20th International Conference on Renewable Energies and Power Quality (ICREPQ'22)
Vigo (Spain), 27th to 29th July 2022
Renewable Energy and Power Quality Journal (RE&PQJ)
ISSN 2172-038 X, Volume No.20, September 2022

Methodology for designing an Energy Community and its application to the municipality of Vinalesa

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Abstract. Energy communities represent a new energy management model for the use of local energy resources, in which different social actors participate in search of energy, environmental, social and economic benefits. Nevertheless, there is still a lack of concise guidelines in the literature dealing with the more technical aspects of energy communities. The aim of this article is presenting a methodology to support the design of new energy communities based on energetic, economic and environmental conditions in order to analyse their technical and economic viability.

The methodology is supported by Homer Grid modelling software for simulating and optimising possible energy scenarios. This is better suited to energy communities connected to the grid, with renewable energy generation assets from local resources and with an equitable distribution of benefits for all members.

The methodology has been applied to a case study in the village of Vinalesa, sizing the community's generation assets as well as the electricity tariff. Their implementation in the case study results in an installation of 870 kW of photovoltaic energy and capacity storage of 1.08 MWh in Lithium-Ion batteries that allows the residents of Vinalesa have additional savings of around 16.4% in their electricity bill.

Key words. Energy community, energy transition, energy democracy, prosumer, energy scenarios.

1. Introduction

Energy associations created to share local energy resources in a distributed manner are not new. However, until recently, these associations lacked a clear status in EU and national legislations and took different forms of legal structure such as energy cooperatives [1]. In recent years, they have gained recognition as a legal form in the new EU legislative framework shaped by Directive (EU) 2018/2001 on the promotion of the use of Energy from Renewable Sources [2] and the recent Directive (EU) 2019/944 on common rules for the Internal Electricity Market [3]. It is an incipient concept that is still in the process of being adapted to the different EU member states. In Spain, this concept is included for the first time in Royal Decree-Law 23/2020 [4].

However, even though the first promotion plans for Energy Communities are starting to be created in some autonomous communities, there is still a lack of a detailed regulatory framework, more technical and concise guidelines to facilitate their configuration and greater public awareness to generate confidence so that they can really make their way in the energy market [5]. Nowadays, the more technical aspects of the design of energy communities is a matter that private companies of energy sector are beginning to take over. At the public level there is little more than general guidelines such as the one from IDAE [6] or the manual of the European Community Energy Coalition [7], which attempt to expand on the definitions contained in the directives and provide some case studies, but not going into detail on the technical aspects that are necessary to configure an energy community and examine its potential and viability. This article aims to expand on the scarce literature on this aspect and shed some light on the more technical aspects of energy communities' design. It will do so through a methodology and its application in a practical case study to support the sizing of the community's generation assets and the electricity tariff according to the conditions of the environment.

Prior to the development of the methodology, several previous cases of energy cooperatives have been studied, especially from north western countries with strong community traditions such as Germany or Sweden [8] and the organisational structure of the first energy communities emerging in Spain such as Comptem [9] or CER Sapiens Energía [10] have also been considered. In addition, the technical regulatory aspects indicated by the CEER have been taken into account [11].

As it can be seen in Figure 1, the methodology is organised of 3 different blocks, each of which provides key information to refine and optimise the design of the Energy Community. They are:

- Phase 1: Selection of energy generation technology and preliminary sizing.
- Phase 2: Final configuration and sizing of the power plant with commercial components.
- Phase 3: Design of the new electricity tariff and economic feasibility analysis.

Regarding the case study, Vinalesa currently has an electricity cooperative, responsible for the distribution and commercialisation of electricity in the village [12]. However, all the electricity supplied is directly purchased from the grid, so it seems highly convenient to consider the implementation of local generation systems, taking advantage of their own distribution infrastructure, the existing social structure, and their electricity trading cooperative to take the next step and become an Energy Community that generates and consumes its own energy.

The results obtained after applying the developed methodology to the case study reveal the profitability of the energy communities since they produce savings in electricity bills and are amortised within a short period of time. Energy communities are therefore an effective way of harnessing natural resources in a way that reduces atmospheric emissions, energy poverty and increases cooperation and social awareness.

