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Integration of heat storage system into district heating networks fed by a biomass CHP plant

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ABSTRACT

Biomass Combined Heat and Power (CHP) plants connected to district heating networks (DHN) are recognized as a very good opportunity to increase the share of renewable sources into energy systems. However, as CHP plants are not optimized for electricity production, their operation is profitable only if a sufficient heat demand is available throughout the year. On the other hand, these plants often work for baseline operations and back-up boilers are used to supply the peak demand. To extend the use of the CHP plants and reduce costs, conventional fuel use and emissions, it is proposed to study the feasibility of using the DHN itself or additional high temperature heat storage as retrofit of an existing CHP plant.

This work is based on a simple and effective methodology that provides accurate estimations of economic, environmental and energetic performances of CHP plants connected to district heating networks. The focus is performed on the integration of the heat storage as retrofit of existing DHN considering the local policies.

The DHN of the University in Liège (Belgium) is used as an application framework to demonstrate the effectiveness of the selected approach. The potential energy, pollutant emissions savings and resulting energy costs are estimated and the current policy limitations will be discussed.

1. Introduction

Biomass Combined Heat and Power (CHP) plants connected to district heating networks (DHN) are recognized nowadays as a very good opportunity to increase the share of renewable sources into energy systems and a convenient way to supply heat to a large number of individual using a unique central heating plant [1,2]. Indeed, large CHP plants combine high conversion efficiency, high availability and low operation costs. From an environmental point of view, the use of biomass allows a significant reduction of CO_2 emissions compared to the use of natural gas due to their low emission levels [3].

The economical optimum of (biomass) CHP plant coupled to a DHN consists in using the CHP plant for the base load as often as possible while keeping the back-up boilers for the peak load. Yet, in practice, the heat demand can widely vary during the day due to a lot of non-controlled variables such as weather conditions, users' habits . . . . Therefore to extend the use of the biomass CHP and maximize its average efficiency, one solution is to consider a heat storage system to supply heat during the peak load by storing the unused energy produced by the plant from the low heat demand periods [4]. Indeed this solution is generally used to make CHP or biomass boilers more flexible leading to a better environmental and economic efficiencies [5–8]. Several technologies of heat storage are commercially available but this contribution is not intended to be a review of these technologies and the reader interested can refer to [4,9,10]. The focus is to assess the impact of the integration of a heat storage system on an existing DHN. Here the thermal energy storage considered uses water as medium to store the thermal energy inside an insulated tank or inside the DHN itself by a dedicated control of the energy supplied to the DHN. This last solution has the advantage to limit drastically the investment costs of the heat storage system but its capacity is limited by the DHN size and the control strategy.

The purpose of the present study is to determine the best integration of a heat storage system which minimizes the cost of heat of a heating plant feeding a DHN while minimizing its environmental impacts and considering or not the current Belgian policies (green certificate and CO_2 carbon price). To achieve this aim, a previous developed and validated model [11] of a biomass

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Nomenclature

CHP	Combined heat and power plant
COH	Cost of heat
DHN	District heating network
HPST	High pressure steam turbine
LPST	Low pressure steam turbine

CHP plant supplying a district heating network taking into account the heat losses and a hot water heat storage system is used. On the other hand, the DHN itself is considered to store energy by using higher water temperatures while considering the related higher heat losses. Moreover, the dynamic model of the DHN was developed to assess the influence of the variable heat demand and the temperature level on the CHP plant efficiency and on the biomass consumption. In order to improve the profitability of the CHP plant, several scenarii of hot water heat storage (short and long term) and heat demand profile are investigated while the integration of the heat storage coupled to a CHP plant has to be carefully studied [12,13]. Indeed this contribution points out heat storage systems could be not economically profitable depending on the subsiding policies allocated to the heating plant. Finally, the Belgian subsiding policy is studied in that context.

The considered approach is performed using the measurements from an existing biomass CHP plant connected to a district heating network installed on the Campus of the University of Liège (Belgium). Due to current electricity regulation and the studied CHP plant constraints (stop to full load cycles take more than 24 h), the SPOT market and the variable electricity selling price won't be analyzed in this study.

2. Problem statement

Thermal energy storage systems will play an important part of the energetic transition. Indeed, they can be integrated into renewable systems which are, by nature, more fluctuating than conventional power and heating plants. On another hand, the integration of heat storage system into a DHN allows the operator to optimize the heating plant. For example, the use of the cheapest production unit can be used continuously when heat storage system is available and well designed. However, the heat demand can vary widely during the year therefore back-up heating systems can be used to ensure the supply of heat demand in peak periods. To reduce their use and their environmental impact, it is proposed to consider a heat storage system to store the surplus of heat produced by the CHP plant during off-peak periods and use in peak periods when the heat demand is higher than the nominal thermal output of the CHP plant. The inherent heat losses of heat storage system are also considered to perform a generic analysis on the CHP plant performances.

On the other hand, seasonal heat storage systems can be used to maintain the profitability of CHP plant and its related high efficiency energy conversion during the summer time when the heat demand is low. In this case too, heat storage systems allow to decouple production and consumption periods on a larger period.

