PHOTOVOLTAIC SELF-CONSUMPTION IN ELECTRIC VEHICLE CHARGING STATIONS

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Summary

The present work addresses the energy and economic impact that the incorporation of photovoltaic self-consumption (PV) in its form of surpluses received under compensation, within the framework of RD244 / 2019, will entail in public car parks that provide electric vehicle (EV) charging services. Presenting the different methodologies developed and integrated into a tool in charge of: statistically planning the number of parking spaces required for a given level of EV penetration based on historical data on individualized parking billing, estimating the energy demand related to charging at one-minute intervals statistically simulating a representative EV mobile fleet, and estimating the generation of a grid-connected photovoltaic installation taking into account different generation limiting effects (shadows, fouling plates, effect of ambient temperature, inverter performance). Finally, the billing module is described for facilities with an access rate of 3.0A under the self-consumption modality with compensated surpluses. Specifically, two photovoltaic generation scenarios are analyzed by installing a different number of PV canopies equipped with double charging points in mode 3 in a car park located in the center of Palma de Mallorca, taking into account the evolution of the levels penetration rate for the next 5 years. The results show how with low EV penetrations, such as 2.35%, the increases in demand and energy billing are relevant, reaching 45.82% and 34.39% respectively. While the different PV self-consumption scenarios will lead to significant reductions in the energy term and in the amount of the energy bill, reaching 29.74% and 20.08% respectively.

Keywords: Photovoltaics; Self-consumption; Pluggable electric vehicle; Monte Carlo method; Artificial intelligence

1. Introduction

The transport sector represents 25% of world energy consumption, with oil and other liquid fuels being the main energy sources related to this sector, responsible for CO_2 and other greenhouse gas (GHG) emissions (EIA, 2016). In order to reduce the pollution generated by this sector, a lot of countries are looking toward a substitution of the internal combustion vehicles for more environmentally friendly alternatives (Amini et al., 2016), as the pluggable electric vehicle (PEV), that seems to be more respectful with the environment and presents lower operational costs (Tulpule et al., 2013). In this framework, it is essential that the public sector take the initiative in the deployment of a charging infrastructure for PEV, thus promoting the PEV adoption by consumers. In turn, the objective of reducing to zero the emissions in 2050 in the EU (EU, 2020) will accelerate the energy transition that will involve massive penetration of renewable sources, mainly of solar PV origin in urban areas. In this scenario, the PEV charging can help the power-grid to maintain the balance between supply and demand; which will allow a greater penetration of renewable energies (Fattori et al., 2014). This work analyzes the energy and economic benefit related to the incorporation of photovoltaic self-consumption in public parking lots to cope with the PEV load.

In the context of the ongoing energy transition that will lead to the massive penetration of renewable sources, mainly photovoltaic (PV) in urban areas related to self-consumption. Where PV generation is characterized by a non-dispatchable and time-varying power supply, while EV load demand is characterized by controllable loads and energy storage capacity, with which it makes sense to combine the load of the EV with PV generation (Nunes

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et al., 2015). In turn, the production of energy from PV origin could also allow a greater penetration of electric vehicles, as it does not lead to a significant increase in net demand if EVs are charged from PV. Although its integration must be carried out with great care so as not to compromise the stability of the electrical network (Poullikkas, 2015; Romo & Micheloud, 2015), related to the variability of PV generation (Nunes et al., 2016) and the increase in specific demand that the load of the EV

Also, EV car parks equipped with photovoltaic solar energy can be deployed on the surface in practically any place that has a basic electrical infrastructure, such as: shopping centers, train and bus stations, universities, public and private car parks... Being the typical infrastructure of the EV solar charging stations composed by a battery parking, covered by solar panels of about 12-15m^2, supported in the air by metal or wooden structures. Under this structure, there are located the different charging stations for electric vehicles. Its usual arrangement being that of groups of two rows of parallel parking spaces separated by a circulation road in between (Amini et al., 2017)

The present work analyzes the energy and economic benefit that the incorporation of photovoltaic generation in self-consumption modality with ex-surplus beneficiaries receiving compensation (Ecológica, 2019), included in RD244 / 2019 recently approved in Spain, on the demand for EV charging located in public car parks. For this, a numerical tool has been developed to plan the needs of new charging infrastructures and the energy impact that these will entail on the base demand of the different public car parks. To this tool, separate estimation modules for photovoltaic generation and estimation of energy billing in self-consumption mode with surpluses received for compensation have been incorporated for this work.

