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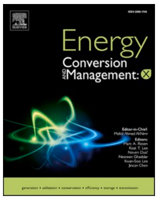

Heat pump integration in a real poly-generative energy district: A techno-economic analysis

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ABSTRACT

This paper presents a techno-economic feasibility analysis related to a heat pump installation in a poly-generative energy district to convert the overproduction of electricity into thermal power, easy to be stored in thermal storage tanks. The heat pump technology is already used for thermal/cooling energy production in different areas although application in energy districts in a power-to-heat modality to improve management of electrical/thermal energy demands is still limited.

In this research, the installation of a heat pump in the poly-generative smart grid located at the University of Genoa Campus is presented. A time dependent one-year techno-economic analysis of the energy district is performed, throughout a model built with a software developed by the authors. The integration of the heat pump in the energy district is analysed, comparing the energetic, environmental and economic performance to the present configuration of the poly-generative energy district. The results show that the heat pump introduction grants several advantages, such as a reduction in gas consumption (24 ton/year, −15%) and an increase in the annual energy efficiency of cogenerative prime movers which can work for a higher number of hours (+23%) close to the design point.

Introduction

In the last decades, the world has experimented a significant growth in terms of energy demand: in particular, the recent industrial development of many Countries has led to a strong increase (+66%) in terms of total energy supply worldwide, from $3.65{\cdot}10^8$ TJ in 1990 up to $6.06{\cdot}10^8$ TJ in 2019, as reported by International Energy Agency (IEA) [1]. As consequence, the concentration of atmospheric CO_2 has increased up to 410 ppm, growing at an alarming rate of 2 ppm per year. In 2019 CO_2 emissions reached the record of 33.6 Gton (+64% compared to 20.5 Gton in 1990), with a significant contribute of 14 Gton by electricity and heat energy producers [1]. However, EU-28 Countries have managed to reduce their total CO_2 emissions from 4000 Mton in 1990 to 2993 Mton in 2019 and 2699 Mton in 2020, [1] thanks to the adoption of different energy policies. In 2007, EU-28 defined the main targets for 2020 and recently EU-28 Countries set the main key targets for 2030: (i) 32% energy share from Renewable Energy Sources (RES) on total energy consumption; (ii) 40% reduction of Greenhouse Gases (GHG) from 1990 levels; (iii) 32.5% increase of energy efficiency compared to the business as usual scenario [2].

To reach such ambitious targets, it is mandatory to introduce innovative technologies and methodologies related to energy generation and distribution [3–5], as well as time increasing the RES contribution in residential and commercial buildings. Several authors investigated RES integration in buildings considering exergy analysis [6–8], while other authors focused their research on their techno-economic feasibility [9–10] or on multi-objective optimization [11–12]. The diffusion of smart grids [13–14] and poly-generative energy districts [15–16] for distributed generation are recent promising solutions to increase efficiency [17–18] reducing simultaneously energy losses related to centralized energy production in large power plants. Local energy districts and smart grids include renewable generators, fed by the locally available RES, and Combined Heat and Power (CHP) devices [19–20] for the high efficiency production of electrical and thermal energy at the same time [21]. Since local electrical and thermal energy demands have different profiles and peaks at different times [22], also depending on the typology of final user, the installation of energy storage systems, i.e. electrical batteries [23], thermal energy storage tanks [24–25], is a key point in order to manage the local demands [26], letting an increase of the district's global efficiency [27–28]. Due to the presence of different kind of generators in the energy districts, in particular not

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Nomenclature

Acronyms

CHP	Combined Heat and Power
DG	Distributed Generation
DHN	District Heating Network
EE	Electrical Energy
GHG	Greenhouse Gas
HP	Heat Pump
ICE	Internal Combustion Engine
IEA	International Energy Agency
LHV	Lower Heating Value
LNG	Liquid Natural Gas
mGT	micro-Gas Turbine
NG	Natural Gas
PE	Primary Energy
PtH	Power-to-heat
PV	Photovoltaic
R&D	Research and Development
RES	Renewable Energy Sources
SPM	Smart Poly-generative Microgrid
TES	Thermal Energy Storage
W-ECoMP	Web-based Economic Cogeneration Modular Program

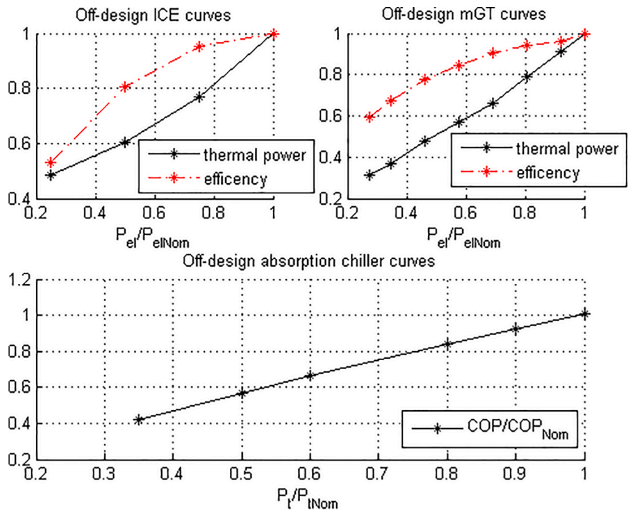

Fig. 1. Example of off-design curves implemented in W-ECoMP.

Table 1
Main features for the SPM devices.