One scope of this study is to investigate the global design and the integration of a heat storage system through available thermodynamic simulation models. It is dedicated to assess the retrofit profitability of an existing biomass CHP plant and back-up boilers connected to a DHN. Here, the focus is put on the determination of volume storage to minimize the operational costs of the global system and its environmental influence; the investments and operating costs of heat storage system come from data available from the literature [14,15]. To achieve this, a thermodynamic simulation model is implemented to assess the efficiency of the CHP plant at part load and the performance of the DHN used in the assessment of the cost of heat. On another hand, a temperature control strategy is defined to store energy inside the DHN for short-term periods to reduce the natural gas use without extra investment considering the related heat losses due to a higher network temperature.

Previous work [11] based on [16] is used to assess the cost of delivered heat to the final consumer of a CHP plant (or boilers) connected to a DHN in function of the operating conditions previously modeled. According to this work, the cost of heat (in €/MWh) of the CHP plant is expressed as:

$$COH = \frac{1}{\zeta_{DHN}}\left[\frac{C\cdot\psi + U_{fix}}{P_{th,chp}\cdot\tau_e} + \frac{y_f}{\overline{\eta}_{th,chp}}\right] + u_{var} - (y_e + \tau_{cv}y_{cv})\frac{\overline{\eta}_{el,chp}}{\overline{\eta}_{th,chp}} \quad (1)$$

where C is the total investment cost, ψ is the annuity factor which takes into account the present value of money and represents the annual repayment for the initial investment expressed in € per year. The annuity factor is assessed according to Eq. (2):

$$\psi = \frac{d}{1-(1+d)^{-N}} \quad (2)$$

where d is the discounting rate per year and N the number of years for which the installation is used (e.g., the life time of the plant considered herein to 20 years). $P_{th,chp}$ is the installed thermal power of the CHP plant in MW and τ_e is the equivalent utilization time at rated power output in hour. τ_e embeds the availability factor of the plant (around 92% for a biomass CHP plant), y_f is the cost of fuel in €/MWh, U_{fix} is the fixed cost of operation, maintenance and administration in €/year and u_{var} is the variable cost of operation, maintenance and repair in €/MWh. $\overline{\eta_{th,chp}}$ is the average annual thermal efficiency taking into account the start/stop procedures (if any) and the part load efficiency. y_e is the price of electricity in €/MWh while τ_{cv} and y_{cv} are respectively the number of green certificates per MWh of electricity produced[1] and their selling price (65€ per green certificate). The term $\tau_{cv}y_{cv}$ is replaced by the premium on the electricity selling when feed-in tariffs are used instead. ζ_{DHN} is defined as the ratio of the heat delivered to the consumers to the heat produced by the plant depending of the temperature level, the insulation of the network and the ambient conditions.

The determination of C, U_{fix},u_{var},d and $N$is not within the scope of the present contribution and reliable estimates can be found e.g., in [16,17].

If the costs of heat generated through Eq. (1) for the CHP plant and backup boiler are denoted respectively by COH_{chp} and COH_{bck} and Θ is the ratio of the thermal energy generated by the CHP plant to the total thermal energy for the considered time interval, the average cost of heat of the global system is assessed through Eq. (3):

$$COH = \Theta COH_{chp} + (1-\Theta)COH_{bck} + COH_{DHN} \quad (3)$$

where COH_{DHN} is the cost due to the investment of DHN trench and pipes.

The influence of fuel costs y_f will not be long discussed herein and representative value of the market in Belgium will be used, as it is relatively straightforward for the reader to include his proper data into the above model. The determination of τ_e, $\overline{\eta}_{e,chp}$ and $\overline{\eta}_{th,chp}$

[1] For the Walloon region of Belgium one green certificate is granted for every 456 kg of CO_2 saving. A maximum of 2 green certificates is allowed per MWh of electricity produced.

is deduced from the thermodynamic model developed before by the authors in [11] and briefly discussed in the following section.

Finally the possible investment costs of the heat storage system can be integrated into this cost model to assess the usefulness of the heat storage system on an economic point of view and assess the payback time of the system.

Concerning the environmental influence, the following emissions are considered according to [18]: 30 g/kWh for biomass combustion, 279 g/kWh for natural gas combustion and 456 g/kWh of power generation.

3. Simulation model

For reasons of simplicity, a brief description of the model is provided in this section but more detailed information can be found in previous works [11,19]. The complete simulation model of the plant is an aggregation of basic components modeled by a zero-dimensional (i.e., input-output) approach verifying the conservation of mass, energy and momentum. The biomass combustion model is handled through a general biomass composition $C_mH_nO_xN_yS_z$ (where the subscripts are the ratio between wet basis mass fraction of each component to its molar mass) able to assess the composition of 15 species of the flue gas products namely H_2, O_2, H_2O, CO, CO_2, OH, H, O, N_2, N, NO, NO_2, CH_4, SO_2, SO_3. Steam turbines are modeled by the Stodola line [20] where the steam turbine is considered as a nozzle whose mass flow rate depends upon the inlet pressure and temperature and the outlet pressure. Through this thermodynamic model, the CHP plant performances can be assessed for partial load or for different ambient conditions.

The assessment of the DHN heat losses and the related coefficient ζ_{DHN} relies on the resolution of a steady-state two-dimensional heat conduction-convection problem. This enables the calculation of a global heat transfer coefficient, Λ (W/K) used to assess the heat losses as a function of ambient temperature and DHN water temperature level as

$$Q_{losses,DHN} = \Lambda(T_{fd} - T_{ambient}) \quad (4)$$

where T_{fd} is an average temperature of the water circulating in the DHN.

