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Technical-Economic Evaluation of Residential Wind and Photovoltaic Systems with Self-Consumption and Storage Systems in Portugal

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Abstract: At present, a worldwide paradigm shift has become apparent, with more and more consumers consuming the energy generated by renewable energy sources (RES) systems, such as wind or photovoltaic (PV) energy, sometimes benefiting from appropriate incentives by individual governments. Consequently, it is necessary to carry out technical–economic assessments to understand the evolution of the viability of RES investments. Within the framework of an intelligent network control environment, the smart grid (SG) concept is associated with this model, and is an important tool in the management of energy distribution networks. This article aims to make a further contribution to this issue by analyzing the economic feasibility of investing in residential consumers, considering different RES configurations. Scenarios covered in this study include: "inject all on the low voltage network/consume all on the low voltage network", self-consumption, net-metering, and storage systems. The economic study results in this article show that self-consumption with and without the injection of excess electricity into the grid is quite attractive. The bi-hourly tariff was found to be more profitable than other tariffs. Variable tariffs (bi or tri-hourly) are more profitable than fixed tariffs. It is also concluded that investment in storage systems is not yet an economically viable solution due to the high price of energy storage.

Keywords: residential PV systems; residential wind systems; self-consumption; battery systems; economic evaluation

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1. Introduction

The paradigm of power generation has changed globally, with more and more users consuming more power, which is generated by RES systems. Consequently, there is an increased interest in residential RES among end-use consumers, which means that consumers are able to generate their own electricity. This increase is related to the paradigm shift in the low-voltage (LV) distribution network in recent years. In countries such as Portugal, residential renewable microgeneration (μG) systems are predominantly low-capacity PV systems, in the range of a few kW, which are directly connected to the LV distribution network [1]. At present, RES, including the storage system, are still not the predominant energy resource in the energy sector, unlike natural gas and fossil fuels. However, RES systems are experiencing an annual growth trend worldwide. Some of the advantages of using RES are an increase in innovation and technical/technological progress and the preservation of the environment in terms of reducing greenhouse gas emissions. Disadvantages of RES include their low capacity for generating electricity, low energy efficiency and great dependence on weather conditions [2,3].

In this context of a paradigm shift in LV distribution networks, the role of end-use consumers as energy producers may be interesting from both a technical and economic perspective, but does not preclude a careful analysis of the cost and benefits that are involved [4]. Normally, a residential consumer can use their renewable generation system, PV and/or wind, in three different ways: (i) Use PV/wind generation for self-consumption, import deficit electricity from the grid and even export the surplus to the grid. In this situation, there is self-consumption without storage; (ii) Use the PV/wind generation for self-consumption, store the surplus in the battery system for later use, and import deficit electricity from the grid. In this case, there is self-consumption with storage; (iii) Export all PV/wind generation to the electricity grid and import all electricity consumption from the grid. In this option, the prosumer does not perform any self-consumption.

In Portugal, an important step was taken with the published legislation (Decree-Law 153/2014) [5] allowing for the model of self-consumption by consumers. This decree encouraged new consumers to invest in renewable energies. The generation from renewable energies such as wind/PV can be improved with the inclusion of storage systems. Storage systems can be used to store the surplus energy generated during the daytime and can be used later when there is no sun, as in the night-time. In addition, the possibility of integrating energy storage systems and RES systems can be increased by combining intelligent energy distribution networks or SG [6,7]. It is commonly accepted that SG provides several benefits to the network in terms of security, economy, and efficiency [7].

The net-metering concept is not allowed in Portugal at present. This model assumes that the power system can be used as long-term storage, where the excess energy that is generated is injected into the LV grid and stored as credit. These credits can later be used to pay for consumption.

In the scientific literature, several studies providing an economic evaluation of wind and photovoltaic systems have been presented. Some of these studies were carried out with the aim of verifying the profitability of renewable energy systems from different perspectives. A brief literature review of the subject is presented below.

The article in [8] proposes a combined data envelopment analysis model and analytic hierarchy process approach for solar resource assessments, looking at various qualitative and quantitative factors. The authors demonstrate the effectiveness of this model through a study of solar energy in Taiwan. A review of studies focused on topics related to residential electricity tariffs was carried out in [9]. Furthermore, these revised studies were placed in the chronological order of the study of electricity tariffs and price equity. The impacts of renewable energy consumption on the economic growth of the 38 top renewal-energy-consuming countries worldwide were evaluated in [10].

Reference [11] assesses the financial support for photovoltaic installations in the residential sector of major European markets such as Belgium, Germany, Italy, Spain, and France. A techno-economic analysis of the potential of PV self-consumption considering different building types, such as residential and commercial, in Germany, Switzerland and Austria is addressed in [12]. An economic analysis of the integration of small wind turbines in residential in 88 regions of Iran was carried out in [13]. The results of this analysis indicate that small wind turbines are cost-effective in approximately 30% of the 88 studied regions in Iran. In [14], a technical-economic study was carried out for hybrid wind/PV systems, considering various storage techniques from the perspective of the rural consumer. A feasibility assessment of this hybrid wind/solar power system was carried out at different locations in India. A techno-economic analysis under different solar radiation conditions in Vietnam was carried out in [15]. This analysis aimed to achieve the optimal configuration of PV-powered EV charging stations. The results show that the tariff price and solar irradiation affect the investment efficiency and optimal configuration of PV-powered EV charging stations in each urban area. The research in [16] evaluates the monthly minimum residential demand for consumers located at different distribution concession areas in the Brazilian interconnected system, guaranteeing the economic viability of installing photovoltaic systems. The results of this study demonstrate that the integration of distributed photovoltaic systems is technically and economically feasible in several regions of Brazil.

Various studies considering the net-metering context present potential benefits related to bill savings from the perspective of residential consumers. The article in [17] establishes a comparison between battery storage and net metering, taking the PV rooftop as a reference. An assessment from the technical–economic perspective was carried out in [18], evaluating the efficiency of China's net-metering subsidies for residential distributed PV systems. The authors conclude that the net-metering efficiency should consider both regional differences at different levels of electricity demand and solar radiation. A comparative study of PV and battery storage sizing in a net-metering context and zero-export systems is discussed in [19]. A discussion about the implications of applying different net-metering methods to a prosumer's energy trades with the network and the consequent effect on self-consumption and costs is accessed in [20].

The conventional intersection of the price of the electricity produced by a renewable energy system, such as a wind/PV system, and the price of conventional electricity production can be defined as grid parity [21]. An evaluation of grid parity for different situations, considering three markets—Germany, Switzerland, and Italy—can be assessed in [22]. Paper [23] investigates and evaluates the impact of different grid parity scenarios considering regional wind energy investments in China. The authors conclude that regions with good wind resources may not have a guaranteed return on investment due to the uncertainty of electricity prices.

An evaluation of the effectiveness of the small PV unit's implementation in the city of Quito-Ecuador is presented in [24]. This research assesses the levelized cost of electricity (LCOE) incurred by constructing and operating a PV system and compared it with the price of purchasing energy from the electrical distribution network. An evaluation of LCOE, considering several implications in renewable energy design, such as wind and PV systems, can be accessed in [25]. The research in [26] discusses the improvements in LCOE and grid parity considering the useful lifetime of the PV technologies.

The parameters and modeling of PV, wind and storage systems are important issues in research studies. The article referenced in [27] presents the latest research on topics relevant to the integration of intelligent energy management systems. This article presents several flexible solutions to facilitate the power flow, such as the technical–economic model, dispatching, system design, and sizing. A study of a dc link energy management scheme considering the storage system integrated on a PV converter dc link can be accessed in [28]. The result of this study shows that the PV performance on a power grid can be improved. A review paper [29] investigates six different areas where the hybrid PV and storage systems system is analyzed. These different areas were optimal sizing, lifetime improvement, cost reduction analysis, optimal control of power system, mitigating various power quality issues, and peak load shifting and minimizing. The reference [30] discusses the effects of sizing on battery life and generation cost in standalone PV, wind, and battery hybrid systems. The results indicates that the oversized storage system has an extended life and reduces the energy generation costs.

The scientific literature contains several forms of technical–scientific research on the configurations of wind, photovoltaic and storage systems. These studies refer to topics ranging from net metering to network parity and LCOE, among other subjects.

