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Contribution to Collaborative Electricity Microgrid Management Strategies of Domestic Prosumers

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Abstract. The aim of this paper is to demonstrate that collaboration between microgrids should be varied and global in order to optimize the collaboration and therefore, decrease the dependence on the electrical grid. In the article, different scenarios will be defined where the prosumers will collaborate by selling or buying their electricity generation through an energy management system. The designed energy management system distributes the energy flows of each prosumer considering a series of constraints, following a peer-to-peer (P2P) collaboration, specifically the store-then-cooperate (STC) method.

Key words. Electricity microgrids, domestic prosumers, collaborative microgrids, P2P energy trading.

1. Introduction

In the context of microgrids (MGs), there are currently a wide variety of energy production and storage mechanisms. It is very important to advance in the development and testing of collaborative microgrid systems of domestic prosumers to optimize such generation and storage and increase energy use [1].

A collaborative microgrid is one in which different microgrids share energy among them, possibly on a subsidiary basis. Prosumers and/or consumers in each of these "simple" microgrids can buy and sell energy and make, if they wish, a profit above the market price. Furthermore, a collaborative system of this type, with a strong impact of renewable energies, would imply a paradigm shift of the current electricity system with the objective of maximizing the use of this energy while minimizing costs for the prosumers involved.

This article analyses the collaboration between domestic prosumers in different circumstances and scenarios, with the aim of obtaining an idea of the strategies that should be carried out to optimize such collaboration. For this purpose, an energy management system has been developed in the Python programming environment, which makes the necessary decisions to distribute energy flows. Finally, the program, called 'energy manager', produces a report that provides a clear view of the benefits and magnitude of the collaboration. The study of this paper will focus on the aforementioned peer-to-peer (P2P) collaboration or P2P energy trading, which is basically a direct collaboration between different consumers and prosumers. In this collaboration, there is no intermediary other than the energy management system that will make the collaboration decisions. Focusing on the P2P modality chosen in this article, the so-called store-then-cooperate (STC), as the name indicates, the prosumer will first store the surplus energy and, in case it cannot store more energy, it will sell this energy to other consumers [2], [3].

2. General Information on Microgrids

A microgrid is a localized electrical network that generates and distributes energy in a local and decentralized manner [4], [5]. These microgrids are generally made up of generation sources (essentially renewable), consumptions, electric generators, storage devices and, in addition, with the possibility of connecting one or several electric vehicles [5]. Likewise, MGs are controlled and managed by so-called 'energy management systems' (or EMS) [6], which constantly analyse energy flows and make the appropriate decisions according to the needs and pre-established conditions.

In the present work, the elements that will make up the microgrids will be photovoltaic (PV) and/or wind generation sources, domestic consumption and storage devices.

3. Simulation environment in Python for collaborative

As already mentioned, the energy manager is designed according to P2P collaboration and among the P2P possibilities, the so-called store-then-cooperate (STC) modality [2]. The energy manager considered in this work has been designed using the Python programming environment. We can divide the energy manager program into two main phases: on the one hand, the individual program of each prosumer's microgrid and, on the other hand, the program for buying and selling between prosumers. Once the program has been executed, we will obtain a final report that will briefly summarize the most relevant results of the studied collaboration.

A. Purchase and Sale of the Individual Microgrid of each Prosumer.

The program studies the microgrid of each prosumer and, for each instant, performs the balance between generated and demanded energy of each prosumer. Once the results of excesses or needs of each prosumer are obtained, the program analyses the state of the batteries and charges or discharges them as needed.

Finally, the program updates the excesses and final needs of each prosumer that will be satisfied through collaboration among them or, as a last option, thanks to the purchase and sale of energy from the power grid.

B. Sale and Purchase of Energy between Prosumers.

In this part, the program analyses the needs of each prosumer and, according to the selling prices established by the prosumers themselves, will make the buying and selling decisions between prosumers. These decisions will be made taking into account that there are many prosumers involved and that, obviously, they all want to buy at the lowest price. A strategy of sharing energy from one seller to several buyers is established in case there is more than one buyer at that moment.