These simulation models are used to assess the exact amount of heat supplied by a CHP plant to a DHN whose heat demand profile is known. Through the calibrated simulation model, the net electricity production of the plant is known for both rated and part load operation together with the heat losses related to the DHN. In the case study detailed in the following section, the steam is expanded into two successive steam turbines to produce electricity. After the steam expansion at the high-pressure steam turbine (HPST), a portion of the steam is extracted to supply heat to the DHN through a heat exchanger. A schematic of the cycle is represented in Fig. 1. Of course, other kind of CHP plant could be modelled by the same approach. The installation costs of the DHN piping is considered herein as 2.25 €./MWh [11,21]. These figures are similar to those of the studied DHN with actualized money value.

Short term (hours/days) and long-term (weeks/months) additional heat storage are considered in this study. The corresponding insulated hot water tanks investigated are up to 1000 m^3 for the short term storage according a sizing of 10 to 50 liters per kW of boiler output [22] and between over 5000 to 30000 m^3 for the long term (seasonal storage) depending on the heat demand curve of the DHN. Thermocline heat storage [23,24] is considered in this study and assumed as a cylinder whose diameter is equal to the height to minimize the heat exchange area and therefore the heat losses of the storage. A heat transfer coefficient of 0.2 $W/m^3/K$ is considered for the heat storage [25]. The capacity considered of one cubic meter of water is 29 kWh for a temperature difference inside the tank of 25 °C. The considered heat storage charge and discharge strategy is quite simple in this contribution. When the heat demand of the district heating network is lower than the nominal thermal output of the CHP plant, all the remaining heat is stored into the heat storage (charge phase). In the opposite way, when heat demand of the DHN is higher than the nominal thermal output of the CHP plant and there is energy available in the heat storage, the storage is discharged. The heat losses of the heat storage system are assessed in the same time.

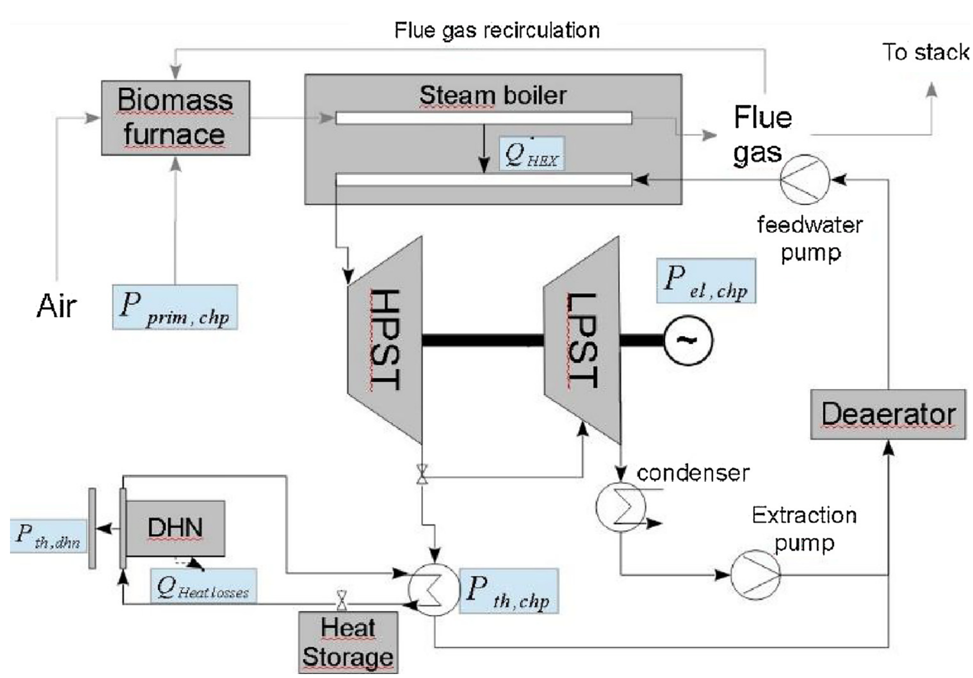

Fig. 1. Schematic of the CHP plant.

Finally, the DHN itself can be used to store energy. In this case, it is proposed to increase the DHN supply temperature. This behavior leads to higher heat losses and the optimum temperature control strategy is searched for. The potential heat storage capacity of a DHN (denoted C) is defined as:

$$C = \sum_i c_p \rho \pi L_i \frac{D_i^2}{4} \tag{5}$$

where $\boldsymbol{L_i}$ and $\boldsymbol{Di}$ are respectively the length and the diameter of the i_{th} segments constituting the DHN, $\boldsymbol{c_p}$ and $\boldsymbol{\rho}$ are the heat capacity and the density of the water at the annual mean temperature of the pipe. Due to the limited storage capacity of this method, only short-term heat storage is considered.

4. Application test case

The aforementioned simulation model is applied to a typical district heating application available on the University campus in Liège (Belgium). The installed network has a total length of 10 km and distributes pressurized hot water at about 125 °C, on average, to approximately 70 buildings located in the University campus representing a total heat area of about 470 000 m^2. Buildings are very different in nature namely, classrooms, administrative offices, research centers, laboratories and a hospital. The hospital represents about 25% of the total heated area and requires steam for the kitchen and air humidity control system that justified this water temperature level. The designed effective peak power of the network is around 56 MW for a normalized total consumption of 61 000 MWh per year. Typical heat demand of the DHN is available in Fig. 2. The heating season approximately occurs between October and May while the hospital is the only building which is fed continuously throughout the year.

