Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Engineering
Department of Energy and Process Engineering

Émilien BOURGÉ

Using Material Flow Analysis for carbon accounting

A study case of a Norwegian paper mill

Master's thesis in Industrial Ecology
Supervisor: Daniel B. Müller
Co-supervisor: Lars Johanson, Miguel Las Heras, Chipo Peveling
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Preface

This thesis was performed and written during the spring semester of 2023 as a conclusion of a two years Master of Science in Industrial Ecology at the Norwegian University of Science and Technology (NTNU).

First and foremost, I would like to thank my supervisors Daniel B. Müller, Lars Johanson and Miguel Las Heras who provided much desired and helpful support and insight on my work. I would also like to thank the people at Norske Skog Skogn: Ruth Astrid Strøm, Tormod Røstad, Johan Vestrum and Jon Henrik Steinsli who helped me understand the different processes and interactions of the mill and for their enthusiasm for the study.

Finally, I would like to give a warm thank you to my bed which kept welcoming me with open arms even in the direst moment of the past six months. And even though you had springs puncturing my back from time to time, I could not have wished for a more loyal and supportive companion to embark with on this journey.

Abstract

The study performs a material flow analysis of the flows containing carbon of a Norwegian paper mill. Both the dry matter and the carbon flows are quantified. The results of the quantification is used to develop a model of the mill. The results of the modelling show a significant potential for the mill to increase both its energy and material efficiency while reducing the carbon emissions at the same time. The re-use of secondary heat to dry the bark used as fuel of the boilers at the mill show a great potential in reducing the amount of non-biogenic emissions of the mill. Removing the recycling paper line of the mill will reduce the amount of direct carbon emissions but will shift most of them outside the system.

The four scenarios developed for the study show that the combination of both the removal of the recycled paper line and the drying of bark can reduce the carbon emissions of the boilers by 23.5% and the overall direct carbon emissions of the mill by 18.6%. Drying the bark showed the most potential in reducing the fossil fuel consumption of the mill. Increasing the dry content of the bark to 70-75 % is enough to phase out most of the oil used by the mill. Increasing the energy recovery of the TMP also showed a huge potential in reducing the direct carbon emissions of the mill which could reach a 30% lower value.

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1 Introduction

In the last few decades, a concern for environmental impacts, especially climate change, has been growing as the UN Intergovernmental Panel on Climate Change's (IPCC) reports continue to warn on the effect of global warming on human activities (Stocker et al., 2013).

This growing concern for environmental impacts and search for sustainability has made both academia and industries looking into ways to improve the energy efficiency of industries (Mahi et al., 2021). Many studies have been developing resource efficiencies metrics, struggling to find one that is at the same time robust, easy to use, relevant, credible and globally accepted (Hernandez and Cullen, 2019). As energy efficiency is a growing concern for industries, material efficiency is usually linked to it when it is for energy purpose (Allwood et al., 2011). Besides the need for improving the efficiencies of the processes, waste management is a crucial step in reaching better material efficiency (Halkos and Petrou, 2018). As most industries produces wastes and by-products, waste management system have become more and more essential in order to achieve a circular economy and reduce both environmental impact and resource scarcity (Alvarez-Risco et al., 2022). Waste cannot simply be disposed anymore due to more constraining regulations and more and more industries lean towards more energy and material recovery as a waste management solution.

The pulp and paper industry is not spared by the concerns of material and energy efficiencies (Hubbe, 2021). Extensive research has been and is still being performed on the available solutions to deal with the wastes and by-products of their production (Monte et al. (2009), Mohammadi et al. (2019))

A recurring solution for both energy and material efficiency in the paper industry is the recovery of energy from the incineration by-products as a way to both produce energy and deal with waste generation (Kraft et al., 1993). The two main by-products used for energy generation in paper mills are the sludge and the bark.

Sludge cannot be used as fuel on its own and is usually mixed with other fuel. The reason behind this practice is that burning sludge is usually seen as a way to dispose of it and not primarily as an energy source. Several issues have been noticed when burning sludge and compiled by Likon and Trebše (2012). The main limitation of burning the sludge resides in its high water content varying from 30% to 50%. For each additional 1% of moisture content, the temperature of the combustion must reach 10°C more to not alter the efficiency of the process. To mitigate the temperature loss, it is a common practice to add fossil fuel to increase the energy output (Coimbra et al., 2015), increasing at the same time the proportion of non-biogenic carbon emitted by the mill.

Additionally, depending on the nature of the sludge (primary sludge from producing pulp from virgin wood or sludge coming from the recycling of paper), the ash and organic content of the sludge can greatly vary, impacting negatively the amount of energy that can be delivered during the combustion.

Norske Skog is a leading pulp and paper company based in Norway. One of their mill, located in Skogn, is an integrated mill: producing both the pulp and the paper.

Norske Skog Skogn has set a target of reducing their carbon emissions by 55% compared to 2015 and to be net zero emissions by 2050 (NorskeSkog, 2021). To assess their performance, the mill perform an accounting of the carbon emissions of the mill. The accounting is based on both measurements of the concentration of $CaCO_3$ of the relevant flows as well as CO_2 factors for all the relevant flows. Whereas the method used by the mill is a physically based accounting, considered as crucial for a serious environmental management for a company (Bartolomeo et al., 2000), the current accounting at the mill only accounts for non-biognic carbon emissions. It is assumed by the mill that the biogenic carbon is considered as neutral. Yet, although quite common, this assumption shows several limitations that limit the robustness of it and can make it quite unreliable (Leturcq, 2020).

A previous carbon accounting of a paper mill has been performed with an energy flow analysis by Zhao et al. (2019). The study indicated that the main source of emissions for the paper mill was from biomass origin. Hence, in the case of the pulp and paper industry, the limitations of the carbon neutrality of biogenic emissions are even more dubious than for other industries as the main flows of material of a paper mill come from biomass.

Carbon accounting is not the only concern of the mill, it also aims at reaching a better sustainable use of material and energy with improved recirculation (NorskeSkog, 2021).

Material flow analysis (MFA) is an analytical method to quantify the flows of good and/or substances of a defined system. It is an important tool to study circular economy and material flow management.

Both a material flow analysis of the wood products (Stránský, 2022) and an energy flow analysis (Émilien Bourgé, 2022) of the mill have already been performed. The quantification of the energy flows of the mill showed that there was a significant potential for more energy recovery, especially of secondary heat at relatively low temperature. The secondary heat of paper mills has been considered as a high opportunity to improve both the material and the energy efficiency of a paper mill (Holmberg and Stenström, 2014). One of the main opportunity to reuse the secondary heat of the mill at Skogn has been evaluated as drying the bark before feeding it to the boilers for energy generation.

The main reason for drying the bark before using it as fuel for boilers is to increase its net energy content. The water contained in the bark will consume a significant amount of energy to evaporate, thus limiting the amount of energy that can be recovered and use from the combustion (Walker, 2006). Removing the water from the bark, which can be achieved in different ways, will thus increase the net energy content of the bark (Orémusová et al., 2014).

There are several technologies to de-water or dry bark. But there are two main ways of doing it: mechanically pressing the bark to remove the water or drying the bark by flowing air at relatively high temperature to capture the moisture.

Bark presses is a common technology used in scandinavian paper mills (Holmberg and Stenström, 2014). The amount of water removed from the bark will depend of the type of bark and the type of installation but final dry content values of around 50% can be expected with such equipments and it has been assessed that increasing the temperature of the press can further reduce the moisture content of the bark (Holmberg and Stenström, 2014).

Air drying the bark works by circulating hot air with a low relative humidity to transfer the water content from the bark to the air. The main difference between this air drying and pressing is the nature of the energy used. Whereas a bark press will proceed with a mechanical dewatering and will require electricity, an air dryer will use heat.

Using secondary heat for bark drying provides several advantages. The main one is that it does not lead to an increase of the heat production of the mill . Additionally, Holmberg and Ahtila (2005) assessed that the use of secondary heat compared to primary heat can also have a financial interest as it is cheaper. Nonetheless, using secondary heat forces the process to work at lower temperature than with primary heat. This aspect also has an influence on the drying time as higher drying temperature will provide a faster drying process than lower temperature (Holmberg and Ahtila (2005), Pang and Mujumdar (2010)).

The mill at Skogn currently only has a bark press that de-water the bark to a final dry content of 50%. The mill could also reuse their secondary heat to further dry the bark. By doing so, the energy content of the bark would increase and thus reduce the need for additional fuel for the boilers, most likely decreasing the associated carbon emissions at the same time.

By performing a study case of the paper mill located at Skogn, this study aims at answering the following research questions:

- What are the characteristics of the direct carbon emissions linked to the production of paper and their origins?
- What solutions could be implemented by the mill to reduce the amount of carbon it emits?
- How using secondary heat to dry the bark can influence the carbon balance of the mill?

To answer these questions, the study will continue as followed. First a quantification of the dry matter flows containing carbon of the mill will be performed through a MFA to then achieve a carbon flow quantification. Next, a model of the mill will be developed in order to perform scenarios to assess the impact of different solutions in reducing the mill's carbon emissions. The model of the mill will implement a new process to dry the bark in order to assess its effects on the material and energy balance.

2 Methodology

2.1 System definition

This study focuses on the Norske Skog owned paper mill located in Skogn in Trøndelag, Norway. It quantifies the flows of dry matter containing carbon and the flows of carbon of the mill for the year 2022. It follows the methodology of Material Flow Analysis (MFA) as described by Brunner and Rechberger (2003).

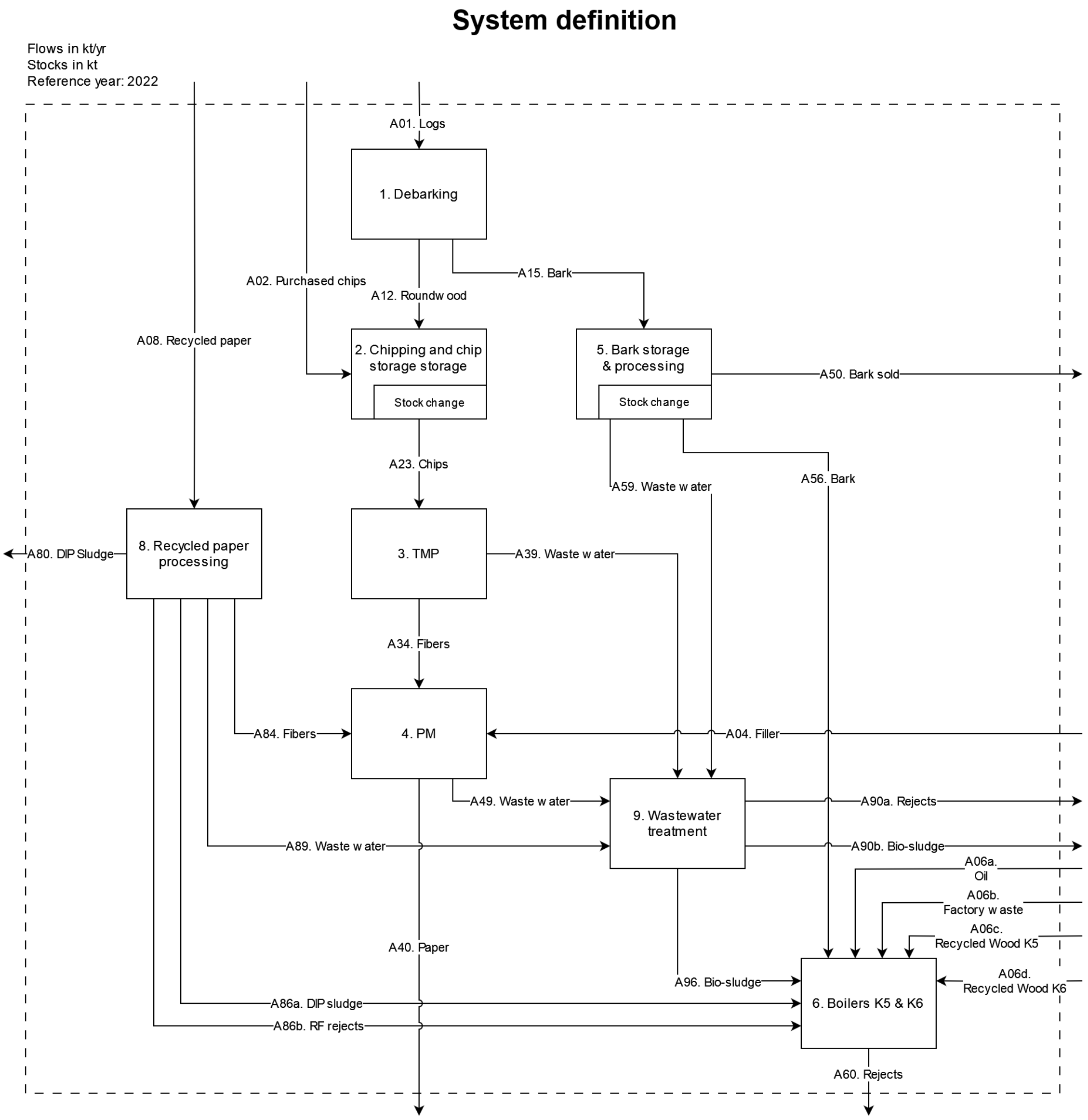


Figure 1: System definition

The system includes all the processes related to the processing of raw material and recycled paper, paper making and the biomass boilers (Table 1). Each flows are defined as going from one process (i) to another (j) and are symbolized as Aij. Process 0 represents the outside of the system and the other processes labels are defined in Table 1. The stock of a process i is symbolized as S_i and its stock-change as ΔS_i.

Table 1: List of processes

Number	**Name**	**Description**
1	Debarking	The logs are admitted to the mill after being collected from the forest. The bark is removed from the logs by going into rotating drums.
2	Chipping and storage	The debarked logs are turned into chips and stored. Not all the chips are produced by logs. Some of it is also bought and imported to the mill.
3	TMP	In the thermomechanical pulping, the chips are heated and refined into fibers. This process requires a high amount of energy that is partially recovered as steam. It is the main source of steam of the mill.
4	PM	The paper machine produces and dries the paper.
5	Bark storage and processing	The bark is pressed to a 50% dry content before being sent to the boilers.
6	Boilers	Uses most of the b-products of the mill as fuel and is the second main source of steam of the mill.
8	Recycled paper processing	Removes the ink and other chemicals of the recycled paper and recovers it as fibers that are used in the PM.
9	WWT	The waste water treatment uses digestion to process the waste waters of the mill.

2.2 Dry matter quantification

The quantification of the flows of dry matter that contains carbon (Aij_d) is based on the company's 2022 data survey that provides the wet mass (Aij) and the dry content (dc_{ij}) of several flows.

The dry mass of each flow is defined as:

$$Aij_d = dc_{ij} \cdot Aij \tag{1}$$

The flows for which the dry mass is not provided by the company are calculated by either a transfer coefficient kij or through the mass balance of a process.

$$Aij_d = kij \cdot Akl \tag{2}$$

Where Akl is another flow, usually the input or the output of process i or j depending on the nature of the transfer coefficient.

The transfer coefficients used for this quantification are derived from the 2020 MFA study of the mill performed by Stránský (2022).

The mass balance equation of process j is defined as followed:

$$\sum_i Aij = \Delta S_j + \sum_o Ajo \tag{3}$$

Where Aij and Ajo represents respectively the inputs and outputs of the process j.

For each flow, 5 layers are calculated: total dry mass (Aij_d), mass of biomass (Aij_w), mass of $CaCO_3$ (Aij_{ca}), mass of plastic (Aij_p) and mass of oil (Aij_o). The relationship between the different layers is defined as followed:

$$Aij_d = Aij_w + Aij_{ca} + Aij_p + Aij_o \tag{4}$$

For most layers, the value is usually calculated with the proportion of each of the substances from the dry matter layer. The biomass layer is mostly calculated by balancing the dry matter mass with the other layer (equation 4).

2.3 Carbon quantification

To quantify the carbon content of each flow, the carbon concentrations of all secondary layers (biomass, $CaCO_3$, plastic and oil) are applied to the previous dry mass quantification. All the concentration are referred to the dry mass (eg. $t_w.t_d^{-1}$).

In the study performed by Jagodziński et al. (2020), the carbon content of Picea Abies (the main wood specie used at the mill) has been evaluated for wood, bark, branches and foliage. The value found by the study for both wood and bark is around 50%. From these values, it has been assumed for this study that all the biomass of each flow of the system has a carbon concentration of 50%.

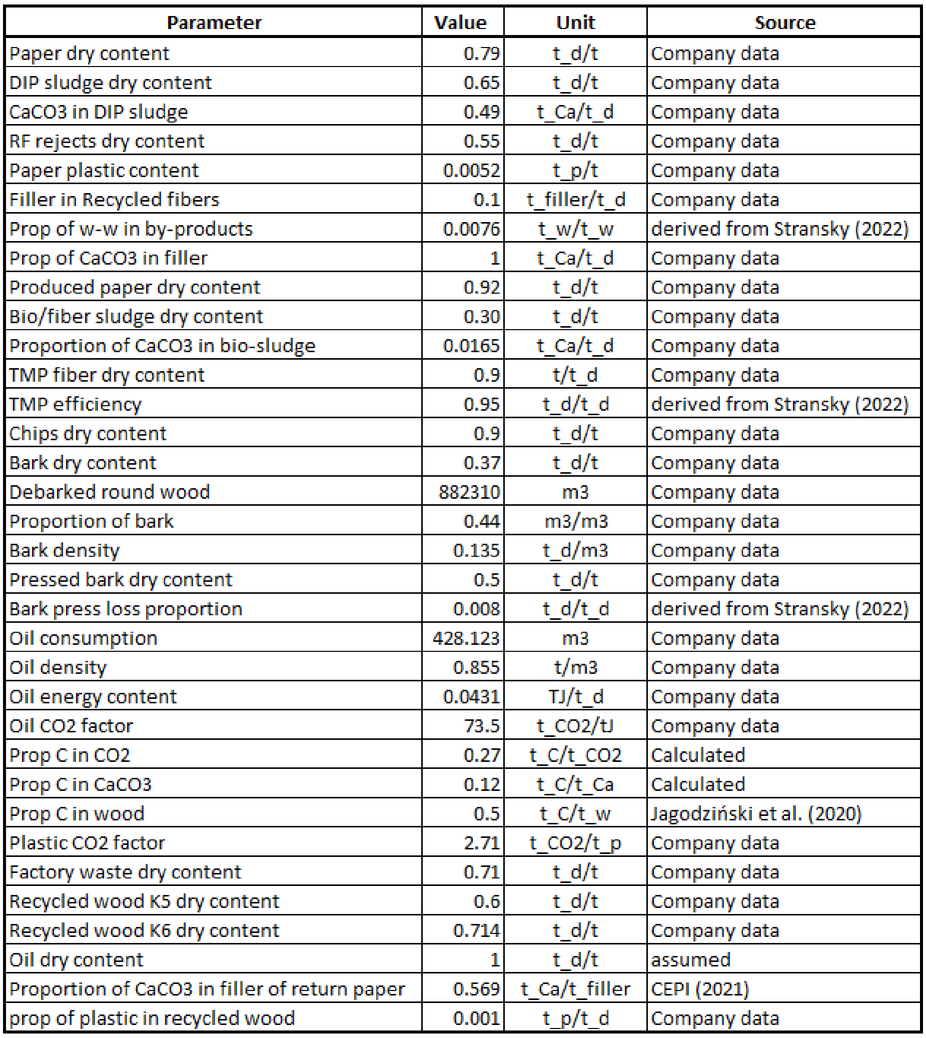
The carbon contents of plastic and oil have been retrieved from the carbon accounting currently performed by the mill which provides a CO_2 emission factor for both. The proportion of C in CO_2 is them multiplied to the resulting CO_2 emissions following the molar mass of each element (Table 2). The proportion of C in $CaCO_3$ is also calculated with the molar mass of the elements.

Table 2: Molar mass of C, O and Ca in g.mol^{-1}

Element	**Molar mass (g.mol^{-1})**
C	12
O	16
Ca	40

All the parameters used for the both quantifications and their values can be found in Table 3.

Table 3: Parameters used for the quantifications



Parameter	Value	Unit	Source
Paper dry content	0.79	t_d/t	Company data
DIP sludge dry content	0.65	t_d/t	Company data
CaCO3 in DIP sludge	0.49	t_Ca/t_d	Company data
RF rejects dry content	0.55	t_d/t	Company data
Paper plastic content	0.0052	t_p/t	Company data
Filler in Recycled fibers	0.1	t_filler/t_d	Company data
Prop of w-w in by-products	0.0076	t_w/t_w	derived from Stransky (2022)
Prop of CaCO3 in filler	1	t_Ca/t_d	Company data
Produced paper dry content	0.92	t_d/t	Company data
Bio/fiber sludge dry content	0.30	t_d/t	Company data
Proportion of CaCO3 in bio-sludge	0.0165	t_Ca/t_d	Company data
TMP fiber dry content	0.9	t/t_d	Company data
TMP efficiency	0.95	t_d/t_d	derived from Stransky (2022)
Chips dry content	0.9	t_d/t	Company data
Bark dry content	0.37	t_d/t	Company data
Debarked round wood	882310	m3	Company data
Proportion of bark	0.44	m3/m3	Company data
Bark density	0.135	t_d/m3	Company data
Pressed bark dry content	0.5	t_d/t	Company data
Bark press loss proportion	0.008	t_d/t_d	derived from Stransky (2022)
Oil consumption	428.123	m3	Company data
Oil density	0.855	t/m3	Company data
Oil energy content	0.0431	TJ/t_d	Company data
Oil CO2 factor	73.5	t_CO2/tJ	Company data
Prop C in CO2	0.27	t_C/t_CO2	Calculated
Prop C in CaCO3	0.12	t_C/t_Ca	Calculated
Prop C in wood	0.5	t_C/t_w	Jagodziński et al. (2020)
Plastic CO2 factor	2.71	t_CO2/t_p	Company data
Factory waste dry content	0.71	t_d/t	Company data
Recycled wood K5 dry content	0.6	t_d/t	Company data
Recycled wood K6 dry content	0.714	t_d/t	Company data
Oil dry content	1	t_d/t	assumed
Proportion of CaCO3 in filler of return paper	0.569	t_Ca/t_filler	CEPI (2021)
prop of plastic in recycled wood	0.001	t_p/t_d	Company data

2.4 Uncertainties

As most of the data used in this study comes from the company reporting, it is assumed that the provided values have a **low uncertainty** as they are the best ones to depicts the state of the mill. All the parameters derived from Stránský (2022) are considered to have a **medium uncertainty**. The values used in his study were also mostly company data but corresponds to the 2020 reports of the company, thus considered as less certain in regards of the 2022 quantification. Finally, all the other values used in this study are considered as **highly uncertain** (from CEPI (2021) or Jagodziński et al. (2020)) as they come from external studies that were not specific to the mill at Skogn.

All in all, most of the values used for the dry matter quantification come as primary data (Table 3). Most of the uncertainties reside in the carbon concentration of the different sub-layers and the characteristics of the recycled paper.

2.5 Model development

2.5.1 Model definition

The aim of the model is to depict the carbon flows of the mill in the context of the 2022 production. The model is mostly based on the dry matter quantification of the mill. All the flows calculated by the model are given as a mass of dry matter. All sub-layers defined in the previous quantifications are also quantified in the model. The carbon concentrations of each layer are then applied on the results to have the complete carbon quantification.

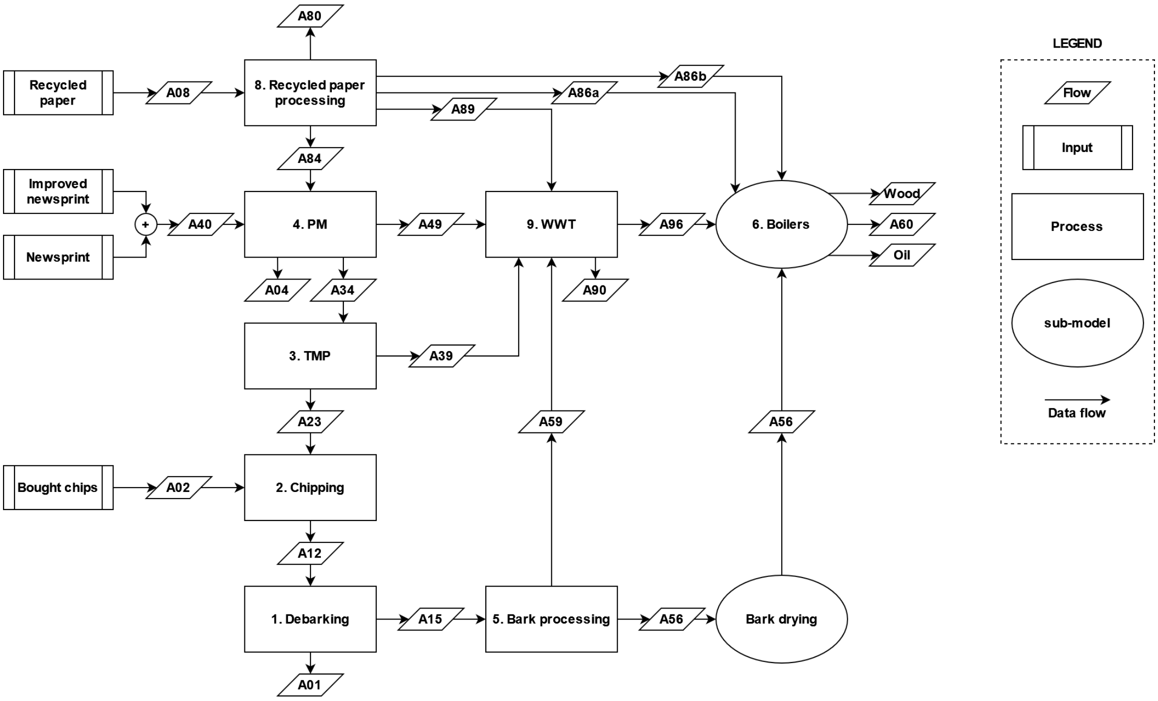


Figure 2: Model definition

First, the inputs of the model are: the amount of newsprint and improved newsprint produced, the amount of recycled paper and the amount of bought chips. These 4 values, defining 3 flows, have been assessed as the drivers of the production of the mill. All these flows drive the amount of logs required by the mill as well as the production of by-products used as fuel. Then, the model takes into account how the final dry content of the bark influences its net energy content and its implication on the additional fuel requirements to meet the energy demand.

