Feasibility Analysis of a Multi-family House Energy Community in Italy

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Abstract. The future energy sustainability largely depends on what will happen in metropolitan cities, therefore the role of the buildings sector and the engagement of citizens in the energy transition will be fundamental. These two dimensions seem to find the perfect match in the so-called energy communities, a group of people that choose to share their energy choices, fluxes and costs, promoting self-consumption configurations. The present paper aims to investigate the energy and economic feasibility of the smallest scale of an energy community: the multi-family house (MFH). Firstly, being these communities an emerging concept, a review of the Italian regulation framework was conducted, to highlight its limits and potentialities. Then, the installation of a community PV plant on the roof of the building was considered for an MFH case study located in the North-West of Italy. The financial convenience of belonging to an energy community was demonstrated through energy and economic evaluation and the definition of specific indicators. Results show that, if the MFH consumers join the community, the economic savings on the energy bill will amount to 40% with respect to the reference case.

Keywords: Energy Communities, Multi-family House, Techno-economic Evaluation.

1 Introduction

In the next few years, a rapid process of urbanization is expected, as outlined by the United Nations Sustainable Development Goals [1], and thus the role of metropolitan cities will be crucial for the development of a sustainable and clean future. In cities the major cause of local air pollution and greenhouse gases emissions is the building sector, that accounts for almost 28% of total CO2 emissions [2]. European Union sets ambitious targets for a transition towards a low-carbon society [3], focusing not only on building energy performances, but also on occupants' health and well-being. Indeed, nowadays, the reduction of the energy consumptions while maintaining high comfort level and wellness of the occupant is becoming a priority issue in the building sector [4]. Therefore, cities must keep up. The massive spread of renewable technologies, one for all the photovoltaic, has led to a reduction of the capital and maintenance costs of such technologies, making them more affordable for a larger number of citizens, thus promoting self-consumption configurations also in the urban context. This economic convenience, coupled with technological devices able to make people aware of their energy consumptions, enable the figure of the prosumers (producers-consumers). In this framework, the new concept of energy community seems to fit perfectly with the ever-growing need of the consumers to play an active role in their own energy choices.

Both from a legislative and a literature standpoint, the energy community can be considered a “young” concept, since before 2018 they were not defined in European directives or regulations. Nowadays, there are two definitions of energy community in the Clean Energy package; in the Renewable Energy Directive (RED II) [5] they are called Renewable Energy Communities (RECs), highlighting a focus on the generation technology aspects, while in the Electricity Market Directive (EMD II) [6], the emphasis is put on the participants, and they are named Citizen Energy Communities (CECs). Since this is a recent topic, only few European Countries has already established a regulatory framework to support energy communities [7], and Italy is not among them. For this reason, the present paper firstly presents an analysis of the Italian regulation framework in order to find the closest standardised configuration to a community setup; then a techno-economic analysis is performed to evaluate the feasibility of an energy community for a multi-family house (MFH) in the North of Italy.

2 Methods

2.1 Italian regulatory framework on energy communities

As mentioned before, in Italy still no law transposes the European Directive on energy communities. Nevertheless, academic and politicians are wondering about finding regulation possibilities for managing these emerging realities in an effective way. Discussing the problem solely from an electric perspective, today in Italy there are just two configurations standardised by ARERA [8], and anything that does not fit with these definitions is allowed. These configurations are the electric networks (reti elettriche) and the closed distribution systems (Sistemi di Distribuzione Chiusi, SDC). Although the Multi-Family House Energy Community (MFH_EC) does not fulfil all the requirements of the standardised configurations, in the hypothesis of overcoming the limitation that does not allow the one-to-many setup in MFH, it could be possible to include the MFH_EC concept within the SDC framework. Currently, when installing a photovoltaic plant on the roof of a MFH, even though the generated electricity can supply the common spaces (i.e. elevators, stairs light, etc.) implementing a 1-to-1 configuration (single user), it is legally forbidden to serve the electricity directly the users (with a 1-to-many setup).

To make these communities economically attractive for citizens, the legislators are discussing on the management of the network charges. Since the MFH_EC exchanges energy fluxes with the grid, the exemption from paying the network burdens is not possible, but they can be reduced.

In order to develop the work, three main assumptions were done:

- MFH_EC were classified as SDC; therefore, network charges were assumed to be paid only for the energy coming from the external grid, and not for the auto-consumed part;
- All the occupants of the MFH were assumed to join the energy community;
- The building was considered a unique user from the electric grid point of view, assuming a single Point of Delivery (POD).

