Life Cycle Assessment of fibres from bioproduct mill compared to fibres from average European and Latin American pulp mills

Fraunhofer IMWS

Fraunhofer-Institut für Mikrostruktur von Werkstoffen und Systemen IMWS

Spotlight report

Study is public available: https://publica.fraunhofer.de/handle/publica/437013

Agenda
Spotlight report

- Intentions & goals
- LCA background information
- Scope & system boundaries
- Main results

- Additional laboratory tests

Intention & goals

- Intended is the increase of available information on the **ecological footprint** of sustainable pulp manufacturing.
- Since pulp is used in paper and tissue products, the study contains relevant **information for the pulp and paper business**.

- Goal is a comparative **assessments of total chlorine-free (TCF) and elemental chlorine-free (ECF) pulp bleaching** and providing of insights into environmental impacts of pulp production at the bioproduct mill Äänekoski, which started its operation in 2018.
- Derive and share objective **information to decision-makers** who have an interest in the further development of the pulp, paper and tissue industry.

The comprehensive study was conducted by the Fraunhofer Institute for Microstructure of Materials and Systems (IMWS). The results of the study were critical-reviewed by independent scientists.

In addition to the life cycle assessment, extensive laboratory tests were carried out on the environmental impact and toxicity of the wastewater from the bioproduct mill and on end products as part of the study.

LCA background Information

Keywords in a holistic approach

Constraints: must be named, as LCA regular uses estimations and science based impact models of varying robustness.

Critical Review: Independent persons with expertise in LCA check the conformity to international standards and regulations.

Data Quality: As a premise, it can be stated that primary data weigh more heavily for the informative value of an LCA than secondary data. For the mapping of the average pulp mills according to the state of the art, secondary data from database ecoinvent 3.8 was used, while primary data was used for the mapping the foreground system in the system boundary of the bioproduct mill Äneksoki model.

DIN EN ISO 14040: can be seen as framework for LCA, **DIN EN ISO 14044** is mandatory for LCA's, for comparative assessments.

FU: Functional unit - describes the product or service on which the input and output flows (reference flow) are balanced.

Goal and scope: Identifies the addressees of the study, describes the decisions to be supported and identifies time and geographical reference.

Impact Categories: Science based impact models are used to describe the environmental influences in the environmental categories investigated; following the Environmental Footprint (EF) approach, the scientific impact models can be divided into three levels of robustness.

LCI: Life Cycle Inventory lists the material and energy flows as input and output flows.

LCIA: Life Cycle Impact Assessment describes the environmental impacts of the input and output flows in relation to the functional unit.

System boundary: Describes directly considered material and energy flows, as well as environmental impacts resulting from the processes.

LCA background Information

Steps of a Life Cycle Assessment

Goal and scope

Description of investigated product or service

- defining aimed insights
- depth of investigation
- relation to geography
- relation to time
- adressees

LCI
Life Cycle inventory

input – output of mass- and energy streams for each process step

- collecting primary data
- selecting suitable secondary data for e.g.: Background systems such as the regional energy mix

LCIA
Life Cycle Impact Assessment

set of categories, to fullfill goal and scope

- Climate Change
- Eutrophication
- Land Use
- Resource Depletion
- Acidification
- Ozone Depletion
- Ecotoxicity
- Ionising Radiation
- Photochemical Ozone Depletion
- Water Depletion
- Human Toxicity

Interpretation Strategy

comprehensive view on multicriteria results

- Robustness Level
- distance to (egological) target
- relation to human health
- relation to ecosystem health
- relation to resources
- check of consistency, if needed back to goal&scope

Interpretation & and Conclusion

Conclusion and recommendations

- Reviewing the consistency of the findings obtained
- stimulate further improvements, related to adressees

Short description of steps conducting a LCA. Detailed description can be found in DIN EN ISO 1040:2006 and DIN EN ISO 14044:2006.

Scope

The following models for the LCA, from raw material supply and technology to fibre extraction and bleaching, were considered in the study:

- model 01 | **Bioproduct mill Äänekoski (ECF)** - feedstock from northern Europe based forest
- model 02 | **Average European pulp mill (TCF)** - feedstock from northern Europe based forest
- model 03 | **Average European pulp mill (ECF)** - feedstock from northern Europe based forest
- model 04 | **Average Latin American pulp mill (ECF)** - feedstock from Latin America based forest