This paper presents an integrated economic evaluation of the different solutions for wind and PV systems that are currently available on the market. The system elements (wind and PV modules, storage systems, inverter, and bidirectional meter) investment and operation and maintenance (O&M) costs are taken from the data, similar to other European countries, as provided by the Portugese manufacturers. The present legislation in Portugal, by allowing for self-consumption, allows for end-users to reduce their electricity bill, as it reduces their electricity imports from the LV network. Additionally, surplus electricity can be injected into the LV network and reimbursed at wholesale market prices.

To conduct an economic analysis, a total of 35 different wind/PV configurations were proposed, along with five groups of scenarios, namely: I—base-case; II—self-consumption with surplus injection; III—self-consumption without surplus injection; IV—net-metering;

V—self-consumption with storage. Classic economic indexes such as internal rate of return (IRR), net present value (NPV), profitability index (PI) and discounted payback period (DPP) were used for economic analysis. In parallel with these, the LCOE index was calculated for each system configuration. The break-even point was also computed, but only in cases where the indices point to unprofitable solutions, verifying the reductions in the investment cost that are necessary to make the project viable.

One of the main contributions of this research is the provision of a common economic framework for residential wind and photovoltaic systems. As far as the authors are aware, there is scarce literature available that provides an integrated economic assessment of the different residential wind and PV systems available on the market. Another contribution is the establishment of the necessary cost reductions that must be satisfied to ensure profitability. This study also investigates three types of existing tariffs to verify which is the most profitable for consumers considering the various systems. This may be valuable for small residential consumers that aim to lower their electricity bill or become autonomous of the power system. Finally, as prices for residential wind and PV and storage systems in the Portuguese market are similar to prices across Europe, the results of this research can easily be generalized to other European countries.

This article is organized in the following way. The methodology used to perform the economic assessment is described in Section 2. The analyzed wind and PV system configurations, and their respective parameters, are characterized in Section 3. Section 4 and Section 5, respectively, present and discuss the results of this techno-economical study. Section 6 depicts the main conclusions of this research.

2. Methodology

2.1. Economic Evaluation

An appropriate project economic assessment is required before making definitive decision on whether to invest in a solar or wind project. The project investment is economically evaluated in terms of profitability, viability and stability, justifying the final decision. Consequently, an economic assessment is made of the project investment, considering some key indicators that establish whether the project is attractive to investors [31,32]. In this paper, the key indicator parameters that were utilized for economic assessment are, respectively: NPV, PI, IRR, DPP, and LCOE.

NPV can be defined as the sum of the present values of the outflows (costs) and inflows (profits) throughout the period analyzed for the project. NPV can be defined by Equation (1):

$$NPV = \sum_{j=1}^{n} \frac{RL_j}{(1+a)^j} - \sum_{j=0}^{n-1} \frac{I_j}{(1+a)^j} + \frac{V_r}{(1+a)^n} \quad (1)$$

where a is the discount rate; V_r refers to recovering the value of the system at the end of the period; n is the project lifetime; I_j is the investment in year j; RL_j is the net income received in the year j, determined from the difference between gross revenues R_j and maintenance and operation costs $d_{O\&M_j}$ as a percentage of total investment I_t (see Equation (2)).

$$RL_j = R_j - d_{O\&M_j} I_t \quad (2)$$

The project is rejected if NPV < 0 and accepted if NPV > 0. The benefit cost/ratio PI is the ratio of the present value of an investment's estimated cash inflows to the present value of its estimated cash outflows [33]. PI can be computed by Equation (3):

$$PI = \frac{\sum_{j=1}^{n} \frac{RL_j}{(1+a)^j} + \frac{V_r}{(1+a)^n}}{\sum_{j=0}^{n-1} \frac{I_j}{(1+a)^j}} \quad (3)$$

The project can be rejected if PI < 1 and accepted if PI > 1.

The IRR is the rate of return applied in a capital expenditure budget to quantify and evaluate the profitability of the investment. This equates to saying that IRR is the rate of return for which NPV is zero. Therefore, the IRR equation is given by Equation (4):

$$\sum_{j=1}^{n} \frac{RL_j}{(1+IRR)^j} - \sum_{j=0}^{n-1} \frac{I_j}{(1+IRR)^j} + \frac{V_r}{(1+IRR)^n} = 0 \tag{4}$$

If IRR < a, the project is not economically profitable, and if IRR > a the project is economically profitable.

The time required to recover the initial investment from the present value of the expected future cash flows [33] defines DPP, which could be computed by Equation (5):

$$\sum_{j=1}^{DPP} \frac{RL_j}{(1+a)^j} + \frac{V_r}{(1+a)^n} = \sum_{j=0}^{n-1} \frac{I_j}{(1+a)^j} \tag{5}$$

If DPP > n the initial investment cannot be salvaged within the project's lifetime; if DPP < n, the project can be accepted.

The key indicator LCOE, over its lifetime, can be defined as the discounted production cost of installing and operating a project, expressed in €/kWh [34]. LCOE is very important when verifying the grid parity, which can be achieved when the cost of solar PV generation or the cost of wind generation becomes equivalent to the household energy price that is obtained [26,35]. LCOE can be calculated by Equation (6).

$$LCOE = \frac{\sum_{j=1}^{n} \frac{I_j + d_{O\&M_j}}{(1+a)^j} - \frac{V_r}{(1+a)^n}}{\sum_{j=1}^{n} \frac{E_j}{(1+a)^j}} \tag{6}$$

E_j is the electrical energy produced in year j.

2.2. Household Clients Considering Wind and PV Systems with Battery Systems

The electricity generated from residential wind systems and PV systems can flow in distinct paths, as illustrated in Figure 1.

The electrical energy generated from wind systems and PV systems is first utilized for prosumer's self-consumption. Accordingly, the prosumer's own consumption can directly reduce the residential electricity costs. The household client can decide his own level of independence, with the possibility of rising to the point of being entirely independent from the LV network and free of bill payments. Alternatively, the prosumers can decide whether to inject all the electrical energy that was not consumed by the LV network. In this way, the surplus of the electricity output that exceeds the electricity demand can be: (i) injected into the LV network; (ii) stored in a battery system for posterior consumption.

In option (i), the surplus can be remunerated through a tariff system [36].

In option (ii), the battery systems begin functioning when the wind/PV system output is considered unable to provide the electrical energy demand. The house loads start to be powered by the LV network after the battery system is discharged. In the discharge procedure, the battery system electrical energy is only used to supply the residential demand. In the charge procedure, the battery system is charged considering only the generated wind/PV electrical energy. Consequently, this study did not consider the ability to charge/discharge the system battery from/to the LV network.

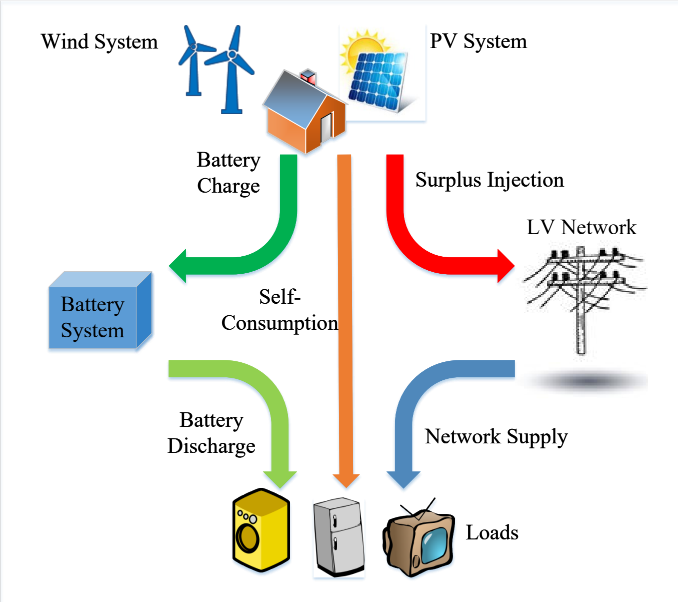

Figure 1. Electricity flows and possible paths in household clients considering the wind system, the PV system, and the battery system.

2.3. Legal Context

The current Portuguese legal context [36] allows for the generation of electric energy for the prosumer's own consumption, with the possibility of injecting excess electric energy into the LV grid. Accordingly, the surplus injection can be remunerated by considering 90% of the average monthly closing price of the Iberian Energy Market Operator (OMIE) [37]. Additionally, according to the current legislation, the individual installed capacity of μG is limited to 100% of the prosumer's contracted power. These legal requirements were considered in this research.