2. Methodology for the design of energy communities

The methodology developed is a roadmap that considers the most important technical and economic parameters when designing an efficient and viable energy community. It consists of 3 different phases depending on the decision that will help us to make, each of which provides key information that will serve as a guide to refine and optimise the design of the Energy Community.

A. Phase 1: Choice of generation technology and preliminary sizing.

In this phase it is defined the input parameters to be taken into account for the design of the energy community, which are: the natural resources and meteorological conditions of the environment; the hourly energy consumption of the community members during a representative period of time; the current tariff with which energy is purchased from the grid; the generation technologies to be considered with the operating parameters and the typical investment, replacement, operation and maintenance costs; and some economic parameters such as the real discount rate, the useful life of the project or the incentives.

Homer Grid software is used as a calculation tool as it can simulate and optimise different energy scenarios depending on the input parameters.

The energy variables involved in each scenario are the size (in kW) of each renewable energy generation technology, the nº of batteries and the size of the electrical converter (if necessary). In each simulation, for each time step, the behaviour and performance of the system and its costs over the lifetime are calculated, until an optimal solution is reached when the convergence criteria of the indicated energy variables and the net present cost converge.

As output, it shows the most relevant economic, energy and environmental values of the set of simulations carried out and classifies the resulting scenarios according to the optimisation criterion of interest. The first criterion is usually the net present or life cycle cost, NPC (€), which tells us immediately whether the simulated system is cheaper or more expensive than the base scenario and by how much. This parameter, together with the levelized cost of energy or LCOE (€/kWh), are the two key results to understand if the solution is suitable or if further iteration is necessary. The LCOE gives a value of the potential cost of each simulated energy system or scenario to produce the energy by considering the total average cost of building, operating and maintaining the power plant and dividing it by the total useful energy generated by the plant over its lifetime. In addition to these two parameters, the resulting renewable fraction, the excess energy of the system, the payback period and the IRR are also very important for decision making. Based on these results, the starting conditions are further refined until a design that meets our needs is achieved.

This first phase will help us to choose the energy technologies that are best suited to each case and to obtain a preliminary dimensioning of the same.

B. Phase 2: Configuration and final sizing of the generation plant with commercial components.

With the information from phase I, where some generation technologies are discarded and the preliminary sizing of the selected ones is obtained, there is a good starting point to know the size of the commercial equipment of our community. Different models can be taken and compared when running simulations again in Homer Grid to obtain more realistic and accurate results. In addition, environmental constraints such as the space available to install the generation equipment should be considered at this point and the choice of one model or another should be made.

