Energy Efficiency Evaluation of the Secondary Heating System at the Södra Cell Värö Pulp Mill

Analysis of seasonal variations and non-energy benefits

Master´s thesis in Sustainable Energy Systems

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Abstract

As sustainability and energy efficiency become increasingly important for both economic profitability and environmental responsibility, industry faces growing demands to minimize resource consumption and emissions. A key tool in this effort is internal solutions for the recovery of energy and material flows, with heat recovery serving as a clear example. By utilizing surplus energy for heating and cooling, dependence on external resources can be reduced. This is especially relevant in energy-intensive sectors such as the pulp and paper industry, where there is great potential to optimize heat recovery through the secondary heating systems.

The energy demand at pulp mills varies significantly over the course of the year. During winter, the need for heat increases, both for internal process requirements as well as for external users, while summer is characterized by a lower heating demand which leads to an excess of heat in the secondary heating system and, thereby, a significant increased cooling demand. The current system at Södra Cell Värö has a limited capacity for cooling, which complicates the energy balance throughout the year. In this study, a mapping of the energy flows was carried out with the objective to identify measures to reduce the plant's utility steam usage as well as the load on the cooling system. Pinch analysis was used to determine the theoretical savings potential and identify opportunities for heat recovery. One of the key observations is that the temperature in the hot water tank currently falls below the design level of 90°C, which limits the possibility of replacing steam, with recovered heat in several processes. By reducing steam usage in operations, the released steam can instead be utilized in the condensing turbine, contributing directly to increased electricity production.

Beyond the energy-related advantages, the study highlights additional benefits, such as reduced freshwater demand, decreased cooling system load and potential noise reduction.

Keywords: softwood kraft pulp mill, secondary heating system, energy efficiency, seasonal variations, non-energy benefits

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Finally, I would like to thank Södra for the opportunity to carry out this project and for creating a pleasant working environment.

Sanna Källmark, Gothenburg, May 2025

List of Acronyms

Below is the list of acronyms that have been used throughout this thesis listed in alphabetical order:

ADt	Air Dry ton
BE	Bleach Effluent
BLC	Black Liquor Vapor Condensate
BLV	Black Liquor Vapor
CC	Composite Curve
CCUS	Carbon Capture, Utilization and Storage
CLT	Cross-Laminated Timber
CW	Cold Water
DH	District Heating
ECF	Elementary Chlorine Free
HP-Steam	High-pressure steam
HW	Hot Water
HX	Heat Exchanger
LP-Steam	Low-pressure steam
LWW	Luke Warm Water
MP-Steam	Medium-pressure steam
PFD	Process Flow Diagram
P&ID	Piping and Instrumentation Diagram
SBS	Södra Building Systems
SC	Steam Condensate
SCV	Södra Cell Värö
SHS	Secondary Heating System
TCF	Totally Chlorine Free
WBL	Weak Black Liquor
WW	Warm Water

Nomenclature

Below is the nomenclature of parameters and variables that have been used throughout this thesis.

Parameters

ΔT	Temperature difference (°C)
ΔT_{min}	Minimum temperature difference (°C)

Variables

c_p	Specific heat capacity ($\mathrm{kJ/kg \cdot {}^\circ C}$)
H	Enthalpy (kJ/kg)
m	Mass flow rate (kg/s)
Q	Heat load (kW)
Qc_{min}	Minimum required cooling duty (MW)
Q_{HX}	Potential for heat recovery (MW)
Q_{XS}	Amount of high-value excess heat (MW)
$\dot{V}$	Volumetric flow rate (l/s)
η	Electrical efficiency

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1

Introduction

In today’s society, sustainability and energy efficiency are key factors for achieving both economic success and environmental responsibility. Within the industrial sector, this necessitates a strong focus on reducing resource consumption and emissions. Internal solutions for recycling energy and material flows are therefore being increasingly important. One example is heat recovery, where excess energy is reused for heating or cooling, thereby reducing reliance on external resources [1].

Particular in energy-intensive sectors such as the pulp and paper industry, there is significant potential to optimize the use of secondary heating systems. This sector accounts for approximately 14% of Sweden´s total energy consumption and approximately half of the energy use in industry [2]. By improving the efficiency of these systems, the industry can reduce energy consumption, emissions and costs, an increasingly important goal given tightening regulations and rising demand for sustainable products. One such regulation is the Energy Audit Act, which aims to reduce the energy consumption and increase energy efficiency in the business sector. This legislation is based on EU´s Energy Efficiency Directive and require large companies to regularly map their energy use and identify opportunities for improvement [3].

Beyond direct energy use, there is also growing attention on other sustainability aspects, such as water consumption. The European Green Deal imposes new and stricter requirements on industry, which may lead to reassessment of existing permits. This reflects an ongoing shift in legislation, both at the EU level, where the focus is on efficient and sustainable resource use, and in Sweden, where regulations and policy instruments are being adapted to support these objects [4].

1.1 Background

This thesis presents an energy efficiency study conducted at the softwood kraft pulp mill Södra Cell Värö. To provide context for the study, a brief background of Södra’s operations at the Värö site is presented, with a particular focus on Södra Cell Värö.

1.1.1 Södra Värö

Södra in Värö is a facility where multiple production units collaborate to optimize resource utilization. Strategically located on the coast by the Viskan River, near

Varberg, the site comprises a pulp mill, a sawmill, a cross-laminated timber (CLT) factory and an innovation center. The synergy is based on exchange of energy and materials. The pulp mill, Södra Cell, primarily produces pulp but also generates valuable by-products. Steam, district heating, and electricity from Södra Cell supply both the sawmill Södra Wood and the CLT factory Södra Building Systems (SBS) with the energy needed for their production. In addition, there is a surplus of electricity and district heating that is sold externally [5]. The site´s annual production volumes are summarized in Table 1.1.

Table 1.1: Annual production data for Södra Värö [5, 6]

Production Type	Amount
Pulp Production Capacity	760 000 ADt
Electricity Production	820 000 MWh
District Heating	150 000 MWh
Biofuel production	810 000 MWh
Sawn Goods	585 000 m^3

Södra Wood produces sawn timber and by-products such as sawdust, bark and wood chips. The chips are used in pulp production at Södra Cell, while the sawdust is used both for pellet production and as fuel in the pulp mill. Bark from Södra Wood is dried at Södra Cell and can either be used as fuel in the mill or sold externally. Södra Building Systems refines timber from Södra Wood into cross-laminated timber panels, with sawdust from this process also being used as fuel at Södra Cell. This integrated production creates a circular flow of materials and energy, where by-products from one process become valuable resources in another. The flows of energy and materials within Södra Värö are visualized in Figure 1.1.

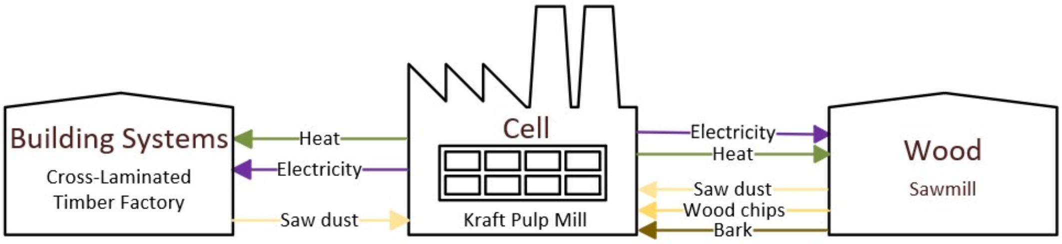


Figure 1.1: Flows of energy and materials within Södra Värö.

1.1.2 Södra Cell Värö

Södra Cell Värö is today one of the world's largest and most modern softwood pulp mills, which also produces biofuels and green electricity [5]. Figure 1.2 provides an overview of the mill's energy flows. Through a long-term focus on energy efficiency and an extensively developed secondary heating system, the plant has an energy surplus and delivers significant amounts of heat to the city of Varberg's district heating network. However, the plant is subject to constant process changes that affect the energy balance, making it essential to keep optimizing energy use to enhance both sustainability and profitability.

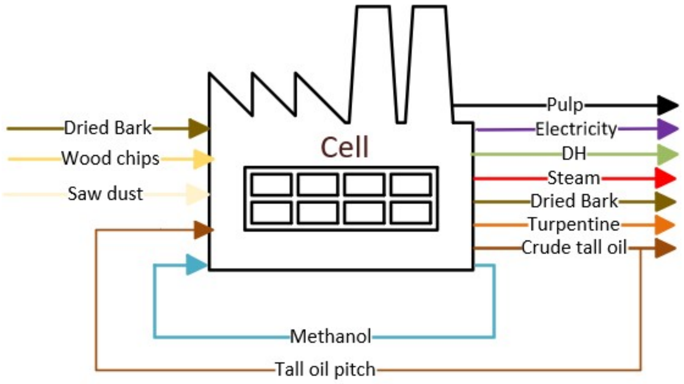


Figure 1.2: In- and outflows of energy for Södra Cell Värö.

After a major expansion of the mill in 2016, a mapping of the energy flows at the pulp mill was carried out [7]. This mapping provided a detailed overview of the secondary heating system and the plant's total energy use as well as identifying potential measures to improve efficiency. At the time, the availability of operational data required to conduct the analysis was limited. Since then, the secondary heating system has been in operation for a longer period, allowing for a more experience-based assessment. Additionally, a minor expansion and several process changes have been implemented, further affecting the system. These developments highlight the need for an updated mapping and analysis.

In the previous mapping seasonal variation were not considered. It is well-known that seasonal variations have a significant impact on the process and thus energy optimization, which makes it interesting to evaluate how different seasons affect both heat demand and handling of excess energy. The secondary heating system experiences excess heat throughout the year, which particularly high levels during extended periods. This excess heat must be discharged, either via cooling towers or by releasing heated water. As a result, the secondary heating system and its operation are linked to other aspects such as water consumption, cooling tower capacity and noise.

1.2 Aim

The purpose of the thesis is to map the secondary heating system at Södra Cell Värö, in order to identify possible improvements in energy efficiency. These are to be evaluated based on viability and economic feasibility. To account for different operating conditions, there will be a focus on seasonal variations. The goal is to also evaluate non-energy benefits such as opportunities for freshwater savings, noise reduction and reduced cooling tower load.

1.3 Objectives

To achieve the aim, this thesis defines a set of objectives focused on assessing potential energy efficiency improvements within the secondary heating system. This includes different scenarios and can be specified by the following questions that are to be answered:

- How can the secondary heating system at Södra Cell Värö be optimized to improve energy efficiency?
- How do seasonal variations affect energy flows and the efficiency of the secondary heating system, and what methods can be used to evaluate these effects?
- What non-energy-related benefits can be achieved through energy efficiency measures, such as reduced freshwater consumption, decreased cooling capacity requirements and lower noise levels?

1.4 Limitations

The results and associated analyses are based on studies conducted at the Södra Cell Värö pulp mill and are therefore not directly transferable to other facilities. However, the methods applied in this study may be applicable to similar studies at comparable mills. Data collection was carried out during predefined seasonal periods over a two-year time frame, with the seasonal divisions based on analyses of the available capacity in the cooling towers.

To ensure comparability of results, data was collected only during periods of stable production. Consequently, variations caused by operational disruptions or other changes in production were excluded from the analysis. These constraints were set to keep the thesis within the designated time frame. For the same reason, the study did not include an in-depth economic evaluation. Factors such as investment costs for equipment, implementation costs, production losses from potential shutdowns or payback periods were therefore not analyzed.

2

Process Description

Chemical pulping is a process that breaks down wood into pulp by dissolving the lignin that binds the cellulose fibers together [8]. There are different methods to achieve this but the most dominant is the kraft pulp process as it allows for efficient recovery of chemicals and energy from the used pulping liquor and consistently produces the strongest pulp [9].

2.1 Kraft Process

In the kraft process, cellulose is separated from hemicellulose and lignin by treating the wood with an aqueous solution containing sodium hydroxide and sodium sulfide at high temperatures [10].The process can be divided into two main parts, the fiber line and the chemical recovery cycle as shown in Figure 2.1. The fiber line, which extends from the wood yard to the dryer, is responsible for producing the paper pulp. The recovery line includes the liquor- and lime cycle, where chemicals are recycled and energy is produced to supply the pulp mill with heat and electricity [11]. The following sections provide a more in depth description of each part to allow for understanding of energy flows.

