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Towards the implementation of Positive Energy Districts in industrial districts: an Italian case study

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Towards the implementation of Positive Energy Districts in industrial districts: an Italian case study

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Abstract. Owing to the opportunity to provide an annual positive energy balance and net-zero carbon emissions, Positive Energy Districts aim at fostering the energy transition of urban city centres. To fully support the decarbonization of cities, it may be interesting to extend their implementation to other energy intensive districts, such as cities' industrial areas. In this regard, this paper addresses the opportunity to apply the Positive Energy District concept within the industrial area of a city in the South of Italy. A mixed-use building, the industrial wastewater treatment plant and an office building have been involved as users and equipped with a 250 kW wind turbine and multiple photovoltaic plants installed on the roof of the buildings, in parking areas and in an unused land, for a total peak power equal to 466 kW. The renewable-based plants' generation has been simulated in HOMER Pro® software, on a quarter-hour basis, and an energy and environmental analysis have been performed using users' real electric load profiles. The proposed configuration allows to save 55% of primary energy and carbon dioxide emissions compared to the baseline case where users' electric energy demand is fully met by the power grid. In particular, the primary energy saving is equal to 1 GWh/y and the carbon dioxide emissions reduction is equal to 150 tCO_2/y.

1. Introduction

Positive Energy Districts (PEDs) are expected to play a major role in the holistic strategy defined throughout Europe for fostering the energy transition of cities [1]. They represent urban areas or groups of interconnected buildings characterized by high energy-efficiency and flexibility, capable of ensuring an annual positive energy balance and producing net-zero green-house gases emissions through the adoption of renewable-based plants [2]. Based on the potentialities offered by PEDs in urban cities' areas, their support to the decarbonization of other energy intensive districts of cities, such as industrial areas, may be of particular interest. Disseminating the PED concept outside urban city boundaries may foster the achievement of the targets set out by the recent European "Green Deal Industrial Plan" [3], which reinforces the commitment of the industrial sector towards carbon neutrality by 2050 [4] supporting the uptake of renewable-based plants. Indeed, large unused surfaces exploitable to install renewable-based plants are usually available in industrial areas [5]. In addition, energy sharing in such districts may take advantage of the complementarities characterizing load profiles relating to different end-use types, which once aggregated would result in a smoother profile capable of increasing the number of generation plants' operating hours and lowering the mismatch between energy demand and supply [6].

Although the implementation of collective energy strategies in industrial districts have been widely discussed in the literature, the constitution of PEDs involving different end-user types in industrial areas represents a field of research still quite new. Therefore, this study aims at enriching the scientific literature on this topic by investigating the constitution of a PED in the industrial area of a city in Southern Italy. The PED under examination involves three users, which have been equipped with multiple photovoltaic (PV) plants and a wind turbine. The proposed scenario has been compared with the baseline case (BC), where users' electric energy demand is fully covered by the power grid (PG).

2. Materials and Methods

In this section, the users under investigation (Section 2.1), the renewable-based plants installed within the PED (Section 2.2) and the methods adopted for carrying out the energy and environmental analysis (Section 2.3) are described.

2.1. Users' characterization

As reported in Figure 1, the PED under examination includes three users: a mixed-used building (Us#1), setting of offices and companies operating in the services sector, the industrial wastewater treatment plant (Us#2) and an office building (Us#3). Each user, except for Us#3, is equipped with a PV plant installed on the roof. PV panels have been installed also in un unused land next to Us#1 and in parking areas through PV canopies. In addition, a wind turbine has been installed too for ensuring a positive energy balance on a yearly basis. In the proposed configuration, electricity sharing has been implemented according to the definition of dynamic PEDs [7]. Users draw electric energy from the primary substation when their electric load exceeds the supply of their own PV plant, taking advantage, whenever viable, of the surplus electric energy fed to the PG by the PV plants owned by other users or the wind turbine. In this way, electric energy virtual self-consumption takes place when the absorption from and injection to the primary substation occur simultaneously. Monitored data about users' electric load profiles on a quarter-hour basis, obtained from the Italian electricity distributor [8] is shown in Figure 2.

