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Optimisation of an aggregator's customer portfolio based on inter-user compatibility

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Abstract – This paper aims to present a methodology for optimizing the customers' portfolio of an aggregator by analysing the compatibility between prosumers (clients). The methodology evaluates two main components: energy and socioeconomic. With this, the intention is to maximise the economic benefits of the aggregator and to establish a personalised tariff according to the user profile.
Since this figure was conceived, efforts have been mainly aimed at meeting only and exclusively the energy demand requirements without taking into consideration prosumers socio-economic profiles and the synergies among them.
This paper, therefore, presents a methodology in which a compatibility index based on the energy and socioeconomic profile of each client is defined. In addition, the application of this methodology to a practical case is presented.

Key words – Aggregator, energy demand management, prosumers, socio-economic, optimisation.

1. Introduction

The European Union is undergoing numerous changes at all scales [1], [2]: the high penetration of renewables in the energy mix [3], [4], micro power generation [5], self-supply [6], [7] and, above all, the exchange of energy between users [8] presents a revolution in the energy market never seen before. As in any sector, with the possibilities that this scenario presents, new business models are appearing. We are talking about virtual power plants [9] and, in particular, aggregators [10].
An aggregator (Fig. 1) is defined as a market agent that combines energy demand and generation to satisfy a portfolio of customers [11], [12]. In this case, users can self-supply, dump their surplus energy into the grid, and the aggregator is responsible for energy planning to supply its portfolio and obtain an economic return for it [13]. This figure has been in force in Europe since the beginning of the 20th century [14], with examples such as the demand management that countries such as Belgium, France and Great Britain offer on a commercial level [15]. However, it was not until the approval of RDL23/2020 that it became legally valid in Spain.
Among the different business activities, we can highlight the following:

- Sending control signals to prosumers to reorganise their consumption or generation profiles.
- Offering prosumers flexibility through the energy market.

In this sense, it is vitally important that the aggregator controls the following pillars on which its business model is based: i) customer characterisation, ii) prediction of energy consumption and generation, iii) market prediction, iv) optimisation of energy planning and v) market and customer portfolio management [16].

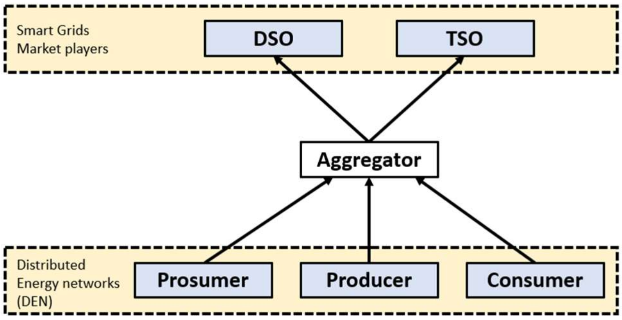

Fig. 1. Aggregator

2. Methodology

In accordance with the basis described in the introduction, the methodology (Fig. 2) is structured in five blocks:
i) energy and socioeconomic characterisation of the customer, ii) analysis of compatibility between users using the AHP technique, iii) hourly energy demand management of the customers´ portfolio, iv) hourly energy price and demand prediction model and v) optimisation of the energy planning (supply and demand).

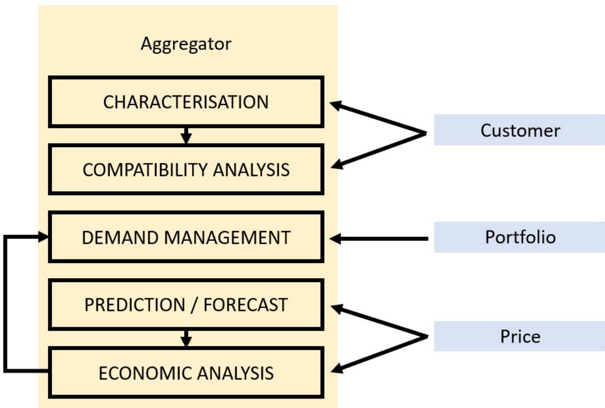

Fig. 2. Methodology

A differentiating condition of the energy matching and planning process that other aggregators can address is the characterisation of the customer based on their socio-economic and energy profile. Their employment status, gender, age, income or the year in which their home was built have a strong influence on the behaviour of the users of an aggregator's customer portfolio.