While all the buildings are heated between 4:00 to 20:00, the hospital needs heating and steam 24 h a day. The CHP plant has started full operation in 2012. It is made of a moving grid biomass boiler with nominal primary power of 12 MW supplying steam to a back-pressure turbine and a condensing turbine with nominal power of 2.4 MW. The extracted steam is condensed in a heat exchanger feeding the DHN with a nominal power of 7 MW. The remaining thermal power required by the DHN is provided by three natural gas boilers with a total installed power of 50 MW. The CHP plant is priori to supply the heat demand and the minimal thermal output could be null due to the extraction stream turbine use. However in this case, the CHP plant efficiency is reduced (Fig. 3b). CHP plant represents about 60% of the total heat demand needs. The maintenance of the CHP plant is planned in July. During this period, energy of about 900 MWh is required by the DHN. The optimal integration of the CHP plant into the DHN cumulative head demand and the efficiency of the CHP plant are respectively available in is Fig. 3a and b. As discussed previously, the use of heat storage system is dedicated to maximize the use the CHP plant while limiting the cost of heat.

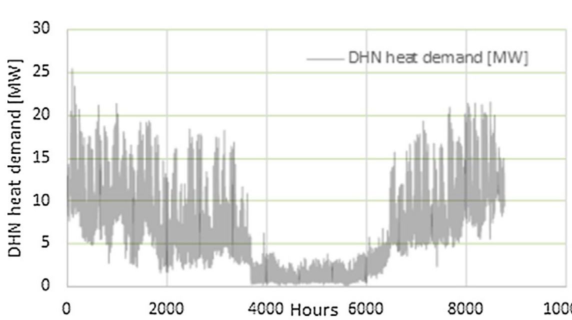

Fig. 2. DHN heat demand and of the system studied. “0” stands for the first hour of the year.

To assess the cost of heat reliable data about operation and maintenance fix and variable costs can be found in the literature as [17]. The biomass and natural gas cost are respectively of 33 and 36.5 € per MWh [15] while the electricity is bought at 112 € per MWh.

The district heating network is divided into twenty-three sections having the same geometric characteristic but pipe diameters ranging from 50 to 350 mm. The insulation used is mineral wool with an identified thermal conductivity of 0.047 W/m K^{-1}. The theoretical storage capacity of the studied DHN (C) is 1.2 MWh/K (Eq. (5)) considering an annual mean temperature of the DHN pipes of 105 °C. Due to the heat profile demand (Fig. 2) and the theoretical storage capacity of the studied DHN, this heat storage system is only dedicated to hourly heat storage use. Indeed a temperature difference of 10 K leads to a DHN thermal capacity of 12 MWh. According to heat demand curve of the studied DHN, this capacity could reach 5 h during the summer heating period and only one or 2 h during the winter period.

With respect to [11,26], the CHP plant studied herein is slightly different as an exhaust gas recirculation at the level of the primary air was added together with a modification of the steam cycle leading to higher boiler and plant efficiencies.

Concerning the heat storage optimization, the maximal heat storage volume considered in this study is 30000 m^3 considering the DHN heat demand during the maintenance of the CHP plant. However this maximal value involves a low utilization time of the heat storage considering the DHN heat demand (Fig. 2). The investment costs are 500€ per cubic meter for short-term storage and 200€ per cubic meter for long-term heat storage [27].

5. Results and discussion

5.1. Neglecting the belgian subsidies

Due to the wide variety of CHP regulation [28], it is proposed to not consider the specific Belgian subsidies in this subsection. Only the selling of CO_2 can be considered at a mean price of 5€ per ton [29]. In the nominal case of the global system (without heat storage), the cost of heat is about 77 €/MWh (Fig. 4–black circles). An optimized heat storage volume of 400 m^3 leads to a COH reduction of 0.25 €/MWh. However due to heat storage investments costs, the payback time is 13 years which is not consistent with the common investment strategy in the energy field [30,31]. As expected, the mean annual efficiency of the CHP plant (red triangle) slightly increases of about 1.5% due to a longer use at nominal output power. On another hand, the CO_2 emissions are decreasing of 250 tons per year due to the reduced use of back up natural gas boilers ($\sim -$ 1GWh) which are partially compensated by the heat storage heat losses.

The selling of CO_2 reduces the COH of about 1€/MWh (blue squares). From here, all the figures consider the selling of CO_2 emissions.

Considering a seasonal heat storage, there is an increase annual efficiency of the CHP plant up to 4.5% (red triangle in left Fig. 5) and reduced CO_2 emissions up to 910 tons of CO_2 (right Fig. 5) while the heat storage volume increases. However, there is not an economic optimum for the seasonal heat storage due to large investment costs compared to the reduced natural gas boiler consumption and CO_2 emissions avoided.

