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SUSTAINABLE LOW CARBON TISSUE MANUFACTURING GUIDELINE

Project carried out with a financial grant of the European Commission

Dr.-Ing. Jens Neumeister | 1st Edition

Editorial

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Sustainable Low Carbon Tissue Manufacturing – Guideline

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To be found on www.7NEU.de

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INTRODUCTION AND GREENHOUSE GAS EFFICIENCY

1 Introduction

OR: WHAT THIS GUIDELINE IS ABOUT?

The tackling of climate changes and the reduction of greenhouse gas emissions by 20%[1] until the year 2020 are among the top priorities of the European Union. Therefore, the emissions trading system was designed to provide incentives for reducing greenhouse gas emissions for energy-intensive industries, such as the paper industry.

Against this background, the present guideline explains the development of optimised energy utilisation concepts with the aim of reducing direct CO_2 emissions. The content of this guideline was elaborated during the Sustainable Low Carbon Tissue Manufacturing project which was carried out by Ingenieurbüro Neumeister, an engineering office focusing on energy efficiency, and Metsä Tissue, a tissue manufacturer. The project was funded by the European Commission under the Sustainable Industry Low Carbon Initiative. It was the aim of the project to find a concept for lowering direct CO_2 emissions caused by the used steam and direct fuel. According to the target of the Sustainable Low Carbon Tissue project, this guideline only deals with low carbon technologies linked to steam usage and direct fuel usage.

The present guideline was compiled based on the experience of sixteen investigated tissue machines. It explains a methodology for analysing and optimising production processes focused on energy efficiency. The guideline takes best available technologies into account and explains the advantages and the use of thermodynamic modelling. The methodology and approaches are underlined by case examples. The paper contains different ready to implement measures for increasing energy efficiency and, thus, for lowering GHG emissions in tissue production. The described method and measures shall support both the paper industry and other energy-intensive industries with a comparable heat demand.

2 Greenhouse gas efficiency in tissue paper production

OR: WHERE DO EMISSIONS COME FROM?

This chapter deals with the tissue making process and especially with the steps in which greenhouse gas emissions occur. First, the general framework for the assessment of greenhouse gas efficiency in the tissue industry is explained. Here, the focus is particularly placed on the perspective of the European emission trading scheme. Then, the production process itself is further described.

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[1] Compared to levels of 1990.

2.1 Context

OR: WHAT ARE THE BASIC CONDITIONS?

Despite continuous efforts by the European paper industry to reduce greenhouse gas emissions from their processes - the specific direct CO_2 emissions decreased from 1991 to 2010 by 37.4% - the third trading period of the EU emissions trading system (2013-2020) presents new challenges for this industry.

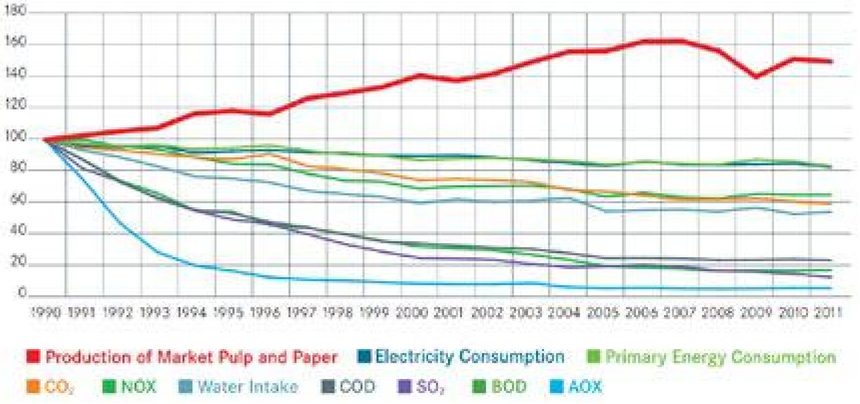

Fig. 1: Environmental impacts of the EU pulp and paper industry (CEPI) [2] 1990-2011[3]

The valid product benchmark for tissue products of 334kg_{CO2} per ton net production depends on the performance of the most efficient plants in the sector and is not differentiated by geographical location within Europe. Other energy-intensive industries are in a comparable situation.

In order to support the competitiveness of European energy-intensive industries, despite this burden, the European Commission (EC) has started the development program Sustainable Industry Low Carbon (SILC) in 2011. The initiative supports projects aimed at the reduction of carbon dioxide intensity in the sectors that are committed to participate in the European emissions trading. This includes the hygienic paper industry. The Sustainable Low Carbon Tissue Manufacturing Project (SLCTM) for the reduction of specific direct CO_2 emissions in the sanitary paper industry is one of the projects funded by the EC.

The project work was divided into four steps: A comprehensive on-site analysis of all the machines, the subsequent data analysis and thermodynamic simulation of the processes and, as a third step, the creation of concepts. In parallel, the guideline to "Sustainable Low Carbon Tissue Manufacturing" was prepared which compiles all findings.

The technical solutions take into account both the specific conditions of the respective sites as well as the best available technology (BAT) and best practice (BP).

EU emission trading scheme (EU ETS)

For the processes taken into account in this project the allocation of emission allowances is determined mainly by two product benchmarks: recovered paper pulp and tissue paper. Because the deinking process[4] is not part of the present guideline, this benchmark can be neglected.

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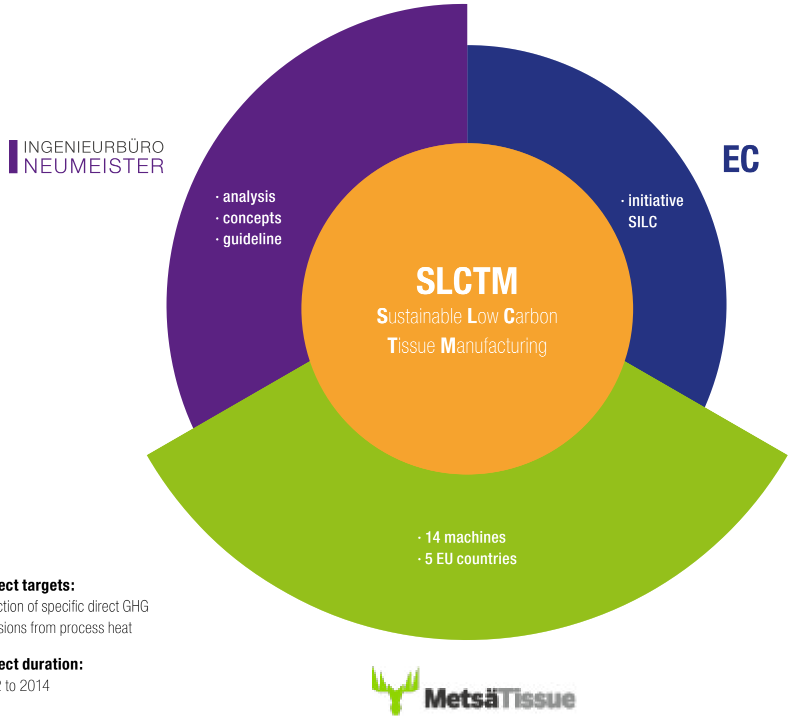
[2] [CEPI 2012]
[3] Index of Specific Value (1990 = 100)
[4] removing ink from recovered paper in order to increase brightness

Within the benchmark, tissue papers are defined as follows: "Tissue papers expressed as net saleable production[5] of parent reel cover a wide range of tissue and other hygienic papers for use in households or commercial and industrial premises such as toilet paper and facial tissues, kitchen towels, hand towels and industrial wipes, the manufacture of baby nappies, sanitary towels, etc. TAD — Through Air Dried Tissue is not part of this group. All processes which are part of the paper production process (in particular paper or board machine and connected energy conversion units (boiler/CHP) and direct process fuel use) are included. Other activities on site that are not part of this process such as sawmilling activities, woodworking activities, production of chemicals for sale, waste treatment (treating waste onsite instead of offsite (drying, pelletising, incinerating, landfilling), PCC (precipitated calcium carbonate) production, treatment of odorous gases, and district heating are not included. The conversion of parent reel weight to finished products is not part of this product benchmark."[6] The allocation is 0.334EUA/t_{Paper}.

Project members

SLCTM was a joint project between Ingenieurbüro Neumeister and Metsä Tissue. The project was carried out by the European Commission under the SILC initiative.



Project targets:
reduction of specific direct GHG emissions from process heat

Project duration:
2012 to 2014

Fig. 2: Overview project members

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[5] marketable net production with a residual moisture content of 6%

[6] [2011/278/EU]

Ingenieurbüro Neumeister is specialised in the optimisation of energy efficiency in industrial plants, power plants, and supports companies within the European Emission Trading System. The engineering office was founded in 2006 by Dr.-Ing. Jens Neumeister. Ingenieurbüro Neumeister analysed all tissue machines within the project, evaluated thermodynamic models, created new innovative concepts for reducing direct CO2 emissions and wrote this guideline. Please find more information on www.7NEU.de.

Metsä Tissue is one of Europe's leading suppliers of tissue paper products to households and professional users in Europe and the market leader in the Nordic countries. Metsä Tissue is also the world's leading supplier of baking and cooking paper products. Sustainability is taken very seriously. Metsä Tissue seeks to minimise the environmental impact of their products throughout their life cycle, from sourcing of raw materials to production and consumption right through to their disposal. Metsä Tissue lowered the specific energy consumption continuously year by year by 1 to 2%. In 2011, Metsä Tissue launched the SLCTM project for reducing direct greenhouse gas emissions. Please find more information on www.metsatissue.de.

2.2 Tissue production process

OR: WHERE DOES TISSUE PAPER COME FROM?

The paper production process has not changed in its basic form since its discovery in China in the 2nd BC. In essence, wet pulp is spread onto a wire mesh, on which the paper is formed. After a pressing and drying process the result is a raw sheet of paper. The industrialised production process has, of course, become vastly more complex in order to meet today's large demand for paper products.

For fabricating the sheet on the paper machine the tissue production process requires energy and water supply. These topics are briefly described in the following chapter.

Energy supply

Power plants or boiler houses in the paper industry produce steam, hot water and electricity to support the paper machines and other processes. Paper machines normally run 8,000 operating hours per year, or even more, and rely on a constant heat supply. In some cases with a combined heat and power production, the boiler houses also meet the mills' need for electricity. As already mentioned, availability is a key factor for energy production. Therefore nearly all of the plants have backup systems. Sometimes the boilers are also able to run on different fuels. On the one hand this is important for availability; on the other hand this is also important for economic reasons. Fuels used are wood, biomass, coal, oil, gas, or residues from tissue production. Depending on the used fuel and the efficiency of the process the CO_2 intensity varies. In some cases the energy supply is outsourced.

Tissue production [7]

Tissue is a collective name for crepe paper used for sanitary and household purposes. For the manufacture of the final products with the required quality, the raw materials pass through a series of important process steps – pulping, cleaning, deinking, refining, forming, pressing, drying, creping, converting, and packaging. A simplified picture of the typical tissue making process is shown in Fig. 3.

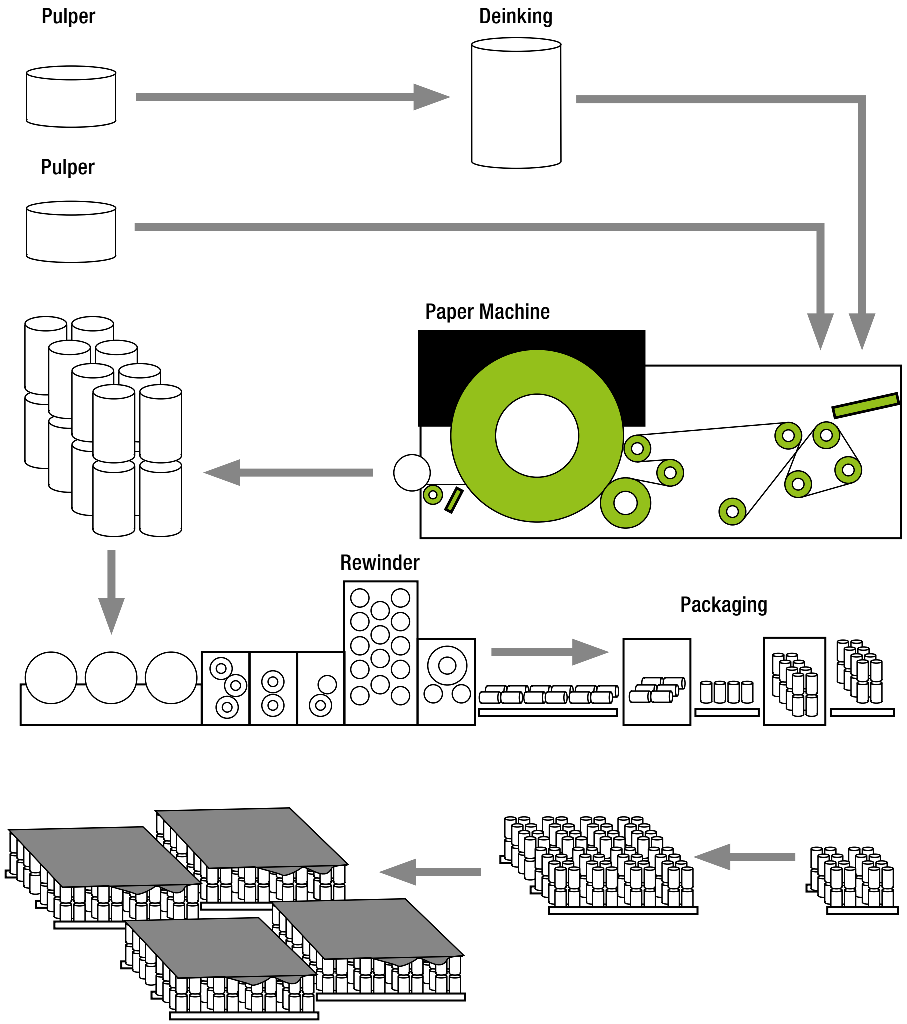

Fig. 3: Schematic of tissue making process[8]

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[7] Blechschmidt 2010; SLCTM 2014

[8] [SLCTM 2014]

Stock preparation and deinking consist of a series of process steps, including pulping, beating, refining, fractionation, screening, etc. For different raw materials, product grades and mill conditions, the stock preparation and deinking system can be different. For the oxidative and reductive bleaching sequences small quantities of steam are required. The paper making process as such consists of the forming, pressing and finally drying sections. The headbox, considered as the key component in the forming section, realises proper sheet formation and basic requirements with respect to machine direction and cross direction strength properties. The consistency of fibres in the headbox can be as low as 0.2% to obtain a unique formation. The stock jet generated in the headbox is retained on the forming fabric (wire) and immediately transferred to the press fabric (felt). The dryness of the web is 9 to 12% before the paper web is dewatered by mechanical pressing. The dryness of the web before press section is about 9 up to 12%. With conventional press configuration an after press dryness (APD) between 37 to 43% can be realised after press nip.

The drying section of the paper machine's function is to bring the dryness of the paper track from 40 to 50% down to the target level of about 4 to 5%. This is achieved by an appropriate heating procedure for evaporating the water and separating the steam.

Today, three methods are used for paper production:

· Contact heating

· Convection drying

· Infrared drying

As part of the tissue production, a combination of contact and convection drying by Yankee cylinder and drying hood is used.

