaging the batteries [23]. They even stated that it could improve vehicle battery life by approximately 10% per year [25]. Also, the company Geotab has carried out a study with 6300 electric cars, in 21 different models and as there are two main

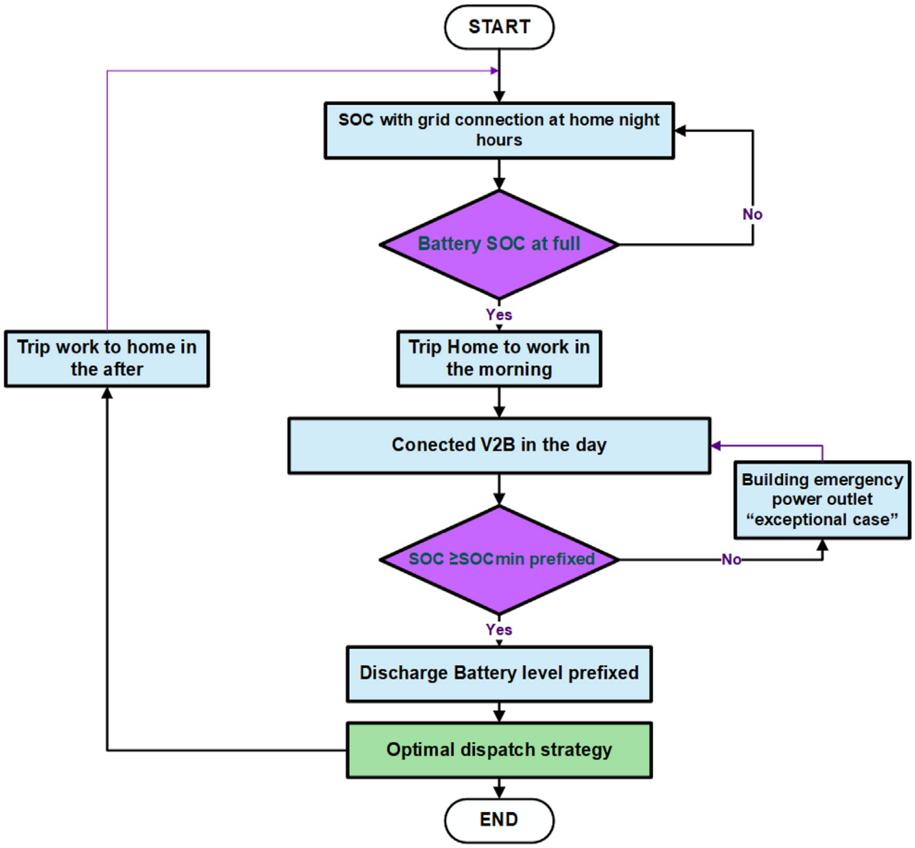


Fig. 1. Flow diagram of the studied process.

conclusions of the study: first one, it can be stated that if the current degradation rates are maintained, most of the batteries of the current electric cars, will have a longer life than the vehicle itself. The second one is that the average annual degradation rate is about 2.3% that means, for example, that for a battery that at the beginning of its life offers 250 km of autonomy, during its first five years of use it will lose about 28 km, an average of approximately 5 km per year [26]. In this research the worst case is considered and therefore degradation cost (D_c, in €/kWh) is considered and calculated as follows, Eq. (3):

$$D_c = \frac{C_B}{DOD \cdot L_{n,DOD}} \tag{3}$$

with:

C_B: Battery cost in €/kWh
DOD: Depth of Discharge (%)
$L_{n,DOD}$: Life cycles before degradation for a fixed DoD

The effective life for each battery will depend on the DOD and, therefore, the maximum numbers of cycles before degradation can be studied.

For each travel energy demand is calculated for the travel and the charging cost can be calculated as shown in Eq. (4). Maximum allowed DOD is fixed and considering the battery capacity C (kWh), the charger efficiency η_c in %, and the specific energy cost in €/kWh (C_r):

$$C_c = C_r \cdot \frac{C \cdot (1 - DOD)}{\eta_c} \tag{4}$$

2.4. Building energy balance

In this model and considering the building energy demand profile, the energy is delivered during working hours. The losses produced by the discharge of the bi-directional charging station are calculated using a performance charging station factor (η_d) and the discharge power of each vehicle must be between the minimum and maximum power that the two-way charger can withstand. Global energy balance for the building, E_b, can be calculated as shown in Eq. (5):

$$E_b = \left(E_{b\_M_{1-4}} - E_{v\_M_{1-4}}\right) + \left(E_{b\_A_{1-4}} - E_{v\_A_{1-4}}\right) + \left(E_{b\_5} - E_{v\_5}\right) \tag{5}$$

with:

$E_{b\_M_{1-4}}$: building energy demand in the morning for Monday to Thursday working hours (kWh)
$E_{v_{M_{1-4}}}$: delivered energy from vehicles in the morning for Monday to Thursday working hours (kWh)
$E_{b\_A_{1-4}}$: building energy demand in the afternoon for Monday to Thursday working hours (kWh)

$E_{v\_A_{1-4}}$: delivered energy from vehicles in the afternoon for Monday to Thursday working hours (kWh)
E_{b_5}: building energy demand on Friday working hours (kWh)
E_{v_5}: delivered energy from vehicles on Friday working hours (kWh)

In case the energy balance for the building E_b is major than 0, exceeding energy will be delivered to grid and a mechanism of net balance will be applied.

2.5. Economic and environmental analysis

For the whole building are calculated the benefits obtained from the energy savings in working hours, due to V2B mechanism. Based on the building energy cost, for each our, and the cost of delivered energy, is possible to calculate the whole economic balance for the V2B mechanism. Using the specific hourly emissions parameter, the global CO_2 balance can be calculated, using for each hour Eq. (6) that calculates CO_2 emissions in kg:

$$CO_2 = E_{month} \cdot CO_{2m} \tag{6}$$

with E_{month} meaning the energy for the calculated month (kWh) and CO_{2m} the specific emissions ratio for the month (kg/kWh).

Generally speaking, by connecting the electric vehicles to the building through the bi-directional chargers and allowing the V2B mechanism, the peak consumption of the building will be reduced and on a general basis, peak hours in the building are coincident with peak hours of the day, ensuring a better regulation and lowering peak demand for the whole electrical system, if the system is extended. Peak hours usually are associated to higher emissions factors, and using energy with lower emissions can also help reducing the carbon intensity of the building and for the global system.

3. Case study

In Spain there are more than 29 million combustion vehicles that are mainly used for people transport and also to transport selling goods, among others [27]. The current dominance of fossil fuels in the transport sector will still last several years, but due to the great efforts currently being made to reduce greenhouse gas emissions, improving electrical stability and next future Carbon Neutrality (CN) programs in Europe, it is mandatory to promote a low CO_2 transport economy [28,29], being the EVs, driven using electricity that was generated using Renewable Energy (RE) [30]. This alternative will result in a decrease in oil consumption while betting on a cleaner, more comfortable and efficient type of mobility. This new mobility model also includes the promotion of shared vehicles policies and optimization schemes [31]. In Spain, a vehicle is only in operation for 260 h a year, barely 3% of the 8760 h it has been available for use for a year, that means that a private car is inactive between 22 and 23 h a day on average [29].

3.1. Electric vehicle industry in Europe

According to the Global EV Outlook 2019 published in May 2019 by the International Energy Agency (IEA) [32], the deployment of electric cars has grown substantially over the past ten years, with electric vehicle stock reaching more than 5.1 million in 2018, with an annual growth rate of 63%. Almost half of the electric cars, 45% exactly, were sold in China, representing a total amount of 2.3 million, followed by 24% in Europe and 22% in the United States. The IEA remarks that according to forecasts, in 2030, world sales of electric vehicles would reach 23 million, that would increase the stock to 130 million EVs in the next decade, not including motorcycles or buses.

However, this study also indicates that, if there is greater progress in ecological policies and more aggressive tax benefits are applied, these figures could reach up to 250 million.

That means that currently, there are more than 1 billion vehicles circulating around the world (motorcycles, cars and buses). If these IEA forecasts would come true, electrified mobility would represent between 10% and 20% of the world's vehicle fleet. Nowadays it is a fact that most drivers and potential buyers continue to opt for gasoline and diesel models, due to a lower price and for other aspects being one of the most important that in many countries or regions there is a lack of an extensive recharging infrastructure [33]. Moreover, another problem is that many consumers, in the case of final users, do not have available a charging point at their homes, both for individual and flat buildings.

In 2019, electric vehicles accounted for only 2.4% of total new car sales throughout the European Union (EU), according to the European Automobile Manufacturers Association [34]. In Spain, according to data provided by the Spanish Road traffic Regulator (DGT), the public organism responsible of road transport regulation, there were more than 76,000 electric vehicles, of which 25,000 corresponded to passenger cars, and whose market share was 0.9%, lower than the European Union average [35,36]. With the sole purpose of promoting sustainable mobility, the European Union proposed a challenge for its member states, in order to ensure that manufacturers have a minimum 25% share of hybrid and electric models in their fleet by 2025, while in 2030 this figure should reach 40%. But what stands out most from this program is the proposal that by 2040 all cars sold in the European Union should be zero emissions, that means that great efforts must be done in many aspects, including lower costs, ensuring charging infrastructure access and in this scenario, V2B and V2H must be a key actor.

