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Techno-economic evaluation of the Portuguese PV and energy storage residential applications☆

Ana Foles[a,b,*], Luís Fialho[a,b], Manuel Collares-Pereira[a,b]

[a] Renewable Energies Chair, University of Évora, 7000-651 Évora, Portugal
[b] Institute of Earth Sciences, University of Évora, Rua Romão Ramalho, 7000-671 Évora, Portugal

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ABSTRACT

In the residential sector, energy micro-generation and its intelligent management have been creating novel energy market models, considering new concepts of energy usage and distribution, in which the prosumer has an active role in the energy generation and its self-consumption. The configuration of a solar photovoltaic system integrating energy storage in Portugal is yet unclear in the technical, energetic and economic point of view. The energy management jointly with the battery operation have great influence in the system configuration's profitability value. The present work evaluates different photovoltaic system configurations with and without batteries for the normal low voltage Portuguese consumer profile with 3.45 kVA contracted power. This study presents the systems' cost-effectiveness, within the Portuguese legislation, which promotes and enables policies for self-generation and self-consumption. The analysis is done in three different representative locations of the country, considering distinct electric tariffs. This work shows that despite the solar photovoltaic system without electricity storage is already economically viable, its integration with storage is not in most of the assessed configurations. However, it is shown that it is already possible to find profitable PV + battery configurations, even potentially improving these positive scenarios if a good energy management strategy is considered.

Introduction

In contrast to the fossil fuelled energy generation, renewable energy (RE) is characterized by an abundance of resources and lower pollution emissions. Developed countries are evolving towards diversifying their renewable energy sources, integrating micro-generation in their low voltage (LV) networks, shaping micro-grids (MG). Micro-grids could be designed for RE to fully meet the local consumption loads, considering the use of storage to balance supply and demand and managing energy flows. Those can require e.g. energy generation, energy shifting or load management in the residential scheme. Electricity generation from RE sources can be described as dispatchable or non-dispatchable, regarding the energy source ability to provide a controlled response to system requirements, such as consumer loads in the residential sector. RE integrated in the existing power grid could require improvements, allowing bidirectional flows of electricity, ensuring grid stability; having efficient grid management to increase grid flexibility, response and security; improvements in the interconnections (increasing capability, reliability and stability), introducing devices and methods of operation to ensure stability and control (voltage, frequency, power balance); and introduction of energy storage (ES) aiming the system flexibility and security of supply [1]. The integration of solar photovoltaic (PV) modules in the residential sector allows the energy efficiency achievement, increase of local reliability, reduction of energy losses, and easy architecture integration. Cost-competitiveness of solar PV and reduction of support schemes had made possible new business models to emerge, mostly in northern Europe. PV electricity generates revenues through the injection into the grid or by optimization of self-consumption, allowing the reduction of the electric bill and the growing of new energy flow models for the householder/businessman. Energy consumers are currently interested to play an active role not only in the use of RE sources, but also in the generation/storage of RE. This new consumer is known as prosumer and is mainly driven by the energy bill reduction, higher electricity independency from the main grid suppliers and the environment sustainability.

The energy storage operations also create flexible markets, data access and management, cooperation between the Transmission System Operator (TSO) and the Distribution System Operator (DSO) [2].

Electric battery technologies will play a significant role in Europe's Energy Union framework. Regarding the ten key actions designated in

* Corresponding author.
E-mail addresses: anafoles@uevora.pt (A. Foles), lafialho@uevora.pt (L. Fialho), collarespereira@uevora.pt (M. Collares-Pereira).

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Nomenclature

Abbreviations Acronyms, Initials and Symbols

ΔS_n Sum value of the annual cash flows net annual costs (€);
C_{bill} Electricity bill of one year, for each location and electricity tariff (€);
$C_{savings}$ Electricity bill savings with the studied configuration (€);
$E_{Batterysent}$ Energy sent to the battery (kWh);
E_{Load} Sum of the energy load profile, for one year (kWh);
$E_{supplied,m}$ Supplied energy in kWh, in month m;
F_n Net cash flow, in year n;
$OMIE_m$ average Iberian electricity gross market closing price (OMIE) for Portugal in €/kWh, in month m;
$PV_{consumption}$ Energy generated through the PV system which is self-consumed (kWh);
$PV_{generation}$ Total generated energy from the PV system (kWh);
Q_n Energy output or saved, in year n;
$R_{UPAC,m}$ Sold energy price in €, in month m;
ΔI_n Nondiscounted incremental investment costs (€);
Analysis Period, N the amount of time or the period an analysis covers.
B/C Benefit-to-Cost Ratio.
Base Year Year to which all cash flows are converted.
BTN Normal low voltage.
BU Battery use quantifies the use of the battery in comparison with the sum of the energy load profile, in one year.
Capex Capital expenditure.
Cash Flow F Net income plus amount charged off for depreciation, depletion, amortization, and extraordinary charges to reserves.
CE Certificate of Exploitation, needed in some of the PV configurations, defined in the Portuguese current legislation.
Contracted Power One of the defined parameters in the electricity contract which defines the maximum power number of household appliances which are generally used simultaneously, in the domestic sector.
DGEG Director General of Energy and Geology.
Discount rate, d Measure of the time value, which is the price put on the time that an investor waits for a return of an investment. In other words, it is the rate used for computing present values, which reflects the fact that the value of a cash flow depends on the time in which the flow occurs.
DL Decree-Law.
DSO Distribution System Operator.
Electricity Tariff Price payed by the consumer for the electricity which is consumed from the electricity company, generally expressed in €/kWh.
ERSE Regulatory Entity of Energy Services.
Inflation Rate, a The rise in price levels caused by an increase in available currency and credit without a proportionate increase in available goods and services of equal quality. Inflation does not include real escalation. Inflation is normally expressed in terms of an annual percentage change.
Investment, I An expenditure for which returns are expected to extend beyond 1 year.
IRR Internal Rate of Return (%).
LCOE Levelized cost of electricity (€/kWh).
LCOES Levelized cost of energy storage (€/kWh)
Life-Cycle Cost, LCC The present value over the analysis period of the system resultant costs.
MiBEL Iberian Market for Electricity.
NPV Net present value (€).
OMiP / OMiE Portuguese/Spanish branch of MIBEL. perspective in the base year.
REN National Electric Grid.
RES Renewable Energy Sources.
SCR Self-consumption rate.
SLR Supplier of Last Resort.
SMR Saved money rate.
SSR Self-supply rate.
TLCC Total life cycle cost (€).
TSO Transmission System Operator.
UPAC Self-consumption Production Unit.
UPP Small Production Unit.
O&M Operating and maintenance costs, OPEX (€);

the SET-Plan, it is established to "become competitive in the global battery sector to drive e-mobility and ES forward" [3]. Electricity storage involves the conversion of electricity in another form of energy and is currently executed through technologies which differ in performance, characteristics and operation. ES can be conducted by pumped-hydro storage, compressed-air ES, electric batteries, superconducting magnets, flywheels, super-capacitors, chemical storage and thermal storage, or can be obtained through end-use technologies, such as plug-in electric vehicles [1]. New and cost-effective storage technologies are being developed. Apart from mitigating power fluctuations, ES systems can play other roles with PV technologies, such as load-shifting (storing energy during low demand periods and discharging in high demand periods). Compared to other storage options, mentioned above, batteries have become popular in residential appliances due to general simplicity, materials availability, technology maturity and relatively low cost. According to BNEF, the average price of lithium-ion battery technology was 1160 $/kWh in 2010, 176 $/kWh in 2018, and for 2030 the expected value is 62 $/kWh [4].

China is the leader in PV solar energy installations, followed by USA, Japan, Germany and Italy. As market leader, China has in force exclusively photovoltaic policies as the "13th Solar Energy Development Five Year Plan (2016–2020)" implemented in 8th December 2016, in which committed to reach to at least 105 GW of solar photovoltaic capacity. Since 2011, the non-tendered PV projects could benefit from a solar PV feed-in tariff [5]. Spain had Royal Decree 900/2015 on self-consumption, but currently the Royal Decree Law 244/2019 is in force, and accounts with different self-consumption schemes, defines communal self-consumption, simplifies the remuneration related with surplus energy for PV installed power no larger than 100 kW (monthly net-metering) [6]. Spain's "National Renewable Energy Action Plan 2011–2020" defined a 20.8% share of generated renewable energy sources in gross final energy consumption [5]. France works almost exclusively with feed-in tariffs, and it does not have a self-consumption scheme, although a community power scheme has been studied. The photovoltaic feed-in tariff is in force since 2006, last updated in 2016, and has two main variants: building installations no bigger than 100 kW, and it is adjusted every semester; and tenders for buildings installations larger than 100 kW and ground-mounted plants. On July 2015 France targeted for 2030 a 32% of RES in gross final energy consumption in its "Law on Energy Transition for Green Growth". Italy has made a storage system regulation in 2015 identifying technical specifications to include storage into the national electricity. Its "Integrated national plan for energy and climate 2030" last updated in 2019 aim the primary energy consumption reduction target at 125 Mtep. The solar photovoltaic financial incentives which started in 10th July 2012 were cut in 25th June 2014. MiSE has presented provisions which will grant financial incentives to purchase electric or hybrid vehicles, or low carbon emission ones, up to the end of 2021 [7].

In 1st March of 2016, Germany has started a subsidy for solar photovoltaic installations with battery storage for residential installations: the scheme offers soft loans up to 2000 €/kW for solar photovoltaic systems and capital grant covering up to 25% of the eligible solar panel. These values are updated (downwards) every six months. The National Energy Action Plan in force in Germany was implemented in 2010 and has the 2020 targets for 18% of energy generated from RE, through 37% of electricity and 13% for transports coming from RES. With the "Renewables Obligation", in force since 2010, United Kingdom has a small-scale (less than 5 MW) feed-in tariff scheme for renewable electricity**.** Targets in 2020 are that RES represent 15% in gross final energy source, 31% of electricity and 10% of energy demand [5].

In India, the "Uttar Pradesh net-metering regulation for rooftop solar" defined net-metering regulations for rooftop solar photovoltaic, running for 25 years. The tariff is set to 7.06 INR/kWh and has entered in force on 20th of March 2015. The Uttar Pradesh Solar Policy support both on-grid and off-grid PV applications and projects, aiming the achievement of 10.7 GW by 2020, from which 4.3 GW from rooftop solar, and 6.4 GW from utility scale PV projects [5].

The Department of the Environment and Energy of Australia 2016 provides funds for the Solar Communities Program, to support community groups in regions across the country to install rooftop solar photovoltaic, solar hot water heaters and solar-connected battery systems. The Renewable Energy Target aims to deliver a 23.5% share of renewable energy in Australia's electricity mix by the year of 2020 [5].

State of the art

Several techno-economic studies have been presented in the recent years. The reference [8] presents a techno-economic study based in future price scenario which considers the application of PV and battery energy storage in the Azores island, with three battery capacities for each battery technology, the lithium-ion and vanadium redox flow. The aim is the minimization of the cost of electricity generation, and the used economic indicators are the NPV and ROI. In [9] an economic analysis is made considering lithium-ion and lead-acid battery technologies with different RE sources applied in India with net-metering. The study addresses the advantages of integrating energy storage in the networks and considering real load and resource profiles data and component prices. It concludes that lithium-ion batteries are more viable to apply in that scenario. In [10] an analysis is made for Almeria (Spain) and Lindenberg (Germany) assessing impacts of orientation and tilt angles in the self-consumption with energy storage. Higher load profiles showed better results for self-consumption, trade-off in self-consumption increase and cost reduction of investment, in the residential sector, and framework regulations. Applied in Australia, the authors of [11] study the PV + battery configuration using NPV, IRR and LCOE economic indicators. The authors conclude that PV-only systems are profitable, unlike the PV + battery setup, reporting that the economic losses of adding a battery can only be balanced with the benefits that it brings to the grid side. In [12] a residential analysis is made for three USA locations, with the configuration PV + lithium-ion battery, concluding that it is possible to be competitive with grid electricity prices through an adequate sizing in those locations, using the LCOE economic indicator. The authors of [13] studied the application of mono-crystalline PV systems and three lead-acid batteries which differ in size, to be installed in Italy, without subsidies. Relevance of the discounted cash-flows (DCF) is highlighted, jointly with NPV economic indicator, giving relevance to the variables of PV and electricity, associated costs, profiles and batteries. In [14] five different cases of storage with net-metering are studied. The study is made for three locations in Italy, considering PV and battery sizing and installation costs. In this study it is concluded that this configuration is not economic feasible, and losses generated by the energy storage are a disadvantage.