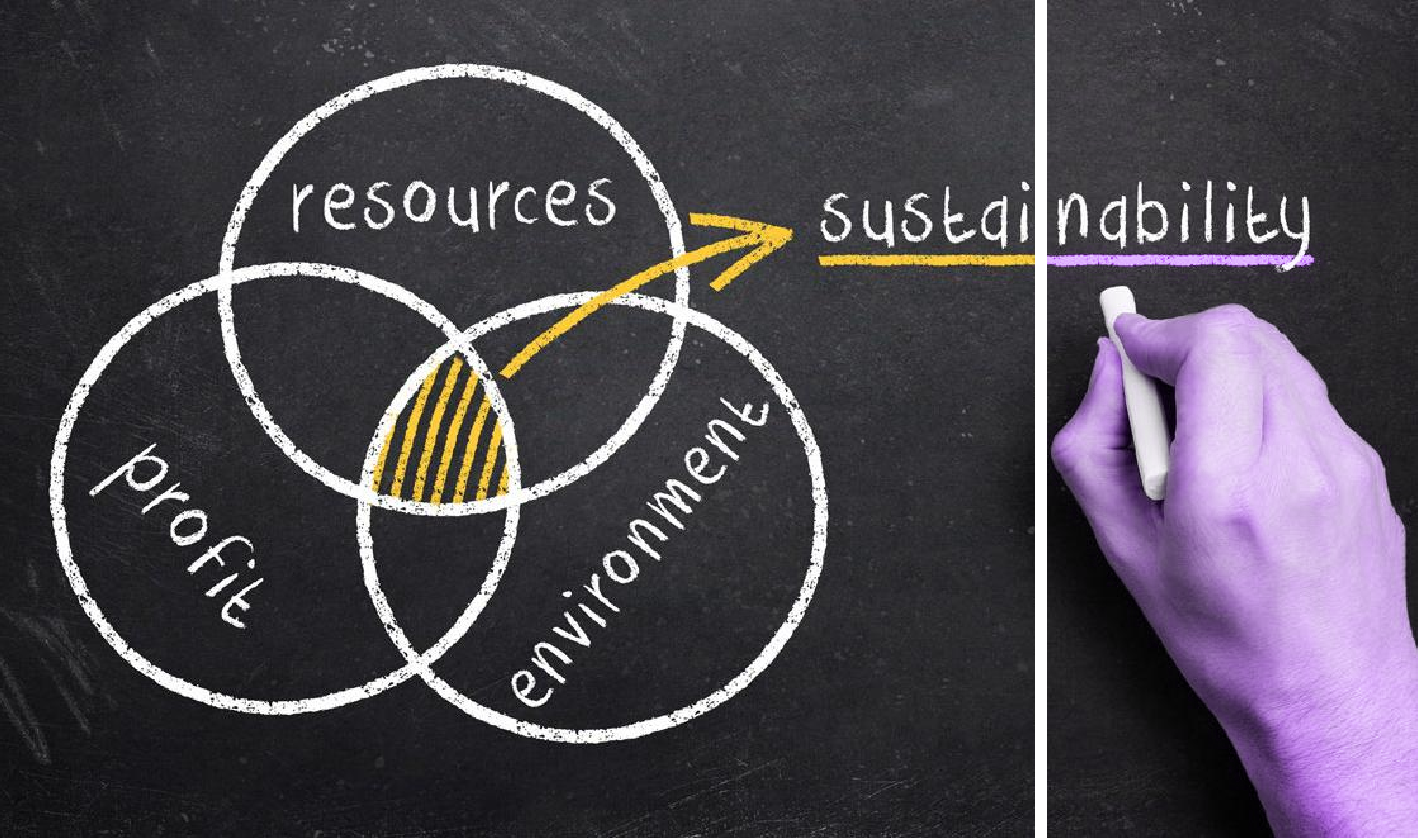
Contact drying is realised by a Yankee cylinder. It is made of cast-iron or, recently, of steel. The steam inside is used to heat the paper sheet that is wrapped around the outside of the cylinder. The moist web is transferred to the Yankee cylinder by the press roll. Special coating chemicals ensure reliable paper sheet transfer and uniform adhesion to the Yankee. In between press section and blade holder the paper sheet is dried up to moisture content of about 6%. The required heat for the water evaporation has to be substituted by overheated steam supplied to the Yankee.

The drying hood is responsible for the convection drying. Hot air is transferred to the paper web by nozzle boxes on an impingement speed level of up to 140m/s. Suction boxes remove the humid air up to a moisture content of 630g of water per kg of dry air. Fresh air supply and exhaust air have to become volume balanced in order to avoid spilling. Several heat recovery stages transfer the heat from the exhaust air to required fresh air, to the process water or to the room ventilation systems.

The produced base paper reels are then further converted and wrapped to finished products. From the perspective of direct GHG emissions, the converting and packaging have no significant impact.

In paper production, water ensures the functions of sheet formation, suspension, transport of fibres and solvent for chemical additives. Furthermore it is used as spray and sealing water in cleaning modules and as cooling medium. Normally the water will be treated and reused. The quality of the water used in the production process has a major influence on the quality and grade of the tissue/paper product.

Fresh water temperature depends on the type of water (surface or ground water), the geographical position, and the season.



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METHODOLOGY
SYSTEM BOUNDRIES AND ANALYSIS

3 Methodology

OR: HOW TO EVALUATE AND OPTIMISE MY PROCESSES?

The following chapter describes step by step how to analyse, evaluate and optimise a production process with regard to GHG emission intensity. The procedure described is always illustrated by a practical example. Every step contains a general description, additional information and the reference to the example installation. Due to the project´s focus the selected production process is tissue production. Please note that all data mentioned do not refer to an existing machine since they are based on an example case study.

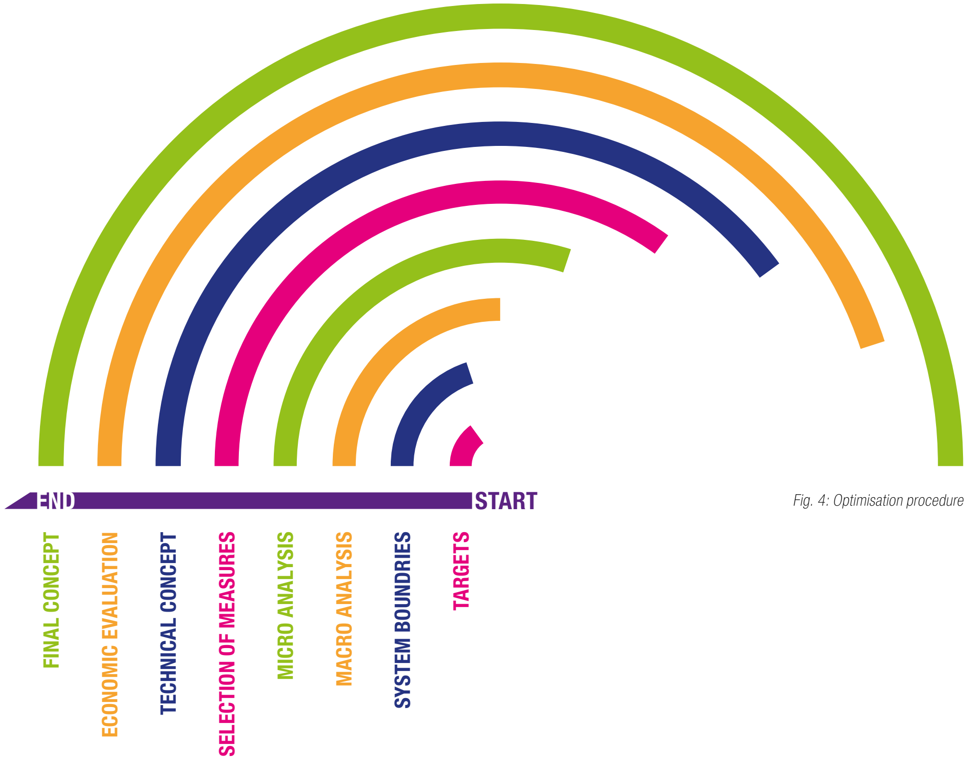

Fig. 4: Optimisation procedure

3.1 Step 1: targets

To find a suitable low energy and/or low GHG emission concept for an installation in step 1, the targets have to be defined. In the case of an installation for tissue production, these emissions directly result from burning gas in the drying section of the machine or from steam production. Since gas and steam usages are interacting, it is recommended to focus on both. A definition of targets is important for the ongoing analysing and balancing work. Possible targets could be:

- **reduction of the specific direct GHG emissions**
- **reduction of the specific indirect GHG emissions**

CASE STUDY:

According to the view of the EU ETS this guideline only focusses on the reduction of direct GHG emissions caused by the use of process heat which will be applied to the case example. Since within the tissue production process, apart from CO_2, no other GHG emissions occur, the analysis will concentrate on the generation of CO_2.

3.2 Step 2: system boundaries

After deciding on the targets, the accounting boundaries of the analysis are to be defined. A helpful way to do so is by defining production areas. It is also important to consider the interactions between them. At first, a schematic showing the chosen areas was prepared.

With regard to the tissue production process the main areas for gas and steam usage are the paper machine itself and energy production. If the installation is using waste paper as raw material, the stock preparation or, more precisely, the deinking process needs steam too. All other areas are mainly using gas or steam only for the purpose of heating.

The above mentioned system boundaries were adopted as they stand. Accordingly, the case example includes the complete tissue making process with regard to the heat demand as well as the internal heat generation.

CASE STUDY:

Definition product benchmark for tissue in the EU ETS:

„All processes which are part of the paper production process (in particular paper or board machine and connected energy conversion units (boiler/CHP) and direct process fuel use) are included. Other activities on site that are not part of this process such as sawmilling activities, woodworking activities, production of chemicals for sale, waste treatment (treating waste onsite instead of offsite (drying, pelletising, incinerating, landfilling), PCC (precipitated calcium carbonate) production, treatment of odorous gases, and district heating are not included.“ [9]

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[9] [2011/278/EU]

[10] [VDI 4600]

3.3 Step 3: macro analysis

After definition of the targets and system boundaries, the macro analysis can be started. Here, data for different products or components are collected by analysing suitable production areas concerning their input and output flows[10].

Reliable sources of information for correct figures could be

- process systems
- sheets from the management controlling system
- energy management system
- monthly energy balances

In the first step it is only important to look at what is going in and out of the different systems.

CASE STUDY:

The following figure shows the schematic of the example mill containing fresh water and waste water treatment, energy production, stock preparation, the paper machine itself as well as buildings with regard to their heating demand. The example machine runs only on fresh fibre as raw material, so there is no deinking line for recovered paper.

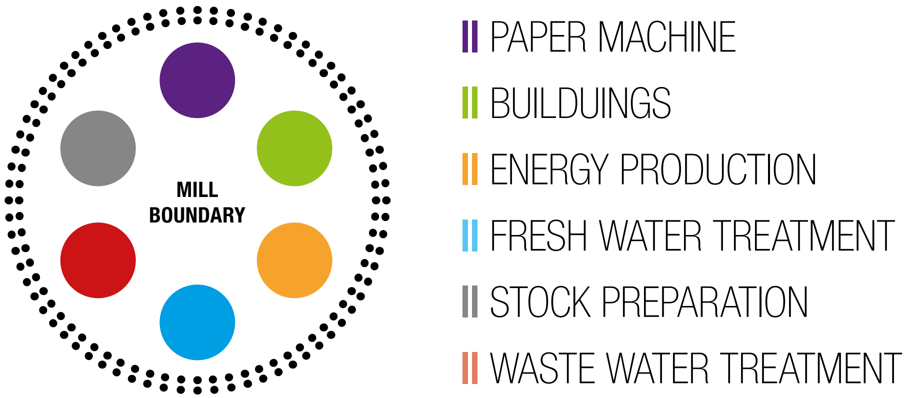

Fig. 5: Schematic example

Based on the targets and system boundaries relevant input and output flows in the macro analysis are limited to the respective heat demand of the different areas, which is illustrated below.

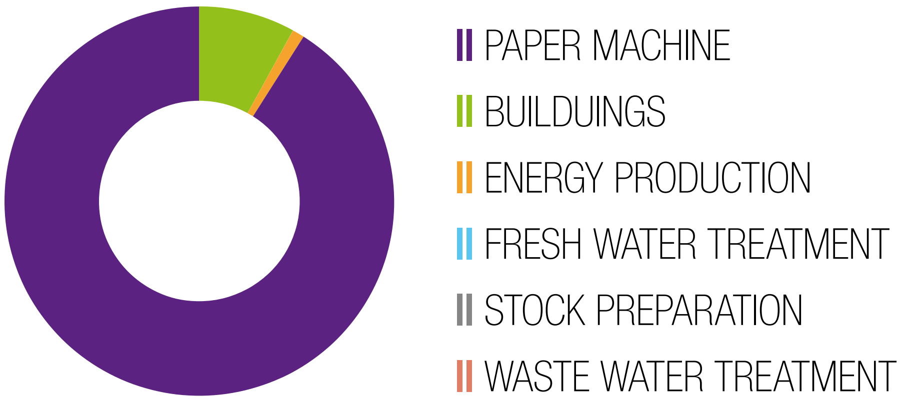

Fig. 6: Overview process heat demand case example

The figure shows that the main heat consumer is the paper machine itself. This case example also includes an amount of heat needed for building heating, and finally there is the own consumption of energy production itself. All other production areas do not require any heat and therefore can be excluded from the micro analysis.

3.4 Step 4: micro analysis

There are various possible approaches to analysing and balancing production processes, such as process modelling or pinch analysis.

Within this project, thermodynamic process models were used to perform the microanalysis. Thus, it was possible to recognise all occurring interactions within the system, including different approaches and operational states to ensure the right selection of measures.

Process modelling can be a helpful tool for visualising and optimising paper making. Data-based models or physical models can be used for modelling the process. Sometimes it is not possible to create a reliable physical model of the process. In that case a data-based model can be useful. One can create offline and online models. Offline models can help to improve the efficiency of the process by using data from the past. Online models are able to get information in time from the process system or to run simulations based on former timestamps. For concept or detail engineering offline models are very useful. For analysing, benchmarking and optimising the process in time online models are needed. Since online models are able to benchmark the process in time, they are also able to give advice for in time optimisations. By doing so it is possible to reduce the steam, fuel and water usage within the process.[11]

11 [COST 2008; Dixit et al. 2012; Fries et. al 2009, Niebe 2009]

CASE STUDY:

The simulation enables to balance the process of the paper mill. In this way, interactions within the process can be recognised. The following figure illustrates the modelling of the paper production process including heat production.

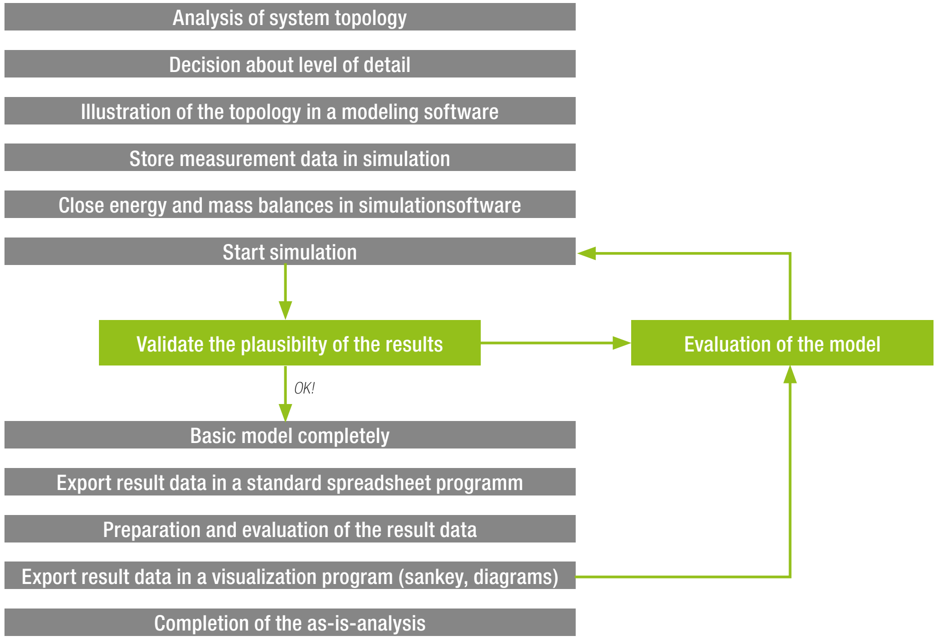

Fig. 7: Simulation process

Starting with the analysis of the topology it is important to decide about the level of detail for the model. Actual thermodynamic modelling software allows creating a visual model of the process within the software. After creating the topology of the process it is important to fill in all important information from process system, measurements or other data sources. Closing the energy and mass balance within the model is essential to build up a running simulation. Sometimes scripting might be part of it. Model results have to be checked each time for plausibility, and the model has to be changed in case of errors. After finalising the basic model, the result can be transferred into standard software to be shared among the project members. Exporting the resulting data to a visualisation programme such as sankey also helps to understand the balance created by the model. In the end, the result shall be a reliable basic model on which all further actions can be based on.