To calculate the different flows of dry matter, transfer coefficients are derived from the previous quantification. Thus, with only the four previously defined driving inputs, the model calculates all the flows of the system using the transfer coefficients.

For each process, the mass balance principle is respected and all transfer coefficient are defined as followed:

$$Aij = k_{ij} \cdot \sum_{h} Ahi \tag{5}$$

Where k_{ij} is the transfer coefficients used to calculate Aij and Ahi the flows considered as input of the model for the process i (eg: $A34 = k_{34} \cdot (A40 + A84)$). Figure 2 shows graphically how the model works and how each flow is calculated.

Each sub-layer (biomass, $CaCO_3$, plastic, oil) is quantified by either the use of transfer coefficient or the use of concentrations.

Finally, it is assumed that there is no stock of bark or chips. It is considered that all the bark and chips produced over the year is used during the same year.

2.5.2 Bark drying

Unlike the current state of the mill, the model includes a new process consisting of drying the bark before sending it to the boilers.

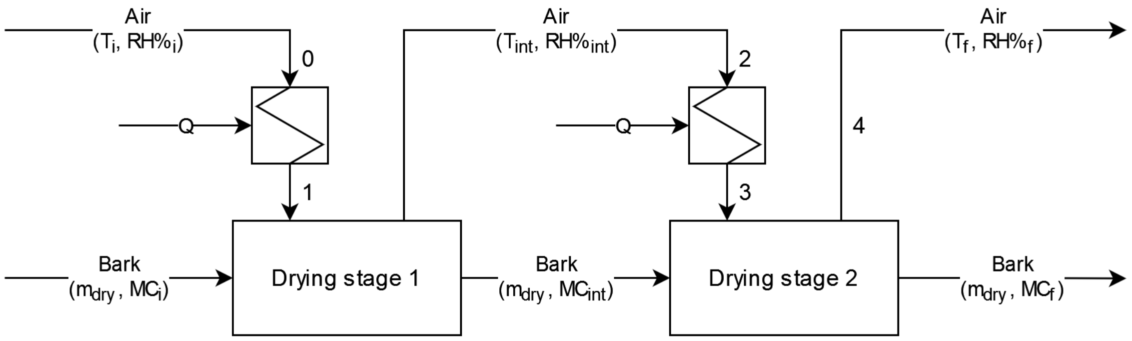
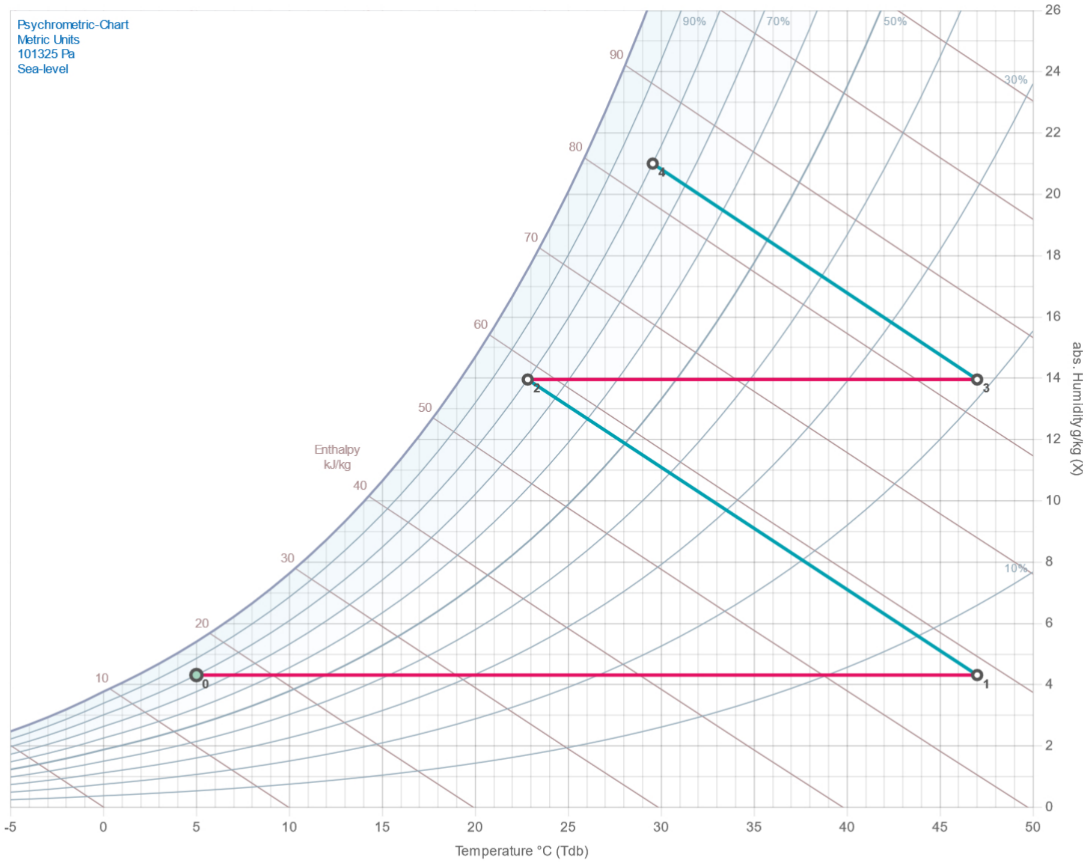


Figure 3: Drying process

The drying consists of a two stages air-drying process (Figure 3). The choice of a two stages drying process has been done while discussing with the representatives of the mill on what would be the most likely choice when considering the installation of such a process.

The outside air is first heated (0 to 1) and then sent to the bark in order to capture the water from the bark (1 to 2). The air is then recirculated to a second heating (2 to 3) and then re-sent to capture the water from the bark (3 to 4). The advantage of using more than one stage is the reduction of the average energy use by gram of water captured.



www.Psych-Chart.com - No responsibility for the calculated values

Figure 4: Psychrometric chart of the drying process

The outside air is considered to be at 5°C with a relative humidity of 80%. For each drying stage, it is considered that the capture of water from the bark will increase the relative humidity of the air back to 80%.

As the mill has a significant amount of secondary heat available, it is used to heat the air for the drying process. This secondary heat comes from a flow of water going to the waste water treatment at a temperature of around 47°C. Hence, by only using this source of energy, the final temperature of the air will also be 47°C. By using these values in a psychrometric chart (Figure 4), the amount of energy required to dry 1 kg of water can be calculated.

The amount of water that needs to be dried m_{water} is calculated as followed:

$$m_{water} = A56_d \cdot (\frac{1}{dc_{bark-i}} - \frac{1}{dc_{bark-f}}) \tag{6}$$

Where dc_{bark-i} and dc_{bark-f} are the initial and final dry content of the bark.

The net energy content of the bark (e_{bark}) is then calculated using the following equation:

$$e_{bark} = a_{bark} \cdot (1 - dc_{bark}) + b_{bark} \tag{7}$$

Where dc_{bark} is the final dry content of the bark, and a_{bark} and b_{bark} are coefficients derived from the work of Orémusová et al. (2014) (Figure 5).

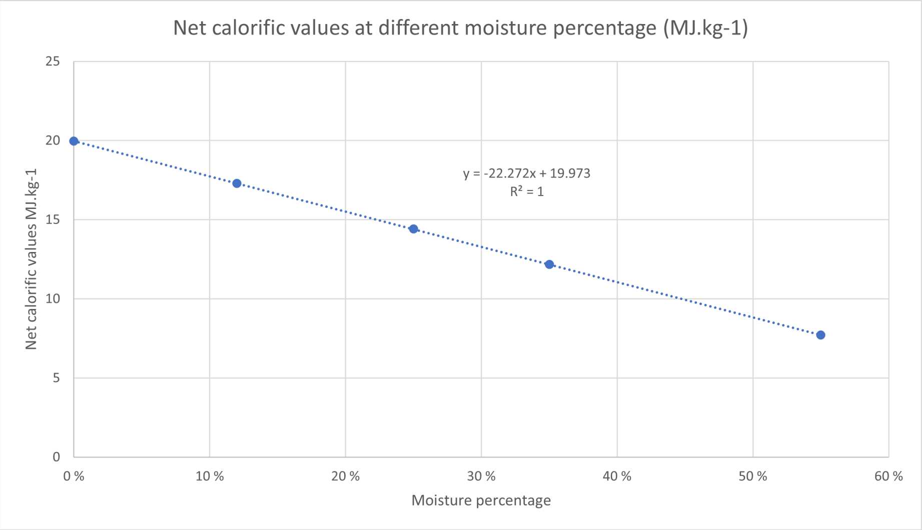


Figure 5: Relationship between the bark moisture content and its net calorific value

2.5.3 Boilers

The biomass boilers are a key-process in the mill at it provides a significant part of the steam needed by the other processes. The boilers energy output is modelled in order to meet the demand of energy of the mill, then depending on the dry content of the fuel, the amount of oil and recycled wood is calculated.

From the company energy and material reports, the specific energy demands of all the processes (spe_i) have been calculated. As the drying of bark uses secondary heat, no additional energy is required for the drying process. The final demand of energy includes the energy demand associated to the processes (depending on the production of each process) (ED_i) and the energy used for heating the buildings (VVF) (ED_{VVF}). The VVF energy is considered as fixed and not dependent on the production of the mill.

$$ED_i = spe_i \cdot prod_i \tag{8}$$

Where spe_i is the specific energy need of process i and $prod_i$ the associated production.

The production of steam has three origins: the production of the electric boiler (E_{eboil}), the production of the biomass boilers (E_{boil}) and the steam production from the energy recovery of the TMP (E_{TMP}). The steam production of the electric boiler is considered fixed to the current value. The specific steam production of the TMP has is derived from the current steam and fiber production. The boilers also provide a continuous surplus of 2 MW of steam ($ED_{surplus}$). Finally, the energy production of the biomass boilers is calculated in order to meet the energy demand:

$$E_{boil} = \sum_i ED_i + ED_{VVF} + ED_{surplus} - E_{eboil} - E_{TMP} \tag{9}$$

Next, the amount of energy required by the boilers is calculated using the boilers efficiency. Yet, as the company changed their energy reporting from 2020 to 2022, some information are not available anymore such as the energy values of the different fuels. Thus the boilers efficiency was calculated using values from the 2020 reports.

The boilers efficiency (eff_{boiler}) is applied to its required production of steam (E_{boil}) in order to assess the amount of energy required from the fuels (E_{fuel}).

$$E_{fuel} = \frac{E_{boil}}{eff_{boiler}} \tag{10}$$

The boilers need a fixed small amount of oil during their start-up. The manager of the mill assessed this fixed need of oil ($e_{oil-min}$) as 20% of the current oil consumption. Then, by using the energy content of the different by-products (e_{i-bp}), the amount of additional fuel energy is calculated ($e_{add-fuel}$):

$$e_{add-fuel} = E_{fuel} - e_{oil-min} - \sum_i e_{i-bp} \tag{11}$$

For each fuel i, the relationship between the dry mass (m_i) and the energy output (e_i) is defined as followed.

$$e_i = m_i \cdot q_i \tag{12}$$

Where q_i is the net calorific value of fuel i.

The additional fuel requirement is met with two other fuels: oil and recycled wood. The calorific value of the oil was given by the mill and the one of recycled wood was calculated with the 2020 reports.

The amount of additional oil required by the boilers is dependent on the moisture content of the fuel. After a discussion with the manager of the boiler, it was assumed that a final dry content of the bark of 70% with the current conditions would lead to a complete phase out of the additional oil use.

In this study, it is assumed that the relationship between the amount of oil required by the boilers and the final moisture content of the fuel is linear.

$$m_{oil} = a_{oil} \cdot MC_{final} + b_{bark} \tag{13}$$

Where m_{oil} is the amount of oil. The coefficients a_{oil} and b_{oil} are defined by assessing the oil content of two cases: the current status of the system and a second value corresponding to a complete phase out of the oil with a final value of the bark dry content of 70%.

The final moisture content of the fuel is defined as:

$$MC_{final} = 1 - \frac{\sum_i m_i}{\sum_i \frac{m_i}{dc_i}} \tag{14}$$

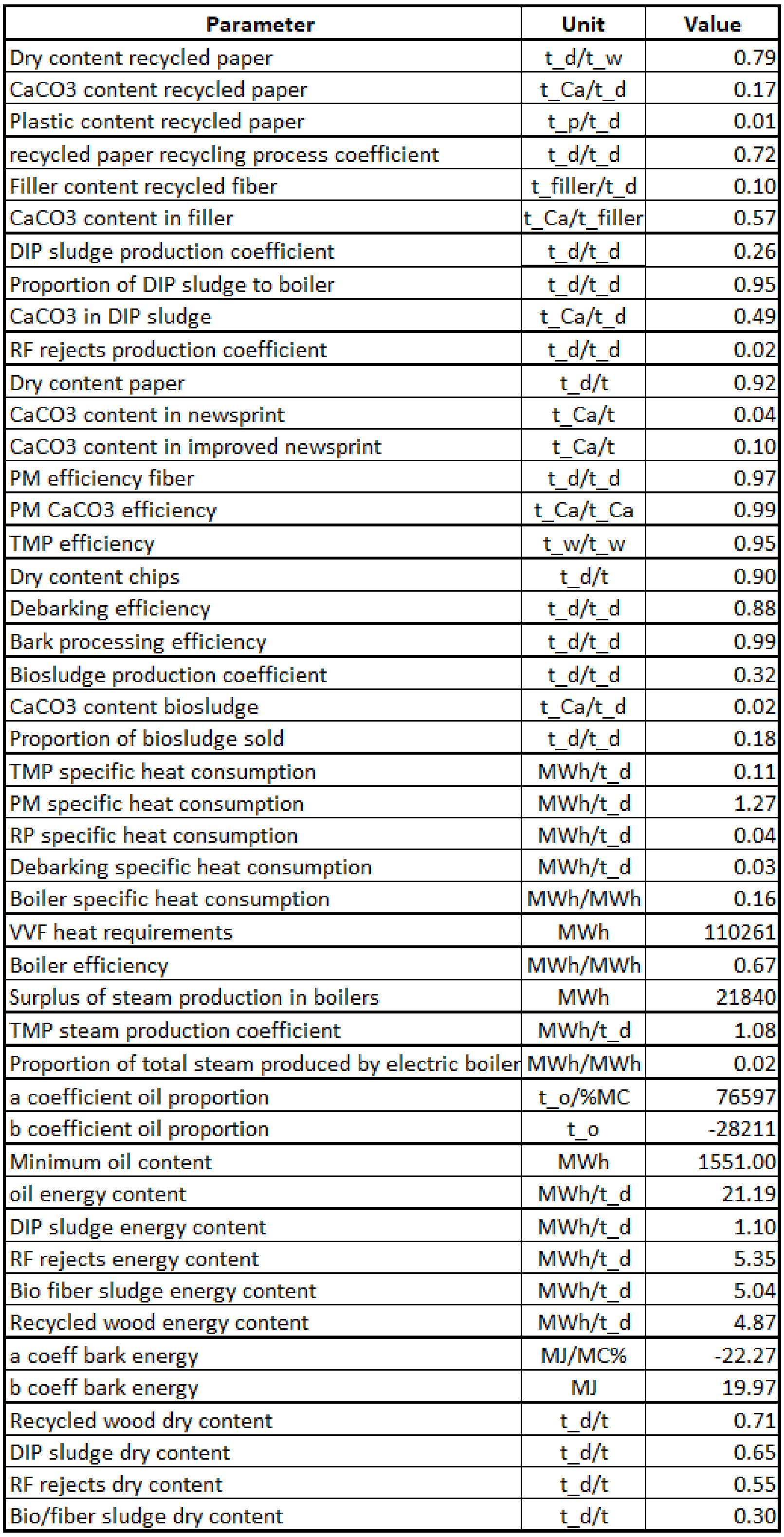
Where m_i is the dry mass of fuel i and dc_i its dry content. All the dry content of the fuels calculated with the 2022 values except for the recycled wood which value was evaluated using the 2020 report.

The amounts of recycled wood and additional oil are calculated by solving the system of equation including equations 11, 12, 13 and 14.

Finally, the flows of carbon are quantified by using the carbon content of each fuel for each sub-layer.

All the parameters used in the modelling are aggregated in Table 4.

Table 4: Parameters used for the modelling



Parameter	Unit	Value
Dry content recycled paper	t_d/t_w	0.79
CaCO3 content recycled paper	t_Ca/t_d	0.17
Plastic content recycled paper	t_p/t_d	0.01
recycled paper recycling process coefficient	t_d/t_d	0.72
Filler content recycled fiber	t_filler/t_d	0.10
CaCO3 content in filler	t_Ca/t_filler	0.57
DIP sludge production coefficient	t_d/t_d	0.26
Proportion of DIP sludge to boiler	t_d/t_d	0.95
CaCO3 in DIP sludge	t_Ca/t_d	0.49
RF rejects production coefficient	t_d/t_d	0.02
Dry content paper	t_d/t	0.92
CaCO3 content in newsprint	t_Ca/t	0.04
CaCO3 content in improved newsprint	t_Ca/t	0.10
PM efficiency fiber	t_d/t_d	0.97
PM CaCO3 efficiency	t_Ca/t_Ca	0.99
TMP efficiency	t_w/t_w	0.95
Dry content chips	t_d/t	0.90
Debarking efficiency	t_d/t_d	0.88
Bark processing efficiency	t_d/t_d	0.99
Biosludge production coefficient	t_d/t_d	0.32
CaCO3 content biosludge	t_Ca/t_d	0.02
Proportion of biosludge sold	t_d/t_d	0.18
TMP specific heat consumption	MWh/t_d	0.11
PM specific heat consumption	MWh/t_d	1.27
RP specific heat consumption	MWh/t_d	0.04
Debarking specific heat consumption	MWh/t_d	0.03
Boiler specific heat consumption	MWh/MWh	0.16
VVF heat requirements	MWh	110261
Boiler efficiency	MWh/MWh	0.67
Surplus of steam production in boilers	MWh	21840
TMP steam production coefficient	MWh/t_d	1.08
Proportion of total steam produced by electric boiler	MWh/MWh	0.02
a coefficient oil proportion	t_o/%MC	76597
b coefficient oil proportion	t_o	-28211
Minimum oil content	MWh	1551.00
oil energy content	MWh/t_d	21.19
DIP sludge energy content	MWh/t_d	1.10
RF rejects energy content	MWh/t_d	5.35
Bio fiber sludge energy content	MWh/t_d	5.04
Recycled wood energy content	MWh/t_d	4.87
a coeff bark energy	MJ/MC%	-22.27
b coeff bark energy	MJ	19.97
Recycled wood dry content	t_d/t	0.71
DIP sludge dry content	t_d/t	0.65
RF rejects dry content	t_d/t	0.55
Bio/fiber sludge dry content	t_d/t	0.30

2.5.4 Sensitivity analysis

To assess the sensitivity of the model on the different parameters, the selected parameters are varied -20% and +20% of their original value. The selected parameters are: dry content of the bark, energy content of recycled wood, energy content of WWT sludge, amount of recycled paper and TMP energy production.

2.5.5 Scenario development

To assess the impact of drying the bark on the carbon balance of the mill, four scenarios have been developed. Additionally, the mill is considering removing the recycled paper line from the line in the future. The impact of this removal will also be assessed within the scenarios.

The first scenario (Y-50) is considered as the baseline scenario. It aims at matching the quantification of 2022. The inputs of the model are the production values of 2022 with the same amount of recycled paper. In this scenario the bark is not further dried and its final dry content is 50%.

The second scenario (Y-50) still includes the recycled paper line. The bark is dried to a final dry content of 80%. The final value of the dry content of the bark as been chosen in agreement with the mill representatives.

In the third scenario (N-50), the bark is not further dried (50% final dry content) and the recycled paper line is completely removed. It has been decided with by the mill that the recycled paper line would be entirely shut down at once and not gradually, hence the complete phase out of the recycled paper line for the scenario.

Finally, the fourth scenario (N-80) includes both the removal of the recycled paper line and the drying of the bark to a final dry content of 80%.

A summary of all the scenario can be found in Figure 5.

3 Results

3.1 System quantification

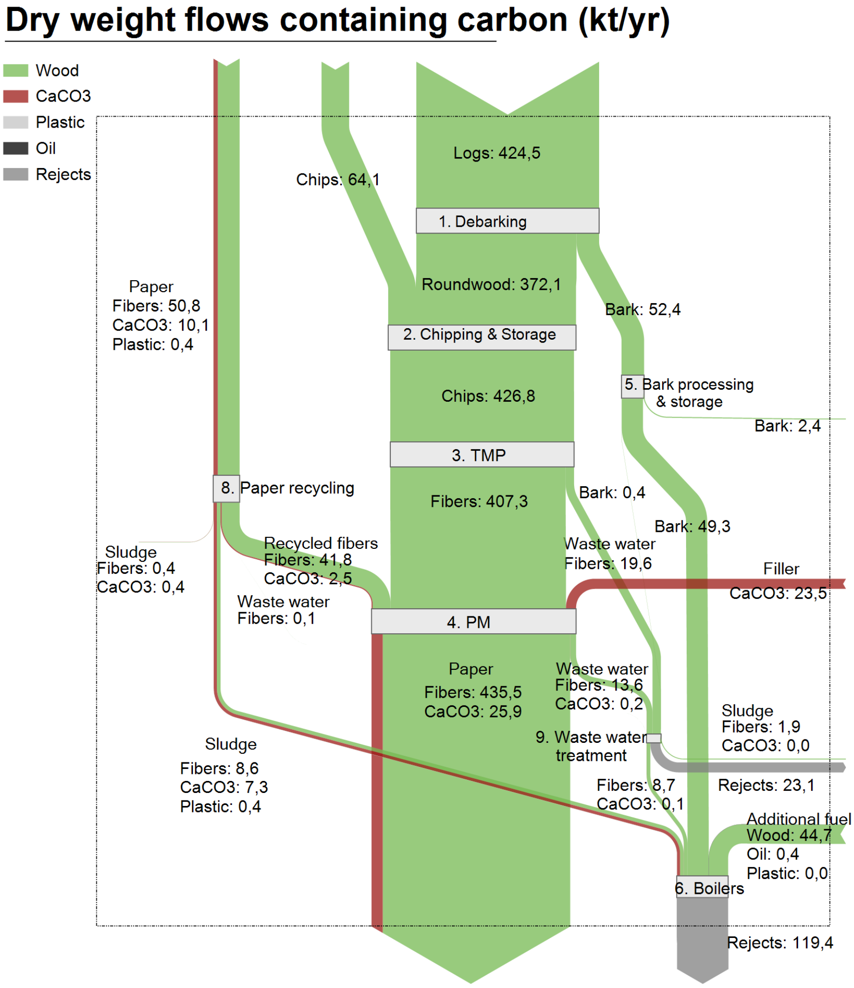


Figure 6: Dry matter flows containing carbon for the year 2022

Figure 6 depicts the mill's flows of dry matter containing carbon in 2022. Most of the carbon input of the mill comes from the logs (424.5 kt) and the main output of carbon is the final product of the mill: paper (461.4 kt).

Most of the carbon flows of the mill are composed of biogenic carbon. The only sources of $CaCO_3$ are the recycled paper (10.1 kt) and the filler (23.5 kt). The input of filler to the paper machines accounts for 90% of the $CaCO_3$ present in the paper, the rest comes from the recycled fibers. Recycled paper represents 30% of the total inflow of $CaCO_3$ of the system and around 28% of it ends in the final paper production.

About 10% of the fibers used in the paper machines were recycled fibers from the recycled paper line. About 15% of the chips used by the TMP were bought from external sources and not produced at the mill.

Concerning the boilers, external fuel input (recycled wood and oil) represented around 38% of the total fuel consumption while bark represented about 41% of the total fuel input. Sludge from the recycled paper represented 14% of the total fuel demand and 98% of the $CaCO_3$ inputs to the boilers.

There are two inputs of plastic in the mill. Most of it comes from the recycled paper

(0.4 kt) whereas the rest comes from the recycled wood (¡0.1 kt) as a small fraction of it is plastic.

From the 103.1 kt$_d$ of by-product produced, around 72% is reused as fuel for the boilers and about 4% has been sold outside the mill (bark and sludge from the WWT). The rest of the by-products is disposed by the waste water treatment. 92% of the by-products dry matter is wood-based.

