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Feasibility study for the application of a high-temperature heat pump in the pulp and paper industry: an Italian case study

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Abstract

The application of high-temperature heat pump (HTHP) in the pulp and paper industry can promote a more efficient and sustainable use of waste energy. In particular, the paper aims to perform a preliminary feasibility study for the upgrade of heat extracted from the wastewater aiming to increase the circularity of pulp and paper production through a combination of technological innovation. In the analysed case study a 1.3 MW th tailored cascade HTHP is designed to supply heat at 120°C at the thermal dryer while cooling the wastewater from 42°C to 28°C. The proposed solution generates several benefits: i) reduction of sludge mass associated with higher heating value for use as secondary fuel; ii) energy saving (i.e. the heating demand of the thermal dryer is not covered by the steam produced by the existing CHP plant) and consequent recovery of waste heat and CO_2 and pollutants emission reduction; iii) wastewater cooling without cooling tower operation, with a consequent reduction of fan power consumption up to 44 kW; iv) reduction of oxygen demand during the wastewater treatment due to temperature decreasing before aerobic stage, with a further power consumption reduction of the air fan. The preliminary techno-economic analysis shows a negative NPV at year 20 for both HTHP integration strategies analysed, that is completely fed by the power produced by the existing natural gas CHP unit or partially fed by a 0.54 MW el peak PV plant. Despite the contribution to emissions reduction, that is 1,989 ton/year of equivalent CO_2 with PV plant and 1,613 ton/year of equivalent CO_2 without PV, the economic sustainability cannot be guaranteed in the conditions examined. The preliminary sensitive analysis highlights a relevant impact of incentives intensity and duration and of the COP of HTHP.

Keywords: High-temperature heat pump; pulp and paper industry; cascade heat pump; energy efficiency.

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1. Introduction

Industrial production processes account for a considerable share of the overall pollution in Europe due to their emissions of greenhouse gases and air pollutants, discharges of wastewater and the generation of waste. The Industrial Emission Directive (IED) aims to achieve a high level of protection of human health and the environment taken as a whole by reducing harmful industrial emissions across the EU [1], in particular through better application of Best Available Techniques (BAT). Increasing energy efficiency and renewable energy in industrial processes is part of the IED and it is also coherent with the Clean energy for all European package (CEP) strategy [2], recently updated after the Covid-19 pandemic through the NextGenerationEU [3] and RePowerEU [4] initiatives. The European industrial sector represents one quarter of the EU28's final energy consumption with 260 Mtoe in 2019 [5], while waste heat sources exist in all industries with a total amount of 300 TWh/year in the EU. Figure 1 shows the distribution of EU28's final energy consumption in the industrial sector for 2019 (based on data extracted from [6]). Chemical and Petrochemical industry ranks first with 20.78% of the whole consumption, while non-metallic minerals (which includes the Ceramic industry in the

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Eurostat classification), Pulp and Paper, and Food industries are, respectively, at the second (13.63%), third (13.05%) and fourth (11.6%) places.

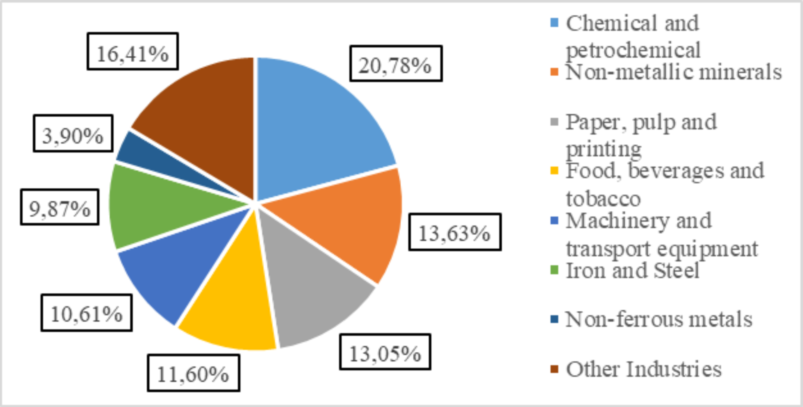

Fig. 1. Distribution of final energy consumption in EU28's industrial sector in 2019 (based on data ex-tracted from [6]).

Industrial process heat accounts for more than two-thirds of total energy consumption in industry, and half of this process heat demand is at low to medium temperatures (i.e. lower than 400°C). Figure 2 shows for each temperature range the final energy consumption share for industrial process heating (based on data extracted from [6]). While more than 85% of heating demand in the iron and steel industry (the industrial sector with the largest final energy consumption) occurs at temperatures over 500°C, Chemical and Petrochemical, Ceramic (included in non-metallic minerals), Food, and Pulp and Paper industries have a relevant heating demand in the range 100-200°C. Furthermore, a good match with the waste heat potential is found in these sectors [7].