	Value	Unit
mGT		
Nominal electrical power	65	kW
Nominal thermal power	110	kW
Nominal electrical efficiency	30%	–
Nominal thermal efficiency	49%	–
Minimum off design	15%	–
ICE		
Nominal electrical power	20	kW
Nominal thermal power	47	kW
Nominal electrical efficiency	28%	–
Nominal thermal efficiency	52%	–
Minimum off design	20%	–
PV panels		
Peak power	77	kW
Installed area	400	m^2
Nominal efficiency	17%	–
Thermal Energy Storage		
Volume	10,000	l
Storage temperature	70	°C
Specific heat	4.186	kJ/kg K
Boiler		
Nominal thermal power	500	kW
Nominal thermal efficiency	90%	–

programmable renewable energy devices such as Photovoltaic (PV) and wind generators [29], a proper control strategy is mandatory to optimize the grid management [30–31]; thus, many authors focused their research on this topic [32–33], modeling the system and developing predictive control strategies [34–35]. In the previous research [27], Thermal Energy Storage (TES) had already proven effectiveness as optimal storage asset from a thermo-economic standpoint for the management of poly-generative District Heating Networks (DHNs). In recent years, according to global tendence of heating sector electrification, power-to-heat (PtH) schemes have been investigated more and more at energy district level [36–37], but always looking at coupling Heat Pumps (HPs) and non-dispatchable RES (like PV), more than optimizing the management and exploitation of local CHP production via a proper coupling of CHP and HP + TES to avoid boilers' driven back-up solutions. The problem of the non-contemporaneity of electrical and thermal peaks of demand and related not optimal management of CHP movers (aiming to satisfy alternatively such demands as “electricity driven” or “heat driven”) has not yet been studied in detail. Furthermore, thermo-economic potential of HPs operating in PtH approach has been always assessed in large DHNs only, where the network itself can operate as storage for the energy system [38].

In a poly-generative district, air-driven-HPs coupled with TES (even simple water tanks) can easily become (as they are already available on the market) sector coupling enabling technologies trying, in a “power-to-heat” approach to maximise local electricity production self-consumption and overall local energy demand satisfaction, enabling the poly-generative district to reduce its import from external grids both at electricity and natural gas level, adding a degree of flexibility in the overall management of the poly-generative grid [39].

The present paper focuses on the Smart Poly-generation Microgrid (SPM) of Savona, located in North Italy [40], which is a poly-generative energy district, characterized by the presence of different kind of generators and energy storage systems [41]. More in details, the following devices are installed: (i) four CHP micro-Gas Turbines (mGTs), with a total installed power of 260 kW_{el} and 440 kW_{th}; (ii) a CHP Internal Combustion Engine (ICE), with an installed power of 20 kW_{el} and about 47 kW_{th}; (iii) a boiler with an installed power 500 kW_{th}; (iv) 400 m^2 of roof photovoltaic panels, with a peak power of 77 kW_{el}; (v) a Thermal Energy Storage (TES) system, with a capacity up to 10,000 L of hot water, connected to the thermal energy distribution grid. The SPM is connected to the local electrical distribution. The mGTs, the ICE and the boiler are fed by natural gas, purchased from the national network.

The present research focuses on the replacement of the boiler with a heat pump (HP) in the SPM, comparing the energy, environmental and economic performance of the two configurations. The potential advantage of the configuration including the HP relates to the management of electrical and thermal energy demands, which can be improved thanks to HP + TES exploitation [42–43].

The optimization of the HP size and the SPM energy management strategy for both the investigated configurations are carried out and compared by using an in-house software for time-dependent analysis of energy systems named W-ECoMP (Web-based Economic Cogenerative Modular Program), developed by the Authors' research group [44]. The goal of the analysis is the minimization of annual costs, at the same time satisfying electrical and thermal energy demands which represent the system's constraints, as well as targeting maximization of local clean energy production for self-consumption in an energy community approach.

This paper takes advantage of two previous research works by the

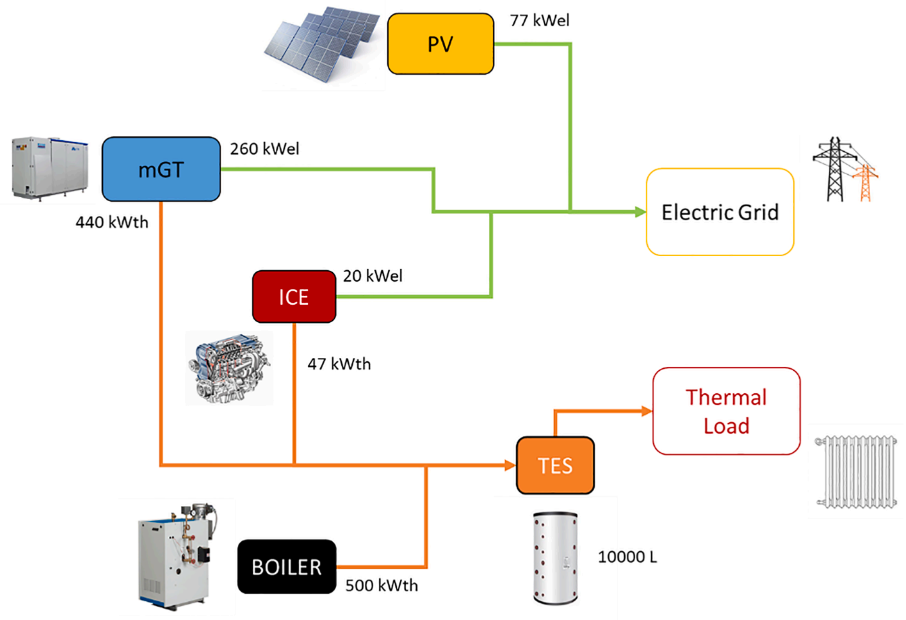

Fig. 2. Configuration with boiler (Configuration A).

