Energy and economic simulation of a renewable energy community applied to a new generation ultra-low temperature district heating and cooling network

Michela Romagnosi[1*], *Marcello* Aprile[1], and *Alice* Dénaré[1]

[1]Department of Energy, Politecnico di Milano, IT

Abstract. The work describes the energy and economic simulation of a renewable energy community with a social purpose applied to a residential and commercial new district in Milan, the eight buildings of which are connected to a new generation low temperature district heating and cooling network. The system is designed considering two substations for each building, each one providing heating and cooling load profiles by means of heat pumps, and an energy centre that exploits groundwater to extract and dissipate compensating heat at low temperature. Some roof mounted photovoltaic panels, owned by the district residents, cover the electricity needs resulting from the net metering of the renewable energy community. The members of the energy communities are in fact the multifamily buildings of the district acting as prosumers and some fragile families from the surroundings as simple consumers. The economic profits, represented by the subsidies coming from the diffuse self-consumed shared energy and from sold overproduced electricity, are distributed among the members to guarantee, first of all, an economic help against energy poverty to fragile families, and, secondly, a short pay-back-time for photovoltaics. Therefore, the operational strategy of the district network is optimized to maximize the shared electricity and the relative economic benefit by shifting, when possible, the electricity demand when the solar production is available. Finally, three different profit distribution mechanisms are analysed. The added value of this work is the evaluation, by means of a specific case study analysis, of the feasibility of an electric energy community from an economic as well as a regulatory point of view under current legislation.

Key words: renewable energy community, 5th generation district heating and cooling, nZEB, low temperature network, MILP

* Corresponding author: michela.romagnosi@polimi.it

1 Introduction

1.1 Focus and Aims of the Research

The aim of this work is to show, through the analysis of a case study, the feasibility, the environmental potential, and the economic and regulatory critical issues of an electric energy community project in Italy for a new district supplied by an ultra-low district heating and cooling network of 5th generation and a photovoltaic (PV) system, considering the Italian transposition of the European directive 2018/2001 on renewable energy community.

1.2 nZEB Italian Legislation

From 2021 in Italy all new buildings or those subject to a major renovation must be nZEB - nearly Zero Energy Building and respect the minimum requirements regarding the energy performance. Current legislation to reduce emissions considers buildings as single entities and doesn't foresee multi-energy systems. At district level, buildings can cooperate to achieve the zero-emission target (PED – Positive Energy District) thanks to technologies, such as micro thermal grids fed by onsite renewables [1] [2] and electric energy communities, which exploit the presence within a district of a multiplicity of thermal and electrical loads different in terms of type and hourly profile to increase the efficiency of on-site production.

1.3 5th Generation District Heating and Cooling

District heating and cooling is a system that efficiently moves heat from a centralized generation site to urban areas, through a distribution network. District heating systems are classified according to distribution temperature, and the resulting technologies used, into generations (GDH) [3]: from the first 1GDH steam networks (T>200°C) to the more recent 4GDH networks (T<60°C) serving new buildings with radiant floors. In this work the most recent technology is considered, a 5th generation district heating and cooling system (5GDHC), which is characterized by [4]:

- Closed energy loop with distribution temperature close to ground temperature (ambient loop): the ultra-low temperature of the water (T < 30°C) al-lows to reduce losses, to have higher efficiency and to use heat pumps al-lowing the electrification of the system;
- Decentralized and demand-driven energy supply: buildings are no longer just an energy consumer, but also an energy supplier;
- Bi-directional network: it allows to cover simultaneously both the heating and cooling demands of different buildings since heat is either extracted or injected from/to the bidirectional network;

However, the expensiveness of the plant makes 5GDHC a system suited mainly for highly populated areas, with great energy demand onsite and different simultaneous thermal loads (heat extracted or introduced), which allow the network to self-balance.

1.4 Electric Energy Community in Italy

An electric energy community, instead, allows to maximize the instantaneous self-consumption of renewable electricity locally produced and it is a powerful way to encourage responsible consumption when there is greater availability. In Italy in December 2021 the

Legislative Decree n.199, 8 November 2021, came into force and defines a renewable energy community as a final customer organization whose primary objective is to provide environmental, economic and social benefits to its members or to the local areas in which it operates, and not to make financial profits; therefore, utilities cannot join.

The electricity production of plants powered by renewable sources that individually have a capacity of no more than 1 MW can access tariff incentives. The incentive is assigned through a tariff paid by the GSE on the amount of energy shared in the configuration of diffuse self-consumption in which plants and consumption utilities are connected under the same primary (high voltage) substation. The economic contributions recognized by the GSE (for 20 years for PV) are of three types, each one described in Table 1.

Table 1. Description of the economic contributions recognized by GSE to a diffuse energy community.

economic contributions by GSE		
valorization of shared electricity by returning the tariff component	$C_{VSC} = CU_{Afa),m} * E_{VSC}$	(1)
incentivization of shared electricity	$C_{ISC} = FA_{VSC} * E_{VSC}$	(2)
collection by the GSE of electricity fed into the grid, where required	$R_{fed\ into\ grid} = P_A * E_{fed\ into\ grid}$	(3)

where:
- The monthly flat-rate unit fee for self-consumption ($CU_{Afa),m}$ in Equation 1) is equal to the variable unit part of the transmission tariff (TRASE) defined for low-voltage consumers [5].
- The fee award for the valorized shared electricity (FA_{VSC} in Equation 2), is defined by the Ministry for the Environment and Energy Security (MASE) [6].
- The electricity withdrawal price by the GSE (P_A in Equation 3) is defined by the Authority (ARERA) and is equal to the Single National Price (PUN) [7].