In the following, the micro analysis for the case study is described, concentrating on energy production on the one hand and paper production on the other.

Micro analysis energy production

The following step focusses on energy production which can be steam, hot water or electricity. In the paper industry it is common to use cogeneration plants.

As a first step the topology of the plant is analysed with regard to the main components, such as:

- boilers
- turbines
- feed water tank
- feed water pumps
- steam system
- condensate system
- reduction stations

A schematic with all relevant parts is needed.

The next step is to gather data from process systems or reporting in order to fill the schematic with representative figures and provide an overview of the process. Based on this information the efficiency of steam and electricity production can be calculated. AGFW-Worksheet FW308 offers a formula for calculating benchmarking figures and can help especially in cases of cogeneration[12].

Now the following important aspects regarding boiler efficiency have to be identified, such as flue gas outlet temperature, O_2 levels, economisers, air preheaters, and soot blowers.

The lowest possible flue gas temperature leaving the boiler depends very much on the used fuels and the technical specifications of the boiler and flue gas system. To prevent dew point undercuts, especially when burning solid fuels with sulfide or chloride or biogas with sulfide, the temperature levels are higher; this has to be kept in mind in case of optimisation. Natural gas, on the other hand, it is much less critical, and flue gas temperatures can be cooled down much more. If temperature levels are not available, they can be measured. The levels and types of fuels as well as the corresponding heat values have to be noted.

Oxygen levels also very much depend on the boiler type and the used fuels. Generally they are higher, if solid fuels are burned in order to ensure a complete oxidation of the C content, thus lowering CO-levels. In case of the gas and steam process, O2 levels are also much higher when using a gas turbine.

Economisers help to achieve higher efficiency levels by preheating the feeding water from the feeding water tank. By balancing the economisers one can ensure that they are working well.

Air preheaters are very common in solid fuel boilers. They preheat the combustion air by using heat from flue gas. Sometimes those preheaters are run by steam or condensate. To check these heat exchangers, data concerning the primary and secondary site of the exchanger is needed.

Soot blowers are commonly applied in boilers burning solid fuels. Solid fuels can cause deposits on the heat exchanger pipes and thereby reduce the efficiency of the system. Optimising soot blowers is quite difficult. Automatic soot blower systems are available on the market.

With regard to the turbines, the most important issue is that steam parameters and the load of the turbine fit the production. Very often, energy production structure and paper production do not match because of different developments, especially an increase or a reduction of paper production or new specifications in steam parameters.

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[12] [AGFW 2011]

CASE STUDY:

The graph below illustrates the topology of energy production for the chosen case study.

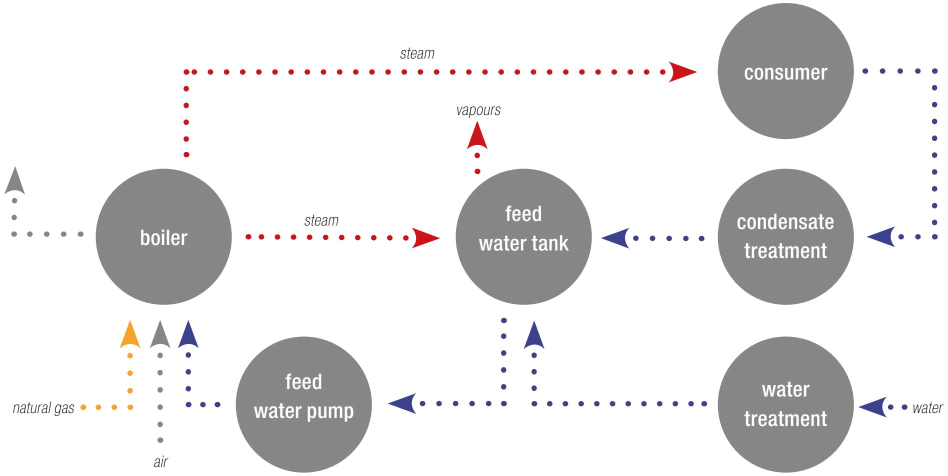

Fig. 8: Overview energy production case example

The plant includes a boiler for steam generation, which is fired by natural gas. The efficiency of heat production was estimated at 90% which reflects the EU ETS benchmark for heat production.

The emissions occurring by burning natural gas can be calculated as follows:

Calculation specific CO_2 emissions fuel usage: $\mathbf{EM_{fuel} = EM_{gas} = 56.1^{kgCO2}/_{GJ} = 202.0^{kgCO2/}{}_{MWh}}$

with, EM_{fuel} = specific CO_2 emissions fuel usage and EM_{gas} = emission factor, at this point: natural gas

Specific GHG emissions resulting from steam production are determined as:

Calculation specific CO_2 emissions process steam:

$$\mathbf{EM_{steam} = \frac{E_{boiler}}{P_{boiler}} * EM_{gas}} \qquad \mathbf{EM_{steam} = \frac{3.70MWh}{3.33MWh} * 202.0^{kgCO2/}{}_{MWh} * 224.4^{kgCO2/}{}_{MWh}}$$

with, EM_{steam} = specific CO_2 emissions process steam production and E_{boiler} = fuel usage

P_{boiler} = heat generation and EM_{gas} = emission factor, at this point: natural gas, 56.1kg_{CO2}/GJ -> $202.0^{kgCO2/}{}_{MWh}$

Micro analysis paper production

The micro analysis of the production process starts with a description, for example in the form of a flow sheet, and the collection of relevant figures. The analysis should focus on those areas that are relevant for the heat demand of the system and the generation of emissions.

With regard to tissue production only a rough survey of the topology including the main steps is needed concentrating on heat usage and occuring waste heat. Important flows are :

- fuels (here: natural gas)
- air
- steam and condensate
- water

In paper production, natural gas is mainly needed in the hood system, if the hood is gas heated. Steam is needed in the drying section of the paper machine, for the deinking process, and for building heating. Air is important for the hood system and for building acclimatisation. Water is also an important flow for a paper mill. Water transports not only fibre but also energy.

Reliable sources of information for correct figures could be process systems, energy management systems or sheets from the management controlling system.

The figure below shows the paper production process of the case study selected, initially only with the most important components and streams.

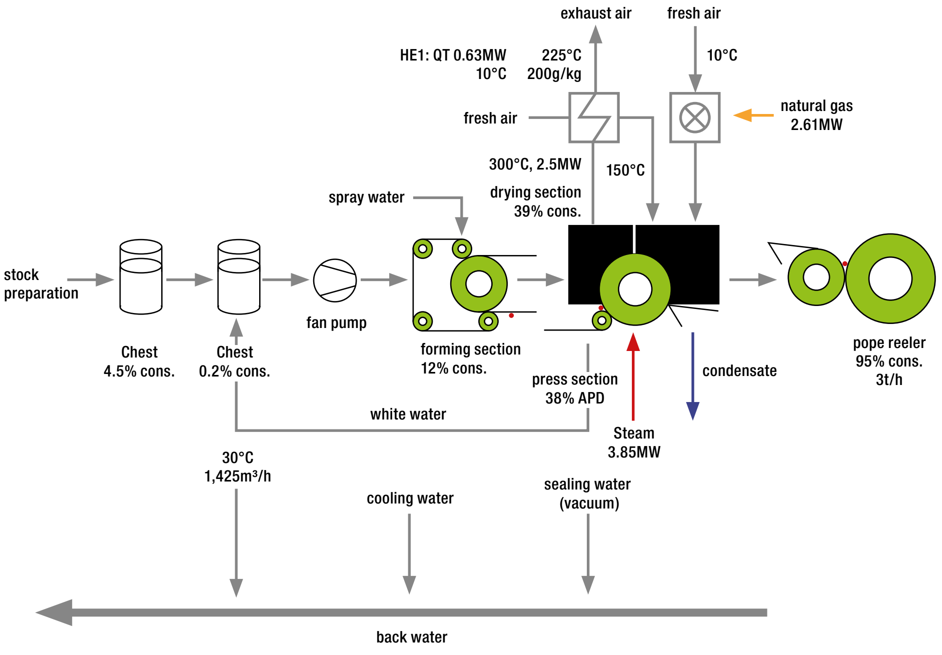

Fig. 9: Overview schematic paper production process

The water quantities moved within the process can be calculated by using the consistency[13]. The dry content after press (APD) as well as the residual moisture in the final products is usually known. The same applies to fuel and steam consumption. With regard to the exhaust air from the drying hood and the downstream heat recovery system, if present, data conditions can be very different. In the event of missing data measurements can be performed in order to reach a balance.

With the aim of creating an energy balance of the process in the next step, values for energy flows or mass flows and associated temperature levels are necessary. Concerning the case study the main values were included in Fig. 9.

The machine is equipped with one exhaust air heat exchanger preheating the supply air for the drying hood and an exhaust air temperature after the heat recovery of 225°C leaving a potential for several optimisation measures in chapter 4.

The gross production is $3t_{paper}/h$ at a steam consumption of 3.85MWh in the Yankee cylinder and a fuel consumption of 2.61MWh in the drying hood. The net production is estimated at 90% of the gross production resulting in $2.7t_{paper,\ net}/h$. Altogether, this results in a specific energy consumption for thermal drying of $2.4MWh/t_{paper,\ net}$.

The after press dryness, which is an important benchmark for the subsequent drying section, is 38%. The importance of this value is further discussed in chapter 4, measure (6). Within the drying section the paper is dried from a dry content of 38% to 95% in the end product.

The specific CO_2 emissions for paper production consist of the emissions by direct fuel and steam consumption and are determined as follows:

Calculation specific CO_2 emissions paper production:

$$\mathbf{EM_{paper}= (E_{fuel,direct} * EM_{gas} + E_{steam} * EM_{steam})/P_{paper,net}}$$

$$\mathbf{EM_{paper}= (2.61MWh * 202.0^{kgCO2/}{}_{MWh} + 3.85MWh * 224.4^{kgCO2/}{}_{MWh})/2.7t}$$

$$\mathbf{EM_{paper}= 514.2^{kgCO2}/t_{paper}}$$

with, EM_{paper} = specific CO_2 emissions paper and $E_{fuel,direct}$ = fuel usage direct

E_{steam} = steam demand and EM_{steam} = specific CO_2 emissions steam

$P_{paper,\ net}$ = net paper production

3.5 Step 5: selection of measures

After concluding the microanalysis of all relevant areas the selection of measures can be started. To be able to choose applicable measures for the identified improvable processes an overview of possible optimisation opportunities is required.

During the SLCTM project based on national and international literature on new technologies, measures or ideas for improving the energy efficiency of tissue machines a BAT and BP research was performed. During the mill surveys the catalogue was complemented by measures already implemented or planned in the mills. As a result, Chapter 4 provides a selection of measures representing best available technology and best practice with regard to the tissue production process. Nevertheless some measures can be of interest also for other production processes.

Creating a BAT data base provides an important tool for evaluating all options and deciding about feasible measures within the on-going project as well as generating future projects aiming at energy efficiency and GHG reduction.

3.6 Step 6: draft of technical concept

For the time being the draft of the technical concept includes all measures which are technically feasible, at this point without any economic evaluation. The goal is to develop a holistic concept that contains an optimal combination of measures. To this end, positive as well as negative correlations between individual measures must be considered.

Using the models elaborated during the micro analysis, the different optimisation potentials are determined by simulating the process.

3.7 Step 7: economic evaluation

Economic evaluations and investment decisions represent the respective business policy and, therefore, cannot be further discussed within the framework of this guideline.

Nevertheless economic decisions shall include all relevant aspects with regard to the project`s targets, costs could be mentioned here, not only for energy but for emission allowances in the EU ETS.

By making use of simulations in micro analysis and conceptual design, effects of interactions of different measures can be revealed. Another benefit consists in the possibility of simulating yearly cycles. In this way, the most accurate savings can be identified and decrease investment risks.

3.8 Step 8: final concept

As a result of the economic evaluation of the draft concept, a final concept will be determined, including a package of all measures which are technically feasible and economically reasonable.

[13] share of fibres in the water

RECOMMENDATION OF TECHNICAL STATE OF THE ART MEASURES

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4 Recommendation of technical state of the art measures

OR: WHAT CAN I DO IN PRACTICE?

In the following chapter, the measures used in this project for reducing the specific GHG emission intensity are presented. The measures are, if possible, first described in general terms, since they should support not only the tissue industry but the entire paper industry. For other energy-intensive industries, which have similar heat utilisation, individual proposals may also be of interest. In addition, the application in the tissue industry is briefly discussed for each proposed measure, sometimes also described with the help of a case study.

Tab. 1: Overview of measures

heat production and distribution		1	application of combined heat and power/ gas and steam	p.28
		2	fuel switch	p.30
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		4	optimisation condensate system	p.32
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		9	regulation air flow	p.36
		10	optimisation burners	p.37
heat recovery	**from hood system**	11	optimisation primary heat recovery	p.39
		12	re-evaporation	p.40
		13	waste heat utilisation for process water	p.40
		14	from vacuum system	p.41
		15	from compressors	p.41
		16	from waste water	p.42
		17	usage heat pumps	p.42
room air conditioning		18	optimisation building heating	p.42
		19	housing raw materials	p.43
water use		20	optimisation fresh water use	p.43
		21	treatment circuit water	p.44
process monitoring		22	energy management	p.45
		23	maintenance program	p.45

The figure below provides an overview of measures linked to the relevant process steps.