The COH reduction is an equilibrium between the use of the heat storage but also the use of the CHP plant and the natural gas boilers. As expected, the capacity factor of the CHP plant is higher when the heat storage volume increases due to the increased time

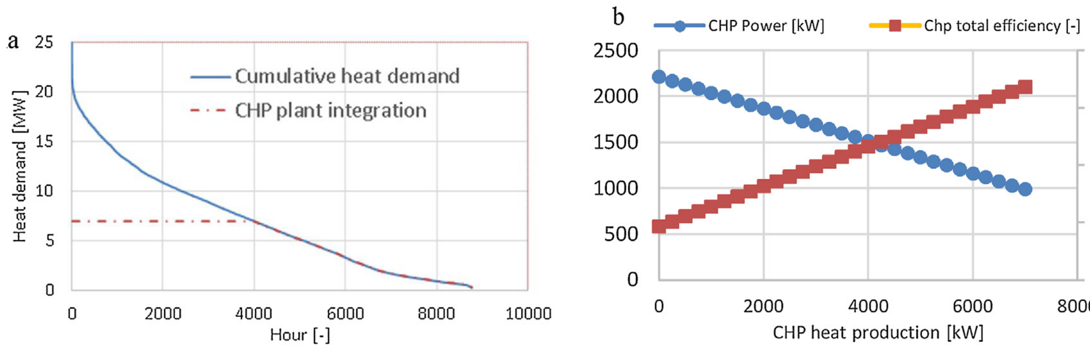

Fig. 3. a) Cumulative heat demand of the application test case and the integration of the CHP plant; b) Power generated (left) and CHP plant efficiency (right) in function of the CHP heat production.

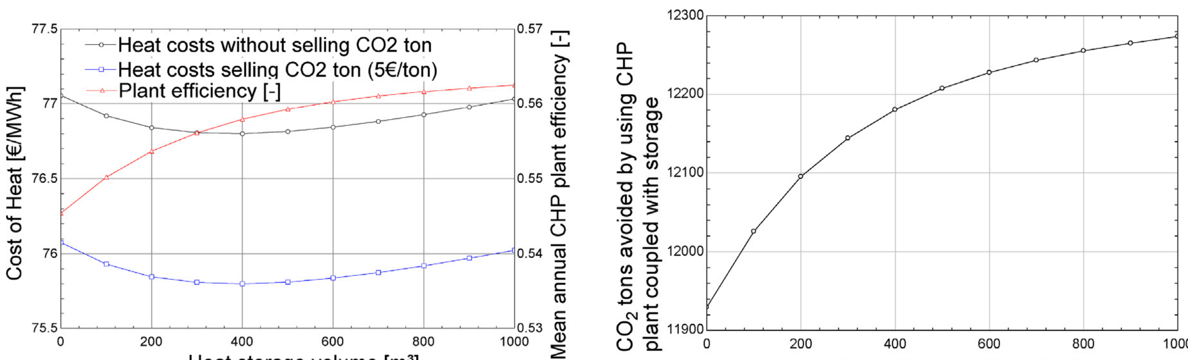

Fig. 4. Cost of heat optimization for heat storage and related CHP plant efficiency (left) and the CO2 avoided by the coupled use of CHP plant and heat storage, if any (right).

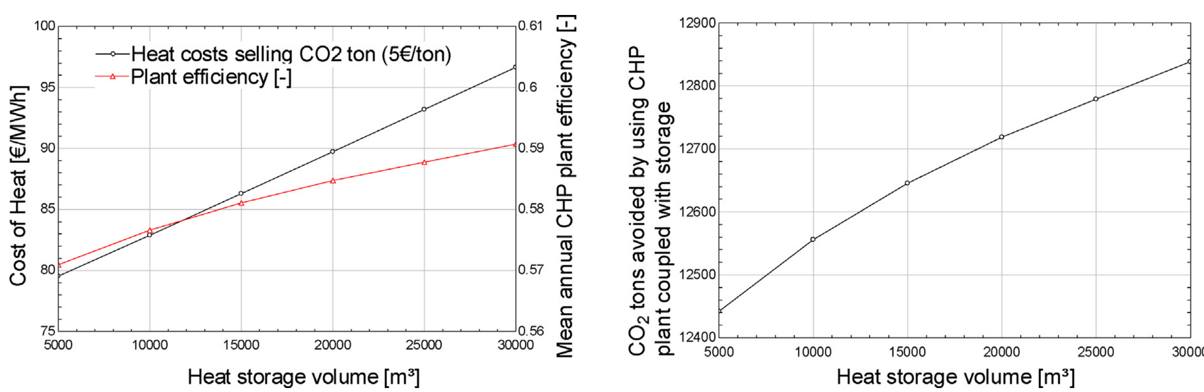

Fig. 5. Cost of heat optimization for the use of heat seasonal storage and related CHP plant efficiency (left) and the CO2 avoided by the coupled use of CHP plant and heat storage, if any (right) without Belgian subsidies.

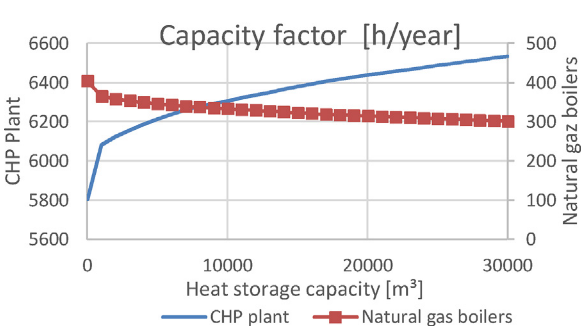

Fig. 6. Capacity factors of CHP plant and natural gas boilers for short and long term heat storage volume.

when the CHP plant works at its nominal load (Fig. 6). In the opposite way, the capacity factor of the natural gas boilers decreased in the same time.