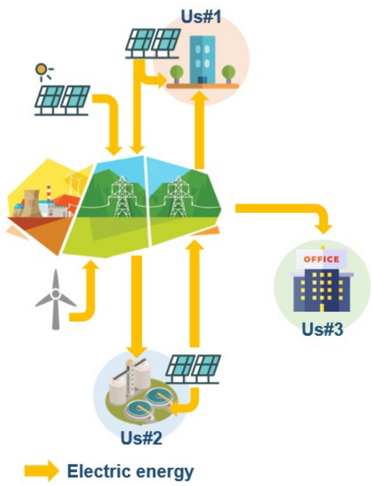

Figure 1. Layout of the proposed PED configuration

Figure 2. Electric load profiles on a quarter-hour basis of Us#1 (a), Us#2 (b) and Us#3 (c)

2.2. Renewable-based plants characterization

The renewable-based plants serving the users under examination have been designed to cover all available surfaces in order to achieve a positive energy balance on an annual basis. Several PV plants and a wind turbine have been supposed to be installed. The choice of this types of renewable-based installations derives from the availability of both space and sources. In particular, the installation of the wind turbine has been favoured to the installation of other PV panels to allow a minimum level of diversification of the renewable energy sources exploited. Monocrystalline PV panels, whose main parameters are reported in Table 1, have been selected. The electric energy production profiles of both the PV plants and the wind turbine have been evaluated with a fifteen-minute timestep using the software HOMER Pro® [9]. The dynamic simulations have been carried out over one year. In total, 1,424 PV panels have been supposed to be installed within the entire PED, corresponding to 466 kW_p. As already mentioned, a 250 kW wind turbine has been installed too and its main technical parameters are reported in Table 2.

Table 1. PV panels technical parameters [10]

Parameter	Value
Peak power [W]	327
Efficiency [%]	20.1
Maximum power voltage [V]	54.7
Maximum power current [A]	6.0
Open circuit voltage [V]	64.9
Short circuit current [A]	6.5
Temperature coefficient of power [%/°C]	−0.4
Temperature coefficient of voltage [mV/°C]	−176.6
Temperature coefficient of current [mA/°C]	2.6
Gross area [m^2]	1.6

Table 2. Wind turbine technical parameters [11]

Parameter	Value
Nominal power [kW]	250
Cut-in wind speed [m/s]	2.7
Nominal wind speed [m/s]	12.5
Rotor diameter [m]	30

2.3. Energy and environmental analysis

The proposed scenario has been compared with the BC, where users' electric energy demand is entirely met by the PG, from the energy and environmental points of view. As for the energy analysis, the self-consumption d_i and self-sufficiency s_i indexes have been evaluated on a monthly basis by using Equations (1) and (2), respectively. Namely, the subscript i accounts for the months in a year and thus ranges between January and December. $E_{el,i}^{RES}$ represents the monthly electric energy supplied by all renewable-based plants, whereas $E_{el,i}^{OSC}$ represents the renewable electric energy consumed on site by all users on a monthly basis. In Equation (2), $E_{el,i}^{Us}$ represents users' monthly electric load.

$$d_i = \frac{E_{el,i}^{OSC}}{E_{el,i}^{RES}} \quad (1)$$

$$s_i = \frac{E_{el,i}^{OSC}}{E_{el,i}^{Us}} \quad (2)$$

The monthly primary energy saving ($\Delta E_{p,i}$) has been evaluated according to Equation (3). The term η_{el}^{PG} represents the average Italian power grid efficiency and is equal to 0.509 in 2020 [12]. $E_{el,i}^{Us}$ keeps the same meaning as in Equation (2), whereas $E_{el,i}^{PG}$ represents users' monthly electric energy demand covered by the PG in the proposed configuration.

$$\Delta E_{p,i} = \frac{E_{el,i}^{Us} - E_{el,i}^{PG}}{\eta_{el}^{PG}} \quad (3)$$

Concerning the environmental analysis, the CO_2 emissions reduction $\Delta CO_{2,i}$ owing to the installation of the renewable-based plants has been evaluated on a monthly basis. To this purpose, Equation (4) has been adopted, where the term α_{CO_2} represents the CO_2 emission factor of the Italian power grid and is equal to 286.55 gCO_2/kWh_{el} in 2020 [12].