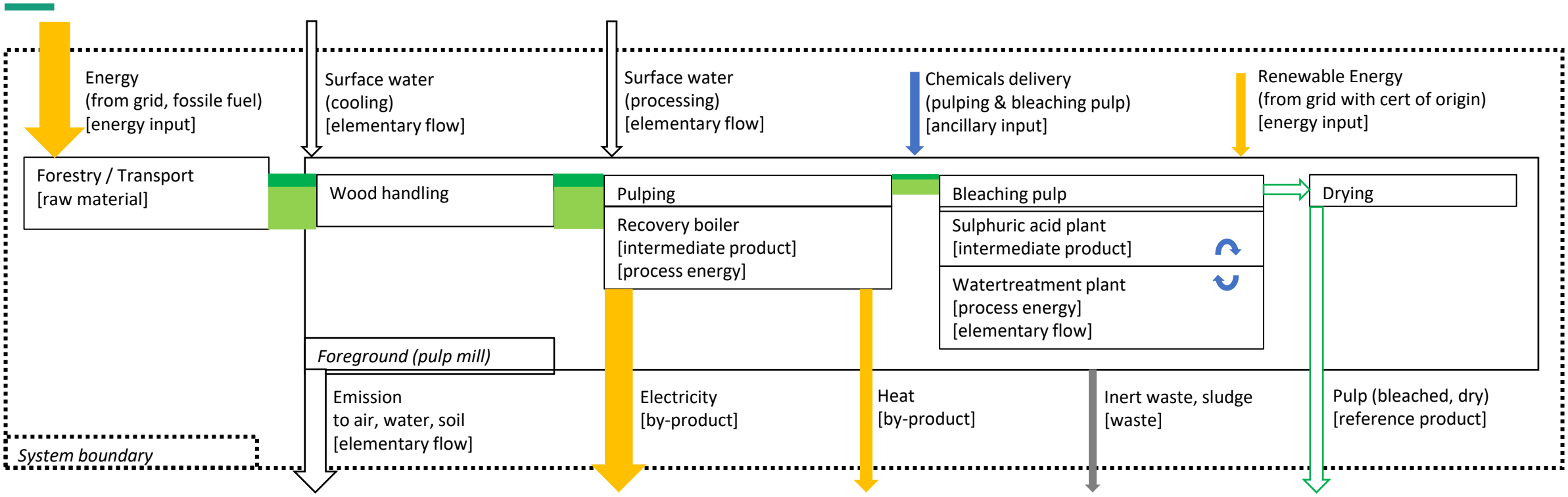
In model 01, primary data from the bioproduct mill Äänekoski (year 2021) are used in the foreground system, and secondary data from the ecoinvent 3.8 database are used in the background system.

In model 02, 03 and 04, secondary data from the ecoinvent 3.8 database are used.

The Functional Unit (FU) is chosen as 1 ADMT (Air Dry Metric Tonne) of bleached pulp.

The models map the "cradle to gate" system boundary (see following slide).

System boundaries



Legend

- Hardwood
- Softwood
- Pulpe
- Energy
- Chemical
- Waste
- Elementary
- Chem. recovery

The flow chart represents the mass and energy flow in the bioproduct mill Äänekoski (model 01). The diameter of the arrows illustrates the ratio of the mass and energy flows. In foreground primary data of bioproduct mill is used. Secondary data is used for modelling energy production, transports, and elementary flows, etc.