Until now, efforts were focused on bill optimisation or energy planning [17], [18]. However, as Kotsis, G comments in [16], the aggregator's work goes beyond energy planning and economic profit. It also has a social and interconnection role between users.

A) Characterisation of the customer

Different customer profiles were considered for customer characterisation: residential, industrial, commercial and tourism. Each profile was characterised through three sub profiles: geographical, socio-economic, constructive and one energetic profile. In order to obtain the required information, forms and surveys were developed and filled in. Since the function of the aggregator is to maximise social welfare and obtain an economic return, optimisation is focused on maximising the economic benefit of its portfolio through energy exchange. For this reason, users whose generation and demand curves differ will get a better rating than those who match more in terms of energy.

Geographical sub profile (F_G)

Depending on the user's location, the temperature will have an impact on consumption. Three climates were considered: peninsular, Atlantic and Mediterranean.

Socio-economic sub profile (F_S)

Among the most significant socio-economic parameters, the following have been considered: Number of people, simultaneity factor, age segmentation, household income and teleworking.

Constructive sub profile (F_C)

In the constructive sub profile, the type of premises, the size in m2 and the year of construction were considered.

Energy profile (D and G)

Once the customer weighting index has been defined, a customer portfolio compatibility index is established. For this purpose, a generation and consumption profile of the total customer portfolio must be defined.

The energy profile consists of the demand profile and the generation profile. While the Generation Profile (P_G) is dependent on the type of source being used, the Demand Profile (P_D) follows a pattern throughout the year marked by the level of productive activity. Temperature, the work calendar and economic activity are some of the factors that have a major impact on the behaviour of energy demand, but there are many more. According to this criterion, these factors were classified as: temporary (t), economic (e), climatological (c) and random or occasional (ra).

$$D_T = D_i \cdot E_t \cdot E_e \cdot E_c \cdot E_{ra} \quad (1)$$

Variables such as peak power, storage capacity, type of renewable energy (RES) and installed RES power were considered.

A general model to characterise prosumer demand was developed. Each consumer has a flexible and an inflexible load. We denote the inflexible load for consumer i at time t as b_i^t. Consumer i can change the flexible load over time and we denote it as $x_i^w = \{x_i^{w,t}, \forall t \epsilon T\}$, where $x_i^{w,t}$ is the flexible load of consumer i at exchange time t under a renewable generation scenario ω. Flexible load planning should satisfy the following constraints:

$$\sum_{t \in \Gamma} x_i^{w,t} = D_i, i \in \aleph\, t \quad (2)$$

$$d_i^{t-} \leq x_i^{w,t} \leq d_i^{t+}, \forall t \in \Gamma, i \in \aleph \quad (3)$$

Where the first constraint specifies that consumer i must consume a total demand D_i to maintain his daily activities. The second constraint specifies the lower d_i^{t-} and upper d_i^{t+}bounds for the consumer's flexible load i in the time interval t.

After changing the flexible load, consumer i will experience a disparity, which can be measured by the following expression:

$$C_i(x_i^w) = \beta_i \sum_{t \epsilon \Gamma} \left(x_i^{w,t} - y_i^t\right)^2 \quad (4)$$

Where β_i is a sensitivity parameter and $y_i = \{y_i^t, \forall t \epsilon T\}$ is the preferred energy consumption profile of the consumer i. If consumer i changes the flexible load and the current energy consumption $x_i^{w,t}$ deviates from the preferred energy consumption profile y_i^t, then the disparity $C_i(x_i^w)$ occurs. It is this disparity that we must satisfy by exchanging energy with our system or the grid.

At the end a demand and generation profiles were defined as follows:

$$P_D = D \cdot F_G \cdot F_S \cdot F_C \quad (5)$$

$$P_G = G \cdot P_i \quad (6)$$

B) Analysis of compatibility between users

Since the input variables of the system change hourly, the AHP method (Table 1) has been chosen for its simplicity and speed of application and considers all alternatives.

When a new user wants to belong to this portfolio, a small survey is carried out to estimate their generation and consumption profile and, at the same time, to obtain this compatibility index with variables other than purely energy variables. Three main criteria have been considered: socio-economic, constructive and energetic. Once the importance of each parameter is defined, the coefficients for each sub-criterion were calculated and a value was assigned to each of the responses. Finally, a customer compatibility index is obtained.