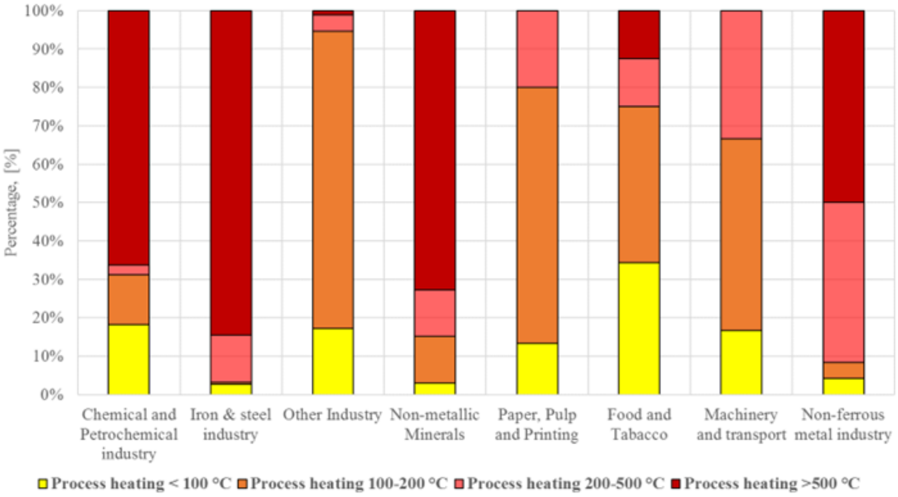

Fig. 2. Industrial final energy consumption for process heating: classification by industrial sectors and by temperature ranges in 2019 (based on data extracted from [6]).

The so-called "heat upgrade technologies" such as traditional heat pumps, mechanical vapour recompression heat pumps, absorption heat pumps and absorption heat transformers allow low-temperature heat (i.e. ambient heat, waste heat or renewable heat) to be upgraded to higher temperatures [8]. Heat upgrade technologies are promising solutions for increasing industrial processes efficiencies and decreasing greenhouse gas (GHG) emissions. In traditional heat pumps the recovered heat vaporizes the working fluid in the evaporator, which is compressed to a higher temperature by electrical power. The working fluid is condensed and expanded in a valve, and then the cycle repeats. In mechanical vapour recompression (MVR) heat pumps the pressure and thus also the temperature of waste gases are increased by a compressor, thereby allowing the heat to be re-used. The most common type of vapour compressed by MVR is steam. MVR heat pumps are widely used in specific industrial applications like in evaporator and distillation installations, in seawater desalination and industrial wastewater treatment plants [9,10]. Absorption heat pumps (AHP) and heat transformers (AHT) are thermally activated heat upgrading technologies in which the compression of the working fluid is achieved in a solution circuit consisting of a generator, an expansion valve, a solution pump and an absorber. The difference between AHP and AHT is that in an AHT, thermal energy required to vaporize the working fluid in the evaporator is supplied at a higher temperature than that of the heat required for separating the working fluid pair in the generator. In the Sustainable Development Scenario of [11] both electrically and thermally driven heat pumps are considered to be a potentially economically viable solution for heat supply at temperature ranges of up to 400°C. However, accordingly to both IEA HPT Annex 35 [12] and 58 [13] findings the commercially available heat pumps are limited to supply temperatures below 100°C, while the availability of systems capable of higher supply temperatures or high-temperature heat pumps (HTHPs) is limited. In particular, HTHPs integration in existing processes still need to be demonstrated at relevant scale in the medium temperature range (90-150°C) to improve market confidence [14].

In 2020, more than 85 million tons of paper and board and 36 million tons of pulp has been produced in the EU. The leading producing countries are Germany, Sweden, Italy, Finland and France. The turnover for the production of pulp, graphic paper, hygiene paper, packaging paper and special papers is expected to be around EUR 90 billion, with an added value of EUR 20 billion and investments of EUR 4.5 billion, directly providing 178,000 jobs in 891 mills and indirectly 3 million jobs along the forest and paper chain [15]. Pulp and paper mills are highly complex, and involve various process steps to transform the wood into the final product, including wood preparation, pulp production, chemical recovery, bleaching and papermaking. In 2019, the European Pulp and Paper industry consumed 380 TWh of primary energy [15], with drying accounting for up to 70% of the fossil energy use. The sector has reduced its CO_2 emissions by 24% since 1991 thanks to improvements in energy efficiency and the reduction of fossil fuel consumption (from 54.6% in 1991 to 37.6% in 2019) by replacement with biofuels (mostly black liquor) [16]. The Confederation of European Paper Industries (CEPI) has elaborated a roadmap [17] to decarbonize by 80% the European forest fibre and paper industry in 2050 compared to 1990. This will represent a decrease of 37 Mton of CO_2 per year in 2050 compared to 2015 and 32% of the reduction will be achieved through higher energy efficiency and the introduction of emerging and breakthrough technologies, including HTHPs. While there is potential for a high impact of HTHPs in the pulp and paper industry [18,19], several barriers (including regulatory ones to implementation, low fossil-fuel prices, adaptation to the industry processes, high investment cost, lack of knowledge and trust) hinder a wider adoption of HTHPs [20]. The first step for the market uptake of HTHPs in the pulp and paper industry is the preliminary techno-economic evaluation of the HTHP integration in existing facilities. Nevertheless, literature about HTHP application in the pulp and paper industry is limited.

