

Wood chip drying in connection with combined heat and power or solar energy in Finland

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Abstract. 20% of the Finnish district heating (DH) power plant fuels are wood-based and the share is increasing. The wood fuel demand probably exceeds the potential supply in the future. The wood fuel drying with waste heat is one profitable opportunity to gain more wood fuel. If the drying energy can be produced with lower primary energy use than combusting the fuel directly, the drying potentially improves the system efficiency. In this study, the drying feasibility in the connection of a combined heat and power (CHP) system, possibly with solar collectors, is calculated. The wood fuel heating can be increased profitably by 6%, using the heat from CHP for drying only when the marginal cost of the heat is low enough, i.e. the electricity price is high enough and there is free capacity after the DH demand. Although the drying is profitable, a larger heat storage can also increase the annual result similarly. The best investment choice depends on the plant properties. Here the optimal system enables 20% DH production cost savings. Solar heat may be profitable, when the solar heat has a 2–3% share of the annual heat demand. However, the dryer or larger storage tank are more profitable investments.

1. Introduction

Drying of wood chips reduces storage losses and transportation cost and increases the lower heating value (LHV) of the wood fuel. The maximal increase of the LHV is in practice about 10–15%, depending on the initial moisture content (MC) of the fuel. [1] If the wood is dried for example from 50% MC to 20%, the LHV increases from 0,81 MWh/loose-m³ to 0,89 MWh/loose-m³, i.e. 10%. The LHV of dry wood is supposed to be 19,5 MJ/kg [1]. If waste heat streams can be used as a heat source for drying, biomass drying usually results in improved total system energy efficiency. Flue gas heat use is in many cases a part of the solution, possibly combined with superheated steam, see e.g. [2] or [3]. There are some cases in which the impact of drying to the CHP process is studied [4, 5], but they are rare. We study here if using only CHP heat for drying is feasible.

Primary energy definition in connection with district heating (DH) and combined heat and power (CHP) is generally described e.g. in the standard EN 15316-4-5. This standard gives an average primary energy factor of about 0,6 for the Finnish CHP heat, i.e. to produce one unit of CHP DH 0,6 units of fuel is used in the defined system level [6]. This is a rough generalisation, since in practice the value has a large variation depending on the plant properties and the timing of the heat energy use.

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Table 1. Wood fuels in Finland in 2012. Moisture is expressed on wet basis [1, 8].

	Estimated average MC, %	Annual amount, TWh
Forest residues	45	15,2
Bark	55	11,6
Sawdust	50	4,1
Other by-products	40	1,6
Recovered wood fuels	30	1,4
Pellets and briquettes	8	0,5

In this study, the feasibility of the drying in the connection of a combined heat and power (CHP) system, possibly added with solar collectors, is calculated. A key issue studied here is the benefits achieved when adjusting the timing of the drying so that the capacity of the CHP and solar heat production is utilised in an optimal way. This means that the drying is done when there is free capacity after district heat production and the production cost of the drying heat is as cheap as possible, i.e. concerning the CHP process, the market price of electricity is as high as possible. Solar energy can be used when excess heat from the CHP plant is not available (e.g. the plant is shut down) or the excess heat from the plant does not cover heat demand of the drying. This, of course, requires that the dryer is equipped with solar collectors and the sun is shining. The research question is thus: “how much the wood fuel can be dried profitably if CHP or solar heat is used?”

2. Wood fuel use in Finland

The total primary energy supply in Finland is about 380 TWh/a and the use of wood fuels about 90 TWh/a [7, 8]. Similarly to other Northern European countries, increased biomass use is in a key position in Finland’s plan to achieve the EU renewable energy target for 2020. The future increase potential for forest fuels is about 25 TWh/a in Finland, mainly in connection to forest industries and municipal CHP plants [9]. However, the additional potential be achieved by fuel drying has been neglected in Finland due to the poor economic profitability of the dryer investments. So far, fuel prices have been low, and as a consequence the biomass drying with waste energy is now very rare in Finland. The average prices of wood fuels in Finland have increased from 13 €/MWh to 20 €/MWh during the last 6 years [7] which can considerably improve the profitability of the dryer investment. The main driver for this development has been the higher demand of wood fuels. The average MC of wood fuels delivered to the Finnish power plants, according to the type of the fuel, is shown in Table 1. The average is around 45%. In the table we also show the annual amounts of wood fuels in different plant types.