2. Evolution of EV penetration

In order to have a forecast of the EV energy demand, it is essential to have a forecast of the evolution of the incorporation of the electric vehicle in the mobile fleet, with a horizon of at least 5 years to establish priorities and horizons in the development of EV charging infrastructures and their associated energy impact. For this, it has been chosen to predict the evolution of the penetration of the electric vehicle in the mobile park of the Balearic Islands from historical data on annual car registrations / sales nationwide. The EV penetration has been forecasted for the next 5 years (2019-2023) from the historical series of monthly electric vehicle sales and through a Box-Jenkins statistical model of the AutoRegressive Integrated Moving Average (ARIMA) family, implemented on MATLAB®, specifically for forecasting time series based on past observations of the own series and previous forecasting errors. The model, expressed as ARIMA (p, d, q), is defined by the parameters p, d, q, where p determines the auto regressive non-stationary coefficient (AR) order, d determines the non-stationary integrative term (I) order and q defines the moving average term (MA) order. Mathematically, the model is expressed as:

$$Y_t = \left(\Phi_0 + \sum_{i=1}^{p} \Phi_i \Delta^d Y_{t-1}\right) + \left(Y_t - \Delta^d Y_t\right) + \left(\epsilon_t - \sum_{i=1}^{q} \theta_i \epsilon_{t-1}\right) \quad \text{(eq. 1)}$$

Where "d" corresponds to the number of differences or derivatives to make to convert the input time series into stationary, the terms $\phi_1,\ldots,\phi_p$ are the coefficients of the autoregressive part of the model, the terms $\theta_1,\ldots,\theta_p$ are the coefficients of the moving averages part of the model, ϕ_o is a constant, ε_t is the error term, and $\Delta Y_t = Y_t - Y_{t-1}$ represents the remainder between the output value of the time series at time t and the previous instant t-1.

Specifically, the model implemented is a Seasonal AutoRegressive Integrated Moving Average (SARIMA), because of its capability of incorporating the effect of the seasonality of the EV sales throughout the year in the model. Once the time series has been analyzed and its basic components identified, a model has been implemented with $\phi_o = 0$, a number of differences d=1 in order to convert the time series into stationary, a term of the non-seasonal moving average of order q=1, and finally a seasonal term of period 12 (months) and unit order of the Seasonal Moving Average SMA = 1, period that corresponds to one year. The results of the forecast of the monthly sales of EV + PHEV have been integrated annually in order to estimate the annual sales for the next 5 years, which are presented in **Table 1**.

The evolution of the electric mobility in the Balearic Islands follows the same characteristics that the mean of Spain, then the main source of historical data used in this work is the national sales of electric vehicles that can be extrapolated to the local behavior. Three main data sources has been used, the first one is the monthly time series of EV and PHEV registrations, at national level, for the period from 01/01/2014 to 31/12/2019, obtained from Instituto de Estudio de Automoción (IDEAUTO) (*Instituto de Estudio de Automoción (IDEAUTO)*, n.d.); the second one is the historical data of EVs monthly sales at national level and the historical data of the passenger car fleet at the Balearic Islands, obtained from the *Direccion General de Trafico* (DGT) (Dirección General de Trafico (DGT), 2019) and the third one is EV sales time series at national level for the period from 01/01/2014 to 31/12/2019, provided by the Spanish Association of Automobile Manufacturers and Trucks (ANFAC) (ANFAC, 2020).

Table 1. Forecasted EV penetration for the period (2019-2023) at the Balearic Islands

YEAR	EV in circulation at the Balearic Islands	Penetration of the EV in the passenger car fleet
2019	1.817	0.28%
2020	3.117	0.47%
2021	5.331	0.81%
2022	9.100	1.38%
2023	15.516	2.35%

In order to have a reliable model, we need to know which are the main models that conform the Balearic Islads fleet. For that, the models of the fleet are going to be approximated as the 11 more sold vehicles in Spain, 6 pure electric vehicles and 5 plug-in hybrid vehicles, obtained from the IDEAUTO database, and with the penetration percentage stablished according to the actual national electric vehicle fleet. In such way, the percentage between BEV and PHEV would be 62.83% and 38.17% respectively, conforming a fleet with almost the same distribution than the real one (62.19% and 37.81%).