3. Case Study Definition

In this research, a comparison of different operating modes of residential wind and PV system configurations was carried out: self-consumption, with and without LV network surplus electricity injections, and battery systems for storage management.

3.1. Wind Kits and PV Kits for Residential Utilization

Typical RES power kits available in the market were selected: PV 0.64 kWp, PV 1 kWp, PV 1.5 kWp, Wind 0.94 kWp, Wind 3.1 kWp, Wind 5 kWp, and a Hybrid kit (PV + Wind).

3.2. Micro-Generation, Consumption, and Wind Speed Profiles

An economic assessment was carried out based on the predictable annual profiles of consumption and µG, , measured at average intervals of 15 minutes, provided by the Energy Services National Regulatory Authority (ERSE) [38]. Figure 2a represents the annual consumption profile, considering a residential consumer with a consumption of 3700 kWh in the year 2021. Figure 2b shows the annual μG profiles, considering a PV system of 1.5 kWp peak power as an example of a typical prosumer. Figure 2c displays the annual wind speed profiles for an area of the coastline in central Portugal, considering that these values were quantified for a height of ten meters from the ground [39].

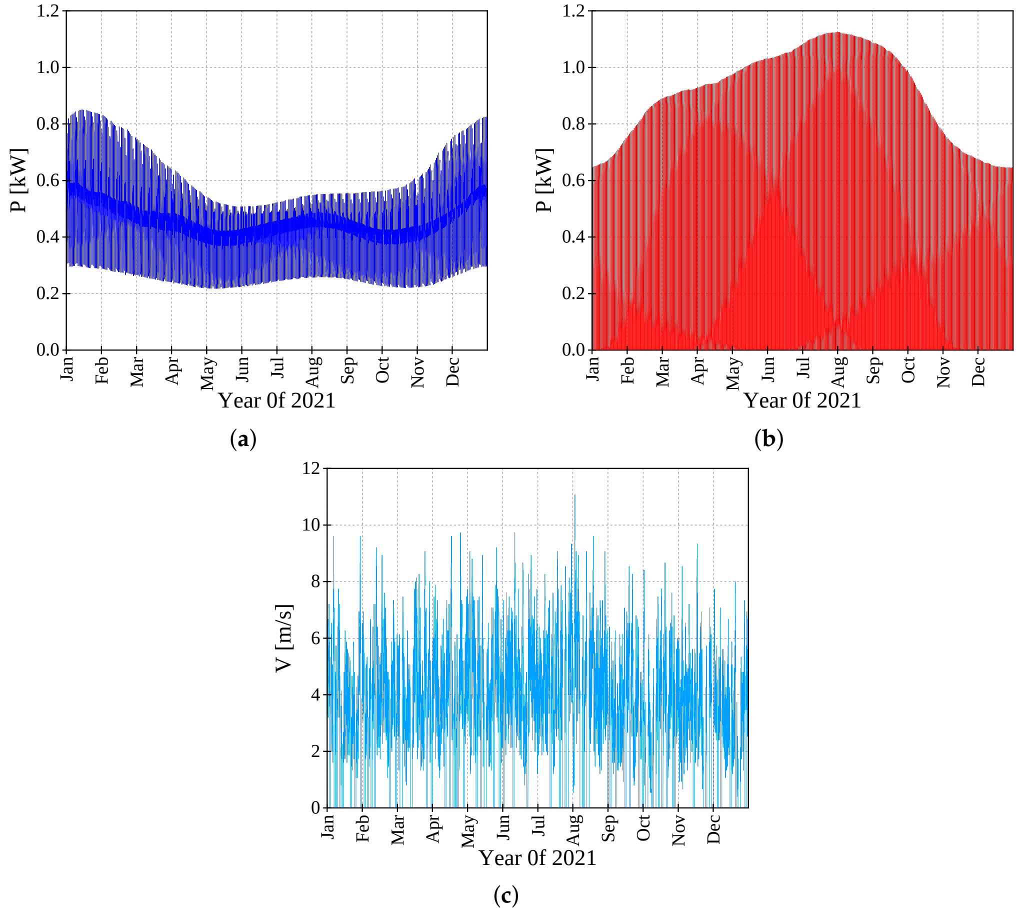

Figure 2. Profiles of consumption, μG, and wind speed over the year: (**a**) The annual consumption profile of a typical prosumer. (**b**) The annual μG profile of a typical prosumer. (**c**) The annual wind speed profile.

3.3. Remuneration of Surplus Injection into the LV Network and Acquisition Tariffs

In Portugal, according to Decree-Law No. 162/2019 [36], to sell surplus energy injected into the grid, the prosumer can sign a contract with the last resort supplier [40] or with another supplier on the free market [41].

The remuneration amount was calculated considering the indexation of the price of electricity in the Iberian Energy Market Operator (OMIE [42]), with a penalty on this amount. This penalty depends on the entity that is purchasing the energy, an can be either a fixed amount or indexed to the energy purchase price.

In this research work, surplus energy is considered to be remunerated considering 90% of the average monthly closing price of the OMIE. In this case, the remuneration is influenced by the market price, from which 10% is deducted to offset the costs related to the injection, translating into a constant of 90%. Consequently, the monthly remuneration [€] of surplus energy injected into the LV network is computed by Equation (7).

$$R_m = 90\% \; E_m \; OMIE_m \tag{7}$$

where [kWh] is the electricity injected into the LV network in month m; [€/kWh] is the value resulting from the simple arithmetic average of the closing prices of the OMIE each month. Figure 3 portrays the average monthly prices for the year 2021, based on the information provided by OMIE (the annual average value is around 0.11 €/kWh).

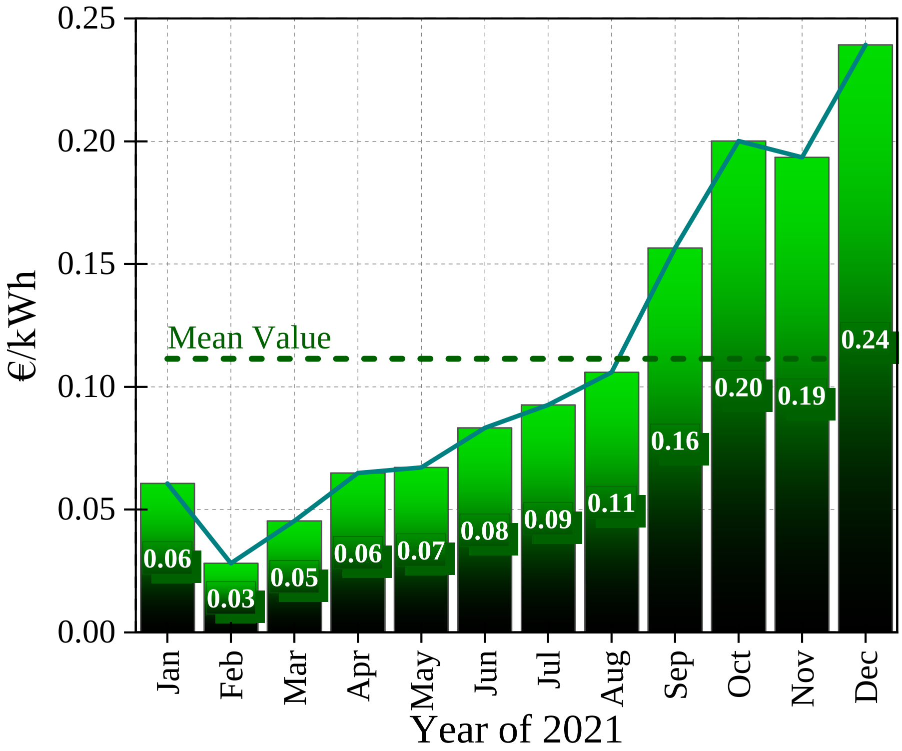

Figure 3. Average monthly Iberian electricity market prices in Portugal for the year of 2021.