3.1.1. Electric vehicles in Spain

One of the main energy issues in Spain is its great abroad energy dependence, especially on oil products. According to government data, in the transport sector, which is equivalent to 43% of final energy consumption in Spain, dependence on oil products is 98% and represents a quarter of CO_2 emissions in Spain (14.2%) [37,38]. The electrification in road transport will directly reduce this dependence on oil products and ultimately the energy dependence on the outside world, by encouraging the consumption of indigenous energy sources, mainly those derived from renewable sources.

The number of registrations of electric cars (both hybrid and pure electric) has grown exponentially in recent years worldwide, in Europe and more specifically in Spain, reaching 12,293 registrations of 100% electric vehicles and 7458 of plug-in hybrids in 2019. Passenger cars occupy the majority of sales in this sector, followed by vans from companies that massively purchase EVs for the renewal of their delivery/transport fleet, being the minimum share electric buses and trucks with an almost residual presence [39]. In the European context the country with the highest percentage of electric vehicle sales in Europe in 2019 was Norway, where nearly 60% of new passenger car sales correspond to electrics, as opposed to less than 1% of current sales in Spain [40].

Although its growth has been significant in recent years, experts consider that it is not occurring at a sufficient pace to meet the objectives of the National Integrated Energy and Climate Plan (PNIEC), whose objectives point to a fleet of five million electric vehicles by 2030 in Spain [41], which would represent 15% of the total fleet of vehicles and, in addition, 65% of the operations carried out have been by companies that use electric vehicles in their fleets. This strategy could be considered as a good practice for introducing zero-emission mobility into the corporate culture, but it should be accompanied by greater implementation of these models by individuals, who must contribute to their purchasing decisions, in order to achieve this goal of five million vehicles within a decade [42]. This research proposes a novel model that increases profitability and benefits both for the companies and for the final consumer, by allowing a mixed model including V2G and V2B strategies.

According to different reports in Spain, and some massive surveys, 75% of those surveyed consider that the electric car is the future and the intention to buy an electric car grew from 7% in 2018 to 12% in 2019. At the same time, those surveyed considered the main reticence when choosing this type of vehicle to be insufficient autonomy, the price, the lack of space or possibility of recharging infrastructure and the superior recharging time compared to a combustion engine vehicle [43].

The economic impact can be positive in Spain if massive EVs shares are implemented in next years, because if is considered an estimate of 30 million electric vehicles in 2030, according to a study, the Spanish state will reduce the tax income 1225 euros for each electric vehicle registered, which is equivalent to 6125 million euros in taxes, while the health costs produced by combustion vehicles are at a rate of 2371 euros per vehicle, according to a study by Bellona Europe. This would mean a saving for that concept of 11,855 million euros in 2030 only in terms of health-related costs and many other additional positive crossed effects, such as a major independence from the import of crude oil that is estimated at about 5000 million tons of fuel, made with data from 2018 [44].

3.1.2. Recharging infrastructure in Spain

According to the recharging infrastructure penetration indicator prepared by ANFAC, Spain is at the bottom of Europe, with a score of 16.7 out of 100, surpassed by France (20.5) and Portugal (21.3), all of which are also below the continent's average of 27.3 points. In absolute terms, there are 5572 public access recharge points in Spain according to Electromaps statistics [35].

Last past years, in the 2014–2019 period, different governmental programs to promote electromobility, including both EVs and Recharging Points (RPs), has been implemented and they have had an important result in the increase of sales of this type of vehicles, but they are still insufficient to reach the European and Spanish proposed objectives. One of the characteristics of the mobility of the future is that it will be partly shared, which would mean a decrease in the car fleet [45]. An example of this is Madrid city, where the business model of shared mobility through the use of electric vehicles is booming, thanks to numerous operating companies [46]. According to different estimations [47] it is estimated that between 65,000 and 95,000 RPs will be needed just in terms of parking on public roads or in public parking lots, if the goal is to reach the circulation of five million electric vehicles by 2030, as contemplated in the PNIEC.

3.2. Building description

The building used for this research is an office building located in León city (Spain), and a parametric study is carried out both for the original location, León, a small city with 124,303 population in 2019 [48], and a simulation is performed for the same building placed in a large capital, Madrid city, with a total of 6,507,184 inhabitants if the metropolitan area is taken into account, being the second largest one in Europe, after Paris. These two different locations, implying both different climatic conditions and transport requirements, ensure the feasibility of the proposal and is quite useful for comparison purposes and future research projects.

The studied building incorporates renewable energies systems, taking advantage of the available resources, and integrating RES to diminish the environmental impacts, making an effort to reduce the energy consumption. It has a building area of 2525 square meters, and consists of 6 floors. The main energy characteristics are detailed below:

3.2.1. Heating system

There is a solar thermal installation with 23.72 m^2 and the energy in used to heat a 500 L accumulator for Domestic Hot Water (DHW) and an additional 200 L accumulator located used for heating. Moreover, passive solar energy is used thanks to accumulation in the building structures, using a double face facade that, in combination with the Building Energy Management System (BEMS), used preheated air in the building if the temperature in the air is enough. The main heating system is based on radiant floor and outdoor air, used for ventilation, is preheated. Heat is produced using a natural gas furnace and a micro combined heat and power system as heat source.

3.2.2. Combined Heat and power

The building uses a Micro Combined Heat and Power (CHP) system powered by natural gas, used for heating and DHW. Heat power is 12 kW and electrical power is 5.5 kW, and the electricity generated is used in the building for self-consumption. This energy production represents only a small percentage of the global energy consumption of the building and the operation strategy is not modified due to the proposed V2B system. During night hours, when energy consumption is lower and the EV are not contributing to reducing building demand, the CHP system operates using the same control strategy.

3.2.3. Cooling system

The building uses cooling ceiling systems in all the spaces, and for production of chilled water is used a high efficiency heat pump with a Seasonal Coefficient of Performance (SCOP) of 4, equipped with two compressors and as an additional system the building uses a 4.5 kW rooftop absorption machine, that uses the energy produced by the solar thermal installation.

3.2.4. Ventilation

The building uses preheated air in the double facade that is finally heated or cooled in the heating/cooling air system, if the temperature is too high, the preheated air is sent back to the outdoor, reducing cooling demand.

3.2.5. Lighting

The streetlights use 100 W sodium vapor lamps, powered by 5 photovoltaic panels (159 W each) combined with a set of centralized gel batteries and indoor lighting is based on low consumption fluorescents and presence control systems, combined with natural lighting control systems integrated in the BEMS.

3.2.6. Control system

The building has a BEMS control system controlling all the parameters and energy variables, with the help of detectors and probes that control the temperature and humidity conditions. Different probes are located in the building and the system handles more than 1700 different parameters, registering main energy parameters such as energy consumption, that is used in this research.

3.3. Generation and grid system in Spain

According to last available data about installed power capacity in the Spanish Peninsula (excluding islands), the peak power

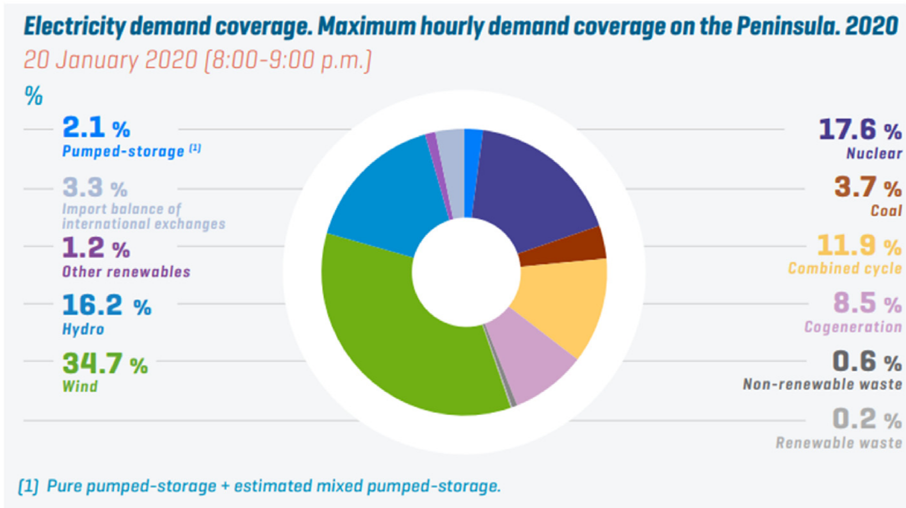


Fig. 2. Electricity demand coverage. Maximum hourly demand coverage on the Peninsula. 2020.

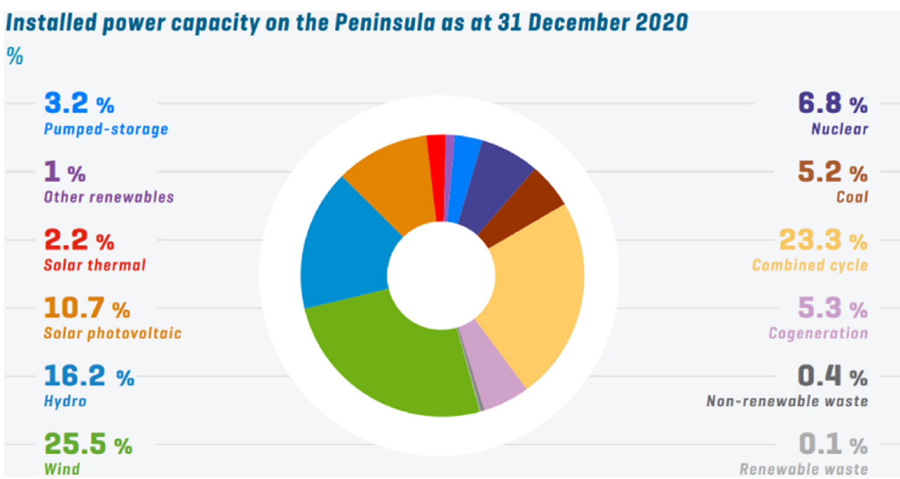


Fig. 3. Generation system on Spanish Peninsula. Installed capacity by source.

generation capacity is up to 105.22 GW, and 55.8% of this capacity comes from RE sources [49]. Fig. 2 shows the maximum hourly demand coverage on the Peninsula in 2020.