5.2. Considering the belgian subsidies

The dedicated Belgian subsidies for CHP plant consists in the allocation of maximum two green certificates by MWh electric produced. The allocation of one green certificate corresponds to the CO_2 emissions avoided by the use of renewable energy (here biomass) instead of a common power generation of gas turbine (456 kg of CO_2 avoided) [18]. It can be sold at a guaranteed price of 65 € per green certificate. In the studied case, the ratio between

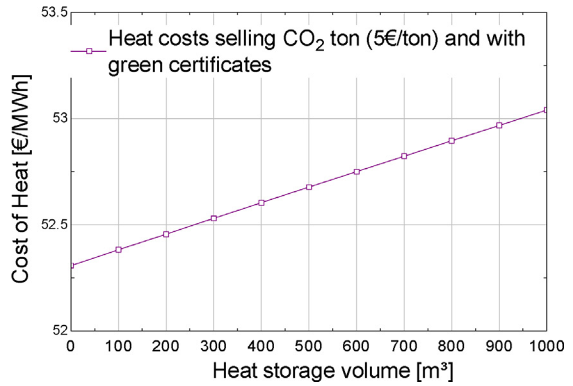

Fig. 7. There is no cost of heat optimization for the use of heat storage when the Belgian subsidies dedicated to CHP plant are considered.

power and heat produced by the CHP plant leads to the allocation of two green certificates by MWh electric produced all the year.

Considering the Belgian subsidies, the COH is reduced by about 24 €/MWh; but there is currently no optimum size of heat storage (Fig. 7) despite the slight increase of annual efficiency of the plant and the CO_2 emissions avoided previously identified in the Section 5.1.

5.3. Heat demand modifications

To extend the present contribution and in order to cope with future heat demand modifications of the current DHN, it is proposed to investigate the optimization of the heat storage volume in two other scenarii. The first one is the insulation of several major buildings dedicating to reduce emissions and heating costs. This scenario leads to a reduction of twenty percent of the daily heat demand (data from internal buildings performance studies), therefore it is expected to reduce heating needs and emissions by the same ratio. However this scenario involves an over-sizing of the current boilers and CHP installations which could increase the related COH (especially the CHP one) leading to a lower total heating cost reduction. On another hand, it is proposed to combine an industrial process which requires 0.9 MWh of heat all the year to the DHN to extend the nominal use of the CHP plant.

When the heat demand is reduced by the buildings insulation (Fig. 8), the COH of the current system increases drastically (about 7.5 €/MWh) due to lower equivalent utilization time at rated power output of the CHP plant and the natural gas boilers (the investment costs are already performed). This cost influence is in correlation with the annual mean efficiency of the CHP plant which decreases of about 3% compared to the nominal case. There is an optimal heat storage volume (500m^3) leading to an extra COH reduction of 0.45 €/MWh, however, it is not economically viable due to large payback time (11 years).

In this case, the annual economy about heating costs is only 12% and the CO_2 emissions avoided are only 3.5% compared to the heat demand reduction of 20% and the related expected costs and emissions economies. This example underlines that a retrofit has to be correctly planned to reach the defined goals (costs and emissions reductions in this case). Finally, the insulation invest-

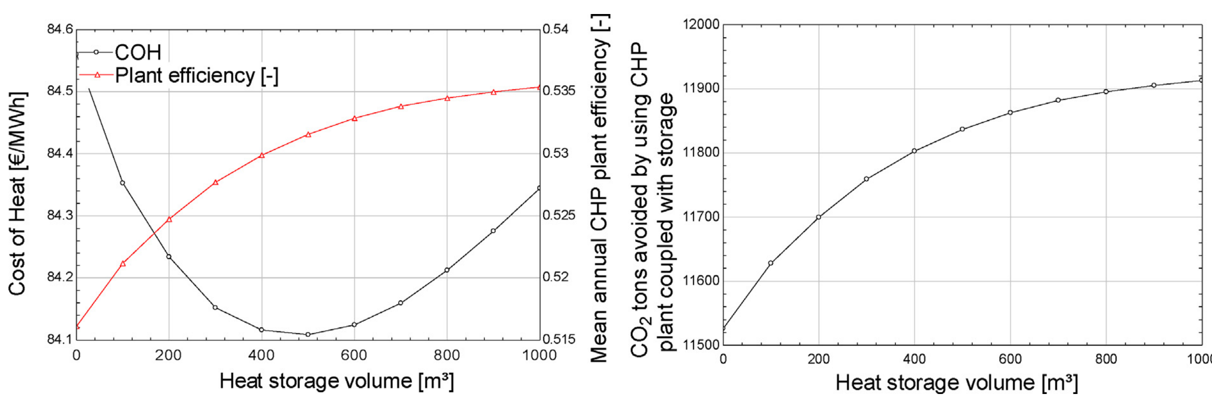

Fig. 8. Cost of heat optimization for the use of heat storage and related CHP plant efficiency (left) and the CO2 avoided by the coupled use of CHP plant and heat storage, if any (right) if the heat demand is reduced by 20%.