Regarding the Portuguese context some relevant approaches have been made considering DL 153/2014, such as the work of [15] which carries a complete economic analysis using the NPV, LCOE, BCR and IRR as economic indicators to evaluate four configurations of PV and OPzV gel batteries (lead-acid), on a 25 year lifetime analysis. It uses PV kits, and concludes that most of the configurations were not economically interesting. In the work [16] economic indicators DPB and IRR are used, and the legislation in Portugal is clarified. An analysis is conducted for different sectors and three different locations (Lisbon, Porto and Faro), with PV systems with different azimuth and tilt angles, evaluating self-consumption. Remarks are made regarding the importance of the tariff, load profile and PV surplus generation. In [17] PV + battery impact is studied, considering two storage control strategies and tariff fee charges, showing that all the configurations are profitable with a payback below 10 years.

Various studies have been also presented to estimate optimum PV + battery configurations, based in the most common economic indicators, for application in the Portuguese context, for the residential case. Recognising the important work done, the present work stands out in the way of evaluating the PV configurations in three different locations in Portugal, for two electric energy tariffs, with current justified market prices, giving support to the decision-making process, in a way is has not been done before. Detailed Portuguese electricity sector remarks are given and legislation for renewable energy micro-generation is clarified, to contribute to a smoother integration of PV-only and PV + battery configurations in the Portuguese residential sector.

Portuguese electricity market and policies overview

The number of RE applications in Portugal is increasing according to the permits request numbers. In March 2018 the electricity generation from RE was higher than the effective consumption of electricity in the Portuguese continent. The Portugal's first PV dedicated auction for 1.4 GW happened in July 2019. The second one will be in the year of 2020 to procure 700 MW. Regarding storage, the aim is to procure 50–100 MW. Two specific PV auctions promote the integration of PV technology from 572 MW in 2018 to 1.6 GW by 2021 and 8.1 GW to 9.9 GW by 2030 [18].

The main supplier and distributor of electricity in Portugal, EDP, has presented plans to install the first PV plant (3.8 MW) coupled with lead-acid batteries storage, focused on self-consumption, in Castanheira do Ribatejo and Azambuja [19].

The Portuguese electric market is divided in three main activities: electricity generation, transmission of electricity through very high and high voltage networks, distribution of electricity through high, medium and low voltage grids and the electricity supply to consumers [20]. The transmission is carried out under an exclusive public service concession contract made with REN - "Redes Energéticas Nacionais, SGPS, S.A. TSO must connect all the entities to its network if the connection is technically and economically feasible, and if the applicant satisfies the requirements for connection. Regarding supply, there are two regimes:

1. Free market supply to eligible consumers – the supply is made by free market companies using freely negotiated conditions (except some Regulation terms defined by ERSE - Regulatory Entity of Energy Services);
2. Supplier of last resort (SLR) – This supplier must ensure specific consumers with regulated tariffs (yearly defined by ERSE). He must buy all the special regime generation at fixed and regulated prices depending of the generation technology (under feed-in tariffs scheme). This doesn't prevent the SLR generators to sell their energy to other suppliers.

In a free market regime, the participants involved in the production can sell the produced electricity and the ones who need electricity can buy it, whatever the finality.

Portugal and Spain have been integrating their electricity markets into one, the Iberian Electricity Market (MIBEL), based in a group of contracting modalities. They share a spot market operator, the OMIE, which operates since July 2007, and a forward market operator, the

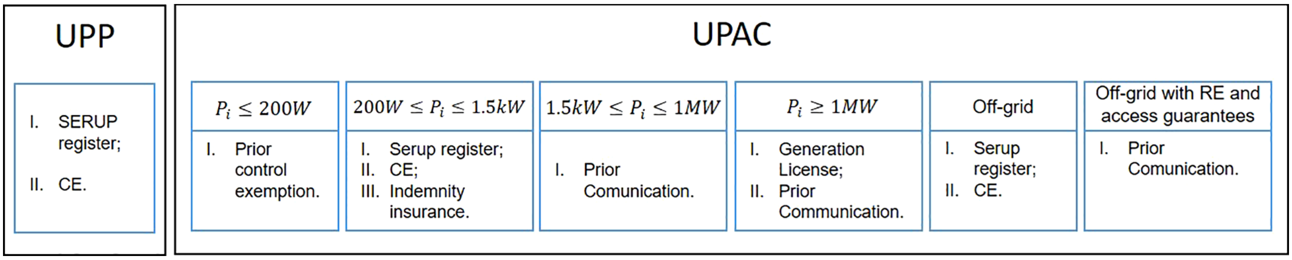


Fig. 1. Resume of DL 153/2015 regimes, the UPP and the UPAC.

OMIP, since July 2006. ERSE defines regulations: commercial relations, tariffs, service quality, network access, interconnections and networks operation. DGEG and independent regulatory entities are responsible by the regulation enforcement. REN owns and maintains on an exclusive basis the electricity transmission system in the Portuguese continent. The DSO of the high and medium voltage is EDP – Distribution SA and has the concession of most LV municipal distribution systems. In Azores the distribution operator is "Eletricidade dos Açores" (EDA), and in Madeira is "Empresa de Electricidade da Madeira" (EEM). Supply is carried out by several companies, the main supplier of last resort is EDP Serviço Universal in the continent, and in Azores and Madeira are the same as mentioned for distribution.

The electricity produced by Portugal is enough to meet the consumption needs, but for commercial reasons Portugal imports electricity from Spain. In 2017 Portugal imported 3,072 GWh, and the surplus production was exported to Spain. Natural gas and coal are the main fossil sources of energy generation in Portugal, nuclear does not exist and the RE production has increased in the last few years. [20]. Currently there are no support mechanisms for RE technologies, except for offshore wind and wave energy (new technologies) and small cogeneration.

On 30th November 2016, the European Commission published a proposal for a revised RE Directive with at least 27% renewables in the final energy consumption in the EU by 2030 is met. Recently, the European Union (EU) has settled at a 32% share of final energy consumption in 2030 as global leader.

In 2015 Portugal has presented a strategic plan, the "Green Growth Commitment 2030", which identifies the targets for 2030, namely 31% of RES in gross final energy consumption by 2020 and 40% by 2030. Portugal energy plan is currently set by PNAER 2020 (National Plan of Action for Renewable Energies 2013–2020), approved by Ministers' Council Resolution No. 20/2013 of April 10. Portuguese Government has committed internationally to reduce its greenhouse gases emissions to achieve carbon neutrality by 2050. This has risen as a form of a report "Roteiro para a Neutralidade Carbónica" – Carbon Neutrality Road Map.

Portuguese legislation framework

The current legislation in force regarding RE decentralized production is the Decree-Law 162/2019, which is in force since January 2020 [21]. This work is based on the previous regulation in force focused on self-consumption, the Decree-Law 153/2014 [22], given the current DL does not changed any of the obtained results on those regimes.

The law establishes the legal regimes of the RE self-consumption, considering two types – the UPP (Small Production Unit) – which includes the former micro and mini generation systems up to 250 kWp, and where the electricity production is exclusively sold to the grid operator, and the installation energy consumption is exclusively supplied by the public grid - and the UPAC (Self-Consumption Production Unit) – which considers the self-consumption based on renewable technologies, but making possible to sell to the grid the surplus energy generation. This law defines the licensing scheme, installation audits and paying regimes of the electricity sold to the grid. DL 153/2014 has established a distribution generation model, which promotes the decentralization – energy generation close to the consumption point -, the generation of energy by RE, the increase of the competition and the security in the supply, the reduction in peak power requirements, the encouragement of the PV industry growing as well as the communities. Given that this legal regime contextualizes the object of study in this work, the general regulation for the UPAC will be presented:

Table 1
Fee charges applicable to UPAC regime with and without grid injection, regarding the installed power in kW – DGEG (Portaria 14/2015) remuneration*.

Installed Power Capacity	UPAC charges with grid injection	UPAC charges without grid injection
< 1.5 kW	30 €	N/A
1.5 kW–5.0 kW	100 €	70 €
5 kW–100 kW	250 €	175 €
100 kW–250 kW	500 €	300 €
250 kW–1000 kW	750 €	500 €

*These fees are not charged; its end or great reduction is expected in future versions of the Portuguese legislation given the approved European Union Directive (RED II)[1], providing the exemption of fees and charges for small self-consumption facilities (up to 30 kW) and the possibility for communities to generate, store and sell the surplus generation.

- Connection maximum power must be ≤ 100% of the contracted power of the consumer installation;
- The generated electricity from the UPAC should be near to the consumption point in the installation;
- If it is connected to the electric grid, the instantaneous generation surplus can be sold to SLR;
- The consumer can install an UPAC for each electric installation, consume the generated energy or export its surplus to the grid. The Production Unit (UP) is installed in the same site of consumption. The consumer could have multiple registered UPs, although each installation is associated with a single UP.
- If a ≥ 1.5 kW UPAC is connected to the electric grid, the consumer is obliged to have a dedicated electricity metering equipment, to account the injected electricity.

If the UPAC installed power is higher than 1.5 kW and is connected to RESP, the consumer has a monthly fixed compensation for the first 10 years after receiving the certificate of exploitation (CE). The licensing process is made through electronic register in the SERUP site (UPs register), managed by the DGEG authority, and its summary is showed in Fig. 1. Table 1 presents the related fee charges.

Portuguese market energy prices and tariffs

For the case in which the generated energy by the UPAC is not fully self-consumed and is injected into the public grid (RESP), according to

[1] Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources.

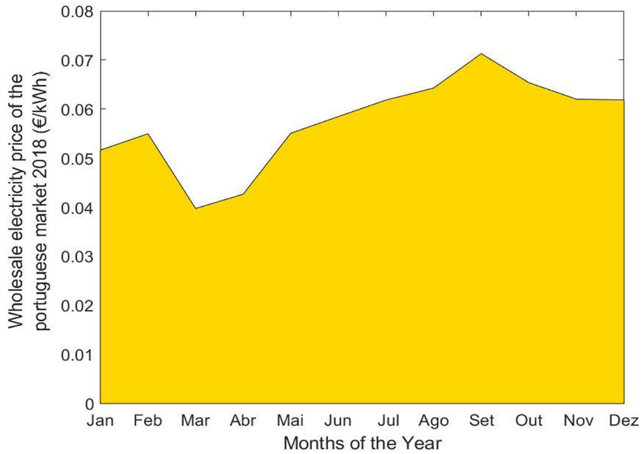


Fig. 2. Average monthly wholesale electricity prices of the year of 2018 for Portugal.

[22], the price of the electricity injected to the RESP is given by 90% of the average Iberian electricity market closing price, and can be expressed through Eq. (1),

$$R_{UPAC,m} = E_{supplied,m} \times OMIE_m \times 0.9 \quad (1)$$

where $R_{UPAC,m}$ is the sold energy price in €, in month m; the $E_{supplied,m}$ is the supplied energy in kWh, in month m; and the $OMIE_m$ is the average Iberian electricity gross market closing price (OMIE) for Portugal in €/kWh, in month m. The average monthly wholesale electricity prices for the year of 2018 are presented next, in Fig. 2, data made available by OMIE [23].

The grid electricity price in Portugal is structured with three tariff regimes, namely the flat, bi-hourly and tri-hourly tariffs. The flat tariff has a constant energy price throughout the day/week. Bi-hourly and tri-hourly tariffs distinguishes, respectively, two and three periods with different electricity price, attributing two or three electric tariffs, for off-peak and peak hours. For the bi-hourly and tri-hourly tariffs, two main variants exist, the daily cycles (Fig. 3) and the weekly cycles. The scheduling of these two tariffs is also different in daylight saving and winter-time, not just reflecting the legal time change adjustment.

The Portuguese continent has different electricity and contracted

Table 2
Flat and bi-hourly tariffs of EDP Comercial of the Portuguese continent and from EDA in the Azores, for the year of 2019.