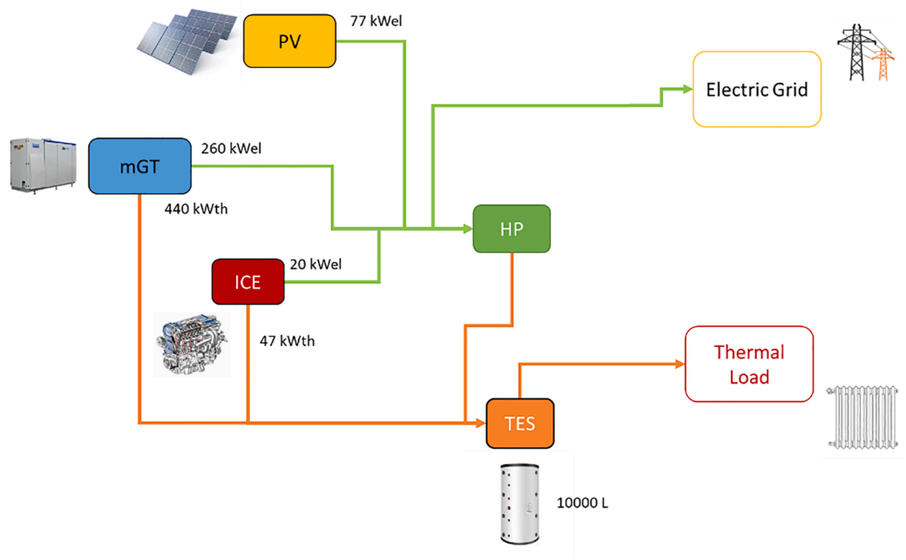

Fig. 3. Configuration with HP (Configuration B).

authors [27,48] where the thermo-economic optimization of the storage size and the management of a real poly-generative district were investigated. Such papers demonstrated how thermal demand satisfaction is the main driver of CHP prime-movers production management as well as the relevant role of TES in the district management (considering lower CAPEX and easier controllability). Such outcomes drove the authors, in addition to recent PtH R&D lines and market strategies, to consider the replacement of existing NG boilers with an air-driven Heat Pump to minimize fuel consumption and maximise electrical energy self-production exploitation towards relevant environmental benefit in terms of primary energy and emission savings. Such approach is driven by two very recent drivers in the EU panorama: i) electrification of heating systems furtherly pushed by recent natural gas crisis (also in order to increase EU independency from NG); ii) promotion of energy communities and schemes for maximization of energy self-production/self-consumption schemes in order to reduce grid disturbance of distributed generation and enable energy district to become grid flexibility actors thanks to dispatchable power generators and electrical load.

W-ECOMP software

W-ECOMP is a software for time-dependent thermo-economic analysis, developed in the last twenty years by the authors' research group at the University of Genoa [44–48] and employed in many international research projects for time-dependent analysis of different energy systems.

In order to guarantee an optimized management of the energy system, this tool controls the different modules within the system, employing a genetic algorithm, to minimize the objective function: the annual variable costs of the plant, as reported in Eq. (1).

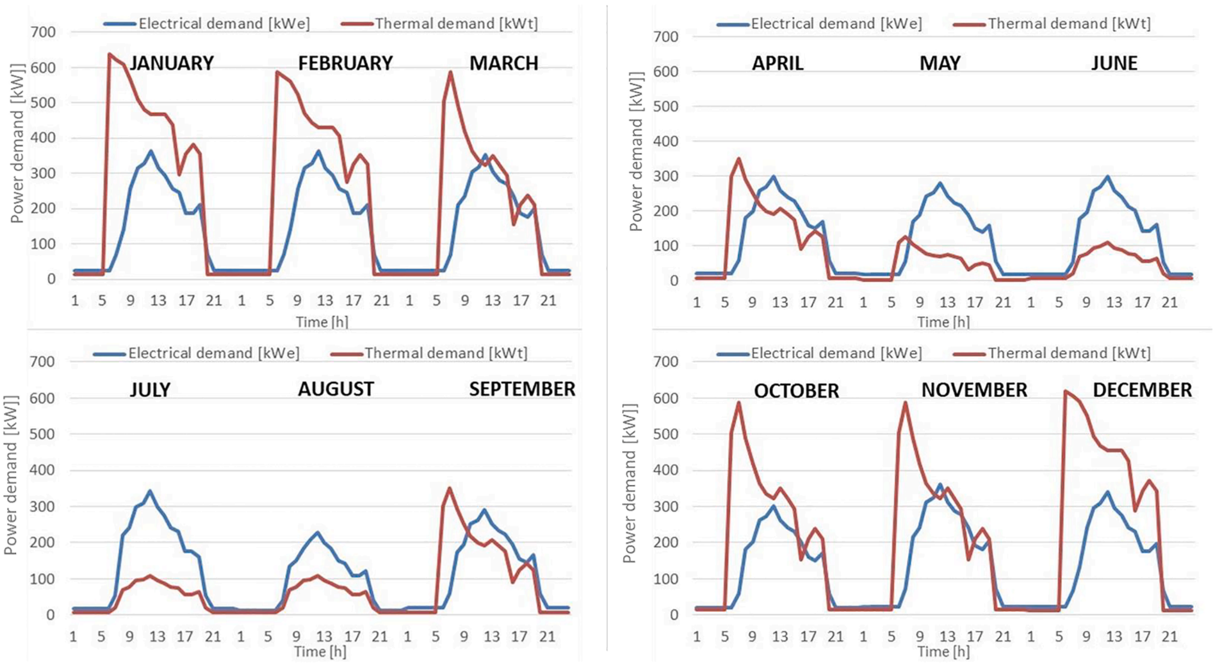

Fig. 4. Electrical and thermal load demands [27,48].

$$C_{var} = F_i \times \sum_{i=1}^{N} c_{fuel,i} + c_{el} \times E_{acq} + c_{virt} \times (F_{virt} + E_{virt} + Q_{virt}) \tag{1}$$

Annual variable costs include: (i) fuel consumption cost, (ii) electrical energy cost and (iii) "virtual costs" associated to virtual energy flows, necessary to satisfy the optimization constraints (i.e. not satisfied load energy demands by the user). Since the plant cannot supply these energy amounts, penalty costs are related to these flows. The term c_{virt} assumes a high value (i.e. two orders of magnitude higher than the other cost terms), and the optimization strategy is performed to avoid them. The same concept is applied to thermal energy balance, as reported in Eq. (2).

$$Q_{req} = \sum_{i=1}^{N} Q_{prod} + Q_{virt} \tag{2}$$

Constraints of the optimization problem are the balance equations between the energy flows required and provided by the different components. The balance includes the electrical energy produced by the prime movers, the purchased energy from national grid, the energy demand and the energy possibly consumed by some components (i.e. compressors, electrolysers).

$$E_{req} = \sum_{i=1}^{N} E_{prod} + E_{acq} + E_{virt} - \sum_{i=1}^{N} E_{cons} \tag{3}$$

At low level, the size of the components is fixed (thus, CAPEX are fixed) and a genetic algorithm operates to determine the best operational strategy, minimizing the objective function (Eq. (1)).