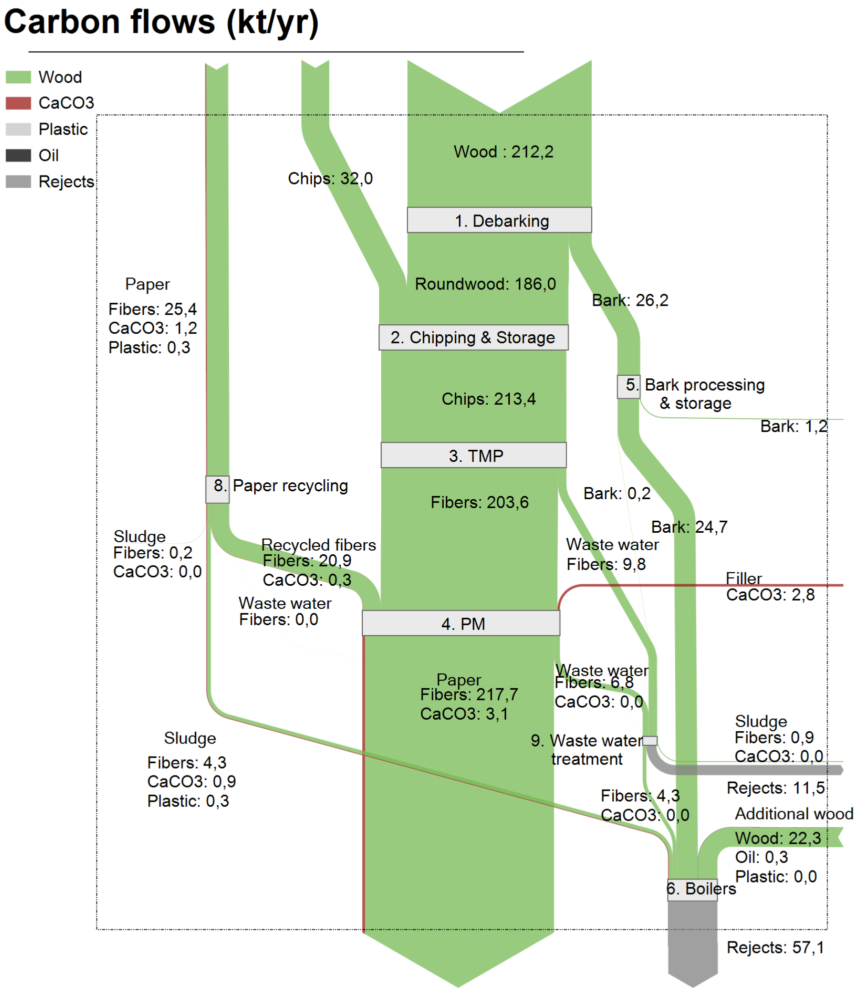


Figure 7: Carbon flows for the year 2022

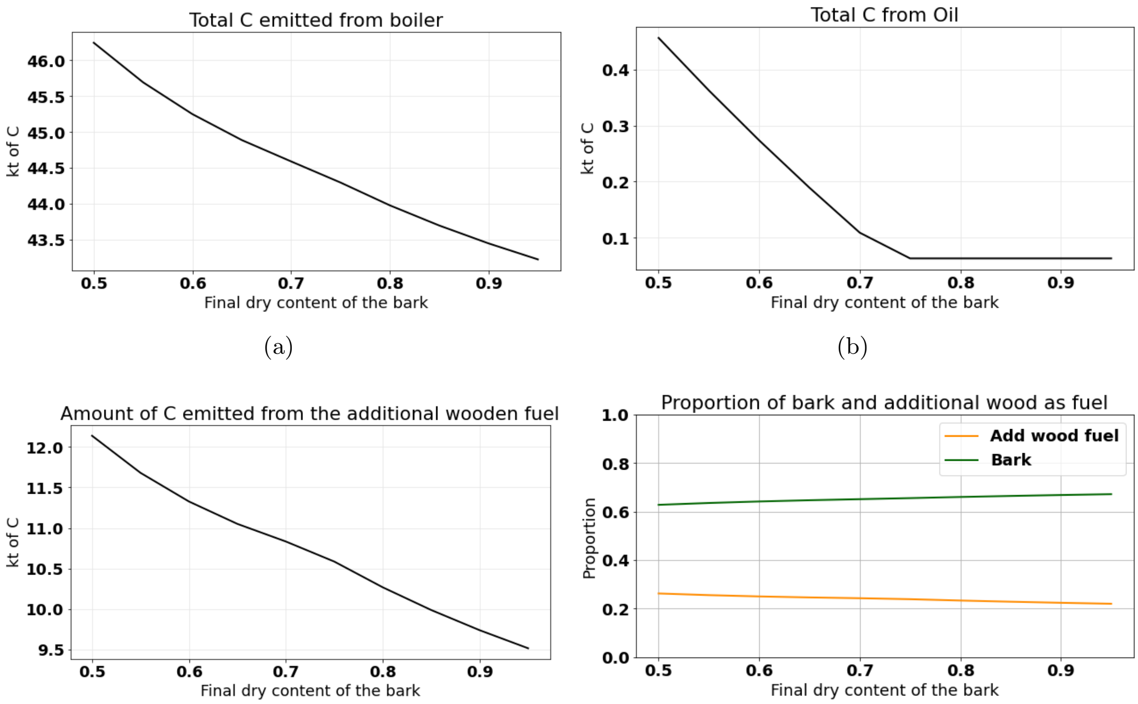
The total input of carbon to the mill is 296.7 kt$_C$ as shown in Figure 7. Out of these, 71.5% comes from the wood, 9.1% from the recycled paper, 10.8% from the purchased chips, 1% from the filler input and the last 7.6% comes from the additional fuel. Nevertheless, most of this carbon exits the system as paper (74.4%), the rest leaves the system as it is sold (2.5%) or emitted to the environment by the waste water treatment or the boilers (23.1%)

The carbon emissions from the combustion of fuel from the boilers emitted around 57,1 kt$_C$. About 30% of the carbon emissions of the boilers come from external fuel and not by-products. Around 97% of the fuel used in the boilers comes from biogenic sources. For the non-biogenic emissions of the boilers, carbon emissions from CaCO$_3$ represents around 59% of them, carbon from plastic around 20% and carbon from oil 21%.

The additional 11.5 kt$_C$ emitted from the waste water treatment leads to a total direct carbon emission from the production of paper of around 0.15 t$_C$.t$_d^{-1}$ of paper.

3.2 Modelling

One of the main point of the model is to assess the effect of the final dry content of the bark on the carbon emissions of the mill.



(a) (b)

(c) (d)

Figure 8: Effect of the dry content of bark on: (a) total amount of C emitted from the boilers, (b) Total amount of C emitted from the oil in the boilers, (c) Total amount of C emitted from recycled in the boilers and (d) proportion of bark and recycled wood in the boilers.

Figure 8 shows the different variations of the total amount of carbon emitted from the boilers, the amount of carbon emitted from the oil and the additional wooden fuel and the proportion of carbon coming from bark and additional wood for a final dry content of the bark ranging from 0.5 to 0.95 in the case of having no recycled paper.

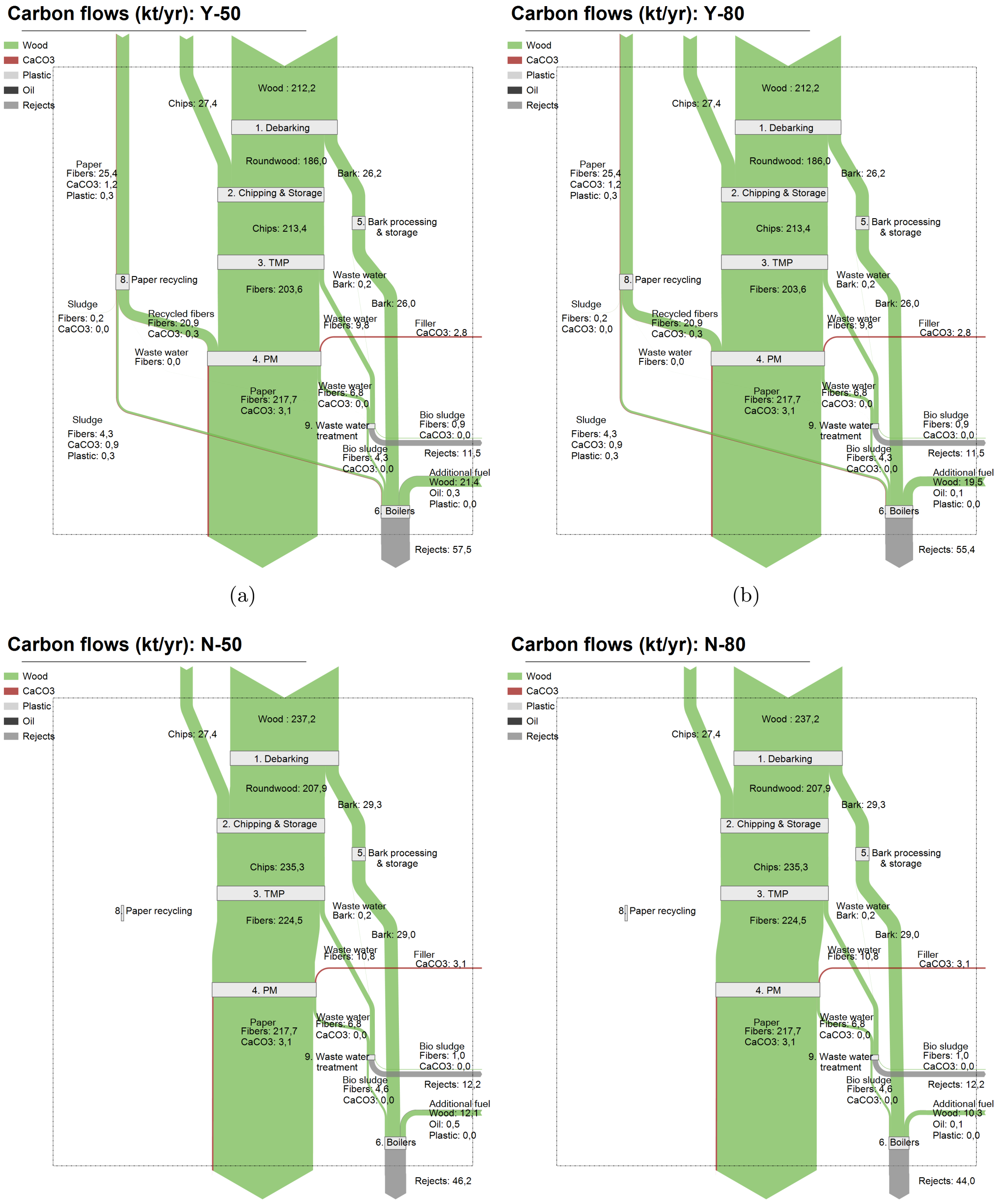
As the dry final dry content increases, the need for additional fuel decreases (c) as well as the need for oil. The amount of oil required by the boilers decreases until it reaches a limit of around 63 t. The share of bark in the total amount of fuel increases slightly from around 63% to around 67%. The share of additional wood decreases from 26% to 22%. The reason behind this results is that drying the bark will increase both its energy content and the final dry content of the input of fuel to the boilers. The increase of energy content will then decrease the amount of energy required from additional fuel sources. The increase of the final dry content of the fuel decreases the need for oil. Only the amount of oil that is required to start the boiler is left when a specific final dry content of the bark is reached (between 70 and 75%).

3.2.1 Scenarios

By applying the model on 4 different scenarios, it is possible to assess the effect of the removal of the recycled paper line and the impact of the final dry content of the mill on the mill's carbon balance.

Table 5: Summary of scenarios

	Recycled paper	Final dry content of the bark
Scenario Y-50	Yes	50%
Scenario Y-80	Yes	80%
Scenario N-50	No	50%
Scenario N-80	No	80%



(a)

(b)

(c)

(d)

Figure 9: Carbon flows of the mill for scenarios (a) Y-50, (b) Y-80, (c) N-50 and (d) N-80

Figure 9 compiles the four different carbon flows of the mill associated with the four scenarios (Table 5) from which scenario Y-50 is the 2022 baseline.

For the scenarios Y-80, N-50 and N-80. The carbon emissions from the boilers decreases from 57.5 kt_C to 55.4 kt_C, 46.2 kt_C and 44.0 kt_C respectively.

Scenarios N-50 and N-80 have a higher amount of wood as input to the system (237.2 kt_C) compared to scenario Y-50 and Y-80 (212.2 kt_C)[1]. This difference of input of wood comes from the removal of the recycled fibers in the system that leads to an increase of the demand for virgin fiber in order to meet the demand of paper. For the same reason, as the amount of wood increases when there is no recycled paper, the production of bark is mechanically increased as well and reaches 29.3 kt_C for scenarios N-50 and N-80, an addition of 3.1 kt_C compared to the baseline.

For the two scenarios with no recycled paper, the emissions from the waste water treatment increases by 6% compared to the ones with recycled paper to reach 12.2 kt_C. This increase of emissions is due to the increase of virgin fibers production that produces more waste water than recycled fibers. Even if the recycled fibers produced a small amount of waste water that are treated at the treatment plant, the amount is significantly smaller than the amount produced by the virgin fibers production and the overall input of waste water increases.

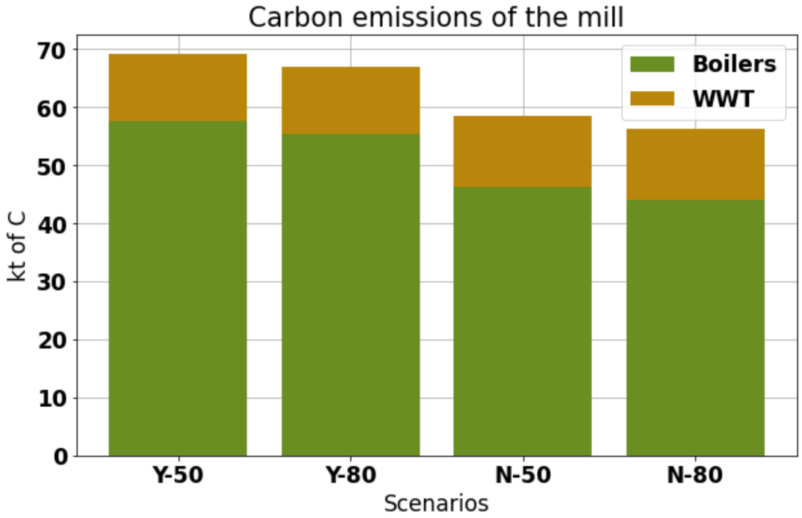


Figure 10: Carbon emissions of the different scenarios

The carbon emissions from the boilers of the three scenarios Y-80, N-50 and N-80 have reduced by respectively 3.7%, 19.7% and 23.5% compared to the 2022 baseline, as shown in Figure 10. The two scenarios with no recycled paper show significantly lower carbon emissions from the boilers compared to the ones with recycled paper. Nevertheless, when accounting for the total carbon emissions, including those from the boilers and the waste water treatment, the reduction of carbon emissions is 3%, 15.4% and 18.6% for the scenarios Y-80, N-50 and N-80 when compared to scenario Y-50. Hence, the removal of the recycled

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[1] As the concentration of carbon in wooden products has been fixed to 0.5 $\mathrm{t}_C.\mathrm{t}_d^{-1}$, the amount of carbon in wooden products (wood, logs, chips, fibers) is directly correlated to the dry amount of the same wooden products

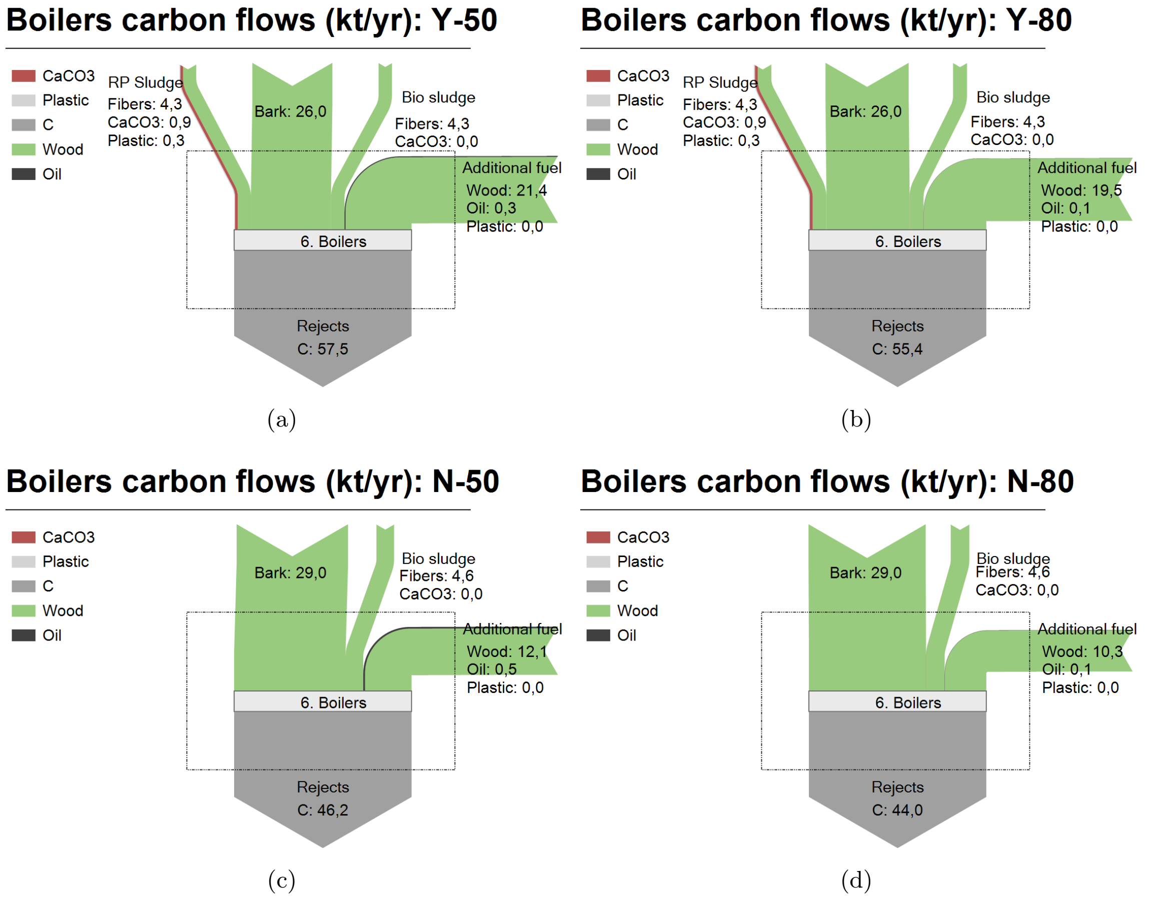


Figure 11: Carbon flows of the boilers for scenarios (a) Y-50, (b) Y-80, (c) N-50 and (d) N-80

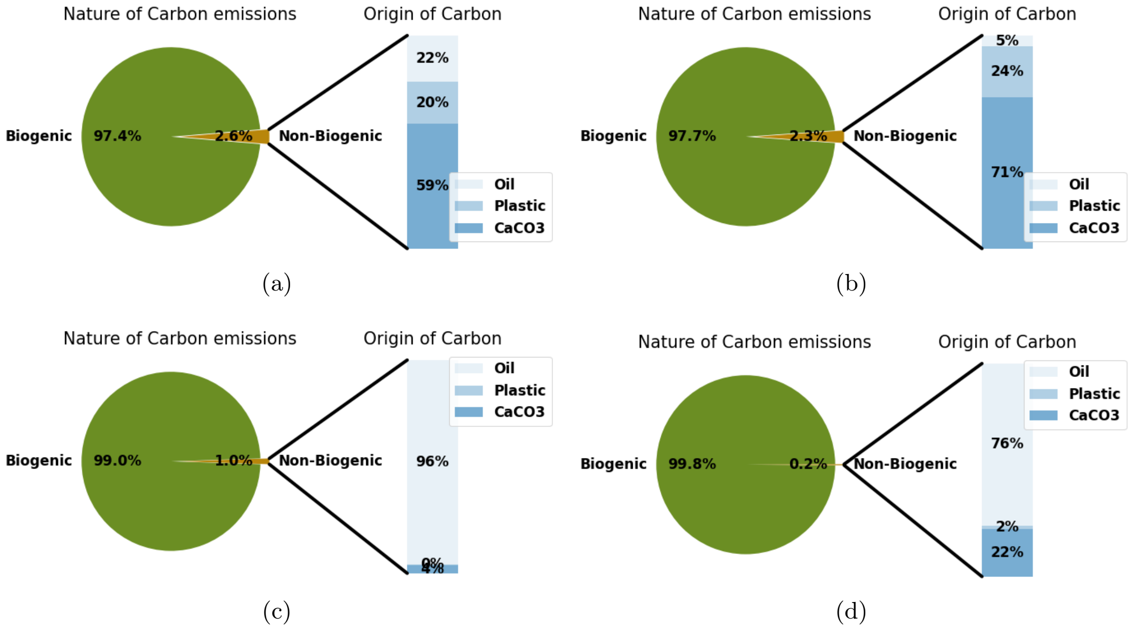


Figure 12: Nature of the carbon emissions from the boilers for the different scenarios (a) Y-50, (b) Y-80, (c) N-50 and (d) N-80

paper line has a positive impact on the reduction of the carbon emissions from the boilers but a negative impact on the reduction of the carbon emissions from the waste water treatment.

Furthermore, the comparisons between scenario Y-50 with scenario N-50 and scenario Y-80 with scenario N-80 shows that independently from the drying of the bark, the removal of the recycled paper line decreases the amount of carbon emissions from the boilers and increases the carbon emissions from the waste water treatment. In addition, when the bark is not dried (scenarios 0 and 2), the removal of the recycled paper leads to a higher moisture content of the fuel and an increase in the demand for oil and its associated emissions: from 0.3 kt_C to 0.5 kt_C.

Moreover, as the recycled paper sludge has a relatively high dry content compared to the bark, its removal increases the average moisture content of the fuel. Besides, the increase of the waste water treatment sludge linked to the removal of the recycled paper also increases the average moisture content of the fuel as it has a sensibly low dry content (around 30%), thus increasing the need for oil.

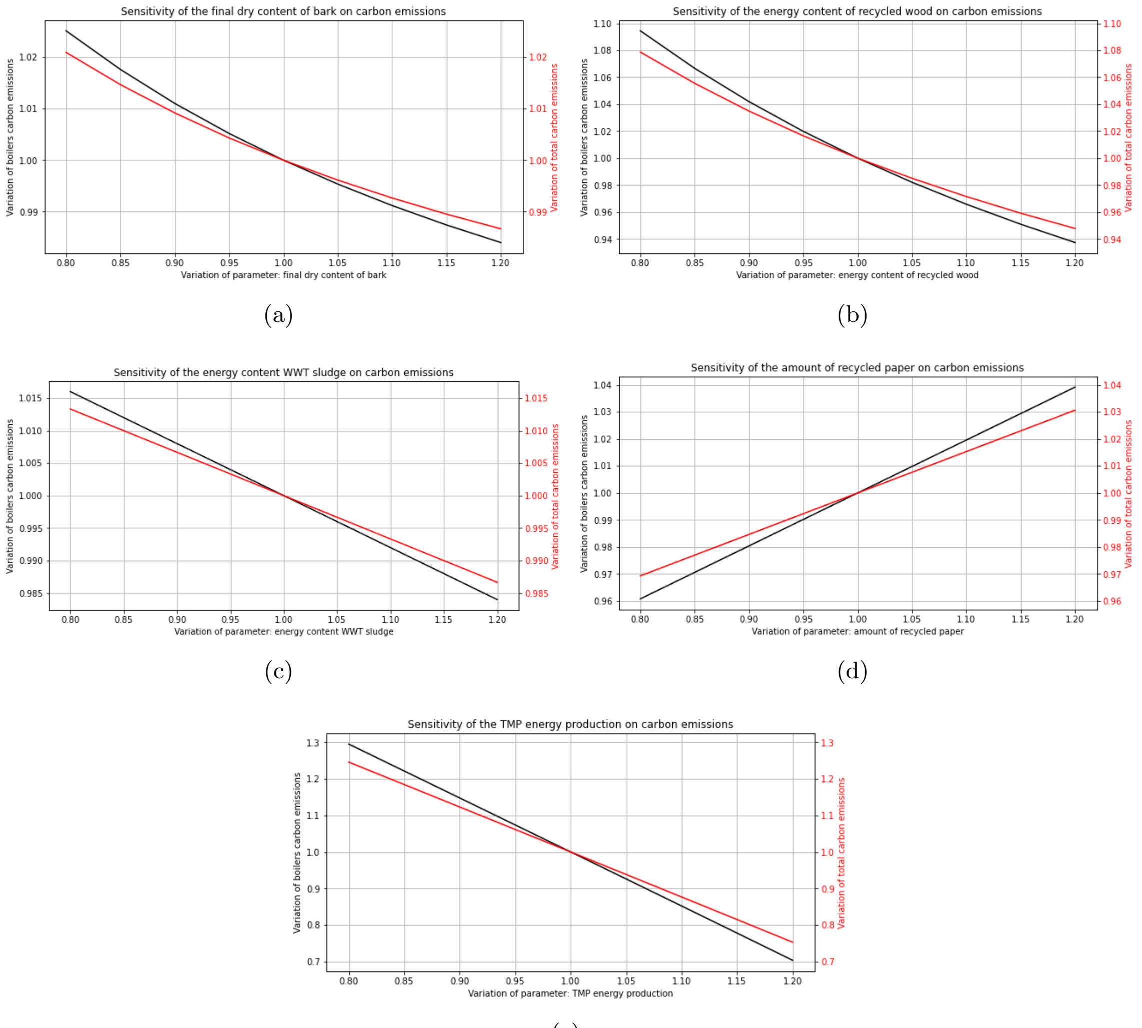
Additionally, removing the recycled paper also removes a significant amount of $CaCO_3$ as input to the boilers, reducing significantly the amount of non-biogenic carbon emitted from the boilers (Figure 12). Whereas $CaCO_3$ is the main source of non-biogenic carbon emissions from the boilers with 59% and 71% of the non biogenic carbon for scenarios Y-50 and Y-80 respectively, it decreases to 4% and 15% for the scenarios N-50 and N-80.

On the other hand, by comparing scenario Y-50 with scenario Y-80 and scenario N-50 with scenario N-80, the impact of drying the bark leads to a reduction of the amount of oil and additional wooden fuel required. The reduction of the oil content in the fuel is due to the high dry content of the bark after drying that significantly decreases the moisture content of the fuel, thus reducing the need for oil. The higher dry content of the bark, increasing its net energy content, leads to a higher associated energy output and a decrease of the need for additional energy sources, hence, a lower need for additional wooden fuel. Both scenarios Y-80 and N-80 in which the bark is dried to a final dry content of 80% only requires the minimum amount of oil needed by the boilers and limit their associated emissions to around 0.1 kt_C.

For both scenarios N-50 and N-80, as shown in Figure 12, the carbon emissions of the boilers reach 99% or more of biogenic nature against 97.6% for the baseline and 97.6% when only the bark is dried. Nonetheless, even if the proportion of biogenic carbon emission in scenario Y-80 is very close to the one for scenario Y-50, there is still a reduction of the total amount of carbon emitted that originates from the oil. In addition, drying the bark reduces the total amount of energy required for the production of steam and thus also decrease the amount of additional wooden fuel needed.

Conjointly for scenario N-50, even if the proportion of non-biogenic carbon is lower than the one for scenario Y-50, the amount of carbon emitted that originates from oil is higher than the other scenarios with around 0.5 kt_C.

3.2.2 Sensitivity



(a)

(b)

(c)

(d)

(e)

Figure 13: Sensitivity of (a) final dry content of bark, (b) energy content of recycled wood, (c) energy content of WWT sludge, (d) amount of recycled paper and (e) energy production of TMP on the carbon emissions of the boilers and the total amount of carbon emissions.

Figure 13 shows the different variations of the boilers' carbon emissions when different parameters varies between -20% and +20%. Whereas four out of the five parameters that have been used for the sensitivity analysis lead to a decrease of the carbon emissions when increased, increasing the amount of recycled paper leads to an increase of carbon emissions.