The generation structure is shown in Fig. 3, for the last available report, December 2020.

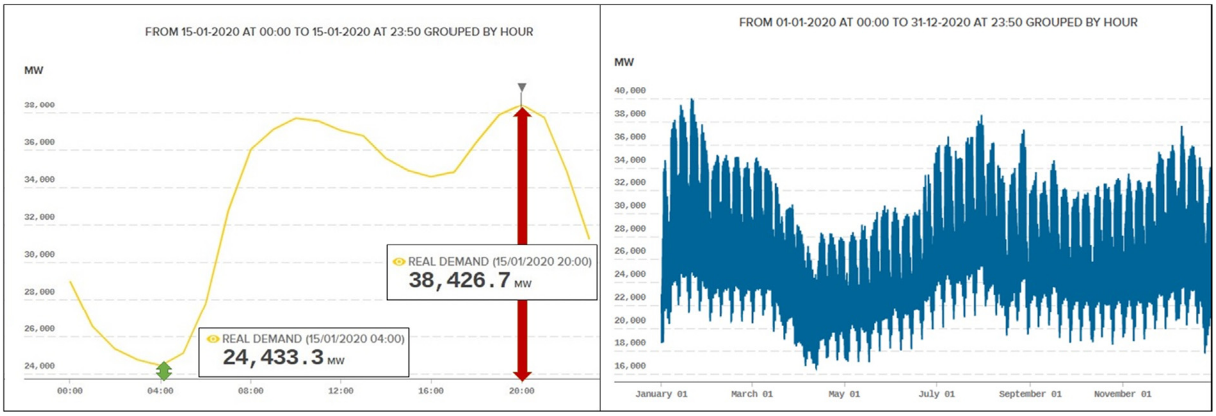
With the present generation and demand structure and pattern, it is not feasible to increase renewable energy share at night due to the low demand in contrast with the high demand during day peak hours, as shown in Fig. 4a for a typical winter day. RE contributing to the generation mix has increased during last years in the overall peninsular electricity mix, achieving its maximum value in 2020, with a 45.5% share.

By technology, wind power is the most important RE generation source by coverage, with 22.5% of total electricity generation, followed by hydro and solar photovoltaic with 12.8% and 6.2%, respectively. Fig. 4b shows the yearly balance of the peninsular grid system where the high difference between peak value and lower values can also be studied for the whole year period.

During summer days, cooling demand increases peak power demand and this situation is worsening, due to the climate change effects. Central and South Spain are one of the most vulnerable regions and a multidisciplinary solution, including V2G and EV, must contribute to climate change adaptation and mitigation. This high demand, combined with the intermittence of generation of most important renewable energy plants (PV and wind) makes necessary a high generation power that will increase the global grid cost and many of these plants will not work at their maximum generation capacity.

Subsequently and due to variable generation structure (% by source) and demand, the specific CO_2 emission factor varies hourly and, in this research, the monthly average factor for each hour is considered. Fig. 5 shows the evolution of CO_{2eq} emissions on the Spanish Peninsula and Fig. 6 shows the generation structure and associated CO_2 emissions on a yearly basis [49].

The proposed technology can contribute to reducing peak demand but it will also allow increase RE peak power, that could produce CO_2 – free electricity that would be use to charge batteries during night and that will be transferred to higher specific emissions hours, lowering both peak demand and hourly CO_2 emission factor. For the selected example day shown in Fig. 4, the generation structure by source is shown for the peak and for the lower demand hours, respectively (Fig. 7). As shown in previous figures and Fig. 7, the low emissions factor is associated to a high share of both RE sources and nuclear energy, that is considered as CO_{2eq} emissions



(4a) **(4b)**

Fig. 4. a and b. Daily demand (4a) and yearly demand (4b).

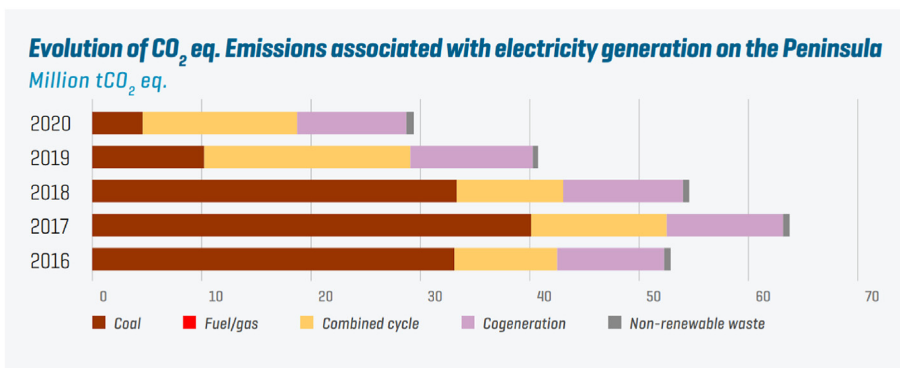


Fig. 5. CO_{2eq} evolution and source.

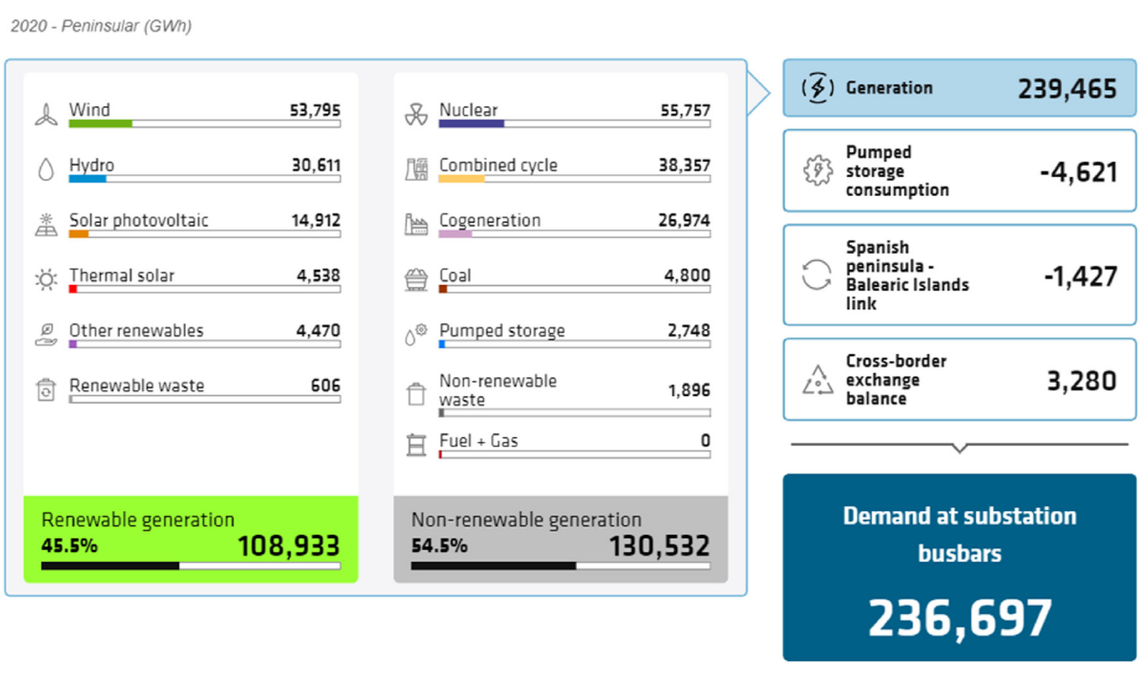
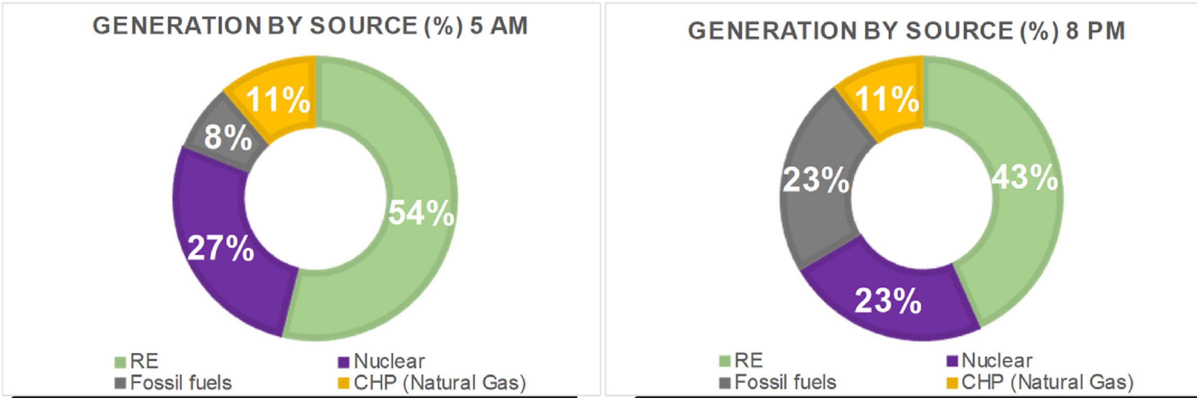


Fig. 6. Yearly generation balance for the Spanish Peninsula (2020).