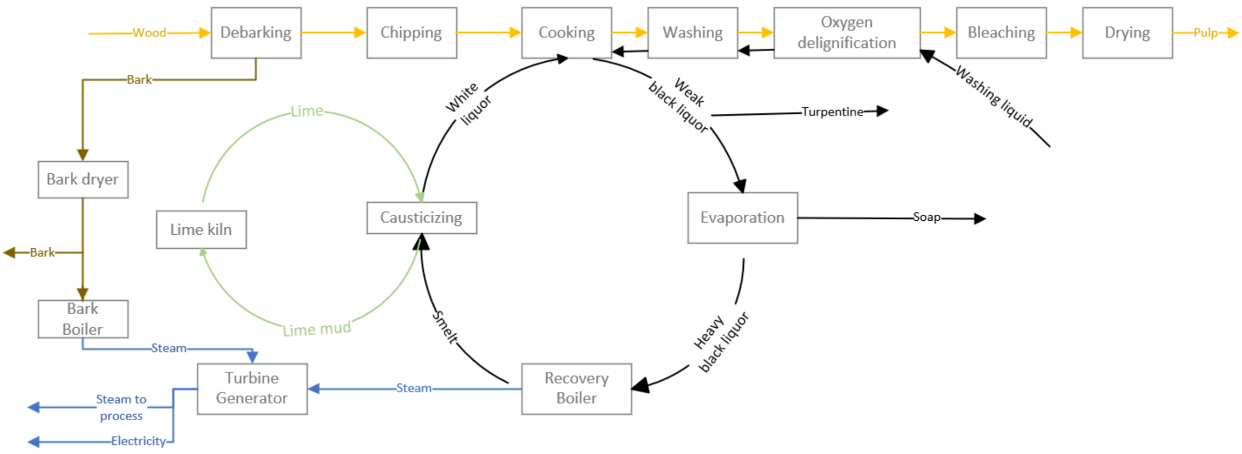


Figure 2.1: Production process at Södra Cell Värö.

2.1.1 The Fiber Line

The fiber line at Södra Cell Värö consists of a series of steps, each of which plays an important role in converting raw wood into pulp. The line extends from the wood yard to the dryer, the detailed process for each step is described below.

2.1.1.1 Wood Yard - Debarking and Chipping

The role of the wood yard is to serve as the starting point of the production process, where raw materials are received, prepared, and stored. Proper preparation and management at this time is crucial to maintaining stable operations throughout the facility [12]. The feedstock comprises softwood logs and residues from the Värö sawmill. The logs are delivered by truck or rail and stored in stacks to ensure continuous production.

The logs are brought into the processing line, where they are first washed to remove impurities such as sand, stones, and dirt. During colder seasons, de-icing may be required to ensure smooth processing. This is done with water heated by lukewarm water from the secondary heating system. Once washed, the logs are debarked in a drum and then chipped into smaller pieces for further processing. The removed bark is dried in a bark dryer using hot water and low-pressure steam. Some of the dried bark is used as fuel in the bark boiler, while the excess is sold [11].

Efficient removal of bark is important because bark in the wood chips reduces the quality of the pulp. Bark contains substances that negatively affect both the cooking and bleaching processes, leading to higher chemical consumption and potential operational problems. After debarking, the logs are chipped into smaller pieces. The size of the wood chips is crucial for how well the chemicals can penetrate the wood. The goal is to produce uniform chips that minimize fiber damage, in order to create strong and consistent pulp [12].

2.1.1.2 Digestion - Cooking, Washing and Bleaching

Before cooking, the chips are impregnated with the cooking liquor. At Södra Cell Värö, the Valmet G2 cooking concept with impregnation and continuous digester is used. The impregnation vessel combines the function of a conventional steaming vessel and impregnation vessel. A mixture of black liquor from the digester and white liquor is added at the top of the impregnation vessel. The liquor mixture has a temperature above 100°C and flashes when entering the vessel, generating steam. This steam heats the chips and displaces air, ensuring even chemical penetration [13].

After impregnation, the treated chips are continuously fed into the digester, where they are cooked under high temperature and pressure. Steam is injected at the top of the digester to heat the mixture and maintain pressure. During cooking, lignin in the wood is broken down and becomes water-soluble. Approximately half of the wood mass becomes pulp, while the rest dissolves and is found in the black liquor [11].

After cooking, the pulp is washed in several stages to remove residual cooking chemicals and dissolved organic substances. The washing is conducted in a countercurrent system, where the cleanest wash water is used in the final washing stages, while the dirtiest water is reused at the beginning of the process. This method reduces fresh water consumption and results in a more concentrated black liquor. A higher concentration is beneficial for the energy system, as it reduces the energy required for evaporation [14].

Subsequent to digesting, the pulp is bleached to remove the remaining lignin and other colored impurities. This begins with oxygen delignification, a process in which oxygen are used under alkaline conditions. After this, the pulp enters the bleaching stages which further brighten the pulp and remove residual lignin [15]. At Södra Cell Värö, the primary bleaching methods used is Elemental Chlorine Free (ECF) bleaching, using chlorine dioxide and hydrogen peroxide. The mill can also produce Totally Chlorine Free (TCF) pulp, where only hydrogen peroxide is used during the bleaching process [5].

2.1.1.3 Drying Section

To facilitate transport, the finished pulp is dried, either in the drying machine or in the flash dryer. First, the pulp is mechanically de-watered using wires and presses to enable a more energy-efficient drying. After this, the pulp is further dried in the air dryer unit, heated by low or medium pressure steam. The exhaust air from the dryer is led to a heat recovery system, where energy is used to heat the supply air to the dryer [16].

In the flash dryer, the pulp is dried in a cyclone, where the fibers are suspended in a stream of hot air heated with low-pressure steam. The dried pulp leaving one of the dryer units contains only 10% water [16].

2.1.2 Recovery Cycle

The recovery cycle plays an important role in both the economy, energy system and the sustainability of pulp production. Chemicals are recovered from the spent cooking liquor and reused in the fiber line, reducing the need to only the make-up chemicals required for process losses. Additionally, the organic portion of the liquor is recovered through combustion, where the energy is used to generate steam and electricity. This allows the pulp mill to become self-sufficient in both steam and electricity and some of the excess energy can be sold [11].

2.1.2.1 Evaporation and Power Section

The majority of the organic compounds removed from the wood during the pulping process are dissolved in the black liquor, along with most of the inorganic substances added during the process. However, a significant portion of the wood extractives does not end up in the solid content of the black liquor. The volatile ones, such as low molecular terpenes, are captured from digester relief condensates and recovered as turpentine. Resin and fatty acids remain dispersed in the diluted black liquor. As evaporation progresses and the solids concentration increases, these extractives begin to separate and form what is known as soap skimmings. When these skimmings are acidified with sulfuric acid, crude tall oil is produced.

The spent weak black cooking liquor, has a dry matter content of approximately 10-20%. To recover the energy stored in the organic components of the black liquor, it needs to be concentrated. This is achieved through evaporation, which increases the solid content to levels suitable for combustion in the recovery boiler. The evaporation is performed in a multi-effect system using steam as the energy source [17].

The principle of multi-effect evaporation is to reuse vapor from one stage as the heating source for the next, significantly reducing the need for fresh steam compared to single-stage systems. A series of evaporators are connected after each other at Södra Cell Värö (SCV), with vapor and liquor flowing in opposite directions. Live steam heats the first effect, causing water to evaporate. The resulting vapor then heats the second effect and the process continues. Finally, the vapor from the last effect is condensed in a surface condenser [11].

The resulting strong black liquor is combusted in the recovery boiler, which serves both as an energy source and a chemical reactor. It generates high-pressure steam while simultaneously contributing to regeneration of pulping chemicals. As the material burns, it forms a char bed at the bottom of the furnace. In this bed, chemical reactions take place where carbon reduces sulfate to sulfide, releasing carbon monoxide and carbon dioxide. The inorganic compounds remain and form a molten smelt composed mainly of sodium carbonate and sodium sulfide, which can be reused in the pulping process after further treatment in the causticization section [17].

2.1.2.2 Causticization Section

The smelt from the recovery boiler mainly consists of sodium carbonate and sodium sulfide which are dissolved in weak liquor to form green liquor. The green liquor is purified by filtration and mixed with calcium oxide (quicklime) in the causticization stage. The quicklime reacts with water to form calcium hydroxide, which reacts with sodium carbonate in the green liquor to produce sodium hydroxide and precipitated calcium carbonate. This reaction results in the so-called white liquor, which is reused in the cooking process [11].

The calcium carbonate (lime) precipitated in the causticization step is collected, washed and sent to the lime kiln. There, the calcium carbonate is burned to regenerate quicklime, which is then quenched with water and converted back to calcium hydroxide for reuse in the caustization process. Since the calcination reaction is endothermic, a large amount of energy is required in the form of fuel. The lime kiln is mainly fueled by wood powder from dried shavings but oil and methanol can also be used [11].

2.2 Energy System

The energy system at Södra Cell Värö can be divided into two main components: the steam system and the secondary heating system, which includes subsystems such as the district heating supply to the town of Varberg and the hot water delivered to the adjacent sawmill and pellet plant. The following subsections describe each of these components in detail.

2.2.1 Steam Production and Electricity Generation

The largest steam producer at the facility is the recovery boiler, which serves as a main component in the chemical recovery process. This boiler generates high-pressure steam at 85 barg, which is supplied to both the back-pressure turbine and the condensing turbine. In addition to the recovery boiler, the facility is equipped with a bark boiler, which is typically not in operation. However, when it is used, it generates steam at 58 barg for the back-pressure turbine [11].

The two turbines, while performing similar functions, operate with slight differences. The condensing turbine is equipped with a condenser stage, where steam expansion continues to maximize electricity generation. Steam is extracted from both turbines at various pressures and distributed throughout the facility for different processes. High-pressure steam (23 barg) is primarily used for soot blowing in the boilers, while medium-pressure steam (11 barg and 8 barg) and low-pressure steam (LP-steam, 3 barg) are mainly consumed by large processes such as digestion, evaporation and drying.

Low-pressure steam is utilized to supplement heating in areas where secondary heat is insufficient, such as district heating and the bark dryer. Excess steam is primarily used for electricity generation. When capacity is insufficient, the steam is either vented to the atmosphere or condensed in a dump condenser, where it is converted into hot water for other applications [11].

2.2.2 Secondary Heating System

To improve efficiency in both energy and water use, pulp mills use heat recovery systems. A key component is the secondary heating system (SHS), a process-wide circular system consisting of tanks and heat exchangers, which manages excess heat and ensures that both cooling and heating requirements in the factory can be met. The system plays four essential roles:

- Delivering warm and hot water for process operations, such as pulp dilution.
- Heating cold process streams to reduce primary energy usage.
- Cooling and capturing excess heat from hot streams, converting it into usable heated water.
- Stabilizing the system by storing heat and water when supply and demand fluctuate [18].

The secondary heating system at Södra Cell Värö consists of chemically purified water at different temperatures, ranging from 20 °C to 90 °C, with specific temperature levels listed in Table 2.1 below. Fresh, chemically purified water is introduced into the system at 20 °C. The excess heat gradually increases the water temperature as it circulates through the system, producing hot water at 90 °C that can be used as a substitute for steam in processes. Steam that can instead be used to generate electricity in the two turbines [19].

Table 2.1: Water temperature levels in the secondary heating system at SCV.

Type	**Temperature (°C)**
Fresh water in	20
Cold water (CW)	22
Lukewarm water (LWW)	50
Warm water (WW)	70
Hot water (HW)	90

The secondary heating system acts as an intermediary network that transports heat from warm process streams to areas requiring heat, both within the mill and for external consumers. The water is stored in separate tanks at various temperature levels, allowing the system to manage and balance the heat needs. Heat is distributed to internal consumers within the pulp mill and to the adjacent sawmill via an internal heat exchanger network. Some pulp mill consumers use the water directly in the process, removing it permanently from the circular system. To compensate for these losses, the system is continuously refilled with chemically purified fresh water from the water treatment plant [19].