In this research, the prosumer's contracted power was assumed to be 4.60 kVA. Three types of tariffs were considered for the LV network purchase assessment, such as a simple tariff (T_{f1}), bi-hourly tariff (T_{f2}), and tri-hourly tariff (T_{f3}). The simple tariff is the same for each day of the week and time of the year. The i-hourly tariff has two different prices, corresponding to the peak hours, in which energy has a lower cost, and off-peak hours, in which energy has a higher cost. The tri-hourly tariff is similar to the bi-hourly tariff, but has three hourly consumption periods with different prices, namely, the peak hours period, full hours period (energy has intermediate cost), and off-peak hours period. Additionally, the tri-hourly tariff considers the daylight-saving time and the winter. Table 1 displays the LV network electrical power purchase for the three types of tariffs in Portugal in the year 2021 [37], in which a 23% VAT is included.

Table 1. LV network electrical power purchase simple tariff (T_{f1}), bi-hourly tariff (T_{f2}), and tri-hourly tariff (T_{f3}) — (2021).

Contracted Power [kVA]	Tariff Type	Capacity [€/day]	Peak Hours [€/kWh]	Full Hours [€/kWh]	Off-Peak Hours [€/kWh]
4.60	T_{f1}	0.2298	0.1580	0.1580	0.1580
	T_{f2}	0.2298	0.1924	0.1924	0.1023
	T_{f3}	0.2298	0.2358	0.1696	0.1023

3.4. Storage System

The storage of electrical energy arises with the intention of using the surplus energy produced by renewable energy systems. At present, storage systems are composed of stationary batteries, in which the technologies of lithium–ion (Li-ion), lead–acid (Pb) and nickel–metal hydride (NiMH) batteries are highlighted. Other kinds of batteries can be also related to renewable systems, namely, German "Ortsfeste Panzerplatte Spezial" (OPzS) and "Ortsfeste Panzerplatte Verschlossen" (OPzV), and absorbent glass mat (AGM) [43]. In this study, the AGM battery technology, from manufacturer EcoSolar [44], was selected as the storage system. This selection was made considering the current market prices for renewable energy storage systems. In accordance with the manufacturer, Table 2 highlights some characteristics of this battery.

Table 2. EcoSolar AGM battery characteristics (temperature of 25 °C).

Manufacturer	Capacity per Unit	$\eta_{Storage}$	Cycles	Lifetime	Technology	Price per Unit
EcoSolar	12 V — 250 Ah (C100)	90%	1750 (30% DOD)	4.7 years	AGM (gel)	359 €

Battery energy storage systems are one of the most common types of energy storage system. The dimensioning of the storage system is very important, mainly when used in parallel with the RES. Reference [45] presents an empirical model that sizes the storage system required for the inertia emulation and damping control. [46] presents a comprehensive study on the design of energy storage systems to control the ramp rate of photovoltaic strings. The results of this study indicate that the inverter sizing and set ramp rate limit are important factors when sizing the storage system for PV ramp rate control. An equivalent circuit for battery modeling, based on a non-linear equation, can be accessed in [47]. The battery was modeled using a controlled voltage source connected to a series resistance.

The efficiency of the electrical energy conversion process and the depth of discharge (DOD) were considered in the dimensioning of the storage system. There were losses in the battery system related to the energy-conversion process, due to the conversion of chemical energy to electrical energy, for utilization when required, and the conversion of electrical energy to chemical energy for storage. In this way, the parameters considered for battery sizing were: the efficiency of the electronic power converters, which was considered to be 95% for every discharge mode $(\eta_{DC/AC})$ or charge $(\eta_{AC/DC})$ [48]; storage efficiency $(\eta_{storage})$ was 90 % according to Table 2. Consequently, these considerations resulted in a total storage system efficiency of $\eta = \eta_{DC/AC} \times \eta_{storage} \times \eta_{AC/DC} = 0.95 \times 0.90 \times 0.95 \approx 81\%$.

3.5. Considerations for the Economic Assessment

The output power of PV/wind/storage systems is basically determined not only by the irradiance/temperature (PV system), the wind speed (wind system), which is based on the nature of the turbine's power curve, but also by technical characteristics such as the PV module/wind turbine/battery technology, inverter, and converter efficiencies, ohmic losses, mismatched losses, and diode losses, among others.

The following parameters were considered before performing an economic analysis: investment period of 20 years, maintenance, and operation costs of 1% of the total project investment, depreciation factor D_f of 0.75% per year and a discount rate of 5% [49,50]. The D_f factor is responsible for the decrease in the efficiency of the PV panel throughout its useful life. The rate of PV modules varies according to the technology, model, and manufacturer; however, the power output of the modules generally decreases by around 0.8% each year, with a greater reduction in the first year between 1% and 3%. However, considering the study presented in reference [51], an average degradation rate per year of 0.75% was considered in this paper.

According to current Portuguese legislation, to sell the surplus, the following conditions must be fulfilled: (1) the production unit for self-consumption must be registered with Direção Geral de Energia e Geologia (DGEG) [52]; (2) the production unit must have bidirectional meter; (3) the production unit must have a production point of delivery code; and (4) the production unit must have energy sales contract with the last resort supplier (CUR) [52].

The actual prices of the components of the RES considered in this research, and their lifetime in accordance with their respective manufacturers, are shown in Table 3.

Table 3. Component prices (23% VAT is included) and their lifetime.

Components	Cost [€]	Lifetime [Years]
PV Kit 0.64 kWp	850.96	25
PV Kit 1 kWp	1210.00	25
PV Kit 1.5 kWp	1520.00	25
Wind Kit 0.94 kWp	1298.00	25
Wind Kit 3.1 kWp	1598.00	25
Wind Kit 5 kWp	1728.00	25
Hybrid Kit (PV + Wind)	2578.96	25
Hybrid inverter for PV system	1533.00	20
Hybrid inverter for wind system	1665.00	20
Hybrid inverter for PV + wind system	1665.00	20
Bidirectional meter	98.39	25
Battery bank of 3 kWh	359.00	4.7

Each wind energy kit comprised the following components: wind turbine, controller, inverter, support structure for wind turbine (with 10 meters support pole), and direct current/alternating current (DC/AC) connection cables. Likewise, each solar energy kit comprised the following components: PV panel (polycrystalline), coplanar support structure for PV panel, micro-inverter, and DC/AC connection cables with MC4 connectors. It should be noted that grid-connected photovoltaic inverters can assume various configurations and be categorized into four main types [53], namely, string inverters, central inverters, ac module inverters, and multi-string inverters.

Finally, only one hybrid case (PV + wind) was considered for analysis. This was generally supplied by the components considered for "PV Kit 0.64 kWp" plus "Wind Kit 5 kWp". When the PV and/or wind kit is combined with a storage system, a hybrid inverter is necessary. The hybrid inverter is a device that incorporates: (i) a battery inverter, which is also responsible for the load regulation function; (ii) a standard solar/wind inverter; (iii) a battery charger. Lastly, it is necessary to install a bidirectional meter to count the electricity injected into the LV network.

A straight-line depreciation was considered to determine the residual value of the components. For example, the battery system is to be replaced every 4.7 years, in accordance with Table 2. In this way, the residual value in year 20 of the last purchased battery, with a total of four replacements, is 74.5% of its investment cost, after 1.5 years of operation.

For powers $\leq$ 30 kW, consumers are relieved from paying any fee to obtain the exploitation certificate, with or without injection into the LV network; only a previous communication in DGEG is sufficient.

Finally, although Portugal has not considered net-metering to date, the authors consider it necessary to analyze this case study to verify whether it makes sense to implement this option.

3.6. Proposed Scenarios for Economic Assessment and Total Discounted Investment

To perform the economic analysis, five groups of scenarios are proposed:

I $B_{ase-}C_{ase}$;
II $S_{elf-}C_{onsumption}\ w_{ith}\ S_{urplus}\ I_{njection}$;
III $S_{elf-}C_{onsumption}\ w_{ithout}\ S_{urplus}\ I_{njection}$;
IV $N_{et}M_{etering}$;
V $S_{elf-}C_{onsumption}\ w_{ith}\ S_{torage}$.

I. $B_{ase-}C_{ase}$—consumes all/injects all: In the base-case scenario, there is no prosumer's own consumption. All electric power consumption is provided by LV network and paid at the rates shown in Table 1. All the electrical energy generated by the PV/wind system is fully injected to the LV network and remunerated at the wholesale market prices described in Section 3.3.