To cover the literature gap about HTHP application in pulp and paper industry, the paper illustrates the design of a 1.3 MW th cascade HTHP to supply heat at 120°C at the thermal dryer of sewage sludge treatment plant of a pulp and paper industry while cooling the wastewater from 42°C to 28°C. The design is optimized to guarantee i) the use of sustainable working fluids and ii) the highest COP. Environmental and economic impact assessments are performed to evaluate CO_2 saving, net present value and payback time of the proposed solution. The sustainability impact of techno-economic parameters on the environmental and economic performances is estimated through a sensitivity analysis.

2. Case study description

The case study is based on a pulp and paper recycling plant located in the North of Italy. The plant, which covers an area of about 290,000 m^2 and employs about 100 workers, currently produces 400.000 tons per year of recycled paperboard. 200,000 Sm^3 of natural gas are daily consumed to supply both electricity and heat to the industrial processes through a gas turbine unit with a nominal power of 21.5 MW el, a recovery boiler with post-combustion for the nominal production of 135 ton/h of steam at 49 bar g and 440°C, and a counter-pressure steam turbine with an electrical power output of approximately 10.44 MW el. The high-pressure steam is sent to the steam turbine which has i) a medium pressure bleed of 105 ton/h of steam at 10 bar g and 275°C for the paper drying machines and ii) a low-pressure discharge of 30 ton/h of steam at 3.5 bar g and 210°C. This steam, after appropriate temperature and pressure adjustments, is destined for the low-pressure processes of the plant. The plant also includes a wastewater and sludge treatment facility. The wastewater treatment plant has the objective of reducing both pollutants and temperature of the water that after being treated is discharged in a superficial water body. The treatment includes both aerobic and anaerobic digestion, which generates 6,000 Sm^3 per day of biogas plus sludge. The sludge is currently dewatered mechanically, reaching a water content of about 50-60%. The relatively high water content of the sludge increases disposal costs and does not allow energy recovery.

3. HTHP integration into pulp and paper industry processes

The first concept was to introduce a new thermal sludge dryer operating in the temperature range 80-120°C to reach a sludge humidity of 5% after treatment. The energy requested for sludge drying process is estimated in 1.3 MW th, that corresponds to a yearly heat demand of 10,920 MWh (i.e. by considering about 8,400 hours of operation per year). The reduction of sludge humidity is beneficial since i) it reduces the mass to be disposed and ii) it increase the lower heating capacity of the sludge, which can be used as secondary fuel. Nevertheless, thermal drying is usually not cost-effective if realized by consuming natural gas. So, sludge thermal drying is not commonly performed in pulp and paper industry facilities [21]. Moreover, due to legislative obligations, the wastewater has to be discharged at a temperature lower to 30°C. In the specific plant the targeted discharge temperature is currently reached by cooling towers, that generate waste heat and high water consumption [22]. Therefore, the second concept was to use the heat content of wastewater as heat source for a HTHP able to dry the sewage sludge, thus generating a combined effect of wastewater cooling and sludge heating.

The identified solution is a cascade HTHP to supply heat at 120°C at the thermal dryer while cooling the wastewater from 42°C to 28°C (see the process flow diagram PFD in Figure 3). A secondary circuit has been foreseen between the HTHP and the wastewater to avoid direct contact and possible fouling of the HTHP evaporator. The configuration generates several benefits for the pulp and paper industry: i) reduction of sludge mass associated with higher heating value for use as secondary fuel; ii) energy saving (i.e. the heating demand of the thermal dryer is not covered by the steam produced by the existing CHP plant) and consequent recovery of heat waste and CO_2 and pollutants emission reduction; iii) wastewater cooling without cooling tower operation, with a consequent reduction of fan power consumption up to 44 kW; iv) reduction of oxygen demand during the wastewater treatment due to temperature decreasing before aerobic stage, with a further power consumption reduction of the air fan.