3. The drying needs from the power plant point of view

The energy wasted for the evaporation in the combustion process decreases accordingly to the decrease of the moisture content (MC) of the fuel, and, on the contrary, the cost of separate drying increases. MC of 25–30% can be seen as a compromise between different moisture dependent properties of the wood fuel. When MC is lower than 30%, the decomposition process slows down significantly and in 20–25% MC decomposition rate is practically zero [10]. The dry mass losses are thus avoided and dry chips can be used as a large buffer storage. Also the potential greenhouse gas emissions as a consequence of the wet material decomposition during the storage can be reduced [11]. The risk for self-ignition may decrease with lower moisture content, since the decomposing biomass rises the temperature, sometimes above the ignition level. However, the most risky situation is when there are wet and dry biomasses side by side: the wet one warms up and ignites the dry one. The MC variation even in the same truck load of fuel can be tens of %-units in the worst case and thus it is important to mix and dry the fuel evenly [12].

The drying rate decreases considerably when the moisture content is below 30% because almost all water is bounded water below this moisture content. This means that dryer dimensions and investment

costs increase rapidly if very low moisture contents are desired. The lower limit of the feasible MC of the fuel is also set by the fire prevention measures in the power plants. In general about 30% is seen as a suitable, practical limit value for MC in this sense. The MC may have a significant influence on the operational parameters of the boiler. The larger purpose-built fluidised bed (FB) boilers, which are normal in the Finnish CHP plants, are designed to be capable of burning also moist biomasses. If e.g. the MC of the fuel is 30% instead of 45%, the boiler efficiency in one case increases from 92% to about 93% [13]. Taking into account all of these, the energy used for evaporation (or melting of the frozen wood), and the timing of it are the most important measures when calculating the feasibility of the fuel drying. Following, the research or design question here is not how to achieve some exact moisture content. The most relevant question in this case is how much the fuel can be dried profitably.

4. The advantages of the heat use flexibility in the CHP or solar heat network

The marginal cost of heat is not the same all the time. It depends on the price of electricity, which fluctuates a lot. For instance, in the Nordic electricity market in summer time these are periods when the marginal cost of electricity is that of nuclear power, i.e. about 10 €/MWh, the other extreme being winter cold spells when peak load GT's are in operation with marginal costs of above 100 €/MWh [14, 15]. Further, drying is not necessarily obligated to be performed at some specific moment, but rather it can be done when there is cheap heat energy available. The impact of the timing of the energy use is often left out from feasibility studies, thus we concentrate here on it.

The logic behind using CHP heat instead of using directly produced heat is the same as in the usual space heating case. Using CHP heat leads to primary energy savings and emission reductions, if the CHP electricity produced together with CHP heat replaces more energy- and emission-intensive marginal electricity from the electricity network [14]. Solar heat, in turn, means direct fuels savings and is therefore feasible from a material efficiency point of view. In a CHP system, solar heat may be feasible most probably when it replaces separate heat production, mainly during low or peak load or in rapid heat load changes.

Our ex-ante assumption is that the timing of the heat consumption is crucial for the profitability of the process. The drying must be allocated to the hours when there is heat producing capacity left after covering the normal heating demand thus avoiding extra investments. In addition, CHP heat must be used as much as possible when the price of electricity is at its highest. The typical Finnish municipal CHP plants have about 5000 annual peak load operating hours, so there is room for the optimization of the timing of the drying. Thus, the drying can be seen as one way of storing heat, which in turn is a feasible way to even out e.g. the fluctuation of wind power [16]. The additional, flexible heat use by the dryer can smoothen the heat demand so that the need for start ups and shut downs and significant load changes of the plant is reduced.

5. The simulated system and methods

5.1 The base case system and the input values

The production system described here represents a modern state-of-art CHP system for solid fuel. In Finland these systems normally use FB technology with high steam values (e.g. 180 bar, 560 °C) for wood fuel boiler and secondary superheater for steam reheat. These make a good power-to-heat-ratio of 0,6 for a wood fuelled CHP plant. The fuel input is supposed to be 100 MW, electrical output 33 MW and heat output 55 MW. Figure 1 shows the layout of the system, with possible dryers and solar collectors.