The variations of the TMP energy production show the greatest sensitivity of the selected parameters on both the total carbon emissions and the carbon emissions of the boilers. This is due to the reduction of the energy demand from the boiler production that is induced by the increase of steam recovery in the TMP. In addition, both the final dry content of bark and the energy content of the recycled wood do not have a linear sensitivity whereas the other parameters have.

Thus, having robust data of the TMP energy recovery is crucial as a slight change of the value can significantly change the output of the model.

In addition, the results from Figure 13 can also be interpreted as how much each parameter has an impact on the final carbon emissions of the mill.

Increasing the different parameters by 20% (or reducing it by 20% for the amount of recycled paper) lead to different reduction in the total carbon emissions: slightly more than 1% for the increase of the final dry content of bark, about 5% for the increase of the energy content of recycled wood, around 1.25% for the increase in the energy content of the WWT sludge, 3% for the decrease in recycled paper and about 25% for the increase of the amount of energy produced by the TMP.

4 Discussion

4.1 Limitation & Robustness

This study is a study case of a specific paper mill in Norway that produces newsprints. The data used was mostly provided by the company itself through their energy and material reporting for the year 2022. By using these values, the quantification of the system represents the mill as it was for the year 2022 and is dependent on the context of this particular year. Most of the data used for the dry matter quantification of the mill are primary data coming from the reports of the mill. thus the results of the first quantification should be quite accurate. On the other hand, the carbon concentrations of the biomass sub-layer of the carbon quantification comes from literature and has been considered as more uncertain than the other values, mechanically reducing the confidence of the carbon quantification.

Nonetheless, the concentration of carbon of the recycled paper sludge that can be calculated with the results of this study (30.9% for a dry basis moisture content of 8.5%) is very similar to the one experimentally found by Strezov and Evans (2009) (30.2% with the same moisture content). This comparison reinforce the choice of the 50% carbon content of the wood products assumption for all the wood-based part of the different goods in the system. The same study also provides the calorific value for this type of sludge. Unfortunately this value cannot be used to compare the value used in this study as the two values are defined at different moisture content. Yet, the energy value used in the current study has been derived from primary data provided by the company. It can be assumed that the value is appropriate.

As the model works by quantifying the dry mass of each flow by deriving transfer coefficients from the first quantification, the uncertainties of the carbon concentration are not spread to the transfer coefficients of the model, thus not increasing the uncertainties of the dry flows. Yet, these uncertainties re-appear when the carbon concentration are re-applied after the calculation of the dry flows.

In addition, by only using yearly aggregated data, the study does not account for the variation in paper production, available resources or energy demand on a shorter time basis. It is important to note that the demand for heat in the mill varies depending on the season (winter will require more heat than summer) and the production of paper. From discussions with the company, it appears that the flows of logs to the system is quite steady, meaning also a constant production of bark. As the amount of bark is the main driver of the final moisture content of the fuel in this study, thus the main driver of oil consumption. If the demand of energy increases during a certain period of the year, an additional amount of oil might be required. Using yearly data will smooth the seasonal variations and the model will not account for these short-time basis differences.

Likewise, this study does not account for the time required to dry the bark. The drying time of the bark has implications on the logistic that must be established with this new process. A steady income of bark will not follow the variations of the demand of heat on short periods. Huttunen et al. (2016) evaluated the drying time of bark at taking around 4 hours to go from a 50% moisture content to a 30% moisture content. These few hours of drying have to be considered in order to minimize the amount of oil used in the boilers. If not enough bark is already dried during a peak of consumption, wet bark or other additional fuel must be used, leading to an increase of the use of oil and/or an additional cost to buy the fuel.

As mentioned previously, this study does not evaluate the electricity consumption of the mill. The demand for electricity in a paper mill is one of the main energy requirement with the demand of heat in a paper mill, especially when the pulping is performed with a thermo-mechanical process (Rogers et al., 2018). In addition, the drying of the bark requires a small amount of electricity as well. The amount varies depending on the type of drying system (Pang and Mujumdar, 2010). This additional electricity demand is not evaluated in this study nor is its price. The study performed by Holmberg and Ahtila (2005) could be adapted to this plant to financially optimize the drying process.

Nevertheless, the electricity consumption is crucial when looking at the environmental footprint of the mill on scope 2 (World Resource Institute, 2004). The environmental footprint of the energy use in the paper industry in Norway is lower than the rest of Europe (Ghose and Chinga-Carrasco, 2013), mitigating the environmental impact of the additional electricity consumption required fro drying bark.

The study does not look into the prices nor the requirement of space that is linked to the implementation of the drying process. Adding a bark drying process to the mill requires funds and space which is a non-negligible parameter when choosing to implement this kind of solution. In addition, once it has been dried, the bark needs to be stored if not used directly. This storage should not be completely open to the exterior, as it usually is with the non dried bark at the mill where the bark is simply piled outside, because the risk of rain falling on the bark will re-increase the moisture content of the bark and negate partially the outcome of the drying process. Additionally, when the bark is stored in piles, its temperature increases over time (Routa et al., 2020). This increase of temperature leads to a higher risk of ignition (Springer et al., 1971).

Hence, it would be required to think about which drying strategies to adopt. If the bark is dried as soon as it is produced, the risk of ignition increases and the need for new infrastructures as well. Yet, if the bark is dried just before being sent to the boilers, a peak of energy demand might lead to the bark not being completely dried and needing more oil. One could try to optimize the logistics with two storage zones, one as it is today, outside with no protection and a second one after the dried is bark, protected from the weather conditions, that needs to be big enough to be used as buffer capacity in the case of a peak of energy demand. A separate material flow analysis could be performed to assess the optimized stock capacity of the two storage zones.

All of the mentions above should be considered by the company and should be the focus of a specific study that addresses these issues.

The robustness of the model is function of the assumptions on which the model has been made. Some of the assumptions made to develop this model can have a significant impact on the robustness. As the model as been developed to match the carbon flows of 2022, it will perform best when using the production values of 2022. Whereas the quantification of the system is mainly built on the 2022 reported values of the company and a few values derived from the 2020 plant level MFA performed by Stránský (2022) for which it can be assumed than the efficiencies of the different process did not change much, the modelling of the mill is based on several other assumptions that can heavily influence the results.

One of the main assumptions in the model is to use energy values derived from the 2020 energy and mass reports of the mill. Yet, the production of the mill has not changed much between the two years and the characteristics of the recycled paper, and by extension, the characteristics of the associated by-products used as fuel, have most likely not changed much either. Thus, re-using the 2020 values should be quite robust.

Nonetheless, the moisture content of the sludge has a significant impact on the energy content of the fuel as it is shown by the great difference in energy content for the recycled paper sludge between the one used in this model and the one found by Strezov and Evans (2009).

Additionally, the values of the concentration of $CaCO_3$ in the recycled paper sludge are important in the energy balance of the boilers. The decomposition of $CaCO_3$ into CaO and CO_2 requires heat. Hence, the more $CaCO_3$ there is in the sludge, the lower the net energy content of the sludge is. Yet, the model assumes that this concentration of $CaCO_3$ in the recycled paper is always the same. The concentration of $CaCO_3$ of the recycled used in this study comes from statistics on a European scale, thus it might not be as precise as statistics on a smaller scale as Norway. Nevertheless, as all the scenarios developed in this model either did not change or completely removed the recycled paper inflow, the impact of this assumption is mitigated for the results of this study.

Another important assumption made when developing this model was made when the relationship between the oil requirement and the moisture content of the fuel was established. It was assumed that the relationship was linear and based on two values. The first value was derived from the energy and mass balance of the boilers in 2022 whereas the second value was defined after a discussion with the manager of the boilers at the mill during which it was considered that if all the bark was dried to a 70% dry content, in the case of the 2022 mass and energy balance, no additional oil would be required to compensate for the loss of combustion temperature. Hence this assumption is not backed by literature but is based on the expertise of the manager of the boilers at the mill.

4.2 Results

The quantifications performed in this study (Figures 6 and 7) provide an overall understanding of the different flows of carbon in the mill from the moment it enters the production line to the moment it leaves it, either under the form of paper or as emissions.

It relevant to notice that most of the carbon directly emitted by the mill are from biogenic sources (either from the logs or the fibers of the recycled fibers). If the quantification of the emissions had been done by following the framework developed by World Resource Institute (2004), none of these biogenic emissions would have been accounted for as scope

1 emissions. The strength of performing a physical accounting of the carbon flows resides in the possibility to easily account for the different types of carbon emissions taking place at the mill. Performing physical accounting has been noted as essential to perform serious environmental management (Bartolomeo et al., 2000). Yet, as indicated by Sun et al. (2018), there is usually an issue of methodology, system definition and carbon neutrality assumption in LCA studies. By quantifying all the flows of carbon, independently from its source (biogenic or non-biogenic), performing a physical accounting of the carbon flows using MFA negates the problem of the carbon neutrality assumption. Nevertheless, whereas LCA has been standardized (ISO ISO 14040:2006, 2006), MFA is not. It is then crucial to pay attention to the system boundaries and assumptions of this study when using the results.

The aim of the modelling of the mill was to evaluate the potential impacts of changing the dryness of bark and the amount of recycled paper on the carbon emissions of the boilers.

The results show that there is a significant potential in decreasing the direct carbon emissions of the mill. Increasing the final content of the bark to 80% has shown its potential in decreasing the amount of carbon emitted by the mill by around 2.1 kt_C. By using the secondary heat of the mill to dry the bark (which would have been lost otherwise), the mill, which has shown a important potential for energy recovery (Émilien Bourgé, 2022), would not only decrease its carbon emissions but increase its energy efficiency and its dependency on oil.

Hence the mill can achieve an increase of energy efficiency as less energy will be lost. And as this energy is used to dry the bark it increases its net calorific content and reduces the need for additional fuel for energy generation, increasing both material efficiency and the related carbon emissions.

The different scenarios and sensitivity analysis performed in the study showed that removing the recycled paper line from the mill would be more effective in reducing the carbon emissions of the mill than simply drying the bark. Nevertheless, this solution presents several drawbacks. First of all, the different scenarios also showed that only removing the recycled paper line from the mill would increase the requirements of oil for the boilers. As the rejects from the recycled paper has been evaluated at a lower moisture content than the non-dried bark, removing this fuel decreases the overall moisture content of the fuel and increases the need for oil, thus increasing the proportion of non-biogenic and fossil carbon emitted by the mill. However, this drawback can be mitigated if other actions that can reduce the final moisture content of the bark can be performed, such as drying the bark. Secondly, if one looks only at this study, it could be conclude that removing the recycled paper line from the mill is better for the environment concerning the carbon emissions as they are reduced. Yet, if the paper is not recycled at this mill, there is a significant risk that this amount of paper will not be recycled must be dealt somewhere else. It has been studied that recycling paper will have a lower environmental impact than burning it for energy recovery or laying it in a landfill (Hong and Li, 2012). If the paper is burnt, it is even possible to assess the amount of additional carbon that will be emitted by the paper that is no longer recycled by the mill as its carbon content as been quantified: 26.9 kt_C, leading to an increse of the overall carbon emission of the global paper cycle. When looking at the global life cycle of paper products, the production of pulp from the recycling of paper has a lower impact than the production of virgin pulp (Sun et al., 2018), further increasing the global impact of paper production. Besides, not recycling paper will also decrease the circularity of the wood and paper industry as it will rely more on raw material.

Also, the recycled paper line plays a significant role in the $CaCO_3$ balance of the system. Whereas most of the $CaCO_3$ inflow as filler is contained in the final paper products, most of the inflow of $CaCO_3$ ends in the boilers and reduces the net energy available. By removing the recycled paper, less $CaCO_3$ ends in the fuel mix of the boiler and increases the net energy availability, thus reducing the need for additional fuel to compensate the loss.

Besides, even though it has not been quantified in this study, reducing the amount of $CaCO_3$ in the boilers will reduce the amount of ash produced. As the decomposition of $CaCO_3$ produces CO_2 that is emitted to the atmosphere, it also produces CaO that is found in the ashes that must be dealt with. Nonetheless, CaO is a chemical compound that is commonly used in several industries. By removing the recycled paper line, this amount of $CaCO_3$ could also end in landfills and increase the environmental impacts of producing additional CaO from $CaCO_3$ from non-circular sources.

Finally, removing the recycled paper line will phase out most of the plastic content sent to the boiler. The only plastic remaining comes from the recycled wood but shares a very small proportion of the total mass input (0.01 %).

The process of drying bark leads to a reduction of the total carbon emissions of the mill and unlike the reduction of recycled paper, the reduction of the carbon emissions of the boiler does not come with an increase of the carbon emissions from the WWT. Even though drying the bark does not appear as the most effective way of reducing the carbon emissions from the boilers (Figure 13), it shows a significant impact on the consumption of oil. As for this model, the bark is the only fuel that is dried and thus can reduce the final moisture content of the fuel without changing the amount of primary fuel from the mill (sludge and bark). The additional oil consumption, that is not used at the boilers start up, can be completely phased out if the bark is dried to around 75% dry content. This reduction of oil leads to a reduction of the amount of fossil carbon that is emitted by the mill and increases the proportion of biogenic carbon in the total carbon emissions.

Yet, this result is very dependent on the nature of the energy used to dry the bark. Given that the model uses secondary heat to dry the bark there is no additional energy for the boilers. Besides, as the current amount of secondary used that is not used is quite important, the drying of the bark does not consume all of it. The mill could also consider using it to either further dry the bark to even lower moisture contents, on the other hand requiring more time to dry it, or to use the heat to dry the other sludge going to the boilers to gain a higher energy content out of it and further reducing the amount of additional recycled wood as fuel for the boilers, reducing at the same time the amount of plastic burnt.

There are other solutions to reduce the amount of carbon emissions without reducing the production of paper, one of them being increasing the amount of energy recovered by the TMP.

The TMPs are the main source of steam of the mill. The important amount of electrical energy used to refine the chips into fiber can be partially recovered as steam. The maximum theoretical recovery rate of the TMP process varies between 61% for single disc refiners and 79% for double discs refiners. The mill at Skogn uses a single disc refiner and reported a recovery rate of 49% on average for 2022. As pinpointed by Émilien Bourgé (2022), there is a significant potential to improve the energy efficiency of the mill by increasing the recovery rate of the TMPs. Additionally, increasing their recovery rates also reduces the demand of steam from the boilers and thus the need for additional fuel. As shown in Figure 13, an increase of 20% of the energy from the steam produced by the TMP could lead to a decrease of about 25% of the carbon emitted by the boilers due to the reduction of fuel requirements.

Besides, an increase of 20% of the energy production of the TMP as used in the sensitivity analysis represents a recovery rate of 58%. Hence, it is even theoretically possible to further reduce the amount of carbon emitted by the boilers by reaching recovery rates close to the maximum of 61% with single discs refiners. Higher recovery rates could be achieved but would demand a change of technology used by the TMP by changing the single disc refiners with double discs refiners.

The model developed in this study considers that all the sludge is used in the boilers. As it is a common practice to dispose of sludge in boilers, there are other use of it that can have a lower impact on the environment. First, the sludge is composed of organic matter that and is usually digested in an anaerobic treatment (Meyer and Edwards, 2014) and produces biogas. A study performed by Mohammadi et al. (2019) assessed the different environmental impacts of different disposal solution for paper mills' sludge and concluded that performing an anaerobic digestion of the sludge to perform biogas had better environmental performances than a simple incineration. Additionally, the same study also assessed that an other possibility of treating the sludge: pyrolyzing the sludge to produce biochar that outperformed the other two solutions when comparing the environmental impacts.

Finally, the sludge could also be used to produce compost (Evanylo and Daniels, 1999) as there is a significant amount of Nitrogen that can be used as a nutrient for crop growth.

Moreover, the combustion of biomass is responsible for the emissions of NO_x (Lee et al., 1997). Even thought the aim of this study is to reduce the amount of carbon emitted by the mill, most of the solutions found in this study affects the amount of fuel used in the boilers. As the fuel used by the boiler comprises mostly of biomass, the amount of NO_x produced by its combustion would also be reduced.

As this study is a study case of one specific paper mill, the results are related to it, though the trend should be similar for other mills that share similar characteristics. Nonetheless, the methodology used in this study is not linked to this paper mill and could be used for other study cases. Similarly, this study focuses on the flows of carbon inside the mill to assess the different emissions and ways to reduce them, the same approach can be performed to assess other chemical compound of interest such as nitrogen.

As it has been noted in this study, the removal of recycled paper lines in mills will most likely increase the global carbon footprint of the paper industry. A material flow analysis of the carbon flows of the paper industry on a broader scale could assess this impact.

5 Conclusion

This study performed a material flow analysis to quantify the carbon flows of a paper mill. A model of the mill was developed by using the previous quantification in order to assess ways of reducing the carbon emissions of the mill.

Several possibilities have emerged from the study in order to reduce the direct carbon emissions. The removal of the recycled paper line of the mill will lead to significant reductions of carbon emissions from the boilers. Nevertheless, this solution is only adequate when only looking at the emissions of the mill. The removal of the recycled paper line will decrease the global circularity of the paper industry and will shift the carbon burden of the end-of-life treatment of paper to another entity. The removal of recycled fibers will lead to an increase of the requirements for virgin fibers and increase the impact of the mill on natural resources.

Using the secondary heat of the mill to dry the bark will increase its energy content and reduce the need for external fuel. The main advantage of it remains in its potential to phase out the use of fossil fuel in the boilers and increase the proportion of biogenic emissions.

Additionally, drying bark not only reduces the direct carbon emissions of the mill, it also increases the overall energy and material efficiency of the mill.

The current model developed for this study could be refined by better assessing the relationship between the need for oil in the boiler as a function of the average moisture content of the fuel used.

As the results of this study is mainly useful for the company owning the mill, the methodology can be applied on any system and is not restricted to the pulp and paper industry.

The study also provides an example of how material flow analysis can be used as a carbon accounting tool and how MFA can be combined with other methods (in this case, combining MFA with the energy consumption of the mill) to provide better insights for industries and decision makers.

Finally, this study is a study case of a Norwegian paper mill and only assess the effects of several solutions on the direct emissions. Further research should be conducted to assess the other implications of said solutions such as the cost or the other associated impacts.

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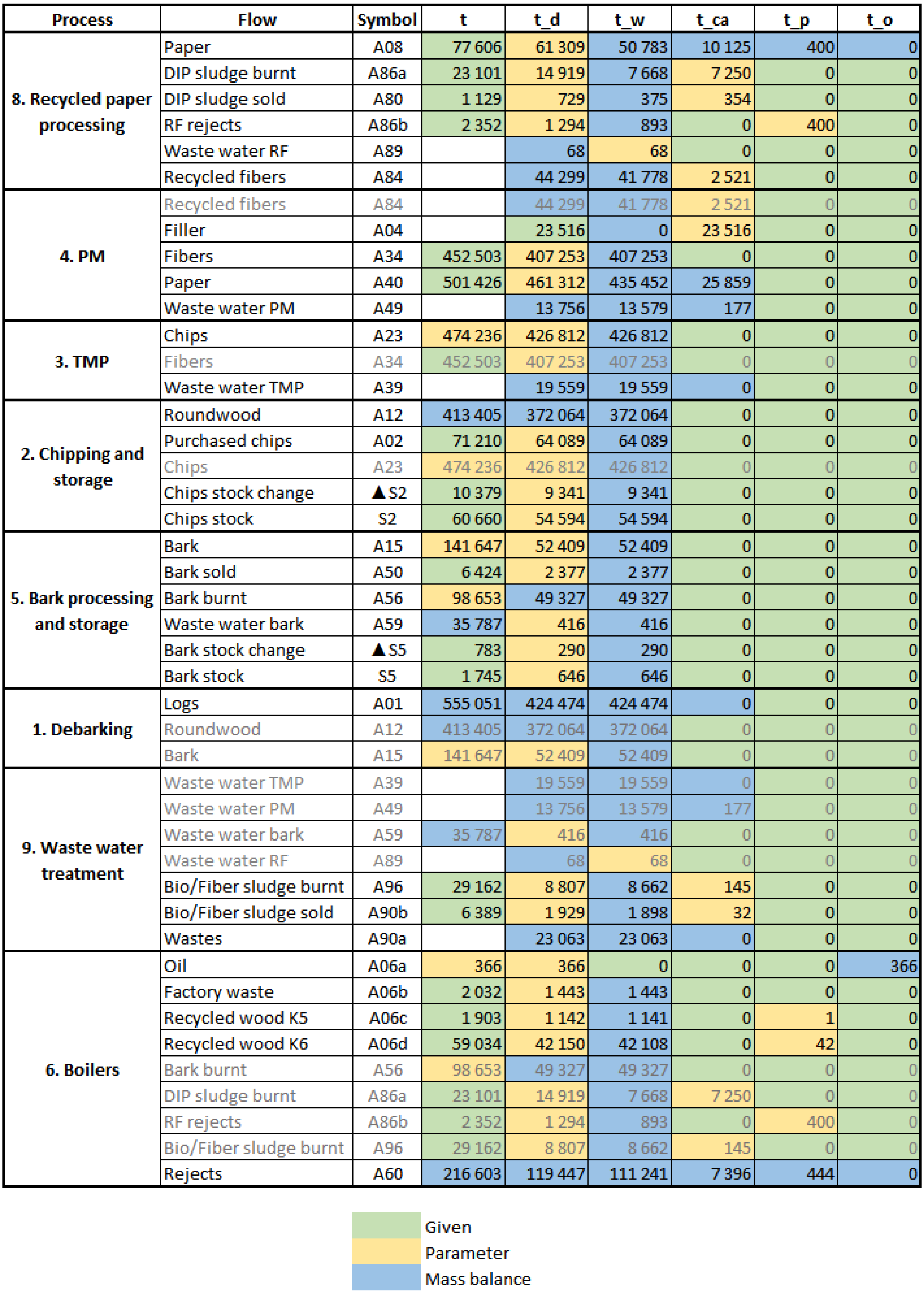
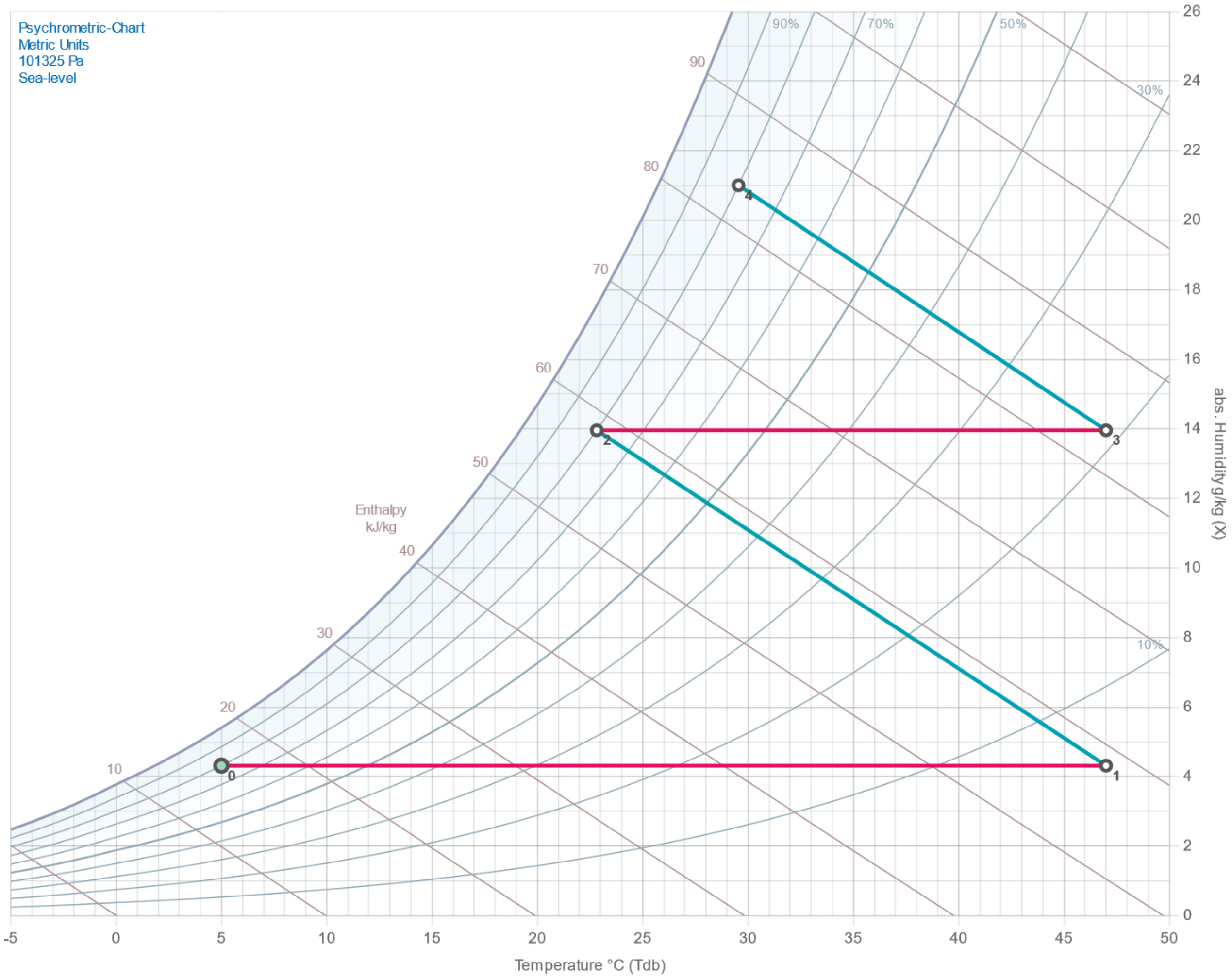
Appendix