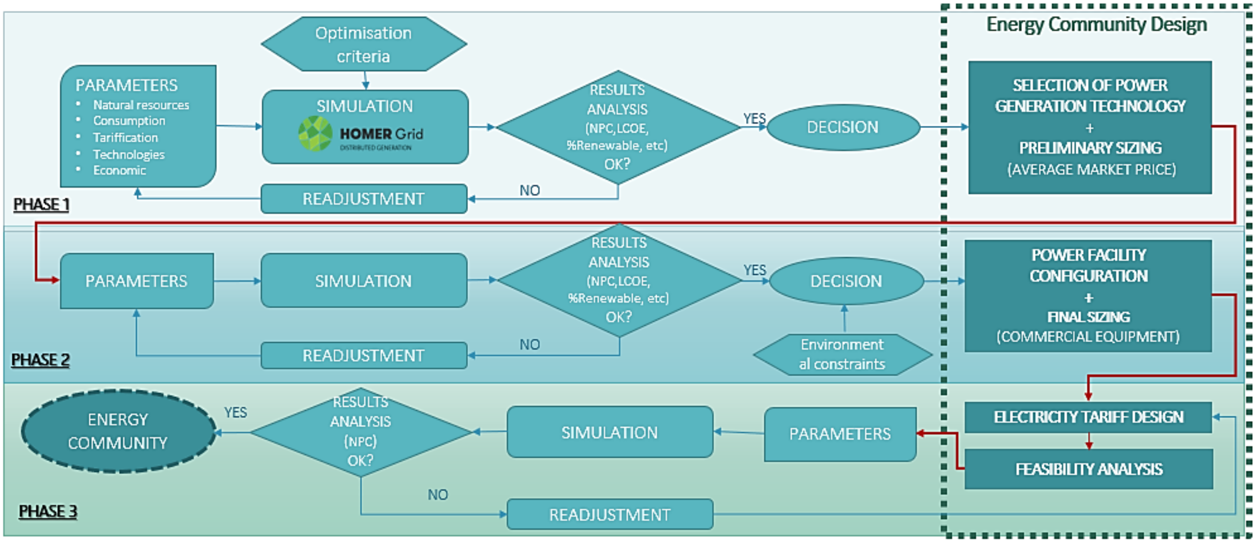


Fig. 1. Methodology proposed for the design of Energy Community

C. *Phase 3: Design of the new electricity tariff and economic viability analysis.*

Finally, for the design of the new electricity tariff for the community, we start from the levelized cost of electricity (LCOE) obtained in the winning simulation system of Phase II. The aim of designing the new tariff is to reflect the shared self-consumption of the new energy community but maintaining the tariff structure and the periods currently used by the electricity cooperative. To this end, a linear extrapolation will be made, as will be explain below.

3. Case study

The objective is to design a renewable energy community in the village of Vinalesa, which currently has an indigenous electricity cooperative, responsible for the distribution and commercialisation of electricity to the inhabitants, businesses and industries of the village. However, all the electricity supplied is purchased from the general grid. Applying this methodology, it is intended to calculate the optimal size of local renewable generators to generate and consume their own energy at a reasonable profitability without any external financing beyond the savings produced by self-consumption and without disconnecting from the general grid. The community to be designed will not sell surpluses to the grid, so the generation facilities will be sized in such a way that self-consumption is the maximum possible and the excess produced is the minimum possible.

A. *Phase 1: Selection of generation technology and preliminary sizing.*

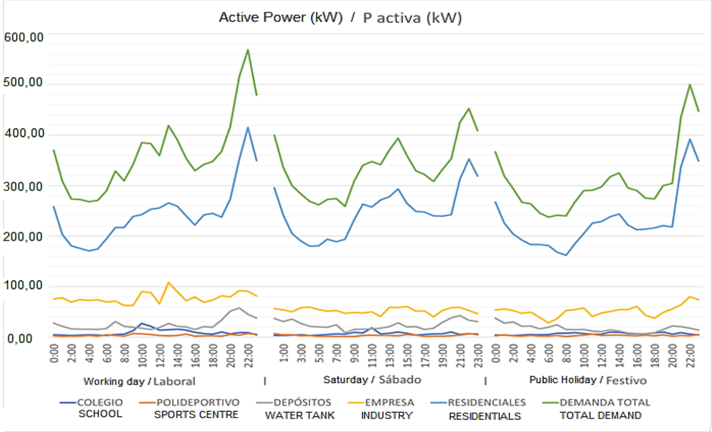
The natural resources available in Vinalesa are solar and wind, whose values for one year were taken from the NASA Prediction of Worldwide Energy Resource (POWER) database. The temperature of the area was also considered as it has a considerable influence on the quality of operation of the components and their deterioration throughout their useful life.

The electricity consumptions considered for the simulations were obtained from real measurements taken at 5 of the town's transformer stations over several months and included quarter-hourly consumptions of residential, commercial, and public entities. Subsequently, hourly demand curves were typified for working days, Saturdays and Sundays and public holidays as shown in *Figure 2*. In addition, to estimate the rest of the hourly demand throughout the year, monthly demand curves were synthesised, adding a typical seasonal variability plus a random variability of 10% between days of the month and between times of the day.

In the aggregate curve, the minimums of total energy consumed would be marked mainly by the consumption of the industrial company, as it needs to have the freezer chambers always connected, while the maximums would be marked by residential consumption, which is the largest and most decisive in the sample. The average hourly total demand over the year is in the order of 327.11 kWh and the maximum peak power is 766.13 kW.