4. Definition of the Domestic Prosumers

The MGs under study in the present work, which work collaboratively, are made up of six homes, each of which will have its own annual consumption and generation profiles.

A. Prosumer Consumption Characteristics.

The consumption pattern of prosumers has been extracted from the hypothetical power installed in the dwelling and its utilization factor. Each consumption pattern corresponds to the usual consumption patterns according to the type of family unit. For example, in the case of prosumer 2, the family unit is made up of two retired people and, therefore, consumption during daytime hours is higher than that of prosumer 1, which is a family that works during the day.

In the case of consumption, it will be necessary to establish the prosumers' tariff so that the program can carry out the economic balance. The prosumers' electricity tariff is the old 2.0DHA tariff which was characterized by the difference in price depending on the period of the day in which we are and depending on whether we are in the winter or summer calendar. The price reference of the tariff is shown in Table I.

B. Typology of Generation of each Prosumer.

In the case of generation, a specific generation is not established for each prosumer, but it will vary according to the case studied. Each installation has been dimensioned (tables II and III) taking into account the particular consumption of each of the prosumers considered in the study and, as a first approximation in this work, possible types of space limitations or technical characteristics that may exist have not been taken into account.

Table I.- Prices of the 2.0DHA electricity tariff considered in this work for the prosumers.

PRICE RATE 2.0DHA	
Peak Period	0,147 €/kWh
Valley Period	0,075 €/kWh
Energy Compensation	0,05 €/kWh

5. Definition of the Scenarios Proposed

The different scenarios or case studies in this paper provide an overview of the optimization of the collaboration. In each case, different geographical locations are studied for the different prosumers in different geographical areas of Spain, as well as different types of generation based on renewable sources.

A. Scenario 1 - Municipal Collaborative Photovoltaic Microgrids.

The prosumers of the different microgrids considered are located in the same municipality and all have PV generation (Table II). The generation varies between prosumers, thanks to the differences in inclination and, above all, orientation of the PV modules installed.

Table II.- Installed power for each of the six domestic prosumers considered in this work when considering exclusively photovoltaic generation.

	Nº Solar panels	Power (kWp)
Pr #1	15	4,65
Pr #2	30	9,3
Pr #3	43	13,33
Pr #4	44	13,64
Pr #5	44	13,64
Pr #6	16	4,96

B. Scenario 2 - Collaborative Photovoltaic Microgrids at the Autonomous Community level.

In this case, the generation of prosumers is maintained, but the location of the prosumers will vary, being located in different towns in Catalonia.

C. Scenario 3 - Collaborative Photovoltaic Microgrids at the National Level.

Prosumers are now located throughout Spain with the intention of improving collaboration between them. The generation of each one continues to have the same characteristics.

D. Scenario 4 - Collaborative Hybrid Microgrids in Autonomous Communities.

Prosumers #4 and #6 change their photovoltaic generation to wind generation and, in order to maximize production, they will be located in areas with the best wind speed in Catalonia. The two prosumers will have two 10 kW mini wind turbines, with the intention of generating a high amount of surplus and being able to sell it to other prosumers (Table III).

Table III.- Installed power for each of the six domestic prosumers considered in this work when two of them are considered to generate with wind energy.

	Nº Solar panels	Power (kWp)
Pr #1	15	4,65
Pr #2	30	9,3
Pr #3	43	13,33
Pr #5	44	13,64
	Power (kW)	
Pr #4	10	
Pr #6	10	

E. Scenario 5 - Hybrid Collaborative Microgrids at the National Level.

The last case contemplates the situation of a hybrid collaborative microgrid with prosumers distributed nationwide, where all the generations of the previous case are maintained. The locations of scenario 3 are maintained, with the exception of prosumers #4 and #6 that are relocated to areas of high windiness.