Under these assumptions, the entire MFH constituted the case study.

2.2 MFH model

The current investigation involved an MFH located in the North-West of Italy. The building is composed of ten apartments, arranged on two floors. Based on the building energy performance certificate, it was possible to deduct that no renewable technologies were already installed and that the electrical demand was met by the grid. Therefore, a retrofit solution with a collective photovoltaic plant was proposed.

Since the real composition of the families of the building was unknown, it was supposed that the MFH perfectly represented the typical population distribution of the macro-region, in terms of households' age clusters defined by ISTAT [9]. The defined MFH composition is reported in Table 1.

Table 1. Assumed family distribution in the MFH.

Household age	15-24 years	25-44 years	45-64 years	Over 65 years
N. of apartments	1	3	3	3

The age composition of an MFH is fundamental to know, since occupant behaviour strongly influences energy consumption. To overcome the unavailability of real electrical consumption profiles, a new methodology based on statistical database was proposed, in order to re-create electric loads in the most general manner. For all the abovementioned age cluster, Time Use Surveys (TUS) were available from 2013 ISTAT statistics [9]. These surveys report, with a 10 minutes time step, households' activities, for different days (weekday, Saturday or Sunday, including also non-working days). Of particular relevance for the current study were at-home activities, done interacting with domestic appliances, i.e. ironing, cooking, do the washing machine. From the TUS, it was possible to extrapolate the daily probability profiles of the housework, with indications of the average minutes dedicated to each activity. Per each activity related to the use of specific electrical appliances, peak power values were defined [10]. Then, the daily electricity consumptions were calculated by multiplying the power per the time of use for each appliance.

With the aim of coupling the electricity demand with the energy produced by the photovoltaic system, knowing the total daily consumption was not enough, since their profile throughout the day were needed; since ISTAT database did not provide any information, it was necessary to find a method to allocate the consumptions. First, the day was divided into four ranges: 10 pm – 7 am; 7 am – 11 am; 11 am – 4 pm; 4 pm –

10 pm. At every time range, activities were arbitrarily assigned. Per each time slot, power was obtained summing the peak power values of the used appliances (1):

$$P_{ts} = \sum_{j=1}^{n} P_{max,appl,j} \quad (1)$$

Where P_{ts} is the power in the time slot (kW), $P_{max,appl}$ is the peak power of each appliance (kW), j is j-th appliance and n is number of appliances for each time slot. While the daily power (P_{day}) in kW, was calculated as follows:

$$P_{day} = \sum_{i=1}^{4} P_{ts,i} \quad (2)$$

Where i represents the i-th time range. By dividing the time slot power by the total daily power, weighting factors (w_{ts}) were defined, in order to identify the most energy intensive time slots, according to (3):

$$w_{ts,i} = \frac{P_{ts,i}}{P_{day}} \quad (3)$$

The weighting factors were then multiplied by the daily probability profile of the home activities; this new weighted daily profile allowed to account both the probability of doing a specific activity, as well as its energy intensity. The daily load profiles were multiplied for the weighted appliances profiles, in order to have energy curves. At last, the annual consumption values were obtained considering 253 workdays, 52 Saturdays, 52 Sundays and 8 non-working days (values of a typical non-leap year). After that, the so-called baseload, independent from the occupant behaviour, was added to the electrical consumptions.

Since the analysis was focused on the building as a unique load, the overall electric load profiles of the MFH_EC were obtained by aggregating the profiles of the single households. The reference case was obtained considering that all the electricity needed to meet the demand came from the grid, performing the economic evaluations coherently.

2.3 PV generation curves

To simulate photovoltaic production, hourly irradiance and temperature values were extrapolated from the JRC software PVGIS, in order to create daily generation profiles. To reduce computational cost, one daily profile for each season was considered. The profiles were obtained analysing ten years (2007-2016) of historical series of weather data (irradiance, temperature) and using the most frequent profile for each season. A monocrystalline silicon cell was chosen for the PV. Knowing the values of irradiance and the technical characteristics of the cell, power generation profiles were created by using the correlation between the efficiency of the solar cell and the temperature of the cell, as suggested in Bottaccioli et al. [11]. A sensitivity analysis was developed in terms of plant size, in order to find the optimal one able to maximize the economic gains, starting from a situation that exploits all the available roof surface (resulting in a 41.4 kW PV plant).

2.4 Techno-economic analysis: Key Performance Indicators

In order to evaluate the feasibility of the MFH_EC, energy and economic balances were done. From an energy viewpoint, the balance between electrical load and PV generation was set. The energy (kWh) input data for the balance, provided with a 15-minutes time step, were:

- the electricity needs of each apartment (E_{ap});
- the electricity needs of the whole multi-family house (E_{MFH_EC});
- the energy produced by the PV plant (E_{pv}).