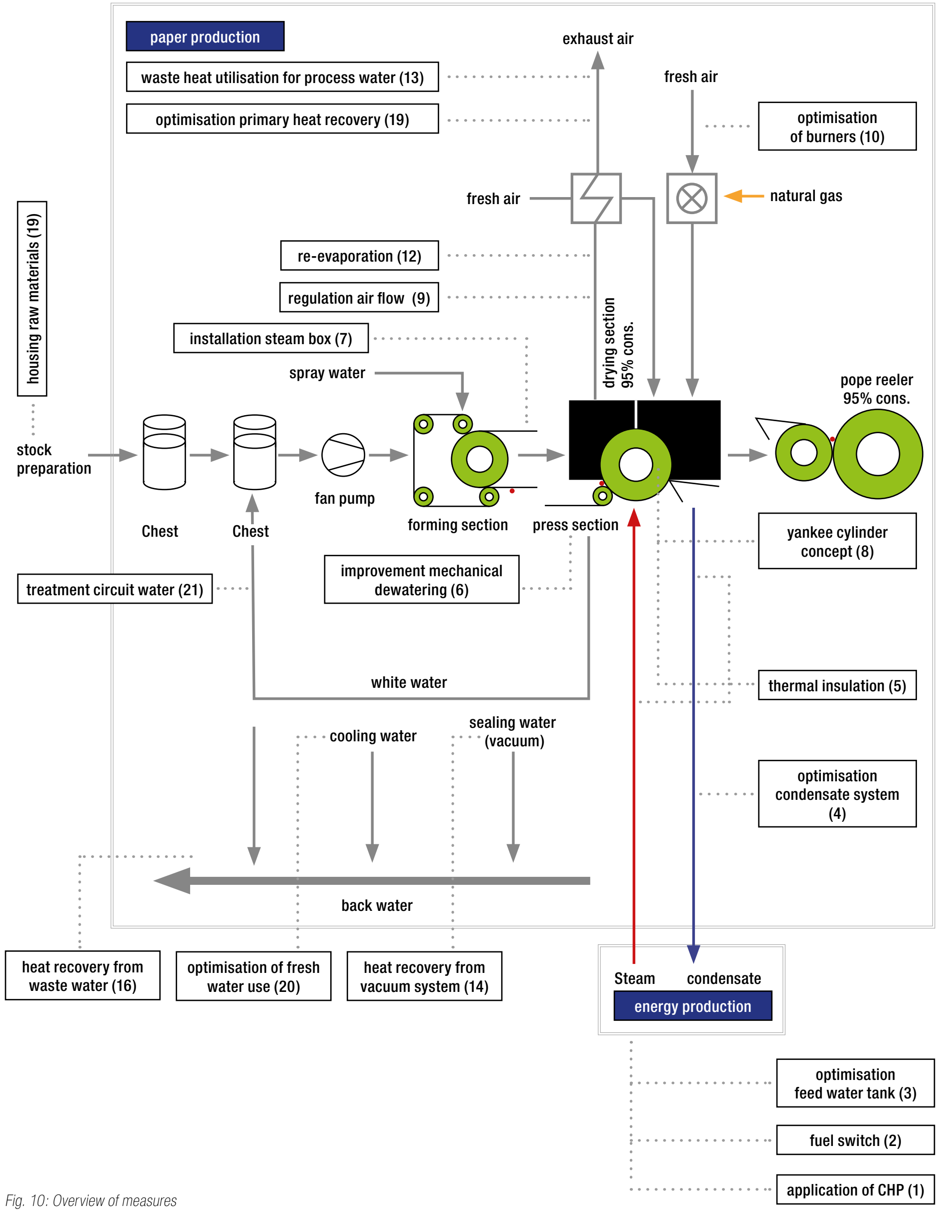

Fig. 10: Overview of measures

4.1 Heat production and distribution

The influence on the development of greenhouse gas emissions from the heat production is given only if it is an internal heating station. The specific CO_2 emissions of the heat arise here, on the one hand, by the fuel input, and, on the other hand, by the efficiency of the boiler.

In tissue production almost the entire quantity of fresh steam is consumed in the drying section of the paper machine, which means Yankee cylinder – and drying hood, if not gas fired. The deinking lines of paper mills with recovered paper need steam for the bleaching process. Additional steam is needed to heat buildings and process water, especially during the winter months. The total specific gas and steam consumption of the mills normally varies between summer and winter time.

Application of combined heat and power/ gas and steam (1) [14]

To optimise the efficiency of the energy supply it is possible to use combined heat and power generation. The structure depends on the relation between heat and electricity usage and on the used fuels. Since the paper production needs high amounts of steam and electricity at the same time, the application of combined heat and power will increase the efficiency of fuel usage. Although producing steam and electricity will lead to a higher total fuel amount than only steam production, combined power plants are still more efficient than the single production of electricity within normal power plants. The efficiency of a modern combined power plant in the paper industry can be higher than 80% where modern high efficient power plants for electricity production still remain below 50%. The combined heat and power process can be run on several fuels. It is also possible to use the gas and steam process. Key factors for combined power production are liquidity, operational availability and fuel costs. An important figure is also the relation between price of electricity and fuel price. For design and efficiency of the combined power plant the relation between electricity and steam usage of the production is very significant.

CASE STUDY:

The following is a comparison of coupled and uncoupled heat and power generation in purely arithmetical terms. The allocation of the fuel use and the resulting emissions of a combined heat and power generation to the two different products heat and electricity make use of the Finnish method[15]. CO_2 emissions will be attributed to the products heat and electricity comparing a combined heat and power process with the uncoupled generation using the following reference values for the efficiencies.

The used fuel is natural gas. The following key figures are used for the comparison.

Electrical efficiency of the CHP plant	$n_{el,CHP}$	0.3
Thermal efficiency of the CHP plant	$n_{th,CHP}$	0.5
Thermal efficiency of separate heat production	n_{th}	0.9
Reference electrical efficiency of the CHP plant	$n_{el,ref}$	0.525
Reference thermal efficiency of the CHP plant	$n_{th,ref}$	0.9

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[14] [COST 2008; Fitzke 2012; Getec 2012; Getec 2012a; Graf 2011a; Jung 2007; UBA 2004]

[15] [2004/8/EC]

Based on these figures the formula is as follows:

$$\text{PEE} = 1 - \frac{1}{\frac{n_{th}}{n_{th,ref}} + \frac{n_{el}}{n_{el,ref}}} = 1 - \frac{1}{\frac{0.5}{0.9} + \frac{0.3}{0.525}} = 0.113$$

$$EF_{el} = \frac{EF_{gas} * (1 - \text{PEE}) * \frac{n_{el}}{n_{el,ref}} * W_{gas}}{W_{th}}$$

$$= \frac{201^{\text{kgCO2}}/\text{MWh}\ (1 - 0.113) * \frac{0.3}{0.525} * 1\text{MWh}}{0.3\text{MWh}} = 340^{\text{kgCO2}}/\text{MWh}$$

$$EF_{th} = \frac{EF_{gas} * (1 - \text{PEE}) * \frac{n_{th}}{n_{th,ref}} * W_{gas}}{W_{th}} = \frac{201^{\text{kgCO2}}/\text{MWh}\ (1 - 0.113) * \frac{0.3}{0.9} * 1\text{MWh}}{0.5\text{MWh}}$$

$$= 198^{\text{kgCO2}}/\text{MWh}$$

With,

EF_{el} = specific emissions electrical power generation and EF_{th} = specific emissions heat generation

EF_{gas} = specific emissions natural gas and $n_{el,CHP}$ = CHP efficiency electrical power generation

$n_{th,CHP}$ = CHP efficiency heat generation and n_{th} = efficiency heat generation

$n_{el,ref}$ = reference efficiency electrical power generation and $\eta_{th,ref}$ = reference efficiency heat generation

W_{el} = energy quantity electrical power and W_{th} = energy quantity heat

W_{gas} = energy quantity fuel and PEE = primary fuel savings

The specific emissions resulting from separate heat generation can be calculated as follows:

$$EF_{th} = \frac{EF_{gas} * W_{gas}}{W_{th}} = \frac{201^{\text{kgCO2}}/\text{MWh} * 1\text{MWh}}{0.9\text{MWh}} = 223^{\text{kgCO2}}/\text{MWh}$$

The next diagram illustrates the occurrence of cogeneration on the one hand and heat production only combined with electricity purchase from the grid. Here the above calculated specific emission factors were used for energy production as well as the emission factor for electrical energy from the German grid for the year 2010[16]. In both cases the consumption is the same at 0.3MWh electric and 0.5MWh thermal energy.

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[16] [UBA 2013]

In this exemplary calculation the combined heat and power process (Fig. 11) causes fewer CO_2 emissions than the separate heat production (Fig. 12) and the electricity purchase from the national grid (Fig. 13).

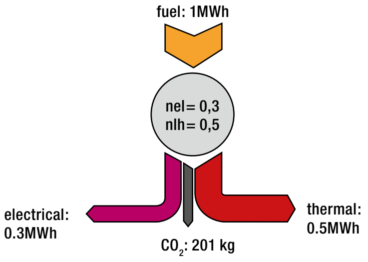

Fig. 11: Emissions cogeneration

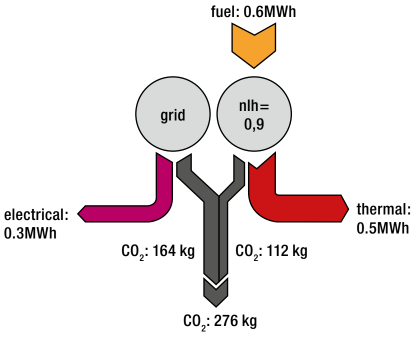

Fig. 12: Emissions separate heat production

Whether the use of a CHP plant is reasonable, can only be decided by taking all conditions of the installation into consideration, such as electricity and heat demand, efficiencies, used fuels, grid factor.

Fuel switch (2) [17]

Burning fossil fuels causes relevant CO_2 emissions. CO_2 originating from regenerative sources is not relevant for the global C balance and thereby regarded as CO_2 neutral. Consequently a reduction of fossil greenhouse gas emissions can be achieved by switching to the use of biogenic fuels. According to the definition used in the EU ETS *"Biomass means the biodegradable fraction of products, waste and residues from biological origin from agriculture (including vegetal and animal substances), forestry and related industries including fisheries and aquaculture, as well as the biodegradable fraction of industrial and municipal waste"*[18].

Today, fuels used in the tissue industry are still coal, oil, and natural gas. But one can find an increase of plants using biomass such as wood, biogas or sludge as an alternative.

This measure, however, only leads to the exchange of fossil by biogenic CO_2 emissions and not to an increase in efficiency.

Thermal recycling of reject materials/sludge[19]

Thermal recycling of rejects or sludge can also be used to substitute fossil fuels. Sludge is a result of tissue making which cannot be used for further paper making. Since there is no use for this sludge it has to be disposed of. Another possibility is the thermal recycling on site. Before burning it has to be mechanically dried up to 45 to 50% dry content. If an attractive heat source is available, thermal drying is also possible. Further thermal drying is technically feasible but can cause odour problems. Sludge from paper making also contains high amounts of ashes, therefore the expected heat values are quite low and burning only sludge is difficult. In general, sludge is burned together with a high caloric fuel. This fuel switch is only partly CO_2-neutral.

Production of biogas [20]

Production of biogas within the waste water treatment plant is sometimes possible. If the waste water quality is suitable, the biogas can be produced in special reactors. There different anaerobe microorganisms help to produce methane. Before burning biogas one has to take care of possible sulfide contents. If these contents are too high, they have to be lowered to prevent damage to the boiler system. Conditioned biogas can be used to substitute fossil fuels and can be regarded as CO_2 neutral.

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[17] [Getec 2012, Fitzke 2012, CED07, MES08, Graf 2011a, UBA 2004, COST 2008]
[18] [2009/28/EC]
[19] [Bellmer 2010, Voith 2012
[20] [HUT10, SCA 2012, COS08]

Optimisation of the feed water tank (3) [21]

During steam generation it is necessary to heat the feeding water tank by using steam. There are possibilities to reduce this steam use.

The degassing process in steam production is essential for avoiding corrosion within the boiler and piping systems. Degassing takes places in the feed water tank. There, condensate and additional highly purified water are heated to above 100°C. For this purpose, steam is required. In general, low pressure steam is used. The amounts of steam highly depend on the degassing temperature level, condensate temperature and on condensate losses in paper making. The higher these losses are, the higher is the amount of cold purified water. To heat additional feeding water, a condenser installed on the feed water tank could be used. The feed water tank is atmospheric and, as a result, flash steam is generated. The condenser can use this flash steam to preheat the additional feed water before going into the feeding water tank. This can reduce the amount of steam needed in the tank. It is also possible to transfer heat from feed water leaving the tank to condensate going into the tank. This reduces the feed water temperature into the economiser. Economiser design has to be checked so that the outlet water temperature of the economiser does not drop. Then, the economiser will recover more heat from flue gas and the higher inlet temperatures of the feeding water tank will cause lower steam usage. Pressurising the condensate system of the paper machine will lead to a returning temperature of the condensate >100°C. This will also reduce the amount of steam for the degassing process.

CASE STUDY:

Installing a flash steam condenser at the feeding water tank helps to reduce steam usage. This example shows the impact of a condenser to preheat additional water into the tank. The temperature of the water rises and thereby the steam usage and the CO_2 emissions caused by the steam usage of the feeding water tank can be lowered. The energy balance is shown by the sankey below.

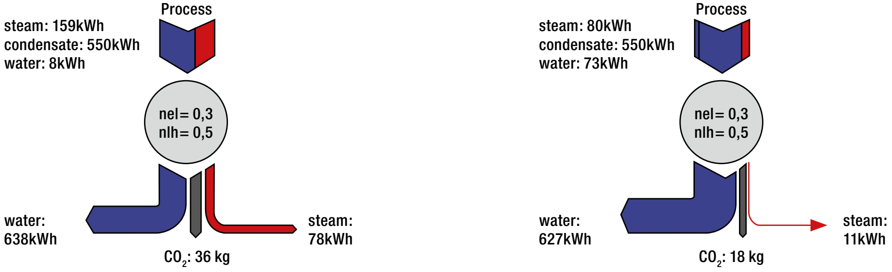

Fig. 13: Results optimisation of feed water tank

The calculated emission factor of steam production within the model power plant drops from $224.51kg_{CO2}$/MWh to $220.41kg_{CO2}$/MWh. Lowering specific emissions of steam production, of course, has an impact on the specific emission of tissue production, too. This emission factor decreases from $530.69kg_{CO2}$/tpaper to $524.55kg_{CO2}$/tpaper.

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[21] [ANG00]

Optimisation of the condensate system (4) [22]

For the minimisation of heat losses within the condensate system it is possible to pressurise this system or to use vapour condensers. It is also important to work on eliminating leakages.

In general, condensate systems are atmospheric. Condensate temperatures above 100°C in the condensate tank at the paper machine thereby cause different amounts of flash steam. This flash steam not only leads to heat losses but also to condensate losses which have to be substituted within the power plant. There are two possibilities to avoid flash steam. One is to install a condenser will help to lower or even avoid flash steam directly at the condensate tank. The other is to change the condensate system from an open atmospheric system to a pressurised system which will also avoid flash steam and allow a condensate temperature above 100°C. In this way, energy is saved by avoiding flash steam and lowering steam demands in the feeding water tank in power plant (see Number 3). Since pressurising a whole condensate system is much more cost intensive than only installing a condenser, the payback of this massive change very much depends on the condensate flows and temperature levels and, of course, on the structure of the power plant. In general, new machines come with a pressurised condensate system since that is state of the art in paper making.

CASE STUDY:

In the example the condensate system is atmospheric and thereby flash steam leaves the system. The flash steam can be recovered by a condenser cooled with process or fresh water. In this example, a certain amount of process water is used as cooling medium.

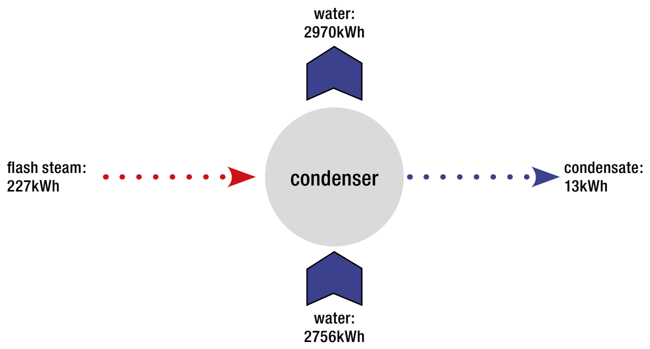

Fig. 14: Results optimisation condensate system

The heat from flash steam can be transferred to process water and stabilise the white water temperature level. Steam or condensate amounts used to stabilise temperature levels can be lowered. This leads to a lower energy usage on machine and lowers the specific emission of tissue production from 530.69kg$_{CO2}$/tpaper to 508.56kg$_{CO2}$/tpaper.