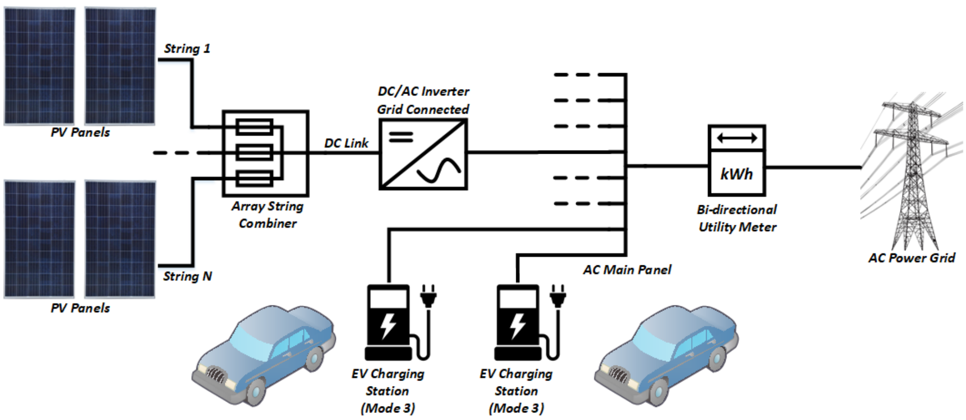

Fig 1. Grid-connected PV generation system architecture to support EV charging.

3. Methodology

The methodology in charge of planning the charging infrastructures and estimating their energy demand presented in this work has focused on analyzing the demand for normal / slow and semi-fast AC load in mode 3 of EVs in a load power range of [2.3-22kW] in car parks. publics in rotation regime, for a relatively low range of EV penetration levels [0-2.35%]. It is supported by 8 sub-modules that implement specific parts of the developed methodology and it implements a Montecarlo algorithm at its core, which will perform a minute-by-minute simulation of parking for a time series of 10 repetitions of the reference year (2017).

3.1. Analysis and Modelling of Parking Occupancy

The first module, the analysis and modeling of parking occupancy module, is in charge of adjusting the statistical distribution of the parking periods and the diagram of average occupancy for the parking, for two annual periods (high and low season), from the historical billing information of the studied parking. In order to know the distribution of the parking periods, the histogram of the parking durations for intervals of 10 minutes in a range of [0, 2000] minutes is constructed, thus eliminating atypical parking periods. Whose shape perfectly follows a continuous distribution like Weibull's We(x, λ, k).

$$f(x;\lambda,k) = \begin{cases} \frac{k}{\lambda}\left(\frac{x}{\lambda}\right)^{k-1} e^{-\left(\frac{x}{\lambda}\right)^k} & x \geq 0 \\ 0 & x < 0 \end{cases} \qquad \text{(eq. 2)}$$

The two parameters that determine the shape of the Weibull distribution are the form parameter (k) and the scaling parameter of the distribution (λ), and are determined by applying a least squares method to the obtained histogram of the input data. After determining the parking periods distribution, the modulus obtains the hourly mean occupancy from the mean number of vehicles that start and end their parking each hour in a determined period.

3.2. Load Demand Curves Generator

The load demand curve generator module is in charge of generating the charging curves of the batteries of the vehicles of the local EV fleet. Specifically, the methodology developed aims to emulate the demand associated with battery charging, using a two-stage function. A first section at constant nominal power and a second one at variable power that will decrease exponentially. The characteristics of the local EV fleet is loaded from an external file that details, for each of the 11 (5 pure electric and 6 plug-in hybrids) EV conforming the fleet, the main characteristics: the absolute percentage of penetration of the model in the fleet, the useful energy of the battery, the charging time and the nominal charging power of the vehicle, in addition to other parameters.

3.3. EV Occupancy Generator

The third module determines the occupancy of the EV from the penetration value of the EV in the mobile park and from the data on the average hourly occupancy of the car park, which will provide the average number of entrances / parking lots of vehicles for all time intervals of the evaluation period. First it generates uniformly distributed random number U(0,1) that determines if the entering vehicle is electric or not, then, for each EV entering in the parking, three new random numbers will be generated. The first one U(1,60) determines the entering minute, the second, that follows a Weibull distribution, will randomly set the duration of the parking characteristic of the parking; and the third one, U(0,1) will determine the EV model that has accessed the parking.