This does not represent any existing system exactly, but presents a typical dimensioning of the system. However, the power-to-heat ratio is in many older and smaller plants less than 0,6, which must

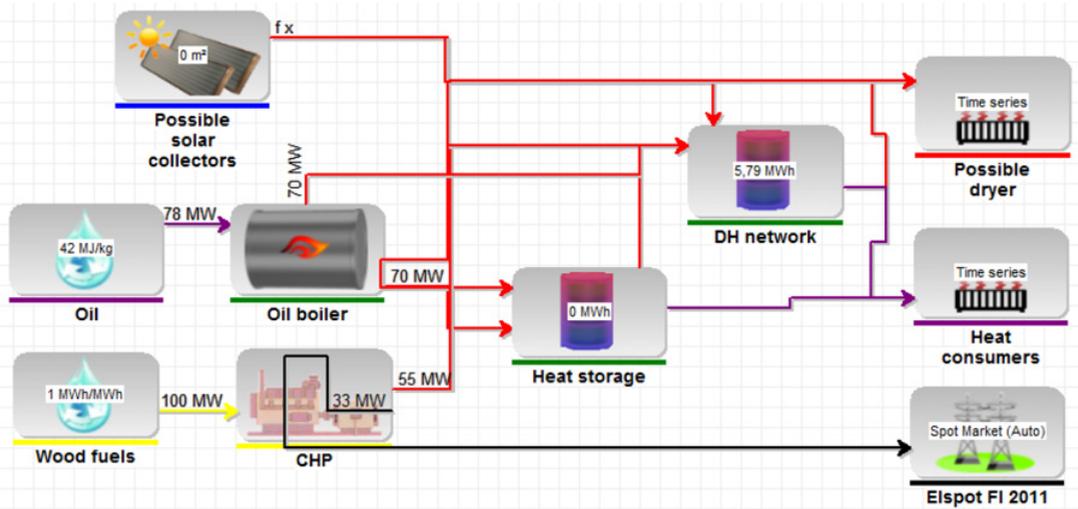


Figure 1. The layout of the studied system.

be noticed when generalising the results. The worse the power-to-heat ratio, the less profitable the drying with CHP heat is. The base case system has a heat storage. 2/3 of the Finnish CHP DH heat was produced in systems with heat storages in 2011 [17, 18]. The storage is usually a very profitable investment. In Table 2 the main properties of the base system are presented.

5.2 The dryer

The drying unit can be e.g. of batch or silo type or alternatively a belt dryer, see [22]. These types of dryers can also use low-temperature heat sources. In a silo type dryer, warm (or in some, especially smaller cases, cold) air is blown through the fuel bed in the silo. The belt dryer, in turn, has a slowly moving belt, through which the drying air is blown. We suppose here that a belt dryer is used. The maximum input heat effect was varied between 10 and 40 MW, i.e. between 20 to 70% of the CHP plant maximum heat input.

The dryer investment is based on the assumption that the hot water temperature supplied to the heat exchanger of the dryer is 80 °C, which is near to the average supply temperature of the typical DH system in Finland. The higher temperature would result in a cheaper dryer, but would also lead to the decrease of the power-to-heat ratio. The specific heat consumption of the dryer is supposed to be 4000 GJ/tonne evaporated water, i.e. 60% of the hot water energy used for drying is gained as a form of better heating value of the biomass. The electricity use of the dryer blowers and other electricity equipment is supposed to be 1/40 of the heat energy supplied to the dryer [23–26].

The following limitations are used for the hours that dryer is in the use:

- The net production price (marginal cost) of the heat is under 12 €/MWh. As the dryer can transfer about 60% of the input heat to the heat value increase of the dried fuel, this is the maximum heat energy cost for the profitable operation, when the fuel cost is 20 €/MWh.
- The sum of the heat use in the DH network and the heat effect fed to the dryer can be maximum 55 MW (the maximum heat output of the CHP unit).

The downside of these limitations is that the annual operation hours of the dryer are reduced and to have the same output, the momentarily effect of the dryer must be consequently increased. Thus the capital cost of the dryer per output unit is higher. However, this is near the best possible operation

Table 2. The main properties of the studied system.