As specified before, a REC has to bring social benefits. In Italy there are few social energy communities with the objective of guaranteeing economic support against energy poverty [8]. The most interesting example is the community of Napoli Est, entered into operation in 2021, that accounts for a PV system of 54.78 kW_P and a storage system. The production is physically self-consumed by the prosumer, whose economic benefit is the saving on bill. The net profits for the incentives are equally distributed to 40 fragile families as final consumers. For a share of shared electricity incentivized of 82% of the total PV production, an annual amount of 437 € per family has been predicted for the first year of operation.

There isn't a regulated or prevailing practice on how to share the economic benefits inside a REC. A study carried out by Politecnico di Torino [9] provided a formal framework to propose relevant sharing mechanisms that could be applied in the real world and understand what mechanism can provide benefits to a given type of user/prosumer. For a community where the consumer members are fragile, a sharing mechanism in which the economic benefits are dis-tributed equally among all the final consumers is proposed. It does not consider the members' consumption profiles or their efforts to maximize the amount of shared energy, otherwise families with low or limited energy demand (because they cannot afford to pay the bill) which might not be synchronized with the generation plan would be penalized. This remuneration scheme does not promote a virtuous energy consumption, however, results to be ethically fair.

2 Method

This section explains the methodology used to carry out the energy and economic simulation.

The district that will be analysed, modeled in compliance with the minimum requirements set by the nZEB legislation, will be equipped with a 5GDHC network with heat pumps and chillers, whose operational strategy will be defined through an optimization based on the participation of the district in a REC. PV system, installed on the roofs of each building in the district, will directly feed condominium consumption. The surplus will be shared in an energy community, in which the energy centre of the DHC network and the participating members will contribute to energy sharing.

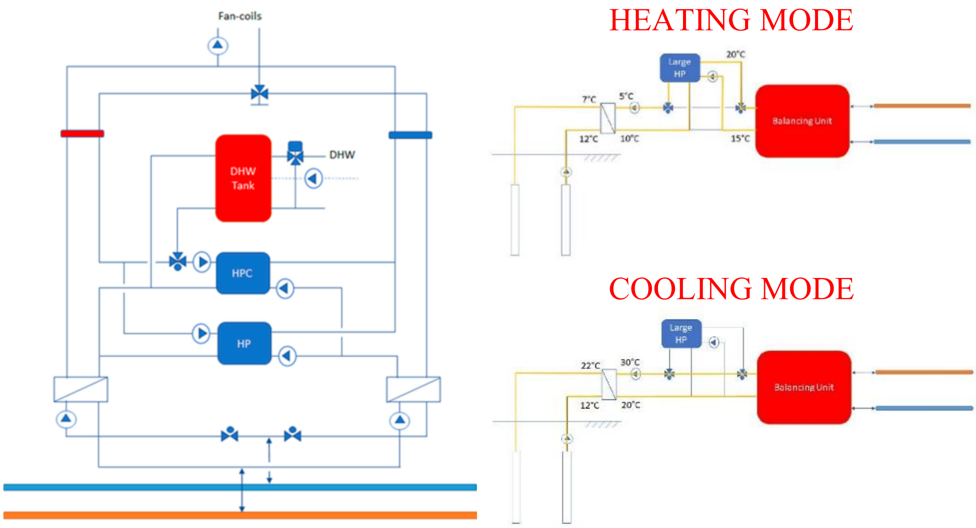
These steps are followed:

- Calculation of the geometry of buildings through GIS map processing;
- Estimation of theoretical energy needs of the district with EN ISO 52016:2017 [10] (hourly dynamic method) including mutual shading of the buildings thanks to the inclusion of the geometry at the previous point;
- Estimation of the actual energy demand of the district considering the distribution systems and sizing of heat pumps and heat pump chillers of substations modeled as in Famiglietti et al. [11]. Their capacities are needed as input for the energy optimization of the network;
- Estimation of the PV production considering meteo data and the shading;
- Definition of the operation strategy of the DHC generation system through a two-level optimization with MILP (Mixed-Integer Linear Programming);
- Definition of the cash flow inside the energy community and economic analysis of the photovoltaic plant pay-back period;
- Analysis of three mechanisms to share the REC profits among the members.