Table 1. Saaty Fundamental Scale

Value	Definition
1	Equally important
3	Moderate importance
5	Major importance
7	Very high importance
9	Extreme importance
2, 4, 6 and 8	intermediate values

C) Demand management

The demand management covers a one-stage stochastic programming problem to minimise the total cost of energy price and customer portfolio as described in [5]. The aggregator coordinates energy supply and demand to minimise the daily operating cost and maximise profits. The energy demand comes from a number of consumers $\aleph = \{1, \dots, N\}$. The aggregator is responsible for energy balancing in its customer portfolio. A planning horizon of several days has been considered, with $H = \{1, \dots, D\}$ of D days. The daily operation by the microgrid will be $\Gamma = \{1, \dots, T\}$ consisting of T trades of energy per day. A 24-hour profile with a combination of solar and wind power generation has been considered as time intervals. EHA, EHE, EHR, A and B were used as primary variables, where:

- EHA: Self-consumed energy (kWh)
- EHE: Surplus Energy (kWh)
- EHR: Energy obtained from grid (kWh)
- A: Energy storage (kWh)
- B: Balance between surplus energy and energy obtained from grid (kWh)

In order to calculate the energies and powers for billing and settlement purposes for collective self-consumption or self-consumption associated with an installation through the grid, the following expression has been used:

$$ENG_{h,i} = \beta_i \cdot ENG_h \qquad (7)$$

Where ENG is the total hourly net energy produced by generator(s) and β_i is the allocation ratio of generated energy among consumers. These parameters change hourly.

D) Market forecasting

A generalized linear ML model was used to forecast the market price. Previous year's hourly variables (8760 values) for training and testing the model were: Market price ($€/MW$), CO_2 price ($€/ton$), Total demand of the country (GWh), temperature ($ºC$), Precipitation (l/m^2), Wind speed (km/h) and Irradiance (W/m^2).

E) Economic optimisation

The power purchase and sale instants are defined through the methodology carried out in the Fig. 3-4 considering two variables: market price (P_{CR}) and generation purchase price (P_{CG})

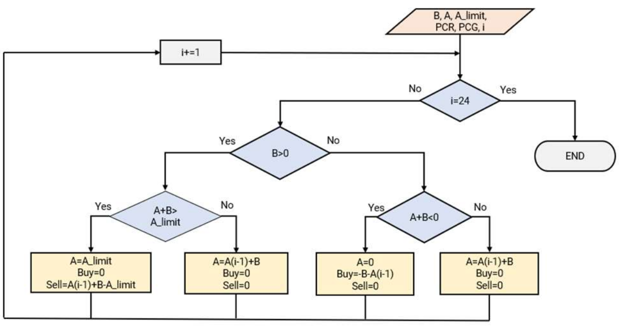

Fig. 3. Energy planning (PCR>PCG)

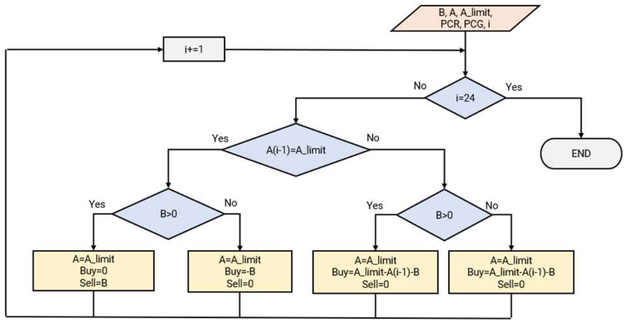

Fig. 4. Energy planning (PCR<PCG)

Fig. 5 depicts the evolution of the grid purchase price and generation leading to the situations described in Fig 3-4.