6. Comparative study of the different scenarios

This section will discuss the results of the program report for each simulation.

A. Scenario 1 - Municipal Collaboration Photovoltaic Microgrid.

This case is of special interest since, due to the fact that PV production occurs during the same hours of the day, all prosumers cover their needs during production hours. Energy is obtained only from PV generation and from the grid (Table IV). Note that the kWh of energy sold or purchased in the collaboration is practically non-existent.

Table IV.- Simulation results for scenario 1. The data represents a full year.

	Demanda Energética (kWh)	Generación total (kWh)	Energía comprada colaboración (kWh)	Energía vendida colaboración (kWh)	Energía inyectada a la red (kWh)	Energía consumida de la red (kWh)
Pr1	2570.4	6764.8	0	0	4409.35	245.21
Pr2	4952.79	12522.57	0	0	8422.47	876.1
Pr3	7090.45	17759.76	0	0	13015.54	2360.2
Pr4	7389.92	19519.8	0.01	0	15221.51	3106.56
Pr5	7384.1	18659.08	0	0.01	14329.98	3063.5
Pr6	2611.32	6966.99	0	0	4408.62	149.61

	Coste energia comprada colaborativamente (€)	Coste energía comprada de la red (€)	Ganancias energía vendida colaborativamente (€)	Ganancias energía inyectada a la red (€)	BENEFICIOS (€)
Pr1	0	23.03	0	220.47	197.44
Pr2	0	78.09	0	421.12	343.03
Pr3	0	257.58	0	650.78	393.2
Pr4	0	326.08	0	761.08	435
Pr5	0	322.44	0	716.5	394.06
Pr6	0	16.17	0	220.43	204.26

B. Scenario 2 - Collaborative Photovoltaic Microgrid in an Autonomous Community.

By varying the location of prosumers to different towns in Catalonia, production varies among prosumers and, as a consequence, there is a small increase in collaboration (Table V). In this case, it can be seen that the economic benefits obtained by the collaboration are still minimal (Table V).

Table V.- Simulation results for scenario 2.

	Demanda Energética (kWh)	Generación total (kWh)	Energía comprada colaboración (kWh)	Energía vendida colaboración (kWh)	Energía inyectada a la red (kWh)	Energía consumida de la red (kWh)
Pr1	2570.4	6871.31	0.2	1.25	4512.8	223.41
Pr2	4952.79	12353.71	6.21	0.58	8262.76	879.62
Pr3	7090.45	17731.55	4.78	15.63	12961.71	2341.78
Pr4	7389.92	19545.83	0.07	2.54	15192.51	3048.57
Pr5	7384.1	16758.17	14.57	7.73	12485.93	3129.83
Pr6	2611.32	6966.99	2.14	0.24	4408.38	147.47

	Coste energia comprada colaborativamente (€)	Coste energía comprada de la red (€)	Ganancias energía vendida colaborativamente (€)	Ganancias energía inyectada a la red (€)	BENEFICIOS (€)
Pr1	0.02	20.71	0.12	225.64	205.03
Pr2	0.45	78.48	0.04	413.14	334.25
Pr3	0.37	253.96	1.17	648.09	394.93
Pr4	0	317.3	0.2	759.63	442.53
Pr5	1.12	333.19	0.56	624.3	290.55
Pr6	0.16	15.87	0.02	220.42	204.41

C. Scenario 3 - Collaborative Photovoltaic Microgrid Nationwide.

In this case, collaboration continues to increase due to variations in production throughout Spain (Table VI). At the same time, the profits obtained from the sale and purchase of energy are increasing.

Table VI.- Simulation results for scenario 3.