3.4. Photovoltaic Generation

The photovoltaic generation module will calculate the energy generated by the PV installation from the meteorological data provided by the *Agencia Estatal de Meteorología* (*AEMET*, n.d.), specifically, the hourly data for global horizontal solar irradiance (DGI), diffuse horizontal solar irradiance (DHI), normal direct irradiance (DNI) and ambient temperature. From the solar position, calculated using the algorithm of the Solar Platform of Almería (PSA) (Blanco-Muriel et al., 2001), and the hourly means of irradiance applying geometric methods, the diffuse irradiance (IDif), the direct irradiance (ID) and the global irradiance that will get to a given photovoltaic panel can be determined. Finally, in order to determine the electrical power P_{AC} delivered by the inverter to the grid, the NRW PVWatts model (Dobos, 2014) was chosen, which proposes for the estimation of the inverter performance an empirical function scaled according to the nominal efficiency of the PV inverter.

3.5. Hourly Base Demand Generator

In order to know the total energy demand of the parking it is necessary to know the parking base demand and the real EV demand. The first, the power demand of the public parking lot is usually related to the lightning and ventilation systems. In this case, as the parking is located on the surface, there is no ventilation and the base demand will be lower than in other public parking lots. The methodology used to evaluate the hourly mean base demand is based on the historical invoices of the parking. This task is performed loading an external file (.csv) with the billing of the last years, that contains all the information of the historical invoices for an access toll 3.0A (P_{Cont}≥15kW @400V_{AC}).

3.6. Real Occupation and Energy Demand Generator

The real occupation and energy demand generator sub-modulus determines the energy demand of the EV charging points from the minute by minute occupation previously generated, taken into account the limitation of vehicles that can be charging at the same time.

3.7. Demand Integrator

It is responsible for integrating the energy demand of energy companies in four-hour periods and hours, for subsequent analysis and evaluation of electricity billing. Where the quarter hourly is needed in order to determine the contribution of the maximeter to the power term[kW], while the hourly demand will be used for determining the contribution to the energy term[kWh]; both related to the energetic billing.

3.8. Energy Billing

Finally, the last module is in charge of calculating the monthly energy bill (Ministerio de Industria Energía y Turismo, 2014) for a 3.0A access toll, a typical typology for public parking lots. It is a billing system that always uses hourly discrimination in three periods: P1 (Peak), P2 (Plan) and P3 (Valley); and each period corresponds to a daily time slot where the cost of energy and contracted power is different. The rates integrated in the tool are presented in **Table 2**, which also include the equipment rental term (€ 414.72 / year), the electricity tax (5.11%) and VAT (21%)

Table 2. Access toll 3.0A

Rate / Power Range	[€] Power Term P1	[€] Power Term P2	[€] Power Term P3	[€] Power Term P1	[€] Power Term P2	[€] Power Term P3
Fare 1 / 15 a 30 kW	41,95	25,17	16,78	0,1272	0,1141	0,0853

4. Results

The proposed methodology has been applied to a public parking lot located in the center of Palma de Mallorca, facing northwest; where their 83 parking spaces are operated in a rotation regime from Monday to Saturday with a schedule from 7 a.m. to 10 p.m. In turn, the car park has a 15kW contract for the three billing periods, and an annual energy consumption of about 8,000 kWh.

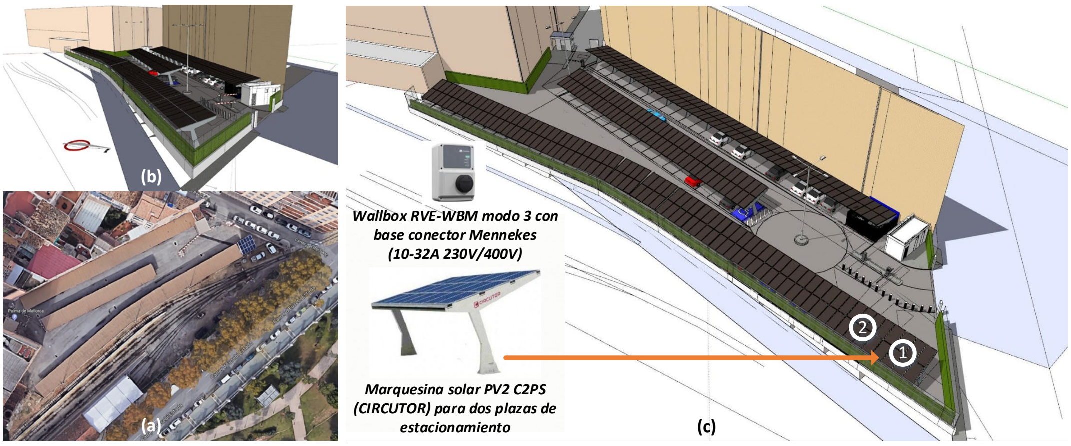

Fig 2. a: Parking location. b: Orientation of the car park. c: Description and location of the solar canopies.