Process	Flow	Symbol	t	t_d	t_w	t_ca	t_p	t_o
8. Recycled paper processing	Paper	A08	77 606	61 309	50 783	10 125	400	0
	DIP sludge burnt	A86a	23 101	14 919	7 668	7 250	0	0
	DIP sludge sold	A80	1 129	729	375	354	0	0
	RF rejects	A86b	2 352	1 294	893	0	400	0
	Waste water RF	A89		68	68	0	0	0
	Recycled fibers	A84		44 299	41 778	2 521	0	0
4. PM	Recycled fibers	A84		44 299	41 778	2 521	0	0
	Filler	A04		23 516	0	23 516	0	0
	Fibers	A34	452 503	407 253	407 253	0	0	0
	Paper	A40	501 426	461 312	435 452	25 859	0	0
	Waste water PM	A49		13 756	13 579	177	0	0
3. TMP	Chips	A23	474 236	426 812	426 812	0	0	0
	Fibers	A34	452 503	407 253	407 253	0	0	0
	Waste water TMP	A39		19 559	19 559	0	0	0
2. Chipping and storage	Roundwood	A12	413 405	372 064	372 064	0	0	0
	Purchased chips	A02	71 210	64 089	64 089	0	0	0
	Chips	A23	474 236	426 812	426 812	0	0	0
	Chips stock change	▲S2	10 379	9 341	9 341	0	0	0
	Chips stock	S2	60 660	54 594	54 594	0	0	0
5. Bark processing and storage	Bark	A15	141 647	52 409	52 409	0	0	0
	Bark sold	A50	6 424	2 377	2 377	0	0	0
	Bark burnt	A56	98 653	49 327	49 327	0	0	0
	Waste water bark	A59	35 787	416	416	0	0	0
	Bark stock change	▲S5	783	290	290	0	0	0
	Bark stock	S5	1 745	646	646	0	0	0
1. Debarking	Logs	A01	555 051	424 474	424 474	0	0	0
	Roundwood	A12	413 405	372 064	372 064	0	0	0
	Bark	A15	141 647	52 409	52 409	0	0	0
9. Waste water treatment	Waste water TMP	A39		19 559	19 559	0	0	0
	Waste water PM	A49		13 756	13 579	177	0	0
	Waste water bark	A59	35 787	416	416	0	0	0
	Waste water RF	A89		68	68	0	0	0
	Bio/Fiber sludge burnt	A96	29 162	8 807	8 662	145	0	0
	Bio/Fiber sludge sold	A90b	6 389	1 929	1 898	32	0	0
	Wastes	A90a		23 063	23 063	0	0	0
6. Boilers	Oil	A06a	366	366	0	0	0	366
	Factory waste	A06b	2 032	1 443	1 443	0	0	0
	Recycled wood K5	A06c	1 903	1 142	1 141	0	1	0
	Recycled wood K6	A06d	59 034	42 150	42 108	0	42	0
	Bark burnt	A56	98 653	49 327	49 327	0	0	0
	DIP sludge burnt	A86a	23 101	14 919	7 668	7 250	0	0
	RF rejects	A86b	2 352	1 294	893	0	400	0
	Bio/Fiber sludge burnt	A96	29 162	8 807	8 662	145	0	0
	Rejects	A60	216 603	119 447	111 241	7 396	444	0

🟩	Given
🟨	Parameter
🟦	Mass balance

Dry matter flow quantification



www.Psych-Chart.com - No responsibility for the calculated values

Point Values

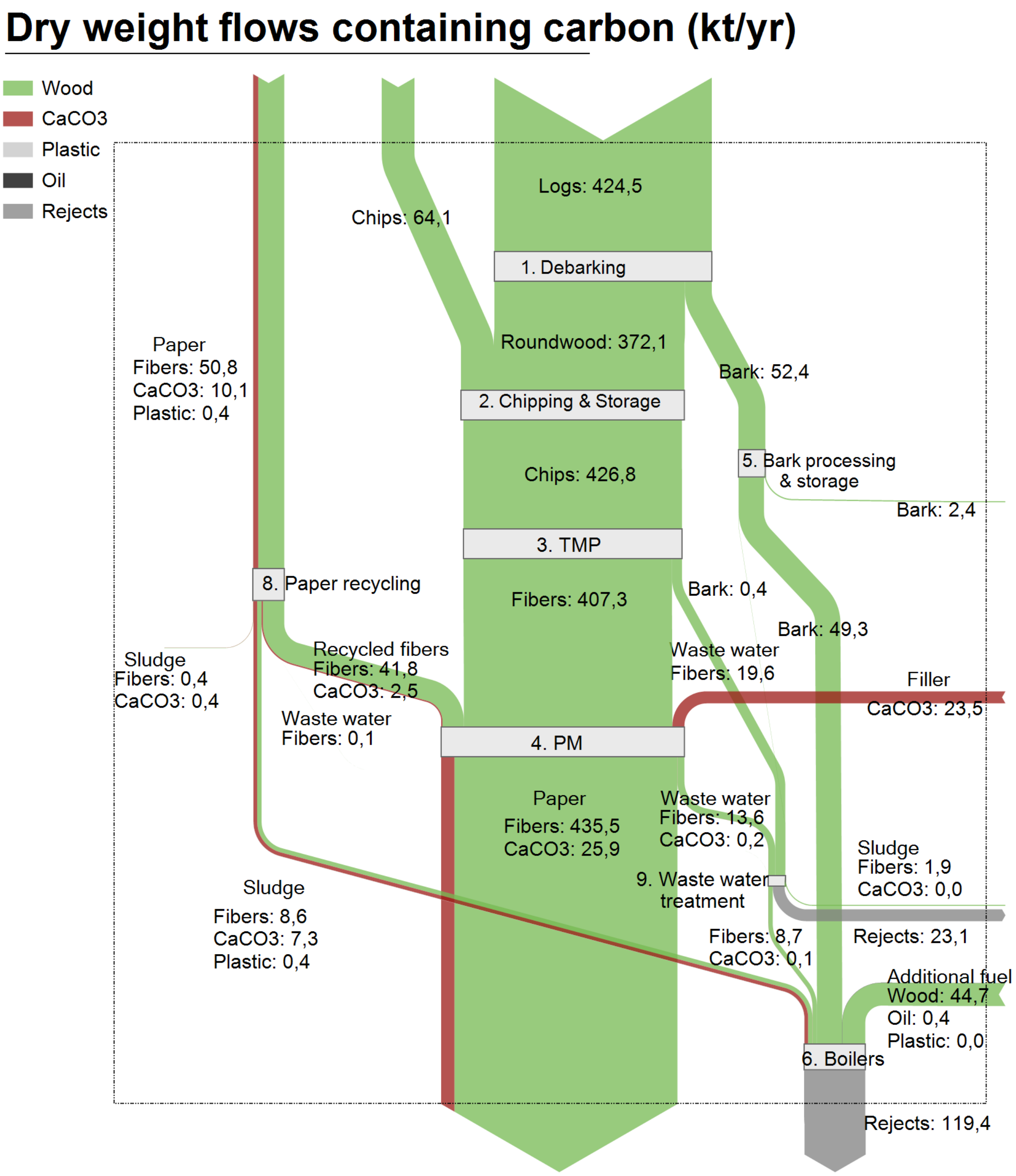
Point	Tdb [°C]	Twb [°C]	Tdew [°C]	X [g/kg]	H [kJ/kg]	RH [%]	ρ [kg/m^3]	Pv [Pa]
0	5	3.6	1.8	4.3	15.9	80	1.266	698
1	47	20.3	1.8	4.3	58.4	6.6	1.1	698
2	22.8	20.3	19.2	14	58.4	80	1.183	2224
3	47	26.6	19.2	14	83.4	20.9	1.093	2224
4	29.6	26.6	25.7	21	83.4	80	1.152	3310

Process Δ-Changes

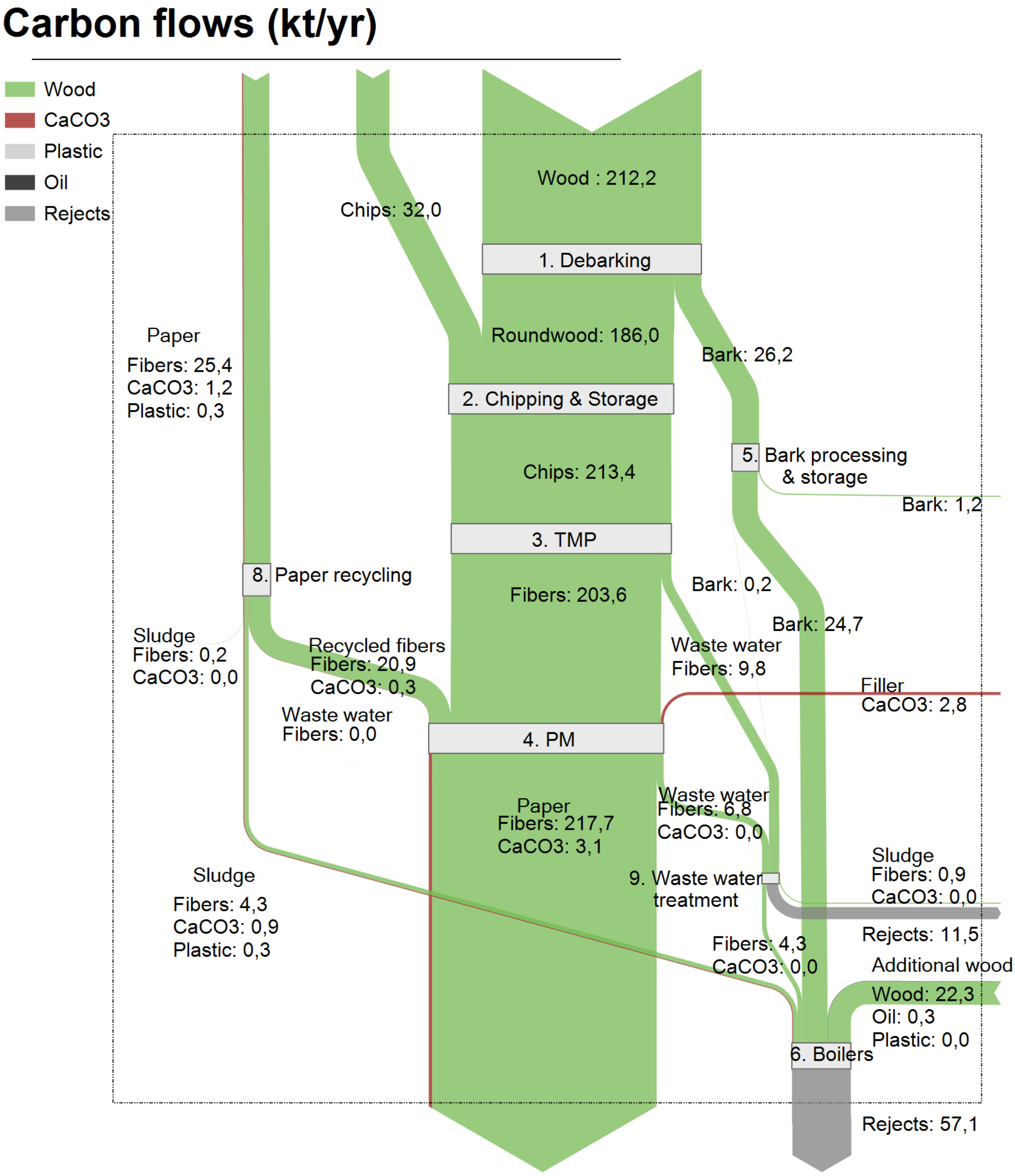
Process	Action	ΔT [°C]	ΔX [g/kg]	ΔX [l/h]	ΔH [kJ/kg]	Power ΔH [kW]	Power ΔT [kW-T]
0-1	**Heat**	**42**	**0**	**0**	**42.6**	**139.9**	**139.9**
1-2	**Humidify**	**-24.2**	**9.6**	**110.4**	**0**	**0**	**-77.7**
2-3	**Heat**	**24.2**	**0**	**0**	**24.9**	**78.8**	**78.8**
3-4	**Humidify**	**-17.4**	**7**	**79.3**	**0**	**0**	**-56.1**

Processes are calculated with: 10000m^3/h

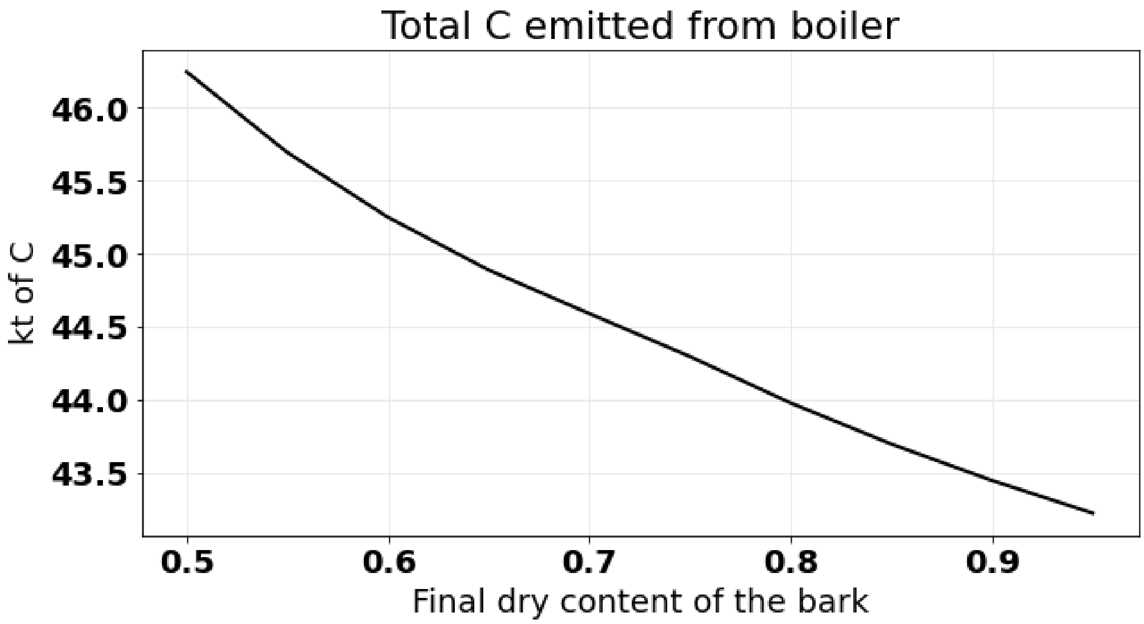
Tdb = Dry Bulb Temperature
Twb = Wet bulb Temperature
Tdew = Dew point Temperature
X = Absolute Humidity
H = Enthalpy
RH = Relative Humidity
ρ = Air Density
Pv = Vapor Pressure

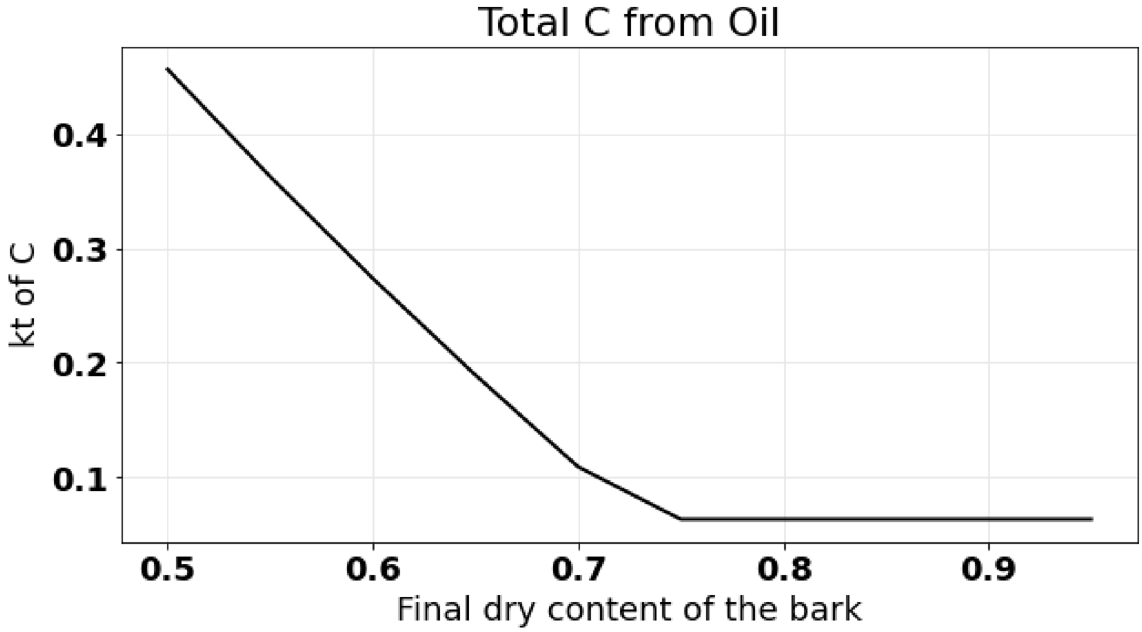


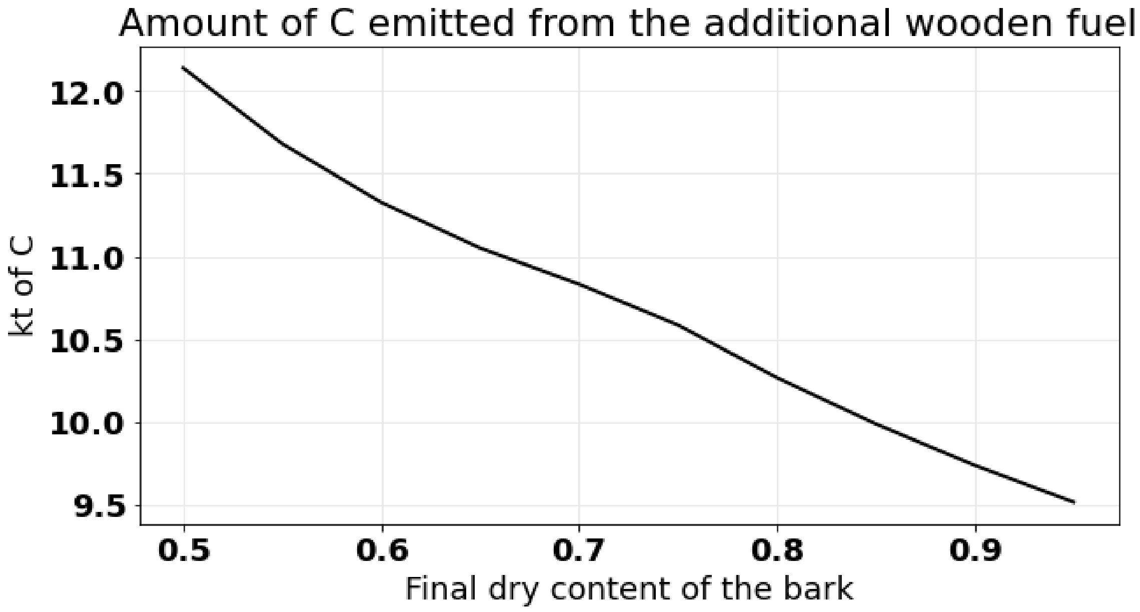
Dry flows quantification

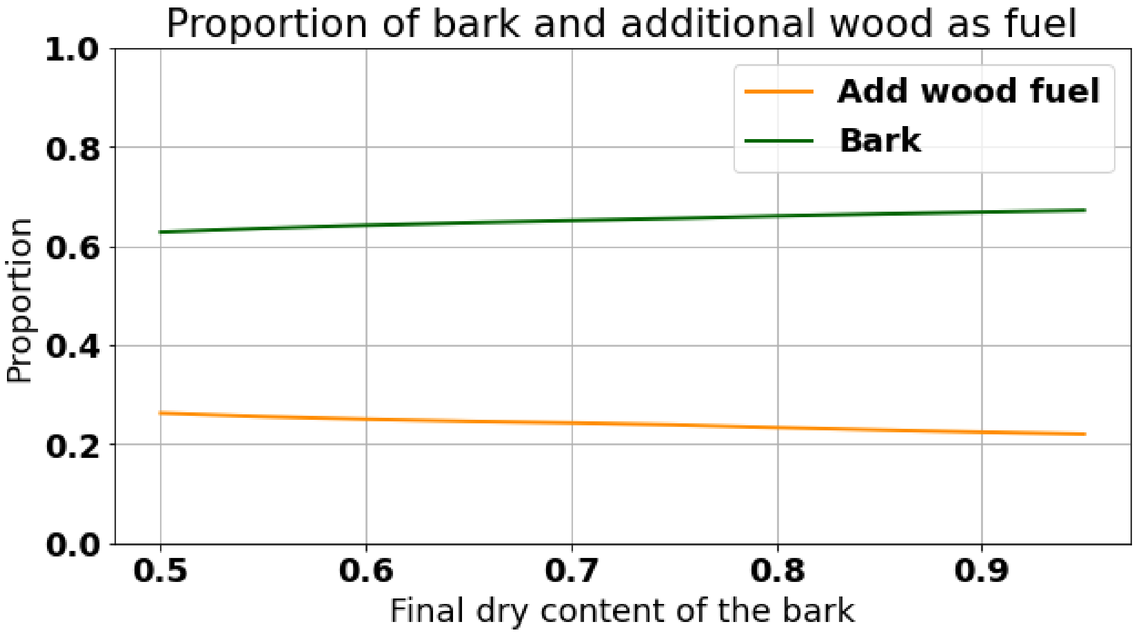


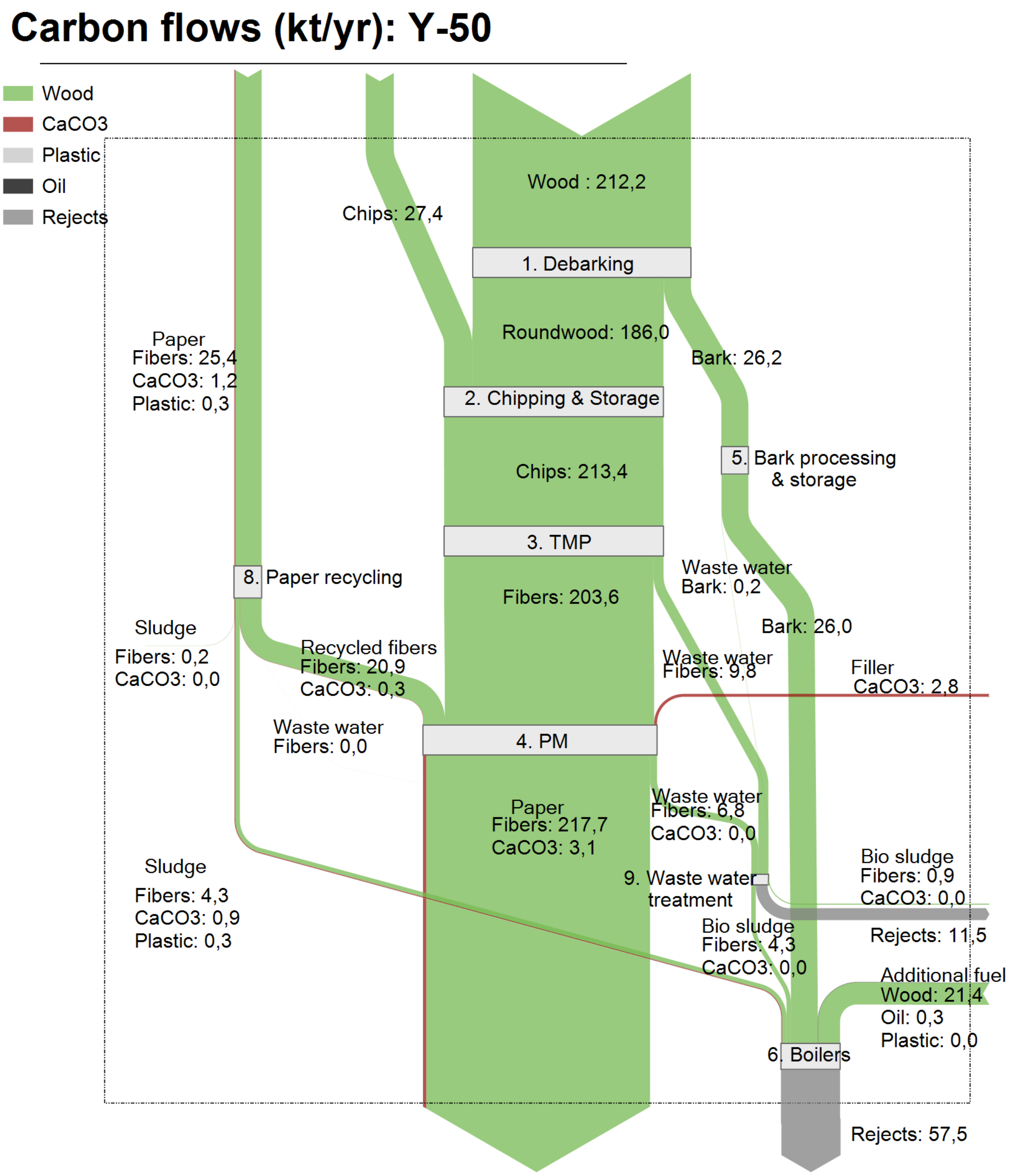
Carbon flows quantification


Total C emitted from boiler
kt of C
46.0
45.5
45.0
44.5
44.0
43.5
0.5
0.6
0.7
0.8
0.9
Final dry content of the bark