Heat that cannot be utilized is transferred to two cooling towers, one dedicated to steam condensation at the turbine outlet and the other to the secondary heating system. This reduces the need for additional cooling water intake from the river Viskan [19]. A schematic representation of the secondary heating system is presented in Figure 2.2

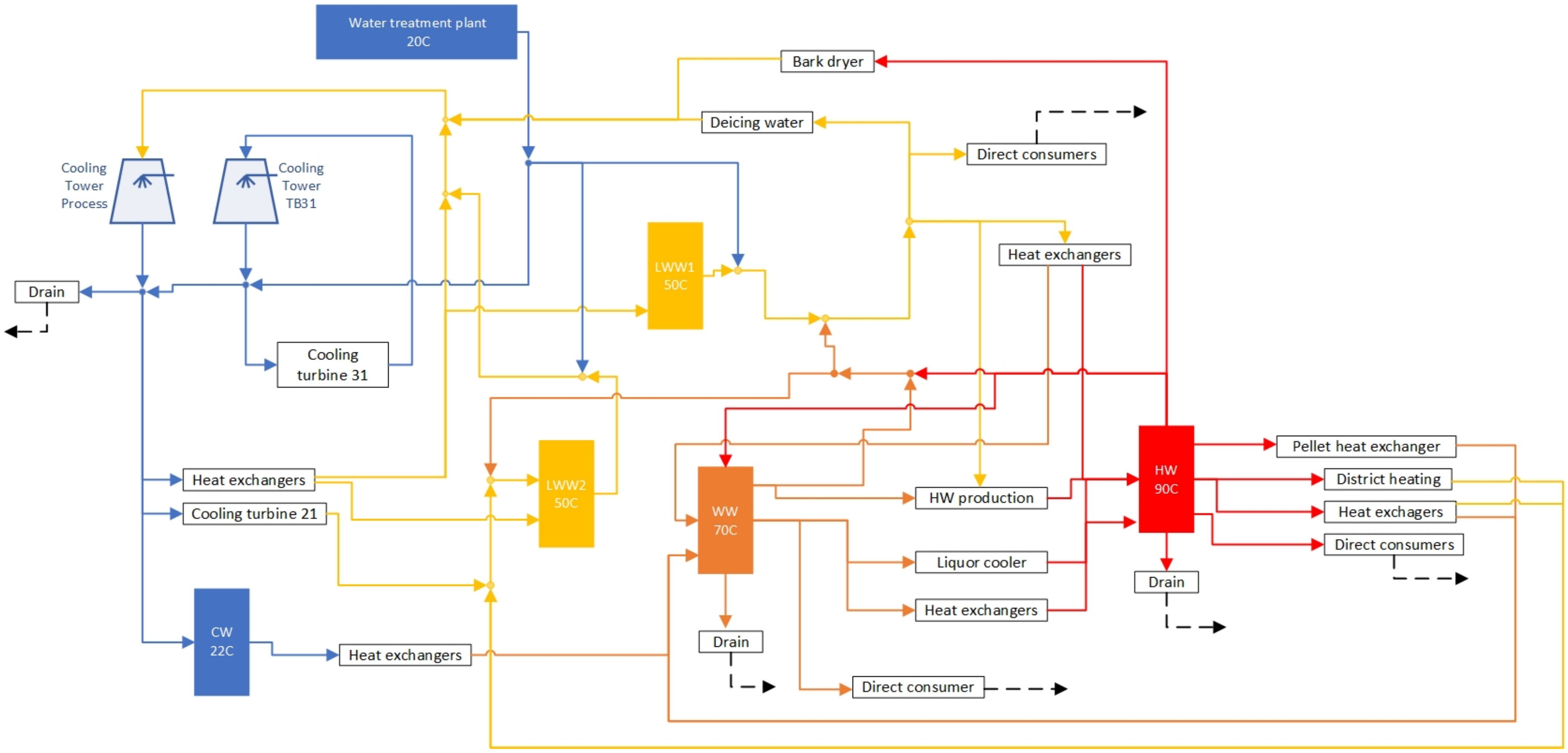


Figure 2.2: Simplified schematic of the secondary heating system; unrelated heat exchangers are grouped under 'Heat Exchangers'.

2.2.3 Sawmill Heating System

The heat supply to the sawmill at the site is integrated into the internal network of heat exchangers. This hot water circuit includes heating of the lumber dryer, the sawdust dryer and the heat delivery to SBS. Excess heat and steam from the pulp mill are transferred to a closed system with circulating water.

The circuit consists of four different heat exchangers: one supplied with heat from hot water in the secondary heating system, two utilizing recovered energy from black liquor evaporation and the remaining demand is covered by low-pressure steam in the steam heat exchanger, see Figure 2.3. The heated water is then used to warm air that is distributed to the drying facilities through a large number of heat exchangers.

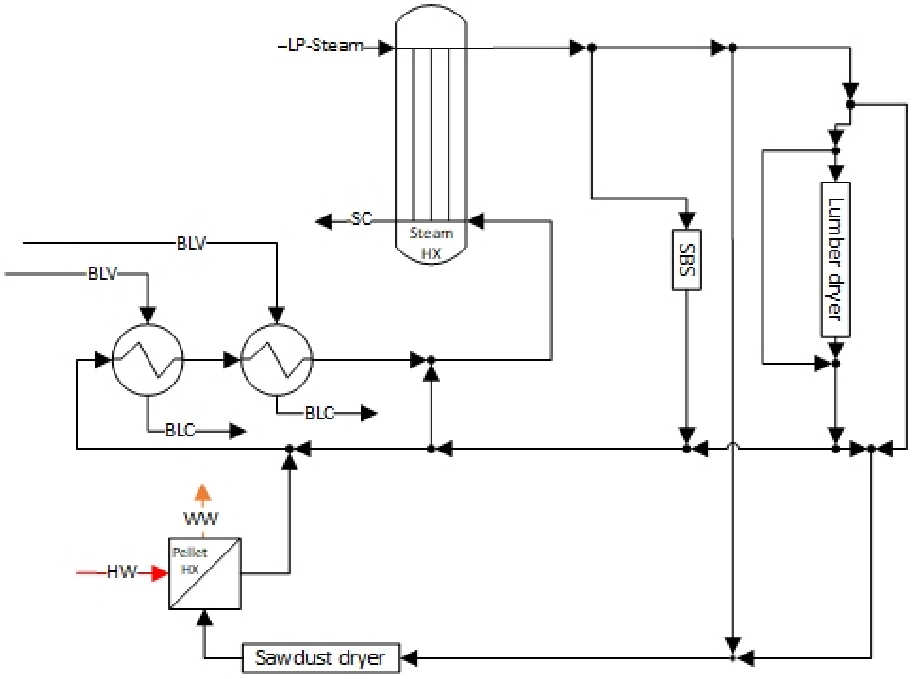


Figure 2.3: Outline of sawmill heating loop.

2.2.4 District Heating - Varberg

In addition to the internal heat network, excess heat from the secondary heating system is transferred to the external district heating loop, which supplies heat to residential buildings in the nearby city of Varberg. The demand for district heating (DH) varies with the ambient temperature, following a seasonal pattern with an average load around 10 MW in summer and 26 MW in winter. The initial heat exchangers in the system are arranged in a parallel configuration, allowing heat to be transferred to the DH water either from hot alkaline bleach effluent and/or from hot water (HW). After this stage, a hot stream of weak black liquor is used to further heat the DH flow. If additional heat energy is still required, low-pressure steam is used in a final steam heat exchanger. A schematic representation of the the system is presented in Figure 2.4.

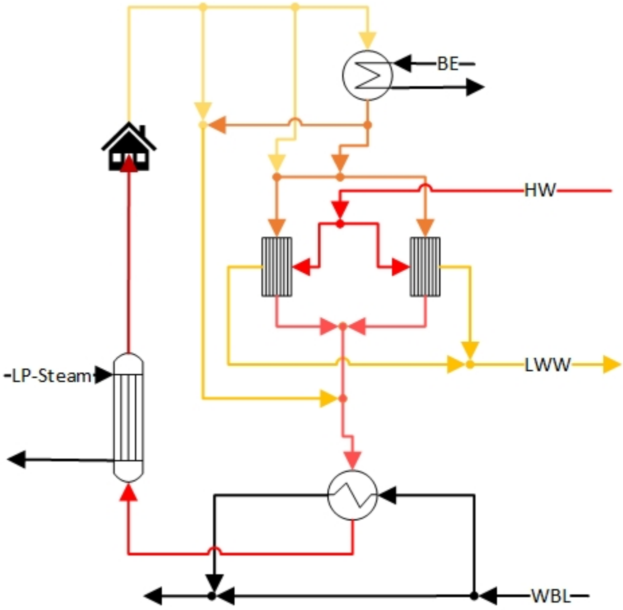


Figure 2.4: Heat exchangers within Varberg district heating loop.

The amount of energy that can be extracted from the SHS to district heating is controlled and limited by the supply and return temperatures. Previous generations of district heating systems have been characterized by high operating temperatures. At Södra Cell Värö, the outlet temperature of the district heating water is around 95 °C, while the return temperature is approximately 45 °C. However, with the emergence of fourth-generation district heating and the adoption of new technologies, systems are now being developed to operate at lower temperatures. These systems typically use supply temperatures between 10-75 °C and return temperatures in the range of 5-35 °C [20]. This enables the utilization of lower-grade heat sources that were previously unsuitable for integration into district heating network.

Heating is not the only thermal need in buildings, demand for cooling is becoming increasingly common in both residential and commercial settings. District cooling offers an energy efficient alternative to conventional, localized cooling systems. Several technologies are available for producing district cooling, some of which use district heating as an energy source [21]. Varberg Energi is planning to implement a district cooling system using surplus heat from Södra Cell Värö, with operations expected to begin in 2027 [22].

2.3 Cooling Towers

A cooling tower removes excess heat from the air by cooling a liquid stream, usually water. At Södra, there are two cooling towers: one connected to the secondary heating system and one dedicated to cooling the condensing turbine outlet flow. Excess low-value heat is removed in the cooling towers through a combination of evaporation and convection. The water is evenly distributed over the cooling surfaces, flows into the basin and is cooled while air fans regulate the temperature [23].

Some of the water exits the secondary heating system and is used as process water, for example in the bleaching plant, while evaporation in the cooling towers also contributes to water consumption. The water level in the cooling tower basins controls the supply of CW from the water treatment system to replace lost water. The low-value heat absorbed from the condensing turbine is not utilized but is cooled away in the cooling tower.

Cooling tower performance is affected by ambient temperature, making them sensitive to seasonal variations, which in turn affect the entire heating system [24]. Under current operating conditions, cooling tower capacity is insufficient during the summer months and noise reduction measures have further reduced their efficiency. As a result, water that needs to be cooled is instead discharged into the wastewater system and must be replaced with fresh water, putting further pressure on the water treatment process [19].

2.4 Harnessing the Benefits of Energy Efficiency Measures

Energy saving measures often lead to a reduced need for fuel in a boiler, but at Södra Värö the situation is different. The recovery boiler is a necessary part of the mill´s recycling cycle and plays a crucial role in chemical recycling. At the same time, the bark boiler is not used during normal operation, which means that energy savings mainly have an effect in other areas.

However, there is great potential to extract valuable by-products from black liquor, which results in reduced steam production. Today, there is a focus on resource efficiency and increasing the production of bio-products. To achieve this, it is important to reduce energy consumption. Tall oil production, methanol purification and potential lignin extraction are all examples of bio-product extraction that reduce steam production in the recovery boiler.

Energy savings in the form of reduced steam consumption also play an important role when considering new investments. For example, projects such as carbon capture for reuse or permanent storage (CCUS) may require significant amounts of steam, while a methanol plant may consume a small amount. In the short term, however, the primary benefit of steam savings is that it enables increased electricity production in the condensing turbine, which both strengthens the internal supply and increases the amount that can be sold externally [11]. A visualization of the mill's steam consumers can be seen in Figure 2.5.

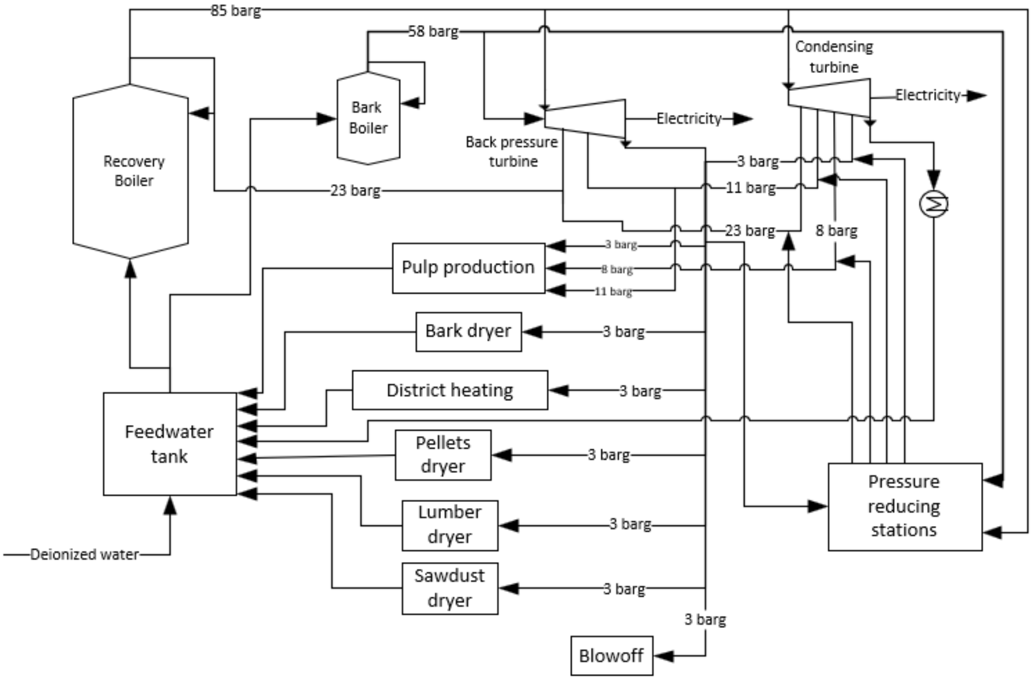


Figure 2.5: Steam network at Södra Värö.