4.1. Planning the Load Infrastructure

Before performing any energetic or economical analysis it is necessary to plan the needed infrastructures for the studied parking. For that, the number of recharging points and number of EV parking lots needed for covering the P_{99} and $P_{99.6}$ percentiles of EV parking attempts which will be given with the EV penetration levels for the next 5 years. A scan be shown in **Fig 3**, either for the percentile P_{99} and the $P_{99.6}$ two parking spaces for EV recharge will be required.

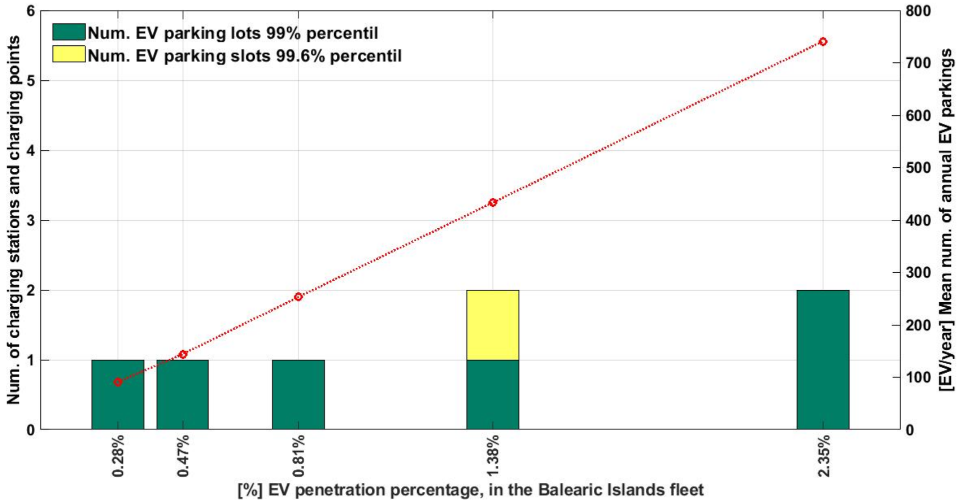

Fig 3. Planning of EV charging stations and spaces requirements

In turn, the two scenarios proposed for photovoltaic generation will consist of the installation of 1 or 2 PV2 canopies from the manufacturer Circutor, the specifications of which are presented in **Table 3**, as shown in Fig. 3c. Both scenarios meet the requirements for parking spaces and charging stations for the period analyzed.

Table 3. Parameters associated with the two PV self-consumption scenarios

Scenario	Num. Modules PV (270 Wp)	[kWp] Power PV	Num. Inversors x [kW] PNominal	Num. lots / Núm. Charging points mode 3
1: 1 x Canopy PV2-2	15	4,05	1 x 3,70	2 / 1
2: 2 x Canopy PV2-2	30	8,10	1 x 7	4 / 2

4.2. Energetic Analysis

Once determined the number of recharging points installed in the parking, the methodology proceeds to estimate the base energy demand of the car park combined with that associated with EV charging based on the penetration level established annually, in minute-by-minute intervals. Then, this energy demand is integrated into quarter-hour periods and schedules that will serve as reference energy demand, for subsequent analysis. The obtained results show that the total energy demand (P1 + P2 + P3) will increase in just 5 years by 45.82%. In turn, if we analyze the increase of energy demand for the three different billing periods, the current energy demand in period P1 (18-22h) will increase by [36-39%], that of period P2 (8-18h and 22-24h) by [79-82%], while that of period P3 (00-08h) will remain practically unchanged. The results on the period P3 is because the parking lot is closed from 10 p.m. to 7 a.m. Next, the methodology estimates the energy demand incorporating the two PV self-consumption scenarios for the different levels of EV penetration; thus, obtaining the combined energy demands by billing period (quarter-hours and hours), and their respective P_{99} percentiles and demand peaks.