RE	**15,456** MWh	54%
Nuclear	7,765 MWh	27%
Fossil fuels	2,235 MWh	8%
CHP (Natural Gas)	3,215 MWh	11%
TOTAL	**28,671 MWh**	**100%**
CO_2 free generation	**81%**	

RE	**14,520** MWh	43%
Nuclear	7,763 MWh	23%
Fossil fuels	7,667 MWh	23%
CHP (Natural Gas)	3,544 MWh	11%
TOTAL	**33,494 MWh**	**100%**
CO_2 free generation	**67%**	

Fig. 7. Example of CO_{2eq} free generation and generation structure for peak and lower demand hours.

free during operation. In Spain, there are five nuclear power plants and seven reactors in operation that came into operation in the 1980s, and their expected life cycle before 40 years is running out [50].

By having renewables in constant growth and receiving all possible financing for their implementation, the process to close the nuclear ones is accelerated all the more. Currently the production percentages are between 23% and 27% overnight and in the morning, respectively.

This generation structure will be deeply modified in the period up to 2030, according to PNIEC. The objective for Spain in 2030 is a 42% share of RE in final energy consumption and a 74% in electrical generation. The prevision for 2030 is a peak power generation up to 161 GW with about 50 GW of wind energy (major share by technology), 39 GW of photovoltaics, 27 GW of natural gas combined cycles, 16 GW hydro, 9,5 GW reversible hydro pumping, 7 GW of thermoelectric solar plants and only up to 3 GW nuclear and a minor share of other technologies, such as biomass, combined heat and power etc.

3.4. Electric vehicle selection

An EV based on the average specifications of the five best-selling electric cars during 2019 in Spain is used in the research, based on the manufacturer specifications, Fig. 8 and Table 1.

Based on the results shown in Fig. 2 and Table 1, the average car autonomy is around 350 km, would have a lithium-ion battery, with a capacity of 48.40 kWh and the consumption of this car is 165.60 Wh/km on average, a value considered in this work, regardless of the mileage traveled by workers.

3.5. Recharging strategy and associated costs

In Spain, as generally happens worldwide, there are three types of tariffs available for low power supply, that will be used by workers to charge the vehicle at home: regulated and de-regulated tariffs. These are available for peak power lower that 10 kW, and they have different tariff periods and prices for the whole day, and are named 2.0A, 2.0DHA and 2.0DHS. A research is shown for the

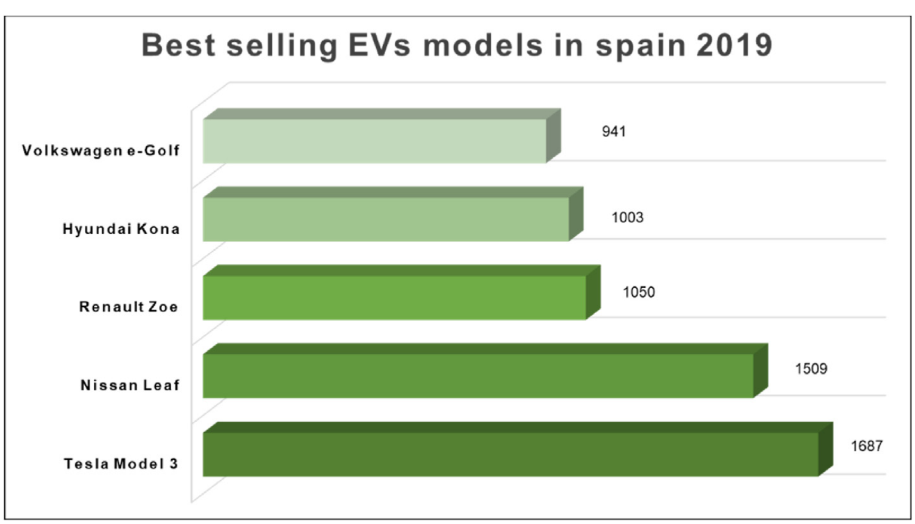


Fig. 8. Bestselling EVs models in Spain (2019).

Table 1
Market share of EVs in Spain (2019).

Number	Model	Units	Market share (%)	Range (km)	Battery capacity (kWh)	Cost (€)	Specific consume (Wh/km)
1	Tesla Model 3	1687	16.79%	530	75	65,000 €	147
2	Nissan Leaf	1509	15.01%	270	40	37,070 €	171
3	Renault Zoe	1050	10.45%	386	52	22,245 €	177
4	Hyundai Kona	1003	9.98%	289	39	32,850 €	179
5	Volkswagen e-Golf	941	9.36%	275	36	35,000 €	154
Total for selected models		6190	62%	Average	Average		Average
Total EVs		10,050		350.00	48.40		165.60

Table 2
Electricity cost for main Spanish suppliers, both in the regulated and in the de-regulated market.

Electricity tariffs							
Type	Company	2.0A tariff (€/kWh)	2.0DHA tariff (€/kWh)		2.0DHS tariff (€/kWh)		
		P1	P1 (Peak)	P2 (Valley)	P1 (Peak)	P2 (Valley)	P3 (Super valley)
Regulated market	REE	0.0738	–	–	–	–	–
Deregulated market	Iberdrola	0.1906	0.2329	0.0382	0.1537	0.1312	0.0968
	Endesa	0.1199	0.1586	0.0794	0.1652	0.0946	0.0729
	Naturgy	0.1437	0.1745	0.0940	0.1928	0.1160	0.0946
	EDP	0.1548	0.1547	0.0846	0.1570	0.1420	0.1093
	Repsol	0.1290	0.1491	0.0741	0.1081	0.0981	0.0791
	Lucera	0.1270	0.1480	0.0730	0.1490	0.0850	0.0680
	Factor energía	0.1394	0.1644	0.0900	0.1562	0.0926	0.0784
	Holaluz	0.1390	0.1700	0.0990	0.1710	0.1040	0.0890

main electricity selling companies in the liberated market and for the regulated price, known as PVPC. All the prices take into account electricity taxes (5.1127%) and the VAT (21%), Table 2.

Cheapest cost is obtained for 2.0DHS tariff, with a super-valley period, that has the lower cost and is coincident with 1:00 to 7:00 period, when the workers will charge the car at home (V2H). Total cost includes both energy cost and access costs, that is the price for demanding the maximum required peak power. The peak power is regulated and only some regulated values can be contracted.

Taking into account the available peak power values that can be used in Spain, a value of 8.05 kW or 6.9 kW would be the optimal, due to low power requirement in the house during night hours, Table 3 and Fig. 9.

Considering Eq. (3) and the existent battery models and the new technologies that are being developed, three scenarios are presented and studied: an optimistic one where EV batteries, with a DOD of 80%, can provide up to 1500 cycles before degradation, and average scenario, up to 1000 cycles and pessimist scenario, up to 800 cycles. For example, optimistic scenario could be achieving using Tesla 3 model [51], that offers up to 1500 full operational charges, average scenario represents the average selling models and the pessimist one could be applied to older models. For the selected car and parameters, the results are shown in Table 4.

Table 3
Required time for complete charging.

		Charging time (hours)			
		Ultra - slow	Slow	Medium	Fast
		Charging Power (kW)			
Model	kWh	2.3	3.7	7.2	50
Tesla Model 3	75	36.23	22.52	11.57	1.67
Nissan Leaf	40	19.32	12.01	6.17	0.89
Renault Zoe	52	25.12	15.62	8.02	1.16
Hyundai Kona	39.2	18.94	11.77	6.05	0.87
Volkswagen e-Golf	35.8	17.29	10.75	5.52	0.80
Studied car	48.4	23.38	14.53	7.47	1.08

This scenario is highly dependable on battery costs and the whole model will be benefit from the future cost reduction that will produced not only by technological development but also because of scale economies, purchasing optimization or assembly optimization, among others [52]. Fig. 10 shows the evolution of specific battery cost for a fixed DOD considering an EV battery cost ranging from -10% to -50%. Extensive deployment of EVs is required to achieve these objectives and a higher share of V2G technologies can contribute to the objective.

3.6. Travelling strategy and battery charge

The building is considered to have an average occupancy of 62 workers, which will work 40 h per week from Monday to Friday with a schedule of 07:30 to 15:00 from Monday to Friday and one eligible afternoon each from 16:30 to 19:00 from Monday to Thursday. Vacations and business trips are not considered for any of the workers during the research simulated period. Three groups of workers are classified and considered according to the distance traveled to their workplace. The percentage distribution is based on the city population, working location and employment/inhabitant ratios, using a Mobility Survey of the Community of Madrid, carried out in 2018 [53] and mobility data extrapolated for León, the city where the building is located. The analysis performed in Madrid as the main location because city size and characteristics are more adequate for the usage of EVs. 3 groups are considered, named as A, B and C, and taking into account all these factors, and considering the results of the mobility studies for Madrid [53], the travel distance and the energy consumption is calculated and shown in Table 5 for each group, considering a 20% margin security.