$$\Delta CO_{2,i} = (E_{el,i}^{Us} - E_{el,i}^{PG}) \cdot \alpha_{CO_2} \quad (4)$$

3. Results and discussion

On a yearly basis, the renewable-based plants supply 998 MWh, whereas users' annual electric load is equal to 956 MWh. The stacked bars in Figure 3(a) quantify the electric energy monthly supplied by the renewable-based plants and serving the users under examination ($E_{el,i}^{RES}$), distinguishing between the electric energy consumed on-site ($E_{el,i}^{OSC}$) and fed to the grid as surplus ($E_{el,i}^{TG}$). Instead, the yellow triangular indicators point out the trend of the monthly self-consumption index d_i. The maximum value of $E_{el,i}^{RES}$ is found in May (i=5) and is equal to 103 MWh, being $E_{el,5}^{OSC}$ and $E_{el,5}^{TG}$ equal to 38 and 65 MWh, respectively. On the other hand, $E_{el,i}^{RES}$ is minimum in December (i=12), when is equal to 64 MWh, being $E_{el,12}^{OSC}$ and $E_{el,12}^{TG}$ equal to 44 and 20 MWh, respectively. The maximum and minimum d_i are found in December and April, being equal to 69 and 32%, respectively. The graph in Figure 3(b) shows instead the distinction in the users' monthly total load ($E_{el,i}^{Us}$) between the load covered through the electric energy supplied by the renewable-based plants and the PG ($E_{el,i}^{PG}$). In addition, the blue squared indicators point out the trend of the monthly self-sufficiency index s_i. $E_{el,i}^{Us}$ is maximum in July (i=7), when $E_{el,7}^{OSC}$ is equal to 63 MWh and $E_{el,7}^{PG}$ is equal to 62 MWh. As a result, s_7 is equal to 51%. s_i is maximum in March, when is equal to 68%, and minimum in October, when is equal to 47%.

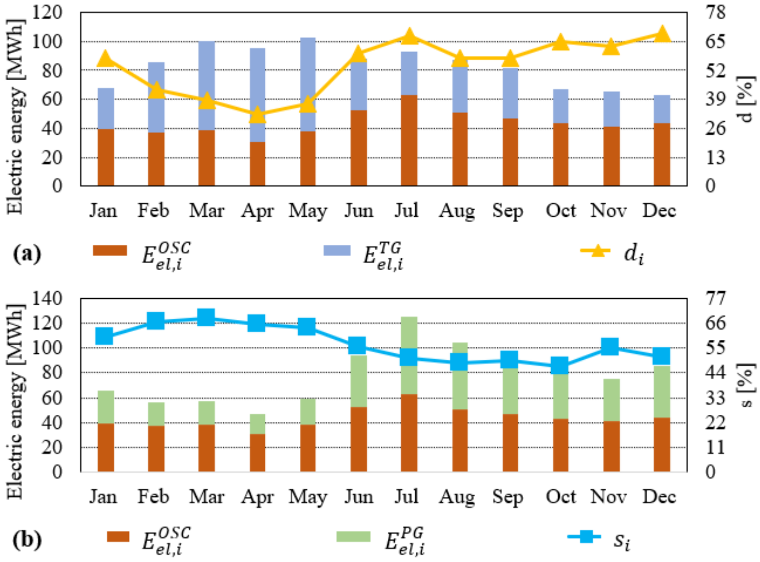

Figure 3. (a) Electric energy consumed on site, fed to the grid and self-consumption index; (b) electric energy consumed on-site, taken from the grid and self-sufficiency index.