	Demanda Energética (kWh)	Generación total (kWh)	Energía comprada colaboración (kWh)	Energía vendida colaboración (kWh)	Energía inyectada a la red (kWh)	Energía consumida de la red (kWh)
Pr1	2570.4	6426.86	2.02	5.18	4090.30	252.39
Pr2	4952.79	12353.71	15.49	10.98	8252.36	870.34
Pr3	7090.45	18049.34	10.89	6.07	13182.99	2246.1
Pr4	7389.92	20926.24	6.88	18.35	16555.82	3045.23
Pr5	7384.1	18407.07	7.96	20.09	14092.53	3101.19
Pr6	2611.32	5307.64	17.47	0.92	2912.19	270.79

	Coste energia comprada colaborativamente (€)	Coste energía comprada de la red (€)	Ganancias energía vendida colaborativamente (€)	Ganancias energía inyectada a la red (€)	BENEFICIOS (€)
Pr1	0.22	23.78	0.51	204.52	181.03
Pr2	1.24	77.25	1.05	412.62	335.18
Pr3	0.9	238.03	0.42	659.15	420.64
Pr4	0.58	309.9	1.44	827.79	518.75
Pr5	0.7	323.53	1.44	704.63	381.84
Pr6	1.29	27.17	0.09	145.61	117.24

D. Scenario 4 - Hybrid Collaborative Microgrid in Autonomous Community

This scenario begins to resemble more closely those we would consider real cases, where we find both photovoltaic power generation and wind power generation. Both have different generation patterns, which causes a considerable increase in collaboration when the photovoltaic installations do not produce (mainly at night) and, on the other hand, the wind ones do (Table VII). As can be seen, there is a total collaboration of 2,693.47 kWh per year. This amount of collaborative energy is already a considerable amount, and represents an economic saving for prosumers by purchasing it at a lower price than their electricity tariff.

Prosumers using photovoltaics buy energy during the months of low production (winter season). The example of prosumer #3 is shown (Fig. 1). However, prosumers #4 and #6, who generate wind, do not have a collaborative purchasing pattern, but buy on days when there is no wind generation (Figs. 2 y 3).

Table VII.- Simulation results for scenario 4.

	Demanda Energética (kWh)	Generación total (kWh)	Energía comprada colaboración (kWh)	Energía vendida colaboración (kWh)	Energía inyectada a la red (kWh)	Energía consumida de la red (kWh)
Pr1	2570.4	6871.31	64.09	20.54	4493.51	159.52
Pr2	4952.79	12353.71	233.16	16.76	8246.58	652.67
Pr3	7090.45	17731.55	444.33	413.47	12563.87	1902.23
Pr4	7389.92	7889.52	934.51	856.63	3000.5	2450.98
Pr5	7384.1	16758.17	593.5	829.93	11663.73	2550.9
Pr6	2611.32	6200.88	425.36	556.14	4087.75	706.41

	Coste energía comprada colaborativamente (€)	Coste energía comprada de la red (€)	Ganancias energía vendida colaborativamente (€)	Ganancias energía inyectada a la red (€)	BENEFICIOS (€)
Pr1	4.97	14.83	2.05	224.68	206.93
Pr2	18.1	57.71	1.31	412.33	337.83
Pr3	36.62	210.41	25.68	628.19	406.84
Pr4	67.75	301.3	68.58	150.02	-150.45
Pr5	49.58	276.47	60.12	583.19	317.26
Pr6	29.48	83.87	48.66	204.39	139.7

Table VIII.- Simulation results for scenario 4.

	Percentage of collaboration
Pr1	2,50 %
Pr2	4,70 %
Pr3	6,30 %
Pr4	12,60 %
Pr5	8,00 %
Pr6	15,80 %

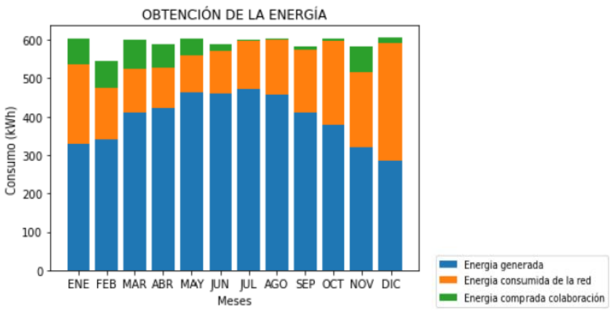

Fig. 1. Example of energy generated, consumed from the grid and purchased from other prosumers collaborating with him for prosumer #3.