Tariff	Flat		Bi-hourly			
Location	Évora/Porto	Azores	Évora/Porto		Azores	
Regime	Normal	Normal	Peak	Off-peak	Peak	Off-peak
Contracted Power (€/day)	0.2187	0.1648	0.2282	0.2282	0.1694	0.1694
Energy (€/kWh)	0.1493	0.1607	0.1867	0.1098	0.1908	0.1000

power prices than the island located installations. Reference prices can be obtained in [24,25], respectively, as shown in Table 2.

Portuguese residential average electricity load profiles

This study was performed using the average electricity load profiles for LV consumers provided by EDP Distribuição [26]. This DSO collects energy data from its clients at 15 min intervals, which made possible the estimation of the electric load for 2019, based on historical data from recent years. The Portuguese residential sector is supplied with low voltage (230/400 V AC); contracted power ≤13.8 kVA and annual electricity consumption (≤7140 kWh). The EDP Distribuição load profiles for this sector are plotted in Fig. 4.

Portuguese self-consumption PV installed capacity

As explained, the licensing scheme of most installations includes the production unit registry in the SERUP database [27], which has made available some data about the concluded and rejected RE installations. Regarding PV installations in the UPAC and prior communication (MCP) regimes, the data made available is from March to December of 2015, January to December of 2016 and from January to July of 2017. The correspondent data comprises 1843 UPAC installations with 95,995 MW and 12,363 MCP installations with 10,845 kW, comprising a total of 106,8 MW of installed power in Portugal, and can be observed in Fig. 5 and Fig. 6.

A domestic costumer with a suitable sized photovoltaic system in the UPAC regime produces energy and can use it to exclusively supply

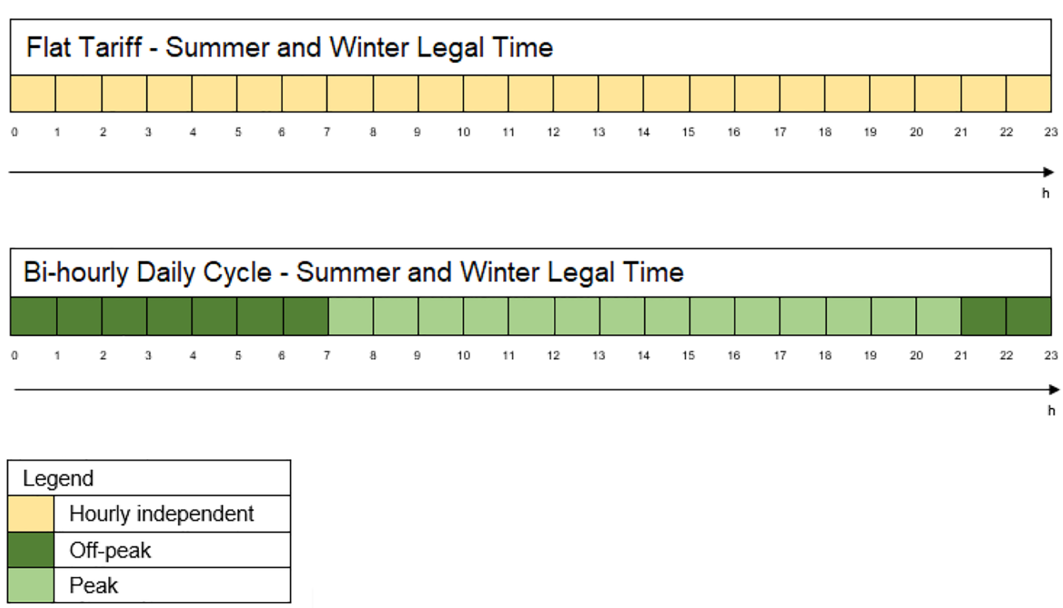


Fig. 3. Peak and off-peak periods of the daily cycles, indifferently for summer and winter legal times [24].

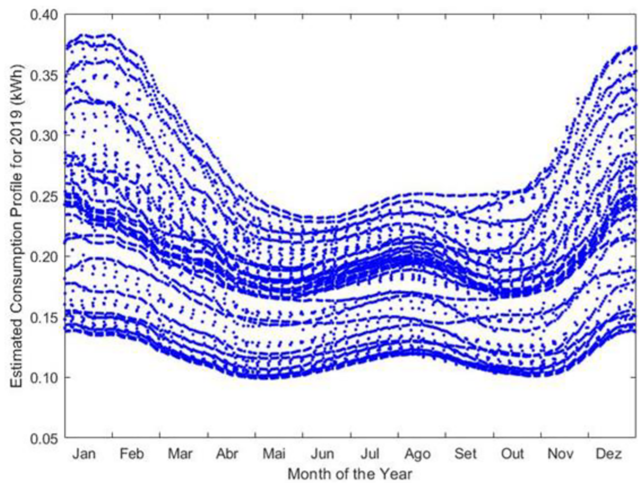


Fig. 4. Estimated electric domestic consumption profile of BTN C for 2019, made available by EDP Distribuição [26].

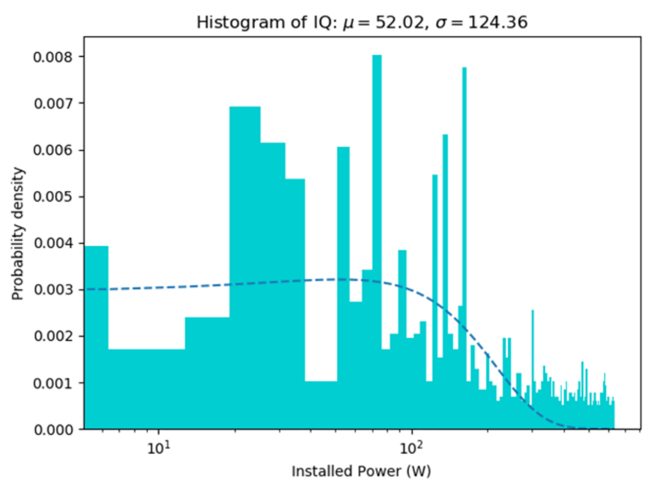


Fig. 5. Installed power distribution of the Portuguese UPAC registered installations from the available data of the SERUP database [27], with 100 bins.

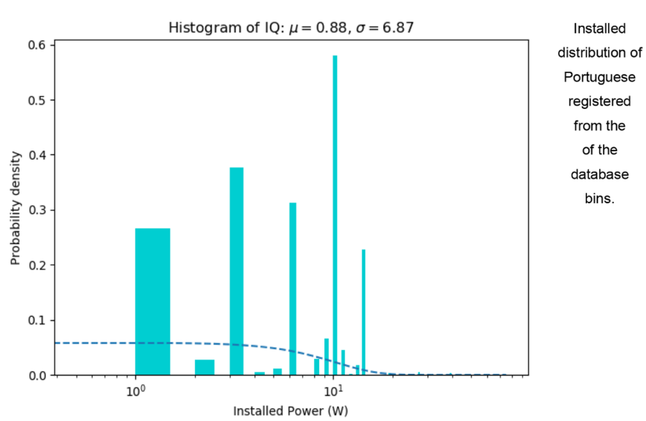


Fig. 6. Probability density of the logarithm MCP installed power (W), made available from the SERUP database [27], with 150 bins.

his loads, generally called exclusive self-consumption. Since the produced energy by the PV system is variable through the day, seasons and years, usually for the household consumption the electricity generated by the photovoltaic system has a surplus or is not enough to totally satisfy the domestic loads. In the first case, the energy surplus can be curtailed, injected into the grid, or stored in batteries for later

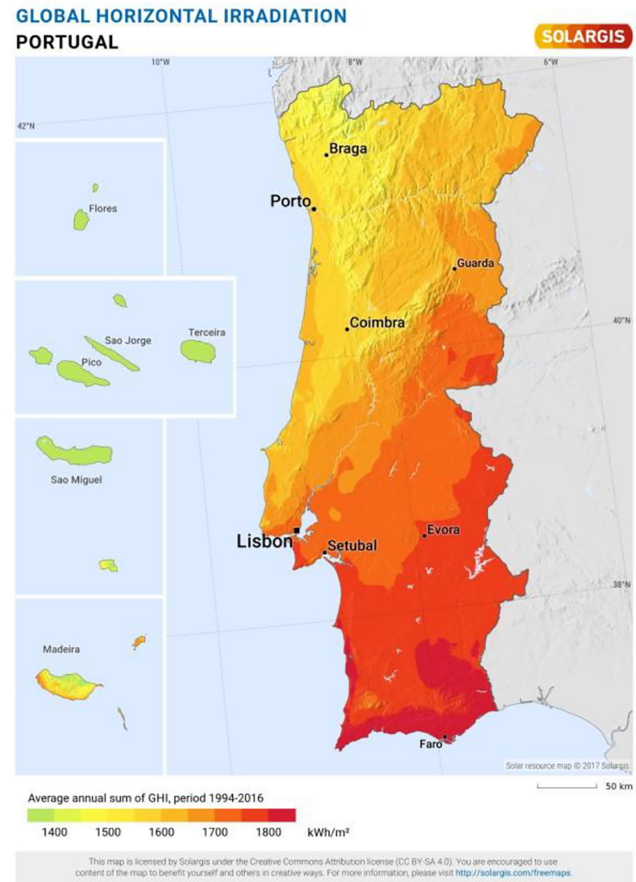


Fig. 7. Solar global horizontal irradiation (GHI) map of Portugal [37]

consumption. If the generated electricity is not enough to totally supply the loads, the resultant consumption needs must be supplied from the electric grid or from other energy source.

Portuguese solar radiation average annual availability

Three representative locations were chosen for this study: Évora, Porto and Azores island, which are showed in Fig. 7. Évora is in a region in the centre-south of Portugal, a city characterized by an average annual sum value of global horizontal irradiation (GHI) of 1846 kWh/m^2 [28], defined as one of the best locations regarding solar irradiation availability in the South of Europe. Porto is the second biggest city of the Portuguese continent, located in a northern coastal region of Portugal, with an average annual GHI of 1706 kWh/m^2 [28]. Azores is a Portuguese archipelago with nine islands and has an annual GHI of 1307 kWh/m^2 [28], and has different electricity tariffs from the continent.

Methodology

A technology project investment assessment is an annual investment analysis, considering all the relevant costs, revenues, taxes and rates. The objective of making a techno-economic analysis is the provision of relevant information to make a judgement or a decision [29]. Thus, this analysis aims, in the end, to find whether an investment in solar photovoltaic systems, with or without electricity storage, is profitable for the domestic end user in Portugal.

The analysis defines a lifetime of 25 years for the full system. The indicators [30] considered in this analysis are the Net Present Value (NPV), the Total Life Cycle Cost (TLCC), the Levelized Cost of Energy (LCOE), the Simple Payback Period (SPB), the Internal Rate of Return

(IRR) and the Benefit-to-Cost Ratio (B/C ratio). These indicators are presented in detail in the next section. Due to the importance of the techno-economic assessment in the decision-making process, the use of key indicators provides market accepted values recognized by the user.

This study intends to be a simplified analysis but taking into account sound and consistent data and consistent economic assumptions. An in-depth approach would require sensitivity analysis for some economic parameters, site-specific maintenance costs or energy losses (e.g. soiling) but requiring additional data is not currently available.

For each of the sites, a simulation in SISIFO [31] online simulator was carried out, considering south orientation and optimum inclination for each region, and the hourly irradiation for each month of the year was extracted. The average values were considered and used in the simulation tasks. The SISIFO software uses the PVGIS solar radiation and temperature database [28] for its simulations, as well as all the technical specifications for the selected PV modules (temperature constants, short-circuit current, open voltage, *etc.*) and inverter (efficiency curve for example) on each case.

The economic and energy analysis were made using the interactive computational software MATLAB.

Key indicators

The NPV examines the cash flows associated with a project, over its duration. It is the value in the base year (usually the present), and can be expressed as follows in Eq. (2),

$$NPV = \sum_{n=0}^{N} F_n/(1+d)^n \tag{2}$$

where F_n is the net cash flow, in year n; N is the period of the project; d is the annual discount rate. This parameter is generally recommended to evaluate the characteristics and decisions of the investment, and social costs. The NPV value can have some variations, as the calculus includes or not the after-taxes values and being in current or constant euros. If the NPV value is positive the project is considered economical and can be accepted; in contrast, if the NPV value is negative, the project is not economical, meaning that returns are worth less than the initial investment, being an indicator of a no-good decision. In theory, if the NPV value is null, the investor should be indifferent whether to accept the project or not. The applicability of this indicator should be carefully analysed, since these considerations are not valid for all applications.