At high level, the size optimization of one or more devices is performed as well: in this case, the objective function includes the sum of annual variable costs C_{var}, calculated at the low level, and annual fixed plant costs C_{cap}, representing plant components sum.

W-ECoMP has a modular approach: each prime mover is characterized by cost functions and off-design curves. The cost functions are used to set the cost of each component starting from a characteristic parameter (such as the installed power) while the off-design curves describe the behaviour of the devices at partial loads. Off-design maps are defined from real data provided by the manufacturers or by experimental tests performed by the authors' research group. As an example, Fig. 1 reports the off-design curves for three different modules implemented in W-ECoMP libraries [48]. Additional information about W-ECoMP software can be found on many recent Authors' publications [45–47]. More details about TES modelling in W-ECoMP can be found in [27].

Case studies

Considering the Savona SPM, different CHP units (mGTs for a total of 260 kWe and 440 kWt, ICE for 20 kWe and 47 kWt), fed by natural gas, and RES generators (PV for 77 kWe) are installed. Furthermore, a TES with a capacity of 10,000 l is present. TES size, currently installed in the SPM, has been identified according to [27] outcomes to better operate CHP units and considering available surface/volume in the energy district close to the CHP units to operate at this purpose. The main technical data related to the installed devices are reported in Table 1. The nominal efficiencies are the same assumed in [48].

Two different configurations are investigated by employing W-ECoMP software:

1. Configuration with boiler (Configuration A).
2. Configuration with HP (Configuration B).

The first studied scenario consists of the reference case, a state-of-the-art representation (Fig. 2). In this case, a natural gas boiler is used to cover the thermal demand that the CHP units cannot satisfy. This scenario is simulated to have base data to be compared with Heat Pump applications (Fig. 3).

A large amount of data is necessary to perform the thermo-economic analysis in W-ECoMP, the main inputs for this analysis are listed below:

- Natural gas cost is assumed to equal to 0.55 €/m^3, which represents the 2018–2020 average cost for small scale industrial users (gas consumption 26,000–260,000 m^3/year) in Italy, inclusive of taxes, as reported in [49];
- The purchasing price from the grid is assumed 0.20 €/kWh, which represents the 2018–2020 average cost for small scale industrial users (electrical energy purchasing 20–500 MWh/year) in Italy, as reported in [49]. The price of the electricity sold to the grid is assumed 0.08 €/kWh, which represents the 2018–2020 average net price for the same user in the Italian scenario [49].
- Prices of electrical and thermal energy sold to users are assumed equal to 0.17 €/kWh and 0.08 €/kWh, respectively.

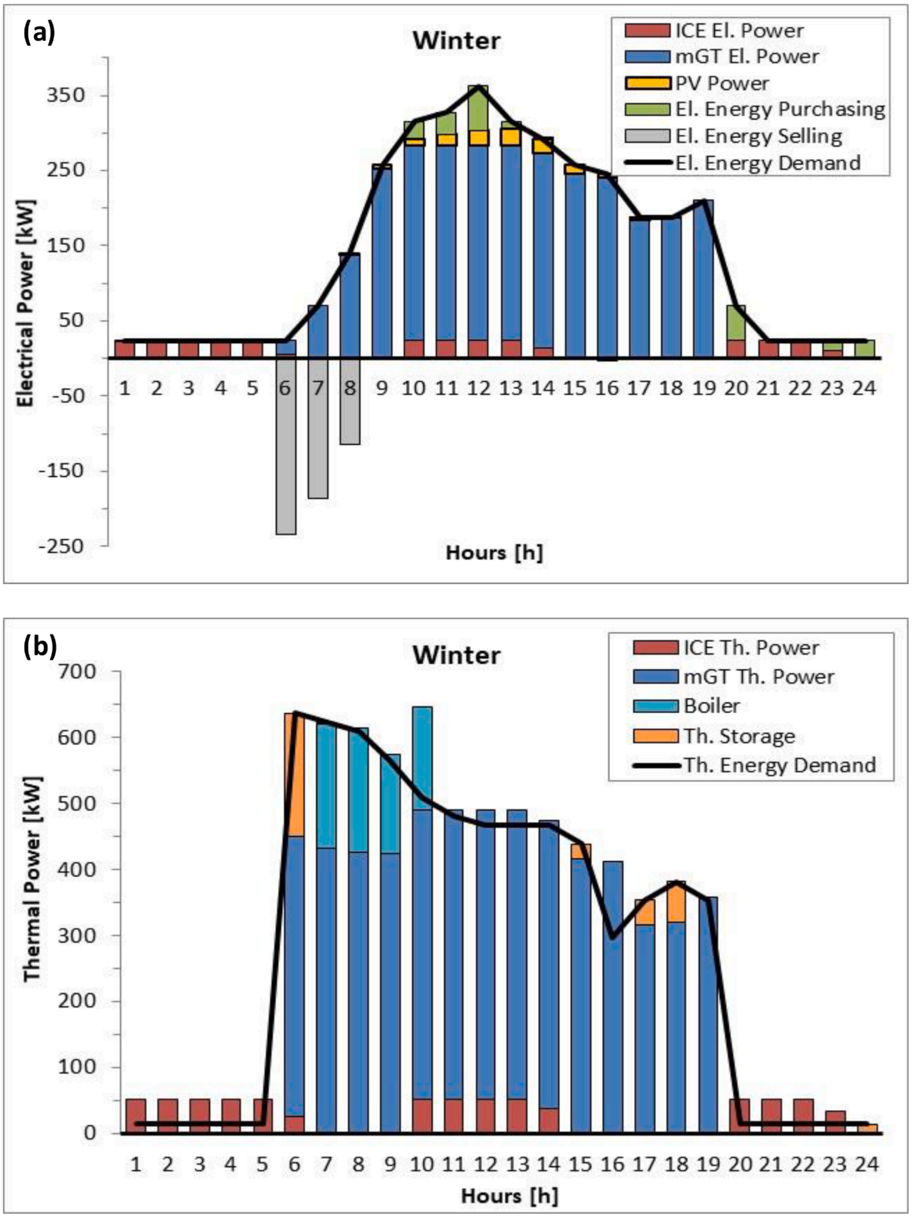

Fig. 5. Configuration A: Wintertime typical (a) Electrical and (b) Thermal energy demand.