Through the data analysis carried out in the present work, we can corroborate that collaboration occurs almost daily to a greater or lesser extent for all prosumers. For example, in Fig. 4, we can appreciate the energy flow for January 15 for prosumer #1. It shows the energy demand of this prosumer (consumption profile) during the 24 hours of the day (upper left graph), as well as the generation produced, in this case totally solar photovoltaic (upper right). The energy needs of the prosumer before the collaboration can also be seen (in the lower left graph), so that the positive values are values of the surplus energy of this prosumer that will be sold to other prosumers or later injected into the network and the negative values are the energy needed to finish covering its demand and will be obtained by buying it from other prosumers or later from the network. Finally (bottom right graph), it shows the energy that, after the possibility of collaborating with other prosumers and not having been sold or bought, is the energy that the prosumer will sell to the grid (positive values) or buy from the grid (negative values).

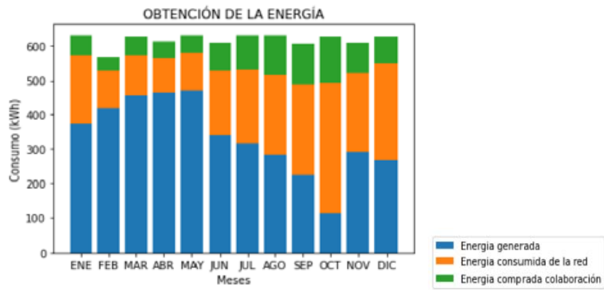

Fig. 2. Example of energy generated, consumed from the grid and purchased from other prosumers collaborating with him for prosumer #4.

Fig. 3. Example of the energy generated, consumed from the grid and purchased from the other prosumers collaborating with him for prosumer #4.

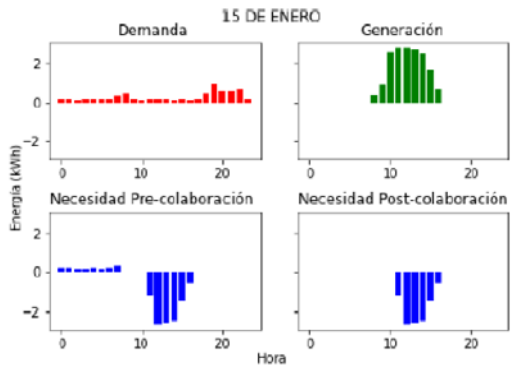

Fig. 4. Profiles of energy consumed, generated, exchanged with other prosumers, and exchanged with the grid for prosumer #1.

The graphs in Fig. 5 belong to prosumer #4 (who generates with wind energy) and in them we can observe that this prosumer covers his needs by buying from prosumers with photovoltaic generation and during night hours from prosumer #6. We can see that the collaborative purchase of prosumers with photovoltaic generation occurs during the hours when there is no generation. On the other hand, in the case of prosumers with wind generation, they will buy energy from both PV and wind prosumers. In addition, it is clear that prosumers with wind installations do not have a clear purchasing pattern and will buy whenever possible at the lowest price.

E. Scenario 5 - National Collaborative Hybrid Microgrid

This last case is intended to demonstrate that a nationwide collaboration with different types of energy generation is of great interest. This type of collaboration would be the optimal collaboration to be able to dispense with dependence on grid-based consumption in the future.

Due to the large differences in location and generation, collaboration is increased in prosumers with photovoltaic generation and, slightly, in those with wind (Table IX). The amount of energy purchased collaboratively is 3,547.21 kWh per year, resulting in savings for prosumers who will no longer obtain this energy from the electric grid but from collaboration.

Table IX.- Simulation results for scenario 5.