The TLCC evaluates differences in costs and the timing of costs, between alternative projects. These costs are referred to the asset acquisition, costs in its life cycle or in the period of interest to the investor. Only the relevant costs are considered, and are discounted to a base year, recurring to the present value analysis. TLCC has three variations, considering no taxes, after tax deductions or before-tax revenue required. In this work, the more suitable form is the no taxes formula, adequate to residential/non-profit/government application, expressed in Eq. (3),

$$TLCC = I + PVOM \tag{3}$$

where I is the initial investment, and $PVOM$ is the present value of all O &M costs, as can be seen in Eq. (4).

$$PVOM = \sum_{n=1}^{N} O\&M_n/(1+d)^n \tag{4}$$

The LCOE is the cost of each unit of energy produced or saved by the system, over the period of the analysis, which will equal the TLCC, discounted back to the base year. In other words, it could be explained as the cost of one unit of energy, which is kept constant in the analysis period, that provide the same net present revenue as the NPV cost of the system. The levelized cost of energy is very useful to compare different scales of operation, investments and/or operating periods. There are many ways of calculating this parameter and the Eq. (5) will be used,

$$LCOE = TLCC/\left\{\sum_{n=1}^{N} [Q_n/(1+d)^n]\right\} \tag{5}$$

where Q_n is the energy output or saved in year n. In the case of PV + battery configurations, the analysis was carried out considering the Q_n value as the PV generation (energy output) plus the energy sent to the storage unit and effectively used (saved), in the year n.

The Internal Rate of Return (IRR) the rate at which the NPV of the future cash flow is set to zero. When applied, this rate brings the expenses values to the present, and make them equal to the return of the investment values. IRR obtained value is generally compared with a "hurdle rate". It allows the comparison between many different investment activities. The rate is given by Eq. (6).

$$IRR = \sum_{n=0}^{N} [F_n/(1+d)^n] = 0 = NPV \tag{6}$$

The SPB is a fast and simple way to compare investments. It is defined as the time (number of years) required for the net revenues associated with an investment of a certain project to be recovered, without accounting the time value of money. It could be described as Eq. (7) explicit.

$$\sum_n \Delta I_n \leq \sum_n \Delta S_n \tag{7}$$

where ΔI_n are the nondiscounted incremental investment costs (including incremental finance charges), and ΔS_n is the sum value of the annual cash flows net annual costs. One of the main disadvantages of using this parameter is the fact that it ignores the value of the money over the period, which implies that the investor doesn't have opportunity cost. It also ignores the returns after the payback year. On the other way, it is simple of calculate, implement and explain.

The Benefit-to-Cost Ratio (B/C ratio) ratio of the SUM of all discounted benefits accrued from an investment to the sum of dl associated discounted costs. It is used to discover at which level the benefits of a project exceed the costs. This indicator is generally used from a social perspective. It can be described in Eq. (8).

$$B/C = [PV(Allbenefits)]/[PV(Allcosts)] \tag{8}$$

where $[PV(Allbenefits)]$ is the present value of all positive cash flows, and the $[PV(Allcosts)]$ is the present value of all negative cash flows.

Energy indicators are studied for one complete year. The self-consumption rate (SCR) is a way of quantifying how much energy is generated and self-consumed locally. The SCR is generally given through the formula given by Eq. (9),

$$SCR = PV_{consumption}/PV_{generation} \tag{9}$$

where, $PV_{consumption}$ is the energy generated through the PV system which is self-consumed, and $PV_{generation}$ is the total generated energy from the PV system. The generated solar photovoltaic energy which is consumed is obtained through the subtraction of the "curtailment" losses or injected into the grid.

The self-supply rate (SSR) is an energetic indicator which quantifies the degree of autonomy from the grid, and is given by the following formula, given by Eq. (10),

$$SSR = PV_{consumption}/E_{Load} \tag{10}$$

where, E_{Load} is the energy load profile.The battery use (BU) can be described as a way of quantifying the usage of the battery, comparing the energy charged to the battery, and the energy load. This indicator can be given by the following expression, presented by Eq. (11),

$$BU = E_{Batterysent}/E_{Load} \tag{11}$$

where, $E_{Batterysent}$ is the energy sent to the battery, in kWh.

The saved money rate (SMR) quantifies the degree of autonomy from the grid in €. This indicator only makes sense to be calculated after the payback time break-even is achieved. The energy that was satisfied by the grid before the PV installation and now isn't – through self-consumption, charging/discharging the battery and injection into the grid – is quantified as money saved, as the Eq. (12) shows,

$$SMR = C_{savings}/C_{bill} \tag{12}$$

where $c_{savings}$, in €, is the money payed with the studied configuration, comparing with the C_{bill}, in €, which is the current electricity bill (only grid consumption), for each location and electricity tariff, for one year.

Studied scenarios

This work has the aim of comparing different photovoltaic system configurations (with/without storage), evaluating its economic feasibility in a variety of options. The analysis is made for the Portuguese residential figure characterized through the load profiles presented in section 1.5 and for a contracted power of 3.45 kVA. Four PV power installations are studied, namely 0.50 kWp, 0.75 kWp, 1.50 kWp and 3.45 kWp, either off-grid or grid-connected, for three different Portuguese locations – Évora, Porto and the Azores archipelago. The two chosen continental sites represent Portuguese regions with different solar resource potential and the Azores, a site with different characteristics (solar radiation, tariffs, etc.), located 1600 km West of Portugal, in the Atlantic Ocean. The chosen installed PV power (PV1 = 0.50 kW; PV2 = 0.75 kW; PV3 = 1.50 kW and PV4 = 3.45 kW) for the studied cases was considered the most relevant regarding the current legislation in Portugal (DL 153/2014). For each of these PV power chosen, two electricity tariffs were addressed - the flat tariff and the bi-hourly tariff, but only daily cycle was considered. Given that this work is focused in the residential sector, three different capacities for the batteries were selected: B1 = 3.3 kWh, B2 = 6.6 kWh and B3 = 9.9 kWh (specific battery parameters can be consulted in Table A1).

The present work has studied four main scenarios (Case I, II, III, IV), summarized in Table 3. All the different configurations (site location, tariff schedule, energy/power prices, PV power, battery capacity) are simulated for each case, when applicable.

- Case I – The domestic prosumer has a photovoltaic system used to perform exclusive self-consumption without energy storage. The surplus of the solar photovoltaic generated electricity is wasted. For the periods in which the photovoltaic generation is not enough to supply the consumer's load needs, being off-grid, the consumer will be without power supply (at night) and should do a careful load management.
- Case II – In this scenario, the prosumer's solar photovoltaic system is grid-connected, and self-consumption is used, without energy storage. The surplus of the generated electricity is sold to the grid. In the periods when the solar power is not enough to supply the loads, the prosumer consumes electricity from the grid.
- Case III – The domestic consumer has a photovoltaic system which performs self-consumption, being off-grid. The solar power surplus is stored in the battery. If the battery reaches its maximum state of charge, the surplus electricity is curtailed. For periods without enough solar radiation and with a depleted battery, being an off-grid system, energy/power constraints are similar to case I.
- Case IV – The prosumer has a grid-connected photovoltaic system and self-consumption is made. The surplus electricity is sent to the battery storage, which has priority over the injection into the grid. If the battery achieves the maximum state of charge, the surplus electricity is sold to the grid. In periods where the solar power is not enough to supply the loads and the battery is depleted, the prosumer uses electricity from the public grid.

The energy flow possibilities for the studied cases are presented in Fig. 8.

Cases III and IV simulate the use of a PV + battery setup. A simple demonstration of the solar photovoltaic energy flows in these scenarios for the 1.50 kW PV power installation in Évora is given in Fig. 9.

For these cases (III and IV) the energy management strategy used was the maximization of the self-consumption rate (SCR).

Economic parameters and assumptions

For each configuration, an investment assessment was carried out. Cases II and IV, the grid-connected photovoltaic configurations also consider the contracted power cost. The assessment is made considering general assumptions to all the cases, such as Capex, or macroeconomic parameters (inflation rate, etc.) which are given in Table 4. The system initial costs used are shown in Table 5.

Table 5 legend: Installed PV power (PV1 = 0.50 kW; PV2 = 0.75 kW; PV3 = 1.50 kW and PV4 = 3.45 kW); installed battery capacity (B1 = 3.3 kWh, B2 = 6.6 kWh and B3 = 9.9 kWh).

All the component prices were obtained from two main Portuguese suppliers and reflect the current real Portuguese market prices [32,33] for domestic systems, verified with a market price survey. Potential discounts associated with the purchase of multiple equipment, e.g. several microinverters, were not considered due to the high subjectivity associated with these commercial discounts. An average value for installation cost was also considered, which may have a substantial variability associated with the selected installer but will tend to be more homogeneous (and possibly lower) with the growth and increased competitiveness of the market. The photovoltaic module prices evolved rapidly in the last years, which justifies the use of the PV spot market prices, with small approximations reflecting the real costs in Portugal [34]. A remark must be made regarding the bidirectional wattmeter. EDP Distribuição is currently replacing the previous analogue wattmeter and deploying new digital versions with bidirectional metering capabilities, in all Portuguese territory, ensuring a 80% replacement rate until 2020 (European Union directive from 2009). In this way, present analysis ignored the bidirectional counter acquisition costs, obliged by DL 153/2014 whenever its applicable.

Lithium-Ion batteries were the selected battery technology, mainly to its efficiency, lowering costs and high energy density, becoming appropriate to domestic applications. The three battery capacity sizes have the same peak power of 3 kW.

Regarding the battery specifications, special attention must be given to its capacity lifetime degradation, depth of discharge and lifetime. To calculate the energy that is stored in the battery storage system and is then effectively used by the prosumer, some aspects were also

Table 3
Summary of the studied scenarios.

Case	Photovoltaic System		Grid Consumption		Storage		Surplus Electricity (Priority)		
	Off-grid	Grid-connected	Yes	No	Yes	No	Battery	Grid	Waste
I	x			x		x			x
II		x	x			x		x	
III	x			x	x		x		
IV		x	x		x		x		

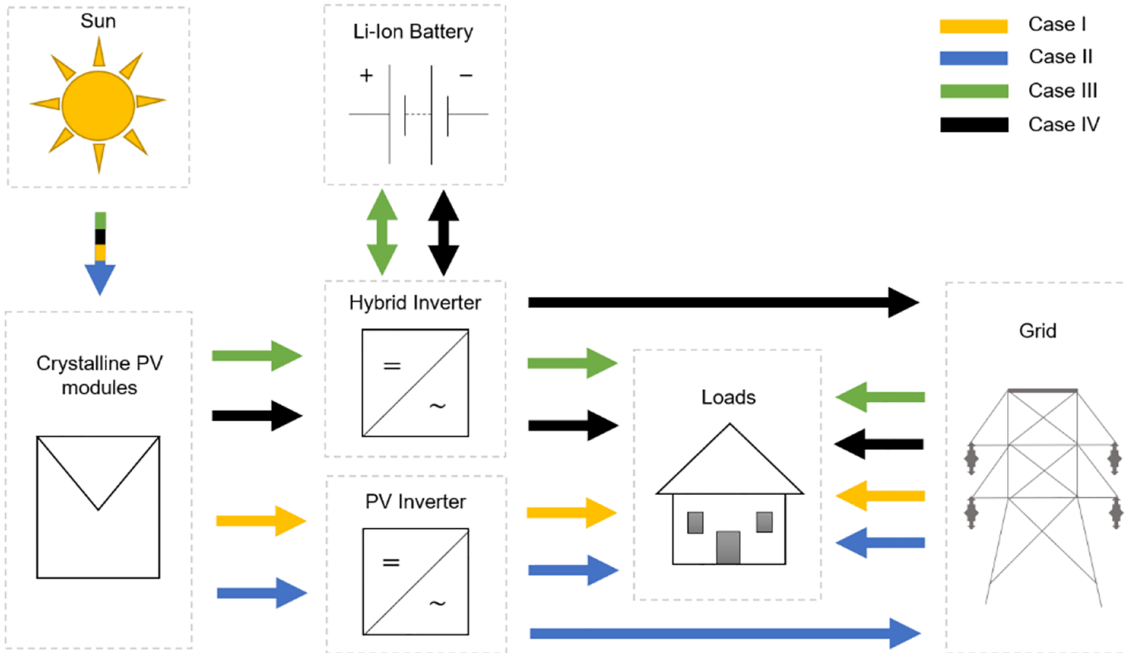


Fig. 8. Energy flows of the proposed scenarios.