- Electrical energy and thermal energy demand profiles are reported in Fig. 4 [27,48]. The load profiles include both residential and commercial users located in the SPM: a strong thermal peak is present in the early morning in winter months. The curves represent one of the constraints of the problem, since electrical and thermal demand must be satisfied by the CHP and RES generators in each period of the year, with the help of TES and power exchanges from/to the electrical grid.

Simulations and results

The simulations are performed using W-ECoMP software. The two different configurations are simulated to understand and estimate their behaviour in a real application considering off-design conditions for winter and summer typical representative days. Mid-season (i.e. autumn) periods of the year are not reported as less representative of HP + TES management to maximise self-exploitation of local clean energy. As reported in previous analyses [27,48], in these periods a proper management of CHP and TES can already achieve considerable improvements in terms of SPM energy independence, avoiding NG boilers use.

Configuration A (boiler)

Fig. 5a and Fig. 5b report electrical and thermal energy management for a typical winter day. It is worth noting that the ICE is employed mainly in night periods, when both demands are low. In this context, the electricity production fits the demand, while heat is stored in the TES. The heat stored during the night periods is sufficient to cover the energy demand peak in the early morning. In the following hours, the heat demand is still high, while the electrical one stands quite low; therefore, even if the mGT operates at maximum load, it is necessary to turn on the boiler selling the exceeding electrical energy to the national grid. The electricity peak hours are partially covered by using the installed components (PV panels and mGT), thus purchasing from the grid is necessary.

Concerning the summer period (Fig. 6a and 6b), the management scenario is quite different when compared to the winter one. The ICE is

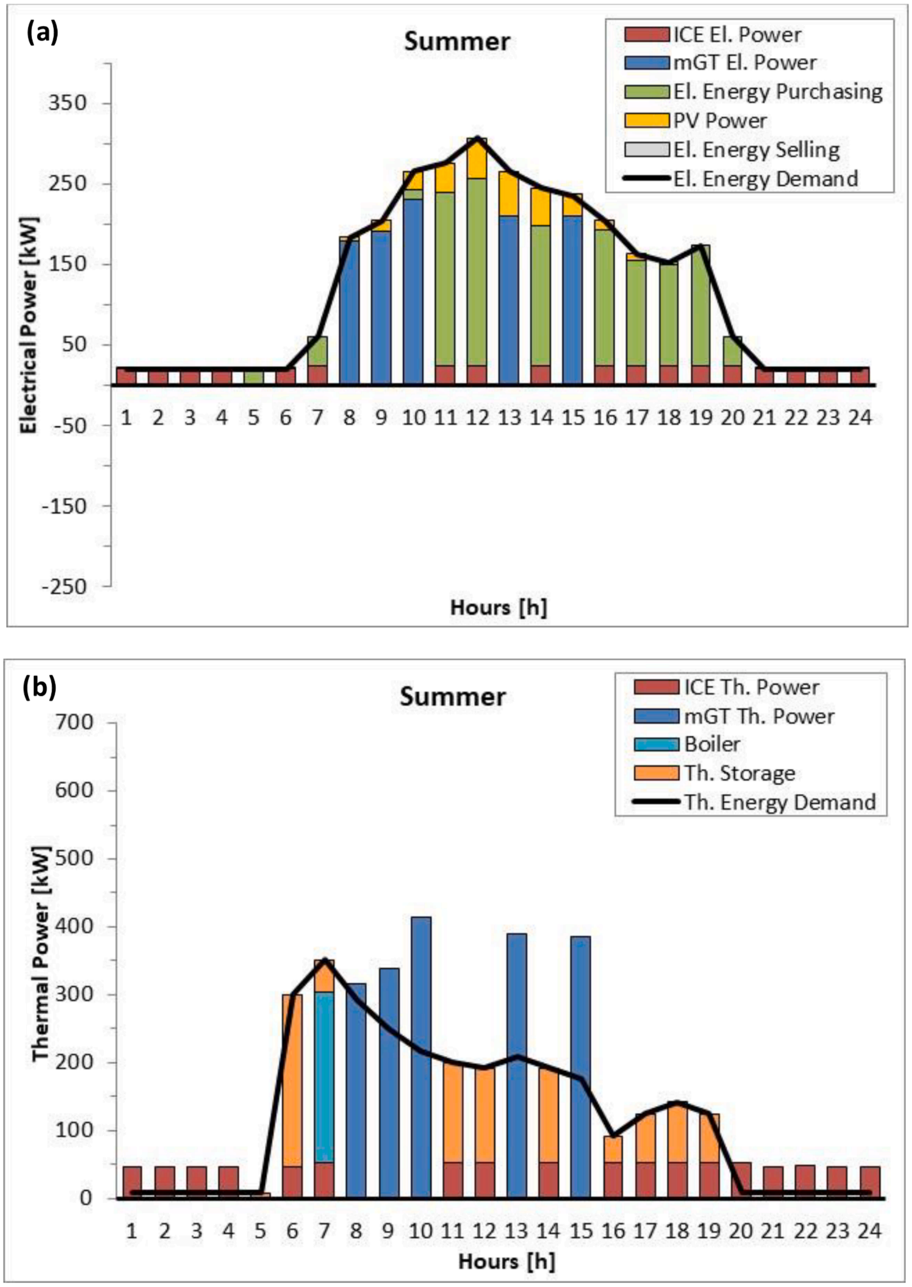

Fig. 6. Configuration A: Summer day typical (a) Electrical and (b) Thermal energy demand.

more used since its small size is more suitable for the proportion between electrical and thermal power. The storage works more frequently, since the heat demand is lower. This aspect allows avoiding the use of the mGT at low partial load (with consequent low efficiency) in the early morning hours. The PV panels can produce more power during the daily hours, while the mGT is used at full load only to charge the storage. When the storage is employed, the mGT is turned off to avoid strong partial loads (considering the need for matching both thermal and electrical demand).