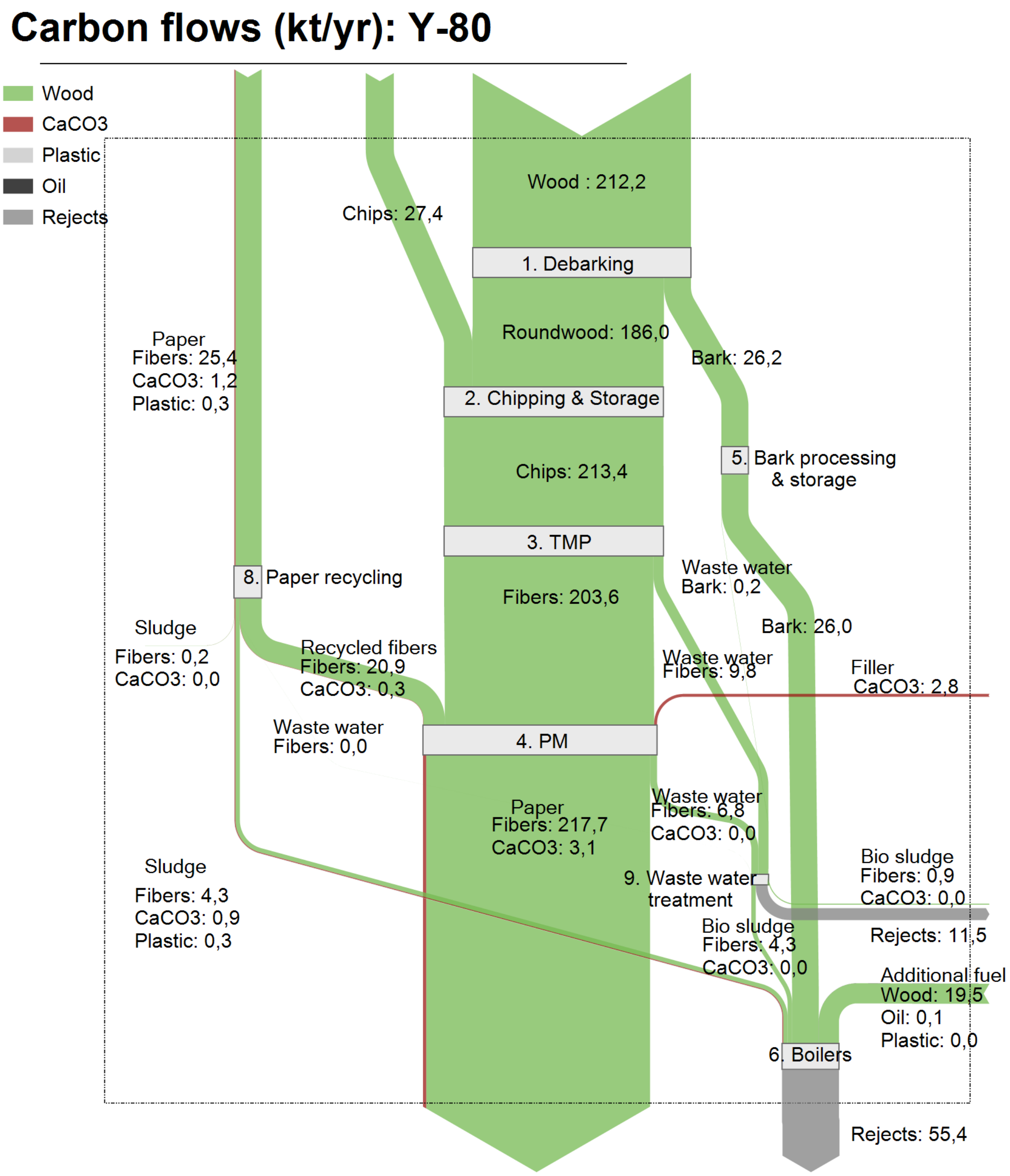

Total C from Oil
kt of C
0.4
0.3
0.2
0.1
0.5
0.6
0.7
0.8
0.9
Final dry content of the bark


Amount of C emitted from the additional wooden fuel
kt of C
12.0
11.5
11.0
10.5
10.0
9.5
0.5
0.6
0.7
0.8
0.9
Final dry content of the bark

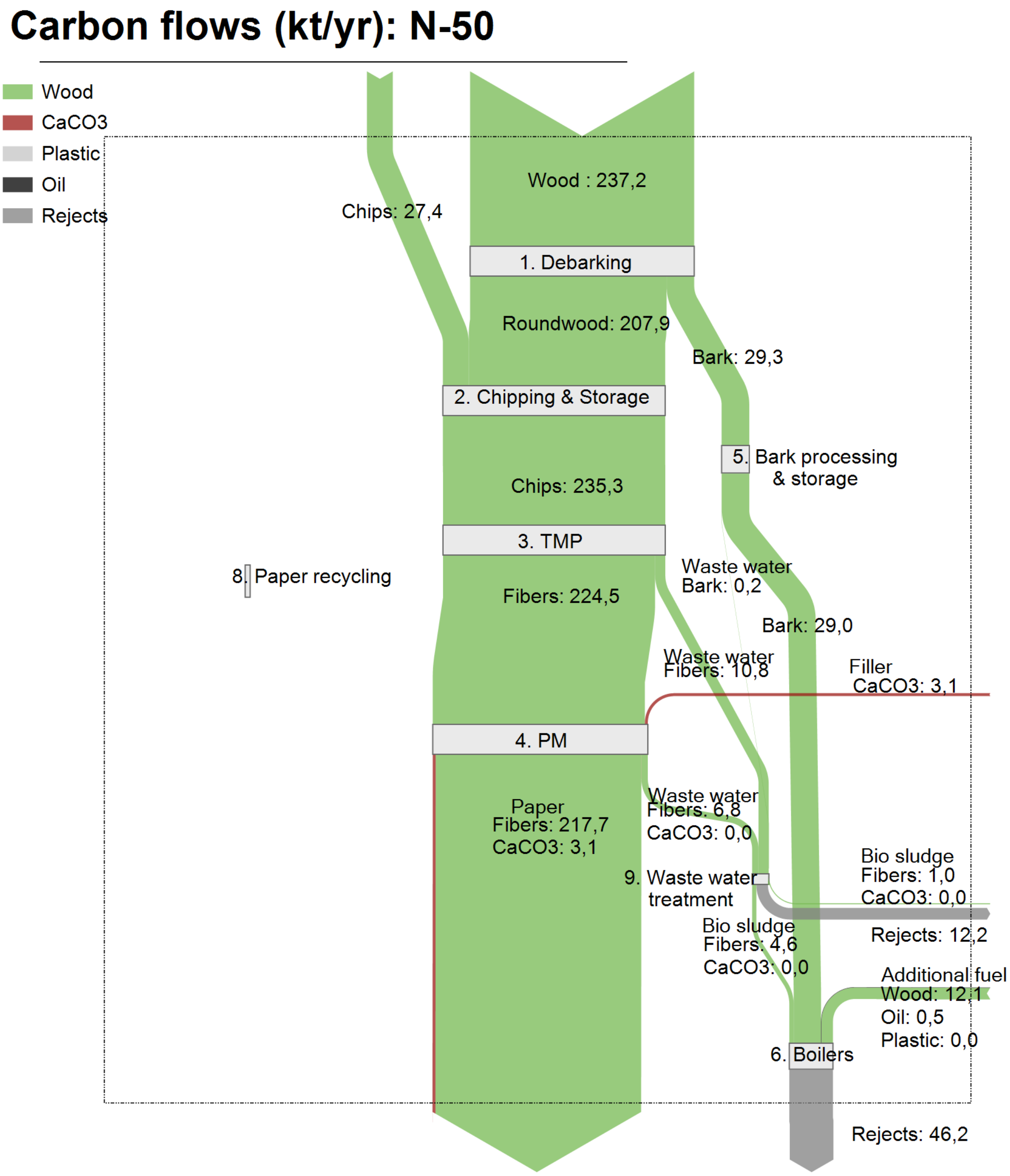

Proportion of bark and additional wood as fuel
Add wood fuel
Bark
Proportion
1.0
0.8
0.6
0.4
0.2
0.0
0.5
0.6
0.7
0.8
0.9
Final dry content of the bark