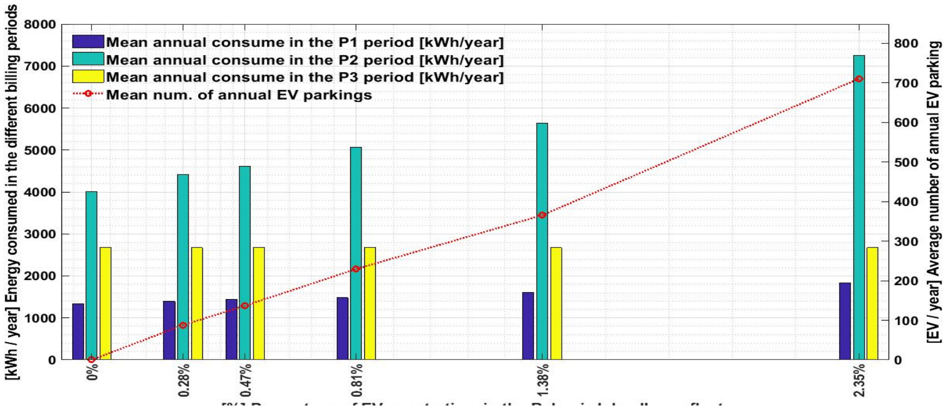

Fig 4. Impact of the penetration of electric vehicles on energy demand, for the different billing periods.

Next, the methodology estimates the energy demand incorporating the two PV self-consumption scenarios for the different levels of EV penetration; thus, obtaining the combined energy demands by billing period (quarter-hours and hours), and their respective P_{99} percentiles and demand peaks. In order to facilitate the interpretation of the results obtained, the demands for the different scenarios of EV penetration and PV self-consumption are presented in **Table 4** as a percentage with respect to the base demand of the reference year 2017 for this car park.

Table 4. Energy demand of the car park for the different PV self-consumption scenarios

Without PV/ VE penetration	**(2017)**	**(2019)**	**(2020)**	**(2021)**	**(2022)**	**(2023)**
	0%	**0,28%**	**0,47%**	**0,81%**	**1,38%**	**2,35%**
Num. Parking lots / Charging stations	0/0	1/1	1/1	1/1	1/1	2/2
Annual Dem. P1 [kWh]	1.337	4,92%	7,95%	13,14%	20,64%	36,81%
Annual Dem. P2 [kWh]	4.011	9,42%	15,42%	26,44%	40,54%	79,34%
Annual Dem. P3 [kWh]	2.674	0%	0%	0%	0%	0,04%
Total Annual Dem [kWh]	8.022	5,53%	9,03%	15,41%	23,71%	45,82%
P99 Quarter-hourly Dem. [kWh]	0	1,69	4,60	6,20	7,52	9,88
Peak Quarter-hourly Dem. [kWh]	0	5,42	7,52	8,28	10,13	14,39
P99 Hourly Dem. [kWh]	0	2,85	4,20	4,99	6,39	8,28
[Scenario 1]: 1 x Canopy PV2-2 → (4,05 kWp)						
Annual Dem. P1 [kWh]	1.337	3,43%	6,65%	9,72%	19,44%	36,61%
Anual Dem. P2 [kWh]	4.011	-38,31%	-33,96%	-23,87%	-11,34%	24,59%
Anual Dem. P3 [kWh]	2.674	0,00%	0,00%	0,00%	0,00%	0,00%
Anual Dem. Total [kWh]	8.022	-18,67%	-15,96%	-10,40%	-2,52%	18,31%
P99 Quarter-hourly Dem. [kWh]	0	1,32	3,22	4,80	6,57	9,10
Peak Quarter-hourly Dem. [kWh]	0	4,86	5,98	7,52	9,44	13,67
P99 Hourly Dem. [kWh]	0	2,15	3,22	4,40	5,41	7,66
[Scenario 2]: 2 x Canopy PV2-2 → (8,10 kWp)						
Annual Dem. P1 [kWh]	1.337	3,60%	5,55%	10,26%	19,14%	39,05%
Anual Dem. P2 [kWh]	4.011	-43,50%	-39,65%	-31,91%	-21,83%	6,82%
Anual Dem. P3 [kWh]	2.674	0,00%	0,00%	0,00%	0,00%	0,00%
Anual Dem. Total [kWh]	8.022	-21,24%	-18,98%	-14,33%	-7,81%	9,83%

P99 Quarter-hourly Dem. [kWh]	0	0,92	2,38	4,60	6,19	8,28
Peak Quarter-hourly Dem. [kWh]	0	4,37	5,40	7,52	8,28	12,34
P99 Hourly Dem. [kWh]	0	1,44	2,70	4,03	4,88	7,32

The results presented clearly show how the incorporation of PV generation in a self-consumption regime has a beneficial effect, reducing the global energy demand. The first scenario (1x PV canopy (4.05 kWp)) analyzed shows a reduction in the average demand of 25.81% for PEV penetration levels in the range [0, 2.35%], while for second scenario (2xPV canopy (8.10 kWp)) this reduction reaches 29.74%.