Configuration B (HP)

In the second part of the analysis the boiler replacement with an air to water Heat Pump (HP) is investigated. The HP electricity demand is locally supplied by the PV and/or mGT and ICE. The HP presence significantly modifies the management scenario, since it increases the electricity demand, producing heat more efficiently.

Initially, a calculation has been performed throughout W-ECoMP algorithm (size optimization of one plant component) to determinate the optimal HP size, equal to 350 kWt. Considering a COP of 2.7, it is possible to obtain the respective electricity consumption of the Heat Pump. As a consequence the use of the heat pump gives the chance to increase the electrical demand, allowing the mGT to work closer to the design point, at maximum efficiency. Fig. 7 shows the system management during a winter day. The HP is used during the night periods to charge the TES for utilization to be used in the morning peak. During the day, the mGT works at full load, with a surplus in electrical energy production. Part of the exceeding energy is employed to supply the HP demand; the remaining part is sold to the grid. Compared to the previous configuration with the boiler, the main difference consists in the use of the CHP unit (mGT). The electrical energy management (Fig. 7a) highlights that this unit runs almost constantly very close to its design point, while in the boiler configuration strong partial loads occurred.

Fig. 8 shows the summer period management. W-ECoMP software

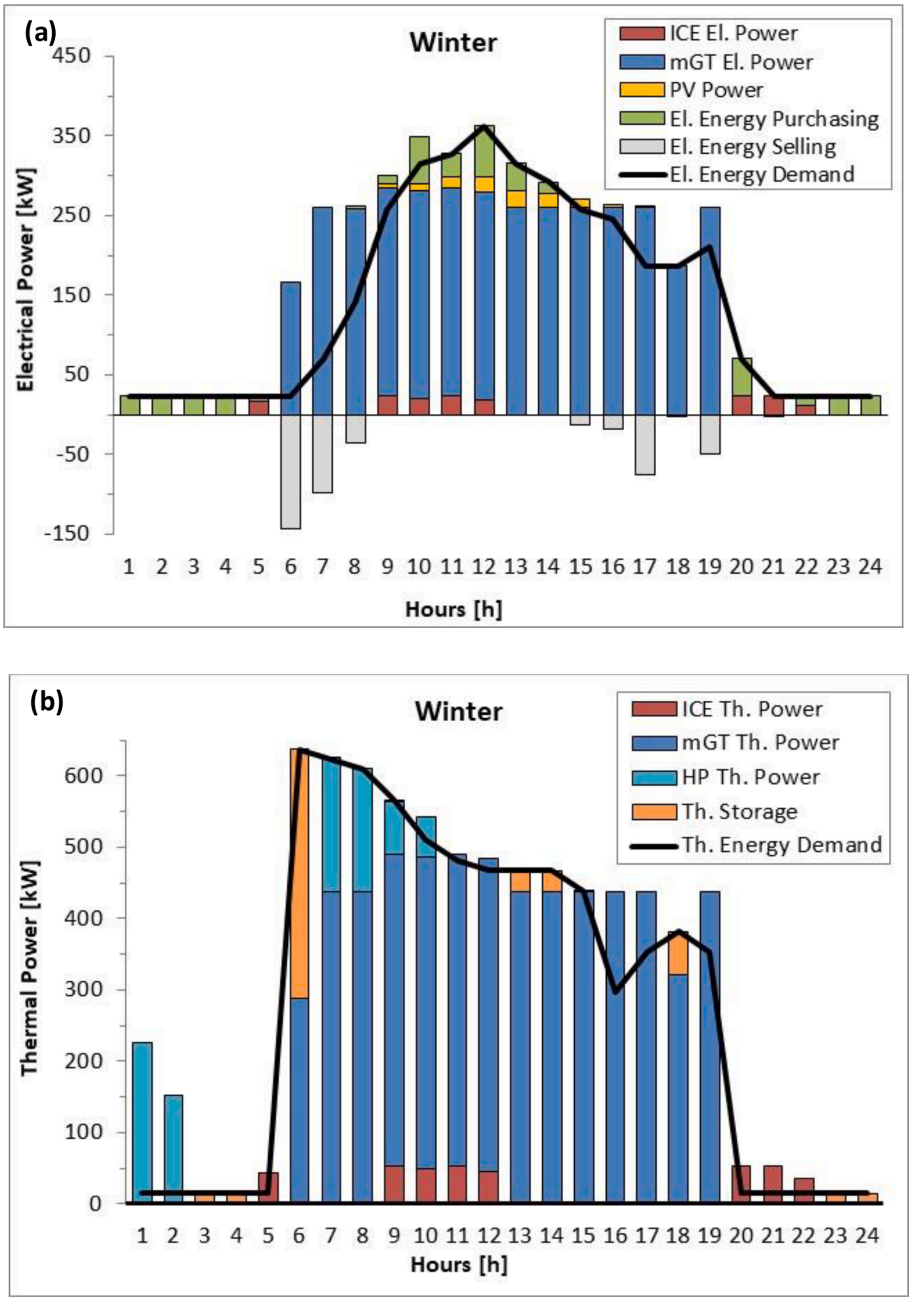

Fig. 7. Configuration B: Winter day typical (a) Electrical and (b) Thermal energy demand.

suggests a strong purchase from the grid, while the mGT is used just to produce the heat amount to satisfy the demand and fill the TES. Then, in this context, the thermal load is mainly satisfied by using the CHP units and the thermal storage, while the HP is only used to cover the night thermal demand throughout the TES. The ICE, also in this case, is used as baseload. Comparing the configuration adopting the boiler with the one adopting the Heat Pump in summer periods, it can be stated that in the latter case the HP has a lower impact on the system efficiency than in winter periods.