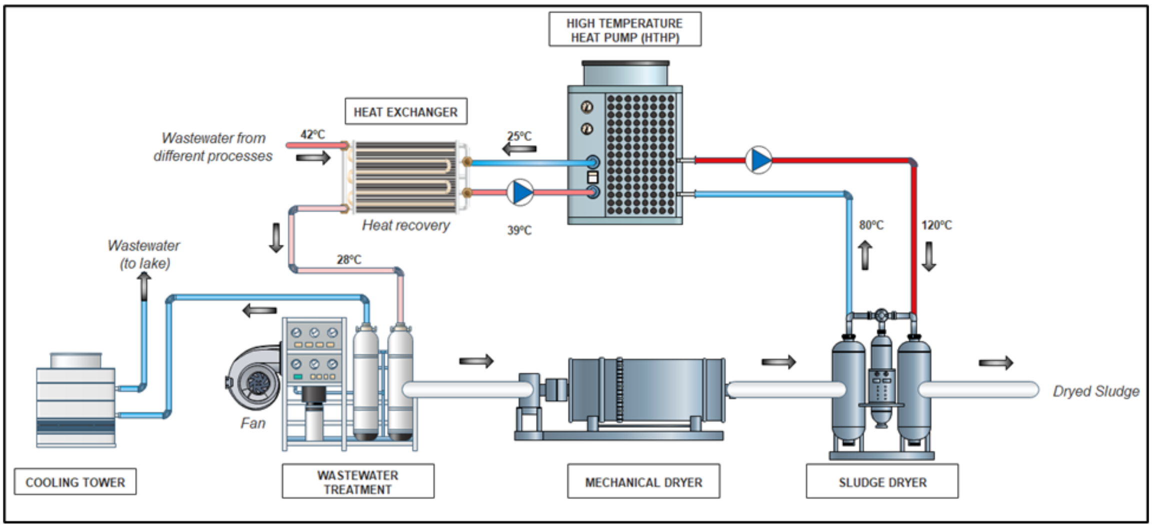

Fig. 3. Process flow diagram of the suggested integration of HTTP in pulp and paper industry.

The cascade HTHP is a 1.3 MW th customized solution offered by a renowned heat pump manufacturer. The size of the HTHP has been identified on the basis of available commercial components and based on heat demand for sludge drying on site. The cascade HTHP (see Figure 4) consists of two separate cycles, called "low temperature" and "high temperature" cycles, interconnected through a cascade heat exchanger. Each of the two cycles will employ two screw compressors in parallel to share the flowrate since the maximum capacity of commercial compressors is not sufficient to cover heat demand. The cascade heat exchanger acts as a condenser for the "low-temperature" cycle and as an evaporator for the "high-temperature" cycle. The pre-selected refrigerants are R1234ze(E) and R1233zd(E), respectively. The heat sink fluid is water, which is pumped from the end-user and recirculates back to it: the water enters the condenser at 80°C and exits as superheated water at 120°C. The economizers play a key role in optimizing heat flows among low and high temperature cycles and contribute to guarantee a relatively high COP despite the large temperature lift requested by the end-user. The expected COP of the whole system is 2.4, but it can be higher (up to 3.5) if the cooling effect on wastewater is considered as positive side effect.

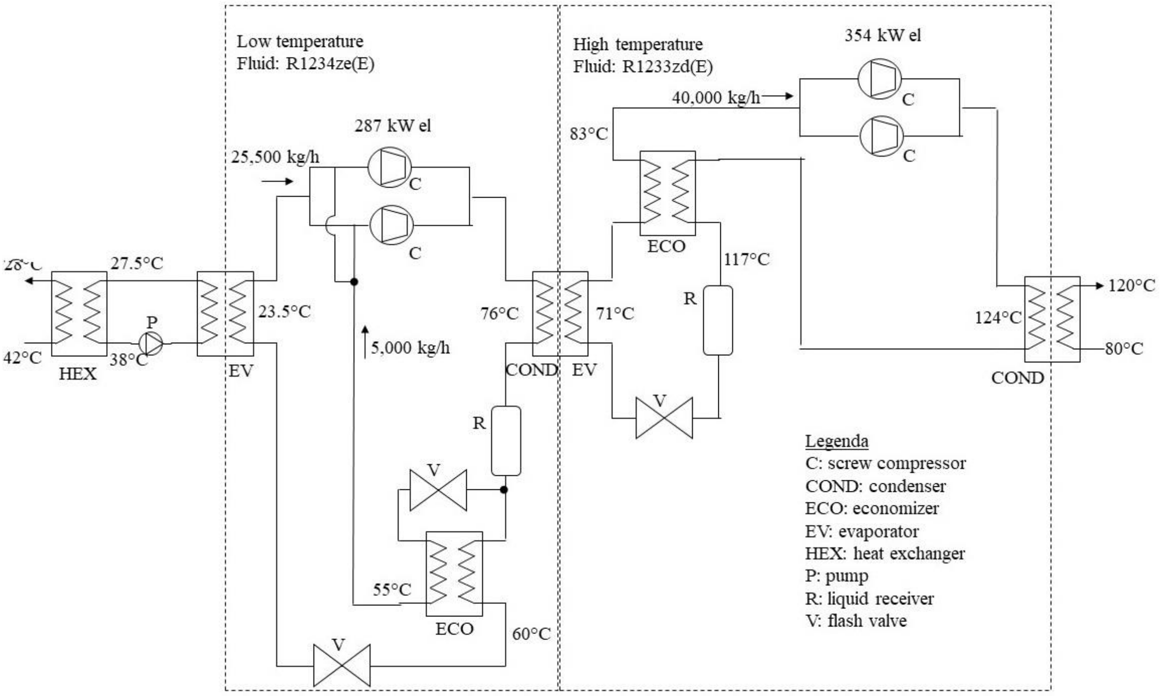

Fig. 4. Process flow diagram of the cascade HTTP. The reported power demand of compressors is the total one.