The pricing of the energy purchased from the grid is going to be done considering the tariff that the Vinalesa supplier had. In the base case or current case of Vinalesa, all the energy will be purchased from the grid, while in the study scenarios only the percentage that cannot be covered by the community's own assets and batteries will be purchased.

Fig. 2. Demand curve by consumption profile and aggregated in spring.



The generation technologies considered are photovoltaic panels, wind turbines, the inverter and batteries of different technologies for comparison (Lead Acid, Lithium Ion and Vanadium redox flow). The chosen parameters and costs shown in the following tables are typical values for today and have been extracted from different studies of the International Renewable Energy Agency [13],[14].

The economic parameters considered were 25 years of project lifetime, a 5.88% real discount rate and an additional fixed plant O&M cost of €20,000/year.

B. *Phase 2: Final configuration and sizing of the power plant with commercial components.*

This phase is starting from the results obtained in phase I, where wind energy and storage with lead-vanadium batteries have been discarded and PV, lithium-ion batteries and the grid have been chosen to configure the hybrid system. In addition, a preliminary sizing of these elements has been obtained to seek for commercial models that adapt to this range. Some of the commercial equipment considered and some of their main characteristics are shown in Table 1. In this second simulation, different models were taken and iterated until sufficiently good results were obtained.

Table 1 Commercial technologies finally considered for the energy community

Technology	**Model**	**Main features**	**Investment cost**	**Life span (years)**
Photovoltaic	FV Model A-330p Ultra	330 W	500€/module	25
Battery modules	LGChem M48126P3B	126 Ah / 6,44kWh	5000 €	10
	EnerDel Secure plus	168 Ah / 101 kWh	45.000 €	10
	Tesla PowerPack 2	553 Ah / 210 kWh	150.000 €	10
Conversion system	Centralised Inverter	500 kW	76.500€	10

	Sinexcel 500 kW			

The input parameters related to natural resources, consumption and electricity tariff have been left the same as in phase 1, except for adding an additional fixed capital cost of €100,000 to the economic parameters to consider all those additional installation elements such as the anti-spill system and to make the system more conservative.

C. Phase 3: Design of the new electricity tariff and analysis of economic viability.

For the design of the new tariff, only the energy term is taken into account and the power term is left the same than the current tariffs of the electrical cooperative, as it is a term that is practically legally regulated in its entirety.

Firstly, it is necessary to find relationships within the current Vinalesa tariffs in order to be able to use them in the design of the new tariff. We will start with the 2.0 TD tariff and then transfer the results to the 3.0 TD and 6.1 TD tariffs. To do this, the ratios that directly relate the levelised cost of electricity (LCOE) obtained with Homer for the base system (0.189 €/kWh) with the prices of the Energy Term (ET) of the current 2.0TD tariff of the Vinalesa cooperative are sought. What is going to be done is simply to calculate the average of the energy term of the three periods of the 2.0TD tariff and obtain the relation with the LCOE of the base case (1). On the other hand, the ratios between the prices of the energy term of each period (ETi) and the average of the three periods will be calculated (2).

$$r_{LCOE} = \frac{\frac{TE_1 + TE_2 + TE_3}{3}}{LCOE} \qquad (1)$$

$$r_{periodo\,i} = \frac{TE_i}{\frac{TE_1 + TE_2 + TE_3}{3}} \qquad (2)$$

With these 4 ratios, a first approximation of the new tariff can be made. The average energy term of the new tariff for the community will be obtained by multiplying the LCOE of the hybrid system obtained in phase 2 (0.155 €/kWh) by the ratio of the LCOE calculated with the base case (r_{LCOE}). On the other hand, to obtain the new prices for each tariff period, simply multiply this average by the ratios for each period calculated with the base case ($r_{period\ i}$). The results of the calculations are shown in the table below:

Table 2 Calculations of the new 2.0 TD tariff of the Vinalesa Energy Community

	BASE CASE VINALESA	**RATIOS**	**VINALESA ENERGY COMMUNITY**
ET PERIOD 1 (*10-14,18-22 h*)	0,226660 €/kWh	$r_{period\ 1}$=1,55648	0,185885 €/kWh
ET PERIOD 2 (*8-10, 14-18, 22-24 h*)	0,129453 €/kWh	$r_{period\ 2}$=0,88896	0,106165 €/kWh
ET PERIOD 3 (*0-8h, Weekend)*	0,080756 €/kWh	$r_{period\ 3}$=0,55455	0,066228 €/kWh
LCOE	0,189 €/kWh	r_{LCOE}=0,77049	0,155 €/kWh
AVERAGE ET	0,145623 €/kWh	→	0,11788529 €/kWh

The new energy term calculated would correspond to an average of the cost of self-consumed electricity (which is the depreciation of the energy system) and that of the grid (including tolls and regulated charges).

To check the feasibility of the tariff, a scenario has been simulated again in Homer with the same consumption and natural resources but where all the energy is purchased from the grid at the price of the new tariff designed. NPC values obtained are slightly higher than those obtained in phase 2, which means that all the costs of the energy community (amortisation of the hybrid renewable system + purchases from the grid) would be covered and in addition an extra profit margin would be obtained for the supplier which could amount to 8,596.3 € and be used as a reserve to cover possible unforeseen risks or reinvested in one of the social causes of the community itself.

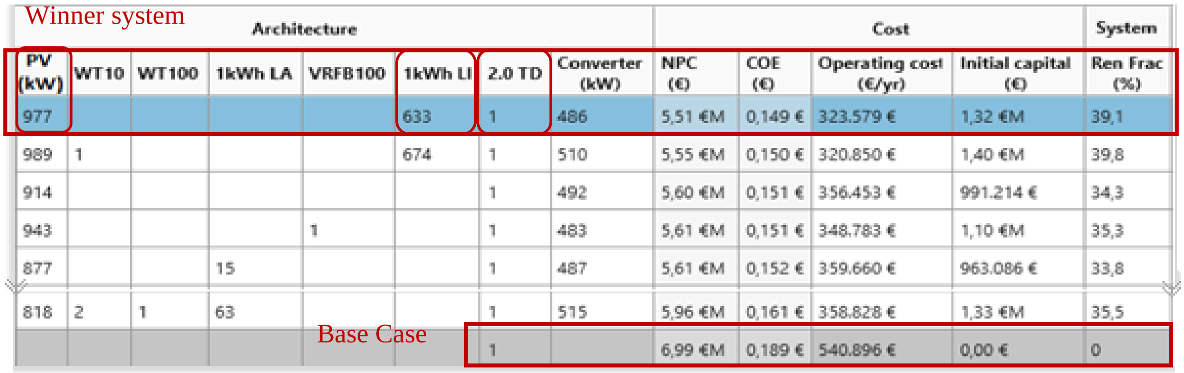
4. Results

A. Phase 1

Fig. 3 shows the results obtained after the simulation, where the energy scenario with the lowest net present cost (NPC) is the one composed of photovoltaic panels (PV), lithium batteries (1kWh LI) and the grid (2.0 TD). With this hybrid system of 977 kW of power and a storage capacity of 633kWh, a levelised cost of energy (COE) of 0.149€/kWh is obtained, 4 cents lower than the base case (0.189€/kWh), which is not negligible as it represents a reduction in the cost of electricity of 21%. The fraction of useful consumption that is covered by renewable energies is 39.1%.

Few years ago, it would be hard to imagine that the addition of batteries to a hybrid PV/grid system could be profitable, this simulation shows the steep year-on-year falls in the price of PV panels and batteries (of the order of more than 85% in the last 10 years), which are making this combination of technologies increasingly interesting, especially for medium-scale distributed generation and shared self-consumption. Wind power (WT10 and WT100) as well as lead-acid (1kWh LA) and vanadium (VRFB100) batteries are left out of the most cost-effective options.