3

Theory

To provide a deeper understanding of the subject and establish a foundation for the analysis, this chapter presents relevant theoretical concepts. The focus is on highlighting the central terms and principles important for the study, as well as providing a framework for interpreting the results. The areas covered are seasonal variations and their impact on the energy system, process integration with particular emphasis on pinch analysis and the role of non-energy benefits as an important outcome of energy efficiency measures.

3.1 Seasonal Variations

Seasonal variations have a major impact on the potential for energy savings in pulp mills. Energy use is a central part of operations, with heating, drying, steam production and electricity generation requiring significant resources. Seasonal temperature changes affect the total energy demand, especially through increased heating demand during winter. This requires more energy to heat both production processes and factory buildings, while the demand for district heating increases, reducing the heat surplus when the potential for utilizing excess heat is greatest. These variations play a crucial role in the feasibility and economic sustainability of optimizing energy management [25]. At Värö Pulp Mill, there is also a cooling demand during the summer months that is difficult to meet with the current system, further complicating the balance of energy use throughout the year. Cooling towers are used to remove excess low-value heat, but their performance is affected by the surrounding temperature, making them sensitive to seasonal variations [24]. Seasonal variations also require adjustments in the operation of the plant to ensure efficient and stable production. These changes impact the heat balance [11].

3.2 Process Integration

Industrial plants often consist of a large number of process streams with different heating and cooling requirements that are interconnected in a complex system. Structured methods are required to analyze and optimize such a system in a systematic way [26]. Process integration is a set of methods that can be used to analyze and optimize the interaction between different subprocesses. One of the most important aspects of process integration is heat recovery. To identify heat-saving potential, pinch analysis is often used [1]. Pinch analysis is a thermodynamically based technique where minimum targets for external heating and cooling are calculated [27].

3.2.1 Pinch Analysis

In order to analyze and optimize complex process systems, systematically structured methods are required. Pinch analysis is a systematic method consisting of a group of techniques that analyzes heat flow and based on identified inefficiencies, identifies possible improvements of a system. The method derives from a flowchart of the process as well as heat-and material balances to establish minimum energy targets [28].

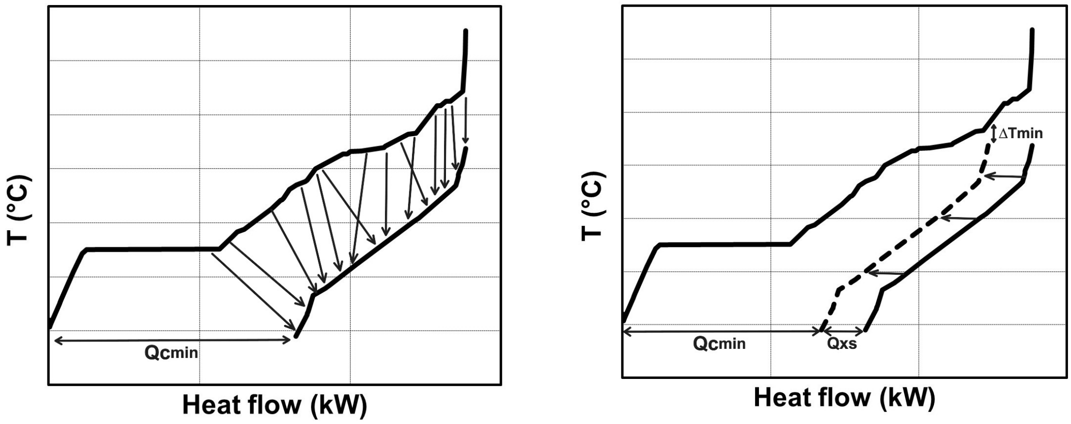
3.2.1.1 Data Extraction

Extraction of data is a central part of pinch analysis as it is important to obtain reliable temperature- and heat load data for the different streams involved in the process. It is a sensitive phase where different methods can result in different end results. A number of steps can be followed to ensure reliable data collection and create a good foundation for further pinch analysis. The process begins with constructing a process flow scheme, with information about temperature, flow and heat capacity. Based on this data, heat- and mass balances can be performed. Thereafter, the hot and cold streams are identified, extracted and compiled. A common assumption is to use constant heat capacity for the streams. However, in reality this parameter varies with temperature and significant variations are handled by segmenting or separating into multiple streams. This is especially true when phase changes occur in the stream [29].

3.2.1.2 Composite Curves

To support the analysis, tools such as Composite Curves (CC) are used to visualize energy flows within the system. Composite curves represent a process by combining the temperature-heat load values of all streams. For the cold streams, their temperature-heat load values are calculated and distributed over a consistent set of temperature increments, forming a composite curve. The same procedure is applied to the hot streams, creating another composite curve. The overlap between these two curves indicates the potential for heat recovery (Q_{HX}) within the process [28]. This is illustrated with arrows in Figure 3.1a.

To perform energy targeting using composite curves, it is first necessary to define a minimum value for heat exchange driving force, ΔT_{min}. This can be either a global value or individual values assigned to different streams. By allocating a higher ΔT_{min} to streams that are difficult to exchange, such as gases, their poorer heat transfer characteristics can be accounted for. This results in a larger temperature difference in matches involving these streams [29]. The pinch point is the location within the process where the driving force for heat tranfer reaches its minimum allowable value. More specifically, it is defined as the point where the hot and cold composite curves approach each other at the minimum temperature difference, ΔT_{min}. This point represents the most constrained point for heat transfer in the system and limits the amount of recoverable heat [30].



(a) Composite Curves showing heat recovery.

(b) Shifting the cold curve until the pinch point ΔT_{min} is reached, thereby maximizing the excess heat, Q_{XS}.

Figure 3.1: Composite curve analysis.

As illustrated in Figure 3.1b, a leftward shift of the cold composite curve leads to an increase in the amount of excess heat (Q_{XS}) available at high temperature, which can allow for better utilization of this energy. At the same time, this shift leads to a decrease in ΔT_{min}, which results in an increased requirement for heat exchanger surface area to enable the same heat transfer. It is important to note that the cooling demand from the process streams remains constant, despite the changes in temperature profile and heat exchange area [18].

3.2.2 Software ProPi

Use of software is almost essential when performing pinch analysis, as manual calculations are time consuming and involve a high risk of error, especially when analyzing larger systems. There are several different types of tools for this, one of them is ProPi. It is an add-in program for Excel developed at Chalmers Industriteknik. ProPi makes it possible to visualize composite curves, identify hot and cold utility demands as well as the system's pinch point.

3.3 Non-Energy Benefits

Non-energy benefits related to energy efficiency projects are the benefits that arise as a result of implementing energy saving measures. These benefits can be both economically feasible or not, but often have positive impacts on individuals, communities or environments. They are often of significance and in some cases may exceed the value of the energy savings, even if they do not directly reduce energy costs. Taking these benefits into account is important and can be a decisive factor in motivating investments in equipment that increases energy efficiency [31]. Two aspects that Södra Cell Värö focuses on and that will be examined in this work are reduced noise and freshwater intake.

3.3.1 Freshwater Intake

In recent years, summers with water shortages and droughts have become increasingly common, which has had major consequences for society. Industry accounts for 70% of Sweden's water consumption, with the pulp and paper industry being the largest consumer. In order to manage water shortages, it is therefore important to work towards reduced freshwater use [32]. This area has also received increased focus in the EU, as shown in the update of the EU Industrial Emissions Directive (IED) from 2024. The new guidelines emphasize the importance of resource efficiency and strive for more sustainable consumption [33].

Södra Cell Värö has experienced challenges with an increased raw water demand for the secondary heat system during the summer months, see Table 3.1. This issue arises as the cooling towers lack sufficient capacity to effectively cool the process heat, leading to water being discharged into the effluent system instead of remaining within the circular system [11]. As a result, additional fresh water intake is required, which is not only undesirable in terms of the goal to reduce water consumption but also places a strain on the water treatment process. This, in turn, leads to lower-quality water entering the system, increasing the risk of fouling in heat exchangers and other process equipment [34]. Moreover, during the summer months, the temperature of the incoming cooling water increases, further limiting the system's ability to effectively remove excess process heat.

Table 3.1: Average water withdrawal from the river Viskan during different periods [35].

Period	$\dot{V}$ **(m^3/s)**
Summer 2023	1.04
Winter 2023	0.82
Summer 2024	1.10
Winter 2024	0.84

The availability of water in Viskan is generally good most of the year, with natural flow rates typically ranging from 15 m^3/s and up to 100-200 m^3/s during periods of heavy rainfalls. However, during dry periods like the summer months, the flow can drop significantly, often reaching levels as low as 2.5-5 m^3/s. The current water right permit allows a maximum withdrawal of 2 m^3/s. Although this is not a limiting factor under normal conditions, it could become a limitation in the event of a more prolonged or severe drought [36].

3.3.2 Noise Pollution Reduction

Industries are subject to noise regulations aimed at minimizing their impact on the surrounding environment [37]. The extent to which noise is perceived as disturbing depends on several factors, including the type and quality of the sound, such as its intensity and frequency content, as well as the time of day, the activities being performed and whether the noise is accompanied by vibrations, for example. Noise is the environmental factor affecting the greatest number of people in Sweden [38]. The limits that apply to Södra Cell Värö state that noise most not exceed an equivalent outdoor sound level at nearby homes of 55 dB(A) during the day, 50 dB(A) during evening hours and 45 dB(A) at night [39]. Measurements have identified the cooling towers as a significant source of noise, which has led to implementation of noise reduction measures to mitigate the impact on the surroundings [40].

4

Methodology

This chapter presents the methodology applied in this study, including the selection criteria used to determine which data were included for analysis. Particular focus is placed on the selection process, such as the time period considered, the inclusion and exclusion criteria as well as how seasonal variations were taken into account. In addition, the approach for handling the secondary heating system in pinch analysis is presented.

4.1 Mapping of Energy Flows in the Secondary Heating System

The work began by identifying the system boundaries for the study. The focus was on the secondary heating system within the facility, while the wider energy system was excluded. Including the entire energy system could have provided a more comprehensive and detailed understanding of the heat flows and energy interactions across the site, but given the time constraints and scope of the project, this was not considered feasible.

A central part of the work was to map and visualize the secondary heating system. This was achieved through a thorough review of process flow diagrams (PFDs) and piping and instrumentation diagrams (P&IDs), complemented by site visits and direct observations within the facility. The mapping process also included discussions with representatives from mill process departments involved in or affected by the secondary heating system, as well as discussions with individuals who had participated in the original design of the system to gain a deeper understanding of its intended function and overall configuration. Based on the insights gathered, a flowchart and supporting table were developed to describe the secondary heating system, listing all relevant heat exchangers, consumers, and available sensors for flow and temperature. While the detailed flowchart is excluded from this report, a simplified schematic showing the key producers and consumers of warm and hot water is presented in Section 2.2.2.

4.2 Stream Data Extraction

The process of data collection and filtering constituted the most extensive part of this work and was crucial to ensuring the reliability and quality of the results.

The following subsections describe the procedures used for data extraction, the approach to seasonal categorization and the filtration methods applied throughout the analysis.

4.2.1 Evaluation of Seasonal Variations

In the initial step of the data extraction process, the seasonal variations and the corresponding time periods for summer and winter operations were assessed. As previously discussed in Sections 2.3 and 3.1, the cooling demand of the secondary heating system is influenced not only by operational parameters but also by external factors, including heat demand and outdoor temperature. These factors vary significantly between seasons, requiring careful categorization to properly understand system performance.

During the summer months, the cooling demand cannot be fully met by the process cooling tower due to limited capacity. As a result, excess heat is not sufficiently removed from the system, leading to discharge of secondary heating system water into the wastewater system. Accordingly, the summer period was defined as the time periods which the cooling tower operates at maximum capacity, while the winter period was defined as the intervals between these phases. Data for two years, 2023 and 2024, were collected to analyze seasonal variations. However, the primary focus was placed on 2023 because the variations were more apparent. An analysis of these variations is provided in Section 5.1 and the seasonal distinctions are illustrated in Figure 5.1.