This scenario is used for the simulation and for validation of the proposed model but it can be adopted to different scenarios and cases that will greatly vary depending on many parameters such as city size, or working hours. The proposed model can be, therefore, used in different scenarios and optimized for each of them and the results could be improved using additional optimization strategies such as travelling using a shared vehicle strategy (higher vehicle

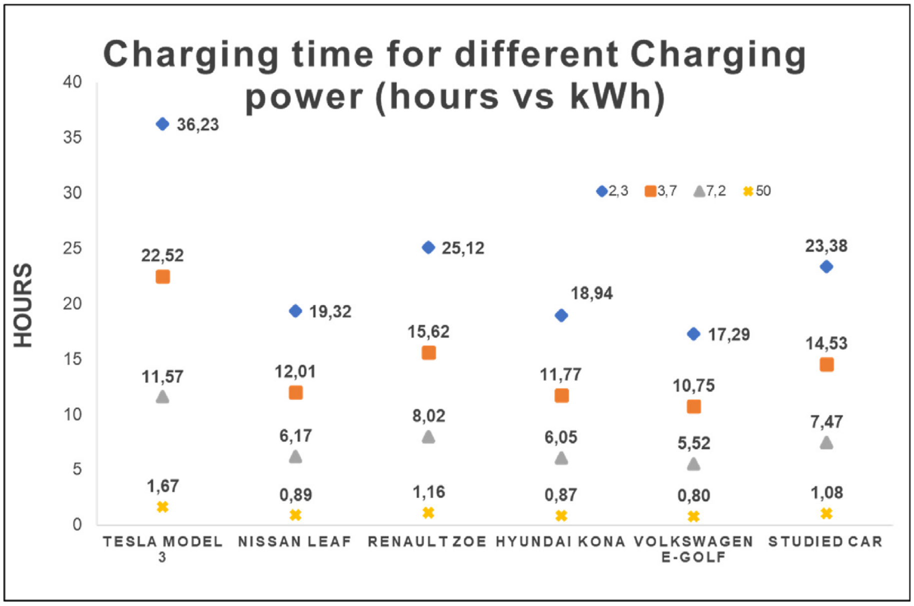


Fig. 9. Comparison of recharging times for different power supply.

Table 4
Degradation costs for different life cycles and DoDs.

DoD	Maximum cycles			Specific cost (€/kWh)		
%	Optimistic	Average	Pessimist	Optimistic	Average	Pessimist
20%	26,667	17,778	14,222	0.026663	0.039994	0.049992
30%	9167	6111	4889	0.051709	0.077564	0.096955
40%	3333	2222	1778	0.106650	0.159975	0.199969
50%	2667	1778	1422	0.106650	0.159975	0.199969
60%	2333	1556	1244	0.101571	0.152357	0.190446
70%	1833	1222	978	0.110805	0.166208	0.207760
80%	1500	1000	800	0.118500	0.177750	0.222188

occupation), route optimization or autonomous driving systems, among others.

Workers will charge the EV battery at their homes, using the lowest tariff [54], as described in previous sections. Using Eq. (4) a fixing a maximum allowed DOD will be 80% and considering a battery of 48.40 kW, a η_c of 90%, the charging cost C_c (€) is calculated.

Each group will deliver the energy in the building ensuring enough energy for travelling and avoiding reaching the maximum DOD, with the results presented in previous Table 4. According to these data, the DOD costs are calculated for each working group and scenario, and results are detailed in Table 6, considering the maximum DOD percentage.

As stated in previous sections, a future decrease of battery cost will greatly contribute to reduce these costs and the results will be also improved by the development of new battery technologies that will offer a higher life expectancy for a fixed DOD or that would increase the maximum allowed DOD before degradation. For the present research all these scenarios are not considered but they will greatly improve the whole strategy results.

3.7. Building energy balance

The electrical consumption for the building is taken from the BEMS and using a regression, the predicted consumed energy in Madrid is calculated, based on the results of a regression for the original building, using CDD. Energy consumption in the climatization system is only used for cooling, as stated in the building description section. Fig. 11a and Fig. 11b show respectively the regression model and adjusted energy consumption for the building in the new location [55], Table 8.

Average energy consumption for the building, for each month and hour, is shown in Fig. 12 and Fig. 13. In Fig. 12 the format of the heat map allows to interpret the hours and months of maximum consumption during the year. While Fig. 13 shows the consumption curves for the entire year, calculated as the average of each hour of the month.

Using Eq. (5) and aη_d of 0.95 the whole energy balance is calculated.

3.8. Economic and environmental analysis

For the case study, the building has 3 period tariffs, meaning that it has three different tariff periods and varies according to the season (winter and summer). Spanish regulation states that months from March to October will apply the summer costs and the rest of the months will use winter ones. Using the specific emissions parameter, published hourly and monthly for the Spanish electrical system by the Grid System Operator (TSO), the global CO_2 balance is calculated for each hour, with Eq. (6). In Spain the emission factor is highly dependable on the generation structure that ranges hourly and monthly, as shown in Section 3.3.

4. Results and analysis

According to previous sections, the delivered energy by each vehicle for every group and working shift is calculated and shown in Table 9.

For the studied building, and based on the implementation of the Vehicle to Building technology, the annual electricity consumption of the building was 153,769.5 kWh. After the implementation it was reduced by 78,952.1 kWh, leaving an annual consumption of 74,817.4 kWh, that is, a saving of 49% with respect to the original, Fig. 14.

As the workers, in case of being the owners of the EVs, will suffer a degradation in the battery and therefore, a lower battery life, a

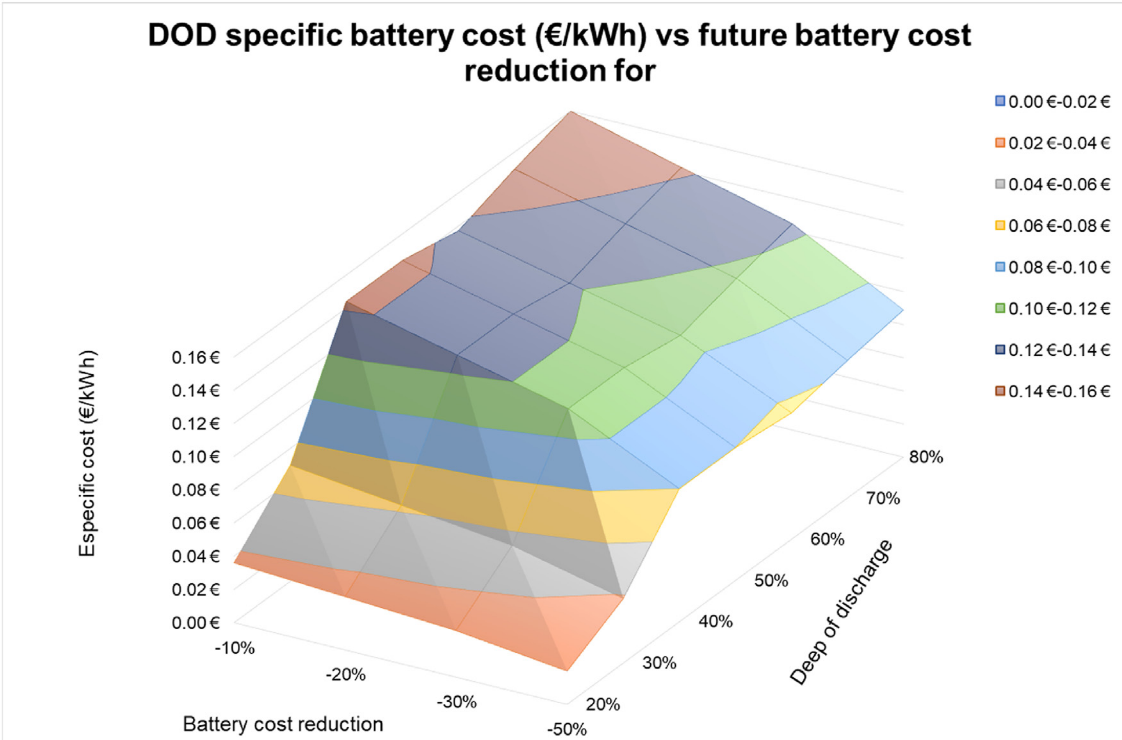


Fig. 10. Comparison of recharging times for different power supply.

Table 5
Mobility groups for Madrid.

	Group A	Group B	Group C
Travel distance (TD)	<11 km	11 km ≤ TD < 22 km	TD ≥ 22 km
Percentage	60%	75%	7%
Transport mode	A	B	C
Private vehicle	75%	57%	83%
Public transport	20%	40.5%	13%
Others	5%	2.5%	4%
Total	100%	100%	100%

Table 6
Battery degradation cost for each mobility group.

—	—	DoD	Energy	Specific cost (€/kWh)			Annual degradation cost (€/kWh)		
		%	kWh	Optimistic	Average	Pessimist	Optimistic	Average	Pessimist
Group A	25	74.40%	36.0	0.1228 €	0.1842 €	0.2303 €	27,653 €	41,480 €	51,850 €
Group B	11	66.90%	32.4	0.1124 €	0.1686 €	0.2107 €	10,008 €	15,012 €	18,765 €
Group C	3	57.50%	27.8	0.0993 €	0.1490 €	0.1863 €	2074 €	3111 €	3889 €

Considering the results shown in Table 6, the yearly battery degradation cost can be calculated for each group and scenarios, and results are shown in Table 7.

Table 7
Yearly battery degradation cost for each mobility group.