2.1 . 5th Generation District Heating and Cooling Network

The 5GDHC network layout has been already described by Famiglietti et al. [11] and it is schematically represented in Fig. 1. In the substation, the heat pump (HP) supply heat to fan coils while the reversible heat pump chiller (HPC) can perform DHW heating and space cooling simultaneously, thus enhancing the seasonal energy efficiency. Two heat exchangers allow bidirectional thermal energy exchange with the DHC network, alternating heat extraction (right) and rejection (left) depending on the operation conditions. A two-pipe bidirectional DHC network interconnects substations with the energy centre, constituted by groundwater wells, a heat exchanger, a central heat pump, and a thermal storage. Ground water (thermal renewable energy source) is extracted by means of a hydraulic pump from the unconfined aquifer and then discharged in an open-loop, after the exploitation of the energy content. Building substations can either extract or reject heat from the balancing unit, which shall be maintained within suitable temperature levels for efficiency. The amount and direction of the flow in the network is a result of the interactions among the different decentralized pumps of the substations. The network is heated up by the central heat pump and cooled down through a direct exchange at the groundwater heat exchanger. The consumption of the ”equivalent chiller” is only due to the pumping work.

 https://doi.org/10.1051/e3sconf/202452305003



(a) Substation layout. (b) Energy centre layout.

Fig. 1. District heating and cooling network layout.

2.2 Optimization

To assess the energy performance of energy systems is required a control strategy, which consists in the definition of the scheduling of the different subsystems through an optimization. Since the network temperature is not known a priori, a two-level optimization is necessary. A first optimization, for each individual substation, defines the best operating strategy to satisfy the loads required by the building units for each of the possible temperatures preliminarily defined. At the second level, once the thermal loads that the network must support have been defined, by aggregating the thermal loads of all the substations, the optimization of the energy centre defines the operational strategy of the central heat pump and of the equivalent chiller, therefore schedules the heating or cooling of the network and its actual temperatures.
Optimization is implemented in Matlab using MILP in Gurobi [12]. The implementation regarding variables and constraints for the heat and energy flows of the DHC network and for its control is based on Famiglietti et al. [11], only the main formulas for the economic optimization are reported below.

2.2.1 Substations Optimization

At this step, the presence of an energy community is not yet considered. The PV production of modules, assumed installed on the roof of each building, supplies directly the POD (Point Of Delivery) of the condominium consumption, while the excess production is assumed sold to the grid. An integer variable (δ in Equation 4), that can only assume the values 0 (false) or 1 (true), tells, for each time step, if the electricity is purchased or injected from/into the grid. In both cases, limitations on power must be respected: the power exported from the grid cannot be higher than the capacity of the POD; the power of dissipation of electricity into the grid must be lower that the PV system peak power.

$$\begin{cases} \delta_{buy} + \delta_{grid} \leq 1 \\ 0 \leq E_{buy} \leq \delta_{buy} * P_{exp,grid} \\ 0 \leq E_{grid} \leq \delta_{grid} * PV_{peak\ power} \end{cases} \tag{4}$$

The objective of substation optimization is to maximize the direct physical self-consumption of energy produced by PVs (Equation 5) to maximize the savings on bill for the district (Equation 6). The total self-consumption is defined as the minimum between the PV production and total common demand of a building unit, so the substation consumptions for the HP and HPC and the HVAC system consumption for fans.

$$E_{selfcons} = min\ (PV_{prod}, W_{inp,HPC} + W_{inp,HP} + W_{HVAC}) \tag{5}$$

$$savings\ bill = electricity\ price * E_{selfcons} \tag{6}$$

Minimization of the net daily expense, given by the difference between the energy purchase cost and the economic earning by the sale to the grid at the single national price, can be considered closely related to the maximization of self-consumption.

$$E_{buy} = E_{grid} + W_{inp,HPC} + W_{inp,HP} + W_{HVAC} - PV_{prod} \tag{7}$$

$$obj = electricity\ price * E_{buy} - PUN * E_{grid} \tag{8}$$

The optimization with MILP minimizes the objective function in Equation 8 respecting the imposed equalities and inequalities. Under the assumption that the purchase price of energy [13] is always higher than the PUN [7], and that it is therefore always less convenient to sell than to self-consume, the operational strategy will lead to shifting the programmable consumption of the plants (DHW heating) to the hours of the day when it is possible the physical self-consumption.

2.2.2 Energy Centre Optimization

The objective of energy centre optimization is to maximize the consumption of the PV electricity shared inside the REC, to maximize, for social purpose, the economic benefit given by incentivization. The shared electricity in the community (Equation 9) is the minimum between the PV production net of the direct physical self-consumption at substation/building level and the energy community total demand, which consider the energy centre demand for the central heat pump and for the pumping, and the electric demand for appliances of the community members.

$$E_{shared\ REC} = min\ (PV_{available\ REC}, W_{inp,equivalent\ chiller} + W_{inp,central\ HP} + W_{appliances,community\ members}) \tag{9}$$

The excess of electricity, not instantaneously virtually consumed in the configuration of diffuse self-consumption, is sold to the grid. As before, the limit at the power of dissipation into the grid is the nominal power of the photovoltaic system. If the PV production cannot satisfy the energy community demand, the electricity is purchased from the grid. Since all the members of the diffuse energy community must be connected under the same primary (high voltage) substation, the limit pow-er for the exported electricity is its size. An integer variable (δ in Equation 10), that can only assume the values 0 (false) or 1 (true), tells, for each time step, if the electricity is purchased or sold from/to the grid.