II. $S_{elf-}C_{onsumption}\ w_{ith}\ S_{urplus}\ I_{njection}$: self-consumption can reduce the electrical energy required by the LV network. However, if surplus electricity is generated by the PV/wind systems, two options are considered: (A) surplus electric energy is injected to the LV network and remunerated according to Equation (7); (B) surplus electrical energy is lost, and the energy produced only supplies the residential load. Group II considers the option (A).

III. $S_{elf-}C_{onsumption}\ w_{ithout}\ S_{urplus}\ I_{njection}$: Group III considers ,option (B), described in Group II.

IV. $S_{elf-}C_{onsumption}\ w_{ith}\ N_{et}M_{etering}$ this group is like group II, with the difference that the surplus is injected into the LV network, and the same quantity of energy (in kWh) can be recuperated later from the LV network, without payments or remunerations of any kind, with commercialization being entirely electric.

V. $S_{elf-}C_{onsumption}\ w_{ith}\ S_{torage}$ Self-Consumption with Storage – in this group, if surplus electricity is generated by the PV/wind system, the storage system was considered. The storage system was dimensioned considering the efficiency and the depth of discharge (see Section 3.4). Surplus electricity is stored in batteries and later used to satisfy prosumer's self-consumption necessities. After the batteries' charge is exhausted, the electrical energy required for residential consumption is imported from the LV network, paid according to the tariffs displayed in Table 1.

Table 4 displays the total discounted investment in wind, solar and storage systems considered for economic analysis. It is notable that the total investment is duly discounted considering the periodic replacement of elements such as the storage system.

Table 4. Total discounted investment for wind, solar, hybrid and storage systems.

Group	System Configuration	Kit [€]	Hybrid Inverter [€]	Bidirectional Meter [€]	Storage System [€]	Total Discounted Investment [€]	Specific Investment [€/Wp]
I $B_{ase-}C_{ase}$	PV 0.64 kWp	850.96		98.39		**949.35**	1.48
	PV 1 kWp	1210.00		98.39		**1308.39**	4.09
	PV 1.5 kWp	1520.00		98.39		**1618.39**	1.08
	Wind 0.94 kWp	1298.00		98.39		**1396.39**	1.49
	Wind 3.1 kWp	1598.00		98.39		**1696.39**	0.55
	Wind 5 kWp	1728.00		98.39		**1826.39**	0.37
	Hybrid (PV + Wind)	2578.96		98.39		**2677.35**	0.54
II $S_{elf-}C_{onsumption}$ w_{ith} $S_{urplus}\ I_{njection}$	PV 0.64 kWp	850.96		98.39		**949.35**	1.48
	PV 1 kWp	1210.00		98.39		**1308.39**	4.09
	PV 1.5 kWp	1520.00		98.39		**1618.39**	1.08
	Wind 0.94 kWp	1298.00		98.39		**1396.39**	1.49
	Wind 3.1 kWp	1598.00		98.39		**1696.39**	0.55
	Wind 5 kWp	1728.00		98.39		**1826.39**	0.37
	Hybrid (PV + Wind)	2578.96		98.39		**2677.35**	0.54
III $S_{elf-}C_{onsumption}$ w_{ithout} $S_{urplus}\ I_{njection}$	PV 0.64 kWp	850.96				**850.96**	1.33
	PV 1 kWp	1210.00				**1210.00**	3.78
	PV 1.5 kWp	1520.00				**1520.00**	1.01
	Wind 0.94 kWp	1298.00				**1298.00**	1.38
	Wind 3.1 kWp	1598.00				**1598.00**	0.52
	Wind 5 kWp	1728.00				**1728.00**	0.35
	Hybrid (PV + Wind)	2578.96				**2578.96**	0.52

Table 4. *Cont.*

Group	System Configuration	Kit [€]	Hybrid Inverter [€]	Bidirectional Meter [€]	Storage System [€]	Total Discounted Investment [€]	Specific Investment [€/Wp]
IV $S_{elf-}C_{onsumption}$ w_{ith} $N_{et}M_{etering}$	PV 0.64 kWp	850.96		98.39		**949.35**	1.48
	PV 1 kWp	1210.00		98.39		**1308.39**	4.09
	PV 1.5 kWp	1520.00		98.39		**1618.39**	1.08
	Wind 0.94 kWp	1298.00		98.39		**1396.39**	1.49
	Wind 3.1 kWp	1598.00		98.39		**1696.39**	0.55
	Wind 5 kWp	1728.00		98.39		**1826.39**	0.37
	Hybrid (PV + Wind)	2578.96		98.39		**2677.35**	0.54
V $S_{elf-}C_{onsumption}$ w_{ith} S_{torage}	PV 0.64 kWp	850.96	1533.00		1309.34	**3693.30**	5.77
	PV 1 kWp	1210.00	1533.00		1309.34	**4052.34**	12.66
	PV 1.5 kWp	1520.00	1533.00		1309.34	**4362.34**	2.91
	Wind 0.94 kWp	1298.00	1665.00		1309.34	**4272.34**	4.55
	Wind 3.1 kWp	1598.00	1665.00		1309.34	**4572.34**	1.47
	Wind 5 kWp	1728.00	1665.00		1309.34	**4702.34**	0.94
	Hybrid (PV + Wind)	2578.96	1665.00		1309.34	**5553.30**	1.11

4. Results

The purpose of the research shown in this Section is to verify the economic attractiveness of the prosumer's investment, for the different RES system configurations listed above.

To provide further insight on the impact of self-consumption on the annual electricity bill, Figure 4 presents the savings resulting from self-consumption for some kinds of RES systems, considering the first year of operation. The types of RES systems considered in this introductory analysis are as follows: PV 0.64 kWp, PV 1.5 kWp, Wind 0.94 kWp, Wind 3.1 kWp, Wind 5 kWp, Hybrid (PV + Wind), and PV 1.5 kWp + Storage. The electricity bill was calculated using the current tri-hourly tariff for Portuguese electricity consumers, as shown in Table 1. The annual electricity bill is represented by the first bar, where no PV system is considered to be installed. The following blue bars represent the annual electricity bill, where different types of wind/PV/Hybrid system are installed. The orange bars display the savings compared to the case in which no PV system is installed. As can be seen, each type of wind/PV/hybrid system allows for a reduction in the electricity bill. In these calculations, the investment costs in the analyzed systems were not considered; these calculations refer only to the net electricity bill.

As can be seen from Figure 4, in the middle bars, the RES systems increase and basically continue with a similar economy. This is mainly due to the characteristics of annual μG and wind speed profiles throughout the year. With regard to the "Hybrid (PV+Wind)" bar, it was considered that, in this hybrid system, the PV system only works during a certain period of the day (daylight), and that only the wind system works during the rest of the day. The last bar, "PV 1.5 kWp + Storage", characterizes the higher electricity cost savings. Nevertheless, this may not be sufficient to compensate the total PV system investment, as will be seen in the simulation results. The following subsection presents the economic indicators results obtained from a simulation of all the considered configurations.

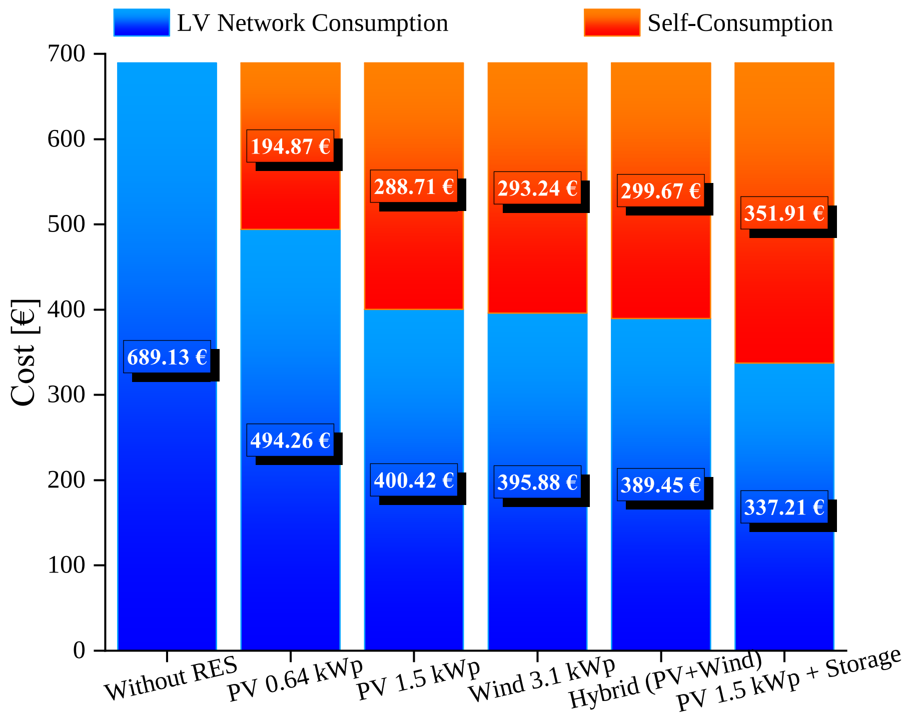

Figure 4. Bill savings resulting from self-consumption.