—	—		Yearly battery degradation cost		
		DoD (%)	Optimistic	Average	Pessimist
Group A	25	74.4%	1159 €	773 €	618 €
Group B	11	66.9%	1283 €	855 €	684 €
Group C	3	57.5%	4344 €	2896 €	2317 €

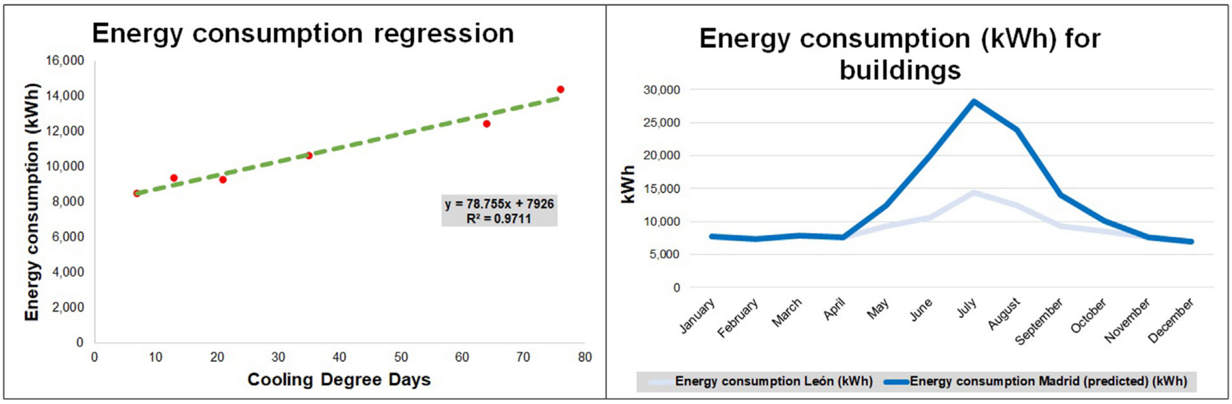


Fig. 11. a and b. Energy consumption for buildings (kWh).

Table 8
CDD regression model for León and Madrid.

Month	CDD León	Energy consumption León (kWh)	CDD Madrid	Energy consumption Madrid (predicted) (kWh)	Difference (%)
January	0	7788	0	7788	0%
February	0	7294	0	7294	0%
March	0	7842	3	7842	0%
April	0	7601	8	7601	0%
May	13	9338	57	12,415	33%
June	35	10,622	154	20,054	89%
July	76	14,388	258	28,245	96%
August	64	12,452	203	23,913	92%
September	21	9281	77	13,990	51%
October	7	8487	28	10,131	19%
November	0	7578	0	7578	0%
December	0	6951	0	6951	0%
TOTAL	216	109,621		7926	

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DIC	TOTAL
00	135	113	137	180	131	616	937	773	289	159	131	137	**3,738**
01	128	102	136	98	219	570	827	689	280	162	134	130	**3,474**
02	234	201	246	181	338	576	757	703	285	160	136	141	**3,958**
03	243	272	205	256	338	538	747	673	285	170	142	141	**4,011**
04	241	218	250	315	414	523	719	663	270	170	136	140	**4,058**
05	257	247	299	231	311	532	694	647	268	164	138	141	**3,928**
06	292	281	243	278	376	532	895	672	423	294	237	233	**4,756**
07	306	258	282	235	592	686	815	687	492	414	319	292	**5,375**
08	464	413	452	422	599	899	1,071	897	754	601	453	421	**7,447**
09	442	449	414	477	843	1,024	1,271	1,045	892	712	569	488	**8,628**
10	566	447	483	500	895	1,201	1,360	1,173	995	811	**617**	**537**	**9,585**
11	556	573	**672**	**550**	984	1,225	1,484	1,203	976	816	608	513	**10,160**
12	536	544	684	531	826	1,239	1,629	1,318	959	767	570	498	**10,101**
13	452	**497**	588	621	**996**	**1,285**	1,734	1,405	1,028	818	**582**	495	**10,501**
14	**578**	526	520	527	915	1,192	**1,811**	**1,516**	**1,059**	**776**	569	478	**10,469**
15	506	457	340	526	641	1,092	1,668	1,441	932	645	439	388	**9,075**
16	385	304	428	275	700	1,004	1,534	1,351	803	552	354	339	**8,030**
17	375	309	378	296	459	912	1,473	1,316	790	518	359	349	**7,534**
18	357	337	346	377	608	1,010	1,353	1,206	663	468	362	343	**7,428**
19	228	212	250	238	384	745	1,284	1,058	411	265	191	210	**5,478**
20	122	171	115	127	252	687	1,157	968	320	169	139	137	**4,363**
21	131	102	118	80	173	753	1,087	882	290	166	132	135	**4,050**
22	132	107	141	163	169	617	967	840	272	164	133	131	**3,836**
23	121	155	112	118	255	616	925	783	279	159	129	137	**3,790**
TOTAL	**7,788**	**7,294**	**7,842**	**7,601**	**12,419**	**20,075**	**28,200**	**23,908**	**14,015**	**10,099**	**7,578**	**6,951**	**153,769**

Fig. 12. Heat map for building energy consumption in kWh for Madrid.

compensation cost is stated for each of them, as detailed in previous section. In case of a shared car fleet the economic balance will be applied to the car owner company. The proposed strategy is quite flexible and could be applied to many different scenarios and easily adapted for all of them. For example, in case of using a leasing or renting EV model, the positive economic results will contribute to reducing the effective leasing or renting const for the vehicle and if the company owns the car, the positive economic balance will be used for the battery replacement costs. For each month the total costs are calculated as the cost of battery degradation

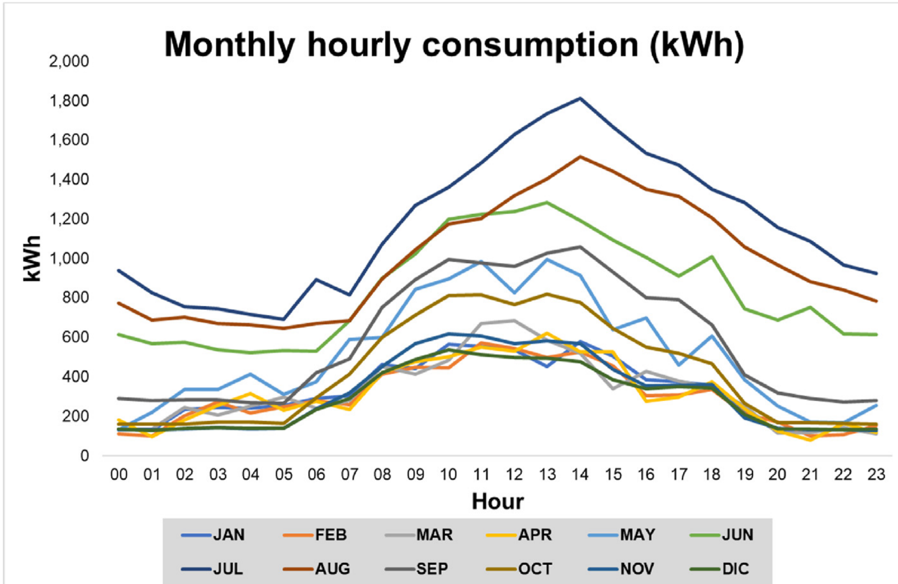


Fig. 13. Monthly consumption profiles by hour.

Table 9
Energy Balance for the Building using V2B.

Monday to Thursday			
Morning period	EVs	Delivered energy (kWh)	Total delivered energy (kWh)
Group A	19	36.03	684.57
Group B	8	32.38	259.04
Group C	2	27.84	55.68
TOTAL			999.29
Afternoon period	EVs	Delivered energy (kWh)	Total delivered energy (kWh)
Group A	6	36.03	216.18
Group B	3	32.38	97.14
Group C	1	27.84	27.84
TOTAL			341.16
Friday			
Morning period	EVs	Delivered energy (kWh)	Total delivered energy (kWh)
Group A	25	36.03	900.75
Group B	11	32.38	356.18
Group C	3	27.84	83.52
TOTAL			1340.45

compensation and the recharging cost for each worker and for the total number of workers in the building and the whole energy and emissions balance is shown in Table 10. Results are positive for the building owners and, moreover, the workers will not incur in any additional cost when they use the V2B strategy, as all the cost are compensated by the building operators. The high reduction in energy consumption could also have additional benefits from an environmental and energetic point of view because lower peak demand and lower demand in the whole building would make more feasible reaching a zero emissions building, for example, using Photovoltaic energy for building supply. That strategy will reduce the peak power of the plant, battery size and increase economic feasibility.

Environmental results are shown in Table 10, showing a reduction of 30,071 kg of CO_2 for the studied year using the daily, monthly and year balances published by the Spanish TSO, REE [56].

These results could also be improved in case the workers would use renewable energy sources for vehicle charging, for example, by using PV energy generated in their homes and storage in local battery systems.

As analyzed before, the economic savings for the yearly balance could be applied to improve the economic performance of the model associated to EV battery degradation. The positive economic results could be applied for battery replacement costs. Table 11 shows the battery life expectancy, the replacement cost and the cumulative savings for each travel group and scenario and the battery replacement cost coverage.

Results show that the proposed strategy leads to combined benefits including peak reduction, increases uses of EVs, allows higher RE share and improves economic balance, among others.