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[22] [Jung 2009, Maier 2010, Lang-Hafner 2010, Niebuhr 2010, Hameister et al. 2012, EnergieAgentur.NRW 2010, COST 2008]

Thermal insulation (5) [23]

To reduce heat losses caused by radiation and convection, insulations have to be improved. This could be realised in Yankee, hood, pipes (steam and condensate system) or other areas. The insulation of pipes must satisfy various requirements; the condensate system requires materials which, even at temperatures above 160°C, do not lose their properties. For this aim fibre mats are used. The most common ways are fibre composites, textile mats and plates.

The losses increase proportional to surface, heat transfer coefficient and the difference between inside and outside temperature. The heat losses or the effectiveness of various insulation materials can be assessed, so that costs can be calculated exactly for an increase in efficiency, and the time period can be determined in which the costs are refinanced.

A useful step to determine heat losses is a thermographic investigation. Focusing on high temperature surfaces in the beginning will help to lower the work time. Missing insulation is the main reason for heat losses by thermal radiation. Very often insulation is missing on valves or after maintenance work. During tissue production, the major spots are steam and condensate system, hood system, Yankee cylinder, boiler house. As already mentioned heat losses very much depend on surface temperature level, surface size, and ambience temperature. For example, pipe insulation payback for pipes bigger than DN80 in the steam and condensate system is very often less than one year. The efficiency of the steam consumption from the entire system can be increased by 1 to 3%. By Yankee insulation a potential of up to 5% can be achieved.

4.2 Drying technology

To achieve an efficient drying of products, it is necessary to choose a suitable dewatering technology. The tissue production process includes mechanical (press section) as well as thermal procedures (drying section) whose optimisation possibilities are described below.

As an alternative technology dry sheet forming is able to produce special tissue products without using water. This technology has a lower heat use but a higher electricity use.[24] Since it is a completely different production process, there will be no further focus on dry sheet forming.

Improvement of mechanical dewatering (6) [25]

The function of the press section is to dewater the paper mechanically. Here a balance between dry and wet content must be found, because if the paper is too wet, the full potential is not exploited. If the paper sheet is too dry, there are risks of sheet breakage or the paper igniting on the Yankee.

The shoe press is a very efficient way for mechanical dewatering. A combination of a conventional roll and a shoe roll creates a larger area for applying pressure on the felts. The following figure shows the pressure distribution in a pressure nip in between two conventional rolls and a pressure nip with one conventional and one shoe roll.

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[23] [Jung 2009, Voith 2011a, EnergieAgentur.NRW 2010, Maurer-Fritz 2010, Kramer 2010]

[24] [Anglani et al. 2000]

[25] [Jung 2009, Schuster et al. 2010, Kääpä 2011, Tjernberg 2010, Huyck.Wangner 2010, EnergieAgentur.NRW 2010, Cedra et al. 2007, Meßmer 2008, Maurer-Fritz 2010, Kramer 2010, Schlegel 2008, COST 2008]

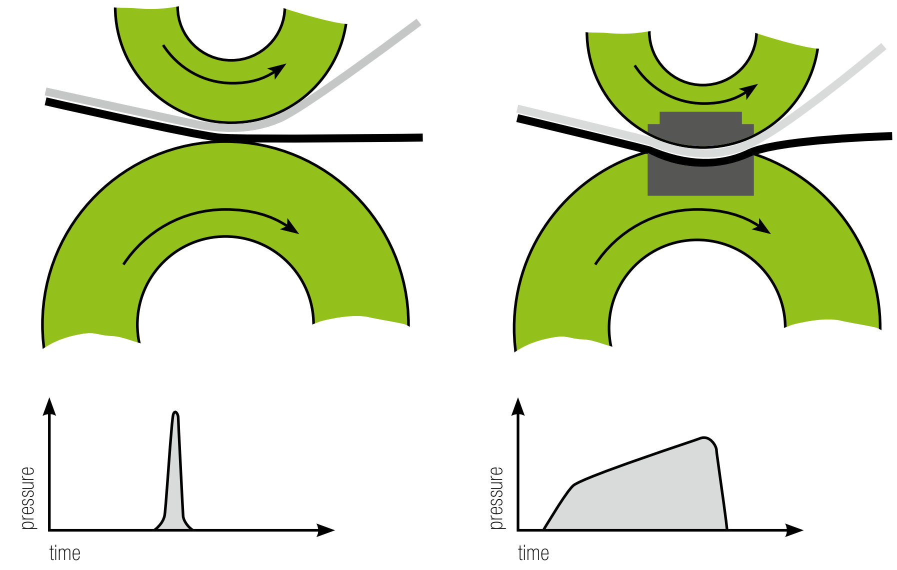

Fig. 15: Comparison of 2 conventional rolls with 1 conventional and 1 shoe roll[26]

This can increase the dry content by 5% up to 45 to 50%. In addition, the paper volume is retained by this form of drainage. As a result, a higher dry content before thermal drying is achieved. This requires less gas to dry the paper sufficiently. So gas is saved in the long run and the emissions are lower.

The removed moisture is discharged to a continuous felt and then carried away. This type of dewatering is very efficient, even though the specific pressure does not increase during pressing.

CASE STUDY:

Installing a shoe press is one way to improve mechanical dewatering within the press section. In the example an improvement of a 5% increase in APD was calculated. That will reduce the amount of evaporated water in the hood system by 20% and thereby reduce fuel and steam usage. The Sankey below shows the mass balance of the model machine.

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[26] [Blechschmidt 2010]

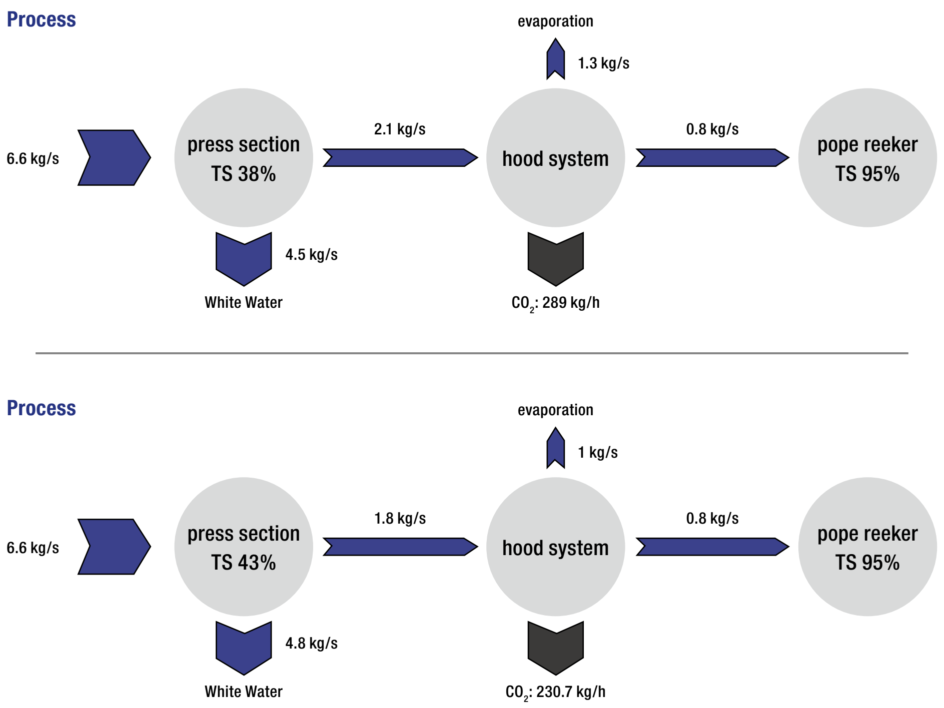

Fig. 16: Results installation shoe press

As a result the CO_2 emissions will decrease. That will lower the specific emissions for tissue production from 530.69kg$_{CO2}$/tpaper to 441.65kg$_{CO2}$/tpaper.

Installation steam box (7) [27]

The steam box has advantages in production, consistent sheet moisture, increase of the dry content after the press section, improvement of run ability, thinning of the steam demand, and improvement of paper quality and, therefore, improvement of profitability.

As one result, a higher dry content before thermal drying is achieved. This requires less gas to dry the paper sufficiently. So gas is saved in the long run and also the expelled emissions are lower.

Even when the temperature increases only by 10K, the dry content can be increased by 1%. This is possible because the paper can be more efficiently drained by the pressing section because of the lower viscosity. By this gentle form of drainage, the volume of paper is widely retained. The steam box can be used to counteract moisture spikes. Uneven moisture profiles are a major problem in the drying process, their correction results in lower energy consumption.

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[27] [EV Group Oy et al.. 2012, Ammann 2009, Schuster et al. 2010, Maurer-Fritz 2010, Anglani et al. 2000, COST 2008]

Yankee cylinder concept (8) [28]

Improvement of drying by optimisation of dewatering and heat transfer in order to decrease the steam demand is the target of new Yankee cylinder concepts. There are new technologies for Yankee dewatering and alternative Yankee materials (steel). The application highly depends on the current life expectancy of existing Yankee cylinders and products running.

From an energy point of view using new Yankee materials such as steel, offers a lot of advantages compared to cast iron. Since steel has better solidity properties than cast iron, the design of the Yankee can be much lighter and the thickness of the surface can be up to 20% thinner. The weight of the Yankee will lead to lower power consumption. Its thinner thickness will lead to a better heat transfer and thereby increase the direct drying process. Compared with the same steam pressures, direct drying by the Yankee can be increased by 5 to 7%. A higher amount in direct drying can lead to lower gas consumption in the hood system. The CO_2 intensity has to be calculated based on the specific emissions of steam and gas. Steel Yankees can also improve the production of the machine and provide higher safety levels. Due to losses in stability the pressure in cast iron Yankees has to be reduced over the years. By using steel Yankees this pressure drop is not necessary. That means that the efficiency of the steel Yankee might remain on a higher level compared to cast iron Yankees. Steel Yankees are also runnable on TAD machines.

Another possibility to improve the efficiency of the Yankee by increasing the heat transfer of the surface is the optimisation of the condensate dewatering system of the Yankee and the optimisation of the condensate film thickness within the Yankee contact surface. Since the thermal resistivity of condensate is much higher compared to cast iron, the thickness of the condensate film is very important for the heat transfer. Special siphon designs and turbulence bars help to reduce that thickness and, thus, improve the heat transfer of the Yankee surface.

Reduction of radiation losses of the Yankees can also help to save energy. Since the surface temperature of the Yankee is very high, there are high radiation losses on the front sides. Insulating these surfaces will lower the losses and thereby reduce the energy usage in thermal drying.

An alternative Yankee heating concept is direct Yankee firing[29].

Regulation of the air flow (9) [30]

Minimising the volumes of air into the hood system will help to save fuel. This can be realised by optimising pressure conditions, temperature levels, volume flows and pipe layout. An important parameter for assessing the air balance of the hood system is the ratio of fresh air to exhaust air mass flow. The water content of the exhaust air is linked to this ratio. By reducing the amount of fresh air the water load increases. There are technical limits due to paper quality and drying capacity within the hood system. Less fresh air will reduce the amount of fuel within the system. It will also have an impact on the heat recovery of the hood system.

Within the hood system leakage air appears to be a disturbing factor. Diminishing leakage air amounts helps to increase efficiency and thereby leads to lower fuel consumption. Since leakage air is not preheated, it lowers the system temperature which has to be compensated by the burners. Installing a permanent and reliable humidity measurement provides information about the actual situation of the hood system in different operating states of the tissue machine. Regulating the inlet air flow by using frequency converters on the fan and humidity measuring should be the first choice. These measures will not only lower the fuel consumption but also the power usage. A detailed hood inspection should also help to find out where most of the leakage air is going into the system. Besides the gap between Yankee and hood, weak spots are very often heat exchangers, fans and pipe dampers.

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[28] [Bauböck 2008, Voith 2011a, Not stated 2011a, Niebuhr 2010, Wind 2012, Hameister et al. 2012, Graf 2011b, Not stated 2011b]

[29] [Anglani et al. 2000]

[30] [Jung 2009, EnergieAgentur.NRW 2010, Slawtschew 2010, Blickle 2011, Kramer 2010, COST 2008]

CASE STUDY:

Increasing the water load of the hood system will lead to a reduction in fresh air inlet and, as a consequence, to a decrease in fuel usage within the system. The sankey below shows an example calculated with an increase of the water load per dry air starting with 200g/kg up to 400g/kg.

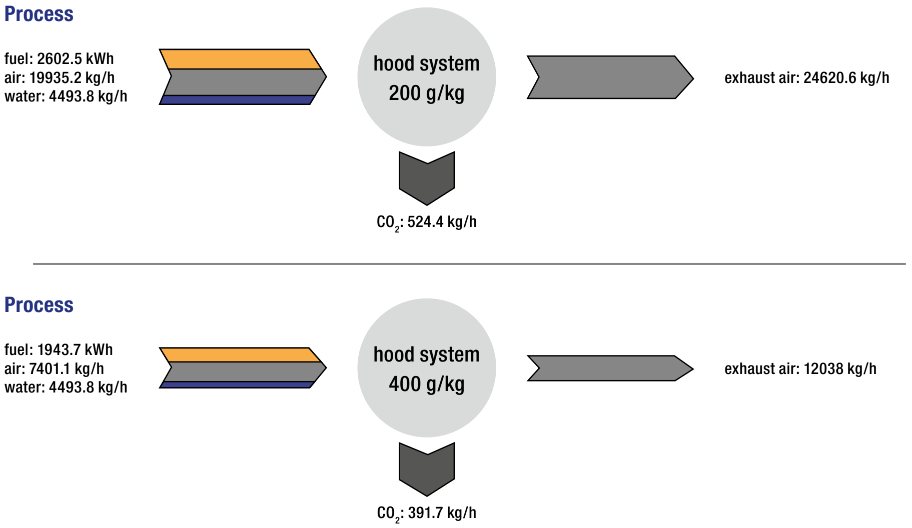

Fig. 17: Results optimised air flow

As a result, the CO_2 emission due to the fuel usage drops. Lowering the fuel usage in the hood system will lower the specific emissions of tissue production. The specific emissions of the example machine could be lowered from $530.69kg_{CO2}$/tpaper to $481.49kg_{CO2}$/tpaper.

Optimisation of burners (10) [31]

A large part of the energy is used by the burners. Therefore an optimisation of the burner has a positive effect on the total energy consumption.

The monitoring of the burner system is important. Here, important values are O_2 levels or other combustion indicators such as CO levels.

In this way, anomalies are discovered very quickly and can be solved. A certain content of carbon monoxide, for example, indicates incomplete combustion. Reducing CO levels can help to increase the burner efficiency.

Another possibility to save energy in a burner system is the preheating of the combustion air. This will also reduce the amounts of fuel. It is also possible to preheat the fuel itself which will also lead to a certain amount in fuel reduction.

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[31] [Kramer 2010, COST 2008]

CASE STUDY:

Preheating combustion air for burners will reduce fuel usage in the hood system. The maximum temperature level of the combustion air is limited by the technical specifications of the burner system. In the example it is preheated to 150°C. The sankey below shows the changes within the balance of the burners.

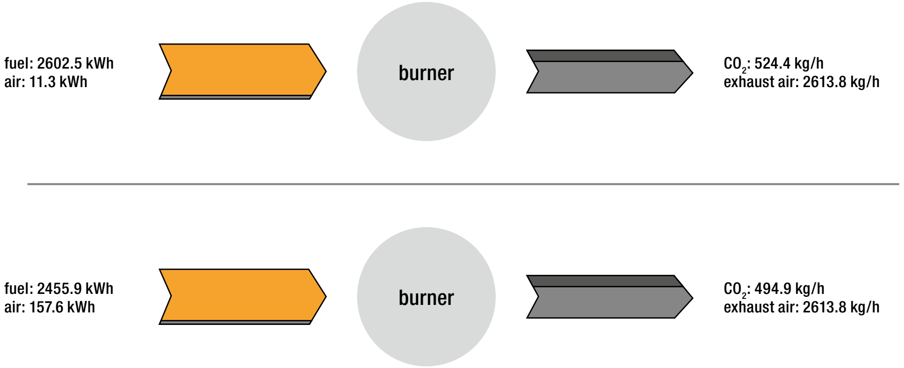

Fig. 18: Results optimisation of burners

The reduction of fuel usage in a hood system will reduce the specific emission for tissue production from 530.69kgCO2/tpaper to 519.74kgCO2/tpaper.