While the outputs of the analysis were:

- the self-consumed energy at condominium level (E_{sc});
- the electricity taken from the grid in order to meet the demand in periods when PV was not enough (E_{taken});
- the surplus electricity fed into the grid (E_{fed}).

To better show the potentialities of the community, two indexes were calculated, self-consumption (SC) and self-sufficiency (SS), defined as follows:

$$SC = \frac{E_{sc}}{E_{pv}} \quad (4)$$

$$SS = \frac{E_{sc}}{E_{MFH\_EC}} \quad (5)$$

where SC represents the portion of the electricity generated by the PV plant that is self-consumed by the MFH users while SS is the contribution of the self-consumed energy on the total energy consumed by the community (E_{MFH_EC}).

Focusing on the economic evaluation, the objective was to demonstrate the convenience of being part of the energy community. Energy outputs were input for the economic analysis, which allowed to calculate the following economic performance indicators:

- Net Present Value (NPV) defined as:

$$NPV = \sum_{t=0}^{N} \frac{C_t}{(1+i)^t} \quad (6)$$

where N is the average lifetime of the PV technology, assumed equal to 25 years, t is the considered time step, i is the discount rate, set equal to 1% [12], and C_t is the net cashflow at time t. The cashflow is the sum of income and expenses. The positive flux accounts for:

- Tax deduction for the first 10 years of the plant, defined by the Italian support scheme (Ecobonus, Law 27 December 2017, n. 205);
- Net Metering service, as Surplus (Ci) and contribution on account of exchange (Cs), regulated by the Italian Regulatory Authority for Energy, Networks and Environment (ARERA) [8].

On the contrary, the negative flux is caused by:

- investment, operation and maintenance costs;
- fuel cost and excise on the electricity taken from the grid, defined by ARERA [8].

- Payback time (PBT) defined as:

$$\sum_{t=0}^{\tau} \frac{C_t}{(1+i)^t} = 0 \tag{7}$$

where τ represents the year in which positive and negative fluxes counterbalance. From this year on the NPV assumes only positive values.

3 Results and discussion

The following section describes the results of the energy and economic analysis, aiming to demonstrate the convenience of the MFH_EC and to find the optimal PV system capacity that led to the highest benefits. The analyses were done for each season and for the three defined typologies of days (weekday, Saturday, Sunday). Some examples are given below.

3.1 Energy results

Starting from the consumptions data, Fig. 1 shows the daily demand profile for the MFH in an average weekday. The profiles are coherent with real load profiles, since they present two peaks, at lunch and at dinner time. The typical profiles for Saturdays and Sundays present similar trends.

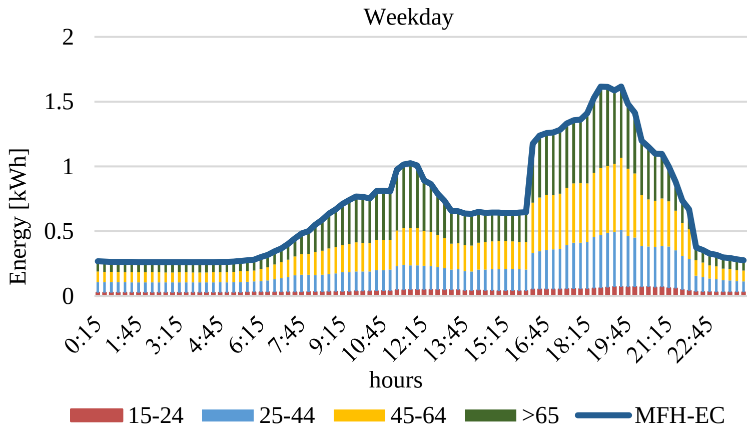

Fig. 1. MFH_EC load profile divided for age-range.

Fig. 2 shows an example of the matching between the electricity demand of the MFH_EC and the PV generation curve in a typical weekday in spring. The total consumption of the building is divided into self-consumed energy (green area) and energy taken from the grid when the solar power was not available (yellow areas). The blue area represents the portion of PV-produced electricity that exceeds the building needs and, in order not to be wasted, is injected into the grid.