4.2.2 Data Collection and Filtration

It was of interest to base the analysis on a representative operating case characterized by stable and high production levels. Therefore, all days with production rate below 2000 Air Dry ton (ADt), corresponding to 75% of the maximum capacity, were excluded for the dataset. Data were extracted as daily averages for the period between 2023-01-01 00:00 and 2025-03-29 00:00. The number of days that fulfilled the production criterion and were therefore included in the analysis, as well as the proportion of the total production represented by these days, are presented in Section 5.2.1. After filtering for production, the data were categorized into seasons according to the definitions provided in Section 5.1. For each season, average values for temperature, flow rate and thermal load were compiled in a summary table along with their respective standard deviations. This filtration resulted in a dataset consisting of selected time intervals distributed across the full period of study. Further details on the filtration process are provided in Section 5.2.1.

During the studied period, modifications and equipment upgrades were carried out at the production facility, including the secondary heating system. Due to this, in 2024 several new heat exchangers were in operation that had not yet been installed during the corresponding period in 2023, leading to missing measurement data for those earlier intervals. In such cases, data from the same season in 2024 were used as a proxy for 2023.

4.2.3 Excluded Streams

Some heat exchangers and hot water consumers lacked the necessary flow and/ or temperature measurements required to estimate thermal loads. Due to an extended maintenance during the study period, it was not possible to conduct temporary measurements. Instead, mass and energy balances were performed wherever feasible. Thermal energy transfer was estimated using the standard relation:

$$Q = m\, c_p\, \Delta T \tag{4.1}$$

where Q is the heat transfer (kW), m is the mass flow rate (kg/s), c_p is the specific heat capacity (kJ/kg · °C) and ΔT is the temperature difference (°C). In cases where balances could not be performed, assumptions were made in collaboration with operations and process engineers, often based on available design data. A few components were excluded from the analysis, either because they were considered insignificant in size, no reasonable assumptions could be made due to a lack of supporting data or because they are only active during start-up periods or other major operational disturbances.

4.3 Energy Use Optimization

When performing pinch analysis, it is necessary to take into account the minimum permissible temperature difference, ΔT_{min}, between hot and cold streams. To enable realistic energy targeting, all stream temperatures in the system are adjusted by $\Delta T_{min}/2$. This ensures that there is a sufficient temperature driving force for heat exchange, which is crucial for the process to be technically feasible. The adjustment is performed according to the principle that all hot streams are shifted downwards by $\Delta T_{min}/2$, while all cold streams are shifted upwards by $\Delta T_{min}/2$. Since the ΔT_{min} values varies between different streams depending of their physical characteristics, stream-specific values were applied. These values were obtained for a previous study [7] and are presented in Table 4.1.

Table 4.1: Temperature difference for heat exchangers for various types of streams.

Stream classification	$\boldsymbol{\Delta T_{min}/2}$
Live Steam	0.5
Contaminated Steam	2
Clean Water	2.5
Contaminated water	3.5
Air	8
Moist Air	7
Flue gases	7

4.3.1 Pinch Analysis and Handling of the Secondary Heating System

The pinch analysis was performed using the ProPi tool. A composite curve figure was constructed, where both the hot and cold composite curves were plotted to enable visual identification of potential heat recovery. The hot streams were defined based on available process heat and entered with parameters such as temperature load, heat load and $\Delta T_{min}/2$. The cold streams, which included both internal and external cooling demands as well as direct consumers, were specified with corresponding parameters. Direct consumers refer to water from the secondary heating system that is fed directly into process streams without any heat recovery. For these streams, the outlet temperature was specified as the systems lowest temperature level (22°C) and the inlet to the temperature at which the water was delivered. ΔT_{min} was set to 0°C, since no temperature difference is required in these cases.

As ProPi lacks built-in support for modeling secondary heating systems, this was integrated manually. A theoretical secondary heating system was implemented between the hot and cold composite curves in order to maximize the recovery of hot and warm water, while maintaining ΔT_{min}. The results of this integration are illustrated and discussed in Section 6.1.

The cold composite curve was then manually shifted to the left to explore the potential increase in high-temperature excess heat that could be recovered and decrease low-value heat being cooled away in the cooling towers. This adjustment was carried out by gradually shifting the curve until the minimum driving force, ΔT_{min}, between the process streams and the secondary heating system was achieved.

4.3.2 Evaluation and Potentials of Excess Hot Water

Shifting from high-grade to low-grade heat is only meaningful if the recovered heat can be utilized elsewhere in the system. Therefore, a key component of the analysis was to develop understanding of, and identify, potential locations within the process where this heat could be used to replace steam. This is discussed further in Chapter 6. The approach was to identify existing steam consumers where all or part of the required heat could in principle be supplied by the secondary heating system instead. The analysis also included an assessment of how the saved steam could be used instead.

5

Data Screening and Evaluation

An analysis of the data set underlying the study is provided below. The defined time periods for summer and winter operations are first established. This is followed by a review of the data filtering process to confirm relevance of the data. The section also includes an assessment of data variability. Lastly, the potential impact of excluding certain streams is discussed.

5.1 Time Period Definition for Seasonal Variations

A clear distinction between summer and winter periods was established to support the analysis of seasonal variations. This classification was based on cooling tower fan operation, as seasonal effects are strongly connected to limitations in heat rejection capacity. The seasons were defined by the periods during which the three cooling tower fans operated at maximum capacity (100%), highlighting the limited cooling capacity and challenges in rejecting excess heat during summer period. This is illustrated in Figure 5.1.

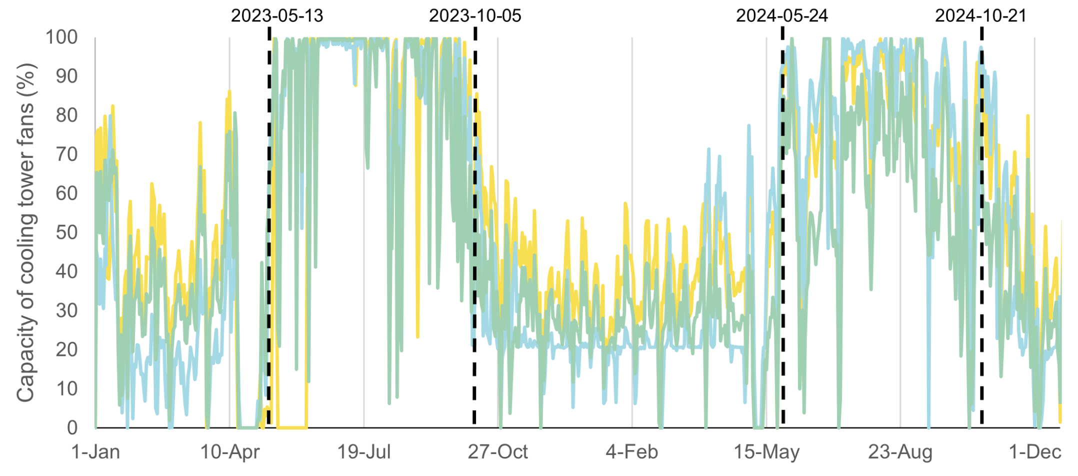


Figure 5.1: Variations in capacity of the three cooling tower fans.

The specific time periods for the respective seasons in 2023 and 2024 are listed in Table 5.1.

Table 5.1: Division of seasonal time periods.

Period	**Start Date**	**End Date**
Summer 2023	2023-05-13	2023-10-05
Winter 2023	2023-10-06	2024-05-23
Summer 2024	2024-05-24	2024-10-21
Winter 2024	2024-10-22	2025-03-26

Primary focus was placed on the year 2023, as it exhibited more pronounced and clearly distinguishable seasonal fluctuations. By concentrating on a year with greater variation, the analysis aims to better capture the system's behavior under challenging conditions.

5.2 Data Analysis

Data limitations necessitated the exclusion of several heat exchangers due to insufficient or missing measurement data. These excluded units include adsorption chillers and condensers in the chlorine dioxide production process, the generator cooler for the back pressure turbine and the system for producing mechanically purified warm water. Even among the heat exchangers included in the analysis, variations in data availability and measurement accuracy may affect the overall reliability and representativeness of the result.

5.2.1 Data Filtration

To ensure that the analysis is based on normal operating conditions, the data set was filtered to exclude periods of unstable or deviating production. After filtration, 32% of the data for the summer period 2023 and 25% for the winter 2023 were excluded. Although some of the data were excluded, the remaining days represent a very large portion of the production. The days included in the analysis accounted for 76% and 87% of the total production volume during the measurement periods, see Table 5.2. This means that the remaining dataset largely reflects the actual values under stable operating conditions.

Table 5.2: Approved measurements – summer and winter 2023.

	Summer 2023	**Winter 2023**
Days included	68%	75%
Corresponding Production	76%	87%

5.2.2 Assessment of Data Variability

The dataset consists primarily of daily mean values derived from measured data. Given that the analysis differentiates between seasons, it is essential not only to compare mean values across these periods, but also account for variability within the periods. To quantify the degree of variation and assess the reliability, standard deviation was employed. The temperature data showed relatively low standard deviations, generally ranging between 1 and 3, indicating a high degree of stability and representativeness within each period. The flow data showed a greater variability, with standard deviations generally between 4 and 8. With more time available, a closer investigation of the heat exchangers showing high standard derivations would have been appropriate to better understand the reasons behind this variability.

6

Energy Targeting

This chapter presents the generated composite curves, which serves as the foundation for the evaluation of potential energy efficiency measures within the system. The major hot water producers and potential consumers are then identified to assess the opportunities for steam reduction. Additionally, the chapter includes an analysis of how changes in the district heating supply to Varberg may affect the functionality and performance of the secondary heating system. Finally, an assessment of the non-energy benefits associated with the proposed measures is given.

6.1 Hot and Cold Composite Curves

Figures 6.1 and 6.2 presents the combined composite curves for the summer and winter cases, respectively. The curves representing the cold (blue) and hot (red) process streams are integrated with the curve representing the secondary heating system water flows (purple). The secondary heating system acts as both heat sink and heat source, but has no minimum temperature difference ΔT_{min}, as the same water circulates within the system. Consequently, it is represented as one single curve.

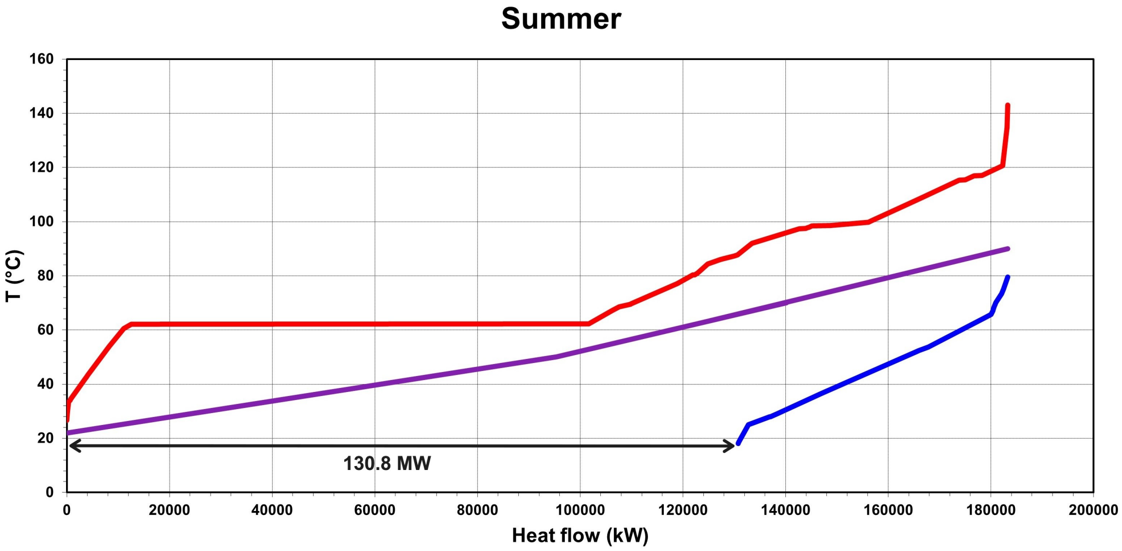


Figure 6.1: Hot and cold composite curves, including secondary heating system, at Södra Cell Värö during summer.

The seasonal variations are clearly observable. During summer, the heat demand for both process streams and external heat sinks is lower compared to winter. The minimum cooling demand, Qc_{min}, during summer amounts to 130.8 MW, while in the winter it is 107.3 MW.