4. Feasibility study and preliminary techno-economic and environmental assessment

The assessment of HTHP integration into industrial processes requires a detailed techno-economic analysis to justify the investment in a real application. Furthermore, the reduction of the existing environmental impacts should be estimated as well since it can generate benefits from both economic and social community perspectives. The following methodology is proposed for the preliminary assessment. First of all, it is necessary to clearly define the scenarios under assessment. While in the new scenario sewage sludge drying and wastewater cooling are both reached through the integration of HTHP, the existing scenario needs some adaptation to make a proper comparison. In fact, in the current scenario the wastewater is cooled by cooling towers, which are not effective in reaching the expected temperature of 28°C for wastewater discharge in the superficial water body all over the year, especially in summertime. Therefore, in the paper the comparison is made between the cooling effect of the HTHP and the cooling effect that a traditional air-to-water chiller would have to reach the same wastewater output temperature. Figure 5 resumes the two scenarios; the HTHP integration scenario includes also the option of HTHP feeding by renewable electricity (i.e. PV plant), which will be discussed below.

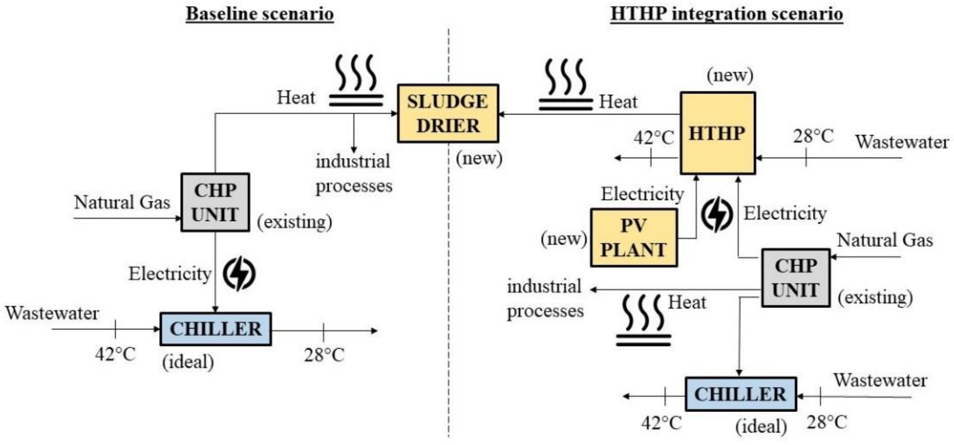

Fig. 5. Scenarios definition.

The comparison among the two scenarios is performed by considering two different parameters: the net present value (NPV), measured in Euros, and the payback time (PT), measured in years. The NPV is computed as in Equation 1, where t (years) is time, n (number of years) is the time period considered for the investment evaluation (which will be assumed equal to both depreciation and technical life time of plants for treatment simplicity purpose), i (%) is the discount rate, F_t (Euro) is the net cash flow at year t. The contribution of tax is not taken into account to simplify the economic assessment.

$$NPV = \sum_{t=0}^{n} \frac{F_t}{(1+i)^t} \qquad (1)$$

The net cash flow F_0 at t=0 corresponds to the starting investment: the simplifying hypotheses of full investment payment and plant operation start in the same year (t=0) are also assumed. The net cash flow for period t > 0 was computed taking into account the main costs C_t and revenues R_t components, as highlighted in Equation 2.

$$NPV = -F_0 + \sum_{t=1}^{n} \frac{[R_t \cdot (1+e)^t - C_t \cdot (1+e)^t]}{(1+i)^t} \qquad (2)$$

Revenues R_t include i) natural gas consumption saving in sludge drying process due to HTHP integration, ii) power consumption saving in wastewater cooling due to HTHP integration, iii) emission of new energy efficiency certificate, and iv) CO_2 emission certificate saving, both caused by a reduction in natural gas consumption. In this preliminary economic assessment, the benefits related with lower power consumption for the wastewater treatment due to lower air flow rate demand caused by wastewater temperature reduction before entering the anaerobic digestor are not taken into consideration. Energy efficiency certificate can be accounted as revenues only for the first 7 years of HTHP operation, accordingly to the Italian procedure [23]. On the other hand, costs C_t account for i) missed revenues due to electricity not sell to the grid operator while being self-consumed by the HTHP, and ii) operation and maintenance costs of the HTHP integration (not including the sludge dryer, which is the same for both scenarios). Equation 3 and Equation 4 define, respectively, how R_t and C_t have been computed: E_{th} is the yearly heat demand requested for sludge drying (MWh/year), c_{ng} is the cost of natural gas (€/MWh), η_{th} is the thermal efficiency of the existing CHP plant (%), η_{el} is the electric efficiency of existing CHP plant (%), COP is the efficiency of the HTHP (%), E_{fr} is the yearly cooling energy demand for wastewater cooling (MWh/year), c_{el} is the electricity selling price (€/MWh), EER is the efficiency of the traditional air-to-water chiller considered for the comparison with HTHP cooling effect (%), N_{eec} is the yearly number of energy efficiency certificate (#/year), c_{eec} is the market value of one energy efficiency certificate (€/eec), t_{CO2} is the yearly saving of equivalent CO_2 emission (ton of eq CO_2/year), c_{CO2} is the trading emission cost of CO_2 (€/t_{CO2}), $C_{O\&M}$ is the operation and maintenance cost of the HTHP integration. The yearly natural gas saving V_{ng} (Nm^3/year) can be computed as in Equation 5 and is equal to about 781,610 Nm^3.