It is also relevant to highlight that TES role is different in Configuration A and Configuration B: in the second case, thanks to HP coupling, TES is exploited in more depth charging and discharging, enabling CHP units to work at higher efficiency in both summer and winter period (see Figs. 5-6-7-8).

Simulation results analysis and comparison (emission assessment, energy and economic performances)

In order to have a complete overview of the HP role in the SPM, a comparison of the two configurations was performed from the energetic and economic standpoints, underlining the differences in terms of energy consumptions (gas purchasing and electricity exchange with the national grid). In Table 2, the data related to the gas and electrical energy consumptions are reported. It is worth noting the significant fuel consumption reduction due to the replacement of the boiler with the HP (about −16%). On the other hand, as HP is an electrical device, the electrical energy brought from the grid increases (+20.8%). At the same time, the overall CHP energy production is higher, enabling a larger selling to the National grid.

Such values brought to an assessment of environmental benefits in terms of primary energy consumption and emissions in the two district

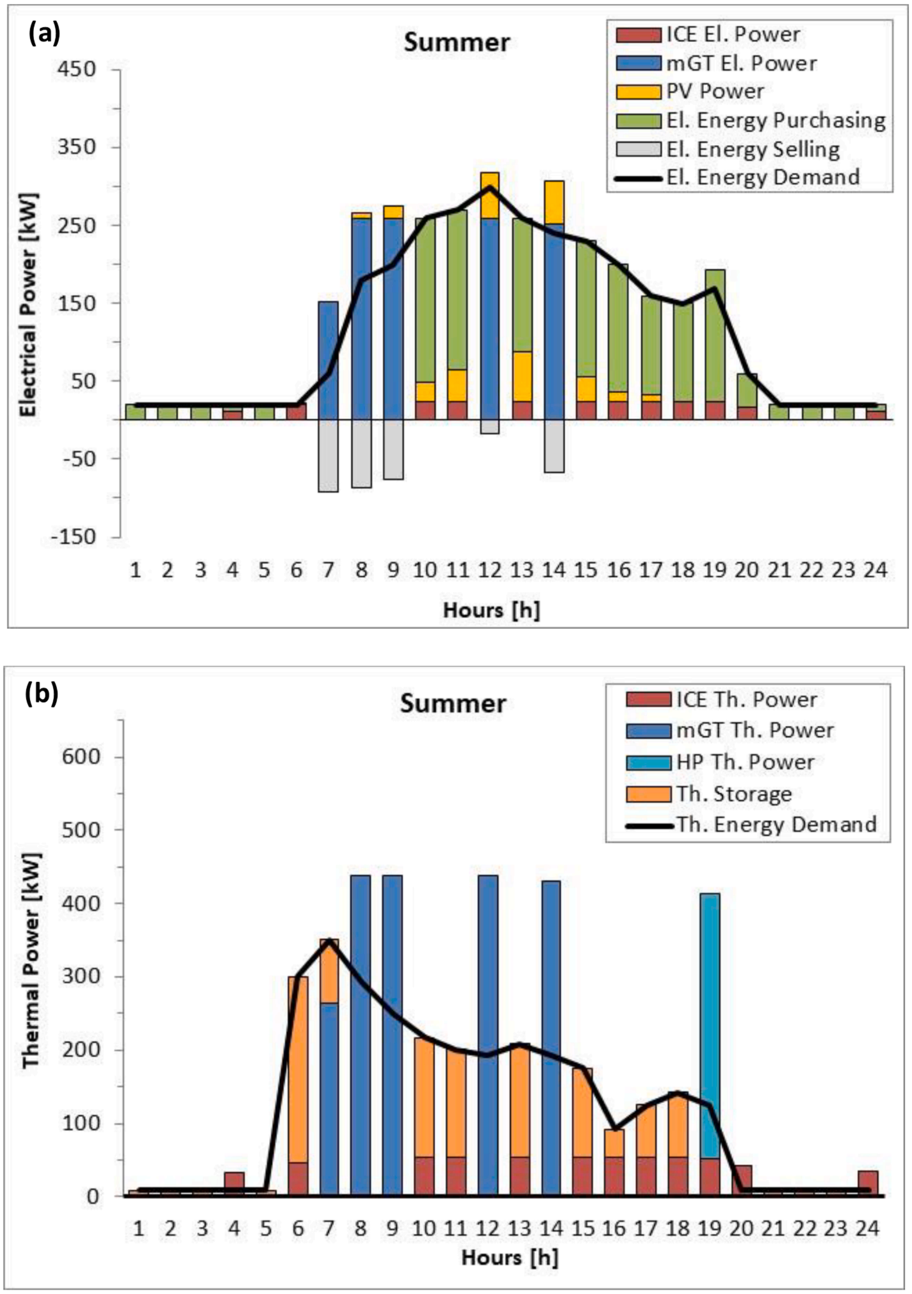

Fig. 8. Configuration B: Summer day typical (a) Electrical and (b) Thermal energy demand.

Table 2
Energy comparison.

		Configuration A (Boiler 500)	Configuration B (HP 350)
Electricity purchasing from the grid	[kWh]	317,442	383,834 (+20.8%)
Electricity selling to the grid	[kWh]	27,898	58,864 (+114.8%)
Natural Gas Consumption	[m^3]	219,440	184,900 (−15.7%)
Yearly Operating Period (Boiler or HP)	[h]	506	814 (+60.9%)

Table 3
Emission and primary energy saving assessment.

