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Combined vs separate heat and power production – Primary energy comparison in high renewable share contexts

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HIGHLIGHTS

- Separate and Combined Heat and Power primary energy consumptions are compared.
- The high penetration of renewables in the electricity mix has changed the context.
- In the current Italian context CHP has still the lowest primary energy consumption.
- Heat pumps show lower primary energy consumption than natural gas boilers.

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ABSTRACT

Natural Gas Combined Cycle (NGCC) units are currently the most efficient power plants based on fossil fuels. When used for Combined Heat and Power (CHP) production, serving District Heating (DH) systems, they have been usually promoted by stating their lower primary energy consumption compared to separate production of power and heat with conventional technologies. However, a significant increase of the share of Renewable Energy Sources (RES) in power generation and Heat Pumps (HP) for heat production in buildings could undermine this assumption. This paper evaluates a case study in Northern Italy, by comparing the real operation of three NGCC plants serving a DH network against the separate production of power (from real data of the National electricity mix) and heat (considering two scenarios based on natural gas boilers and heat pumps). The analysis is performed on hourly data over a two-years' time frame, to highlight the variations across the hours of the day and the seasons. To perform a comprehensive analysis, the entire system performance is considered, by comparing the useful energy supplied to the users to the primary energy consumption. The results show how the primary energy savings of fossil CHP technologies are strongly related with the available alternatives, which have been going through a significant evolution in last years. The separate production of heat and power can now be performed with competitive technologies, which benefit from the high share of RES in electricity production. Therefore, the comparison between combined and separate production is influenced by the high variability of the electricity generation mix, which needs to be carefully considered.

1. Introduction

Combined Heat and Power (CHP) generation traditionally allows for higher energy performances than separate production of heat and electricity [1]. CHP plants have seen a significant development in last decades, especially when coupled to District Heating (DH) networks, which allowed to optimize the operation of CHP plants and to benefit from the better performances of large-size power plants [2,3]. Multiple policies, both at European and National level, support CHP technologies as an effective way to promote energy savings and environmental benefits at both global and local levels [4].

Among CHP technologies, large size natural gas combined cycles (NGCC) show the highest performance, reaching electrical efficiency close to 60% and total efficiencies up to 90%, if they are properly designed and operated [5]. Due to their size, the exploitation of the available heat usually requires a connection to a DH network, and they are usually coupled with integration boilers and heat storage systems to maximize their performance by allowing an optimal operation in different contexts and energy demand conditions [6,7].

However, the relevant increase in electricity production from

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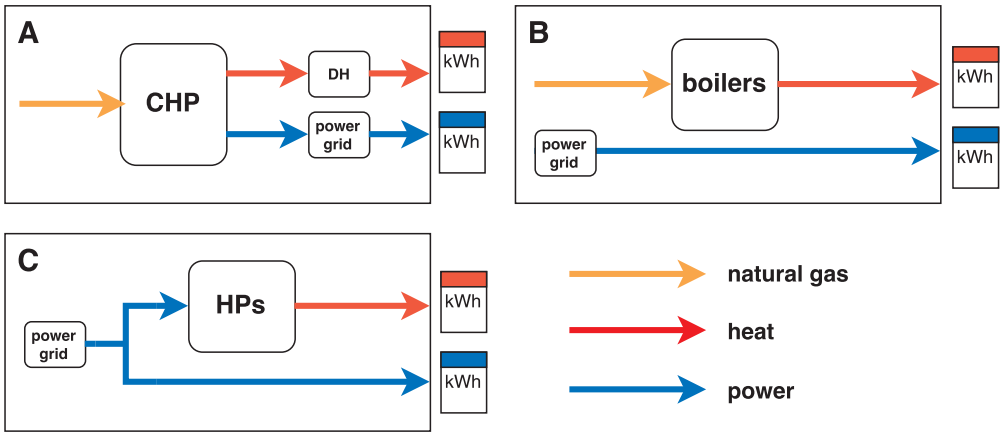

Fig. 1. Different cases in the analysis: CHP (A), separate production with boilers (B) or heat pumps (C).