The bar chart in the Figure 4(a) quantifies the primary energy demand due to the drawing of electricity from the PG in the BC ($E_{p,i}^{BC}$) and in the proposed configuration ($E_{p,i}^{PED}$). In addition, the yellow triangular indicators point out the trend of the monthly primary energy saving $\Delta E_{p,i}$. Its maximum value is found in March (*i*=3) and is equal to 68%, being $E_{p,3}^{BC}$ and $E_{p,3}^{PED}$ equal to 112 and 36 MWh, respectively. On a yearly basis, ΔE_p is equal to 55%, corresponding to 1 GWh/y of primary energy saved. The bar chart in Figure 4(b) shows instead the CO_2 emissions relating to the drawing of electricity from the PG in the BC ($CO_{2,i}^{BC}$) and in the proposed configuration ($CO_{2,i}^{PED}$). The green squared indicators point out the trend of the monthly carbon dioxide emissions reduction ($\Delta CO_{2,i}$). Its maximum value is found again in March and is equal to 68%, being $CO_{2,3}^{BC}$ and $CO_{2,3}^{PED}$ equal to 16 and 5 tCO_2, respectively. On a yearly basis, ΔCO_2 is equal to 55%, corresponding to 150 tCO_2/y avoided.

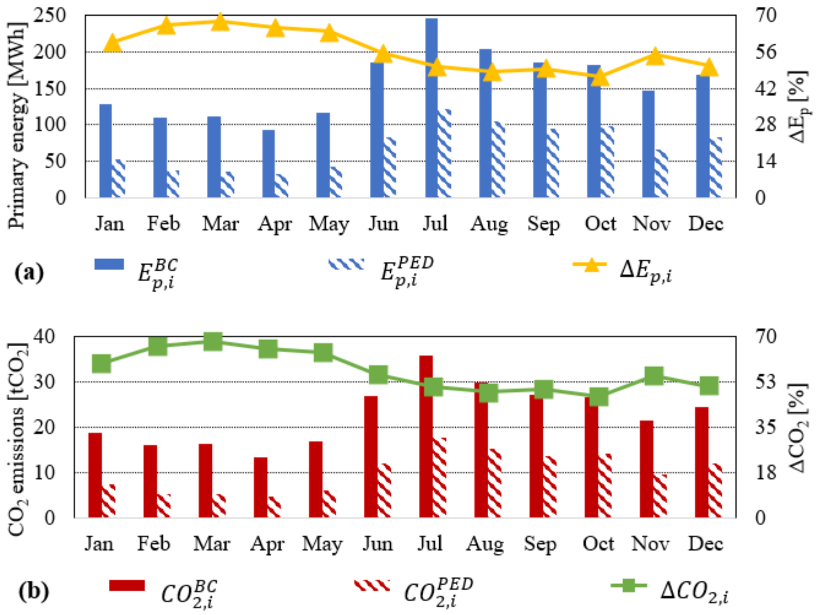

Figure 4. (a) Primary energy demand in the baseline case and proposed configuration and primary energy saving; (b) CO_2 emissions in the baseline case and prosed configuration and CO_2 emissions reduction

Based on the results obtained, the implementation of the PED concept in industrial districts may encourage the achievement of energy and climate goals also within the industrial sector, which heavily relies on energy-intensive processes. The energy and environmental benefits highlighted in this study could push the diffusion of such systems at national level and stimulate the definition of policies including industrial areas in the development of sustainable cities, which should rely on the cooperation between small and medium-sized enterprises operating in their best interest, sense of community and social responsibility, and openness to innovation.

4. Conclusions and future works

This work aims at assessing the implementation of the Positive Energy District concept within the industrial area of a city in the South of Italy. Three users are involved, namely a mixed-use building, setting of offices and companies operating in the services sector, the industrial wastewater treatment plant and an office building. They have been equipped with a 250 kW wind turbine and a 466 kW_p photovoltaic plant, in order to achieve an annual positive energy balance. The proposed configuration has been compared with the baseline case, where users' electric energy demand is fully met by the power grid. The renewable-based plants have been modelled in HOMER Pro® for simulating their electricity generation on a quarter-hour basis. As regards users' requests, real data about their electric energy demand have been collected from the Italian electricity distributor on a quarter-hour basis.

From the energy point of view, the yearly primary energy saving characterizing the proposed configuration is equal to 55% and corresponds to 1 GWh/y. Consequently, the annual carbon dioxide emission reduction is equal to 55% too, and corresponds to 150 tCO_2/y. In future works, the installation of electric energy storage systems may be investigated too in order to increase users' energy self-consumption and self-sufficiency, as well as the installation of other renewable-based technologies and the inclusion of other industrial members.

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