4.3. Economic Analysis

From the information linked to the access tariff that the car park has contracted and the energy demands obtained in the previous section, the billing sub-module has been used to determine the annual amount of energy billing (adding the monthly billings from the car park). To facilitate the subsequent analysis of the energy costs evaluated for the different EV penetration levels and shown in **Table 5**, it has been chosen to present the energy amounts broken down in euros for the scenario without PV contribution; while the PV self-consumption scenarios are presented as a percentage with respect to the energy costs of the year 2017, taken as a reference.

Table 5. Energy billing associated with the energy demand of the car park for PV self-consumption scenarios

Without PV/ VE penetration	**(2017) 0%**	**(2019) 0,28%**	**(2020) 0,47%**	**(2021) 0,81%**	**(2022) 1,38%**	**(2023) 2,35%**
ΔEnergy Term [%]	855,99€	6,01%	9,16%	15,57%	25,59%	51,33%
ΔPower Term [%]	1.258,52€	4,65%	6,59%	9,08%	13,60%	33,66%
Invoice amount [€/year]	3.191,18	3.330,95	3.396,40	3.506,01	3.687,42	4.288,72
ΔAnnual invoice amount [%]	0	4,38%	6,43%	9,87%	15,55%	34,39%
[Scenario 1]: 1 x Canopy PV2-2 → (4,05 kWp)						
ΔEnergy Term [%]	855,99€	-30,16%	-27,21%	-21,27%	-11,79%	12,30%
ΔPower Term [%]	1.258,52€	3,11%	4,82%	7,09%	11,26%	29,99%
Invoice amount [€/year]	3.191,18	2.923,31	2.982,63	3.083,46	3.252,99	3.814,22
ΔInvoice amount [%]	0	-8,39%	-6,54%	-3,38%	1,94%	19,52%
Surplus Amount [€/year]	0	86,58	85,58	83,46	80,93	73,26
Amount of Energy given away [€/year]	0	0	0	0	0	0
[Scenario 2]: 2 x Canopy PV2-2 → (8,10 kWp)						
ΔEnergy Term [%]	855,99€	-50,19%	-47,18%	-41,16%	-33,58%	-13,25%
ΔPower Term [%]	1.258,52€	2,64%	3,08%	7,02%	10,39%	25,85%
Invoice amount [€/year]	3.191,18	2.716,22	2.755,70	2.883,65	3.019,29	3.486,08
ΔInvoice amount [%]	0	-14,88%	-13,65%	-9,64%	-5,39%	9,24%
Surplus Amount [€/year]	0	236,51	232,82	228,57	221,84	204,92
Amount of Energy given away [€/year]	0	0	0	0	0	0

It should be noted that savings are concentrated in the P2 period (08-18h). In turn, in the P1 period (18h-22h) the solar contribution can only slightly contain the increase in demand. Meanwhile, the economic analysis shows how small PEV penetration rates will lead to significant increases in the energy bill. A PEV penetration of 2.35% will lead to an increase of 34.39% of the energy bill. At the same time, the PV self-consumption of 4.05kWp reached the saving average of 13.25% of the energy bill for the different levels of PEV, while the PV self-consumption of 8.10kWp the savings grew to 20.08%.

The reduction in demand comes from self-consumption, that is, from the subtraction of instantaneous power demand with that generated for each instant of time While surpluses, generated energy that cannot be self-consumed instantly, cannot be discounted from the global energy demand for a specific billing period in accordance with RD244 / 2019, as if it happens with the net balance in other countries from the EU.