4.3 Heat recovery

With regard to tissue production the main waste heat flow occurs at the drying hood of the paper machine. The first heat exchanger is always an air-to-air heat exchanger to preheat make-up air (and often combustion air). The purpose of the following air-to-air or air-to-water heat exchangers is to heat process water or buildings.

In addition to the hood exhaust air there are other sources of waste heat that can be harnessed. For example there are possibilities to recover heat from the vacuum system, compressors or waste water by finding an attractive heat sink.

The heat recovery system of the hood can be divided into two steps, primary and secondary heat recovery. Primary means the heat transfer within the hood system. In general, this is the first heat exchanger for preheating make up air and combustion air. Secondary means the heat transfer out of the hood system. Commonly, these are heat exchangers for building heating, process water or fresh water.

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29 [Anglani et al. 2000]

30 [Jung 2009, EnergieAgentur.NRW 2010, Slawtschew 2010, Blickle 2011, Kramer 2010, COST 2008]

Optimisation of the primary heat recovery of the hood (11) [32]

The improvement of the efficiency of the hood heat recovery system shall start with the primary step. It is most important to avoid or reduce leakage air to its minimum. Leakage air is cold air sucked into the system by underpressure through various leakages causing a higher fuel demand on the burners as a result of stabilising the system temperature level. Weak spots for leakage air are very often heat exchangers, fans, and pipe dampers. Combustion air shall also be preheated. It is possible to combine the preheating of combustion air with the preheating of make-up air. With combustion air it is possible to take care of the maximum temperature due to the burner and combustion fan design. Preheating combustion air will reduce the fuel demand on the burner. Preheating make-up air is the biggest potential to reduce fuel usage in the hood system. This is generally already state of the art, but very often heat exchangers are inefficient which leads to a bigger upper temperature differential. One reason for an inefficient heat transfer can be dust deposits on the pipe or plate surfaces. Those deposits are to be removed regularly in order to improve the heat transfer. Another reason is a faulty heat exchanger design which does not fit actual temperature levels and mass flows. This is very often caused by continuous improvements of the machine speed without increasing the primary heat exchanger. Therefore, the heat exchanger surface has to be increased in order to lower the upper temperature differential and increase the total heat transfer from exhaust air to make-up air.

CASE STUDY:

Increasing the primary heat exchanger recovers more heat directly for the hood system. That will lead to an increase of the temperature level of fresh air and lower the exhaust air temperature behind the heat exchanger. The sankey below shows the energy balance of the example.

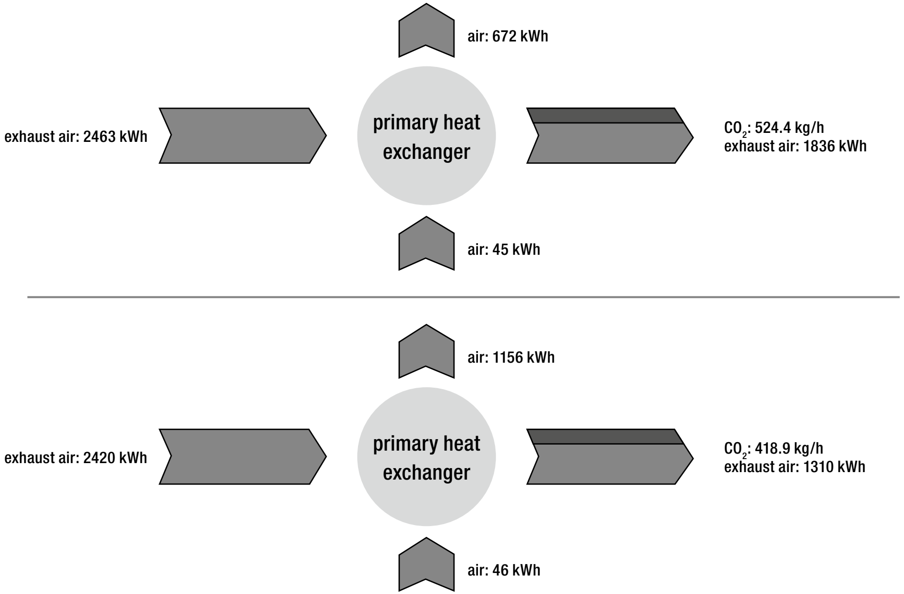

Fig. 19: Results optimised primary heat recovery

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[32] [Jung 2009, Lang-Hafner 2010, Hutter et al. 2010, EnergieAgentur.NRW 2010, Kramer 2010, UBA 2004, COST 2008]

There, the upper temperature differential is lowered from 150K to 50K. The fuel usage of the hood system will decrease accordingly. As a result, the specific emissions for tissue production are lowered from 530.69kg_{CO2}/tpaper to 491.58kg_{CO2}/tpaper.

Steam production with waste heat (12)

In paper production, a large amount of steam is required for the drying process. The steam is used in the Yankee cylinder, in a steam box, or as an additive heat source. To save energy, either the steam consumption can be reduced, or the steam can be generated from waste heat.

The alternative steam generation is an important factor in the production of paper. For this purpose, a re-evaporation unit can be used. However, a high temperature level is needed. These high temperatures occur only in the hood system. There are re-evaporation systems to generate steam by using waste heat from the hood system. The steam could be reused in tissue production.

Waste heat utilisation for heating process water/ spray water (13) [33]

It is possible to use waste heat from the hood system to heat process water. This optimises the tissue production process.

As described above, the heat recovery system of the hood system can be divided into two steps: primary and secondary heat recovery. The secondary heat recovery commonly consists of heat exchangers for building heating or process water, fresh water. Depending on mass flow and temperature levels heat from exhaust air of the hood system is suitable for building heating and thereby substituting steam or other necessary fuels. Recovering heat for heating from hood system behind the primary heat exchanger can be handled by a common air to air or air to water heat exchanger, depending on the heating system. For example this heat can be used for heating up fresh air for machine hall ventilation or for heating up central heating systems. The next step in heat recovery can be used to heat up process water or fresh water. For heating process water very often scrubbers are used. This technology is useful if it comes to process water loaded with particles which can cause problems in normal heat exchangers. Scrubbers are also very effective, since there is a direct heat transfer. For preheating fresh water it is recommended to use heat exchangers since there are particles in the exhaust air. The order of several heat exchangers very much depends on the temperature and mass flow levels of both sites. Usually, scrubbers are the last step. But it can also be attractive to install fresh water heat exchangers on top of the scrubbers to lower the exhaust air temperature level even more. If the machine showers are running on fresh water, preheating that water up to process temperature level or even higher is attractive, since process water temperature level increases. But also preheating water for chemicals can be interesting; or a combination of both. Besides preheating, additional fresh water for the process can be attractive since cold water can cause problems with fibres. Heating process water has several advantages. A higher process temperature can lead to a better mechanical dewatering resulting in a lower fuel and steam usage in thermal drying to reach the final drying content of the paper. Roughly one can say that increasing the temperature level of white water by 10K can lead to an increase of mechanical dewatering behind press section by 1%, which leads to a lower steam and fuel usage in hood system by 4%. Of course, there are technical limits regarding the maximum temperature of white water. The heat recovery system for process water can also help to reach a stable temperature level over the year and, thus, lowering steam amounts formerly necessary to stabils the process. If the mechanical dewatering can be improved due to a higher process temperature level, that can also improve the run ability of the machine.

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[33] [COST 2008]

CASE STUDY:

Heating up white water will lead to a better mechanical dewatering in the press section and thereby lower fuel and steam usage in the drying section. Commonly an increase by 10K in white water will lead to an improvement of 1% mechanical drying in press section and, thereby, lowering the amount of water evaporation in hood system by 4%. Within the model machine the water temperature could be raised by 16K and steam usage for stabilising white water temperature level could be lowered. The sankey below shows the energy balance of an example heat recovery for heating up white water.

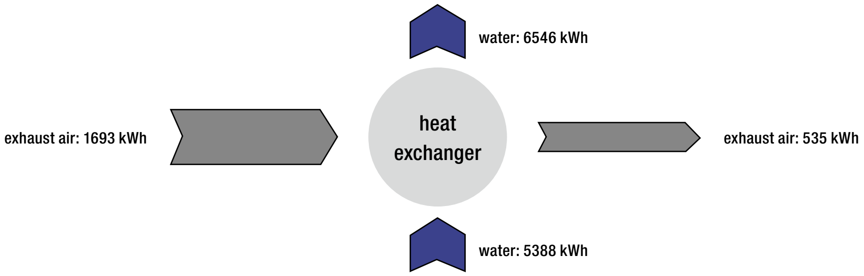

Fig. 20: Results installation heat recovery for process water

In the example the specific emissions of tissue production are decreasing from 530.69kg_{CO2}/tpaper to 438.23kg_{CO2}/tpaper.

Usage waste heat vacuum system (14)

Depending on the type of vacuum system it could be attractive to recover waste heat from vacuum pumps. The exhaust air temperature level and the volume flow are very much dependent on the type of the vacuum pumps and the vacuum demand on the machine. Water ring pumps have much lower exhaust air temperature levels than turbo blowers. Typical exhaust temperatures of water ring pumps are between 30 to 50°C. It is highly dependent on sealing water temperature level and mass flow. Since the efficiency of the water ring pumps are very much dependent on sealing water temperature levels, it is recommended to keep them at a low level. This will also lead to a lower exhaust air temperature, which makes the design of a heat recovery system more complicated. But with a suitable heat sink it is, of course, possible. The exhaust air temperature of turbo blowers is above 100°C and, therefore, much more suitable for heat recovery systems. It is possible to find several attractive heat sinks within the paper making process for this heat source, such as building heating, process water or fresh water.

Usage waste heat compressors (15)

Recover waste heat from compressors could be attractive to substitute other heat sources. In general, there are two different types of cooling systems for compressors. On the one hand there are air cooled compressors, on the other hand there are water cooled compressors. The temperature level of the cooling medium is very much dependent on the inlet temperature and on the mass flow. Using the warm air from air cooled compressors can be attractive for direct building heating during the heating period. Air to water heat recovery system are also available for air cooled heat exchangers, which makes the heat source not only attractive for central heating, but also for other heat sinks in the production process, such as process water and fresh water. This is the same for water cooled compressors. Very often only small compressors are available directly for paper making, but much bigger ones for running converting lines.

Usage of waste heat from waste water (16) [34]
A lot of heat is leaving the plant by waste water on a low temperature level. Recovering this low caloric heat is possible, if an attractive heat sink can be found. This is difficult, since waste water has nearly the same temperature level as process water. One of the most suitable heat sinks is fresh water. Preheating fresh water by transferring heat from waste water can help to stabilise the process water temperature and, thereby, reduce heat consumption. Sometimes cooling of waste water is necessary due to regulations regarding the maximum waste water temperature level. Cooling waste water by using fresh water can decrease or eliminate power consumption for running cooling towers and even avoid problems with smell. So transferring heat from waste water has not only energy saving aspects but also process stabilising points.

Usage of heat pumps (17) [35]
The installation of heat pumps to support heat recovery in order to decrease the heat demand could be attractive. It highly depends on temperature levels and correlation of heat source and sink.

In paper production, a lot of heat is required for drying; usually this energy is not optimally recycled, so that a certain amount of heat is lost. The heat is usually lost through the exhaust gas and is released to the atmosphere. Therefore, the main focus should be the optimal usage of waste heat. One way of recovery is the heat pump. Heat pumps are used to increase the temperature level of heat sources. This is done to make the waste heat available for other processes. Without upgrading the heat, the energy would be lost.

However, the heat pumps also require energy. This can happen through use of primary energy or waste heat streams. Heat pumps are suitable for the supply of building heating. Water can also be heated; this can be done by the use of waste water. As another heat source, the sealing water of the vacuum system can be used.

In the paper industry, there are not many heat pumps; the reason is that there are better and more direct heat sources. This energy can be better used for multiple systems. In general, heat pumps can be used in three areas: supply air, heating cycle and possibly district heating.

4.4 Room air conditioning

This chapter concentrates on heating; air-conditioning and exchange are not considered.

Optimisation of hall/ building heating (18) [36]
A mentionable part of the energy use is required for building heating. It is helpful to check temperature levels, air change rates, to implement a control system, a dew point regulation, and central heating including the use of waste heat.

An important aspect is the optimisation of heating the machine hall and other buildings such as converting or administrative. First of all, the heat loss can be reduced by insulating walls and roofs. In the machine hall, heating is also intended to prevent the corrosion and mould growth.

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[34] [Hutter et al. 2010, Schuster 2011, Kramer 2010]
[35] [Kuitunen et al. 2011, Arens et al. 2010]
[36] [Jung 2009, EnergieAgentur.NRW 2010, Niebe 2009]

These problems should be countered by good ventilation and sufficient heating. An easy way of heating the building is the extraction of heat from the exhaust. For example, this can be realised by a heat exchanger after the primary heat exchanger of the hood system or by using other exhausts in the system that are suitable for the required temperature levels in the heating system. Also heat recovery from the exhaust building air might be suitable to preheat fresh air in a first step.

With rising energy prices, it is becoming uneconomic to operate the heating with steam; instead existing and unneeded heat should be used. To achieve the maximum potential, the heating system should be monitored and automated. Only with an optimal adjustment to the current operating status of the machine can the maximum potential be retrieved.

Even with successful optimisation, two factors in the machine hall must be considered: the dew point and the air exchange rate. Depending on the system, the hall temperature can be reduced by a few degrees, without falling below the dew point. Also the air exchange rate can be optimised by an optimal air flow. Ideally, the warm air is supplied to the machine level; there will not be any interference by other natural air flow currents. Since less air is supplied, also less power is required for the heating, and the fans save power.

Housing of raw materials (19)
Since the process temperature is between 30 and 50°C, cold raw materials cause a temperature drop in the system balance which has to be compensated by additional heat. To lower the additional heat rate or to increase the process temperature level, which can lead to advantages in several process steps and mechanical dewatering, increasing the temperature level of raw materials can be useful. In general, raw materials are stored in non-heated buildings or even outside. Housing all raw materials and heating the buildings will lead to a higher average temperature. These storage buildings can be a possible heat sink for low caloric heat sources within the production.

4.5 Water use and water treatment

In paper production, large quantities of water are used, typically of fresh water. As a consequence, there are also large amounts of waste water, which is often directed straight to the channel. In this way, much potential is lost, as fresh water must be supplied constantly, only to compensate the losses caused by the waste water. In addition, the waste water often has temperatures of 20 to 40 °C; also the potential of this heat is simply wasted. It would be much more useful to filter and recycle this water; thus its heat remains in the system. As less fresh water has to be used, through the use of process water, the temperature in the system is also stabilised.

The optimisation of water cycles is, thus, a target within the reduction of GHG emissions. There are possibilities of cleaning process water to reuse it at a higher quality level. Furthermore, there are possibilities to improve the use of water at a higher temperature level for more efficiency. Aspects that are examined in this section are the optimisation of sealing and the use of cooling water as well as the treatment of process water in order to replace fresh water.