$$\begin{cases} \delta_{buy\ primary} + \delta_{sell} \leq 1 \\ 0 \leq E_{buy\ primary} \leq \delta_{buy\ primary} * P_{exp,primary} \\ 0 \leq E_{sell} \leq \delta_{sell} * PV_{peak\ power} \end{cases} \tag{10}$$

The revenues obtained from the REC come from the incentives of the electricity shared (Equation 12) and from the selling of the exceeding amount (Equation 11).

$$R_{sell,REC} = PUN * E_{sell} \tag{11}$$

$$R_{shared\ \ REC} = incentives * E_{shared\ REC} \tag{12}$$

As before and under the same assumption, the net daily expense of all the REC, given by the difference between the energy purchase cost and the economic earning by the sale to the grid at the single national price (Equation 14), is minimized in the optimization. The operational strategy will lead to shifting the programmable consumption of the energy centre (central heat pump and equivalent chiller) to the hours of the day when the PV production for the community is avail-able and still not consumed by the community members' appliances.

$$\begin{aligned} \mathrm{E_{buy\ primary}} = \mathrm{E_{sell}} + \mathrm{W_{inp,central\ HP}} + \mathrm{W_{inp,equivalent\ chiller}} \\ + \mathrm{W_{appliances,community\ members}} - \mathrm{PV_{available\ REC}} \end{aligned} \tag{13}$$

$$\mathrm{obj} = \mathrm{electricity\ price} * \mathrm{E_{buy\ primary}} - \mathrm{PUN} * \mathrm{E_{sell}} \tag{14}$$

2.3 Cash Flow and REC Sharing Mechanism

Once the optimisation has defined the operation scheduling of the DHC net-work generation system, and therefore, hour per hour, the electricity flow of the district, the financial analysis is performed for a time horizon of 21 years, considering that incentives are guaranteed for 20 years. The cashflow is then calculated with the aim of evaluating the pay-back period of the PV system installed by prosumer and the profits of the REC to understand how convenient it can be to be part of a REC. The owners of the district PV systems, obtain a profit for the savings on bill, suited to return to the costs of investment (CAPEX), maintenance (OPEX), and for the insurance premium. The incentive of 50% of the invested capital as a tax deduction for 10 years is also considered.

In Table 2 are reported the values used for the cash flow simulation.

Table 2. Cost items for the cash flow simulation.

cost items		
turnkey plant	1400 €/kWpeak	only the first year
annual O&M costs	20 €/kWpeak/year	from the second year
insurance price	12 €/kWpeak/year	from the first year
REC constitution	2000 €	only the first year
REC administration	2000 €/year	from the first year

The REC members do not receive the incentives directly. The community manager obtains the revenues proportional to the shared electricity and the remuneration for the electricity sold; then community net profits are distributed among the members using a sharing mechanism algorithm. The distribution of profits respects the share of shared energy assigned to each member of the energy community.
There is no prevailing practice on how to share the economic benefits between the REC members; each community define its own in the constitution contract. According to the goals of this paper, the rationale behind the sharing mechanism must be the social one of allowing economic help to fragile families in conditions of energy poverty. Therefore, the net profit is shared directly between district residents and fragile families, without remunerating the contribution to the sharing by the energy centre to not decrease the amount of profit for fragile families. Three scenarios are proposed in Fig. 2.

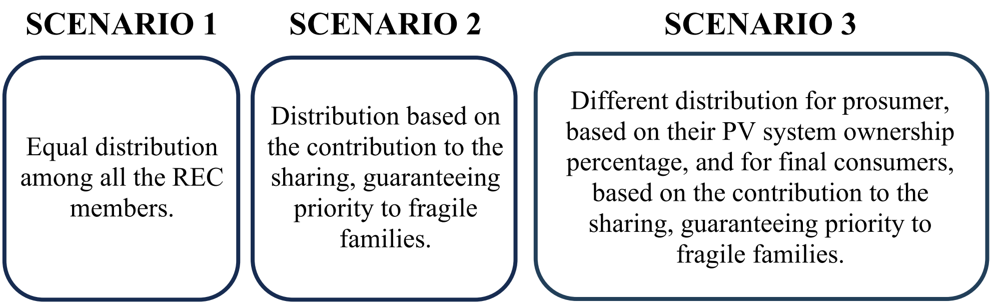


Fig. 2. Three scenarios for the distribution of the REC profits.

In the second scenario, two groups are defined and the priority over the allocation of shared electricity is guaranteed to the group of fragile families. This means that the PV production contributing to the shared electricity allocated to district residents is, on hourly basis, net of the instantaneous consumption of the first group; then, within both groups, there is the opportunity to increase or decrease the individual profit through responsible consumption during peak of availability. The third scenario differs from the second one only for the distribution concerning the prosumer group. The benefits allocated to the district residents' group, net of the first group, are divided on the basis of the amount of PV nominal power owned by the prosumers.