Fig 3 Results of the optimal scenarios of simulation 1 in Phase I



Architecture								Cost				System
PV (kW)	WT10	WT100	1kWh LA	VRFB100	1kWh LI	2.0 TD	Converter (kW)	NPC (€)	COE (€)	Operating cost (€/yr)	Initial capital (€)	Ren Frac (%)
977					633	1	486	5,51 €M	0,149 €	323.579 €	1,32 €M	39,1
989	1				674	1	510	5,55 €M	0,150 €	320.850 €	1,40 €M	39,8
914						1	492	5,60 €M	0,151 €	356.453 €	991.214 €	34,3
943				1		1	483	5,61 €M	0,151 €	348.783 €	1,10 €M	35,3
877			15			1	487	5,61 €M	0,152 €	359.660 €	963.086 €	33,8
818	2	1	63			1	515	5,96 €M	0,161 €	358.828 €	1,33 €M	35,5
						1		6,99 €M	0,189 €	540.896 €	0,00 €	0

It is also interesting to look at the results in table 3. As can be seen, the IRR is a quite acceptable value considering that the investment is intended to generate savings rather than profits. On the other hand, an amortisation of the system including discounting in 7.37 years is considered quite reasonable, so it can be stated that the community energy approach is economically viable.

Table 3 Relevant results of winning system parameters in phase 1

Energy excess	7,64%
Battery autonomy	1,55 h
Internal rate of return (IRR)	16,30 %
Discounted payback period	7,37 years
Annual savings in the purchase of electricity from the grid	237.911€
Total savings in the purchase of electricity from the grid	5,95 M€

B. Phase 2

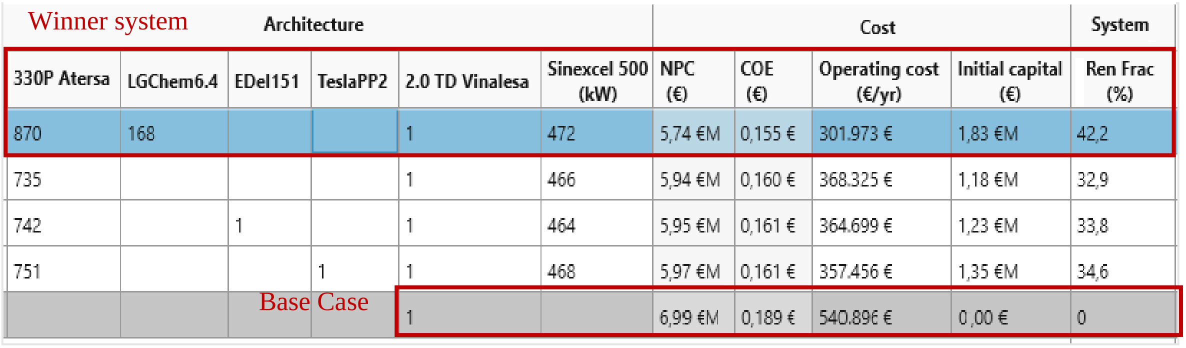
Entering the parameters of the commercial models into Homer Grid yielded the results in Fig.4. As we can see, the levelized cost of energy (COE) in the optimal scenario is 0.155 €/kWh, which is not very far from the first generalised simulation where it was 0.149 €/kWh without considering the percentage of additional fixed costs, so at first sight it seems to be an acceptable system. The battery model that best suits our case is the LGChem. The software recommends installing 168 modules of this battery, which would be equivalent to a storage capacity of 1.08 MWh. This hybrid system has a higher storage capacity and a lower photovoltaic capacity than the one in phase 1, however the fraction of useful consumption covered by renewables is higher (42.2% compared to 39.1%), making it more efficient.

Regarding the economic parameters of the IRR and the payback period reflected in table 4, the system has become slightly more expensive compared to phase 1 (mainly due to the fixed capital cost considered and the increase in battery capacity), however, this system makes better use of self-production as it has more autonomy and fewer excesses. Therefore, the annual savings in grid purchases are 13.46% higher in this second simulation compared to phase 1.