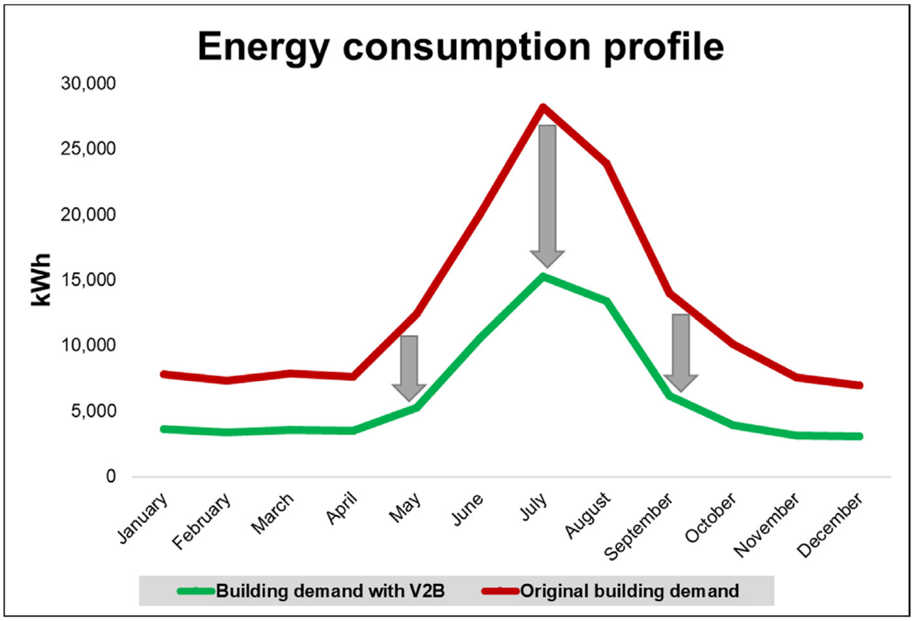


Fig. 14. Building energy savings.

Table 10
Economic results for the building.

Yearly balance					
Month	kWh	Cost savings V2B (€)	Recharging costs (€)	kg CO_2/kWh	kg CO_2
January	7788	2424 €	2000 €	0.24	1869
February	7294	2108 €	1739 €	0.23	1678
March	7842	2025 €	1826 €	0.16	1255
April	7601	2585 €	1913 €	0.17	1292
May	12,419	2933 €	2000 €	0.17	2111
June	20,075	3210 €	1739 €	0.19	3814
July	28,200	3955 €	2000 €	0.21	5922
August	23,908	3581 €	1913 €	0.21	5021
September	14,015	2823 €	1826 €	0.20	2803
October	10,099	2769 €	2000 €	0.21	2121
November	7578	2328 €	1826 €	0.16	1212
December	6951	2140 €	1913 €	0.14	973
Total	153,769	32,882 €	22,699 €	Total	30,071
		Global yearly balance	10,183 €		

Table 11
Battery replacement cost coverage scenarios.

			Battery life expectancy (years)			V2B cumulative savings (€)			
		DoD (%)	Optimistic	Average	Pessimist	Optimistic	Average	Pessimist	
Group A	25	74.4%	4.6	3.1	2.5	47,199 €	31,466 €	25,173 €	
Group B	11	66.9%	5.1	3.4	2.7	52,263 €	34,842 €	27,874 €	
Group C	3	57.5%	17.4	11.6	9.3	176,922 €	117,948 €	94,359 €	
						276,385 €	184,256 €	147,405 €	Total savings
						103%	69%	55%	% Battery cost

5. Conclusions

Interest in V2B technology has been growing and in recent years, it has become more important due to the numerous acquisitions of electric vehicles and its key paper in grid regulation, stability and carbon reduction. In this research electric vehicles are considered as a system that has storage while it is in motion, in this case from its home and final destination for its work. Therefore, it allows to introduce a large amount of electrical storage in the network system but without any additional investment and with the great advantage of flexibility and mobility, something viable and especially in cities that have a high level of penetration of electric vehicles.

The proposed scheme, that can be used for owned EVs, renting or shared fleets, among others, proves the feasibility and advantages of increasing EVs share combined with V2B strategies. As shown, if the building is being supplied by stored electrical energy for peak hours where the energy turns out to have a higher price, global cost is reduced and additional benefits, such as peak demand reduction are achieved. Results show that the carbon intensity of the building is reduced drastically, maximum demand is up to 50% less than the usual demand in the peak hour of the day, and that the proposal is profitable for both employers and employees. The proposed strategy leads to combined benefits including peak reduction, increases uses of EVs, allows higher RE share and improves economic balance, among others.

This proves that technically it is possible to carry out these energy transfer processes; the possibilities of increasing growth are very promising and the benefits much greater. The new models and energy management structures must include the electric vehicle as a very important element in energy dynamics and it is proved that is possible to apply V2B, generating flexibility but without affecting the normal functionality of any of the buildings. The results can be greatly improved according to the perspectives of both battery cost reduction and technology improvement and, therefore, adapted to each future case.

Motivated participation in companies by workers is key, their level of contribution begins with a greater incidence of EV in society in terms of decarbonization of energy, but with it they bring other benefits that go through the economic than in some way. In this way, receiving an economic retribution is not bad, it diversifies the economy and integrates the staff in organizational terms. This method can be applied in further developments aimed at the location of other climatic zones, applications and also to specific types of buildings, such as organic houses and zero energy buildings.

Credit author statement

David Borge-Diez: Conceptualization, Methodology, Software, Writing- Original draft preparation, Data Curation, Daniel Icaza: Conceptualization, Methodology, Software, Writing- Original draft preparation, Data Curation, Emin Açıkkalp: Conceptualization, Methodology, Software, Writing- Original draft preparation, Data Curation, Hortensia Amaris: Conceptualization, Methodology, Software, Writing- Original draft preparation, Data Curation

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] Oh S, Seshadri R, Azevedo CL, Kumar N, Basak K, Ben-Akiva y M. «Assessing the impacts of automated mobility-on-demand through agent-based simulation: a study of Singapore». Transp. Res. Part Policy Pract 2020;138:367–88. https://doi.org/10.1016/j.tra.2020.06.004. ago.

[2] Mourad A, Puchinger J, Chu y C. «A survey of models and algorithms for optimizing shared mobility». Transp Res Part B Methodol may 2019;123: 323–46. https://doi.org/10.1016/j.trb.2019.02.003.

[3] Bischoff J, Maciejewski M, Schlenther T, Nagel y K. «Autonomous vehicles and their impact on parking search». IEEE Intell. Transp. Syst. Mag. 2019;11(4): 19–27. https://doi.org/10.1109/MITS.2018.2876566. winter.

[4] Peng C, Zou J, Lian y L. «Dispatching strategies of electric vehicles participating in frequency regulation on power grid: a review». Renew Sustain Energy Rev feb. 2017;68:147–52. https://doi.org/10.1016/j.rser.2016.09.133.

[5] Jian L, Zechun H, Banister D, Yongqiang Z, Zhongying y W. «The future of energy storage shaped by electric vehicles: a perspective from China». Energy jul. 2018;154:249–57. https://doi.org/10.1016/j.energy.2018.04.124.

[6] Sami I, et al. «A bidirectional interactive electric vehicles operation modes: vehicle-to-grid (V2G) and grid-to-vehicle (G2V) variations. In: Within Smart Grid», en 2019 International Conference on Engineering and Emerging Technologies. ICEET); feb. 2019. p. 1–6. https://doi.org/10.1109/CEET1.2019.8711822.

[7] Hao H, Cheng X, Liu Z, Zhao y F. «Electric vehicles for greenhouse gas reduction in China: a cost-effectiveness analysis». Transp. Res. Part Transp Environ oct. 2017;56:68–84. https://doi.org/10.1016/j.trd.2017.07.025.

[8] Byeon G, Yoon T, Oh S, Jang y G. «Energy management strategy of the DC distribution system in buildings using the EV service model». IEEE Trans Power Electron 2013;28(4):1544–54. https://doi.org/10.1109/TPEL.2012.2210911. abr.

[9] Roy JV, Leemput N, Geth F, Büscher J, Salenbien R, Driesen YJ. «Electric vehicle charging in an office building microgrid with distributed energy resources». IEEE Trans. Sustain. Energy oct. 2014;5(4):1389–96. https://doi.org/10.1109/TSTE.2014.2314754.

[10] Zhang Y, Xu Y, Yang H, Dong y ZY. «Voltage regulation-oriented co-planning of distributed generation and battery storage in active distribution networks». Int J Electr Power Energy Syst feb. 2019;105:79–88. https://doi.org/10.1016/j.ijepes.2018.07.036.

[11] Arias NB, Hashemi S, Andersen PB, Træholt C, Romero y R. «Distribution system services provided by electric vehicles: recent status, challenges, and future prospects». IEEE Trans Intell Transport Syst 2019;20(12):4277–96. https://doi.org/10.1109/TITS.2018.2889439. dic.

[12] Wu D, Zeng H, Lu C, Boulet y B. «Two-Stage energy management for office buildings with workplace EV charging and renewable energy». IEEE Trans. Transp. Electrification mar. 2017;3(1):225–37. https://doi.org/10.1109/TTE.2017.2659626.

[13] Zhang Y Wu y L. Can the development of electric vehicles reduce the emission of air pollutants and greenhouse gases in developing countries? Transp. Res. Part Transp Environ mar. 2017;51:129–45. https://doi.org/10.1016/j.trd.2016.12.007.