$$R_t = E_{th} \cdot c_{ng} \cdot \left(\frac{1}{\eta_{th}} - \frac{1}{COP \cdot \eta_{el}}\right) + E_{\mathrm{fr}} \cdot c_{ng} \cdot \left(\frac{1}{EER \cdot \eta_{el}}\right) + N_{eec} \cdot c_{eec} + t_{CO_2} \cdot c_{CO_2} \quad (3)$$

$$C_t = E_{th} \cdot c_{el} \cdot \left(\frac{1}{COP}\right) + C_{\mathrm{O\&M}} \quad (4)$$

$$V_{ng} = \left[E_{th} \cdot \left(\frac{1}{\eta_{th}} - \frac{1}{COP \cdot \eta_{el}}\right) + E_{\mathrm{fr}} \cdot \left(\frac{1}{EER \cdot \eta_{el}}\right)\right] \cdot \frac{1{,}000 \cdot 3{,}600}{LHV} \cdot \frac{273.15}{298.15} \quad (5)$$

Table 1. Assumptions about economic assessment.

Item	Symbol	Value	Comments
HTHP integration cost	F_0	1,115,000 €	HTHP specific cost of 550 €/kW plus integration cost of 400,000 € (including design and permit procedures), as communicated by the HTHP manufacturer.
Heat demand	E_{th}	10,920 MWh/year	For the operation of the 1.3 MW th sludge dryer coupled with HTHP for 8,400 hours per year.
CHP thermal efficiency	η_{th}	56%	Measured in the pulp and paper facility.
CHP electric efficiency	η_{el}	30%	Measured in the pulp and paper facility.

HTHP COP	COP	2.4	Estimated by HTHP manufacturer based on the expected operating conditions.
Natural gas cost	c_{ng}	20 €/MWh	Mean value for March 2021 in Italy.
Cooling energy demand	E_{fr}	6,880 MWh/year	For the operation of the 0.819 MW fr of the HTHP evaporator for 8,400 hours per year.
Electricity selling price	c_{el}	60 €/MWh	Mean value for March 2021 in Italy.
Traditional air-to-water chiller EER	EER	5.5	A high efficiency EER is considered due to the relatively high wastewater outlet temperature.
Number of energy efficiency certificate	N_{eec}	641/year	Equal to the ton of equivalent oil (TOE) saved per year, that is 0.82 TOE per 1,000 Nm^3 of natural gas saved.
Market value of energy efficiency certificate	c_{eec}	267.4 €/eec	Mean value for 2021 in Italy (min 250 €/eec – max 299.99 €/ecc) [24].
Ton of CO_2 emission saved per year	t_{CO2}	1,613 ton/year	Computed by considering an emission factor 1.956 ton CO_2 per 1,000 Sm_3 of natural gas.
Trading emission cost of CO_2 emission	c_{CO2}	56.5 €/ton	Mean value for 2021 (min 34 €/ton – max 79 €/ton) [25].
HTHP O&M costs	$C_{O\&M}$	33,750 €/year	Assumed as 3% of HTHP integration cost.
Natural gas LHV	LHV	35,880 kJ/m^3	As guaranteed by contract to the pulp and paper industry. The reference conditions are 25°C and 1 bar.
Discount rate	i	5%	
Inflation rate	e	2%	
HTHP lifetime	n	20 years	

Figure 6 shows the NPV based on the values included in Table 1. The NPV is computed with and without incentives: the results clearly shows how incentives are crucial to make the investment more profitable. Nevertheless, NPV is negative anyway by considering or not incentives. Therefore, the tuning of incentives duration and intensity is crucial accompanying energy efficiency actions like HTHP integration in industrial processes. The reduction of CO_2 emission during the HTHP lifetime is relevant, being about 32,260 ton. If initial investment F_0 is divided per ton of CO_2 avoided in 20 years, we obtain a value of 34.6 € per ton of CO_2, which is lower than trading emission costs of CO_2. So, incentives are apparently well-designed. Indeed, the high selling price of electricity is the parameter that does not allow to make the investment profitable. So, the main barrier to HTHP integration is the high revenues that electricity selling can generate even by power production through natural gas combustion in CHP units.