	Demanda Energética (kWh)	Generación total (kWh)	Energía comprada colaboración (kWh)	Energía vendida colaboración (kWh)	Energía inyectada a la red (kWh)	Energía consumida de la red (kWh)
Pr1	2570.4	6426.86	135.14	24.64	4070.93	120.17
Pr2	4952.79	12353.71	382.31	33.05	8230.29	503.52
Pr3	7090.45	18049.34	833.19	249.67	12939.39	1423.8
Pr4	7389.92	13784.4	857.41	1521.12	7350.05	1660.34
Pr5	7384.1	18407.07	1084.04	574.53	13538.09	2025.11
Pr6	2611.32	10207.92	257.62	1144.2	7037.76	418.09

	Coste energía comprada colaborativamente (€)	Coste energía comprada de la red (€)	Ganancias energía vendida colaborativamente (€)	Ganancias energía inyectada a la red (€)	BENEFICIOS (€)
Pr1	10.7	10.85	2.36	203.55	184.36
Pr2	29.69	44.52	2.52	411.51	339.82
Pr3	69.02	155.54	14.65	646.97	437.06
Pr4	66.24	203.28	122.57	367.5	220.55
Pr5	90.86	218.65	42.33	676.9	409.72
Pr6	18.7	50.01	100.67	351.89	383.85

The prosumers with the highest profits are #4 and #6 because they have wind, and because they can sell this energy to all prosumers who have PV and do not generate energy at night. The collaboration percentages increase as shown in the table X.

Table X.- Percentage of collaboration for the six prosumers considered in scenario 5.

	Percentage of collaboration
Pr1	5,20 %
Pr2	7,70 %
Pr3	11,70 %
Pr4	11,50 %
Pr5	14,60 %
Pr6	9,50 %

In this scenario, prosumers with PV buy energy mostly in winter, when PV production decreases, although we can observe an increase in purchases in the summer months. The example of prosumer #5 is shown throughout the 12 months of the year (Fig. 5).

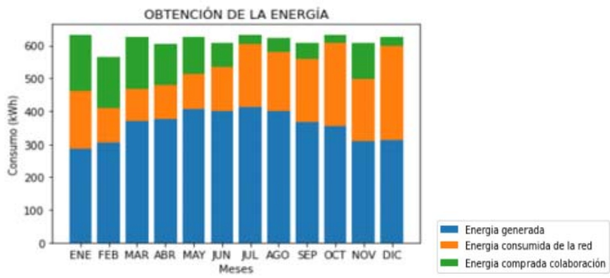

Fig. 5. Example of energy generated, consumed from the grid and purchased from the rest of the prosumers collaborating with him for prosumer #5 in scenario 5.

In the daily graphs we can observe a reduction of the need, especially in the night hours or where there is no PV production. The graphs shown in Fig. 6 belong to prosumer #2 on a typical day in September.

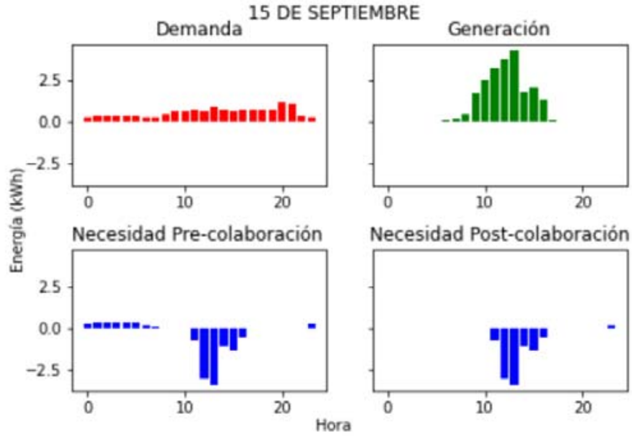

Fig. 6. Profiles of energy consumed, generated, exchanged with other prosumers, and exchanged with the grid for prosumer #2.

The graphs in Fig. 7 show the amount of energy collaborated annually among prosumers in the different cases studied.