Optimisation of fresh water use (20) [37]
Fresh water is used for several purposes. Such as

- additional process water
- sealing water, e.g. for the vacuum pumps
- chemical preparation
- cleaning water, e.g. showers for the felt and wire conditioning
- cooling water, e.g. for hydraulic units and air compressors

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[37] [COST 2008]

Sealing water for vacuum pumps needs to be at a low temperature level. This sealing water can be recovered and added to the process. Cooling water can also be recovered and be used as process water. Recovering these water flows can reduce cold water inlet and stabilise or even increase process water temperature level.

Treatment of process water (21) [38]

The target of water treatment is the increase of efficiency of material by recovery of fibres and provision of cleaned clarified water as replacement for fresh water and the increase of productivity by removing interfering substances from the water cycle. Water treatment takes place at the paper machine and in the stock preparation. The same types of cleaning modules can be used in both areas. Treatment is by mechanical and chemical separation methods.

The task in the paper machine is the recovery of fibres and the provision of clarified water, and in the stock preparation the discharge of interfering substances and the increase of material efficiency.

In some cases it is possible to use clarified water instead of fresh water. For this purpose, the clear water must have a high quality, especially at high pressure nozzles and for use as sealing water, where particulate matter can lead to higher wear or even destruction of materials and equipment. The disparity in the amount of clear water required and a simultaneously required high quality at very few processes throughout the plant, leads to the development of multi-stage water treatment solutions.

As a result, a reduction of the heat demand within the system can be achieved. A well designed water system within a paper plant will not only lead to a reduction in the fresh water intake and thereby lowering acquisition costs, but it can raise the process water temperature because of closed circuits. As an estimate it is possible to calculate that a 10K increase of process water temperature leads to a 1% increase in dryness after the mechanical drying process, and this in turn leads to 4% less thermal energy consumption in the drying section.

Precision cleansing of pre-treated water is often based on filtration processes. Several filter types are available, for example drum filters with very fine lining (microfiltration), reversible flow filters, cartridge filters, sand filters, including filters for ultra-filtration and nano-filtration. Of course, pumps, pipes, and other hydraulic systems are required. It could also be necessary to apply ozone and carbonate removal systems. The type of purification system depends on the target quality of the needed water and the level of water recovery.

By using ultra-fine membrane filter systems, a very good water quality is reached. This type of filter removes all solids, microorganisms, and the anionic trash content decreases by 50%, also the separation efficiency is up to 1.000 times higher than in the microfiltration.

Reducing the specific amount of fresh water inlet into the circuit can cause several problems, such as the increase in the concentration of organic and inorganic substances. These effects are important to note.

For organic material this can reach 25 to 40gCOD/l in facilities with closed loops and using recovered paper. These substances can disrupt the production process and are, therefore, unwanted impurities. Another important aspect of concentration is the rising levels of electrolytes in the process water, which can be accurately measured with conductivity.

Microorganisms find the ideal surroundings to thrive within water circuits. Organic extracts from fibres, leftovers from a number of additives, starches and impurities from the employed recovered paper provide an abundant food source. Temperatures of about 25 to 45 °C are also almost perfect conditions. Biocides are employed to inhibit microbiological activity in water circuits. Further problems of rising concentrations, due to narrowing of the water circuits, are odours, which result from the feeding process of some bacteria, organic slime resulting from the growth of biofilm, high levels of calcium oxide, which lead to deposits, rise in salinity levels and corrosion.

[38] [Blechschmidt 2010; Metso 2006, Althöfer et al. 2007, Locher et al. 2012, Hellwich et al. 2009, Rother 2007, Dörfer et al. 2007, COST 2008]]

4.6 Process monitoring

Energy management (22) [39]

As an applicable tool, energy management is able to detect potentials of energy savings and leakages in the system in order to reduce energy use.

An energy management system linked to the ISO 50001 standard is very helpful for reducing the total energy use of the plant. ISO 50001 helps to build a structure with the target of energy reduction. It creates task forces within the company for analysing the process, finding essential optimisation work and developing a plan for process optimisation over the next decade. Creating an energy management is a lot of work but worth it. Since process optimisation is a continuous effort, it has to be well planned and organised. An energy management system is one of the most sustainable management tools for lowering energy consumption of the plant. It helps to find the right decisions for increasing energy efficiency.

Maintenance program (23)

A well-functioning maintenance program is able to improve efficiency in all areas of energy use. Therefore it is necessary to combine the maintenance programme with ideas of energy saving.

Since tissue making is a very complex process, it is essential to have a structured maintenance program. The efficiency of the process is highly influenced by the proper functioning of all parts. For example, in the hood system the amount of leakage air can be reduced by regular inspections and preparation of piping dampers, heat exchangers or fans. Also leakages in steam and condensate systems can be found in time before they cause increased energy consumption over the year. There are many more places within the production where regular inspections and short term maintenance can help to avoid an increase or even to lower energy consumption.

CASE STUDY:

In the example it was possible to reduce fresh water usage by making several changes within the process. Cooling water for hydraulic systems and sealing water for vacuum pumps was recovered. Sealing water for pumps was reduced. Furthermore, cleaned process water was used for felt showers. As a result, fresh water usage dropped by $16.3m^3/h$ in this example. This increases the white water temperature level and, thus, reduces the amounts of steam or condensate to stabilise the white water temperature level. The increase of white water temperature level can also improve mechanical dewatering in press section. In the example it was possible to lower the specific emission of tissue production from $530.69kg_{CO2}$/tpaper to $477.83kg_{CO2}$/tpaper.

[39] [Banecki et al. 2011, Baumann 2012, Althöfer et al. 2010, Voith 2011b, DIN EN ISO 50001, COST 2008]

COMBINATION OF MEASURES AND CONCLUSIONS

5 Combination of measures

When looking at the ETS benchmark for tissue with 334kg$_{CO2}$/tPaper as a long term target for the optimisation, this can only be reached by a combination of different technical changes within the process. An example in this chapter gives an impression of the impact of different technical combinations on the CO_2 intensity. All results, of course, are based on the model machine that has been used before in this guideline.

For the example of the combination the following technical changes have been chosen,

(A) Improvement of mechanical dewatering

A possible technical change in the press section could be the implementation of a shoe press to improve the mechanical dewatering. In this example an improvement of a 5% increase in APD was calculated. The machine starts at a level of 38%TS after press section. The maximum level of TS after press by using a shoe press very much depends on constructive, functioning and product issues of the machine and, of course, on the shoe press itself. An optimum of shoe press technology is now between 50 to 55%TS in tissue production.

(B) Regulation of air flow in hood system

An important figure within drying processes is the waterload of the exhaust air. The waterload, of course, varies considerably, depending on the type of the drying process and, in tissue production, also very much on the construction of the hood, functioning of the machine and the product itself. For the example, an increase of the waterload from 200g$_{Water}$/kg$_{Air}$ to 400g$_{Water}$/kg$_{Air}$ was calculated. This can be realised by using a regulation system for fans based on a permanent humidity control.

(C) Preheating combustion air for burners

Preheating the combustion air for burners is a well known technical change for reducing fuel. The combustion air in tissue production can be preheated by using waste heat from the exhaust air. The heat transfer can be linked to the heat transfer for make up air or realised by using a separate heat exchanger. In the example, the same heat exchanger already installed to preheat make up air was used. The temperature, thus, depends on the make up air temperature. It was limited to 250°C.

(D) Increasing primary heat exchanger

The primary heat exchanger transfers heat from exhaust air to make up air/ combustion air in the first step of the heat recovery system. In the example, the capacity of this heat exchanger was increased to an upper temperature differential of 50K. In this way, the temperature level of make up air/ combustion air could be increased.

(E) Waste heat utilisation for process water

Increasing process water temperature has many advantages within the tissue making process, not only for stock preparation, but also for the tissue machine. Increasing the temperature level of the white water by 1 circuit can lead to an increase of mechanical dewatering. In the example, an increase of mechanical dewatering by 1% leads to 10K of process water temperature increase.

(F) Waste heat recovery for building heating

When substituting steam/ fuel used for building heating, it can be attractive to recover heat from the exhaust air of the hood system. Therefore, a heat transfer of 500kW in maximum to the heating cycle within the example was calculated to substitute steam.

(G) Optimisation of fresh water usage

When reducing fresh water or recovering cooling water, sealing water from vacuum pumps can help to reduce the energy needed for stabilising the process water temperature level or even increase it. In the example, sealing water was reduced, cooling water was optimised, and fresh water was substituted by using filtered process water.

The following graphic shows the results obtained by the combination of the seven technical changes mentioned before. It is obvious that only some of the results are below the ETS benchmark. In reality it is not always possible to lower CO_2 intensity below EU ETS benchmark level using BAT and BP technologies. The reasons are technical limits and different technical circumstances of the existing machines.

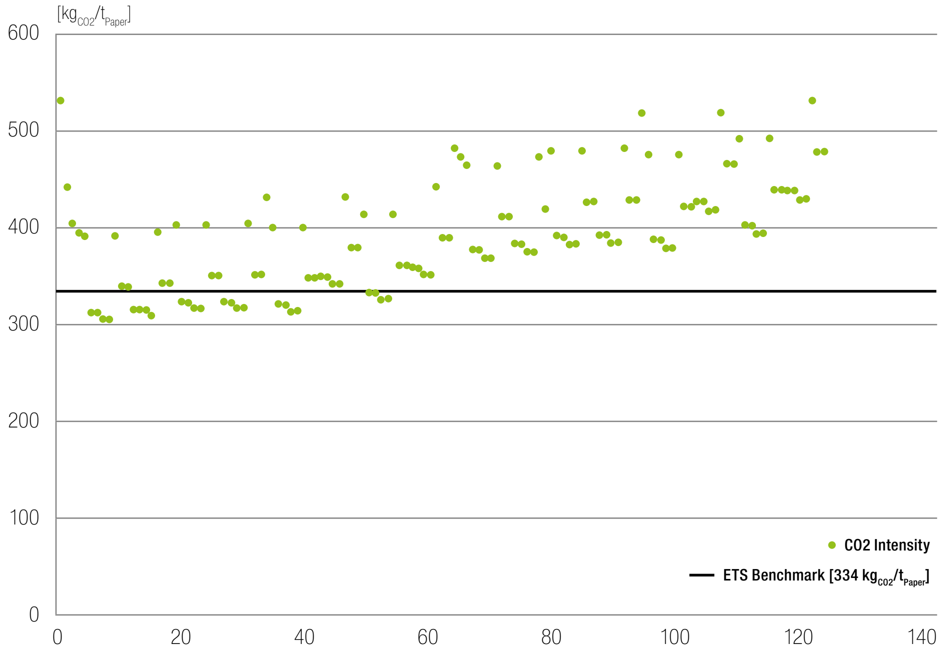

Fig. 21: Results CO2 intensity scenarios

The following chart gives an overview over the combinations, summarising all combinations which are able to lower the CO2 intensity of the example below EU ETS benchmark. Each scenario includes the optimisation of the mechanical dewatering (A) and the waste heat utilisation for process water (E). Both technical changes increase the APD and, thereby, lower the energy usage in the hood system. The regulation of air flow in the hood system (B) is also important in order to reduce energy usage in the hood system, too.

Tab. 2: Overview results ETS benchmark combinations

Profiles	**CO_2 Intensity [kg_{CO2}/tPaper]**
ABCDE	311.93
ABCDEF	311.60
ABCDEFG	305.22
ABCDEG	305.55
ABCE	315.26
ABCEF	314.92
ABCEFG	314.92
ABCEG	308.82
ABDE	323.12
ABDEF	322.77
ABDEFG	316.31
ABDEG	316.64
ABE	323.31
ABEF	322.96
ABEFG	316.41
ABEG	316.75
ACDE	320.28
ACDEF	319.95
ACDEFG	313.43
ACDEG	313.75
ADE	332.53
ADEF	332.18
ADEFG	325.56
ADEG	325.90

6 Conclusions

As described above, best available technology and best practice offer many possibilities for reducing the specific GHG emission intensity in tissue production. Balancing a combination of different technical changes leads to a different result than simply balancing each technical measure itself. Therefore, thermodynamic modelling is essential for calculating interactions between the technical changes within the process.

As an example of a possible optimisation of a tissue machine, several technical changes on the model machine were calculated to show the effect on the CO_2 emission intensity. Therefore, a six step optimisation was designed.

Based on the design of the model machine with a specific emission factor of 530.73kg_{CO2}/tpaper , the mechanical dewatering of the press section was improved in the first step. This could be done by a shoe press, for example. An improvement by 5% behind press section was calculated, leading to a reduction of 20% evaporated water in the hood system and, thereby, to a reduction of steam and fuel usage. The specific emissions decrease by 17% compared to the design to 441.65kg_{CO2}/tpaper.

Based on step one, the primary heat exchanger was increased in step two and, consequently, the heat recovery directly in the hood system. The heat flow from exhaust air to fresh air increased and, thus, the gas usage of the hood system could be lowered. The upper temperature differential was calculated by 50K for the new heat exchanger. Together with step one, step two lowers the specific CO_2 emissions compared to design by 22% to 413.06kg_{CO2}/tpaper.

The next step, step three, shows the effect of an optimisation of the burner system. In this step a preheating of combustion air up to a temperature of 150°C was added. That lowers the fuel usage of the burners and reduces the specific CO_2 emissions compared to design by 24% to 405.02kg_{CO2}/tpaper.

The following step, step four, shows the influence of the air regulation within the hood system. Therefore, the water load of the exhaust air was increased to 400g/kg. This lowers the fresh air exchange rate of the hood system and, as a result, the fuel needed within the burners. The specific emissions could be lowered by 25% compared to design to 395.66kg_{CO2}/tpaper.

In the next step, step five, the fresh water usage of the machine was optimised. Therefore, cooling water and sealing water for vacuum pumps were recovered. A certain amount of sealing water for pumps was reduced by installing a temperature regulating system. Finally, filters to clean process water were installed to use filtered process water for low pressure and high pressure showers. In this way, it was possible to reduce the amount of fresh water for stabilising the process water temperature so that the former energy input for the stabilising temperature level could be lowered. The specific emissions could be lowered by 35% compared to design to 343.03kg_{CO2}/tpaper.

In the last step, step six, a secondary heat recovery system was installed for preheating process water. That leads to an increase of the white water temperature level to its maximum by 50°C and, consequently, to an improvement of mechanical dewatering by 2%. By reducing the evaporated water in the hood system, this step also decreases the steam and fuel usage in the drying section.

The table below gives an overview of the results of the different simulated scenarios.

Tab. 3: Overview results of optimisation scenarios

n°	scenario	EF [kg_{CO2}/tPaper]
0	design	530.73
1	improvement of mechanical dewatering	441.65
2	optimisation of the primary heat recovery of the hood	413.06
3	optimisation of burners	405.02
4	regulation of the air flow; reduction of leakage air	395.66
5	optimisation of water usage	343.03
6	waste heat utilisation for heating up process water	310.65

Compared to design the specific emissions could be lowered by 41% to 310.65kg_{CO2}/tpaper. The iterative emission reduction for the example is illustrated in the figure below including the ETS benchmark.

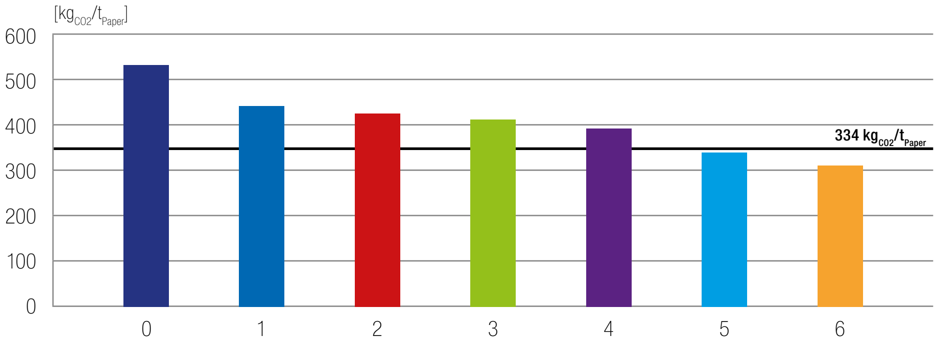

Fig. 22: Results of combined optimisation scenarios

The described example shows that by using best available technology and best practice standards it could be possible to lower specific emissions for tissue production by 41%. The result was even below the ETS standard benchmark for tissue by 334kg_{CO2}/tpaper.