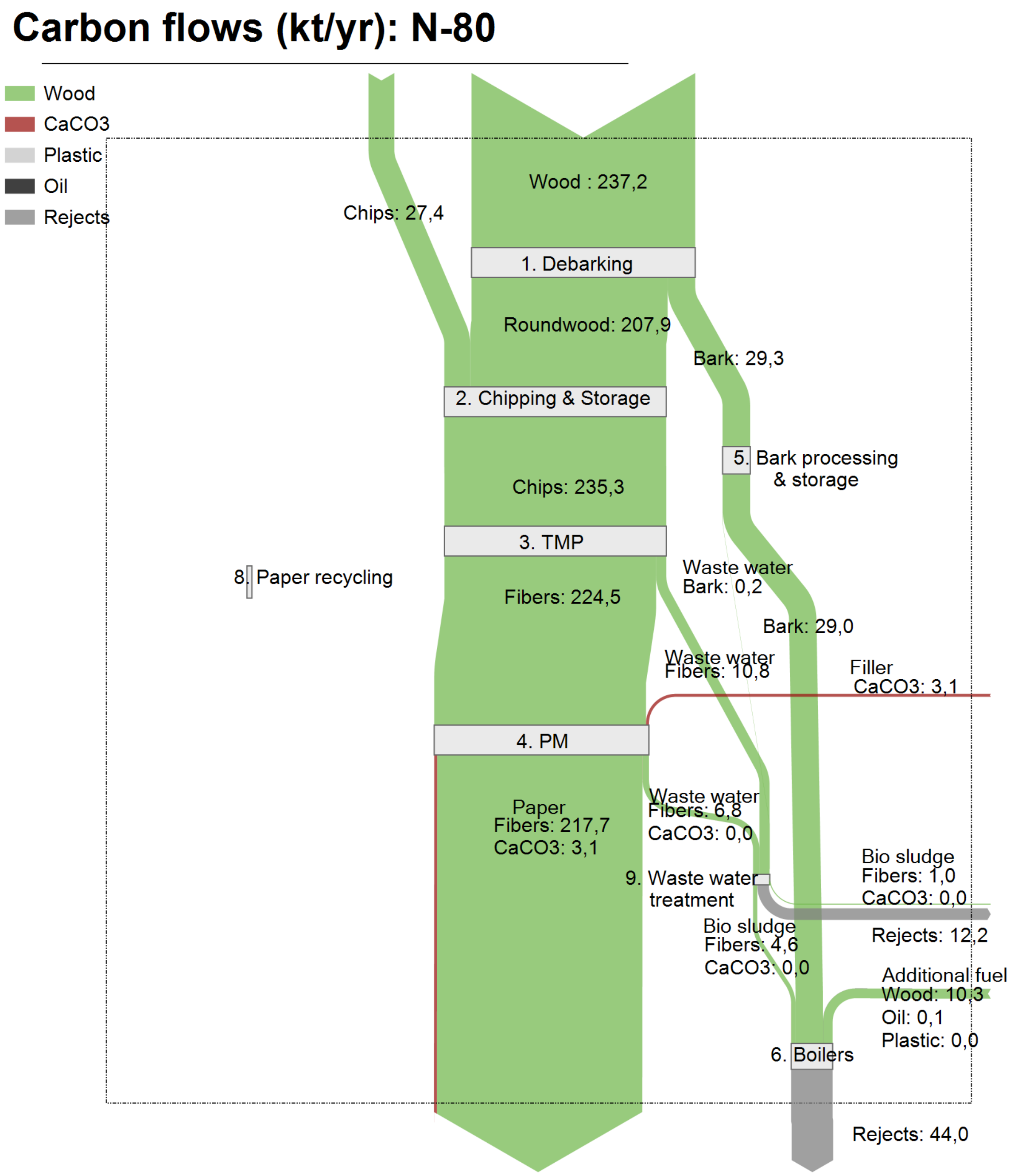
Y-50 carbon quantification



Y-80 carbon quantification

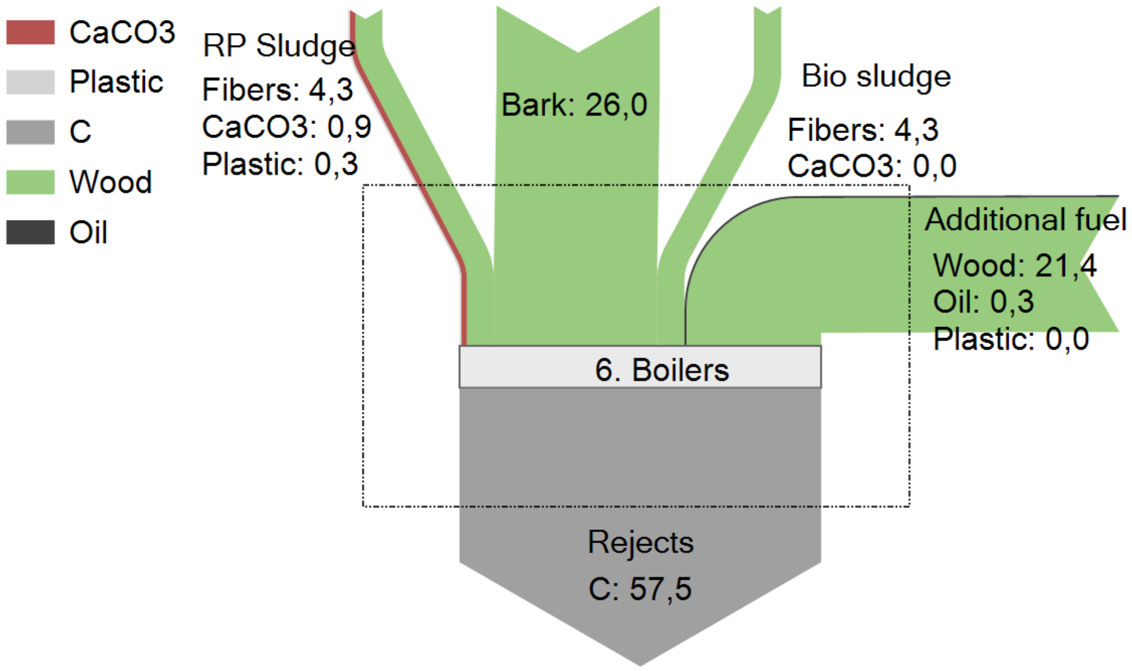


N-50 carbon quantification

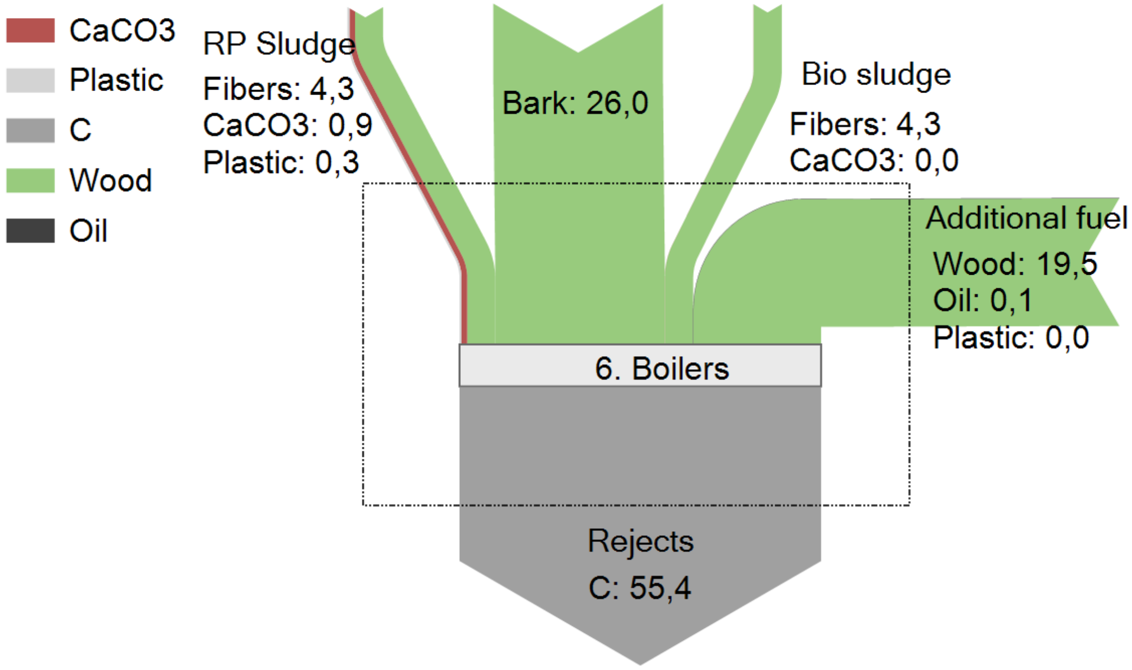


N-80 carbon quantification

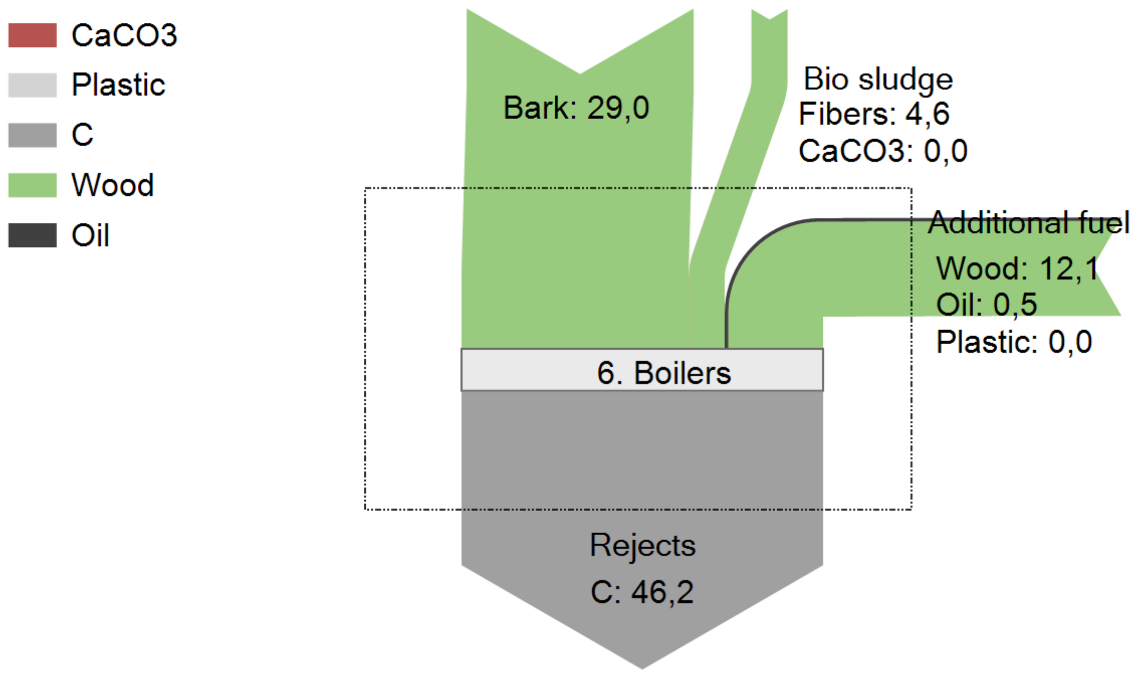
Boilers carbon flows (kt/yr): Y-50



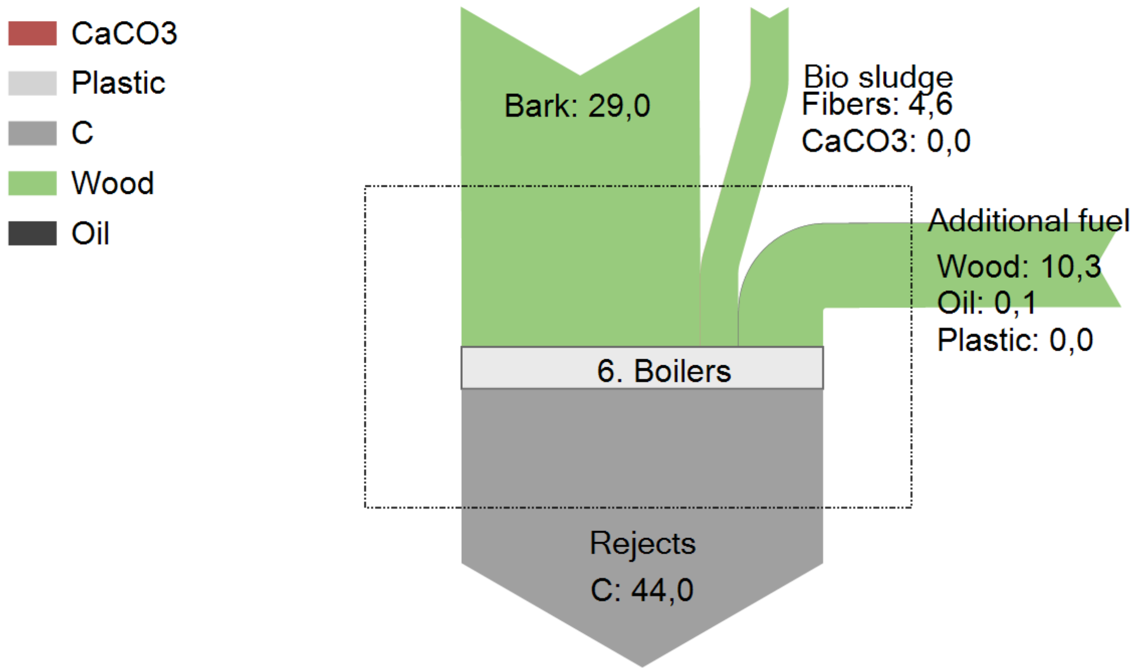
Boilers carbon flows (kt/yr): Y-80

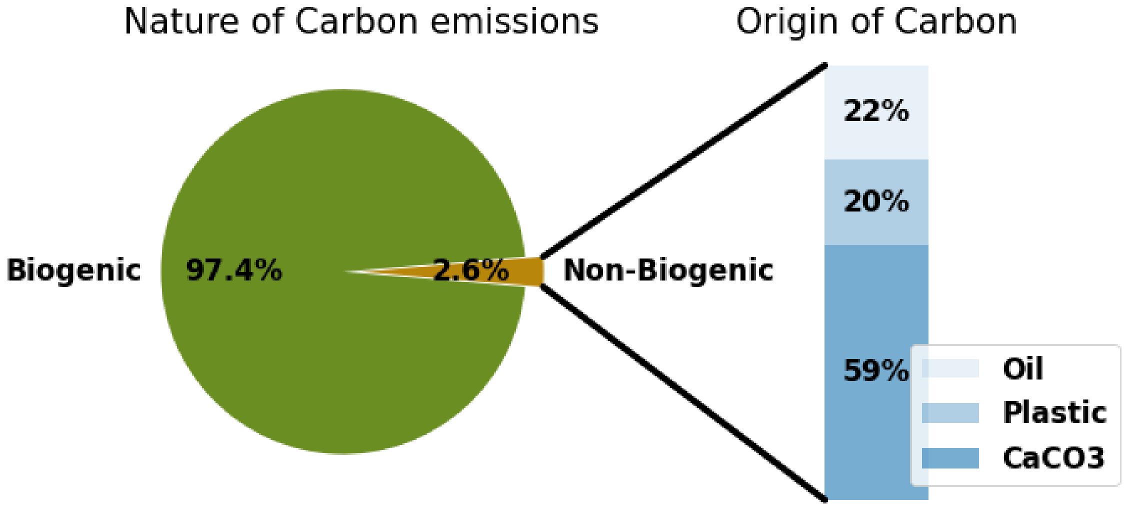


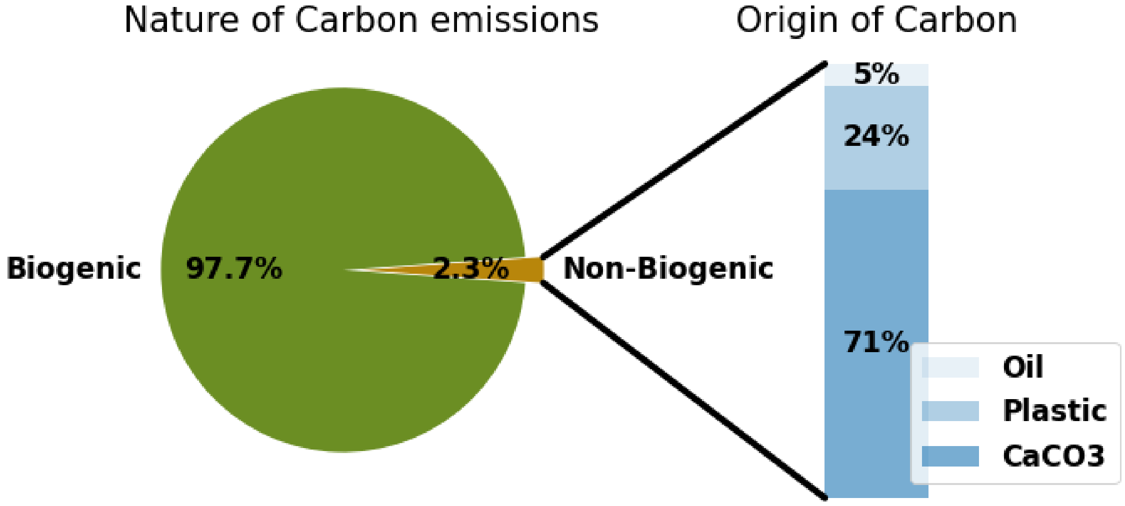
Boilers carbon flows (kt/yr): N-50

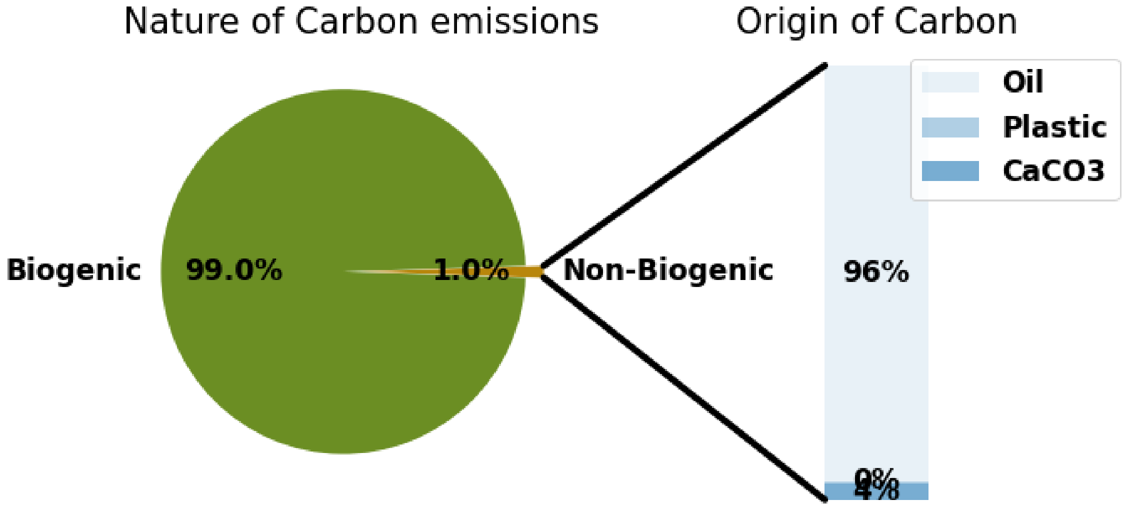


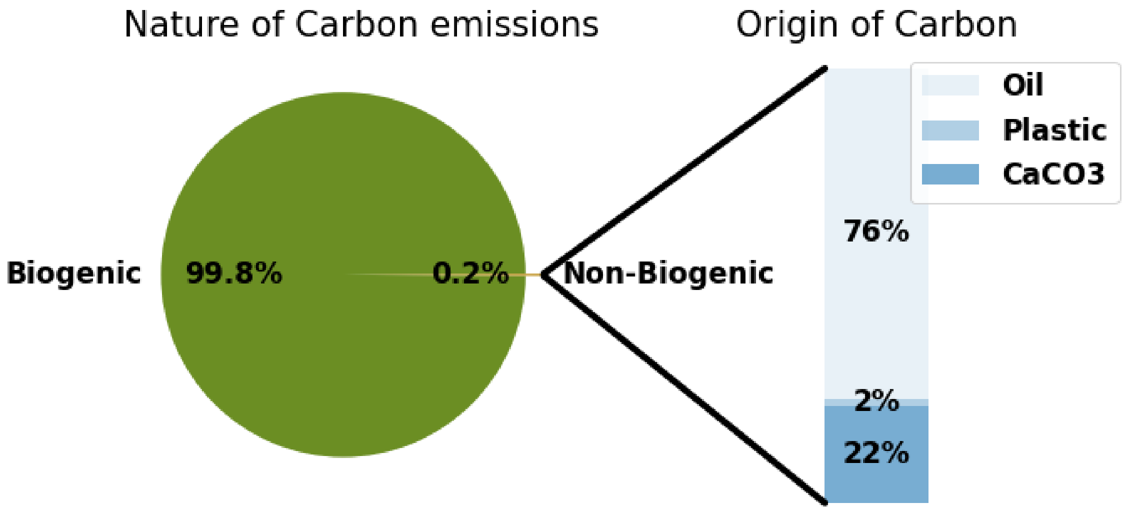
Boilers carbon flows (kt/yr): N-80

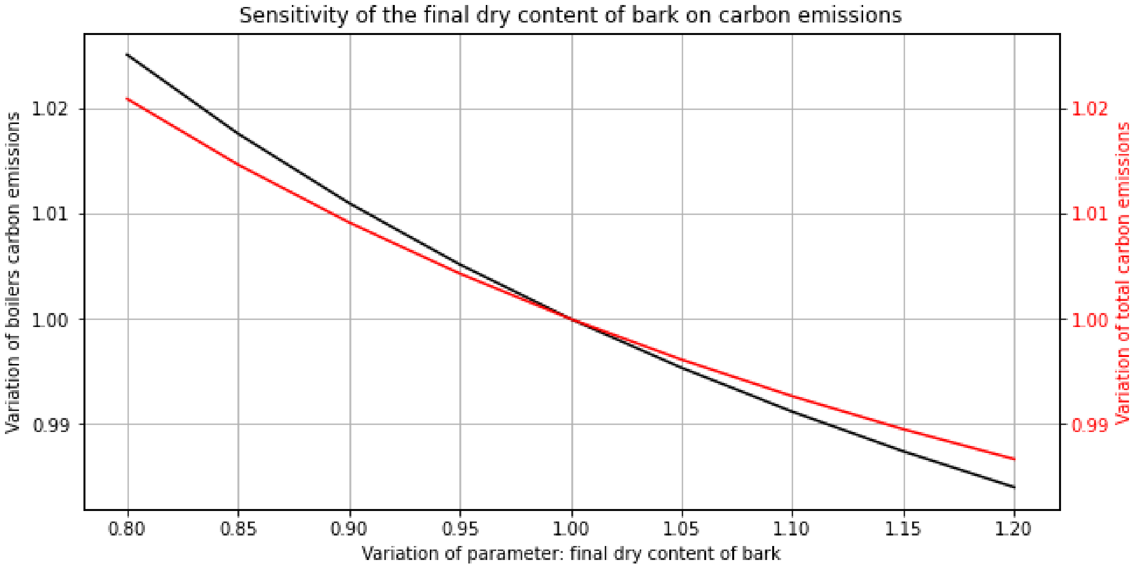


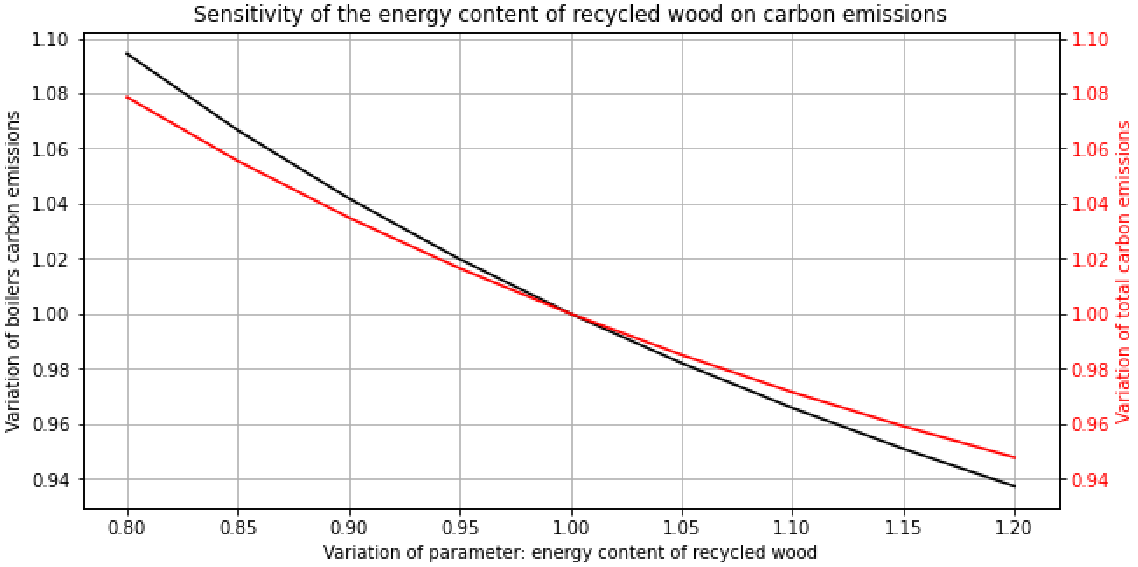

Nature of Carbon emissions
Origin of Carbon
Biogenic
97.4%
2.6%
Non-Biogenic
22%
20%
59%
Oil
Plastic
CaCO3

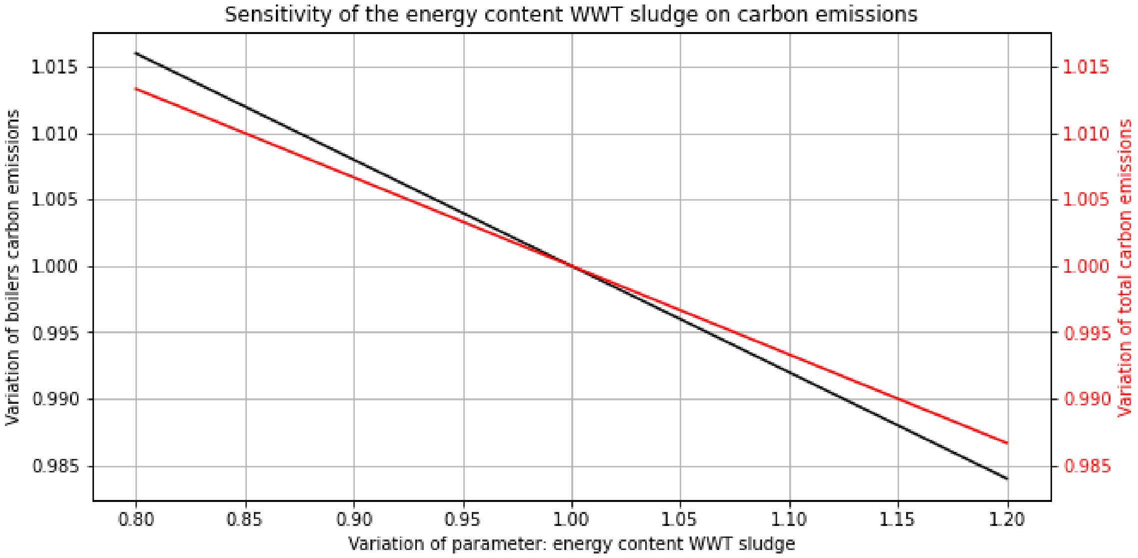

Nature of Carbon emissions
Origin of Carbon
Biogenic
97.7%
2.3%
Non-Biogenic
5%
24%
71%
Oil
Plastic
CaCO3

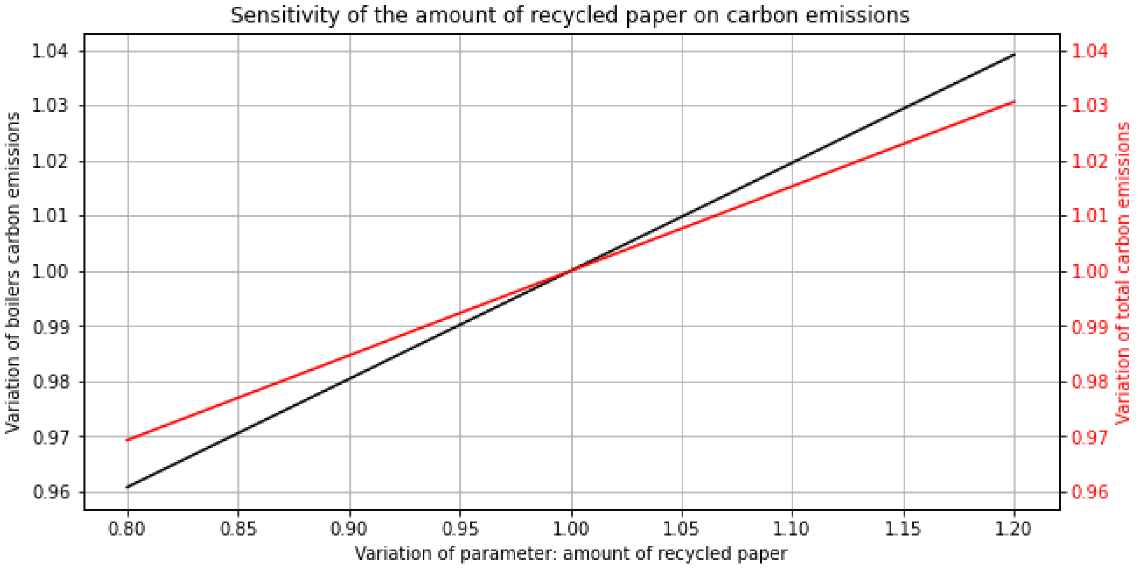

Nature of Carbon emissions
Origin of Carbon
Oil
Plastic
CaCO3
Biogenic
99.0%
1.0%
Non-Biogenic
96%
0%
4%

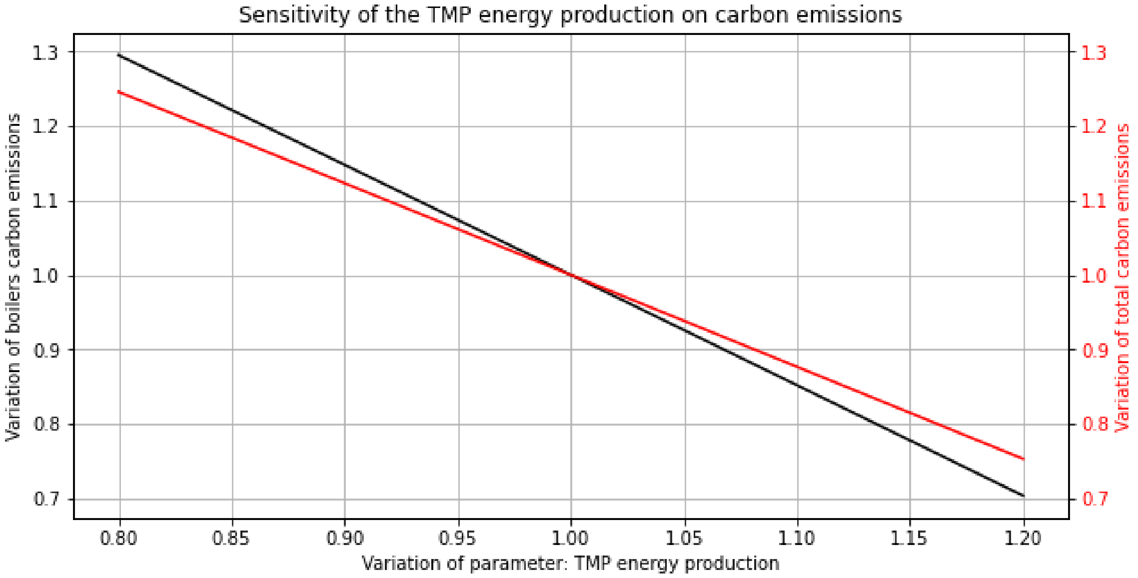

Nature of Carbon emissions
Origin of Carbon
Biogenic
99.8%
0.2%
Non-Biogenic
Oil
Plastic
CaCO3
76%
2%
22%


Sensitivity of the final dry content of bark on carbon emissions
Variation of boilers carbon emissions
Variation of total carbon emissions
0.99
1.00
1.01
1.02
0.80
0.85
0.90
0.95
1.00
1.05
1.10
1.15
1.20
Variation of parameter: final dry content of bark


Sensitivity of the energy content of recycled wood on carbon emissions
Variation of boilers carbon emissions
Variation of total carbon emissions
0.94
0.96
0.98
1.00
1.02
1.04
1.06
1.08
1.10
0.80
0.85
0.90
0.95
1.00
1.05
1.10
1.15
1.20
Variation of parameter: energy content of recycled wood


Sensitivity of the energy content WWT sludge on carbon emissions
Variation of boilers carbon emissions
Variation of total carbon emissions
0.985
0.990
0.995
1.000
1.005
1.010
1.015
0.80
0.85
0.90
0.95
1.00
1.05
1.10
1.15
1.20
Variation of parameter: energy content WWT sludge


Sensitivity of the amount of recycled paper on carbon emissions
Variation of boilers carbon emissions
Variation of total carbon emissions
1.04
1.03
1.02
1.01
1.00
0.99
0.98
0.97
0.96
0.80
0.85
0.90
0.95
1.00
1.05
1.10
1.15
1.20
Variation of parameter: amount of recycled paper


Sensitivity of the TMP energy production on carbon emissions
Variation of boilers carbon emissions
Variation of total carbon emissions
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.80
0.85
0.90
0.95
1.00
1.05
1.10
1.15
1.20
Variation of parameter: TMP energy production

VT Energiforbruk månedsrapport

		01/2022	02/2022	03/2022	04/2022	05/2022	06/2022	07/2022	08/2022	09/2022	10/2022	11/2022	12/2022	
		JANUAR	FEBRUAR	MARS	APRIL	MAI	JUNI	JULI	AUGUST	SEPTEMBER	OKTOBER	NOVEMBER	DESEMBER	Gj.snitt
1.2 Spesifikt varmeforbruk PM1	MWh/t	1,03	1,04	1,14	1,19	1,11	1,13	1	1,01	1,04	1,04	1,11	1,18	**1,08**
2.2 Spesifikt varmeforbruk PM2	MWh/t	1,19	1,27	1,18	1,18	1,19	1,22	1,15	1,13	1,13	1,21	1,2	1,32	**1,2**
3.2 Spesifikt varmeforbruk PM3	MWh/t	1,1	1,1	1,17	1,17	1,06	1,11	0,99	1,09	1,14	1,1	1,22	1,32	**1,13**

		01/2022	02/2022	03/2022	04/2022	05/2022	06/2022	07/2022	08/2022	09/2022	10/2022	11/2022	12/2022	
		JANUAR	FEBRUAR	MARS	APRIL	MAI	JUNI	JULI	AUGUST	SEPTEMBER	OKTOBER	NOVEMBER	DESEMBER	Sum
1.1 Brutto produksjon PM1	tonn	14 223	12 759	13 975	12 829	14 248	9 764	13 152	13 534	13 568	12 650	11 396	12 515	**154 614**
1.3 Energi damp tørkeparti PM1	MWh	11 146	10 068	10 907	10 272	11 175	7 786	9 740	10 114	10 504	9 714	8 978	10 101	**120 506**
1.4 Energi damp dampkasse PM1	MWh	1 776	1 665	1 766	1 702	1 883	1 425	1 787	1 887	1 843	1 680	1 496	1 721	**20 629**
1.5 Energi damp 10MW PM1	MWh	2 927	2 685	2 819	2 749	2 121	1 364	1 062	1 149	1 230	1 245	1 677	2 157	**23 186**
1.6 Energi VVF PM1	MWh	0	0	545	563	594	512	650	621	545	582	601	784	**5 995**
1.7 Totalt varmeforbruk PM1	MWh	14 624	13 291	15 956	15 263	15 762	11 034	13 197	13 731	14 111	13 135	12 638	14 718	**167 462**
2.1 Brutto produksjon PM2	tonn	13 868	11 369	13 672	13 626	13 696	10 140	13 148	14 093	13 324	10 879	12 413	11 626	**151 855**
2.3 Energi damp tørkeparti PM2	MWh	10 976	9 648	11 150	10 872	10 925	8 525	10 481	11 069	10 413	8 620	9 804	9 651	**122 134**
2.4 Energi damp dampkasse PM2	MWh	1 321	1 068	1 154	1 121	1 284	1 106	1 445	1 490	1 444	1 180	1 412	1 444	**15 470**
2.5 Energi damp 10MW PM2	MWh	3 641	3 164	3 361	3 579	3 571	2 404	2 716	2 954	2 772	2 874	3 165	3 441	**37 641**
2.6 Energi VVF PM2	MWh	594	564	513	481	482	375	480	441	416	495	547	794	**6 182**
2.7 Totalt varmeforbruk PM2	MWh	16 531	14 439	16 176	16 052	16 262	12 407	15 121	15 953	15 044	13 166	14 928	15 330	**181 409**
3.1 Brutto produksjon PM3	tonn	19 958	18 116	19 811	18 566	19 637	13 841	18 707	18 750	15 925	19 442	18 031	18 177	**218 962**
3.3 Energi damp tørkeparti PM3	MWh	16 429	14 759	16 658	15 729	16 588	12 080	15 657	15 815	13 509	16 070	14 902	15 247	**183 444**
3.4 Energi damp dampkasse PM3	MWh	1 469	1 299	1 478	1 391	1 465	718	835	764	604	622	618	907	**12 167**
3.5 Energi damp tystkoker PM3	MWh	19	19	27	41	8	85	14	20	28	35	121	48	**467**
3.6 Energi damp brettvann PM3	MWh	1 827	2 080	3 005	3 053	2 013	1 768	1 262	2 740	2 382	2 548	3 378	4 679	**30 736**
3.7 Energi VVX 8MW PM3	MWh	588	438	621	540	370	539	361	433	484	613	647	538	**6 170**
3.8 Energi VVF/VVC PM3	MWh	1 803	1 685	1 447	1 341	899	367	567	577	868	1 006	1 764	2 312	**14 637**
3.9 Energi diverse VVF PM3	MWh	1 478	1 160	1 469	1 201	1 048	664	758	941	943	1 197	1 204	1 275	**13 340**
3.10 Totalt varmeforbruk PM3	MWh	22 022	20 006	23 130	21 781	20 828	15 332	18 501	20 430	18 101	21 380	21 950	24 020	**247 480**
4.1 Produksjon TM1	tonn	10 860	7 926	11 056	9 584	11 698	6 639	11 037	10 772	9 675	11 140	10 616	8 109	**119 112**
4.2 Produksjon TM2	tonn	30 355	27 466	29 417	28 505	30 313	22 240	29 671	30 572	29 839	26 547	23 410	25 056	**333 391**
4.3 Dampforbruk TM1	MWh	186	319	163	155	14	104	15	30	72	84	206	389	**1 737**
4.4a Dampforbruk raffinører TM2A	MWh	95	73	128	136	115	131	90	87	111	133	275	140	**1 515**
4.4b Dampforbruk raffinører TM2B	MWh	1 448	1 948	1 861	1 389	1 035	496	296	616	1 311	1 510	276	122	**12 308**
4.4c Dampforbruk vannsplitt TM2	MWh	3 393	3 959	4 408	4 524	3 848	3 072	2 052	1 349	1 576	1 019	955	1 546	**31 699**
5.1 Energi VVF avd 16 og 67	MWh	241	220	210	178	164	72	98	122	108	106	124	211	**1 853**
Produksjon renseri (sum bil, båt, tog og truck)	fm³	83 173	73 813	75 797	74 528	74 625	50 240	85 445	79 832	63 662	70 345	63 904	61 576	**856 939**
6.1 Dampforbruk renseri 3	MWh	1 558	1 445	1 014	606	920	111	841	727	722	484	392	1 307	**10 128**
6.2 VGV til R3, tinetransportør	MWh	417	390	506	556	373	52	0	0	0	0	15	75	**2 385**
7.1 Produksjon til RF-tårn	tonn	4 640	4 339	4 743	4 994	4 322	4 035	4 706	4 788	3 993	4 917	6 040	7 001	**58 518**
7.2 Dampforbruk RF	MWh	33	35	24	96	203	656	278	218	171	193	403	285	**2 596**
7.3 VVF Avd. 25 RF	MWh	1 454	1 471	1 618	1 404	1 265	372	169	463	316	879	790	895	**11 097**
8.1 MaVa-beredning Fyrhus	MWh	129	214	1 343	1 508	2 533	668	6	1 391	338	259	0	0	**8 389**
1.11 Kondensatortap	MWh	3 751	2 826	3 862	5 679	4 568	3 310	5 240	3 986	2 929	3 900	3 230	3 319	**46 600**
8.3 Luft VVF Fyrhus	MWh	954	845	791	603	603	445	521	483	610	548	731	1 030	**8 164**
9.3 Sum VVF forbruk PM3	MW	3 869	3 283	3 537	3 083	2 317	1 570	1 686	1 951	2 294	2 816	3 615	4 124	**34 147**
9.4 VVF TM1 salventilasjon	MWh	179	163	183	154	178	162	209	196	190	182	181	204	**2 180**
9.5 VVF TM2 salventilasjon	MWh	340	307	247	191	103	19	28	31	77	152	200	428	**2 122**
9.8 Renseri 3 (40-MAN-EnergiRenseri3)	MWh	1 470	1 328	1 486	1 424	1 472	1 424	1 472	1 472	1 424	1 474	1 424	1 472	**17 339**
9.9 VVF Kontor verksted	MWh													
9.11 VVF Diverse forbruk	MW	10 443	4 352	4 408	3 649	3 248	1 391	3 462	2 868	2 570	2 504	1 516	1 577	**41 989**
9.12 Sum VVF forbruk	MW	18 089	11 062	11 920	10 325	9 160	5 971	8 605	8 183	8 234	8 860	8 938	10 624	**119 971**
10.1 Gj.vinning VVF TM1(A+B+kond.)	MWh	7 983	1 863	4 090	4 320	5 841	2 865	5 126	4 929	4 199	4 193	4 445	3 346	**53 201**
10.3a Energi VVF / TM2A	MWh	2 485	1 371	1 507	1 364	117	0	15	0	0	0	0	430	**7 291**
10.3b Energi VVF / TM2B	MWh	588	379	111	0	353	147	366	380	327	235	113	132	**3 130**
10.4 Gjenvunnet til VVF	MWh	11 057	3 613	5 709	5 684	6 312	3 012	5 507	5 309	4 526	4 428	4 558	3 908	**63 621**
10.5 Damptilskudd VVF	MWh	3 289	4 311	3 026	2 623	1 377	1 923	1 482	1 450	1 950	2 277	3 241	5 546	**32 495**
11.1 Slam til silo	tonn	2 405	1 865	1 718	2 323	2 631	1 399	2 136	2 148	1 143	2 090	2 003	2 520	**24 381**
11.2 Slam til mellomlager	tonn	271	82	11	22	33	74	22	169	910	291	571	243	**2 700**
11.2a Slam fra mellomlager	tonn	0	0	0	0	0	0	0	0	0	0	0	0	**0**
11.3 Slam totalt	tonn	2 405	1 865	1 718	2 323	2 631	1 399	2 136	2 148	1 143	2 090	2 003	2 520	**24 381**
12.1 Dampproduksjon	MWh	72 296	66 418	73 255	71 581	69 625	50 849	59 535	60 166	54 957	59 302	59 707	67 961	**765 651**
12.2 Dampforbruk	MWh	45 441	44 372	47 957	45 966	44 447	31 985	33 818	37 855	37 265	34 805	36 572	43 637	**484 119**
12.3 Dampavvik	MWh	26 856	22 045	25 298	25 616	25 178	18 864	25 716	22 311	17 692	24 497	23 135	24 324	**281 532**
13.1 Varme over-/underskudd	MWh	1 739	1 515	1 361	3 799	2 011	1 201	4 816	3 165	2 426	1 845	705	780	**25 363**
14.1 Spevannsforbruk	tonn	22 857	21 291	22 196	23 367	21 940	18 511	20 095	18 819	18 484	18 419	20 253	22 731	**248 965**
14.2 Lutvask omformere	tonn	390	390	456	396	414	336	372	414	438	456	492	432	**4 986**
14.3 MAVA-tap dampkasser	tonn	7 123	6 290	6 859	6 573	7 226	5 068	6 343	6 458	6 070	5 430	5 500	6 353	**75 294**
14.4 Varming TM	tonn	2 698	3 651	3 357	2 620	1 816	1 140	626	1 143	2 331	2 695	1 181	1 016	**24 273**
14.5 Diverse tap fyrhus	tonn	3 009	2 667	3 062	3 179	3 606	3 071	3 454	3 406	2 115	3 251	3 758	5 166	**39 744**
14.6 Avvik kondensat	tonn	9 556	8 208	8 382	10 386	8 548	7 740	8 843	7 027	7 218	6 231	8 504	9 245	**99 888**
14.7 MAVA-tap Tystkoker PM3	tonn	30	30	42	64	13	132	22	31	44	55	190	75	**728**
14.8 Forbruk kondensat RF	tonn	51	55	38	150	317	1 024	434	340	267	301	629	444	**4 051**
Kjøling VVX BIO / Spillvarme	MWh	9 698	9 523	11 490	11 740	12 266	8 584	9 992	10 386	8 905	7 595	8 179	6 395	**114 752**