3 Case Study

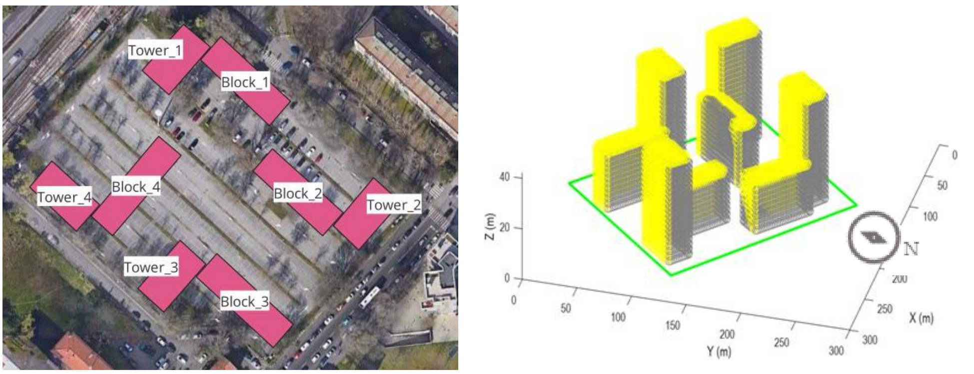
The aim of the case study is to propose a tailored decarbonised solution for a new district in Milan that strives to meet the following objectives:

- Design a Positive Energy District;
- Create an energy community with a social purpose.

PV systems are installed to cover the district's common electricity consumption and to supply a REC which includes residents of the district and fragile families from the surroundings. The aim of the REC is to support those families who find themselves in conditions of economic poverty, through the appropriate redistribution of the profits obtained thanks to the incentivization of the shared electricity. For this last purpose, the operation strategy of the 5GDHC system is obtained by maximizing the sharing of electricity inside the energy community, so shifting, as far as possible, the hours of operation of the plants when solar energy is available and when it is not already needed by fragile consumers.

3.1 Case Study Model

The new district in Milan, described in Fig. 3, consists of 8 independent buildings, the layout of which provides for a "Tower building", adjacent to "Block building". Each of them has the ground floor dedicated to commercial services, while the other floors are for residential purpose. The opaque and transparent envelop respects the minimum requirements of the regional Italian legislation and PV panels are placed on the roofs of all the buildings in the district with an inclination of 30 degrees.



(a) District layout (from: Qgis) (b) Solar exposure in January 12 a.m. (from: Matlab).

Fig. 3. Layout of the district and solar exposure.

3.2 Energy Modeling of Buildings

Residential apartments and retail shops are characterized by different hourly schedules and different specific data according to ASHRAE 90.1 [14] [15]. For the residential apartments the heating period goes from the 15th of October to the 14th of April, for commercial floors from 15th November to 14th March, and the temperature setpoints are for both of 20°C for the heating period and 26°C for the cooling period. The ventilation is mechanical and the air handling unit (AHU) with an efficient air-to-air cross-flow heat exchanger (75%) allows the heat recover.

3.3 5th Generation District Heating and Cooling Network

The DHC network of the case study is composed of 16 substations, one for the commercial and one for the residential unit, for each of the 8 buildings, so that, if maintenance is needed to the plant of the commercial unit, this doesn’t generate any problem for residents.

3.4 Renewable Energy Community

Since utilities cannot be part of an energy community, to make the generation system of the DHC network account for the energy shared in the configuration, the DHC network has to be owned by households. In the analysed case study, the residents of the district buildings are owners of the DHC network plant and of the PV plants in a percentage defined by the condominium and super-condominium allocation table.

The electricity flow inside the energy community is described in Fig. 4.

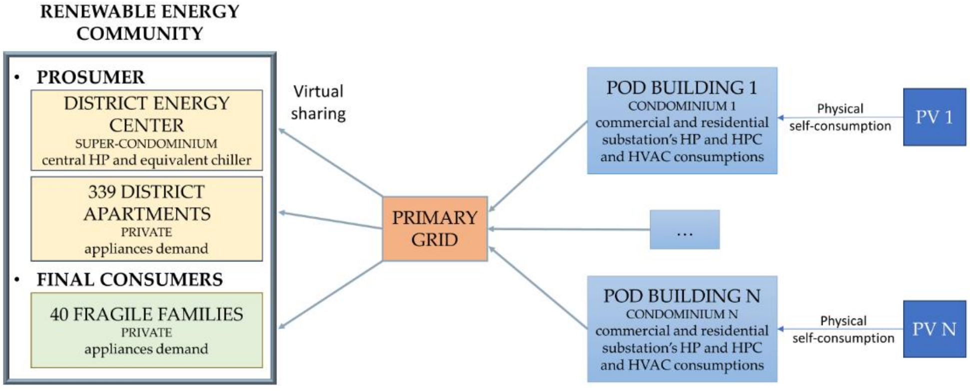


Fig. 4. Electricity flow from the district PV systems to the REC.

In each building, the PV system is directly connected to the condominium POD. Physical self-consumption generates an economic benefit for the condominium in terms of savings-on-bill, the relevance of which, for each owner, will be de-fined on the basis of the condominium allocation table. The excess electricity in this first step is fed into the distribution grid and accounts for the amount of electricity virtually available to the energy community. The instantaneous consumption of shared energy by the REC members is incentivized, while the remaining electricity is sold to the grid and remunerated by the GSE at the PUN. The incentive and remuneration are for the economic benefit of the community.

4 Results

The results of the energy and economic simulation are analysed and the goals of the study commented.