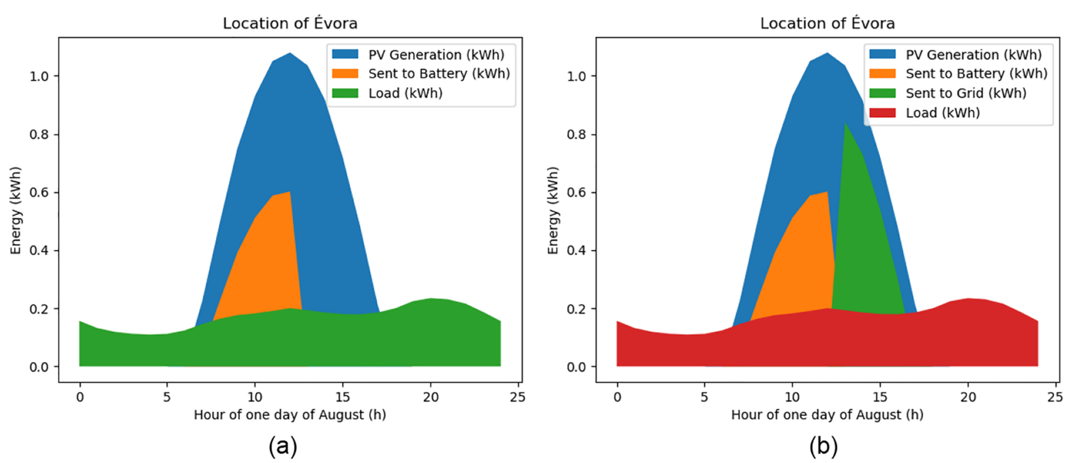


Fig. 9. Example of the Évora 1.50 kW PV installed power with the (a) Case III, energy stored with a 3.3 kWh battery, and (b) Case IV, energy stored to the 3.3 kWh battery and/or exchanged with the grid.

Table 4
General assumptions of the case study.

Variable	Value
Photovoltaic unit Power (Wp)	250
Photovoltaic Module (€/Wp)	0.35
Power of the Module in year 25 (%)	80
Battery Degradation Capacity (%/year)	2.0
Discount Rate (%)	3.0
Inflation Rate (%)	2.5

considered, as the power electronics efficiency, the battery efficiency (charge–discharge) the yearly battery capacity degradation and, finally, the depth of discharge.

The photovoltaic micro-inverters were chosen for some cases: the APS YC 500 micro-inverter (0.5 kW) and the APS 250 (0.25 kW nominal power). The selected hybrid inverter is the Solax SK-SU3000E X-HYBRID SERIES G2.

As a simplification and in order to be able to assign a value to the electricity in off-grid systems, it was considered for these installations the same energy cost and tariff structure as those connected to the grid.

As regards energy and power prices used, the grid electric energy and contracted power prices are from EDP Comercial company [35] (continent) and for the Azores island are used the EDA prices [25], as depicted in Table 2. The surplus energy, injected into the public grid, is valuated accordingly to the Equation (1) and the average monthly wholesale electricity prices for 2018 (Fig. 2).

Regarding the stored energy, it is valuated at the price on the moment of its usage, depending on the selected tariff schedule.

Generally, tariff peak periods are associated with higher prices, so that when sizing the batteries, special care must be given to the number of charge and discharge cycles over the lifetime of the battery and its discharged energy prices, lowering the Levelized Cost of Energy Stored (LCOES).

Results

In the following tables, the results are shown, with the best results highlighted with a blue coloured cell. Regarding these figures, the

Table 5
Components prices and considered rates, for the year of 2019.

	Case I				Case II				Case III				Case IV			
Identification	PV1	PV2	PV3	PV4	PV1	PV2	PV3	PV4	PV1	PV2	PV3	PV4	PV1	PV2	PV3	PV4
Structures (€)	50	50	200	300	50	50	200	300	50	50	200	300	50	50	200	300
Micro-Inverter or Inverter (€)	199	324	597	1393	199	324	597	1393	1833	1833	1833	1833	1833	1833	1833	1833
Cables and Others (€)	50	50	100	100	50	50	100	100	50	50	100	100	50	50	100	100
Installation (€)	100	150	200	300	100	150	200	300	100	150	200	300	100	150	200	300
Battery (€)	N/A				N/A				B1 – 1625€;B2 – 4060€;B3 – 5370€.				B1 – 1625€;B2 – 4060€;B3 – 5370€.			
Obligations fees by DL-153/2014 (€)	0	0	0	0	30	30	30	100	0	0	0	0	30	30	30	170

initial letter "F" corresponds to the flat tariff, and the letter "B" represents the bi-hourly tariff. In the payback presentation tables, "nan" values correspond to payback periods higher than 25 years (the considered project lifetime) and are interpreted as uninteresting results for the analysis.

Economic analysis

In order to improve the readability of this study, the results for the remaining key indicators are presented in the appendix section.

Energy analysis

The following tables present the energy analysis results. Regarding the SMR (Saved Money Rate) indicator the comparison case was the grid-connected (without battery or PV system), for all the four considered configurations (I to IV).

Discussion

As a general comment, cases I and II, which consider the PV-only configurations, are the most profitable. PV + battery configurations are already profitable in very specific conditions, and only with the configuration which has the highest PV power installation (3.45 kW), being slightly better with the bi-hourly tariff. The bi-hourly tariff is the most profitable electric tariff to use in all the cases. Generally, the Azores site configurations are the less profitable and the Évora site are the most profitable, mostly due to the available solar irradiation levels and consequently higher PV power generation. Although energy management strategies are relevant for PV + battery configurations profitability, the geographical location and electric tariff choice are essential factors in the configuration's economic and energetic viability. The 25 years analysis period considers the investment in two batteries units over that time period. This decision was made considering the useful lifecycle of the lithium-ion batteries available indicated in the consulted bibliography and warranty by the battery manufacturers.

In the following, the main three obtained economic indicators are discussed. Regarding NPV, the three locations have similar scenarios, in the sense of a go/no go decision regarding the investment, as can be observed in Fig. 10, Fig. 11 and Fig. 12. Case II is profitable in all configurations regardless of the electricity tariff or location, although in some locations this result is more positive than others. Including a battery is only economically viable when the generated PV energy is the biggest, namely in the IVB1 configuration with 3.45 kW installed PV power, and only for the by-hourly tariff. Case I presents one unviable project, the 3.45 kW size, regardless tariff, since the oversizing of the installation.

Payback time is depicted in Fig. 13, Fig. 14 and Fig. 15. As general remark, the payback time is positive for cases I and II, and mostly negative for cases III and IV. With the considered conditions, case III is unprofitable in all locations. This case doesn't consider the potential additional costs of a RESP connection, generally associated with off-grid connections (since off-grid configurations are usually characterized by being distant from the available grid point of connection), and which would have had impact in the economic indicators in all the studied locations. The best PV + battery scenario for the Évora site is the bi-

Table 6
Energetic analysis for the Évora site.

Installed PV Power (kW) / Parameters	SCR (Self-consumption Ratio)	SSR (Self-supply Ratio	BU (Battery Use)	SMR (Saved Money Rate)			
	Case I and Case II			Case I		Case II	
	Tariff independent			Flat	Bi-hourly	Flat	Bi-hourly
0.50	0.7601	0.3230	N/A	0.2439	0.2529	0.2713	0.2787
0.75	0.5797	0.3695	N/A	0.2790	0.2831	0.3506	0.3510
1.50	0.3238	0.4128	N/A	0.3117	0.3126	0.5413	0.5309
3.45	0.1450	0.4253	N/A	0.3211	0.3213	0.9884	0.9559
Installed PV Power (kW) / Parameters	SCR (Self-consumption Ratio)	SSR (Self-supply Ratio	BU (Battery Use)	Saved Money Rate (SMR) (€)			
				Flat	Bi-hourly	Flat	Bi-hourly
	Case III, Case IV	Case III	Case III, Case IV	Case III		Case IV	
0.50 B1	0.7601	0.3230	0.0697	0.2965	0.2814	0.2965	0.2814
0.50 B2	0.7601	0.3230	0.0697	0.2965	0.2814	0.2965	0.2814
0.50 B3	0.7601	0.3230	0.0697	0.2965	0.2814	0.2965	0.2814
0.75 B1	0.5797	0.3695	0.1833	0.4173	0.3961	0.4173	0.3961
0.75 B2	0.5797	0.3695	0.1833	0.4173	0.3961	0.4173	0.3961
0.75 B3	0.5797	0.3695	0.1833	0.4173	0.3961	0.4173	0.3961
1.50 B1	0.3238	0.4128	0.4388	0.6429	0.6101	0.7021	0.6662
1.50 B2	0.3238	0.4128	0.5760	0.7465	0.7084	0.7465	0.7084
1.50 B3	0.3238	0.4128	0.5760	0.7465	0.7084	0.7465	0.7084
3.45 B1	0.1450	0.4253	0.5341	0.7243	0.6874	1.1420	1.0837
3.45 B2	0.1450	0.4253	0.5747	0.7550	0.7164	1.0522	0.9985
3.45 B3	0.1450	0.4253	0.5747	0.7550	0.7164	0.9035	0.8574

Table 7
Energetic analysis for the location of Porto.

Installed PV Power (kW) / Parameters	SCR (Self-consumption Ratio)	SSR (Self-supply Ratio	BU (Battery Use)	SMR (Saved Money Rate)			
	Case I and Case II			Case I		Case II	
	Tariff independent			Flat	Bi-hourly	Flat	Bi-hourly
0.50	0.7901	0.2964	N/A	0.2238	0.2356	0.2448	0.2556
0.75	0.6070	0.3416	N/A	0.2579	0.2659	0.3165	0.3219
1.50	0.3489	0.3927	N/A	0.2965	0.2998	0.4906	0.4853
3.45	0.1569	0.4061	N/A	0.3066	0.3082	0.8852	0.8606
Installed PV Power (kW)/Parameters	SCR (Self-consumption Ratio)	SSR (Self-supply Ratio	BU (Battery Use)	Saved Money Rate (SMR)			
				Flat	Bi-hourly	Flat	Bi-hourly
	Case III, Case IV	Case III	Case III, Case IV	Case III		Case IV	
0.50 B1	0.7901	0.2964	0.0538	0.2644	0.2509	0.2644	0.2509
0.50 B2	0.7901	0.2964	0.0538	0.2644	0.2509	0.2644	0.2509
0.50 B3	0.7901	0.2964	0.0538	0.2644	0.2509	0.2644	0.2509
0.75 B1	0.6070	0.3416	0.1512	0.3720	0.3531	0.3720	0.3531
0.75 B2	0.6070	0.3416	0.1512	0.3720	0.3531	0.3720	0.3531
0.75 B3	0.6070	0.3416	0.1512	0.3720	0.3531	0.3720	0.3531
1.50 B1	0.3489	0.3927	0.3889	0.5901	0.5600	0.6338	0.6015
1.50 B2	0.3489	0.3927	0.5011	0.6748	0.6404	0.6748	0.6404
1.50 B3	0.3489	0.3927	0.5011	0.6748	0.6404	0.6748	0.6404
3.45 B1	0.1569	0.4061	0.5249	0.7028	0.6670	1.0599	1.0059
3.45 B2	0.1569	0.4061	0.5939	0.7550	0.7164	0.9545	0.9058
3.45 B3	0.1569	0.4061	0.5939	0.7550	0.7164	0.8825	0.8375

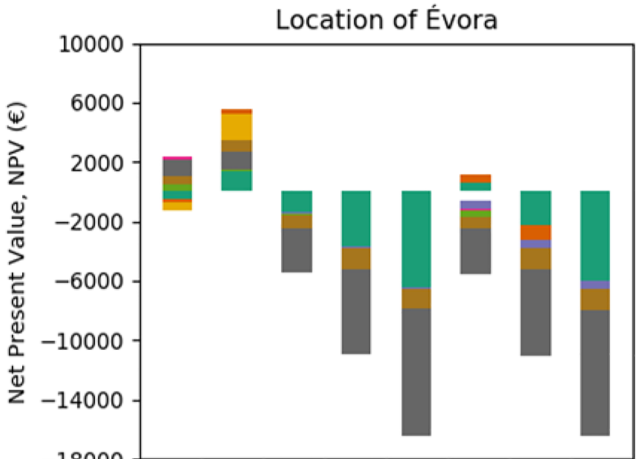
hourly tariff with 3.45 kW PV installation IVB1, although still considered slightly high − 16 years - compared with a 25 years investment. An interesting aspect is the difference between the obtained results of case IV in Évora, Porto, and in Azores, because of the different (higher) electricity tariff in this last location, and even though associated with the smallest solar resource, presents the worst scenarios, concluding that although having a higher electricity tariff still can't compensate the lowest solar irradiation. Case I average payback is 9.5 years for the location of Évora, 10 years for Porto and 9.8 years for Azores. Case II average payback is 7.8 years for Évora, 8.6 years for Porto and 9.0 years for Azores. This result shows that the grid-connected installations in Portugal have better payback, location independent, due to the increased income of selling the energy surplus to the grid. This means that in average, its 22% more economic to invest in a grid-connected installation (case II) in Évora, 16% in Porto and 9% in Azores.