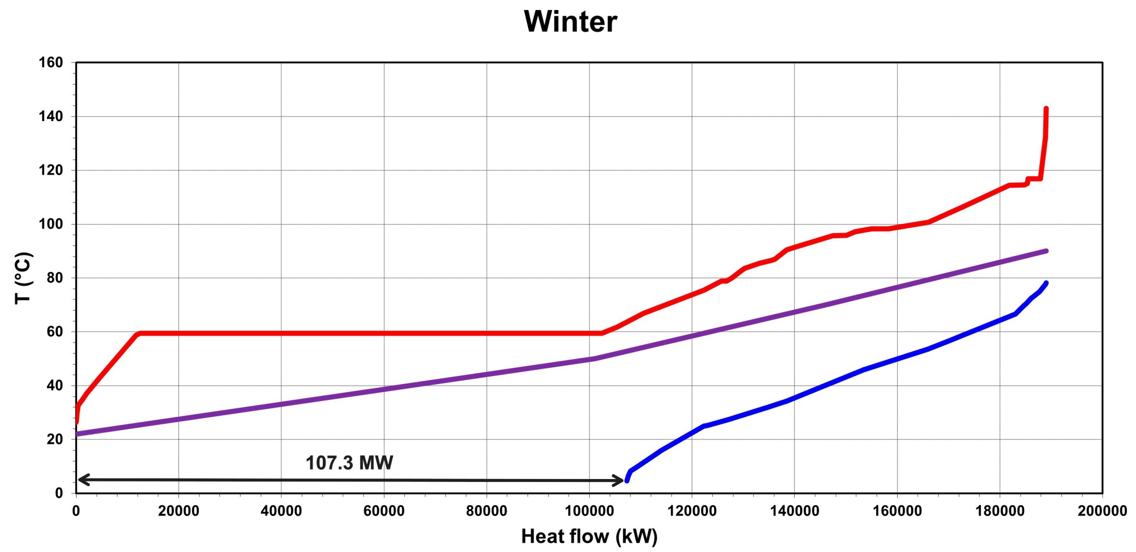


Figure 6.2: Hot and cold composite curves, including secondary heating system, at Södra Cell Värö during winter.

The shifted cold composite curves are visualized by dotted lines in Figures 6.3 and 6.4. By shifting the curves horizontally to the left towards ΔT_{min}, an excess of high-value heat, Q_{xs}, can be achieved. Under current operating conditions, this corresponds to 11.8 MW during summer and 14.4 MW during winter.

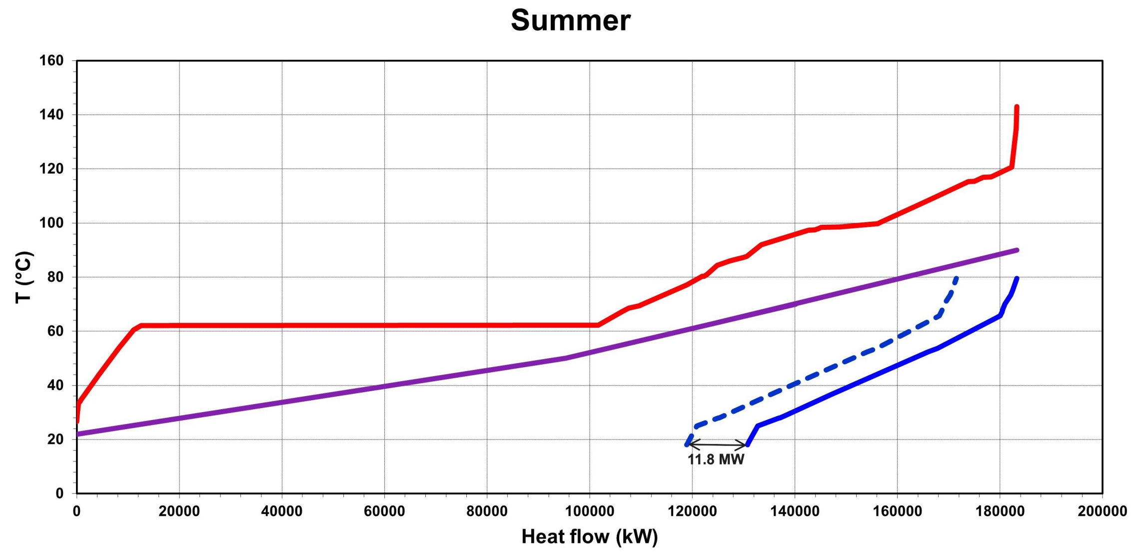


Figure 6.3: Shifted cold composite curve for summer period at Södra Cell Värö.

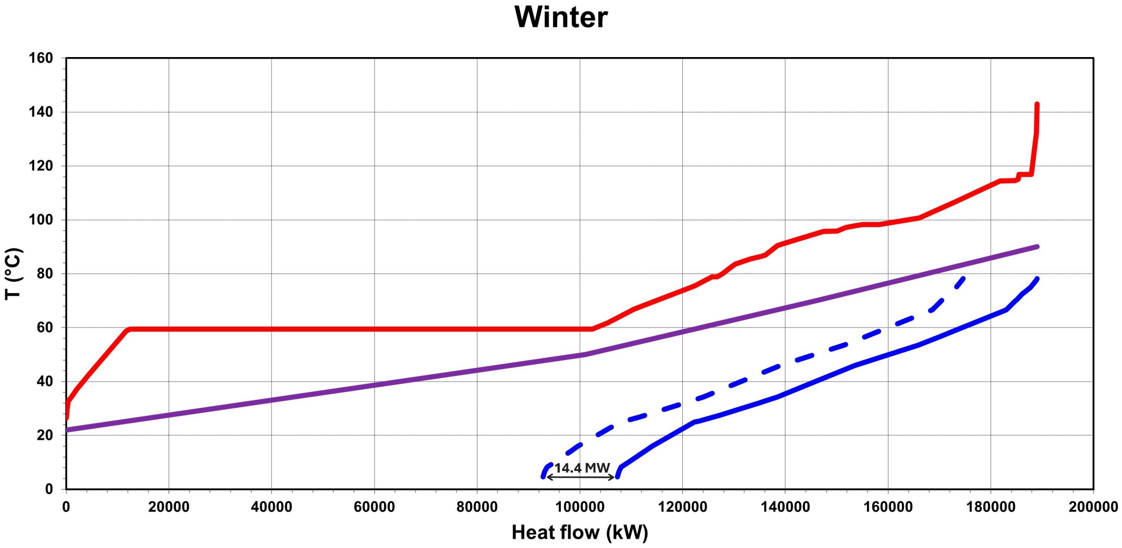


Figure 6.4: Shifted cold composite curve for winter period at Södra Cell Värö.

The amount of excess heat, Q_{xs}, that can be obtained by shifting the composite curves is limited by the high temperature segment of the cold curve. This section corresponds to the heat supply to the sawmill district heating system as well as the bark dryer.

6.2 Hot Water Producers

An important aspect in the design of a secondary heating system is the temperature levels in the water tanks, as these determine the amount of process heat that can be recovered. The system is designed with a maximum temperature level of 90 °C which sets an upper limit on the amount of heat that can be transferred from and to process streams. Several streams have temperatures above 100 °C and require cooling, which means there is potential for high-quality heat recovery. To utilize this potential heat source, the system would need to handle temperatures above 90 °C, which in turn requires pressurization of the secondary circuit to avoid boiling and is not a viable option. An alternative could be to apply direct heat exchange or use other types of heat transfer fluids, though this option is less flexible.

However, it is important to note that the temperature in the hot water tank does not reach the desired 90 °C under current operations. In 2023, the average temperature in the tank was 83.7 °C during summer and 82.7 °C during the winter. This means that the system is already not using its full capacity for heat recovery, which makes it more difficult to utilize waste heat from higher temperatures in the process streams and replace steam.

Table 6.1: Average values based on measured temperature and flow in hot water production for summer and winter periods.

Heat exchanger	**Summer 2023**			**Winter 2023**		
	T (°C)	Δ T	$\dot{V}$ (l/s)	T (°C)	Δ T	$\dot{V}$ (l/s)
Liquor cooler	84.6	-5.4	270.7	83.1	-6.9	221.6
Dumping condenser	93.8	3.8	19.7	86.5	-3.5	21.6
Primary condenser	89.5	-0.5	42.0	88.4	-1.6	50.3
Evaporation HW production	93.0	3.0	37.0	90.0	0.0	70.7
HW tank	83.7	-6.3	371.4	82.7	-7.3	364.2

As shown in Table 6.1, the liquor cooler is responsible for the largest share of hot water production but fails to reach the target temperature of 90 °C. This makes it a key component to consider, as its efficiency directly impacts the systems ability to recover heat.

6.2.1 Liquor Cooler

The liquor from the digester is withdrawn and flashed to remove steam. It is then cooled in several stages before entering the evaporation step. Initially, the liquor is cooled through direct heat exchange with the district heating loop supplying Varberg, followed by additional cooling via the secondary heating system. The liquor temperature entering the secondary heating system heat exchanger remains relatively high, averaging 120.6 °C during summer due to reduced demand from the district heating network. In winter, this temperature drops slightly to approximately 115.1 °C. Both the liquor and water flow rates are higher than the original design, and the inlet liquor temperature exceeds the design temperature of 106 °C, indicating that the heat exchanger is undersized for the current operating conditions. The average temperatures are summarized in Table 6.2.

Table 6.2: Measured average inlet and outlet temperatures for streams at the liquor cooler.

Stream	**Type**	**Summer 2023 (°C)**		**Winter 2023 (°C)**	
		T_{in}	T_{out}	T_{in}	T_{out}
Black liquor	Hot	120.6	92.0	115.1	90.5
Water	Cold	56.4	84.6	54.0	83.1

Despite the high liquor temperature and the large temperature difference, driving heat transfer, the target temperature of 90 °C for the outgoing secondary heating water is not achieved. This shortfall is primarily due to the heat exchanger being undersized for the increased flow rates and elevated inlet temperature. Additionally, fouling on the liquor side, caused by accumulation of unwanted materials on the surface, further reduces the exchange's heat transfer capacity. As a result, the heat exchanger is unable to transfer sufficient heat to the cooling water, making it too small when considering the impact of fouling. To compensate for the reduced cooling capacity, cold and lukewarm water are mixed into the cooling water, which lowers the inlet temperature from the intended 70 °C to the measured values of 56.4 °C and 54 °C, respectively. By adding an additional heat exchanger, better cooling efficiency could be achieved, allowing the water to reach 90 °C.

6.3 Potential Uses of Hot Water

The potential for heat recovery is largely dependent on availability of high temperature heat in the secondary heating system. Insufficient hot water temperature limits the ability to effectively utilize residual heat. However, achieving the design temperature of 90 °C for the hot water increases the potential to replace steam. Furthermore, a shift towards smaller temperature differences within the system can increase the amount of hot water, enabling use by both existing and future consumers. Specific areas of applications are identified below.

6.3.1 Utilization of Hot Water in the Bark Drying Process

The bark separated from the wood is first de-watered in bark presses and then transported to the bark dryer, where it is dried to a dry matter content of 55%. The drying process is carried out with ambient air, which is heated sequentially, first with hot water and then with low-pressure steam in three parallel stages, as shown in Figure 6.5. The heat transfer surface between the air and the hot water in the bark dryer is a limiting factor, as it was not designed for the production capacity at which the system currently operates.

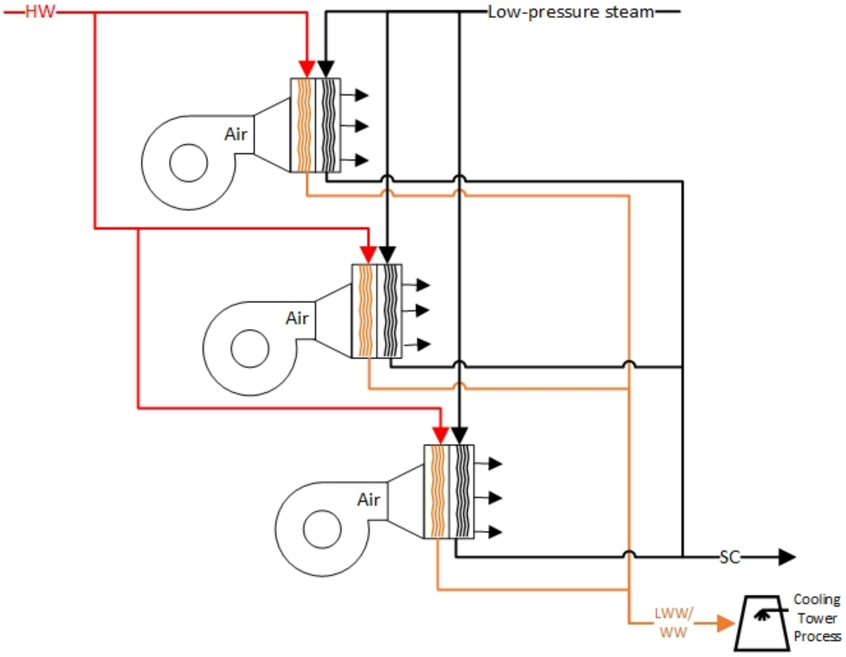


Figure 6.5: Schematic of the bark dryer at SCV.