Economic Results

In the following tables, Tables 5–14, all values highlighted in **bold** are the best investment solutions. Conversely, all results highlighted in *italic* are those that are not profitable.

Group I ($B_{ase-}C_{ase}$) – The simulation results of economic analysis of Group I (consumes all/ injects all) are presented in Tables 5 and 6. It is possible to perceive that apparently only two RES systems of this group, "Wind 0.94 kWp" and "Hybrid (PV + Wind)", are not profitable. However, the RES systems, "PV 1.5 kWp" and "Wind 5 kWp", are the most lucrative, with a DPP period of less than 11 years.

Table 5. Economic analysis results for Group I considering the three tariffs (T_{f1}, T_{f2}, T_{f3}) (1).

System Config.	NPV [€]			PI [%]			IRR [%]		
	T_{f1}	T_{f2}	T_{f3}	T_{f1}	T_{f2}	T_{f3}	T_{f1}	T_{f2}	T_{f3}
PV 0.64 kWp	83.3	83.3	83.3	1.1	1.1	1.1	6.0	6.0	6.0
PV 1 kWp	327.0	327.0	327.0	1.3	1.3	1.3	8.0	8.0	8.0
PV 1.5 kWp	**877.5**	**877.5**	**877.5**	**1.5**	**1.5**	**1.5**	**11.0**	**11.0**	**11.0**
Wind 0.94 kWp	*−1103.6*	*−1103.6*	*−1103.6*	*0.2*	*0.2*	*0.2*	*−9.0*	*−9.0*	*−9.0*
Wind 3.1 kWp	293.9	293.9	293.9	1.2	1.2	1.2	7.0	7.0	7.0
Wind 5 kWp	**1499.4**	**1499.4**	**1499.4**	**1.8**	**1.8**	**1.8**	**14.0**	**14.0**	**14.0**
Hybrid (PV + Wind)	*−658.1*	*−658.1*	*−658.1*	*0.8*	*0.8*	*0.8*	*2.0*	*2.0*	*2.0*

Table 6. Economic analysis results for Group I considering the three tariffs (T_{f1}, T_{f2}, T_{f3}) (2).

System Config.	DPP [Years]			LCOE [€/kWh]		
	T_{f1}	T_{f2}	T_{f3}	T_{f1}	T_{f2}	T_{f3}
PV 0.64 kWp	17.6	17.6	17.6	0.1	0.1	0.1
PV 1 kWp	14.3	14.3	14.3	0.2	0.2	0.2
PV 1.5 kWp	**10.7**	**10.7**	**10.7**	**0.1**	**0.1**	**0.1**
Wind 0.94 kWp	*>20*	*>20*	*>20*	*0.3*	*0.3*	*0.3*
Wind 3.1 kWp	15.9	15.9	15.9	0.1	0.1	0.1
Wind 5 kWp	**8.8**	**8.8**	**8.8**	**0.1**	**0.1**	**0.1**
Hybrid (PV + Wind)	*>20*	*>20*	*>20*	*0.6*	*0.6*	*0.6*

Group II ($S_{elf-}C_{onsumption}$ w_{ith} S_{urplus} $I_{njection}$)—The results of the economic analysis of Group II are presented in Tables 7 and 8. It can be seen that only "Wind 0.94 kWp" is not profitable. The most lucrative RES system configurations for this group are "PV 1.5 kWp" and "Wind 5 kWp", with a DPP period of less than 7 years. Furthermore, the type of tariff has an impact on the DPP period. For instance, considering the "PV 1.5 kWp" system, it is possible to see a DPP of 6.8 years for a simple tariff T_{f1} and a DPP of 5.6 years for a bi-hourly tariff T_{f2}.

Table 7. Economic analysis results for Group II considering the three tariffs (T_{f1}, T_{f2}, T_{f3}) (1).

System Config.	NPV [€]			PI [%]			IRR [%]		
	T_{f1}	T_{f2}	T_{f3}	T_{f1}	T_{f2}	T_{f3}	T_{f1}	T_{f2}	T_{f3}
PV 0.64 kWp	841.6	1245.6	1230.7	1.9	2.3	2.3	14.0	18.0	18.0
PV 1 kWp	1327.0	1866.9	1847.0	2.0	2.4	2.4	16.0	19.0	19.0
PV 1.5 kWp	**2008.6**	**2626.6**	**2585.3**	**2.2**	**2.6**	**2.6**	**18.0**	**21.0**	**21.0**
Wind 0.94 kWp	*−769.2*	*−679.2*	*−705.4*	*0.5*	*0.5*	*0.5*	*−3.0*	*−2.0*	*−2.0*
Wind 3.1 kWp	1569.4	1758.6	1707.7	1.9	2.0	2.0	15.0	16.0	16.0
Wind 5 kWp	**3052.2**	**3298.5**	**3248.7**	**2.7**	**2.8**	**2.8**	**22.0**	**23.0**	**23.0**
Hybrid (PV + Wind)	1534.2	1720.0	1692.3	1.6	1.6	1.6	11.0	12.0	12.0

Table 8. Economic analysis results for Group II considering the three tariffs (T_{f1}, T_{f2}, T_{f3}) (2).

System Config.	DPP [Years]			LCOE [€/kWh]		
	T_{f1}	T_{f2}	T_{f3}	T_{f1}	T_{f2}	T_{f3}
PV 0.64 kWp	8.4	6.5	6.6	0.1	0.1	0.1
PV 1 kWp	7.7	6.2	6.2	0.2	0.2	0.2
PV 1.5 kWp	**10.7**	**10.7**	**10.7**	**0.1**	**0.1**	**0.1**
Wind 0.94 kWp	*>20*	*>20*	*>20*	*0.3*	*0.3*	*0.3*
Wind 3.1 kWp	8.2	7.6	7.8	0.1	0.1	0.1
Wind 5 kWp	**5.5**	**5.2**	**5.3**	**0.1**	**0.1**	**0.1**
Hybrid (PV + Wind)	10.6	10.0	10.1	0.6	0.6	0.6

Group III ($S_{elf-}C_{onsumption}$ w_{ithout} S_{urplus} $I_{njection}$) – The results of an economic analysis of Group III are presented in Tables 9 and 10. The two RES systems of this group, "Wind 0.94 kWp" and "Hybrid (PV + Wind)", are not profitable. "PV 0.64 kWp" is suggested to be the most suitable system for investment, with a DPP of 5.8 years for both the bi-hourly tariff T_{f2} and tri-hourly tariff T_{f3}.

Table 9. Economic analysis results for Group III considering the three tariffs (T_{f1}, T_{f2}, T_{f3}) (1).

System Config.	NPV [€]			PI [%]			IRR [%]		
	T_{f1}	T_{f2}	T_{f3}	T_{f1}	T_{f2}	T_{f3}	T_{f1}	T_{f2}	T_{f3}
PV 0.64 kWp	**936.4**	**1340.7**	**1325.8**	**2.1**	**2.6**	**2.6**	**16.0**	**21.0**	**21.0**
PV 1 kWp	1177.1	1716.8	1696.9	2.0	2.4	2.4	15.0	19.0	19.0
PV 1.5 kWp	1230.3	1848.3	1807.0	1.8	2.2	2.2	13.0	17.0	17.0
Wind 0.94 kWp	*−660.2*	*−570.3*	*−596.5*	*0.5*	*0.6*	*0.5*	*−2.0*	*−1.0*	*−2.0*
Wind 3.1 kWp	1409.4	1598.6	1547.6	1.9	2.0	2.0	14.0	16.0	15.0
Wind 5 kWp	**2002.9**	**2249.2**	**2199.5**	**2.2**	**2.3**	**2.3**	**17.0**	**18.0**	**18.0**
Hybrid (PV + Wind)	*−394.6*	*578.6*	*550.9*	*0.9*	*1.2*	*1.2*	*3.0*	*8.0*	*7.0*

Table 10. Economic analysis results for Group III considering the three tariffs (T_{f1}, T_{f2}, T_{f3}) (2).