DH system		
Annual heating energy	300 GWh	
Heat demand	10... 110 MW	
Location	Southern Finland	
Outside temperature	Minimum -26°C , average 8°C	
Hot water temperature	75... 110°C [17], hottest in the cold weather, weighted avg 80°C	
Return water temperature	44... 59°C [19], coldest in the outside temp of 0... 10°C , weighted average 45°C	
Energy production plants		
	CHP plant	Oil boiler
Fuel input	30... 100 MW	0/78 MW
Electricity output	10... 33 MW	–
Heat output	16.5... 55 MW	0/70 MW
Full load hours per year	4700 in base case	600 in base case
Starting-up time	4 hours	0
Shutting down time	4 hours	0
Cost of start-up + shut down	2000 euros	0
Annual maintenance period	24.6.–22.7.	–
Fuel	Wood fuels: forest residues, by-products from forest industries	Heavy fuel oil
Fuel price in average	20 euros/MWh	79 e/MWh, incl taxes and carbon trade price
Variable maintenance cost	4 euros/MWh _e	5 euros/MWh _{heat}
Heat storage tank		
Volume	5000 m ³ , i.e. 150 MWh, in base case	
Temperature in the bottom	Return temperature of DH + 5K	
Temperature in the top	Forward temperature of DH – 5K or max. 98°C	
Storage loss	Noticed, insulation 300 mm mineral wool	
Storage price	33*volume (m ³)+ 400 000 € [20]	
Lifetime	20 years, interest rate in calculation 5%, no residual value	
Solar collector		
Size	0... 100 000 m ²	
Inclination and orientation	45° , South	
Efficiency without losses	84%	
Thermal loss coefficient	$3.77 \text{ W/m}^2\text{K} + 0.012 \text{ W}/(\text{m}^2\text{K})^2$	
Temperature to collector	DH return + 3K	
Temperature from collector	DH return + 13K	
Collector price	200 €/m ² [21]	
Lifetime	20 years, interest rate in calculation 5%, no residual value	

strategy, i.e. the unit is run always when the operation makes profit, calculated from marginal costs and income.

5.3 EnergyPRO model

The energy system studied here contains heat storage. Therefore the optimization cannot be done just hour by hour individually, but rather taking into account the optimal strategy for a longer time. The optimisation is here done by using the energyPRO software [27–29], which fulfills this requirement. It has been used in various cases for example in Denmark, see eg. [30–32], UK [33, 34] and Germany [35].

The idea of the optimisation is to find the plant operating pattern to fulfil the energy demand with the lowest annual operation cost. When performing the simulation, the model searches first the most profitable moments for energy production. The reason for this is that each new production has to

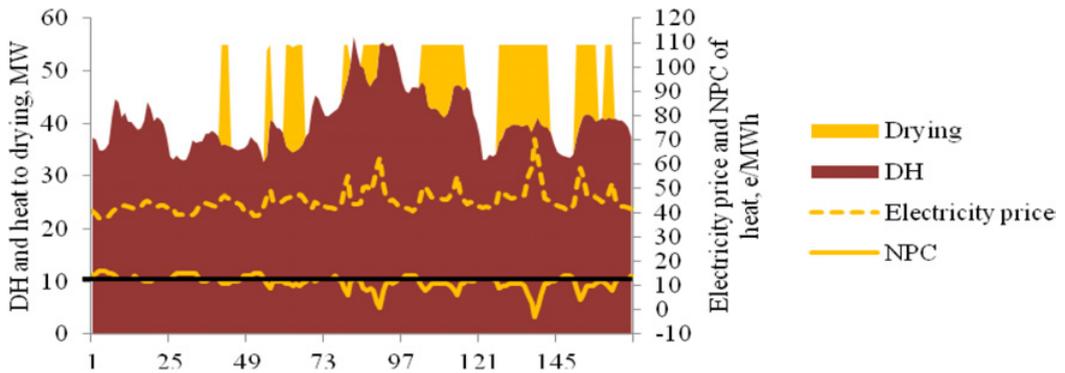


Figure 2. An example of the dryer use optimisation. Horizontal axis shows hours of one week. The red area shows the DH demand and the yellow area the heat use of the dryer. The dashed line is the electricity price and the continuous line net production cost (NPC) of heat. When the electricity price is high enough (NPC of the heat is low enough, here under 12 €/MWh), the dryer is used.

be carefully checked to avoid disturbing the already planned future production to avoid problems for example with varying electricity prices [33]. Concerning CHP, the production is most profitable when the electricity price is at highest. Also the start-up cost affects the issue, i.e. if the plant is not already running, it is not started for just one hour of profitable operation. We used hourly resolution in the modelling. Input values are either heat demand, cooling demand or/and electricity demand depending on the optimisation task. They also include information of environment (such as electricity prices, outdoor temperatures), fuels (such as heat values, possible restrictions, prices, etc.) and production units (such as production figures, minimum power, operation&maintenance costs, taxes, etc.).