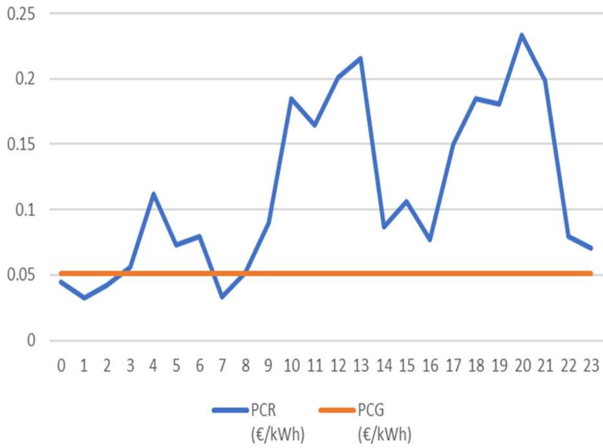

Fig. 5. Evolution of daily PCR and PCG (€/kWh)

The aggregator's profit is given by (8).

$$B = EHR(t) \cdot \left(T_i(t) - PCR(t)\right) - EHE_i(t) \cdot PCG(t) \qquad (8)$$

Where:

- EHR(t): hourly network energy of each consumer
- $EHEi(t)$: hourly surplus energy of each consumer
- $Ti(t)$: tariff associated to each user on an hourly basis
- $PCR(t)$: hourly grid purchase price
- $PCG(t)$: purchase price of surplus generation energy.

In accordance with [13], an economic optimisation was carried out to maximise the economic benefit of the aggregator.

3. Case study

The methodology was applied to a case study, involving 19 users, of which 11 belonged to the residential sector, 3 to the industrial sector, 2 to the tourism sector and 2 to the commercial sector, with an average energy demand of 25 MWh/day for the customer portfolio.

The energy planning and purchasing moments can be seen in Fig. 6.

Fig. 6. Energy balance

4. Results

Results of the implementation showed an average profit of approximately 300 €/day obtained by the aggregator and a 2% reduction of the consumers' energy price (tariffs) (Table 2).

Table 2. one day's portfolio benefit

Hour	Payments (€)	Receipts (€)	Benefit (€)
0	1.39	103.52	4.82
1	1.42	99.60	4.55
2	1.49	98.95	4.45
3	1.92	99.10	4.02
4	2.27	98.07	3.61
5	2.75	104.95	3.54
6	2.59	109.92	4.00
7	2.26	145.64	6.48
8	1.57	180.66	9.27
9	0.16	246.17	14.61
10	0.30	250.56	14.73
11	0.42	249.40	14.54
12	0.49	249.32	14.47
13	0.45	241.11	14.01
14	0.41	246.62	14.39
15	0.35	247.41	14.50
16	0.26	245.84	14.49
17	0.15	248.77	14.78
18	0.04	230.55	13.80
19	-	194.92	11.69
20	-	191.48	11.49
21	-	167.97	10.08
22	-	134.56	8.07
23	-	106.57	6.39
TOTAL	20.69	4,291.66	236.78

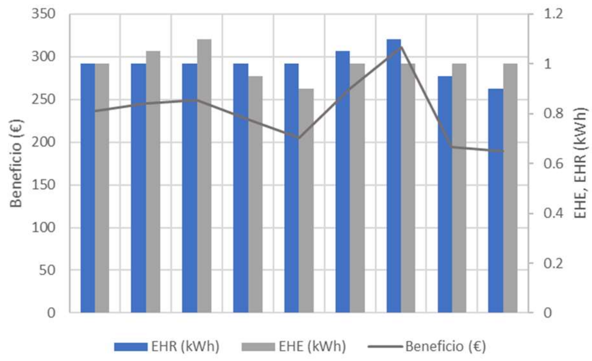

Fig. 5. Risk analysis

It can be highlighted that the more energy purchased from the grid, the higher the profit. This is due to the volume of energy exchanged is greater and the profit margin associated with the exchange. There is also a dependence on surplus energy, since the purchase price of generation is lower than the market price. What is noteworthy about this parameter is that, in spite of this, due to the prediction model used, the profit obtained is lower than through an increase in energy purchased from the grid.

5. Conclusion

The aggregator plays a vital role in the energy management of its customer portfolio, from energy planning to the establishment of the different tariffs to be applied. For this reason, it is vital that not only energy optimisation, but also individualised optimisation, based on the socio-economic situation of each user, is carried out properly. It can be noted that:

- For proper energy planning, it is necessary to obtain as close a prediction of the market price as possible, as the estimation of tariffs and the timing of buying and selling energy is based on it. Zero net balance does not exist in demand-side management systems. It is very difficult for demand and generation to coincide.
- There are always deviations that the aggregator must deal with and that must be considered when setting tariffs, establishing an adequate margin.

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