System Config.	DPP [Years]			LCOE [€/kWh]		
	T_{f1}	T_{f2}	T_{f3}	T_{f1}	T_{f2}	T_{f3}
PV 0.64 kWp	**7.3**	**5.8**	**5.8**	**0.1**	**0.1**	**0.1**
PV 1 kWp	7.8	6.2	6.2	0.2	0.2	0.2
PV 1.5 kWp	8.7	6.8	6.9	0.1	0.1	0.1
Wind 0.94 kWp	*>20*	*>20*	*>20*	*0.3*	*0.3*	*0.3*
Wind 3.1 kWp	8.4	7.8	8.0	0.1	0.1	0.1
Wind 5 kWp	**7.1**	**6.6**	**6.7**	**0.1**	**0.1**	**0.1**
Hybrid (PV + Wind)	*>20*	*14.9*	*15.1*	*0.5*	*0.5*	*0.5*

Group IV ($S_{elf-}C_{onsumption}\ w_{ith}\ N_{et}M_{etering}$): The results of an economic analysis of Group IV are portrayed in Tables 11 and 12. In this group, all system configurations deal with net-metering, using the power system as a long-term and infinite storage equipment. The conclusion is that only the "Wind 0.94 kWp" kit is not economically feasible. This is because this system does not produce enough electrical power to be injected into, and profit from, the grid. "PV 1.5 kWp" and "Wind 5 kWp" were presented as the most profitable systems, with a DPP period of less than 6 years. A notable IRR score of 27.0% was obtained for the "Wind 5 kWp" configuration. The "PV 1.5 kWp" configuration showed the second-best IRR of 25.0%.

Table 11. Economic analysis results for Group IV considering the three tariffs (T_{f1}, T_{f2}, T_{f3}) (1).

System Config.	NPV [€]			PI [%]			IRR [%]		
	T_{f1}	T_{f2}	T_{f3}	T_{f1}	T_{f2}	T_{f3}	T_{f1}	T_{f2}	T_{f3}
PV 0.64 kWp	844.2	1248.2	1233.2	1.9	2.3	2.3	14.0	18.0	18.0
PV 1 kWp	1508.9	2048.6	2028.7	2.2	2.6	2.6	17.0	21.0	21.0
PV 1.5 kWp	**2656.7**	**3274.7**	**3233.4**	**2.6**	**3.0**	**3.0**	**21.0**	**25.0**	**24.0**
Wind 0.94 kWp	*−768.2*	*−678.3*	*−704.5*	*0.5*	*0.5*	*0.5*	*−3.0*	*−2.0*	*−2.0*
Wind 3.1 kWp	1792.8	1982.0	1931.1	2.1	2.2	2.1	16.0	17.0	17.0
Wind 5 kWp	**3913.4**	**4159.7**	**4110.0**	**3.1**	**3.3**	**3.3**	**26.0**	**27.0**	**27.0**
Hybrid (PV + Wind)	2436.4	2622.2	2594.5	1.9	2.0	2.0	15.0	15.0	15.0

Table 12. Economic analysis results for Group IV considering the three tariffs (T_{f1}, T_{f2}, T_{f3}) (2).

System Config.	DPP [Years]			LCOE [€/kWh]		
	T_{f1}	T_{f2}	T_{f3}	T_{f1}	T_{f2}	T_{f3}
PV 0.64 kWp	8.3	6.5	6.6	0.1	0.1	0.1
PV 1 kWp	7.1	5.8	5.3	0.2	0.2	0.2
PV 1.5 kWp	**5.6**	**4.8**	**4.8**	**0.1**	**0.1**	**0.1**
Wind 0.94 kWp	*>20*	*>20*	*>20*	*0.3*	*0.3*	*0.3*
Wind 3.1 kWp	7.5	7.1	7.2	0.1	0.1	0.1
Wind 5 kWp	**4.6**	**4.4**	**4.4**	**0.1**	**0.1**	**0.1**
Hybrid (PV + Wind)	8.3	7.9	8.0	0.6	0.6	0.6

Group V ($S_{elf-}C_{onsumption}$ w_{ith} S_{torage}) – The results of economic analysis of Group V are displayed in Tables 13 and 14. It is apparent that no scenarios for this group are profitable. This is explained by the fact that storage systems are still expensive today.

To investigate the necessary conditions for project profitability, a break-even point (BEP) analysis was performed. The price of the RES kits was set as the variation parameter and the IRR as the target parameter. The objective was to find the RES kit price that leads to an IRR that is equal to the considered discount rate (5%). The results obtained for all groups, considering only the non-profitable systems, are portrayed in Table 15.

Table 13. Economic analysis results for Group V considering the three tariffs (T_{f1}, T_{f2}, T_{f3}) (1).

System Config.	NPV [€]			PI [%]			IRR [%]		
	T_{f1}	T_{f2}	T_{f3}	T_{f1}	T_{f2}	T_{f3}	T_{f1}	T_{f2}	T_{f3}
PV 0.64 kWp	*−1613.0*	*−1068.2*	*−905.4*	*0.6*	*0.7*	*0.8*	*−1.0*	*1.0*	*2.0*
PV 1 kWp	*−1372.6*	*−692.1*	*−534.4*	*0.7*	*0.8*	*0.9*	*1.0*	*3.0*	*4.0*
PV 1.5 kWp	*−1319.5*	*−560.6*	*−424.3*	*0.7*	*0.9*	*0.9*	*1.0*	*3.0*	*4.0*
Wind 0.94 kWp	*−2733.3*	*−2513.1*	*−2374.9*	*0.3*	*0.3*	*0.4*	*−7.0*	*−6.0*	*−5.0*
Wind 3.1 kWp	*−1309.5*	*−990.0*	*−876.6*	*0.7*	*0.8*	*0.8*	*1.0*	*2.0*	*3.0*
Wind 5 kWp	*−715.9*	*−339.4*	*−224.7*	*0.9*	*0.9*	*1.0*	*3.0*	*4.0*	*4.0*
Hybrid (PV + Wind)	*−2326.1*	*−2010.0*	*−1873.3*	*0.6*	*0.6*	*0.7*	*−1.0*	*0.0*	*0.0*

Table 14. Economic analysis results for Group V considering the three tariffs (T_{f1}, T_{f2}, T_{f3}) (2).

System Config.	DPP [Years]			LCOE [€/kWh]		
	T_{f1}	T_{f2}	T_{f3}	T_{f1}	T_{f2}	T_{f3}
PV 0.64 kWp	*>20*	*>20*	*>20*	*0.3*	*0.3*	*0.3*
PV 1 kWp	*>20*	*>20*	*>20*	*0.4*	*0.4*	*0.4*
PV 1.5 kWp	*>20*	*>20*	*>20*	*0.4*	*0.4*	*0.4*
Wind 0.94 kWp	*>20*	*>20*	*>20*	*0.3*	*0.3*	*0.3*
Wind 3.1 kWp	*>20*	*>20*	*>20*	*0.4*	*0.4*	*0.4*
Wind 5 kWp	*>20*	*>20*	*>20*	*0.4*	*0.4*	*0.4*
Hybrid (PV + Wind)	*>20*	*>20*	*>20*	*0.5*	*0.5*	*0.5*

In Group I, “Hybrid (PV + Wind)” is the nearest BEP configuration, as it would be lucrative if the price was reduced to about 25% of its current value. The “Wind 0.94 kWp” configuration needs to lower to 77% of its current price.

In Group II and Group IV, according to the sensitivity analysis, only the “Wind 0.94 kWp” system must decrease by 48% in a bi-hourly tariff T_{f2}, or 54% if the simple tariff of T_{f1}, or all tariffs, were considered.

In Group III, "Hybrid (PV + Wind)", it would be lucrative if the price was reduced to about 15% of its current value, but only in the simple tariff T_{f1}. The "Wind 0.94 kWp" configuration needs to lower to about 47% of its current price if all tariffs are considered for the investment.