6. Results and discussion

Figure 2 shows an example of the dryer use with the operation principles described here. The horizontal axis represents a time period of one week in October. This period shows a high electricity price variation between day and night. The dryer is mainly used when the electricity price is at its highest.

As a simulation result, we found that the most profitable alternatives are those with either 10 000 m³ heat storage or 5000 m³ storage added with a dryer. When comparing these, it can be for example further calculated that the marginal cost of the drying energy is on average 6 €/MWh. This cheap price is explained by e.g. the optimised timing of the drying.

In the most profitable sizing case, the maximum heat input to the dryer is 20–30 MW, about 30–50% of the studied CHP plant full heat output. The annual heat use of the dryer is correspondingly 55–75 GWh, which means approx. 2500–3000 full load hours for the dryer. With this input, if the average MC of the incoming wood fuel is 45%, after dryer it is consequently 28%. This MC is a good compromise between energy efficiency and fire prevention. As a consequence of this kind of heat use for drying, the electricity production increases 20–25% while the DH output remains the same.

When varying the max. dryer heat input between 0...40 MW and the heat storage size between 3000...10000 m³, the differences of the total annual cost between the alternatives, including investment payback and operation costs, are small, max. about 1 euros/MWh_{DH,NPC}. Without heat storage or dryer, the annual cost is however about 3 euros/MWh higher, due to the decreased electricity production and heat-only oil boiler use, with no possibility to have some production flexibility.

Compared to the base case, 2–3% of the DH demand could be produced at least nearly profitably by solar heat with assumptions used here and when the return of the investment needed is low. This partly explains the increasing interest for solar heat in Finland even in the CHP networks, in addition to

imago reasons. However, the investment in the dryer or heat storage is more profitable. Also, the dryer can increase the useful share of the solar heat significantly with large collectors, e.g. 20% in the case of 100 000 m³ collector area. In this case, the solar share of the total heat supply is over 10%.

When generalising the results, it must be remembered that the better the power-to-heat ratio, the better is the profitability of drying is using CHP heat. This limits the potential of drying in older and smaller CHP plants. There are also some uncertainties in the calculation method and basic data, which must be corrected when continuing the study. First, there should be more test years. Also the ramping up and down rates should be considered more precisely. Now they are noticed only when the plant is run down or started from a zero. Further, the investment data for drying equipment can be gathered more widely and the maintenance costs of the dryer must be noticed.

7. Conclusions

One overall goal in energy system planning is to find the solutions which cope well in the future environment of probably more fluctuating electricity prices and increasing use of residual biomass for energy. The price fluctuation is a consequence of the larger share of variable renewables (wind, solar), on one hand, and nuclear power with constant production, on the other hand, on the Nordic market.

There are many possibilities to handle the mismatch between the consumption and production timing. However, many of the stakeholders (both power plants and consumers) do not realise even well profitable investments. This is due to the lacking knowledge, transaction costs, high requirements for investment return rate etc. To achieve the ambitious goal, it is recommended to continue with the wide front, at least concerning the solutions that do not require massive R&D efforts compared to the future potential. Wood fuel drying can be one of the mature and relatively cheap technologies in that sense.

In this study, two possible heat sources were available for the dryer: heat from the CHP plant or heat from solar collectors. Both of these concepts would already at present be competitive in countries with higher biomass prices than in Finland, e.g. in the Netherlands. Also in Finland, they can in many cases offer a less costly alternative to high-quality wood fuels such as pellets and torrefied biomass, which are currently under significant R&D effort in Finland. In our calculations, the dryer drying in connection with CHP plant with smart drying timing seemed to be profitable even with the current Finnish wood fuel prices. Solar heat seems to be a slightly profitable investment in the base case with no drying, but if these investments are competing with each other, the drying alternative is more profitable. However, from e.g. the energy company image and brand point of view, solar heat may still be interesting. In the future, the rising fuel prices improve the competitiveness of solar energy.

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