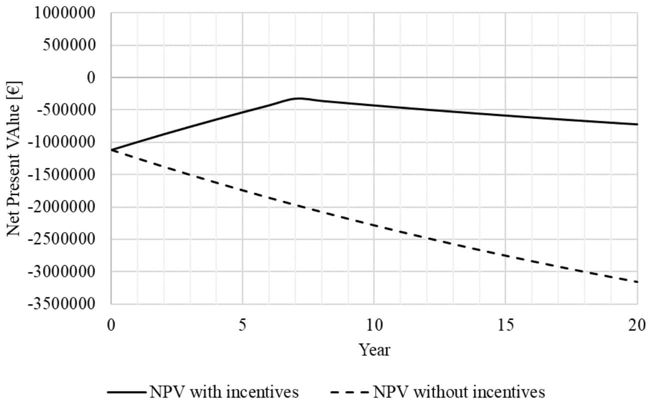

Fig. 6. NPV with and without considering incentives.

But since March 2021 a strong variation in both natural gas cost and electricity selling price has led to enormous stress on the energy market, substantially changes may be expected on the cost framework and related investment NPV and payback time. Table 2 summarizes natural gas cost and electricity selling price variation in 2021. Figure 7 shows how NPV varies by considering the different costs and prices (the NPV is computed with incentives). No relevant results can be reached in terms of investment profitability, since the high selling prices of power produced by natural gas CHP units. Discussion on how disincentivize power production by fossil fuel combustion is an open question which has implication on both environmental and economic sustainability of electricity market [26].

Table 2. Natural gas cost and electricity selling price variation in 2021.

Item	Symbol	Value at Mar-21	Value at Jun-21	Value at Sep-21	Value at Dec-21
Natural gas cost	c_{ng}	20 €/MWh	30 €/MWh	67 €/MWh	100 €/MWh
Electricity selling price	c_{el}	60 €/MWh	100 €/MWh	160 €/MWh	250 €/MWh

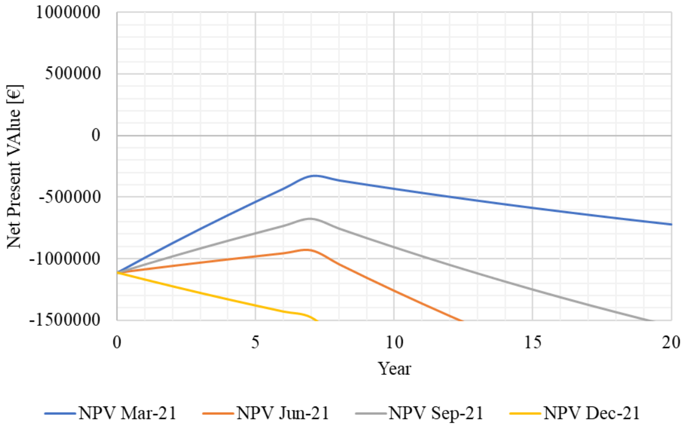

Fig. 7. NPV by considering incentives and with different natural gas cost and electricity selling prices.

The logic consequence of the techno-economic assessment is to prefer HTHP operation fed by renewable energy locally generated. In this case, the requested investment is higher, but the cost related to missing power selling as in Equation 4 can be avoided or, at least, reduced. Renewable energies availability is strongly related with local resources, and so it is highly site specific. When biomass and hydropower are not available in large amount, wind and solar energies are the most common renewable resources available at any site. But both solar and wind sources are characterized by being unpredictable and variable over time (both daily and seasonally) [27]. In the site of the pulp and paper industry under analysis only solar energy can be considered as a sustainable resource, and so photovoltaic (PV) can be taken into account to reduce the carbon footprint of HTHP operation.

Optimization of PV plant and battery storage requires complex modelling taking into account technical, economic and environmental concerns [28]. Since the scope of the paper is only to show how to foster HTHP application in industrial processes, a preliminary assessment of the impact of PV installation is given by considering a size of about 0.54 MW el peak. This configuration simplifies the analysis since no storage is needed and ideally all the electric energy is consumed by the HTHP. Based on the industrial site location, it is expected a mean annual production of 596 MWh. The specific cost of PV plant is assumed equal to 1000 €/kW peak installed [29]. Figure 8 shows the NPV (with and without incentives) in the case of HTHP integration and 0.54 MW el peak PV installation to make HTHP operation less dependent from natural gas consumption. The NPV is computed by considering energy values as in March 2021. The partial switch from natural gas to PV decreases natural gas consumption while increasing CO_2 emission saving, that are, respectively, about 857,679 Nm^3/year and 1,770 ton of CO_2 per year. The increased CO_2 emission reduction also has positive effect in terms of higher number of energy efficiency certificate release, that are 703 per year. But NPV at year 20 is still negative (-490,000 €). Finally, if the initial investment for HTHP plus PV plant is divided per ton of CO_2 avoided in 20 years, we obtain a value of 46.8 € per ton of CO_2, which is in line with the value of trading CO_2 emission certificate considered in Table 1.