Considering all sites, in some of the studied situations grid-parity is achieved, observing the obtained LCOE values (Fig. 16, Fig. 17 and Fig. 18). The lowest values, and so best results, are observed in cases I and II, for all PV configurations and all the locations. The use of the batteries presents positive economic interest in case IVB1 for the 3.45 kW PV installation. The lowest PV + battery energy profit occurs in Azores. The most striking economically unviable cases are the case scenarios IIIB3 and IVB3 0.50 kW, due to the low usage of the battery capabilities, and high cost (inexistence of a balanced trade-off). The same comment regarding the case III because of the absence of additional costs associated with the connections with RESP, related to off-grid configurations, which aren't considered in this work.

The IRR obtained results are presented in Table A2, Table A3 and Table A4, and a general comment can be done regarding the high obtained values in the unprofitable configuration's cases. The B/C ratio,

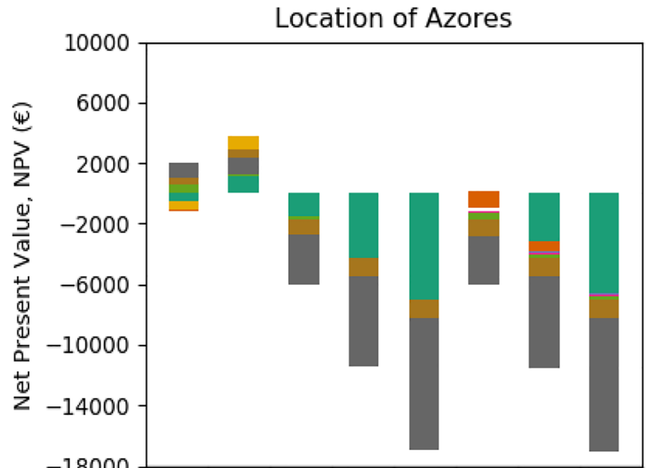
Table 8
Energetic analysis for the location of Azores.

Installed PV Power (kW)/Parameters	SCR (Self-consumption Ratio)	SSR (Self-supply Ratio	BU (Battery Use)	SMR (Saved Money Rate)			
	Case I and Case II			Case I		Case II	
	Tariff independent			Flat	Bi-hourly	Flat	Bi-hourly
0.50	0.8664	0.2829	N/A	0.2314	0.2449	0.2432	0.2568
0.75	0.6748	0.3305	N/A	0.2703	0.2789	0.3126	0.3223
1.50	0.3958	0.3877	N/A	0.3171	0.3177	0.4731	0.4789
3.45	0.1841	0.4147	N/A	0.3392	0.3368	0.8229	0.8375
Installed PV Power (kW) / Parameters	SCR (Self-consumption Ratio)	SSR (Self-supply Ratio	BU (Battery Use)	Saved Money Rate (SMR) (€)			
				Flat	Bi-hourly	Flat	Bi-hourly
	Case III, Case IV	Case III	Case III, Case IV	Case III		Case IV	
0.50 B1	0.8664	0.2829	0.0298	0.2558	0.2648	0.2558	0.2648
0.50 B2	0.8664	0.2829	0.0298	0.2558	0.2648	0.2558	0.2648
0.50 B3	0.8664	0.2829	0.0298	0.2558	0.2648	0.2558	0.2648
0.75 B1	0.6748	0.3305	0.1089	0.3594	0.3722	0.3594	0.3722
0.75 B2	0.6748	0.3305	0.1089	0.3594	0.3722	0.3594	0.3722
0.75 B3	0.6748	0.3305	0.1089	0.3594	0.3722	0.3594	0.3722
1.50 B1	0.3958	0.3877	0.3702	0.6199	0.6419	0.6339	0.6564
1.50 B2	0.3958	0.3877	0.4048	0.6482	0.6712	0.6482	0.6712
1.50 B3	0.3958	0.3877	0.4048	0.6482	0.6712	0.6482	0.6712
3.45 B1	0.1841	0.4147	0.5259	0.7693	0.7966	1.0368	1.0736
3.45 B2	0.1841	0.4147	0.5853	0.8179	0.8469	0.9732	1.0077
3.45 B3	0.1841	0.4147	0.5853	0.8179	0.8469	0.8543	0.8847



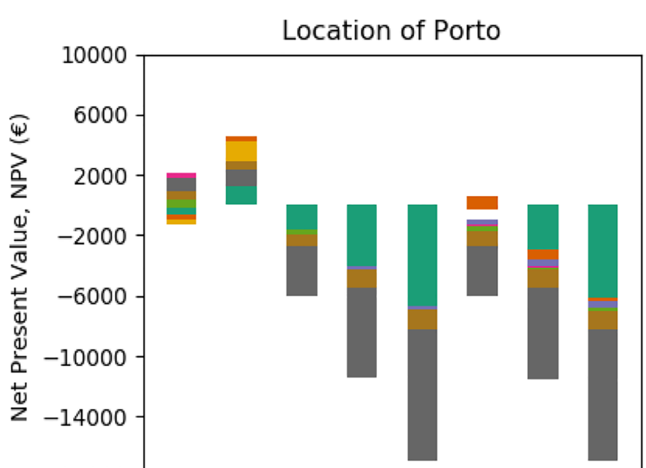
	I	II	III-B1	III-B2	III-B3	IV-B1	IV-B2	IV-B3
F_0.50 kW	1075	1230	-3041	-5773	-8504	-3071	-5803	-8534
F_0.75 kW	1050	1504	-2454	-5185	-7917	-2484	-5215	-7947
F_1.50 kW	485	2008	-1648	-3790	-6522	-1678	-3820	-6552
F_3.45 kW	-1217	3265	-2145	-4702	-7433	-2245	-4802	-7533
B_0.50 kW	1228	1382	-1506	-4237	-6969	-1255	-3987	-6718
B_0.75 kW	1181	1634	-1509	-4240	-6972	-1174	-3906	-6637
B_1.50 kW	606	2131	-1391	-3685	-6417	-590	-3283	-6015
B_3.45 kW	-1099	3393	-2008	-4610	-7341	1165	-2252	-5988

Fig. 10. Results of the NPV economic indicator for the 8th studied configurations, for the location of Évora.



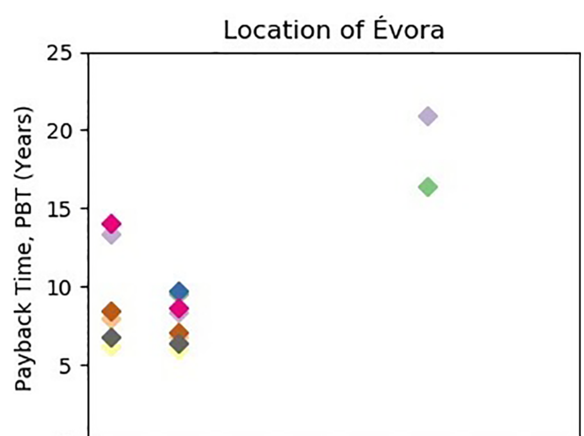
	I	II	III-B1	III-B2	III-B3	IV-B1	IV-B2	IV-B3
F_0.50 kW	1012	1063	-3263	-5994	-8726	-3293	-6024	-8756
F_0.75 kW	1017	1277	-2760	-5492	-8223	-2790	-5522	-8253
F_1.50 kW	552	1591	-1719	-4288	-7019	-1749	-4318	-7049
F_3.45 kW	-1063	2224	-1803	-4255	-6986	-1903	-4355	-7086
B_0.50 kW	1047	1096	-1536	-4268	-6999	-1304	-4036	-6767
B_0.75 kW	1010	1268	-1554	-4285	-7017	-1230	-3962	-6694
B_1.50 kW	481	1519	-1676	-4306	-7038	-1132	-3858	-6590
B_3.45 kW	-1159	2127	-2090	-4647	-7379	176	-3151	-6697

Fig. 12. Location of Azores NPV results, for each of the studied configurations.



	I	II	III-B1	III-B2	III-B3	IV-B1	IV-B2	IV-B3
F_0.50 kW	939	1051	-3245	-5977	-8709	-3275	-6007	-8739
F_0.75 kW	907	1274	-2734	-5466	-8197	-2764	-5496	-8227
F_1.50 kW	383	1665	-1965	-4214	-6946	-1699	-4244	-6976
F_3.45 kW	-1315	2568	-2282	-4717	-7449	-2382	-4817	-7549
B_0.50 kW	1105	1217	-1583	-4315	-7046	-1381	-4112	-6844
B_0.75 kW	1058	1427	-1597	-4328	-7060	-1319	-4051	-6782
B_1.50 kW	514	1806	-1629	-4002	-6734	-967	-3637	-6368
B_3.45 kW	-1192	2714	-2113	-4624	-7356	624	-2952	-6171

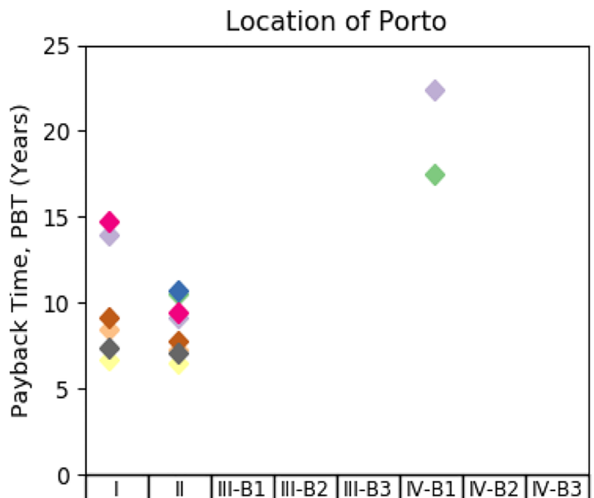
Fig. 11. Economic indicator NPV for the location of Porto, for all the studied configurations.