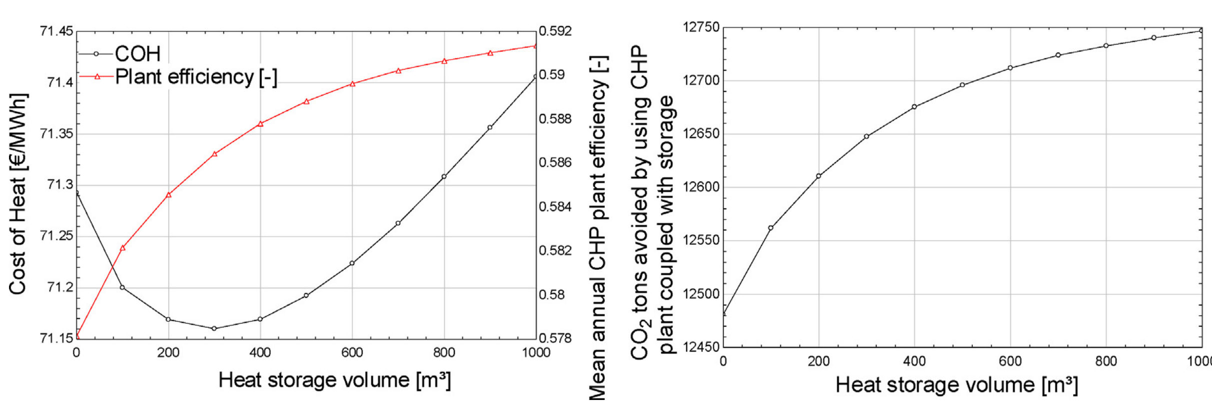

Fig. 9. Cost of heat optimization for the use of heat storage and related CHP plant efficiency (left) and the CO2 avoided by the coupled use of CHP plant and heat storage, if any (right) if the heat demand is increased.

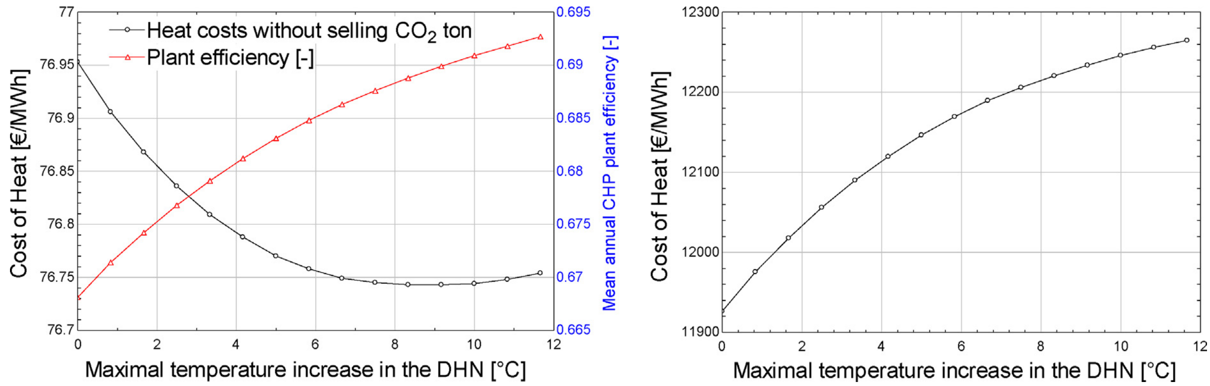

Fig. 10. Cost of heat optimization for heat storage performed inside the DHN by increasing the temperature and related CHP plant efficiency (left) and the CO2 avoided, if any (right).

ment costs could be compared to the expected heat cost reduction expected to check if others primary measure should not be investigated as control strategy to reduce the electric consumption pump of such DHN. However, the insulation costs are very different by nature while there are a lot of insulation available on the market. Therefore, this aspect will be not considered into this study.

In the opposite way (Fig. 9), connecting an industrial process to the current DHN leads to an extra reduction of the COH (~5.5 €/MWh), an increase of the mean annual efficiency of the CHP plant and the avoided CO_2 emissions as expected.

The optimal heat storage volume is 300 m^3 and involves an extra slight COH reduction of 0.13 €/MWh leading to a payback time of 16 years despite an increase of 1% of the annual efficiency of the plant and a saving of 167 tons of CO_2.

If the Belgian subsidies are considered, there is no optimal heat storage volume in both the complementary cases as in the Section 5.2.

5.4. DHN as heat storage system

Due to the large payback time of a heat storage tank studied in the previous sections, another studied solution is to use the DHN as heat storage system which does not involve extra investment costs. When the heat demand is lower than the nominal thermal output of the CHP, it is proposed to increase the temperature supplied to the network with a limit temperature value of 140 °C (due to technical constrains).

Despite the use of the heat storage inside the DHN increases the cogeneration's use at nominal load, the related heat losses increase due to a higher DHN temperature, leading to a lower ζ_{DHN}. Therefore, the maximal temperature increase is investigated to optimize the cost of heat. The mass flow rate and so the related electric pump consumption are considered as constant.

Using this temperature control strategy, the cost of heat can decrease up to 0.2 €/MWh for an optimal temperature increase of 8.5 °C (Fig. 10). This cost of heat reduction is smaller than the one get when heat storage tank is used but in this case, there is no payback time while there is no extra investment costs.[2] On another hand, the CO_2 emissions are decreasing of 295 tons per year due to the reduced use of back up natural gas boilers which are partially compensated by the heat losses due to a higher water temperature in the DHN. In this case too, there is no optimal temperature increase if the Belgian subsidies are considered in the analysis. Due to these last results, the following section is dedicated to point out why the Belgian subsidies don't encourage a better use of the energy to reduce CO_2 emissions.