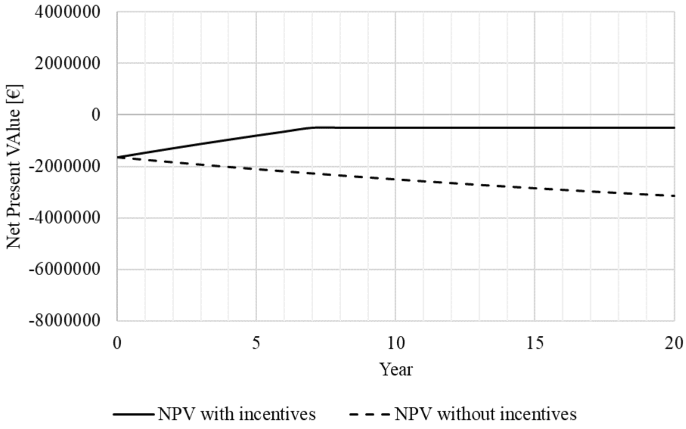

Fig. 8. NPV by considering or not incentives and including a 0.54 MW el peak PV plant for HTHP power feeding. Energy costs are from March 2021.

Due to the innovative design of the HTHP, also the COP of the HTHP needs to be assessed. Figure 9 shows how the NPV is influenced by relatively small COP variation (±8%). The variation has large potential influence on NPV; the increasing of COP generates a NPV increasing at year 20 up to about 0.5 million €, with a payback time up to 7 years. The impact of incentives is high, since without incentives the investment would be negative. A 7 years payback time investment may be perceived as risky since over such a long period variation in the framework conditions (like natural gas and electricity prices, inflation rate, incentives' values) is likely to occur, having potential negative impact on NPV estimation. Therefore, it is essential to pay attention to the COP of the HTHP integration, since an apparently negligible efficiency reduction or increasing can have a huge impact on the economic sustainability of the investment.

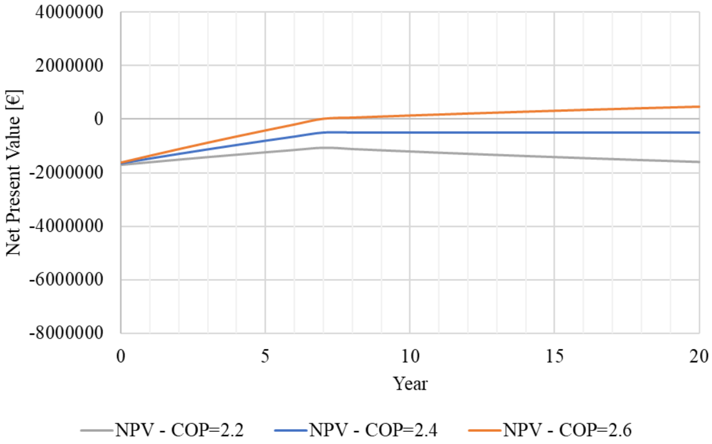

Fig. 9. NPV by considering COP variation ±8%. Energy costs are from March 2021, the integration includes a 0.54 MW el peak PV plant.

5. Conclusions

The paper analyses the application of a HTHP in a pulp and paper industry localized in Northern Italy. In particular, the paper introduces an innovative cascade HTHP to simultaneously generate heat for sludge drying and cool wastewater before wastewater anaerobic digestion treatment section. The temperature lift from the heat source to the heat sink allows to reach a COP limited to 2.4 by applying state-of-the-art technologies. The initial hypothesis is to feed the HTHP with the electricity locally generated by the existing natural gas CHP unit. The HTHP integration in the industrial process produces a more efficient use of the energy. In fact, about 1,613 ton of CO_2 equivalent emission per year can be avoided through the described approach. Nevertheless, the economic sustainability of the HTHP integration is hindered by the high selling price of electricity produced by the existing CHP unit, and that is no longer sold but self-consumed. Despite the rocketing of natural gas price in 2021 (and still on going in 2022), the connection among natural gas and electricity price makes difficult to predict the existence of a combination of prices able to make the investment profitable.

The solution is to combine the HTHP integration with local renewable power generation. In the paper the realization of a PV plant able to produce the peak power requested by HTHP is considered. The yearly power production is limited to 13% of HTHP power demand, which generates insufficient benefits in terms of NPV increasing. Once again, despite the energy efficiency performance reached by the system (1,770 ton of equivalent CO_2 emission avoided per year), the economic sustainability of the HTHP integration cannot be achieved. Through an optimization of the PV plant, to be coupled with batteries for energy storage, it would be possible to gain positive NPV and sustainable payback time. Such a configuration will be assessed in a following paper. Nevertheless, it is relevant to highlight how incentives intensity and duration play a key role in the promotion of energy efficiency actions. Finally, COP of the HTHP can strongly affect economic performance of the integration process: in fact, by reaching a COP increase of only 8%, it would be possible to have payback time of 7 years with a NPV at year 20 of about 0.5 million €.

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