4.1 Case Study Energy Consumption and Production

For a district useful area of 44938.49 m^2, 4903.81 m^2 for commercial units and 40034.68 m^2 for residential ones, specific results are showed in Table 3.

Table 3. Building energy needs and energy demand of the distribution system.

specific loads		commercial	residential	district
specific heating load	[$kWh_{th}/m^2/year$]	14.73	25.84	24.63
specific cooling load	[$kWh_{th}/m^2/year$]	44.61	15.15	18.37
specific DHW load	[$kWh_{th}/m^2/year$]	0.12	24.10	21.48
specific load for appliances	[$kWh_{el}/m^2/year$]	72.50	19.16	24.98
specific parasitic energy demand	[$kWh_{el}/m^2/year$]	5.96	4.21	4.40

The installation of PVs results in a nominal peak power installed in the district of 766.82 kW_P and an annual electricity production of 821.7 MWh_{el}.

4.2 Energy Simulation Results

The optimization objective is to maximize the PV self-consumption, both physical and virtual, by shifting the operation of HPs and HPCs, when possible, to the hours of the day in which there is great availability of solar source. In Fig. 5 is presented the energy flow for the energy community for a typical day of June/July, characterized by the greatest cooling load and the greatest PV production. During winter months the PV production is so low that it is almost completely self-consumed at substation level.

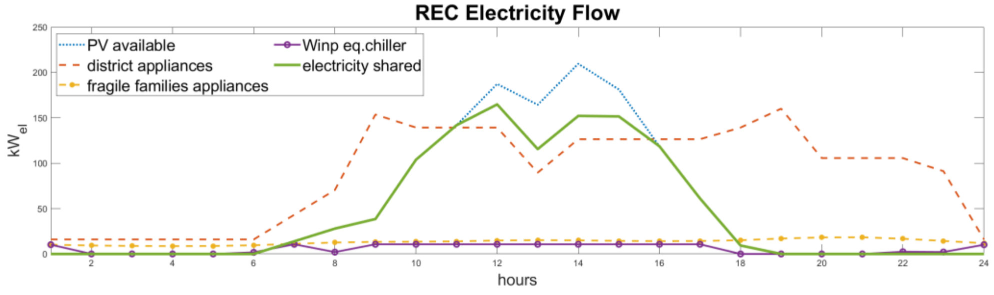


Fig. 5. REC electricity flows for a typical day of the period from the 15th of June to the 14th of July.

In summer, the only consumption of the energy centre is the one for the pumping of the water through the groundwater heat exchanger (equivalent chiller consumption). The network is cooled in the central hours of the day when there is the solar source. At the same time, PV production is high, so that a large amount is available to the energy community, and what is not instantly virtually consumed is sold to the grid.

Once the scheduling of the different subsystems has been defined, the annual results, reported in Table 4 are obtained.

Table 4. Energy simulation results of district consumption and PV production.

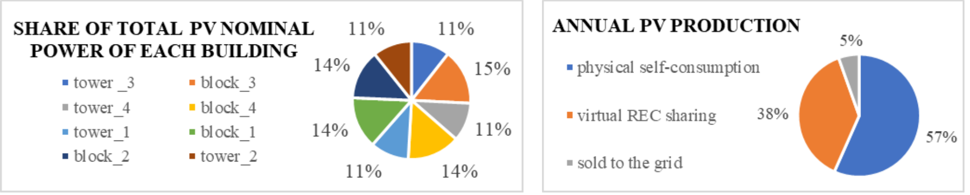
annual electricity production and consumption of the district		
appliances	1122.4	MWh_{el}/year
parasitic consumption of HVAC system	197.8	MWh_{el}/year
heating, cooling and pumping	730	MWh_{el}/year
total consumption	2050.2	MWh_{el}/year
PV production	821.7	MWh_{el}/year

The total annual energy electricity production from renewable energy is lower than the annual electricity consumption of the district and so, in this configuration, the district cannot be considered as a positive energy district (PED). The presence of commercial spaces in each building, with higher consumptions for space cooling, ventilation, appliances and lighting with respect to residential units, increases the energy demand of the district. Furthermore, the installation of two substations per building increases the energy consumption for recirculation pumping.

 https://doi.org/10.1051/e3sconf/202452305003

4.3 REC Economic Simulation Results

More than half of the electricity produced by the district's PV systems is directly self-consumed for the condominium consumptions and thanks to the presence of an energy community the 38% is locally consumed and only the 5% is fed into the grid and sold (Fig. 6.b).



(a) Share of district PV nominal power owned by each condominium.

(b) Share of PV production directly self-consumed, shared inside the REC or sold to the grid.

Fig. 6. Photovoltaic share.