	I	II	III-B1	III-B2	III-B3	IV-B1	IV-B2	IV-B3
F_0.50 kW	6.8	6.4	nan	nan	nan	nan	nan	nan
F_0.75 kW	8.5	7.1	nan	nan	nan	nan	nan	nan
F_1.50 kW	14.1	8.6	nan	nan	nan	nan	nan	nan
F_3.45 kW	nan	9.7	nan	nan	nan	nan	nan	nan
B_0.50 kW	6.2	6.0	nan	nan	nan	nan	nan	nan
B_0.75 kW	8.0	6.7	nan	nan	nan	nan	nan	nan
B_1.50 kW	13.4	8.4	nan	nan	nan	21.0	nan	nan
B_3.45 kW	nan	9.5	nan	nan	nan	16.5	nan	nan

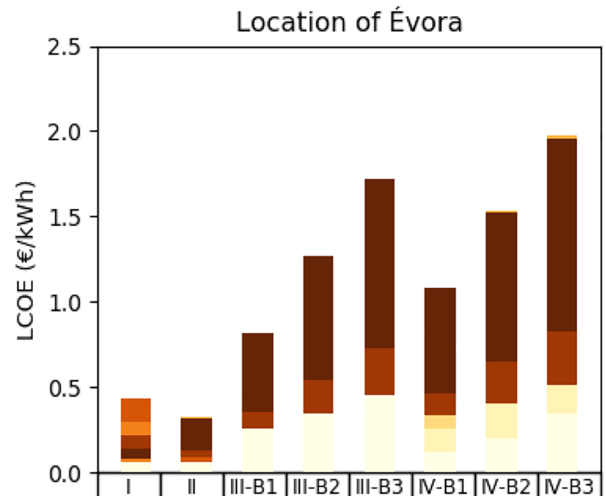
Fig. 13. Results of the PBT, for the location of Évora, for the configurations studied.

present in Table A5, Table A6 and Table A7, and the higher value, the better project viability. The indicator corroborates the three main discussed economic indicators in this analysis. The energy analysis made, presented in Table 6, Table 7 and Table 8 allows a more detailed analysis of the generated energy use. The SCR decreases with the increase of the PV installed power, which confirms the existing trade-off between PV generation and effective consumption of this energy. SCR indicator is showing how much of the produced energy is effectively self-consumed and is always dependent of the load diagram and PV generation. In Évora case I, SCR is lower than the one in Porto, and Azores has the highest because the PV generation is the lowest, so the energy ratio is more influenced, compared to the other locations. SSR increases with the increase of the PV installed power, because the



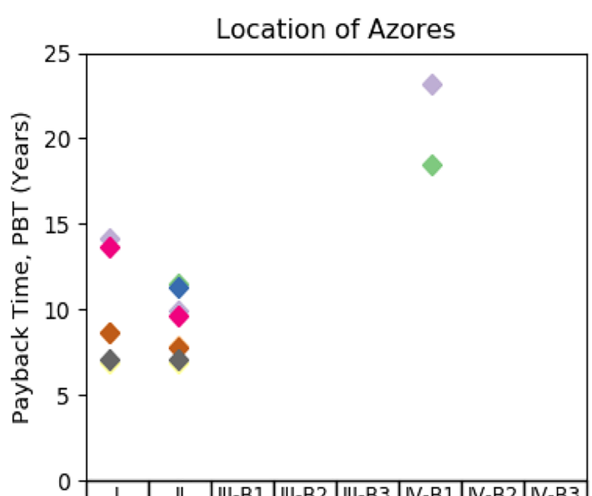
	I	II	III-B1	III-B2	III-B3	IV-B1	IV-B2	IV-B3
F_0.50 kW	7.3	7.1	nan	nan	nan	nan	nan	nan
F_0.75 kW	9.2	7.8	nan	nan	nan	nan	nan	nan
F_1.50 kW	14.7	9.5	nan	nan	nan	nan	nan	nan
F_3.45 kW	nan	10.8	nan	nan	nan	nan	nan	nan
B_0.50 kW	6.7	6.5	nan	nan	nan	nan	nan	nan
B_0.75 kW	8.5	7.3	nan	nan	nan	nan	nan	nan
B_1.50 kW	13.9	9.1	nan	nan	nan	22.4	nan	nan
B_3.45 kW	nan	10.5	nan	nan	nan	17.5	nan	nan

Fig. 14. Results of the PBT for all the configurations studied, for the location of Porto.



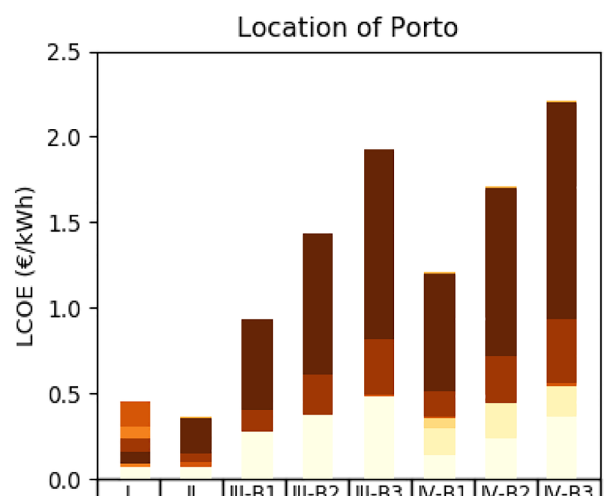
	I	II	III-B1	III-B2	III-B3	IV-B1	IV-B2	IV-B3
F_0.50 kW	0.06	0.18	0.47	0.73	0.99	0.62	0.87	1.13
F_0.75 kW	0.08	0.13	0.35	0.54	0.73	0.46	0.65	0.83
F_1.50 kW	0.14	0.09	0.26	0.34	0.45	0.33	0.40	0.51
F_3.45 kW	0.29	0.06	0.27	0.37	0.48	0.34	0.43	0.54
B_0.50 kW	0.06	0.18	0.47	0.73	0.99	0.62	0.88	1.14
B_0.75 kW	0.08	0.14	0.35	0.54	0.73	0.46	0.65	0.84
B_1.50 kW	0.14	0.09	0.26	0.34	0.45	0.26	0.40	0.51
B_3.45 kW	0.29	0.06	0.27	0.37	0.48	0.12	0.20	0.34

Fig. 16. Results of the LCOE for the location of Évora, for the studied configurations.



	I	II	III-B1	III-B2	III-B3	IV-B1	IV-B2	IV-B3
F_0.50 kW	7.0	7.0	nan	nan	nan	nan	nan	nan
F_0.75 kW	8.6	7.8	nan	nan	nan	nan	nan	nan
F_1.50 kW	13.7	9.7	nan	nan	nan	nan	nan	nan
F_3.45 kW	nan	11.3	nan	nan	nan	nan	nan	nan
B_0.50 kW	6.9	6.9	nan	nan	nan	nan	nan	nan
B_0.75 kW	8.7	7.8	nan	nan	nan	nan	nan	nan
B_1.50 kW	14.1	9.9	nan	nan	nan	23.2	nan	nan
B_3.45 kW	nan	11.5	nan	nan	nan	18.4	nan	nan

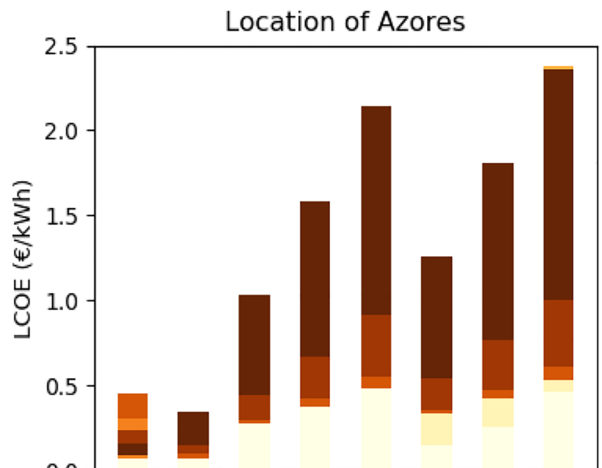
Fig. 15. Obtained results of the PBT economic indicator for all the studied configurations, for the region of Azores.



	I	II	III-B1	III-B2	III-B3	IV-B1	IV-B2	IV-B3
F_0.50 kW	0.07	0.20	0.53	0.82	1.11	0.69	0.98	1.27
F_0.75 kW	0.09	0.15	0.40	0.61	0.82	0.51	0.72	0.93
F_1.50 kW	0.15	0.10	0.28	0.37	0.49	0.36	0.44	0.56
F_3.45 kW	0.30	0.07	0.28	0.37	0.48	0.35	0.44	0.54
B_0.50 kW	0.07	0.21	0.53	0.82	1.11	0.69	0.98	1.27
B_0.75 kW	0.09	0.15	0.40	0.61	0.82	0.52	0.73	0.94
B_1.50 kW	0.15	0.10	0.28	0.37	0.49	0.29	0.44	0.56
B_3.45 kW	0.30	0.07	0.28	0.37	0.48	0.14	0.24	0.36

Fig. 17. Results of the LCOE for the location of Porto, for the studied configurations.

biggest the PV generated electricity, the biggest the consumed energy, and considering the energy load constant. The BU indicator helps in the evaluation of need of a battery system, and its value is high when its use is high. In the cases III and IV, the BU indicator confirms that the 0.50 kW and 0.75 kW PV installed power, the PV generation is too low to justify a battery acquisition, so its size is irrelevant in the final gross of energy, in the three locations. With the 1.50 kW and 3.45 kW PV installed power, the use of the battery increases a lot and helps the energy independency. For most of the locations, SMR is smaller for the



	I	II	III-B1	III-B2	III-B3	IV-B1	IV-B2	IV-B3
F_0.50 kW	0.07	0.19	0.59	0.91	1.23	0.72	1.04	1.36
F_0.75 kW	0.09	0.15	0.44	0.67	0.91	0.54	0.77	1.00
F_1.50 kW	0.15	0.10	0.29	0.42	0.55	0.35	0.47	0.61
F_3.45 kW	0.30	0.07	0.28	0.37	0.48	0.33	0.42	0.53
B_0.50 kW	0.07	0.19	0.59	0.91	1.23	0.72	1.04	1.37
B_0.75 kW	0.09	0.15	0.44	0.67	0.91	0.54	0.77	1.01
B_1.50 kW	0.15	0.10	0.29	0.42	0.55	0.33	0.47	0.61
B_3.45 kW	0.30	0.07	0.28	0.37	0.48	0.15	0.26	0.46

Fig. 18. Obtained LCOE results for the location of Azores, for all the studied configurations.

Table A1
Lithium-ion battery characterization data, given by the manufacturer [36].

Battery Identification	B1 (3.0 kW/3.3 kWh)
Model	METERBOOST-48-LTO6-3.3
Nominal Voltage (V)	48.0
Maximum/minimum Voltage (V)	32.0–58.4
Nominal Capacity (Ah)	63
Nominal Capacity (kWh)	3.3
Nominal Power (kW)	3.0
Weight (Kg)	17
Length × Width × Height (mm)	430x360x76
Useful lifecycle (years)	greater than17

bi-hourly tariff cases. This indicator compares the energy saved with the current configuration, considering the energy prices at which the electricity is effectively sold, and the electricity bill, in one year, after the payback achievement. The relevance of the introduction of this indicator is mostly to represent the major differences among the use of different electric prices and different electric companies' prices of the contracted power and of energy (EDP commercial and EDA). The fact that Azores has a distinct tariff is well observed in the SMR indicator, because it has the lowest PV generation, but the highest remuneration for the energy makes it have some of the best SMR values. For the case IV, it is noticeable that values above the unity means that one is earning money with the configuration, even though the configuration is already paid. The 23rd article of the DL 153/2014 doesn't establish a limit for the UPAC's injection in RESP, so this configuration is very interesting. The biggest differences between cases III and IV is prominent in the higher PV installed power, as the grid injection remuneration is very low.

Conclusion

The main aim of this study was the evaluation of the viability of different solar PV configurations in different situations. Four cases were investigated, two cases with PV-only configurations, differing from each other by the injection of the surplus to the grid, and two PV + battery configurations which differ also from the injected surplus, and the inclusion of batteries. The most profitable PV-only configurations for the locations of Évora, Porto and Azores is the case II (0.50 kW PV power with bi-hourly tariff). These are followed in a general way by case I (0.50 kW PV power). The most profitable PV + battery configuration for Évora, Porto and Azores is case IVB1 (3.45 kW PV installed power + 3.3 kWh battery). Although these are very positive results from a PV-only configuration perspective, most of the studied cases of PV + battery are not profitable, but the scenario shows a very positive future perspective. The bi-hourly tariff presents better results, with the used load profile, which doesn't have a profile with striking load variations. The energy management strategy used in this study was the simplest, but the usage of an intelligent energy management strategy can, by itself, improve the results obtained in this study, particularly considering a multi optimization strategy.