Finally, in Group V, a reduction is required in all configurations for respective investments to be viable. In the worst case, it is necessary to reduce this to about 72% of its current price to obtain a potentially interesting project. It is worth noting that the configuration "Wind 5 kWp" requires a minor reduction of 15% in the system price to become lucrative.

Table 15. BEP analysis considering only the not profitable case groups.

Group	System Configuration	Kit Current Price [€]	[€/Wp]			[% of Current Price]		
			T_{f1}	T_{f2}	T_{f3}	T_{f1}	T_{f2}	T_{f3}
I $B_{ase-}C_{ase}$	PV 0.64 kWp	1.38	0.32	0.32	0.32	77%	77%	77%
	Hybrid (PV + Wind)	0.52	0.52	0.52	0.52	25%	25%	25%
II $S_{elf}C_{onsumption}$ w_{ith} S_{urplus} $I_{njection}$	Wind 0.94 kWp	1.38	0.64	0.72	0.69	54%	48%	50%
III $S_{elf}C_{onsumption}$ w_{ithout} S_{urplus} $I_{njection}$	Wind 0.94 kWp	1.38	0.73	0.81	0.79	47%	41%	43%
	Hybrid (PV + Wind)	0.52	0.44	–	–	15%	–	–
IV $S_{elf}C_{onsumption}$ w_{ith} $N_{et}M_{etering}$	Wind 0.94 kWp	1.38	0.64	0.72	0.69	54%	48%	50%
V $S_{elf}C_{onsumption}$ w_{ith} S_{torage}	PV 0.64 kWp	3.93	2.16	2.75	2.91	45%	30%	26%
	PV 1 kWp	4.05	2.63	3.32	3.49	35%	18%	14%
	PV 1.5 kWp	2.91	2.01	2.50	2.62	31%	14%	10%
	Wind 0.94 kWp	4.55	1.27	1.50	1,64	72%	67%	64%
	Wind 3.1 kWp	4.57	3.34	3.61	3.70	27%	21%	19%
	Wind 5 kWp	3.13	2.66	2.88	2.95	15%	8%	6%
	Hybrid (PV + Wind)	1.11	0.68	0.73	0.76	39%	34%	32%

5. Discussion

This research concludes that the most economical solution is "Wind 5 kWp", Group IV, although net-metering, unfortunately, is still not considered in Portugal. The second most interesting solution from an economic perspective is "PV 1.5 kWp", also from Group IV. It should be noted that the selection of tariff type can have a relevant impact on the viability of the project. For example, "PV 1.5 kWp" has a DPP of 5.6 years (5 years, 7 months, and 6 days) on the simple tariff T_{f1}, while the bi-hourly tariff option T_{f2} allows for the DPP to be reduced to 4.8 years (4 years, 9 months, and 18 days). It was demonstrated that, at present, the bi-hourly tariff T_{f2} is the best of the three existing tariffs for residential customers, while the simple tariff T_{f1} was the worst.

At present, "Wind 5 kWp" and "PV 1.5 kWp", in Group III, are obvious solutions to consider for investment, thanks to the reduction in the bidirectional meter's price and the increase in the amount paid for the injected power, as shown in Figure 3.

The RES system configuration "PV 0.64 kWp", Group II, also remains an excellent investment solution for the prosumer. In this way, this RES system configuration, which is designed only for self-consumption, should be sized to the lowest possible peak consumption throughout the day, avoiding the electrical power injection in LV network.

Group I projects, which provided the base case, mostly have a return on investment at present; however, they are not recommended because they have a longer payback period than the solutions to the other analyzed groups.

None of the Group V (storage system) projects are available for investment. As seen in Figure 4, the last bar "PV 1.5 kWp + Storage" illustrates the higher electricity cost-savings. However, this economic is not worthwhile, mainly due to battery costs. At present, RES system configurations with storage are still not really economically viable, mainly due to the high price of storage, even though its price decreased each year.

The solutions of wind configurations, mainly "Wind 5 kWp", can be interesting for investment, mainly in a rural area. However, due to their characteristics, they have the drawback of being difficult to implement in an urban area, unlike PV configurations, which are more flexible in this regard. This research verified that the RES hybrid configuration is not interesting for investment due to its high initial cost.

The network parity can be verified by the LCOE parameter, which determines whether the cost of generating and consuming any kind of RES electrical energy is more cost-effective than buying it from the LV network. From this research, it is possible to perceive that the LCOE values of all non-viable RES configurations from all five considered groups are higher than the mean cost of the LV network power purchase tariff (nearly 0.16 €/kWh).

6. Conclusions

The RES generation paradigm has changed worldwide, and more consumers are choosing to "consume" energy generated by RES systems, such as wind or photovoltaic systems, benefiting from incentives supported by government-backed policies. The concept of SG is close to this model and can be of critical relevance in the management of intelligent energy distribution networks. Consequently, it is necessary to carry out technical–economic assessments to understand the evolution of RES investment viability.

This article presents an economical study that investigates the feasibility of prosumer investment, considering various RES configurations and scenarios. Seven RES configurations were proposed for investment analysis: "PV 0.64 kWp", "PV 1 kWp", "PV 1.5 kWp", "Wind 0.94 kWp", "Wind 3.1 kWp", "Wind 5 kWp" and "Hybrid (PV + Wind)". Additionally, five groups of scenarios were proposed for economic analysis: (I) the prosumer consumes all electricity from the LV network and injects all produced energy into the LV network; (II) the prosumer self-consumes the RES-generated electric power and injects all surplus electricity into the LV network; (III) the prosumer only self-consumes the RES-generated electric power; (IV) the prosumer self-consumes the RES-generated electric power and injects all surplus electricity into the LV network, following the net-metering model; (V) the prosumer self-consumes the electricity produced by RES and stores the surplus electricity in the storage systems for later consumption.

This research concludes that the most economical solutions are both "Wind 5 kWp" and "PV 1.5 kWp", from Group IV, which contain self-consumption with net-metering. In the actual Portugese framework, the increase in the amount paid for the injected power and the reduction in the price of the bidirectional meter contribute to the selection of other RES configurations as investments of interest, such as "Wind 5 kWp" and "PV 1.5 kWp" of Group III, self-consumption with surplus injection. "PV 0.64 kWp" of Group II, which contains self-consumption without surplus injection, is another excellent alternative to prosumer investment, in which this kind of RES system configuration, which is designed only for self-consumption, should be sized to the lowest possible peak consumption throughout the day, avoiding surplus injections in the LV network. [Authors]The results indicate that all configurations that include storage systems are not viable for investment, due to the storage investment costs, which are still high.

It is also concluded that the type of tariff has an important relevance regarding the project's viability. It was demonstrated that, at present, the bi-hourly tariff, T_{f2} is the best of the three existing tariffs for residential customers, where the simple tariff, T_{f1}, turns out to be the worst. For the "PV 1.5 kWp" configuration of Group IV, while the bi-hourly tariff has a DPP of 4.8 years (4 years, 9 months, and 18 days), the simple tariff has a DPP of 5.6 years (5 years, 7 months, and 6 days).

The verification of the LCOE parameter leads to the conclusion that a reduction in the prices of RES kits will improve the economic viability of residential RES system projects. The economic viability of all RES configurations with storage systems is only possible with a sustained decrease in storage system prices and a longer lifetime, although battery technology has evolved greatly in recent years.

Finally, the net-metering context is the most cost-effective for residential consumers, for most RES configurations. In this way, the authors suggest the implementation of the net-metering model due to its obvious advantages. One way to facilitate the adoption of this model in electrical system planning is the adjustment of reasonable net-metering rules, where consumers pay a fee for using the LV network as long-term storage.

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Abbreviations

The following abbreviations are used in this manuscript:

RES	Renewable Energy Sources
PV	Photovoltaic
SG	Smart Grid
LV	Low Voltage
μG	Microgeneration
EV	Electric Vehicle
LCOE	Levelized Cost Of Energy
CUR	Last Resort Supplier
O&M	Operation and Maintenance
IRR	Internal Rate of Return
NPV	Net Present Value
PI	Profitable Index
DPP	Discounted Payback Period
ERSE	Energy Services National Regulatory Authority
OMIE	Iberian Energy Market Operator
DOD	Depth Of Discharge
DGEG	Direção Geral de Energia e Geologia

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