[14] Manic M, Wijayasekara D, Amarasinghe K, Rodriguez-Andina y JJ. «Building energy management systems: the age of intelligent and adaptive buildings». IEEE Ind. Electron. Mag. mar. 2016;10(1):25–39. https://doi.org/10.1109/MIE.2015.2513749.

[15] Barone G, Buonomano A, Calise F, Forzano C, Palombo y A. «Building to vehicle to building concept toward a novel zero energy paradigm: modelling and case studies». Renew Sustain Energy Rev mar. 2019;101:625–48. https://doi.org/10.1016/j.rser.2018.11.003.

[16] Rosales-Asensio E, de Simón-Martín M, Borge-Diez D, Blanes-Peiró JJ, Colmenar-Santos y A. «Microgrids with energy storage systems as a means to increase power resilience: an application to office buildings». Energy 2019;172:1005–15. https://doi.org/10.1016/j.energy.2019.02.043. abr.

[17] Sheng Lei. «Effect analysis on thermal profile management of a cylindrical lithium-ion battery utilizing a cellular liquid cooling jacket». Energy 2021;220:119725. https://doi.org/10.1016/j.energy.2020.119725. abr.

[18] Behi Hamidreza, Karimi Danial, Jaguemont Joris, Heidari Gandoman y Foad. «Novel thermal management methods to improve the performance of the Li-ion batteries in high discharge current applications». Energy jun. 2021;224: 120165. https://doi.org/10.1016/j.energy.2021.120165.

[19] Xie Y, et al. «Microsimulation of electric vehicle energy consumption and driving range». Appl Energy jun. 2020;267:115081. https://doi.org/10.1016/j.apenergy.2020.115081.

[20] Li Y, Wang S, Duan X, Lui y S. «Multi-objective energy management for Atkinson cycle engine and series hybrid electric vehicle based on evolutionary NSGA-II algorithm using digital twins». Energy Convers Manag feb. 2021;230: 113788. https://doi.org/10.1016/j.enconman.2020.113788.

[21] Tian Man-Wen. «Energy cost and efficiency analysis of building resilience against power outage by shared parking station for electric vehicles and demand response program». Energy ene. 2021;215:119058. https://doi.org/10.1016/j.energy.2020.119058.

[22] Li Yiding. «A safety performance estimation model of lithium-ion batteries for electric vehicles under dynamic compression». Energy 2021;215:119050. https://doi.org/10.1016/j.energy.2020.119050. ene.

[23] Uddin Kotub. «On the possibility of extending the lifetime of lithium-ion batteries through optimal V2G facilitated by an integrated vehicle and smart-grid system». Energy 2017;133:710–22. https://doi.org/10.1016/j.energy.2017.04.116. ago.

[24] Peterson SB, Apt J, Whitacre y JF. «Lithium-ion battery cell degradation resulting from realistic vehicle and vehicle-to-grid utilization». J Power Sources 2010;195(8):2385–92. https://doi.org/10.1016/j.jpowsour.2009.10.010. abr.

[25] Uddin Kotub. «The viability of vehicle-to-grid operations from a battery technology and policy perspective». Energy Pol feb. 2018;113:342–7. https://doi.org/10.1016/j.enpol.2017.11.015.

[26] Chen TD, Kockelman KM, Hanna y JP. «Operations of a shared, autonomous, electric vehicle fleet: implications of vehicle & charging infrastructure decisions». Transp. Res. Part Policy Pract 2016;94:243–54. https://doi.org/10.1016/j.tra.2016.08.020. dic.

[27] «ANFAC Yearly report». 2019. https://anfac.com/categorias_publicaciones/informe-anual/.

[28] «Impact, vulnerability and adaptation». https://www.miteco.gob.es/es/cambio-climatico/temas/impactos-vulnerabilidad-y-adaptacion/.

[29] Ibáñez. 97 % time the car is not being used». Xataka, Dic 2016;13. https://www.xataka.com/automovil/el-97-del-tiempo-tu-coche-esta-aparcado.

[30] Tushar MHK, Zeineddine AW, Assi y C. «Demand-Side management by regulating charging and discharging of the EV, ESS, and utilizing renewable energy». IEEE Trans. Ind. Inform. 2018;14(1):117–26. https://doi.org/10.1109/TII.2017.2755465. ene.

[31] Miao H, Jia H, Li J, Qiu y TZ. «Autonomous connected electric vehicle (ACEV)-based car-sharing system modeling and optimal planning: a unified two-stage multi-objective optimization methodology». Energy feb. 2019;169:797–818. https://doi.org/10.1016/j.energy.2018.12.066.

[32] Global EV, Outlook. Analysis». IEA; 2019. https://www.iea.org/reports/global-

ev-outlook-2019.
[33] Ortega-Cabezas Pedro Miguel, Colmenar-Santos Antonio, Borge-Diez David, Jorge-Juan Blanes-Peiró y. «Can eco-routing, eco-driving and eco-charging contribute to the European green deal?». Energy 2021:120532. https://doi.org/10.1016/j.energy.2021.120532. abr.
[34] «Economic and Market Reports | ACEA - European Automobile Manufacturers' Association». https://www.acea.be/statistics/tag/category/economic-and-market-outlook.
[35] «ANFAC | Electro-movility report». https://anfac.com/barometro-de-electro-movilidad/.
[36] «Long-term production technology mix of alternative fuels for road transport: a focus on Spain». Energy Convers Manag 2020;226:113498. https://doi.org/10.1016/j.enconman.2020.113498. dic.
[37] Research L. «Lux Research | The Energy Transition is Inevitable». https://www.luxresearchinc.com/the-energy-transition-is-inevitable.
[38] Elcano research. http://www.realinstitutoelcano.org/wps/portal/rielcano_en/contenido?WCM_GLOBAL_CONTEXT=/elcano/elcano_in/zonas_in/climate-change/ari63-2019-caldes-escribano-lazaro-lechon-kiefer-delrio-thonig-lil-liestam-policy-pathways-for-spains-energy-transition-mustec.
[39] «Oservatory of EV and sustainable mobility Comillas University». https://evobservatory.iit.comillas.edu/.
[40] Sorman AH, García-Muros X, Pizarro-Irizar C, González-Eguino y M. «Lost (and found) in Transition: expert stakeholder insights on low-carbon energy transitions in Spain». Energy Res. Soc. Sci. jun. 2020;64:101414. https://doi.org/10.1016/j.erss.2019.101414.
[41] Marín y PF, Úbeda JR. «EV: current situation and future perspectives». Econ Ind 2019;411:11–20. https://dialnet.unirioja.es/servlet/articulo?codigo=6932909.
[42] «AutoCrypt V2G| Vehicle-to-Grid Security», AUTOCRYPT. https://www.autocrypt.io/.
[43] «Cetelem observatory 2020». https://elobservatoriocetelem.es/observatorio-cetelem-consumo-espana-2020/; oct. 29, 2020.
[44] «Why EV is not being used in Spain». El Motor 2019;15. ago, https://motor.elpais.com/electricos/coche-electrico-pinchando-espana/.
[45] Tirachini A, Chaniotakis E, Abouelela M, Antoniou y C. «The sustainability of shared mobility: can a platform for shared rides reduce motorized traffic in cities?». Transport Res C Emerg Technol 2020;117:102707. https://doi.org/10.1016/j.trc.2020.102707. ago.
[46] Alkadri MF, De Luca F, Turrin M, Sariyildiz y S. «Understanding computational methods for solar envelopes based on design parameters, tools, and case studies: a review». Energies 2020;13(13):3302. https://doi.org/10.3390/en13133302. ene.
[47] Aparca Plan. Madrid regional goverment. Dic. 2016;12. https://www.comunidad.madrid/servicios/vivienda/plan-aparca.
[48] León (León, Castilla y León, Spain) - Population Statistics, Charts, Map, Location, Weather and Web Information». https://www.citypopulation.de/en/spain/castillayleon/le%C3%B3n/24089__le%C3%B3n/.
[49] «Renewable energy already exceeds the installed power capacity of other sources of energy on the Spanish peninsula | Red Eléctrica de España». https://www.ree.es/en/press-office/news/press-release/2020/03/renewable-energy-already-exceeds-installed-power-capacity-of-other-sources-of-energy-on-the-Spanish-peninsula.
[50] «Nuclear energy the main generation source ». LaSexta 2021;29. mar, https://www.lasexta.com/noticias/medio-ambiente/la-energia-nuclear-se-mantiene-como-primera-fuente-de-produccion-de-electricidad-en-espana-pese-al-impulso-de-las-renovables_202103286060fc8cdbb78d0001d4c48e.html.
[51] Charging. Tesla. https://www.tesla.com/charging.
[52] «Improving electric vehicle economics | McKinsey». https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/making-electric-vehicles-profitable#.
[53] Buonomano A. «Building to Vehicle to Building concept: a comprehensive parametric and sensitivity analysis for decision making aims». Appl Energy mar. 2020;261:114077. https://doi.org/10.1016/j.apenergy.2019.114077.
[54] Wu Wei. «Benefits of electric vehicles integrating into power grid». Energy jun. 2021;224:120108. https://doi.org/10.1016/j.energy.2021.120108.
[55] Gokturk Poyrazoglu y Elvin Coban. «A stochastic value estimation tool for electric vehicle charging points». Energy jul. 2021;227:120335. https://doi.org/10.1016/j.energy.2021.120335.
[56] REE. https://www.ree.es/en.