Although increasing the temperature of the hot water could theoretically improve heat transfer and reduce steam requirements, this would at the same time result in a higher outlet temperature due to the insufficient heat exchange area, thereby limiting the overall efficiency of the system. In addition to physical limitations, operational strategy also constrains the system's performance. Currently, the bark dryer is mostly operated manually. The hot water flow rate is set to a fixed value, and any necessary adjustments to the drying air temperature are made using low-pressure steam. Both the steam input and the air temperature are manually regulated in order to achieve the desired final bark moisture content. With a more automated control strategy, the hot water flow rate could be more accurately monitored and adjusted in real time, enabling improved heat utilization and reduced steam consumption.

Disregarding equipment that limits heat transfer, there is a theoretical potential to save steam by increasing the hot water temperature, as shown in Table 6.3. Although a certain amount of steam is still required to reach the target temperature, a reduction in steam demand of approximately 0.91-1.02 MW could be achieved, corresponding to an increase in electricity production of 0.23-0.25 MW. Assuming an electricity price of 600 SEK/MWh and no limitations in the condensing turbine, this corresponds to an increase in electricity revenue of approximately 1.28 MSEK/year. The calculation method is described in Appendix A.

Table 6.3: Potential savings for bark dryer.

Parameter	**Summer 2023**	**Winter 2023**
Saved Steam (MW)	0.91	1.02
Saved Steam (kg/s)	0.39	0.44
Electricity production (MW)	0.23	0.25
Revenue (MSEK)	0.47	0.80

This amount of heat can be recovered from the secondary heating system during both summer and winter conditions, as can be observed in Figures 6.6 and 6.7.

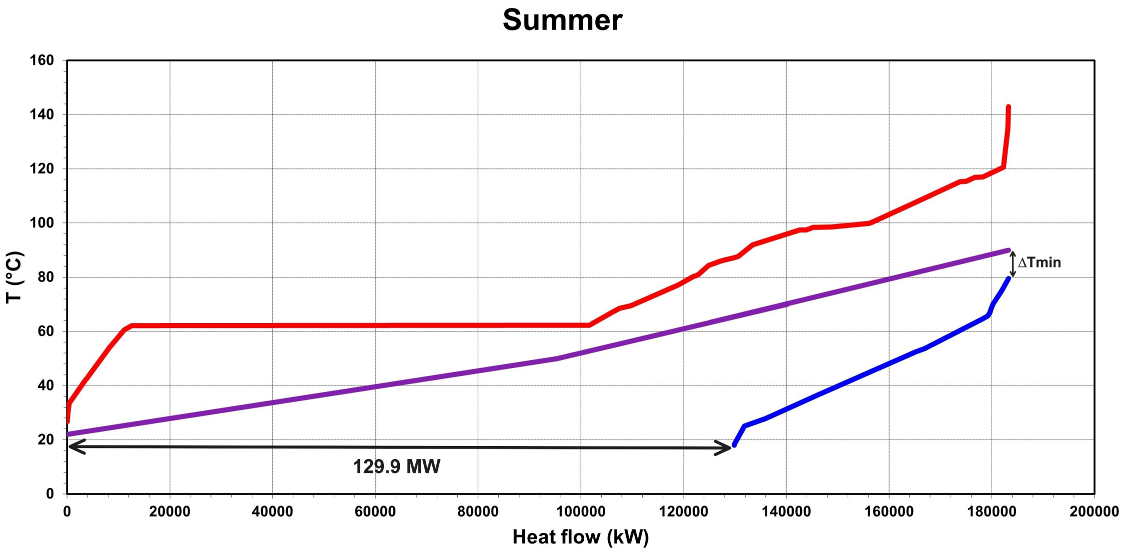


Figure 6.6: Composite curve for summer case including increased demand for bark dryer.

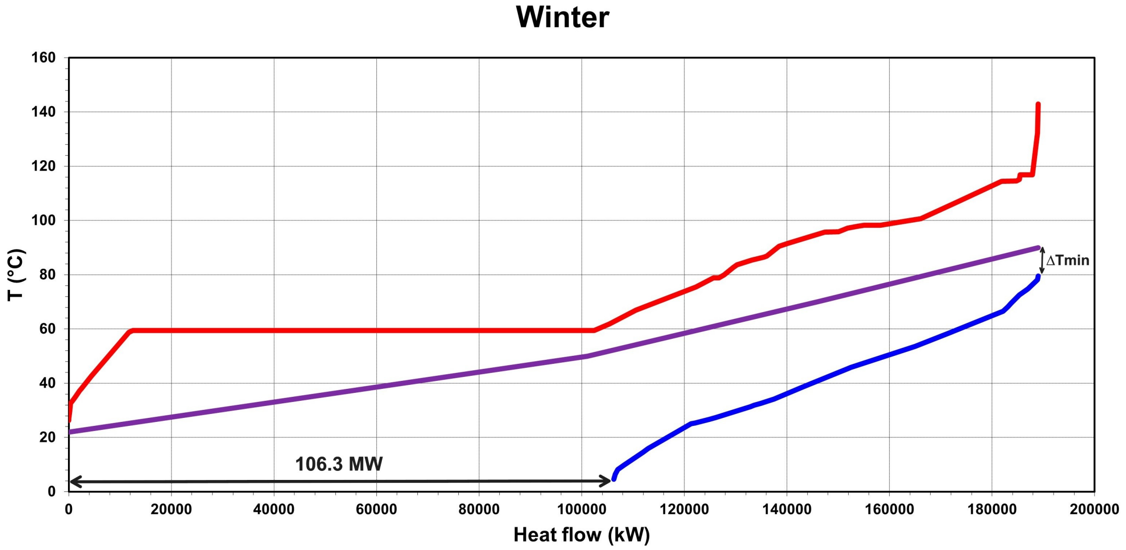


Figure 6.7: Composite curve for winter case including increased demand for bark dryer.

6.3.2 Sawmill Heating Using Hot Water

Another potential area to reduce steam consumption is the heating loop that supplies the sawmill. As previously described in Section 2.2.3, this loop is currently heated via four different heat exchangers that use secondary heat, black liquor vapor and low-pressure steam as heat sources. The distribution of heat power across these exchangers for both summer and winter 2023 is shown in Table 6.4.

Table 6.4: Heat load distribution between heat exchangers in the sawmill heating loop.

	Summer 2023		Winter 2023	
Heat Exchanger	**Q (MW)**	**%**	**Q (MW)**	**%**
Pellet	1.8	10%	1.6	5%
Evaporation	7.7	45%	17.7	58%
Steam	7.6	45%	11.3	37%
Total	**17.1**	**100%**	**30.6**	**100%**

Although the pellet heat exchanger currently only supplies a small portion of the total heat output to the district heating loop, it was originally designed to supply up to 19 MW. This indicates that the existing equipment has significant unutilized capacity. In theory, this heat exchanger could take on a larger portion of the heat load, if the incoming hot water temperature were increased. As shown in Table 6.5, even minor adjustments in the temperature of hot water up to 90 °C can result in steam savings, with an estimated reduction of approximately 1.49 MW in summer and 1.04 MW in winter. In addition to reducing steam consumption, these adjustments would also allow more steam to be directed to the turbine for electricity production, as mentioned in Section 2.4, leading to an expected increase in electricity production of 0.37 MW in summer and 0.26 MW in winter. With an electricity price of 600 SEK/MWh and assuming capacity in the condensing turbine, the resulting annual increase in electricity revenue is estimated at around 1.59 MSEK. The method used for this estimation is outlined in Appendix A.

Table 6.5: Potential savings for the pellet heat exchanger.

Parameter	**Summer 2023**	**Winter 2023**
Saved Steam (MW)	1.49	1.04
Saved Steam (kg/s)	0.64	0.45
Electricity Production (MW)	0.37	0.26
Revenue (MSEK)	0.77	0.82

The full extent of this heat recovery potential is available through the secondary heating system, in combination with the preciously identified potential associated with the bark dryer. This is illustrated in Figure 6.8 and Figure 6.9.

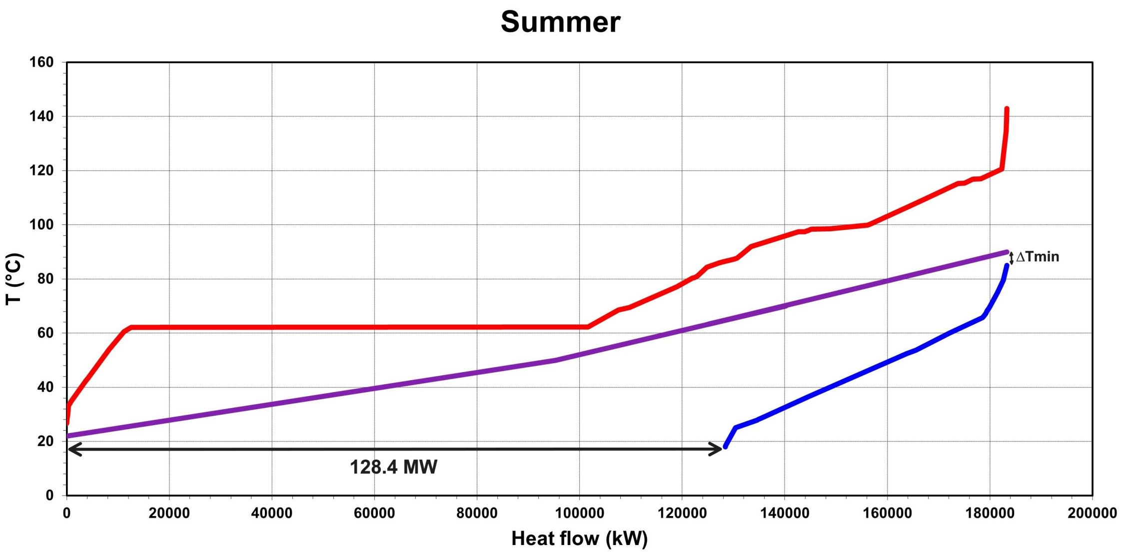


Figure 6.8: Composite curve for summer case including increased demand for bark dryer and pellet heat exchanger.

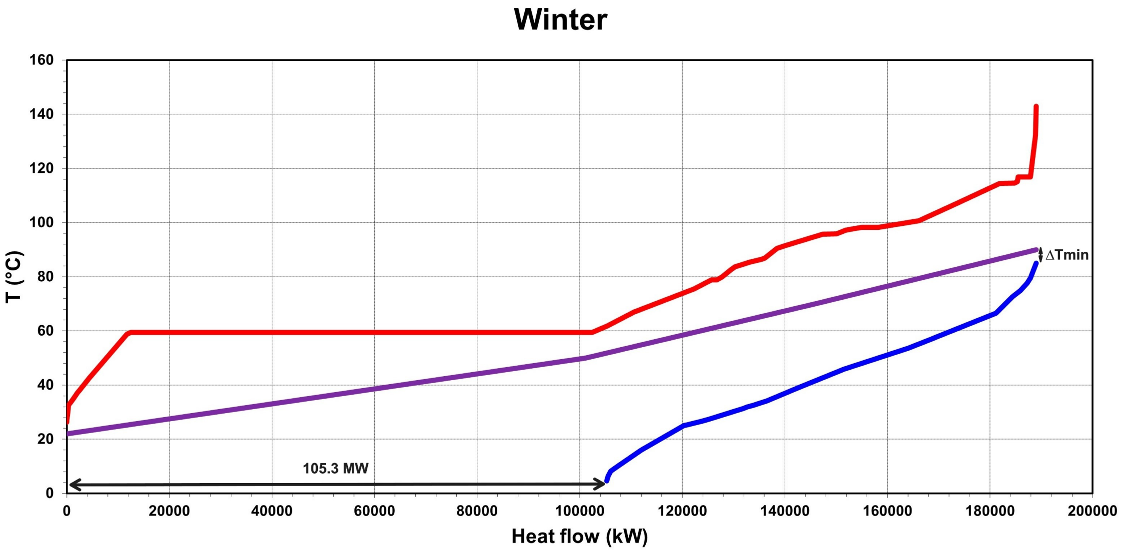


Figure 6.9: Composite curve for winter case including increased demand for bark dryer and pellet heat exchanger.