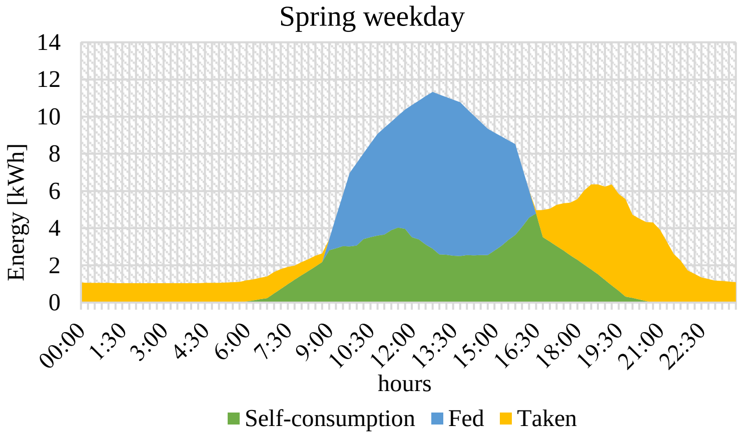

Fig. 2. Electricity fluxes during a spring weekday.

From energy balances it was possible to calculate the SC and SS indicators reported in (5) and (6). The obtained values are reported in Table 2.

Table 2. Results of the energy analysis.

	Winter	Spring	Summer	Autumn	Total
Self-sufficiency [%]	34	53	56	38	45
Self-consumption [%]	53	44	33	46	41

Table 2 highlights the difference between the two indicators, which are characterized by a specular behaviour. As expected, focusing on self-sufficiency, it results higher in spring and summer. Indeed, PV production depends on the values of solar irradiance, which are higher in summer and spring, thus increasing the weight of the PV generation over the consumed energy. On the other hand, self-consumption is maximum in winter since, being the electric load constant during the whole year, the generation is lower, thus resulting in greater auto-consumed quota. Due to the inversely proportional behaviour, a sensitivity analysis was developed in order to evaluate the optimal PV size able to maximize both indices. As depicted in Fig. 3, sizes were varied from 5.2 kW up to the maximum capacity installable on building roof of 41.4 kW (in case the whole available surface is covered with PV panels). In the graph, the dimension of the bubbles represents the self-consumption percentage. Due to their inverse characteristics, SC reaches the maximum value for the smallest size, while SS for the biggest size. Looking at the trend of the self-sufficiency curve it is noteworthy that after 25 kW it presents a plateau. This result is interesting because it points out that, from an energy point of view, increasing too much the size of the plant (with a consequent economic effort) corresponds just to a minimum advantage in terms of self-sufficiency. This consideration will have implications also on the economic evaluation. For all the above-mentioned reasons, a 20-kW capacity is found out to be a good compromise between SC and SS.

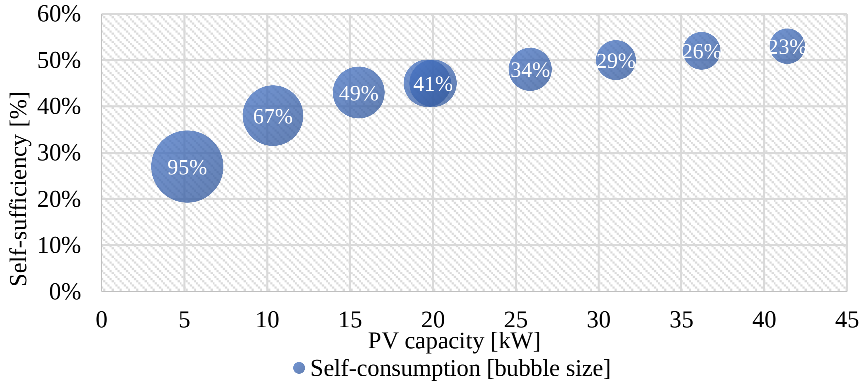

Fig. 3. Self-sufficiency and Self-consumption variations with respect to PV size.

3.2 Economic evaluations

Before entering the discussion of the financial results, a brief comment on the contribution of positive and negative fluxes on the NPV calculation is necessary. As mentioned before, the positive fluxes are composed of tax deduction, electricity surplus sold to the grid (Ci) and contribution on account of exchange (CS). The support scheme differentiates the incentives by the PV size as PV smaller than 20 kW receive higher CS contribution [13]. On the contrary, Ci increases when the installed capacities grow, because the difference between the taken and injected electricity is higher. The tax deduction is proportional to the initial investment cost, so it raises with the installed capacity. Given this, the advantage in electricity bill of being part of an MFH_EC is twofold. Indeed, the energy community adds value to the PV production enabling to share the produced electricity among the apartments, increasing the self-consumption and consequently reducing the cost of energy. In addition, this configuration allows saving on the fixed rate (€/POD) and on the power rate (€/kW) of the network charges, since the community was assumed to be a unique load from the grid standpoint.