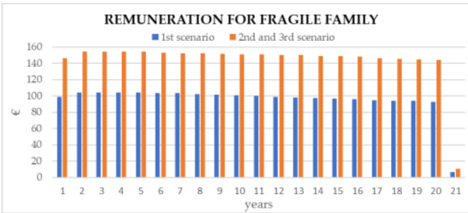
4.3.1 Prosumer Pay-Back Time

The ownership of the PV systems has been assigned to the district residents and the benefits are redistributed on the basis of the condominium allocation tables. However, even though the direct self-consumption of the whole district is very high (Fig. 6.b), the percentage varies according to the type of building. For Blocks, which have larger power plants (Fig. 6.a), with consequent higher costs, the direct self-consumption is around 48-42% of their production, with a saving on bill which leads to reach the pay-back-period of the plant in 10 years. A long period of time in comparison to the residents of Towers, with smaller PV systems and greater self-consumption (70-73%), which reach the return on investment in 7 years. This difference could be compensated by a proper redistribution of the REC profits based on the different peak power ownership between prosumers and it will be taken into consideration in the scenario 3 of the sharing mechanism analysis.

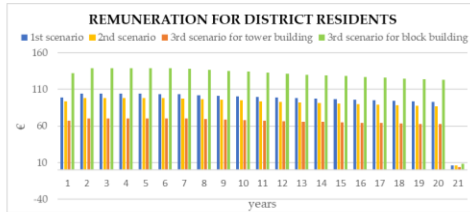
4.3.2 REC Members Economic Benefits

The resulting economic benefits in 21 years for different REC members and for the three proposed sharing mechanism are presented in Fig. 7. The simulation shows how the presence of an energy community and the choice of the profit redistribution mechanism, can be useful for multiple purposes. The first sharing mechanism, which provides for an equal distribution among all members, is only beneficial for the resident owners of the *Tower buildings*' PV systems but does not take into consideration either the social purpose of the community, or the difference in the contribution of PV production between the buildings, or to promote virtuous behaviour to maximize the virtual sharing. The second scenario, in which the distribution is based on the contribution to the sharing and the priority is guaranteed to fragile families, doesn't show the differences within the respective groups, that could arise with different electricity consumption profiles, but, nevertheless, it highlights the benefit given by the priority in the allocation to fragile families, whose profit is approximately 57% higher than that of prosumers. In this case, both the social purpose and the virtuous consumption are taken into consideration, but the difference between the return on investment of the different condominiums is still not balanced. The third scenario allows fragile families, at which the priority is guaranteed, to have an ever-greater profit than prosumers, while maintaining the possibility of increasing it by shifting consumption to the peak hours of PV availability.

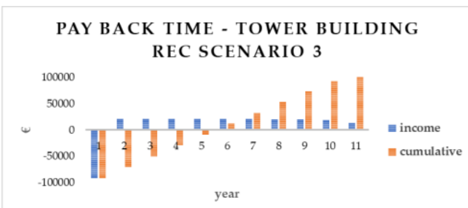
Furthermore, thanks to the allocation mechanism of the group of prosumers, based on the PV system ownership percentage, it allows for a higher profit of the residents of the Block buildings, which leads to a decrease in the pay-back time of the investment to 8 years (Fig. 7.c; Fig. 7.d).



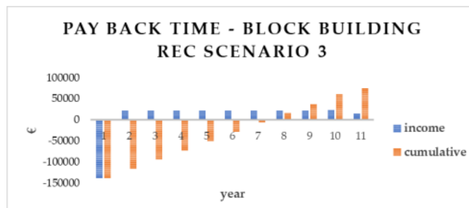
(a) Economic benefit for a fragile family.



(b) Economic benefit for a Tower building resident and a Block building resident.



(c) PV system pay-back time for Towers with the energy community benefit.



(d) PV system pay-back time for Blocks with the energy community benefit.

Fig. 7. Contribution of the REC benefits.

In each of the three scenarios, profits are very low, considering that they are on an annual basis, since all the residents of the district are included in the REC, a very large number of members to split the benefits among. Considering that participation in the community is voluntary, in front of insignificant earnings, fewer residents may be interested in participating, thus increasing the share of profits of those who decide to be part of it. At the end of the 20-year incentive period, the community's economic earning become negligible. The energy community continues to make sense to exist only to fulfill the commitment to maximize the production and the consumption of renewable energy on site.

5 Conclusions

As further demonstration of the difficulty of achieving climate neutrality in highly populated cities with high consumption and limited space available for renewable energy sources, even in the analysed case study in Milan the PV production is too low compared to the district demand. The production is not enough even to guarantee to the members of the energy community significant profits on the annual budget of a family. At first, the possibility of increasing production that accounts for the REC by placing modules even outside the district geographical boundary should be studied. Secondly, it would be appropriate to carry out a sensitivity analysis for the profits of fragile families as the number of members of the community and the families-to-residents ratio varies.

In the case study, the DHC system is assumed owned by residents. A 5th generation DHC network has a huge investment cost; a new technology could lead to mal-functions and consequent extra-maintenance costs. Currently, in a more realistic scenario, the network would remain the property of a utility that repays the investment through the sale of the heating and cooling service. However, utilities, by Italian law, cannot be part of a REC, so the DHC system should be optimized to minimize energy consumption and the energy community should be made up of private residents with the purpose of sharing for the residential electric demand. It cannot be excluded that the scenario considered in this case study may not become a viable way in the future when the DHC networks will become more widespread.