Renewable Energy Sources (RES) has modified the context in which CHP operates [8]. The separate production is now capable of providing an higher attractiveness, thanks to a significant share of electricity generation from RES that has lowered the average Primary Energy Factor (PEF) of the electricity mix of many countries. Moreover, the diffusion of heat pumps (HPs) for space heating of buildings can extend those benefits to the separate heat production [9]. In this situation, the convenience of CHP technologies to lower primary energy consumption could potentially be undermined: both heat and power can now be produced with lower primary energy consumption and a significant share of energy from RES.

CHP advantages against separate production have traditionally been evaluated by considering yearly or nominal values for the performance of each generation unit. However, the strong fluctuations of RES production along the day and the year are continuously modifying the PEF of the electricity available from the power grid [10,11]. For this reason, in the current conditions a proper comparison needs to deal with those variable conditions, as annual analyses could lack in precision. However, the increase of the time resolution of the analysis also requires to consider the energy consumption profiles of the users [12]. The higher the energy demand in a specific hour, the higher the weight of that hour in the total results of the analysis. DH systems operators are already dealing with variable conditions both on the demand and supply side, [13,14], and optimization tools are fed by real time data to adapt the energy system operation and guarantee their best configuration under any condition [15–17].

Multiple research works have deeply evaluated the convenience of using CHP systems with respect to traditional separate generation. Martens [18] highlights the importance of considering accurate alternative scenarios, as the use of CHP needs to be justified by a correct comparison of the systems' performance. Multiple methods have been proposed to model CHP systems and evaluate their primary energy consumption [19,20], by considering traditional alternative generation systems based on fossil fuel boilers. Other studies consider the environmental impacts of CHP operation, on local and global scale, [21–23], but also in these studies the alternative scenarios, where available, are limited to fossil fuel boilers.

However, the context in which CHP units are operating is undergoing a significant evolution, mainly because of the increase of electricity production alternatives. The balance of electricity is gaining importance, and CHP operation needs to be focused on scheduling [24] or on electricity reserve market opportunities [25]. The increase of RES share in electricity mixes is also another major aspect to be considered when evaluating the PEF of a CHP unit.

Many research activities have also been carried out on the evaluation of the energy performance of heat pumps for buildings' space heating, either with a simulation-based or experimental-based approach [26,27,9,28]. The performance of HPs is verified by means of field tests, resulting in lower primary energy factors with respect to different fossil fuel boilers [28,29]. Different authors [26,9] point out the importance of increasing RES share in electricity production in the primary energy savings associated to HPs. As a result, HPs are becoming more and more interesting as an alternative solution for heat production, potentially capable of obtaining lower PEFs than CHP-based systems.

However, while the above-cited studies evaluated the performance of these technologies, a comparison between the operation of CHP and the separate heat and power production using HPs is not available in the literature. The increasing share of RES in electricity production could have a massive impact on the comparison of CHP against separate production, with a double effect: both separate power and heat production (by using HPs) would benefit from the lower PEFs of the electricity available from the grid. A precise evaluation of CHP convenience in the current context would be a valuable support for decision makers and energy planners.

This paper presents a comparison between the operation of three NGCC units serving a large DH network and the corresponding separate production of heat and electricity. The separate heat production is analyzed considering both natural gas boilers and heat pumps, while the power production is based on the actual performance of all power stations operating in Italy, taking into account both the fossil fuel and the RES ones. The analysis is based on real hourly operation data of the CHP units over the years 2015 and 2016.

The main objective of this work is the comparison of the performance of high-efficiency CHP units against separate production of heat and power by means of primary energy consumption. Primary energy consumption has been chosen as a comprehensive indicator for measuring the energy performance of the whole system, by comparing the useful energy supplied to the users with the related primary energy consumption of the entire energy system under analysis.

2. Methodology

The comparison is performed by considering the primary energy factor of the system, i.e. the ratio between the primary energy consumption of the entire system and the useful energy supplied to the users. Fig. 1 shows the three scenarios considered in this study: (A) CHP operation, (B) Separate heat production with natural gas boilers and electricity from power grid, (C) Separate heat production with HPs and electricity from power grid. The analysis of CHP (case A) against separate production (cases B and C) is also an evaluation of centralized vs distributed generation. Therefore, the performance of the distribution networks for electricity and heat have been included in the calculation. This choice is consistent with the most common application of CHP units, which show higher performance at medium-to large sizes, and are usually coupled to large users or groups of small users in DH networks.