As a result, it was possible to obtain a 40% global saving on electricity bill with respect to the reference case, due for approximately 80% to the increased self-consumption and 20% to the charges savings. A sensitivity analysis on the PV size was run, in order to find the optimal value, able to maximize the NPV and minimize the PBT at once. Fig. 4 illustrates the trend of the two indicators with respect to the installed capacity. At first sight, it stands out that at a 20-kW capacity value, NPV curve (blue) presents a global maximum, while the PBT (orange) reaches its local minimum. Deepening on the NPV curve, three different slopes can be observed; from 10 to 20 kW the slope is positive, because the CS has a higher value and excise duties are paid only on the electricity taken from the grid. Between 20 and 20.01 kW a rapid decrement can be registered, because CS values are lower and excise duties are paid also on the self-consumed portion of energy. Finally, from 20.01 to 41.4kW the slope returns positive, since the contribution of the Ci becomes relevant and the weight of the investment cost is less impacting with respect to global expenditures. As regard PBT, instead, its growth with the plant size depends mostly on the raise of the investment cost. The optimal PV size is approximately 20 kW, capacity value that leads to an 8 years PBT and a community NPV of around 42’000 €. Depending on the decisions of the community members, these moneys should be used for common expenditures of the MFH or can be redistributed through the households. All the economic results are coherent with the energy ones obtained before.

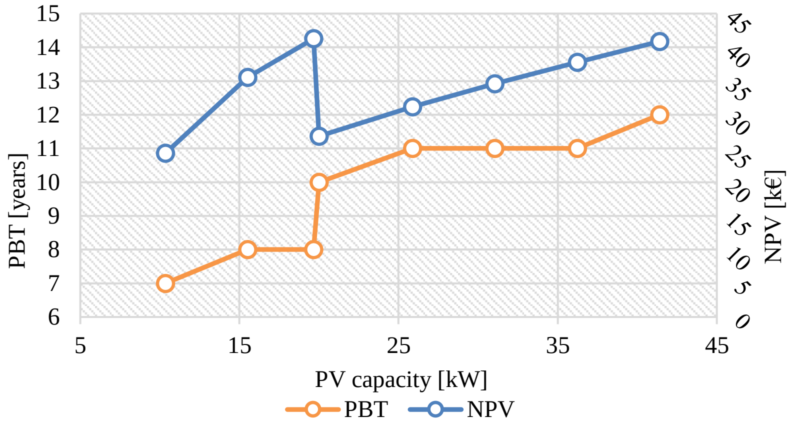

Fig. 4. NPV and PBT variations with respect to PV size.

4 Conclusions

Nowadays the energy sector is in changing, so newly developed concepts of shared electricity fluxes are taking place. In this scope, the emerging energy community seems to fit perfectly with the concepts of decentralization, integration of renewable energy sources and engaging of citizens. Since in a foreseeable future city will be the centre of human activities, the focus of this paper was on one of the smallest components of the city: the multi-family house. Thus, with some legislative assumptions, the energy and economic convenience of the belonging to a multi-family house energy community sharing PV electricity was demonstrated. Once characterized the building from a geographical point of view, a methodology to re-create electrical load and PV generation curves was proposed. The newly developed methodology is based on ISTAT statistical data; thus, it is easily generalizable to any MFH in Italy. From both energy and economic analyses, it emerges that this configuration is feasible and convenient from consumers’ standpoint. Moreover, a sensitivity analysis was performed in order to identify the optimal PV size to be installed (equal to 20 kW) in order to reach a good compromise between self-sufficiency and self-consumption indicators, to maximize the NPV, and to minimize the PBT. This calculation allowed to highlight how only 47.5% of the roof should be covered by PV panels, to reach this result. Economically speaking, the benefit of participation to this community is twofold. On the one hand, the high level of self-consumption provides a reduction in the fuel cost, while on the other hand the fact that the community is a unique load for the grid makes the charges on the fixed rate lower. The strong point of the current work is the flexibility of the used methodology, that allows to evaluate different configuration and technology scenarios. Indeed, future works can study other retrofit interventions, i.e. electrical storage to better manage the PV generated electricity, cogeneration plants or heat pumps for considering also thermal loads, or can be extended to multiple MFHs in order to evaluate the possible electricity exchanges within a set of buildings. In addition, also social evaluations (i.e. health) could be done, to investigate deeply the impact of these energy community on consumers' well-being.

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