	Unit	Configuration A (Boiler 500)	Configuration B (HP 350)
Primary energy consumption (electricity + NG)	[MWh$_{PE}$]	2609.46	2366.75
Emissions generated	[tCO$_2$]	569.95	519.36

layouts (Table 3): actually, even considering a larger electricity grid purchasing, the relevant reduction of NG consumption grants a lower environmental impact of the HP layout (Configuration B). The analysis has been performed considering a primary energy factor of 1.13 kWh/kWh for NG and 1.9 kWh/kWh for electricity as stated in [50] and emission factors of 0.202 kg$_{\mathrm{CO2}}$/kWhfor NG and 0.483 kg$_{\mathrm{CO2}}$/kWe for electricity as reported in [5152].

One of the main advantages of installing the HP is that this device can exploit the electrical energy surplus of PV or CHP, allowing them to

Table 4
Operation of different CHP devices.

Unit		Case A (Boiler 500)	Case B (HP 350)
mGT	High-Efficiency operation [h]	1232	1518 (+23.2%)
	Low-Efficiency operation [h]	550	132 (−76.4%)
ICE	High-Efficiency operation [h]	3058	2200 (−26.2%)
	Low-Efficiency operation [h]	770	704 (−8.6%)

Table 5
Economic results.

	Case A (boiler 500)	Case B (HP 350)
Capital Cost of the Generator	**45,000 €**	**115,000 €**
Variable Costs		
• Maintenance	10,000 €	10,000 €
• Natural Gas	122,086 €	103,543 € (−15.1%)
• Electricity Purchasing from the Grid	63,488 €	76,766 € (+20.6%)
Total Costs	195,574 €	190,310 € (−2.7%)
Revenues		
• Electricity sold to Users	144,381 €	144,381 €
• Electricity sold to the Grid	2,231 €	4,709 € (+114%)
• Thermal Energy sold to Users	78,624 €	78,624 €
Total Revenues	225,237 €	227,715 € (+1.1%)
Net Income	**29,663 €**	**37,404 € (+26%)**

operate at nominal conditions more frequently, increasing their global efficiency. It is important to remember that the yearly operating time of the SPM is 6240 h, as in the weekend the campus is closed, and the SPM is not operative.

In Table 4, the number of operating hours at high and low efficiency (at partial load lower than 80%) are reported for both the mGT and ICE in different cases. The HP installation admits an average increase of the high-efficiency operations (partial load higher than 80%) of about 20% for the mGT. The difference in the overall number of operating hours of the mGT and the ICE is related to a different approach in the heat demand management, which is the main guideline, like in all the CHP plants. The HP introduction guarantees better exploitation of the TES, allowing the use of the mGT at higher load, as low heat demand periods are satisfied by the storage or by the heat pump itself, replacing the thermal contribution by the ICE.

The heat pump introduction has an impact both on the energy management and on the economics of the SPM. Table 5 shows annual variable cost and revenues in the two configurations.

Thanks to the HP installation, in case B total annual costs are reduced by about 3% due to lower gas consumption; the annual revenues increase of about 1% due to higher electricity selling to the grid and the annual net income results 26% higher. The reported maintenance costs are based on a yearly contractual rate that the company managing the Savona Campus SPM applies to the district: this value does not change in either case.

According to these results, a further investigation on the possibility to install an air-to-water heat pump (or other kinds of heat pump technology, suitable to the environmental location) instead of a natural gas boiler to manage heat demand peaks, can represent a worthy solution from both energy efficiency and economic standpoints. On the other hand, the discrepancy of investment cost between boiler and heat pump technology is significant and may increase the payback period of the whole plant. For this reason, characteristics, performances, and dimensions of the heat pump system must be carefully investigated and defined before installation.

Conclusions

The present work investigated technical and economic feasible solutions for heat pump integration in poly-generation energy districts as a valuable way to store exceeding self-produced electrical energy through a PtH approach. The potentialities of replacing an existing boiler with a heat pump in a multi-energy district were investigated and the performances in terms of energy consumption, emission reduction and economic balance were evaluated.

The management strategy was simulated on one year basis considering the boiler-based system (as reference case) and the heat-pump-based system (HP size was defined via an optimization approach). The study was carried out with the W-ECoMP software, a tool for the thermo-economic time-dependent analysis developed by the University of Genoa. The main results can be summarized as follows:

- The use of a boiler to cover the thermal energy demand ensures a major degree of freedom in the system management, as it grants decoupling electrical and thermal energy productions. On the other side, it negatively affects the fuel consumptions.
- By replacing the boiler with a heat pump, it is possible to reach a higher level of integration between the generators, allowing for better exploitation of local clean energy generation resources (PV, CHP) and a reduction of electricity exchanged with the grid. Furthermore, HP + TES driven PtH approach permits higher energy efficiency of CHP prime movers, as they can work close to the design point for longer periods, reducing emissions and increasing their lifetime. These two aspects bring to significant emission reduction and primary energy saving due to replacement of NG with electricity as main energy vector.
- The reduction of NG consumption (-15%) has an impact from an economic standpoint, also because the potential increase of electrical energy needed in some periods of the year is always compensated by CHP devices and PV electrical energy surplus, leading to energy exchange reduction.
- In terms of capital investment, the HP configuration results more expensive compared to boiler-configuration, affecting the payback period of the whole plant; nevertheless, it is worth noting that potential extra-revenues (e.g., the possibility for the energy district to operate as a grid flexibility actor producing heat to be stored via TES and then used in the DHN) have not been considered.

In conclusion, this research shows how HP + TES can play an effective role in energy districts management in presence of non-dispatchable RES and CHP units. The study can be considered as a preparatory work for further R&D activities to investigate how to make HP + TES solution as key assets to increase grid flexibility of energy district to make them more remunerative thanks to potential grid flexibility services provision.

CRediT authorship contribution statement

S. Barberis: Conceptualization, Methodology, Writing – original draft. **M. Rivarolo:** Data curation, Software, Writing – original draft. **D. Bellotti:** Writing – review & editing, Writing – review & editing. **L. Magistri:** Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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