Table 4 Relevant results of winning system parameters in phase 1

Energy excess	3,19%
Battery autonomy	3 h
Internal rate of return (IRR)	13,40 %
Discounted payback period	8,83 years
Annual savings in the purchase of electricity from the grid	269.946.78 €
Total savings in the purchase of electricity from the grid	6,74 M€

Fig 4 Results of the optimal scenarios of the simulation in phase 2



Architecture						Cost				System
330P Atersa	LGChem6.4	EDel151	TeslaPP2	2.0 TD Vinalesa	Sinexcel 500 (kW)	NPC (€)	COE (€)	Operating cost (€/yr)	Initial capital (€)	Ren Frac (%)
870	168			1	472	5,74 €M	0,155 €	301.973 €	1,83 €M	42,2
735				1	466	5,94 €M	0,160 €	368.325 €	1,18 €M	32,9
742		1		1	464	5,95 €M	0,161 €	364.699 €	1,23 €M	33,8
751			1	1	468	5,97 €M	0,161 €	357.456 €	1,35 €M	34,6
				1		6,99 €M	0,189 €	540.896 €	0,00 €	0

C. Phase 3

The new tariff designed based on the levelized energy price of the system that configures the energy community has an energy term 18% cheaper than that of the old 2.0 TD tariff. The same percentage reduction will be applied to the other 3.0 TD and 6.0 TD contracts, so that the price table will be as it showed in Table 5.

Table 5 Comparison of the new tariff of the Vinalesa Energy Community and the current tariff

			Old Tariff	***New EC Tariff***
		DEMAND CHARGE	**CONSUMPTION RATE**	**CONSUMPTION RATE**
2.0 TD	PERIOD 1	0,089514 €/kW day	0,226660 €/KWh	0,185885 €/kWh
	PERIOD 2	0,020341 €/KW day	0,129453 €/KWh	0,106165 €/kWh
	PERIOD 3	----	0,080756 €/KWh	0,066228 €/kWh
3.0 TD	PERIOD 1	0,061781 €/KW day	0,175590 €/KWh	0,144002 €/KWh
	PERIOD 2	0,044828 €/KW day	0,149824 €/KWh	0,122871 €/KWh
	PERIOD 3	0,022043 €/KW day	0,120355 €/KWh	0,098703 €/KWh
	PERIOD 4	0,018897 €/KW day	0,104521 €/KWh	0,08571 €/KWh
	PERIOD 5	0,012923 €/KW day	0,088205 €/KWh	0,072337 €/KWh
	PERIOD 6	0,008095 €/KW day	0,079431 €/KWh	0,065141 €/KWh
6.1 TD	PERIOD 1	0,090952 €/KW day	0,133862 €/KWh	0,109781 €/KWh
	PERIOD 2	0,078236 €/KW day	0,115644 €/KWh	0,094840 €/KWh
	PERIOD 3	0,044805 €/KW day	0,097066 €/KWh	0,079604 €/KWh
	PERIOD 4	0,036127 €/KW day	0,086470 €/KWh	0,070915 €/KWh
	PERIOD 5	0,010983 €/KW day	0,072677 €/KWh	0,059603 €/KWh
	PERIOD 6	0,005970 €/KW day	0,065821 €/KWh	0,053980 €/KWh

Considering the cooperative's annual consumption, the new tariffs would provide members with an annual saving of 89.312€, which would be distributed equally among all members' bills, or in other words, the saving on their electricity bill would be 16.4%.

5. Conclusion

The proposed methodology is a useful tool for designing energy communities that remain connected to the grid, share generation assets with renewable energy and make an equitable distribution of the energy and economic benefits that can be obtained. It allows the selection and sizing of renewable generation assets in a precise and optimal way, as well as the economic and technological feasibility of the hybrid system to be installed in the community. It also offers a simple calculation method to calculate new electricity tariffs for the members of the community based on the levelized cost of energy obtained with the hybrid system.

Thanks to this methodology it has been possible to verify that with the installation of 870 kW of photovoltaic energy and a capacity of 1.08 MWh in Lithium-Ion batteries, the residents of the municipality of Vinalesa could have additional savings of around 16.4% on their electricity bill considering a depreciation of the power plant of 8.83 years.

This reveals that energy communities can be indeed one of the main pillars for the energy transition by achieving a more efficient, accessible, inclusive, and environmentally friendly energy system.

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