Please note that the calculations were done only for a model machine. Technical changes in reality will, of course, deviate from these results due to several technical limits of the existing systems.

Whether the CO_2 intensity of a real machine can be lowered beneath the EU ETS benchmark very much depends on the technical topology of the machine and, of course, on economic aspects. During the SLCTM project19 sixteen tissue machines were analysed and low carbon concepts based on BP and BAT were designed. In some cases it was not possible to lower the CO_2 intensity of the process beneath EU ETS benchmark level. Of course, the CO_2 intensity of new tissue machines can be realised beneath the benchmark level by using BAT and BP. To lower the CO_2 intensity even more, new breakthrough technologies will be needed.

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40 Please find more information on www.7NEU.de.

Acronyms

APD	after press dryness
BAT	best available technology
BP	best practice
CHP	combined heat and power
cons.	consistency
DN	nominal width
E_{boiler}	fuel usage boiler
EC	European Commission
EF	emission factor
EFel	specific emissions electrical power generation
EFgas	specific emissions natural gas
EFth	specific emissions heat generation
EM_{fuel}	specific CO2 emissions fuel usage
$EM_{fuel, direct}$	fuel usage direct
EM_{gas}	emission factor for natural gas
EM_{paper}	specific CO_2 emissions paper
EM_{steam}	specific CO_2 emissions process steam production
E_{steam}	steam demand
EU ETS	European emissions trading system
EUA	European Emission Allowances
FW308	district heating worksheet 308
GHG	greenhouse gasISO (International Organization for Standardization)
O_2	oxygen
P_{boiler}	heat generation boiler
PCC	precipitated calcium carbonate
PEE	primary fuel savings
$P_{paper, net}$	net paper production
PCC	precipitated calcium carbonate
SILC	Sustainable Industry Low Carbon
SLCTM	Sustainable Low Carbon Tissue Manufacturing
THD	through air dried tissue
TS	dry matter
W_{el}	energy quantity electrical power
W_{gas}	energy quantity fuel
Wth	energy quantity heat
$n_{el,CHP}$	CHP efficiency electrical power generation
$n_{th,CHP}$	CHP efficiency heat generation
n_{th}	efficiency heat generation
$n_{el,ref}$	reference efficiency electrical power generation
$n_{th,ref}$	reference efficiency heat generation

Bibliography

AGFW 2011: AGFW: AGFW- Arbeitsblatt FW 308. Certification of CHP plants. Determining the CHP electricity. 2011

Althöfer et al. 2007: Althöfer, P.; Feuersänger, G., Schulte, J.: Wiederverwendung von „Biowasser". Wochenblatt für Papierfabrikation. 14-15/2007. p. 773-776.

Althöfer et al. 2010: Althöfer, P.; Feuersänger, G.; Taeger, K.: BiWA „Best intelligent Water Access & Analysis". Wochenblatt für Papierfabrikation. 08/2010. p. 688-691.

Ammann 2009: Ammann R.: Im Auftrag der Papiertrocknung unterwegs. Aktuelle Papier-Rundschau. 07-08/2009. p. 16-18.

Anglani et al. 2000: Anglani, N.; Einstein, D.; Khrushch, M.; Martin, N.; Price, L.K.; Worrell, E.: Opportunities to improve energy efficiency and reduce greenhouse gas emissions in the U.S. pulp and paper industry. Lawrence Berkeley National Laboratory (LBNL-46141). p. 1-59.

Arens et al. 2010: Arens, M.; Bödecker, M.; Idrissova, F.; Jochem, E.: Die Nutzung industrieller Abwärme – technisch-wirtschaftliche Potenziale und energiepolitische Umsetzung. Bericht im Rahmen des Vorhabens „Wissenschaftliche Begleitforschung zu übergreifenden technischen, ökologischen, ökonomischen und strategischen Aspekten des nationalen Teils der Klimaschutzinitiative. p. 1-49.

Banecki et al. 2011: Banecki, R.; Heinonen, L.; Turunen, T.: 17 Thesen zur Steigerung der Energieeffizienz. Wochenblatt für Papierfabrikation. 03/2011. p.184-189.

Bauböck 2008: Bauböck, J.: Einsatz eines Stahlzylinders in Tissuemaschinen. Wochenblatt für Papierfabrikation. 07/2008. p. 355-358.

Baumann 2012: Baumann, V.: DIN EN ISO 50001-Energiemangement als Chance. Aktuelle Papier-Rundschau. 07/2012. p. 18-19.

Bellmer Kufferrath Machinery 2010: Bellmer Kufferrath Machinery: Hochmoderne Rejektentwässerungsanlage. Wochenblatt für Papierfabrikation. 08/2010. p. 692-694.

Blechschmidt 2010: Blechschmidt, J. [Hrsg.]: Taschenbuch der Papiertechnik. Dresden, 2010

Blickle 2011: Blickle, P.: Energetische Optimierung einer Trockenpartie. Wochenblatt für Papierfabrikation. 05/2011. p. 342-343.

Cedra et al. 2007: Cedra, I.; Köster, S.; Staiger M.: Energieeffizienz durch innovative Prozesstechnologie. Wochenblatt für Papierfabrikation. 18/2007. p.1000-1004.

CEPI 2012: CEPI: Key statistics 2011. European pulp and paper industry. 01.07.2012. http://cepi.org

COST 2008: COST strategic workshop: Improving Energy Efficiency in Papermaking. Schiphol, The Netherlands. 9 – 11 June 2008.

Dixit et. al 2012: Dixit, O.; Kamischke, R.; Kuitunen, S.; Schinke, L.; Treppe, K.: Energetische Optimierung bei der Papierherstellung. Wochenblatt für Papierfabrikation. 04/2012. p.238-240.

Dörfer et al. 2007: Dörfer, T.; Junk, H.-H.; Müller, B.; Strätz, K.: Einsatz der Membranbioreaktor Technologie in der Papierindustrie - Pilotversuche bei der Kölner Pappen GmbH. Wochenblatt für Papierfabrikation. 21-22/2007. p.1220-1222.

EnergieAgentur.NRW 2010: EnergieAgentur.NRW.: Effiziente Energienutzung in der Papierindustrie. Nützliche Informationen und Praxisbeispiele für Unternehmen 2010. p. 1-19.

EV Group Oy et. al 2012: EV Group Oy, fipptec, Gerlander, R.; Haverinen, T.; Mynttinen, S.; Virtanen, E.; Novide, O.; Weise, U.: Energieeffizienz, Runnability und Sauberkeit. Wochenblatt für Papierfabrikation. 02/2012. p.104-106.

Fitzke 2012: Fitzke, M.: Energieversorgungskonzepte für die Papierindustrie. Wochenblatt für Papierfabrikation 6/2012. p. 414-415.

Fries et. al 2009: Fries, E.; Reinschke, J.; Sieber, A.: Steigerung des Durchsatzes und Minimierung des Energieeinsatzes in Trockenpartien. Modellbasierte Lösung von Siemens minimiert spezifischen Dampfverbrauch. Allgemeine Papierrundschau. 09/2009. p. 32-34.

Getec 2012: Getec AG: Energieversorgungskonzepte für die Papierindustrie. Wochenblatt für Papierfabrikation. 04/2012. p. 236-237.

Getec 2012a: Getec AG: Langfristig planbare Energieversorgungskonzepte für die Papierindustrie. Aktuelle Papier-Rundschau. 07/2012. p. 20-21.

Graf 2011a: Graf, K.: Zwei Stäube im Feuer. Wochenblatt für Papierfabrikation. 12/2011, p. 954-955.

Graf 2011b: Graf, K.: Papiermaschinen-Optimierung, Energie-Einsparpotenziale und Möglichkeiten zur Produktions- und Leistungssteigerung. Wochenblatt für Papierfabrikation. 10/2011. p. 790-797.

Hameister et al. 2012: Hameister, M.; Jacobs, J.: Energiekosten reduzieren - Jeder Schritt ist ein Schritt in die richtige Richtung! Aktuelle Papier-Rundschau. 01/2012. p. 22-23.

Hellwich et al. 2009: Hellwich, H.; Kaps, J.: Kreislaufwasseraufbereitung mit Entkarbonisierung. Aktuelle Papier-Rundschau. 01/2009. p. 26-28.

Jung 2007: Jung, H.; Hutter, A.: Energierückgewinnung in der Papierindustrie; In: Institut für Siedlungswasserwirtschaft und Abfalltechnik der Leibniz Universität Hannover (Hrsg.); 11. Hannoversche Industrieabwassertagung (HIT) – Wasser und Energieeffizienz in der industriellen Wasserwirtschaft; Heft 148; Hannover, 2010,

Hutter et al. 2010: Hutter, A.; Jung, H.: Energierückgewinnung in der Papierindustrie. PTS. p. 1-19

Huyck.Wangner 2010: Huyck.Wangner.: Huyck.Wangner stellt neue Bespannungstechnologien vor. Aktuelle Papier-Rundschau. 07-08/2010. p. 31.

ISA 2007: Institut für Siedlungswasserwirtschaft der RWTH Aachen [Hrsg.]: Einsatz weitergehender Reinigungstechnologien zur Verringerung der CSB-Belastung und Abwasserrückführung bei der Produktion von Hygienepapieren bei der Firma Wepa, Giershagen. Aachen, 2007

Jung 2009: Jung, H.: Energieeffizienz in der Trockenpartie. Aktuelle Papier-Rundschau. 07-08/2009.

Kääpä 2011: Kääpä, O.: Drastische Einsparung in der Pressenpartie mit Auswirkungen in die Trockenpartie. Wochenblatt für Papierfabrikation. 10/2011. p. 787-789.

Kramer 2010: Kramer, J.: ENERGY EFFICIENCY OPPORTUNITIES IN THE U.S. PULP AND PAPER INDUSTRY. Lawrence Berkeley National Laboratory (LBNL Paper LBNL-2268E). p. 1-18

Kuitunen et al. 2011: Kuitunen, S.; Pinnau, S.; Treppe, K.: Fallstudie zur Abwärmenutzung mittels Wärmepumpe. Wochenblatt für Papierfabrikation. 01/2011. p. 26-29

Lang-Hafner 2010: Lang-Hafner: Energieeinsparung in der Papiertrocknung. Papierfabrikation. 12/2010. p. 978.

Maier 2010: Maier, J.: Möglichkeiten zur Energieeinsparung in der Papierindustrie. Aktuelle Papier-Rundschau. 07-08/2010. p. 23-27.

Maurer-Fritz 2010: Maurer-Fritz, K.: PTS Tissue Symposium 2010 in München. Wochenblatt für Papierfabrikation. 07/2010. p. 625-629.

Meßmer 2008: Meßmer, P.: Stand der Technik in modernen Stoffaubereitungsanlagen- Chancen zur Energieeinsparung. Wochenblatt für Papierfabrikation. 11-12/2008. p. 687-693.

Metso 2006: OptiCycle W-Prozess- Mehr Effizienz durch Wasserrückführung. Wochenblatt für Papierfabrikation 11-12 /2007. p. 670.

Niebe 2009: Niebe, R.: MD Papier Plattling setzt auf Energieoptimierung. Airinotec realisiert Energieeinsparung mit „energy opt". Allgemeine Papierrundschau. 07-08/2009.

Niebuhr 2010: Niebuhr, V.: Maschinen-, Energie-, und Verfahrenstechnik für eine optimale Papiertrocknung. Aktuelle Papier-Rundschau. 09/2010. p. 17-20.

Not stated 2011a: Not stated: Herz aus Stahl. Wochenblatt für Papierfabrikation. 07/2011. p. 556.

Not stated 2011b: Not stated: Papiermaschinenkreisläufe mit neuer Technologie sauber halten. Aktuelle Papier-Rundschau. 12/2011. p. 28-29.

Not stated 2012: Not stated: Klein, intelligent und effektiv. Aktuelle Papier-Rundschau. 06/2012. p. 28-29.

Rother 2007: Rother, U.: Kalkfalle - eine neue Technologie zur Kalzium-Eliminierung aus Wasserkreisläufen. Wochenblatt für Papierfabrikation. 18/2007. p. 988-991.

SCA 2012: SCA Hygiene Products: Energierückgewinnung aus Abwasser. Aktuelle Papier-Rundschau. 01/2012. p. 24-25.

Schlegel 2008: Schlegel, J.: Erfahrung aus verschiedenen Schuhpressen-Anwendungen. Wochenblatt für Papierfabrikation. 11-12/2008. p. 670-675.

Schuster 2011: Schuster, H.: Maßgeschneiderte Wärmetauscher. Aktuelle Papier-Rundschau. 09/2011. p. 22.

Schuster et al. 2010: Schuster, A.; Voigt, A.: Potenziale zur Kosteneinsparung bei der Trocknung. Wochenblatt für Papierfabrikation. 10/2010. p. 826-827.

Slawtschew 2010: Slawtschew, G.: Optimierung der Lufverhältnisse in der Trockenpartie. Wochenblatt für Papierfabrikation. 07/2010. p. 616-623.

SLCTM 2014: Staszewski, R.; Neumeister, J.: Final Report SLCTM project. 2014

Tjernberg 2010: Tjernberg, S.: Weniger Kosten durch weniger Energie. Aktuelle Papier-Rundschau. 07-08/2010. p. 28-29.

UBA 2013: Umweltbundesamt: Entwicklung der spezifischen Kohlendioxidemissionen des deutschen Strommix in den Jahren 1990 bis 2012. Climate Change. 07/2013. http://www.umweltbundesamt.de/sites/default/files/medien/461/publikationen/climate_change_07_2013_icha_co2emissionen_des_dt_strommixes_webfassung_barrierefrei.pdf

UBA 2004: Umweltbundesamt GmbH (Hrsg.): Energy efficiency in IPPC installations. Wien. 2004.

VDI 4600: VDI Gesellschaft Energie und Umwelt. Fachbereich Ressourcenmanagement in der Energie- und Umwelttechnik: VDI-Richtlinie 4600. Kumulierter Energieaufwand (KEA). Begriffe, Berechnungsmethoden. Düsseldorf, 2012.

Voith 2011a: Voith Paper: EcoChange T und Yankee Deckelisolierung. Wochenblatt für Papierfabrikation. 07/2011. p. 554-556.

Voith 2011b: Voith Paper: Energie sparen in der Papierherstellung mit OnV EnergyProfiler. Aktuelle Papier-Rundschau. 07-08/2011. p. 27-28.

Voith 2012: Voith Paper: Umwandlung von Schlamm in wertvolle Mineralien und Energie. Aktuelle Papier-Rundschau. 07/2012. p. 24-25.

Wind 2012: Wind, E.: Innovative Stahlzylinder für die Trockenpartie. Aktuelle Papier-Rundschau. 07/2012. p. 22-23.

Laws and regulations

2004/8/EC: Directive 2004/8/EC of the European Parliament and of the Council of 11 February 2004 on the promotion of cogeneration based on a useful heat demand in the internal energy market and amending Directive 92/42/EEC

2009/28/EC: Directive 2009/28/EC of the European parliament and the council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC; Article 1 (e)

2011/278/EU: Commission decision of 27 April 2011 determining transitional Union-wide rules for harmonised free allocation of emission allowances pursuant to Article 10a of Directive 2003/87/EC of the European Parliament and of the Council (notified under document C(2011) 2772) (2011/278/EU)

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