5.5. The belgian regulation issue

The previous case studies have pointed out that to consider Belgian subsidies are not in favor of using a heat storage solution. The aim of heat storage solution is to increase the CHP plant use at its nominal rated thermal power. It leads to increase the annual mean efficiency of the CHP and avoids some CO_2 emissions due to the reduced use of the back-up natural gas boilers and a better biomass fuel use. However the Belgian subsidies are dedicated to encourage saving CO_2 emissions and so they should encourage the use of CHP plant at its rated power (and maximal efficiency) to save CO_2 emissions.

A complementary study is performed on the cost of heat of the CHP plant in function of its equivalent utilization rate at full load. Fig. 10 (squares) points out that the cost of heat of the CHP plant slightly increases when the equivalent utilization rate at full load is over 4250 h per year. It is due to the current limitation of the green certificates regulation. Indeed the current regulation limit is to provide to the owner's plant maximum two green certificates by electric MWh produced. But this limit happens once the equivalent utilization rate at full load is over 4250 h per year (Fig. 11–crosses). With this current limitation, the solution to use the CHP plant at its nominal rated thermal power as long as possible (according to the availability factor of the plant) involve a higher cost of heat as it happens when a heat storage system is used. If this current limit is disabled, the cost of heat would reduce by increasing the use of the CHP plant (Fig. 11 - triangles). On the other hand, the use of heat

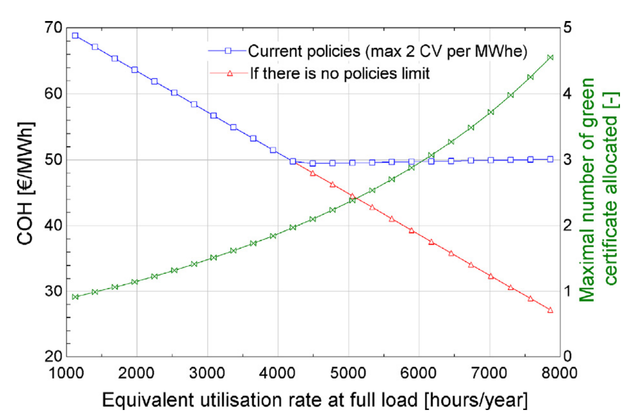

Fig. 11. Cost of heat of the CHP plant in function of its annual mean thermal power.

[2] The cost of the control implementation are considered as negligible while these costs are generally included in the operational and maintenance costs.

storage facilities leads to a lower use of the natural gas boilers by increasing the use the CHP plant and reduced CO_2 emissions. Therefore their equivalent utilization rate at full load is reduced leading to a higher cost of heat of these boilers too. Both the trends lead to a higher cost of heat of the DHN studied in the current case.

6. Conclusions and perspectives

Thermal energy systems are generally used in combination with CHP plant or boilers to use them at their nominal efficiencies as long as possible and reduce costs and energy consumption. In this contribution, a retrofit of an existing system composed of a biomass CHP plant connected to a DHN is investigated. The study aims to optimize the heat storage volume which can be connected to the plant to maximize the energetic, environmental and economic benefits. This retrofit analysis is based on a synthetic way by using simple models from thermodynamic, combustion process, heat transfer and finance.

An economic optimum for hourly heat storage can be found for the studied system if the Belgian subsidies are not considered. However the payback time of this solution is too long to be considered (13 years). At the same time, the CHP plant efficiency increases and CO_2 emissions are reduced. Seasonal heat storage should not be considered while the cost of heat increases due to large related investments for a few operating hours.

A complementary study is investigated to consider a modification of the heat demand by the adding of an industrial process or by insulating the buildings to reduce the annual heat demand. In both cases, there is no economic integration of heat storage systems. Moreover this study points out the requirement of a pre-design study in a CHP plant retrofit case. Indeed a reduction of 20% of the heat demand investigated leads a costs reduction of only 12% due to the COH increase by lowering the CHP plant use.

Due to long payback time of a dedicated heat storage use, it is proposed to consider the DHN network itself as heat storage system since it does not involve any investment costs. A simple strategy is analyzed and leads to a slight reduction of the cost of heat (-0.2€/MWh) for a maximal temperature increase of 8.5 °C.

If the Belgian subsidies are taken into account, there is no economic optimum for hourly, daily or seasonal heat storage despite the energetic and environmental influences are positive. The same conclusion is drawn for the heat storage inside the DHN by increasing its supply temperature. Therefore the contribution ends by an analysis to point out the origin of this behavior. The conclusion is that there is a limit of the green certificates funding which leads to increase the cost of heat when the annual mean thermal power of the CHP plant is increased; for example, by the use of a heat storage solution.

Finally, the simulation model can be used to size or improve any DHN while accounting for energetic, environmental and economic indicators developed in [11], especially for the integration of thermal energy systems.

As perspectives, this approach is dedicated to be extended into a global dynamic simulation model under the Modelica platform. The related objectives are to investigate several temperature control strategies of the DHN as [32] to improve the current DHN situation and reduce the cost of heat while limiting the related heat losses.

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