Despite increasing hot water temperature, the pellet heat exchanger will not reach its design potential. This under-performance is mainly due to two key factors, both of which can be attributed to the sawdust dryer being under-dimensioned. Firstly, the return temperature of the water from the sawmill is higher than originally assumed in the design. While the original design targeted an inlet temperature of around 90 ° C to the sawdust dryer, current operation maintains an inlet temperature closer to 110 °C, to compensate for the under-dimensioning of the dryer. This results in a 10 °C higher temperature entering the pellet heat exchanger, which reduces the available temperature difference for heat exchange, ultimately limiting heat transfer. Secondly, the flow through the heat exchanger is significantly lower than originally intended. A large portion of the hot water bypasses the pellet heat exchanger entirely and flows directly to the evaporation heat exchanger and the steam heat exchanger. This bypass occurs because water from the lumber dryer is not used due to its lower temperature, causing reduced flow through the pellet heat exchanger [41, 11]. As a result, the amount of flow passing through exchanger is currently less than half of the design flow, further limiting its efficiency.

These factors not only reduce the thermal performance of the pellet heat exchanger but also lead to an increased reliance on steam-based heating [41]. To improve the situation, mechanical de-watering before the dryer, for example through a press, could be implemented, potentially reducing the need for higher temperature to the dryer. By fully utilizing the available capacity of the pellet heat exchanger and shifting more of the heat load from steam to secondary heat sources, it would be possible to reduce the overall steam demand of the pellet plant.

There is potential to recovery up to 19 MW from the secondary heating system within the design temperature range. This potential is visualized in Figure 6.10 for summer conditions and Figure 6.11 for winter conditions.

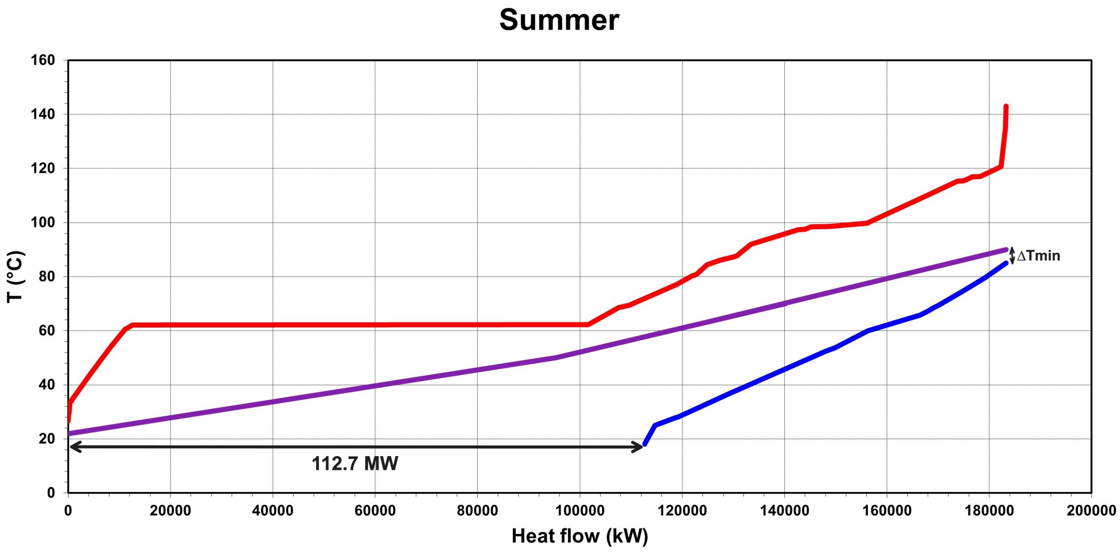


Figure 6.10: Composite curve for summer case with 19 MW demand in pellet heat exchanger.

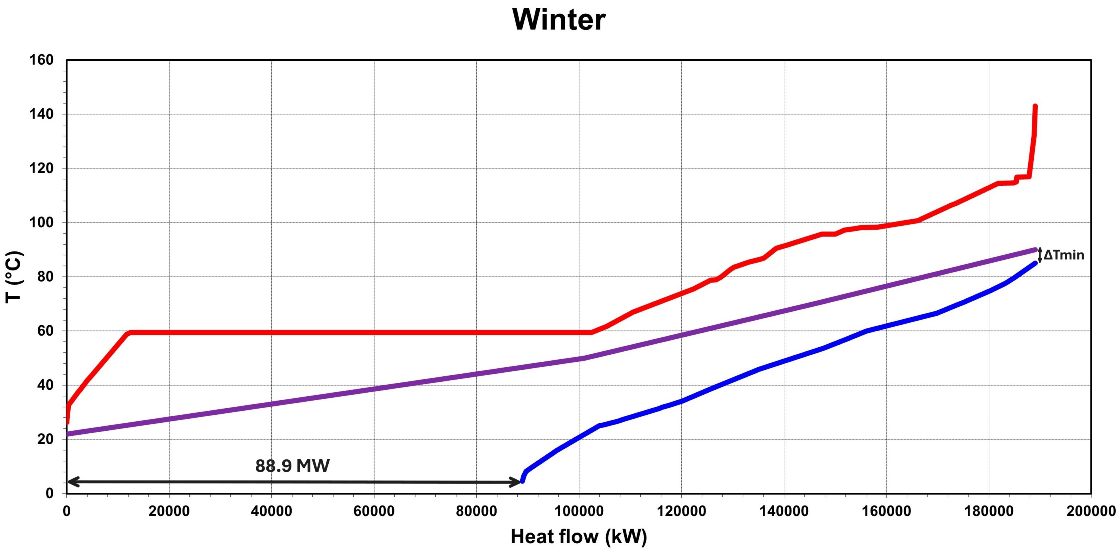


Figure 6.11: Composite curve for winter case with 19 MW demand in pellet heat exchanger.

6.3.3 District Heating to Varberg

The temperature levels in the district heating system have a direct impact on how much energy can be recovered from secondary heat sources. In the current system at Södra Cell Värö, where the supply temperatures is around 95°C, steam is occasionally required to reach the necessary temperatures. This limits the integration of low-value heat sources. A reduction in the supply temperature, in line with the principles of fouth-generation district heating, would enable a greater contribution from the SHS. It would also reduce the demand for steam, which could be allocated to other applications. Lower temperatures in the distribution network increase the flexibility of the system and enable the use of heat sources that are currently not technically viable.

In addition to heat demand, there is a growing need for cooling, particularly during the summer months. District cooling technologies that use heat as driving energy source enable productive use of thermal energy even when the heat demand is low [21]. This can change the operating conditions of the district heating system during summer, allowing excess heat to be directed to cooling production instead of being rejected in the cooling towers.

6.4 Utilization of Saved Steam

For a steam saving measure in the process to be economically and operationally relevant, the released steam must be effectively utilized in other applications. As previously mentioned in Section 2.4, the main short-term benefit of steam savings is the potential for increased electricity production in the condensing turbine. SCV operates two turbines: TB21 and TB31. TB21 has extraction points for 23 barg, 11 barg, and 3 barg steam, while TB31 has extractions for 23 barg, 11 barg, 8 barg, 3 barg, as well as a condensing stage. When planning to use the released steam for power generation, it is important to consider the capacity of the condenser stage. If less steam is extracted at the low-pressure (3 barg) stage, larger volume of steam will be directed to the condenser stage. Therefore, it is important to assess the available capacity in this section. The TB31 turbine is designed for a maximum flow of 43 kg/s in the condenser stage [13].

The steam consumption and capacity of the condensing turbine also vary with seasons. During the summer period, the available capacity in the condenser stage is more limited compared to the winter period, which increases the potential for energy savings during the colder months. In summer 2023, the condenser stage operated below full capacity 88% of the time, with an average available flow of 4.4 kg/s. In contrast, winter operation demonstrated higher and more consistent availability, with the condenser stage operating below full capacity 98% of the time and an average available flow of 12.0 kg/s (see Table 6.6).

Table 6.6: Available capacity in condensing stage of TB31.

	Summer 2023	**Winter 2023**
Full capacity %	12	2
Average remaining capacity (kg/s)	4.4	12.0

The proposed measures in Section 6.3 are expected to result in a redirected steam flow to the condensing stage corresponding to approximately 1.03 kg/s during the summer and 0.89 kg/s during the winter. This flow appears to be utilizable in the turbine, as it is well within the available capacity margins for both seasons. In summer, the proposed redirection of 1.03 kg/s represents less than one quarter of the average available capacity (4.4 kg/s). Since full capacity is only reached 12% of the time, sufficient capacity is likely to be available during most operational hours. In winter, the proposed flow of 0.89 kg/s is negligible in relation to the 12.0 kg/s average remaining capacity. The condensing stage is also operating below full capacity nearly all of the time.

6.5 Analysis of Non-Energy Benefits

An increased utilization of hot water reduces the cooling demand in the cooling towers, which in turn leads to a decreased volume of cooling water being discharged to the wastewater system during summer months. This reduction results in a lower demand for replenishment in the secondary heating system, which relives pressure on the treatment plant and contributes to a more sustainable and efficient water management. The cooling towers constitute a significant source of noise within the facility. To limit noise disturbances, mitigation measures have been implemented. However, these measures has had a negative impact on the capacity of the cooling towers. By reducing the overall cooling demand, the potential need to install additional cooling tower capacity, which would likely increase noise levels, can be avoided.

7

Conclusions and Future Work

The analysis confirms significant seasonal variations in system operation and performance, with a cooling demand of 130.8 MW during the summer months compared to 107.3 MW in winter. An important observation is that increasing the temperature of the hot water tank has considerable potential to reduce steam consumption and thus improve the overall energy efficiency of the process. Under current operating conditions, there is a theoretical potential to release 11.8 MW of hot water capacity in summer and 14.4 MW in winter. However, practical implementation is currently limited by equipment constraints, particularly in the liquor cooler, sawdust dryer and bark dryer, which require further examination. Possible measures to address these limitations include installing a mechanical de-watering system, such as a sawdust press, and installing an additional liquor cooler heat exchanger. The technical feasibility and economic evaluation of these options need to be conducted.

Improved utilization of hot water can reduce the total cooling demand while simultaneously decreasing discharge of hot water into the wastewater system. This not only conserves freshwater resources but also contributes to a more sustainable process operation. Although water availability is not currently limited, improved water management lowers the risk of future production constraints due to scarcity, ensuring more reliable operations. A detailed assessment to quantify potential water savings and evaluate their broader impacts would be of interest. Additionally, the steam saved through these efficiency measures, approximately 1.15 kg/s in summer and 1.03 kg/s in winter, can be redirected the condensing turbine for electricity generation. There is sufficient turbine capacity available during most operating hours to utilize steam, providing an opportunity to increase renewable energy production.

Furthermore, changing conditions in the district heating system, including a shift towards lower temperature ranges and integration of heat supply into district cooling networks, have the potential to transform district heating operations. These developments could enable the recovery and utilization of a larger share of low-value heat, even during periods of low heating demands. However, these possibilities need to be further developed.

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A

Appendix 1

To estimate the monetary value of LP-steam savings, the following methodology has been applied. The approach is based on energy balance calculations and estimated conversion efficiency to electricity.

1. **Energy content of LP-steam per kg (in MWh/kg):**

$$\frac{H_{\text{LP-steam}} - H_{\text{condensate}}}{1000 \cdot 3600} \tag{A.1}$$

   where:
   - $H_{\text{LP-steam}} = 2754.8\,\text{kJ/kg}$ (enthalpy of LP-steam)
   - $H_{\text{condensate}} = 459.8\,\text{kJ/kg}$ (enthalpy of returned condensate)

2. **Potential electricity generation (in $\mathbf{kJ_{el}}$/kg steam):**

$$(H_{\text{LP-steam}} - H_{\text{condensed}}) \cdot \eta \tag{A.2}$$

   where:
   - $H_{\text{condensed}} = 2120.0\,\text{kJ/kg}$
   - $\eta = 0.90$ (assumed electrical efficiency)

3. **Electricity yield per unit of steam energy ($\mathbf{MWh_{el}/MWh_{steam}}$):**

$$\frac{\text{kJ}_{\text{el}}/\text{kg}}{H_{\text{LP}} - H_{\text{condensate}}} \tag{A.3}$$

4. **Economic savings from LP steam reduction:**

$$E_{\text{steam, saved}} \cdot \left(\frac{E_{\text{el}}}{E_{\text{steam}}}\right) \cdot P_{\text{el}} \tag{A.4}$$

   where:
   - $E_{\text{steam, saved}}$ = saved LP-steam (MWh)
   - $E_{\text{el}}/E_{\text{steam}}$ = electricity yield factor (from step 3)
   - $P_{\text{el}} = 600\,\text{SEK/MWh}$ (assumed electricity price)

This calculation provides an estimate of the financial benefit resulting from reduced LP-steam consumption, assuming conversion to electricity at 90% efficiency and a market price of 600 SEK/MWh [42].

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