Current average price of the batteries considered in this study is 492 €/kWh, which is still a very high value, and makes the CAPEX of the PV + battery configuration a competitive value, compared with other alternatives. Further decrease of the battery costs which are expected in the following years will be needed to improve the profitability of PV residential applications, although this study is a remark of that beginning. Independent of the technology chosen, battery energy storage has been quickly evolving, with technical improvements being achieved, as for the capacity, performance, efficiency and the response that manufacturers are giving to the market.

All the configurations implemented self-consumption, considered to be the current most adequate context to implement PV solar energy in Portugal in the residential sector, regarding the Portuguese legislation. A revision of the current DL is ongoing due to the evolution that PV technology and batteries have been showing since 2014 (year of the DL

Table A2
Results of the Internal Rate of Return economic indicator, for the studied configurations cases, for the location of Évora.

Location of Évora								
Electric Tariff	Flat				Bi-hourly			
Configuration	0.5	0.75	1.5	3.45	0.5	0.75	1.5	3.45
I	13.0	8.41	−2.42	−188	14.7	9.65	−1.17	−115
II	14.0	12.0	8.08	5.78	15.6	13.0	8.69	6.13
IIIB1	−200	−199	−194	−194	−196	−195	−78.0	−193
IIIB2	−202	−202	−200	−200	−201	−201	−200	−200
IIIB3	−203	−203	−202	−201	−202	−202	−202	−201
IVB1	−200	−199	−194	−195	−106	−60.1	−19.0	−4.66
IVB2	−202	−202	−200	−199	−201	−200	−199	−85.6
IVB3	−203	−203	−202	−201	−202	−202	−201	−200

Table A3
Obtained results regarding the IRR economic indicator, for the studied configurations cases, for the location of Porto.

Location of Porto								
Electric Tariff	Flat				Bi-hourly			
Configuration	0.5	0.75	1.5	3.45	0.5	0.75	1.5	3.45
I	11.3	6.96	−3.60	−191	13.3	8.49	−2.11	−187
II	12.0	10.1	6.27	3.72	13.9	11.4	7.04	4.17
IIIB1	−201	−200	−196	−195	−196	−196	−194	−194
IIIB2	−203	−202	−200	−200	−201	−201	−200	−200
IIIB3	−203	−203	−202	−201	−202	−202	−202	−201
IVB1	−201	−200	−194	−195	−194	−120	−29.5	−7.12
IVB2	−203	−202	−200	−198	−201	−201	−199	−196
IVB3	−203	−203	−202	−201	−202	−202	−201	−200

Table A4
Internal Rate of Return economic indicator results, for the studied configurations cases, for the location of Azores.

Location of Azores								
Electric Tariff	Flat				Bi-hourly			
Configuration	0.5	0.75	1.5	3.45	0.5	0.75	1.5	3.45
I	12.2	8.08	−1.71	−83.4	12.63	8.02	−2.46	−184
II	12.2	10.1	5.86	2.58	12.56	10.04	5.44	2.24
IIIB1	−201	−200	−195	−134	−196	−195	−194	−194
IIIB2	−203	−202	−200	−199	−201	−201	−200	−200
IIIB3	−203	−203	−202	−201	−202	−202	−202	−201
IVB1	−201	−200	−194	−191	−162	−74.19	−38.4	−9.72
IVB2	−203	−202	−200	−199	−201	−200	−200	−197
IVB3	−203	−203	−202	−201	−202	−202	−202	−201

Table A5
Obtained results of the Benefit-to-Cost Ratio economic measure, for each of the studied configurations, for the location of Évora.

Location of Évora								
Electric Tariff	Flat				Bi-hourly			
Configuration	0.5	0.75	1.5	3.45	0.5	0.75	1.5	3.45
I	4.35	3.42	1.97	0.97	4.76	3.65	2.08	1.02
II	1.34	1.54	1.78	2.07	1.41	1.58	1.80	2.08
IIIB1	0.59	0.79	1.07	1.02	1.06	1.07	1.14	1.05
IIIB2	0.38	0.51	0.83	0.75	0.68	0.70	0.85	0.77
IIIB3	0.28	0.38	0.62	0.58	0.50	0.52	0.64	0.59
IVB1	0.45	0.61	0.85	0.83	0.87	0.90	1.07	1.45
IVB2	0.32	0.43	0.70	0.64	0.61	0.64	0.78	0.99
IVB3	0.25	0.33	0.55	0.51	0.47	0.50	0.61	0.68

Table A6
Results of the BC Ratio, for each of the studied configurations, for the location of Porto.

Location of Porto								
Electric Tariff	Flat				Bi-hourly			
Configuration	0.5	0.75	1.5	3.45	0.5	0.75	1.5	3.45
I	3.99	3.16	1.87	0.93	4.43	3.43	2.00	0.98
II	1.21	1.39	1.61	1.86	1.29	1.45	1.64	1.88
IIIB1	0.53	0.71	0.99	0.99	1.03	1.04	1.08	1.03
IIIB2	0.34	0.46	0.75	0.75	0.67	0.68	0.79	0.76
IIIB3	0.25	0.34	0.57	0.58	0.49	0.50	0.59	0.59
IVB1	0.41	0.55	0.78	0.80	0.84	0.87	0.99	1.35
IVB2	0.29	0.39	0.64	0.64	0.59	0.62	0.72	0.89
IVB3	0.22	0.30	0.50	0.51	0.46	0.48	0.57	0.66

Table A7
Results of the Benefit-to-Cost Ratio, for the location of Azores, for the studied configurations.

Location of Azores								
Electric Tariff	Flat				Bi-hourly			
Configuration	0.5	0.75	1.5	3.45	0.5	0.75	1.5	3.45
I	4.19	3.36	2.03	1.04	4.28	3.34	1.96	1.00
II	1.48	1.64	1.78	1.89	1.48	1.61	1.72	1.84
IIIB1	0.52	0.70	1.05	1.10	1.05	1.05	1.06	1.03
IIIB2	0.34	0.46	0.74	0.82	0.68	0.69	0.73	0.76
IIIB3	0.25	0.34	0.56	0.64	0.50	0.51	0.55	0.59
IVB1	0.43	0.57	0.87	0.93	0.91	0.94	1.01	1.33
IVB2	0.30	0.40	0.65	0.73	0.63	0.66	0.72	0.90
IVB3	0.23	0.31	0.50	0.58	0.48	0.50	0.56	0.62

prevalence), following the example of different and more profitable residential schemes, as net-metering or community sharing PV generation, from an economic, energetic and social well-being point of view.

CRediT authorship contribution statement

Ana Foles: Conceptualization, Software, Validation, Writing - original draft. **Luís Fialho:** Conceptualization, Methodology, Writing - review & editing, Supervision, Funding acquisition. **Manuel Collares-Pereira:** Resources, Supervision, Project administration.

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.

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References

[1] IEA-ETSAP and IRENA, "Renewable Energy Integration in Power Grids, Technology Brief," 2015.
[2] SolarPowerEurope, "Global Market Outlook for Solar Power 2017-2021," 2017.
[3] N. Omar, "Future and Emerging Technologies, Workshop on Future Battery Technologies for Energy Storage," The Publications Office of the European Union, 2018.
[4] L. Goldie-Scot, "BloombergNEF," [Online]. Available: https://about.bnef.com/blog/behind-scenes-take-lithium-ion-battery-prices/.
[5] IEA, "International Energy Agency," 2019. [Online]. Available: https://www.iea.org/policies?q=.
[6] P. S. Molina, "pv magazine," 2019. [Online]. Available: https://www.pv-magazine.com/2019/04/08/spains-new-rules-for-self-consumption-come-into-force/.
[7] E. Bellini, "pv magazine," [Online]. Available: https://www.pv-magazine.com/2019/04/08/italy-offers-incentives-for-evs/.
[8] G. Lorenzi, R. d. S. Vieira, C. A. S. Silva and A. Martin, "Techno-economic analysis of utility-scale energy storage in island settings," Journal of Energy Storage, pp. 691-705, 2019.
[9] Dhundhara S, Vermaa YP, Williams A. Techno-economic analysis of the lithium-ion and lead-acid battery inmicrogrid systems. Energy Convers Manage 2018;177:122–42.
[10] A. Lahnaoui, P. Stenzel and J. Linssen, "Techno-economic analysis of photovoltaic battery system configuration and location," Applied Energy, pp. 497-505, 2018.
[11] Shaw-Williams D, Susilawati C, Walker G. Value of residential investment in photovoltaics and batteries in networks: A techno-economic analysi. Energies 2018.
[12] Tervo E, Agbim K, DeAngelis F, Hernandez J, Kim HK, Odukomaiya A. An economic analysis of residential photovoltaic systems with lithium ion battery storage in the United States. Renew Sustain Energy Rev 2018:1057–66.
[13] F. Cucchiella, I. D'Adamo and M. Gastaldi, "Photovoltaic energy systems with battery storage for residential areas: an economic analysis," Journal of Cleaner Production, pp. 460-474, 2016.
[14] Abdin GC, Noussan M. Electricity storage compared to net metering in residential PV applications. J Cleaner Prod 2018;176:175–86.
[15] Camilo FM, Castro R, Almeida M, Pires VF. Economic assessment of residential PV systems with self-consumption and storage in Portugal. Sol Energy 2017;150:353–62.
[16] Villar CH, Neves D, Silva CA. Solar PV self-consumption: An analysis of influencing indicators in the Portuguese context. Energy Strategy Reviews 2017;18:224–34.
[17] Solano J, Brito M, Caamaño-Martín E. Impact of fixed charges on the viability of self-consumption photovoltaics. Energy Policy 2018;122:322–31.
[18] Martín JR. Exclusive: Portugal in energy storage push as PV auction calendar builds. PVTECH 2019.
[19] E. Bellini, "pv magazine," 2019. [Online]. Available: https://www.pv-magazine.com/2019/04/11/edp-to-build-portugals-first-mw-sized-pv-plant-coupled-with-storage/.
[20] M. C. Pacheco and J. M. Mendes, "Electricity Regulation in Portugal: overview, Practical Law Country Q&A 6-564-1565," Thomson Reuters, 2019.
[21] República Portuguesa, Decreto-Lei n.o 162/2019 de 25 de outubro. Aprova o regime jurídico aplicável ao autoconsumo de energia renovável, transpondo parcialmente a Diretiva 2018/2001, 2019.
[22] O. d. T. e. E. Ministério do Ambiente, Diário da República, 1.ª série — N.° 202 — 20 de outubro de 2014, 2014.
[23] OMIE, "OMIE," 2019. [Online]. Available: http://m.omie.es/reports/index.php?m=yes&report_id=311#.
[24] EDPComercial, 2019. [Online]. Available: https://www.edp.pt/particulares/apoio-cliente/perguntas-frequentes/tarifarios/o-que-preciso-de-saber-para-contratar/o-que-e-a-opcao-horaria-e-qual-a-melhor-para-mim/faq-4823.
[25] EDA, "Períodos e Horários," 2018.
[26] EDPDistribuição, 2019. [Online]. Available: https://www.edpdistribuicao.pt/pt-pt/perfis-de-consumo.
[27] DGEG, "Direcção-Geral de Energia e Geologia," 2019. [Online]. Available: http://www.dgeg.gov.pt/.
[28] EC, "PVgis," [Online]. Available: http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php#.
[29] Short W, Packey DJ, Holt T. A manual for the economic evaluation of energy efficiency and renewable energy technologies. NREL 1995.
[30] Short D, Packey JD, Holt T. A manual for the economic evaluation of energy efficiency and renewable energy technologies. NREL 1995.
[31] "Sisifo," [Online]. Available: https://www.sisifo.info/pt/default.
[32] "Ecosist," 2019. [Online]. Available: https://www.ecosist.net/.
[33] SolarImpact, "SolarImpact," 2019. [Online]. Available: https://loja.solarimpact.pt/.
[34] M. Schachinger, "pv magazine," [Online]. Available: https://www.pv-magazine.com/features/investors/module-price-index/.
[35] ERSE, "Tarifas e Preços para a Energua Elétrica e outros serviços 2019," Lisboa, 2018.
[36] "METERBOOST Datasheet," Lisbon, 2019.
[37] SolarGIS, 2019. [Online]. Available: https://solargis.com/maps-and-gis-data/download/portugal.