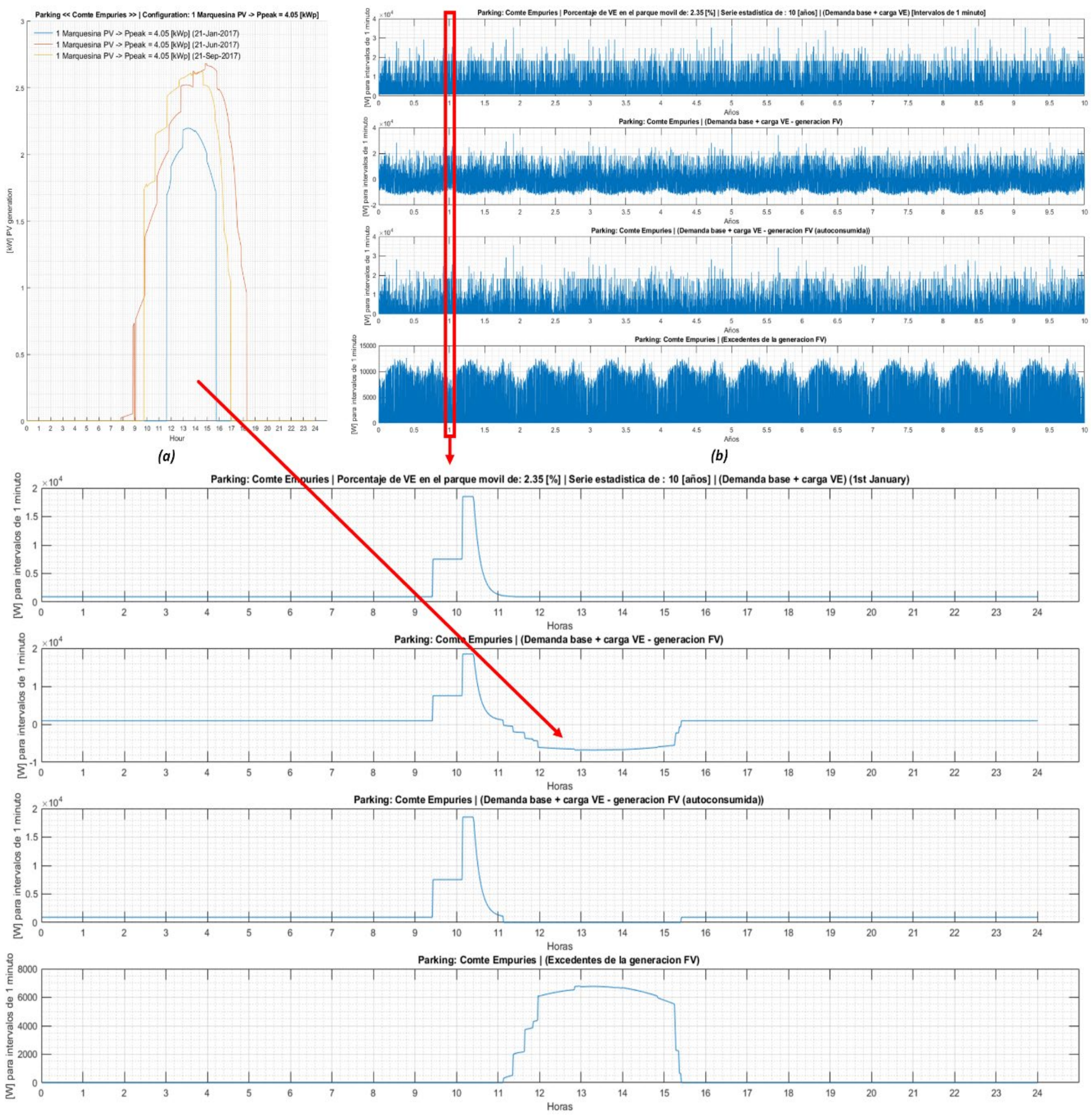

Fig. 3: a) Minute by minute generation of the 4,05 KWp PV installation, for different dates. b) Demands and generations minute by minute for a penetration of 2.35% of the EV, and scenario of self-consumption PV.

5. Conclusions

This work has presented a methodology to plan the PEV charging infrastructure and estimate its associated energy demand. The results show how PV self-consumption is an effective mechanism to mitigate the increase in the cost of the energy bill, essentially impacting the energy term, at least for the current PEV levels of penetration. Where the PV self-consumption of 4.05kWp has achieved an average demand reduction of 25.81% for the different levels of EV penetration, while the PV self-consumption of 8.10kWp has achieved an average demand reduction of 29, 74%. Concentrating most of the savings in the period from 8 am to 6 pm, where PV generation is concentrated. In turn, the results show that the most interesting self-consumption scenario, for a car park with a small base demand as is the case, is the one made up of only one PV canopy (4.05kWp). This is due to the fact that the self-consumption modality with surpluses under compensation, included in RD244 / 2019, is focused on direct self-consumption, penalizing generation surpluses through an asymmetric compensation of generation against demand.

6. Acknowledgements

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