7. Discussion of results

Taking into account the simulation results of the different cases or scenarios considered in the following work, it has been observed that there are four main factors that enhance collaborative energy trading: (1) geographic location, (2) type of generation, (3) consumption patterns, and (4) number of prosumers involved in the collaboration.

A. Geographical Location

One of the key aspects to increase collaboration is that prosumers have different locations. It has been shown that prosumers that produce in the same municipality do not collaborate or do so only marginally, and that if we relocate them to different towns in Spain, collaboration increases considerably.

Scenario 1 shows that, with the same type of generation and a location in the same town, prosumers do not collaborate. This is because when there is production all prosumers have surpluses and their needs are covered.

We can see that in scenario 2, when prosumers are located in different municipalities, collaboration increases, and in scenario 3, when they are located in different municipalities in Spain, collaboration increases again. In these two cases we do not see an exaggerated increase since the production remains the same type. This causes that, with different locations, the production hours are different, but the PV production always follows the same curve; as a consequence, there are small differences.

In scenarios 4 and 5, where some prosumers use wind energy, we can observe that collaboration increases significantly. We can conclude that it is of vital importance that when the location and consumption are similar, the type of generation should be different in order to achieve a high percentage of collaboration.

Fig. 7. Annual amount of energy collaborated among the six prosumers considered and for the five scenarios under study.

B. Type of Generation

The condition that enhances collaboration between prosumers is that they have different generation systems. In scenarios 1, 2 and 3 we can observe that since all prosumers have the same type of generation, photovoltaic, collaboration is minimal. When, in scenarios 4 and 5, prosumers #5 and #6 opt for wind generation systems and relocate to towns with a high level of wind, this generates an increase in collaboration. This increase is due to the fact that wind generation does not follow a fixed pattern, as is the case with photovoltaic, which has similar hourly patterns. The possibility of night-time generation is also introduced, so that prosumers with photovoltaic installations will be able to cover their needs when photovoltaic generation is null. Specifically, this is the case of prosumer #2 in scenario 5 who buys power at night from prosumers with wind.

In winter, solar radiation decreases, PV production decreases and, as a consequence, in scenarios 4 and 5, we can observe that these prosumers will buy energy from prosumers with wind installations.

C. Consumption Patterns

Another aspect that can lead to increased collaboration is the large differences in consumption patterns. In the case of residential homes, almost all of them have the same consumption pattern throughout the day. In this case, it is complicated that in some periods of the day a prosumer does not consume and can sell its energy in a collaborative way. In this work, collaboration has been studied from the residential point of view, but it has a great game if we implement it in any other environment. A clear example of this scenario is the inclusion of office buildings. These usually have a high consumption throughout the day and this combines perfectly with the photovoltaic pattern. As these installations are usually large, the surplus energy can be sold collaboratively to other residential or non-residential buildings.

D. Number of Prosumers

This study was conducted with the participation of six prosumers. If the number of prosumers is increased we can quickly see how collaboration increases proportionally in each case. It is worth noting that a large repertoire of prosumers also allows prosumers to obtain energy from the cheapest possible source and thus get energy at the lowest possible price.

8. Conclusions

In this article, it has been shown that a hybrid and national collaboration model is the ideal scenario for collaboration between domestic prosumers. On the other hand, diversification in the use of generation source maximizes collaboration. Ideally, future collaboration should occur on a national basis with a massive number of prosumers, although we can observe that, with hybrid generation within a smaller geographic area (for example, at the autonomous community level), we can also achieve good results.

We observe that when we have hybrid generation and extrapolate it to the national level, we find that the large differences between all prosumers benefit collaboration considerably. If you increase the number of prosumers, you get large-scale and, economically, very competitive collaboration. Moreover, we could even find ourselves in a situation where consumers with no generation at all choose to buy energy collaboratively. In this way, dependence on the grid would be reduced and consumers would obtain energy at more competitive prices due to the high supply of energy.

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