VT Månedsrapport Varmeproduksjon

		01/2022	02/2022	03/2022	04/2022	05/2022	06/2022	07/2022	08/2022	09/2022	10/2022	11/2022	12/2022	
		JANUAR	**FEBRUAR**	**MARS**	**APRIL**	**MAI**	**JUNI**	**JULI**	**AUGUST**	**SEPTEMBER**	**OKTOBER**	**NOVEMBER**	**DESEMBER**	**Gj.snitt**
3.3 a Andel av oljeforbruk K5	%	56,93	75,94	36,31	40,11	17,35	14,7	69,26	62,15	70,47	77,81	49,63	82,16	**54,4**
3.3 b Andel av oljeforbruk K6	%	43,07	24,06	63,69	59,89	82,65	85,3	30,74	37,85	29,53	22,19	50,37	17,84	**45,6**
Antall barkpresser i drift	stk	1,93	1,98	2,79	2,92	2,75	2,24	1,92	1,57	1,71	1,29	2,35	2,98	**2,2**

		01/2022	02/2022	03/2022	04/2022	05/2022	06/2022	07/2022	08/2022	09/2022	10/2022	11/2022	12/2022	
		JANUAR	**FEBRUAR**	**MARS**	**APRIL**	**MAI**	**JUNI**	**JULI**	**AUGUST**	**SEPTEMBER**	**OKTOBER**	**NOVEMBER**	**DESEMBER**	**Sum**
1.1b Energi olje (målere)	MWh	1 027	573	1 620	933	793	329	122	138	476	154	362	1 227	**7 755**
1.3 Kjelkraft	MWh	985	738	881	947	1 764	1 780	302	683	26	1 900	2 163	1 313	**13 482**
1.4 Fastbrensel K5	MWh	6 879	7 266	9 540	10 662	6 430	6 199	6 013	5 440	8 092	4 506	9 579	12 284	**92 889**
1.5 Fastbrensel K6	MWh	22 666	21 617	23 526	22 637	21 710	18 835	22 144	21 801	11 191	21 941	20 320	23 025	**251 412**
1.6 Fastbrensel K5 og K6	MWh	29 545	28 882	33 067	33 298	28 140	25 033	28 157	27 241	19 284	26 446	29 899	35 309	**344 301**
1.7 Energi damp fra TM1	MWh	4 034	3 014	4 331	3 943	4 925	2 654	4 110	4 071	4 427	4 841	4 515	3 373	**48 239**
1.8 Energi VVF TM1	MWh	7 770	1 848	4 068	4 192	5 412	2 625	4 941	4 817	4 190	4 295	4 553	3 363	**52 075**
1.9 a Energi damp fra TM2A	MWh	20 533	18 847	18 719	18 631	19 709	12 099	14 029	14 437	18 260	13 833	13 159	13 310	**195 567**
1.9 b Energi damp fra TM2B	MWh	16 171	14 364	14 638	13 829	14 294	8 953	12 815	13 596	12 483	12 127	9 608	13 430	**156 308**
1.10 Energi VVF/TM2	MWh	3 112	1 778	1 621	1 380	475	148	384	382	329	235	122	587	**10 552**
1.11 Kondensatortap	MWh	3 751	2 826	3 862	5 679	4 568	3 310	5 240	3 986	2 929	3 900	3 230	3 319	**46 600**
1.12 Varme turbin	MWh	0	0	0	0	0	0	0	0	0	0	0	0	**0**
1.13 Sum Varmeproduksjon - kondenser	MWh	79 427	67 217	75 083	71 474	70 944	50 311	59 620	61 379	56 547	59 932	61 152	68 592	**781 679**
2.1 El fra turbin	MWh	0	0	0	0	0	0	0	0	0	0	0	0	**0**
3.1 Damp K5 + K6	tonn	38 827	37 408	44 052	43 474	36 745	32 211	35 914	34 772	25 095	33 783	38 431	46 401	**447 112**
4.4 Barkfyring K5	timer	736	672	743	417	717	561	708	487	611	540	705	717	**7 615**
4.5 Barkfyring K6	timer	740	672	743	714	742	538	743	734	386	743	699	709	**8 162**

VT Fyrhus månedsrapport

		01/2022	02/2022	03/2022	04/2022	05/2022	06/2022	07/2022	08/2022	09/2022	10/2022	11/2022	12/2022	
		JANUAR	**FEBRUAR**	**MARS**	**APRIL**	**MAI**	**JUNI**	**JULI**	**AUGUST**	**SEPTEMBER**	**OKTOBER**	**NOVEMBER**	**DESEMBER**	**Gj.snitt**
Effekt elektrokjele	MW	1,33	1,1	1,19	1,84	2,43	1,72	0,53	1,66	4,35	2,53	3,04	1,79	**1,96**
Produksjon kjel 5	MW	11,75	12,64	14,73	16,83	11,06	12,61	10,03	13,26	15,14	12,4	14,99	19,54	**13,75**
Produksjon kjel 6	MW	31,8	33,09	33,39	33,08	30,71	31,6	30,43	30,01	30,08	30,11	29,28	32,35	**31,33**
Gjenvinningsgrad TM1	%	28,59	30,25	31,42	32,28	33,15	31,96	29,9	30,68	35,63	34,3	34,04	32,61	**32,07**
Gjenvinningsgrad TM2A	%	68,14	68,64	61,57	64,71	65,18	53,1	45,44	47,93	63,76	59,75	57,48	54,14	**59,15**
Gjenvinningsgrad TM2B	%	63,09	61,03	58,81	57,9	56,36	49,74	53,67	55,93	50,37	50,86	47,99	58,59	**55,36**
Biopr. 1Tørrstoff ut	%	31,06	33	30,2	29,49	29,59	36,32	29,51	31,02	29,75	30,86	31,97	31,76	**31,21**
Biopr. 2Tørrstoff ut	%	30,52	32,19	30,29	27,38	29,25	32,33	29,65	27,84	28,42	28,68	29,55	30,92	**29,75**
RF pr.Tørrstoff ut	%	65,74	63,51	66,57	64,18	64,01	66,73	63,64	62,54	63,13	63,68	64,58	66,36	**64,56**
Dumpekondenser	MW	5,08	4,28	5,2	5,14	6,08	5,16	7,1	5,51	4,15	5,33	4,57	4,38	**5,16**
Effekt fra generator	MW	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	**0,01**
Damp bypass turbin	kg/s	15,39	16,39	17,29	17,93	14,6	13,33	14,17	13,74	10,42	13,3	15,81	18,5	**15,07**
Oljepris pr MWh Damp	NOK/MWh	572,84	572,84	572,84	572,84	572,84	572,84	572,84	572,84	572,84	572,84	572,84	572,84	**572,84**
RK-pris (regulerkraft NO3)	EUR/MWh	0	0	17,55	34,87	18,55	11,55	2,87	0,34	0	0	0	0	**7,14**
Spot-pris NordPool (NO3)	EUR/MWh	1,26	16,59	18,28	40,55	15,54	10,91	1,79	0,22	0	0	0	0	**8,76**

		01/2022	02/2022	03/2022	04/2022	05/2022	06/2022	07/2022	08/2022	09/2022	10/2022	11/2022	12/2022	
		JANUAR	**FEBRUAR**	**MARS**	**APRIL**	**MAI**	**JUNI**	**JULI**	**AUGUST**	**SEPTEMBER**	**OKTOBER**	**NOVEMBER**	**DESEMBER**	**Sum**
Antall stopp L21	#	65	52	135	47	98	75	46	68	60	88	107	73	**914**
Antall stopp L22	#	33	35	34	112	84	48	48	32	56	57	58	55	**652**
Antall stopp L23	#	32	30	51	58	37	69	30	51	40	37	55	27	**517**

		01/2022	02/2022	03/2022	04/2022	05/2022	06/2022	07/2022	08/2022	09/2022	10/2022	11/2022	12/2022	
		JANUAR	**FEBRUAR**	**MARS**	**APRIL**	**MAI**	**JUNI**	**JULI**	**AUGUST**	**SEPTEMBER**	**OKTOBER**	**NOVEMBER**	**DESEMBER**	**Gj.snitt**
Røyktetthet kjel 5	mg/Nm3	10,17	8,8	7,78	4,37	5,73	3,34	4,86	2,83	2,11	6,63	5,5	6,25	**5,7**
O2 kjel 5	%	10,52	10,01	9,88	9,68	11,66	11,27	12,01	11,97	13,23	15,64	13,3	12,34	**11,79**
Røyktetthet kjel 6	mg/Nm3	0,58	0,57	1,45	1,03	0,64	0,5	0,54	1,02	0,57	0,81	15,41	2,58	**2,14**
CO kjel 6	mg/Nm3	38,57	39,52	36,22	30,49	36,63	39,79	44,45	33,14	30,07	32	24,42	16,62	**33,49**
NOx kjel 6	mg/Nm3	270,52	261,42	269,51	263,09	267,71	286,74	301,8	269,18	294,35	259,06	264,43	232,51	**270,03**
SO2 kjel 6	mg/Nm3	14,8	2,87	36,94	9,17	11,48	14,12	13,62	24,66	5,45	0,34	7,77	1,55	**11,9**
HCl kjel 6	mg/Nm3	14,17	12,78	16,42	11,52	9,55	14,11	9,18	9,42	6,62	5,19	6,16	5,31	**10,04**
TOC kjel 6	mg/Nm3	1,63	1,97	1,27	1,87	1,65	1,65	1,73	1,41	1,33	1,65	1,47	1,48	**1,59**
O2 kjel 6	%	9,55	9,43	9,68	9,53	10,46	10,75	11,48	11,39	12,36	11,41	10,08	7,89	**10,33**

VH Bio månedsrapport

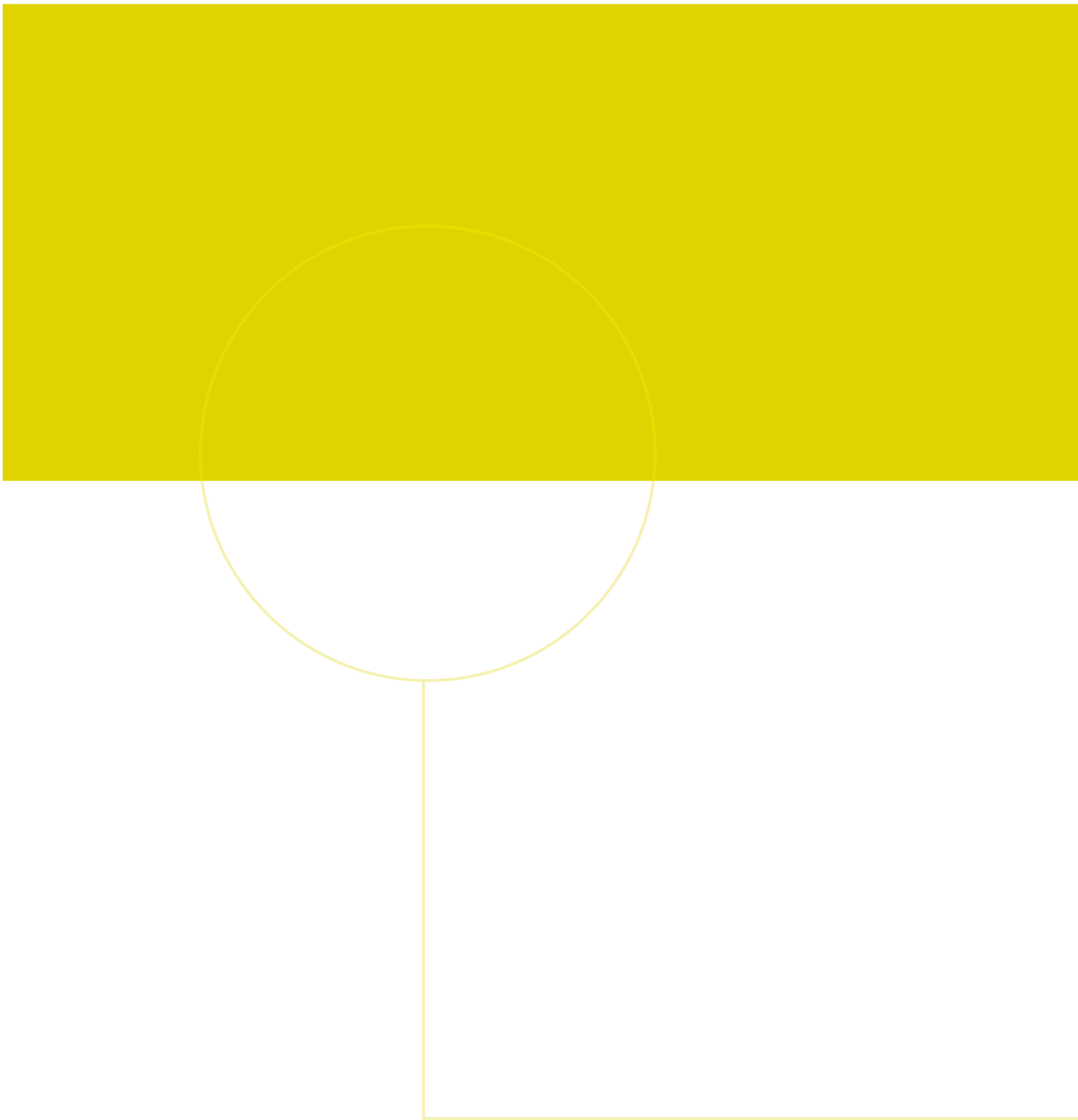
		01/2022	02/2022	03/2022	04/2022	05/2022	06/2022	07/2022	08/2022	09/2022	10/2022	11/2022	12/2022	
		JANUAR	**FEBRUAR**	**MARS**	**APRIL**	**MAI**	**JUNI**	**JULI**	**AUGUST**	**SEPTEMBER**	**OKTOBER**	**NOVEMBER**	**DESEMBER**	**Average**
R3 prod/time	fm^3/h	158,84	181,96	175,51	##########	##########	139,73	167,19	162,97	160,14	165,53	163,9	172,51	**###########**
MOMENT SLAMSKR FORS	%	27,62	8,54	11,9	16,87	14,83	30,71	16,19	19,48	16,67	22,73	27,8	32,46	**20,48**
B.SLAM TIL MULTIFUEL	m3/d	0	0	0	68,59	143,31	13,71	0,19	0,19	0,19	0,19	0,19	0,07	**18,88**
MALT MENGDE REJ ECSB	m3/d	1,58	1,65	1,65	1,65	1,34	0,61	31,09	68,13	29,31	60,47	74,93	61,59	**27,83**
MENGDE AVL V TIL MUF	m3/d	466,2	319,81	263,27	50,66	0,93	0,93	0,93	0,93	0,93	0,93	3,98	0,82	**92,53**
REJEKTMENGDE TIL LB	m3/d	166,08	173,61	159,46	136,29	162,98	75,18	125,48	123,43	118,62	117,72	127,06	112,19	**133,17**
Volum inn forsedimentering	m3/d	21 579,22	21 250,32	21 625,96	21 928,33	21 549,97	18 424,66	20 476,06	21 258,88	20 534,93	20 321,99	20 955,99	21 721,47	**20 968,98**
Volum utenfor renseanlegg	m3/d	-2,16	-4,54	-3,06	-0,33	-2,79	257,9	63,73	62,5	60,64	70,97	65,88	64,22	**52,75**
Bypass Bio til resipient	m3/d	86,89	2 575,75	5 553,42	8 386	2 653,63	813,6	31,69	764,92	493,18	695,12	13,82	620,03	**1 890,67**
Volum til Resepient	m3	22 919,74	22 685,61	23 049,58	24 115,52	22 823,81	19 496,42	22 005,12	23 046,84	21 873,49	21 799,57	22 446,9	23 021,48	**22 440,34**
Snitt SS inn forsed.	tonn/d	43,34	45,77	44,72	35,93	38,05	32,78	36,24	38,59	38,91	39,37	38,48	41,59	**39,48**
KOF inn forsed	tonn/d	122,33	131,69	125,8	116,11	118,19	106,36	83,95	94,07	104,1	93,11	98,01	107,75	**108,46**
Slamalder	døgn	16,93	23,42	24,88	29,26	16,24	18,87	21,91	19,47	17,6	15,3	14,87	16,8	**19,63**
SLAMNIVÅ ETTERSED	%	80,55	87,18	83,58	82,16	70,29	51,18	73,55	44,83	63,91	55,36	32,58	51,18	**64,7**
Utslipp KOF	tonn/d	6,23	24,07	26,1	33,2	8,61	6,19	3,82	5,04	4,71	6,76	4,34	7,87	**11,41**
Utslipp SS	tonn/d	1,37	9,09	7,41	8,83	1,52	1,87	0,25	0,87	0,94	1,5	0,28	1,82	**2,98**
Utslipp fosfor	kg/d	9,16	42,03	38,65	57,73	13,2	12,99	8,11	34,28	5,99	7,44	4,37	9,2	**20,26**
Utslipp nitrogen	kg/d	163,23	353,24	298,32	241,02	151,66	163,12	147,54	166,69	125,88	162,88	169,84	128,43	**189,32**
NIVÅ TANK FOSFORSYRE 75% / Phosphoric	%	75,06	58,95	41,08	24,8	75,9	75,4	61,97	44,74	38,17	29,5	35,71	87,83	**54,09**
NIVÅ TANK PIX/ FENNOFLOC F113	%	59,91	49,05	49,23	59,12	46,05	61,72	53,54	56,21	48,7	49,32	58,49	51,97	**53,61**
Nivå tank UREA-løsning 40%	%	52,65	59,85	64	70,06	57,66	49,56	60,52	45,17	59,1	62,92	50,23	59,76	**57,62**
Biopr. 1Tørrstoff ut	%	31,06	33	30,2	29,49	29,59	36,32	29,51	31,02	29,75	30,86	31,97	31,76	**31,21**
Biopr. 2Tørrstoff ut	%	30,52	32,19	30,29	27,38	29,25	32,33	29,65	27,84	28,42	28,68	29,55	30,92	**29,75**
RF pr.Tørrstoff ut	%	65,74	63,51	66,57	64,18	64,01	66,73	63,64	62,54	63,13	63,68	64,58	66,36	**64,56**
Andel til ECSB	%	0,01	0,02	0,01	0,02	0,02	0,03	0,08	0,15	0,07	0,11	0,07	0,06	**0,05**

		01/2022	02/2022	03/2022	04/2022	05/2022	06/2022	07/2022	08/2022	09/2022	10/2022	11/2022	12/2022	
		JANUAR	**FEBRUAR**	**MARS**	**APRIL**	**MAI**	**JUNI**	**JULI**	**AUGUST**	**SEPTEMBER**	**OKTOBER**	**NOVEMBER**	**DESEMBER**	**Sum**
Produksjon renseri (sum bil, båt, tog og truck)	fm^3	83 173,28	73 812,93	75 797,36	74 527,74	74 624,69	50 240,35	85 445,04	79 831,63	64 339,28	71 330,93	63 903,62	66 822,45	**863 849,3**
Driftstid Renseri 3	t	521,66	404,42	431,09	228,36	427,62	340,72	514,75	490,58	398,89	430,8	391,93	446,18	**5 026,98**
Bioslam	tonn TS/d	691,44	519,79	491,85	439,89	604,47	454,47	456,63	471,42	532,45	604,3	446,04	532,61	**6 245,37**
Fiberslam	tonn TS/d	434,46	400,22	416,69	381,71	518,97	441,61	454,76	482,25	414,02	516,37	517,38	525,4	**5 503,84**
MENGDE TIL ECSB	m3/h	4 797,76	14 493,36	9 500	16 408,53	14 251,08	8 834,33	55 211,73	110 341,75	47 346,05	72 234,95	44 607,53	40 175,98	**438 203,05**
Bio-slam brent TS	tonnTS	850,71	789,57	857,18	702,08	952,77	622,51	835,25	720,4	421,55	764,82	537,85	764,15	**8 818,84**
Bioslam til cont	tonnTS	233,46	74,62	9,48	16,38	14,02	56,41	20,63	168,11	480,24	305,56	354,85	198,42	**1 932,16**
Tid RF-slam til container	min	690,39	122,86	46,39	96,53	300,11	66,45	8,97	89,24	8 649,84	338,94	3 774,51	923,18	**15 107,4**
Tid RF-slam til silo	min	31 415,9	29 068,33	33 609,47	30 819,11	30 135,36	24 348,38	34 350,32	27 606,5	13 944,14	30 437,59	29 980,13	37 319,92	**353 035,16**
Tid BIO-slam til container	min	9 352,06	3 335,74	521,69	1 014,8	696,88	3 278,93	1 121,71	7 929,77	23 410,37	12 799,6	16 451,71	9 041,12	**88 954,4**
Tid BIO-slam til silo	min	35 244,22	36 963,36	44 031,78	42 026,1	43 794,47	29 401,61	43 476,8	35 627,46	19 668,02	31 792,12	25 664,89	33 906,54	**421 597,37**
RP-forbruk	tonn	6 127,87	5 765,87	6 099,2	6 625,27	5 862,11	5 349,74	5 831,09	6 051,33	4 906,04	6 742,07	8 264,43	9 886,71	**77 511,75**

Tallkilder for kartlegging 2022

Parameter 2022	**Enhet**	**Mengde, faktisk**	**TS %**	**Mengde, TS**	**Mengde , vann**	**Kilde**	**Kommentar TS%**	**Annen enhet**	
Lettoljeforbruk	m3	428.1				SAP-rapport			
Tungoljeforbruk	Tonn	0.0	100 %	0.0	0	Peilerapport			
Fabrikkavfall	Tonn	2 032	71 %	1 443	589	Biobrenselbalanse Supply.	Estimert snitt 70% TS		
Innkjøpt biobrensel K5	Tonn	1 903	60.0 %	1 142	761	Biobrenselbalanse Supply og Plukkanalyserapport	Beregnet masseveid gj.snitt lev. Eget ark		
Innkjøpt biobrensel K6	Tonn	59 034	71.4 %	42 144	16 890	Biobrenselbalanse Supply og SPS år/mnd-rapport Termisk produksjon	Veid gj.snitt SPS-rapp. (Uveid gj.snitt plukkanalyser er 71,6%)		
Bark	Tonn	99 485	50.0 %	49 743	49 743	Renseriprod.*0,44*0,135, lagerendring og uttransportert	50 %TS basert på gamle målinger	368 464	lm3
DIP-slam	Tonn	23 101	64.6 %	14 918	8 183	Mengde og veid TS-snitt SPS VT Brensel månedsrapport	64,56 %TS uveid gj.snitt alle analyser i SPS		
DIP-slam levert eksternt	Tonn	1 129	64.6 %	729	400	Mengde og veid TS-snitt SPS VT Brensel månedsrapport			
Bio/fiberslam brent	Tonn	29 162	30.2 %	8 819	20 343	Mengde og veid TS-snitt SPS VT Brensel månedsrapport	30,48 %TS uveid gj.snitt alle analyser i SPS	30.48	
Bio/fiberslam levert eksternt	Tonn	6 389	30.2 %	1 932	4 457	Mengde og veid TS-snitt SPS VT Brensel månedsrapport			
Rundvirke	fm3	882 310				N:\Shared\Rapporter\Økonomi\Månedsrapport\			
Rundvirke	Tonn	414 686				Egenvekt gran 0,47 (internett)			
TMP masse	Tonn	322 879	90 %	290 591		Virke fm3 div. på virkesfaktor 2,41 fm3/tonn ADT (Varmebud.)			
Innkjøpt flis	fm3	170 905				N:\Shared\Rapporter\Økonomi\Månedsrapport\2007\12-Desember\Perioderapport pr. desember 2007, C16			
Innkjøpt flis, masse	Tonn	71 210	90 %	64 089		Flis fm3 div. på virkesfaktor 2,41 fm3/tonn (Varmebud.)			
Returpapir	Tonn	77 741	79 %	61 105		N:\Shared\Rapporter\Økonomi\Månedsrapport\2007\12-Desember\Periodera	Endret utbytte fra 83%, celle C21		
Cellulose	Tonn	0		0		N:\Shared\Rapporter\Økonomi\Månedsrapport\2007\12-Desember\Perioderapport pr. desember 2007, C22			
Vann i røykgass	Tonn	96 908		0	96 908	Summen av F2..F7			
Renset røykgass (minus forbrukt luft)	Tonn	136 699	71 %	96 908		Summen av brensler minus slagg/aske			
Friskvann	Tonn	21 989 052		0		N:\Shared\Rapporter\Auto\RapporterVannforbrukLello\2007			
Pros.vann til forsedimentering	Tonn	7 455 808		0		DROPS - miljøbase - sum fri periode			
Renset avløp	Tonn	7 878 232		0		DROPS - miljøbase - sum fri periode			
Fiberfritt avløp	Tonn	20 000 000		0		Estimat JHS 2007			
RF-rejekt til Fyrhus	Tonn	2 352	55.0 %	1 293		Arena år/mnd-rapport Termisk produksjon	55 %TS ligger inn fast fra tidligere analyser		
Rejekt til ekstern levering	Tonn	0	55.0 %	0		N:\Shared\HMS felles\Miljø-Transport-avfall\2007\Årsrapport Norske Skog 2007-2, H5			
Produsert papir	Tonn	501 426	92 %	461 312		N:\Shared\Rapporter\Økonomi\Månedsrapport\2007\12-Desember\Perioderapport pr. desember 2007, C6		2007:	2009:
Damp fra TM til PF	Tonn	370 744		0		N:\Shared\Rapporter\Varmeteknisk\2007\Ukerapport VT uke 52, 1.7+1.8+1.9+1.10-4.3-4.4-7.2-7.3-10.5 Omregning MWh-tonn: 1tonn = 0,64MWh		427834	238223
Damp fra FH til PF	Tonn	565 477		0		N:\Shared\Rapporter\Varmeteknisk\2007\Ukerapport VT uke 52, PM1 1.7-1.6+PM2 2.7-2.6+PM3 3.10-(3.7+3.8+3.9)-Damp fra TM til PF. Omregning MWh-tonn: 1tonn = 0,64MWh		140860	322585
Div. forbruk og tap	Tonn	63 223		0		N:\Shared\Rapporter\Varmeteknisk\2007\Ukerapport VT uke 52, 1.1+1.6-Damp fra FH til PF. Omregning MWh-tonn: 1tonn = 0,79MWh			34567
Damp til RF	Tonn	54 448		0		N:\Shared\Rapporter\Varmeteknisk\2007\Ukerapport VT uke 52, 7.2. Omregning MWh-tonn: 1tonn = 0,64MWh			
Slagg/aske	Tonn	19 412		0		N:\Shared\HMS felles\Miljø-Transport-avfall\2007\Årsrapport Norske Skog 2007-2			
Matevann til TM	Tonn	*425 192*		0					
Kondensat	Tonn	*936 220*		0					
RF-masse	adt	137 400		0		176.7 %			

937.5



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