Symbology

C_{VSC}	Remuneration for the valorization of shared electricity, €.
$CU_{Afa),m}$	Monthly flat-rate unit fee for self-consumption, €/kWh.
C_{ISC}	Remuneration for the incentivization of shared electricity, €.
FA_{VSC}	Fee award for the valorized shared electricity, €/kWh.
E_{VSC}	Valorized shared electricity inside the energy community, kWh.
$R_{fed\ into\ grid}$	Revenues for the energy sold to the national grid, €.
P_A	Price applied for the electricity withdrawal by the GSE, €/kWh.
E_{VSC}	Valorized shared electricity, kWh.
E	Average power for a time step, Wh/h.
W	Power, W.
P	Power, W.
$PV_{peak\ power}$	Photovoltaic system peak power, W.
$PV_{available\ REC}$	Time step average power from photovoltaics available for the REC, Wh/h.
R	Revenues, €.
obj	Objective function, ND
δ	Integer variable, ND.

References

1. Pozzi M., Spirito G., Fattori F., Dénarié A., Famiglietti J., Motta M., «Synergies between buildings retrofit and district heating. The role of DH in a decarbonized scenario for the city of Milano.,» Energy Reports, vol. 7, pp. 449-457, 2021. https://doi.org/10.1016/j.egyr.2021.08.083
2. Causone F., Scoccia R., Pelle M., Colombo P., Motta M., Ferroni S., «Neighborhood Energy Modeling and Monitoring: A Case Study,» Energies, vol. 14, 2021. https://doi.org/10.3390/en14123716
3. Lund H., Werner S., Wiltshire R., Svendsen S., Thorsen J., «4th Generation District Heating (4GDH): Integrating smart thermal grids into future sustainable energy systems.,» Energy, vol. 68, pp. 1-11, 2014. https://doi.org/10.1016/j.energy.2014.02.089
4. Buffa S., Cozzini M., D'Antoni M., Baretieri M., Fedrizzi R., «5th generation district heating and cooling systems: A review of existing cases in Europe.,» Renewable and Sustainable Energy Reviews, vol. 104, pp. 504-522, 2019. https://doi.org/10.1016/j.rser.2018.12.059
5. ARERA, 2023. [Online]. Available: https://www.arera.it/it/elettricita/trasmissione.htm.
6. MASE, «Consultazione pubblica: Attuazione della disciplina per la regolamentazione degli incentivi per la condivisione dell'energia di cui all'articolo 8 del decreto legislativo 8 novembre 2021, n.199,» 2022.

7. GME - Gestore Mercati elettrici, «PUN,» 2021. [Online]. Available: https://www.mercatoelettrico.org/it/.
8. Illuminato Bonsignore, Italia Solare, 3E-environment energy economy, 25 Marzo 2022. [Online]. Available: https://www.energymed.it/energymed2022/conviniz/atti2022/Illuminato_Bonsignore.pdf.
9. Minuto F.D., Lanzini A., «Energy-sharing mechanisms for energy community members under different asset ownership schemes and user demand profiles,» Renewable and Sustainable Energy Reviews, vol. 168, 2022. https://doi.org/10.1016/j.rser.2022.112859
10. International Organization for Standardization: Geneva,Switzerland, «CEN EN ISO 52016-1; 2017 Energy Performance of Buildings—Energy Needs for Heating and Cooling, Internal Temperatures and Sensible and Latent Heat Loads—Part 1: Calculation Procedures.,» 2017.
11. Famiglietti J., Aprile M., Spirito G., Motta M., «Net-Zero Climate Emissions Districts: Potentials and Constraints for Social Housing in Milan,» Energies, vol. 16, 2023. https://doi.org/10.3390/en16031504
12. Gurobi Optimization LLC, Gurobi Optimizer Reference Manual, Portland, OR, USA, 2022.
13. ARERA, «Andamento del prezzo dell'energia elettrica per il consumatore domestico tipo in maggior tutela.,» 2021. [Online]. Available: https://www.arera.it/it/dati/eep35.htm.
14. ASHRAE, Standard 90.1 - Energy Standard for Sites and Buildings Except Low-Rise Residential Buildings, 2022.
15. Kneifel J.D., National Institute of Standards and Technology, Building Industry Reporting and Design for Sustainability (BIRDS) Technical Manual and User Guide, Gaithersburg, MD, 2013.
16. Allegato A alla delibera 280/07, 2007.
17. Allegato A alla delibera 727/2022/R/EEL, 2022.
18. Decreto 26 giugno 2015 - Applicazione delle metodologie di calcolo delle prestazioni energetiche e definizione delle prescrizioni e dei requisiti minimi degli edifici., 2015.
19. Decreto Legge 4 giugno 2013, n. 63.
20. Decreto Legislativo 8 novembre 2021, n. 199, 2021.
21. Decreto Legislativo 8 novembre 2021, n. 210, 2021.
22. Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources, 2018.
23. Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings, 2010.
24. GSE - Gestore Servizi Energetici, «Gruppi di autoconsumatori di energia rinnovabile che agiscono collettivamente e comunità di energia rinnovabile - Modalità di profilazione dei dati di misura e relative modalità di utilizzo.,» 2022.
25. GSE - Gestore Servizi Energetici, «Regole tecniche per l'accesso al servizio di valorizzazione e incentivazione dell'energia elettrica condivisa.,» 2022.