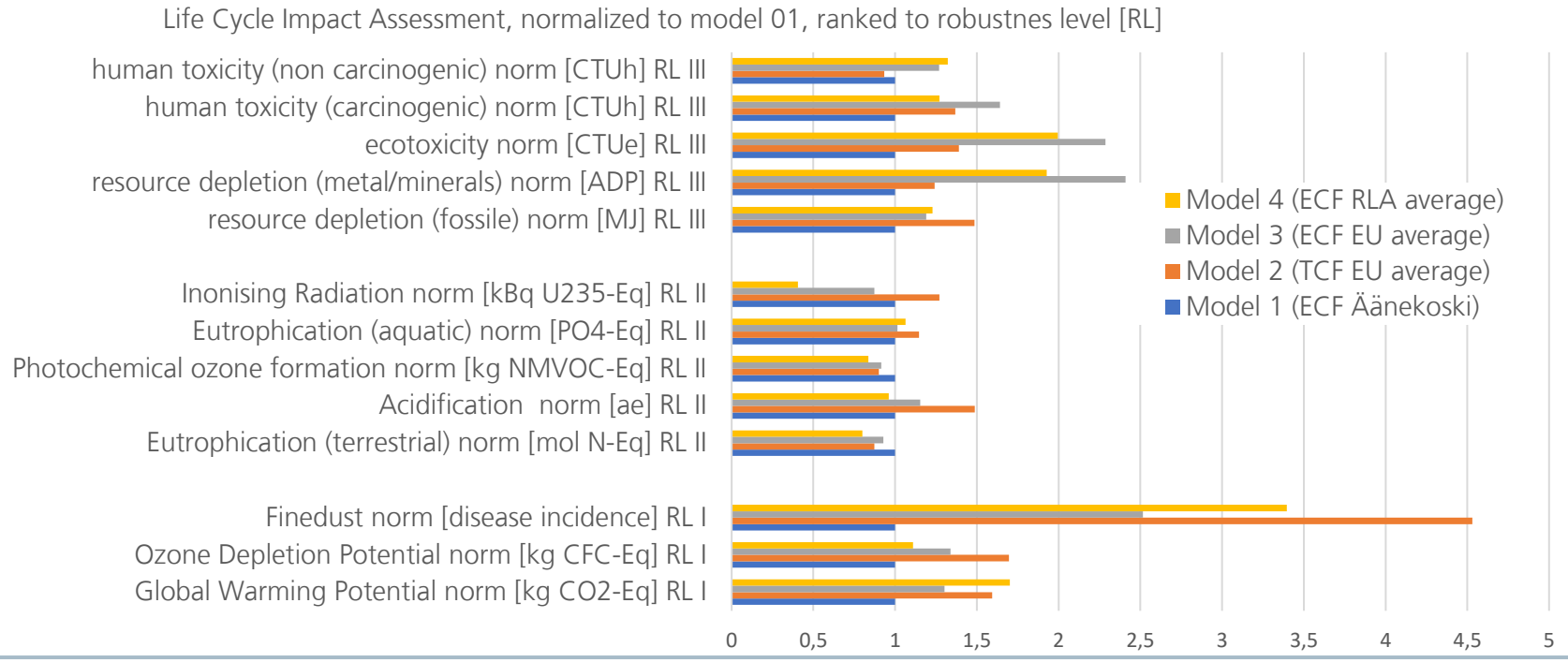
Main results

Life Cycle Impact Assessment, normalised to model 01

In categories of robustness I, the models consistently show stronger influences on the environmental properties compared to model 01, significantly in the category of fine dust emission.

In the categories of robustness II, the models show slightly lower influences on the environmental properties compared to model 01; in the category of ionising radiation, Model 4 shows a significantly reduced emission compared to the comparison models.

In the categories of robustness III, the environmental impacts of the comparative models are above the significance threshold of 10%, with the environmental impacts above those of model 01.



Methodical background:

In preparation of ordering the multi-criteria results, the results of the Life Cycle Impact Assessment were normalised to the model 01 in a first step.

Source: Wüstenhagen, S., Krombholz A. Life Cycle Assessment of fibres from bioproduct mill compared to fibres from average European and Latin American pulp mills, Fraunhofer IMWS, 2022
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Main results

Assessment strategy

Following the assessment strategy of the study, the model 01 impact categories with robustness level I are showing the lowest impacts in comparison to the models 02, 03 and 04. Also for most of all other impact categories the model 01 shows lower impacts in comparison.

The land use indicator requires a cautious interpretation, as the land use model used in EF 3.0 is still research object.

	model 01	model 02	model 03	model 04
Very large ecolgical priority				
Gloabal Warming Potential (RL I)				
Large ecological priority				
Ozone Depletion Potential (RL I)				
Particulate Matter (RL I)				
Eutrophication, terrestrial (RL II)				
Acidification (RL II)				
Ionising radiation (RL II)				
Ressoruce Depletion, fossil (RL III)				
Middle ecological priority				
Eutrophication, aquatic (RLII)				
Low ecological priority				
Photochemical ozone formation (RLII)				
Without ecological priority in context of this study * cautious interpretation, because quality of land use is not reflected in used type of SQI				
Ecotoxicity (RL III)				
Land use (RL III)				*
Evaluation of the LCA results according to the evaluation strategy, orientated to UBA method considering "biological thread" and "distance to target" and "Robustness Level" (Schmitz, 1999). Green: 10% > Orange; Grey: no significant difference to Green.				

Environmental impact category	Ecological threat	Distance to target	Robust-ness level (RL)	Ecological priority
Global Warming Potential	Very large (A)	Very large (A)	RL I	(A)
Ozone Depletion Potential	Very large (A)	Low (D)		(B)
Particulate Matter (fine dust)	not evaluated by UBA			(B)
Eutrophication, terrestrial	Large (B)	Large (B)	RL II	(B)
Acidification	Large (B)	Large (B)		(B)
Photochemical Ozone formation	Low (D)	Large (B)		(D)
Eutrophication, aquatic	Large (B)	Middle (C)		(B)
Ionizing radiation	Not evaluated by UBA			(B)
Resource depletion, fossil	Large (B)	Large (B)	RL III	(B)
Ecotoxicity	not evaluated by UBA			n.n.
Land use	not evaluated by UBA			n.n.
Impact categories ordered under robustness level (RL), and following UBA recommendation: Ecological threat, and Distance to target. Ecological priority n.n. stands for "without ecological priority in context of this study".				

Methodical background:

Although no statistically viable error calculation is possible due to frequent assumptions in the secondary data used, a significance threshold of 10% was assumed, as is common in LCA practice, to made the results comparable.

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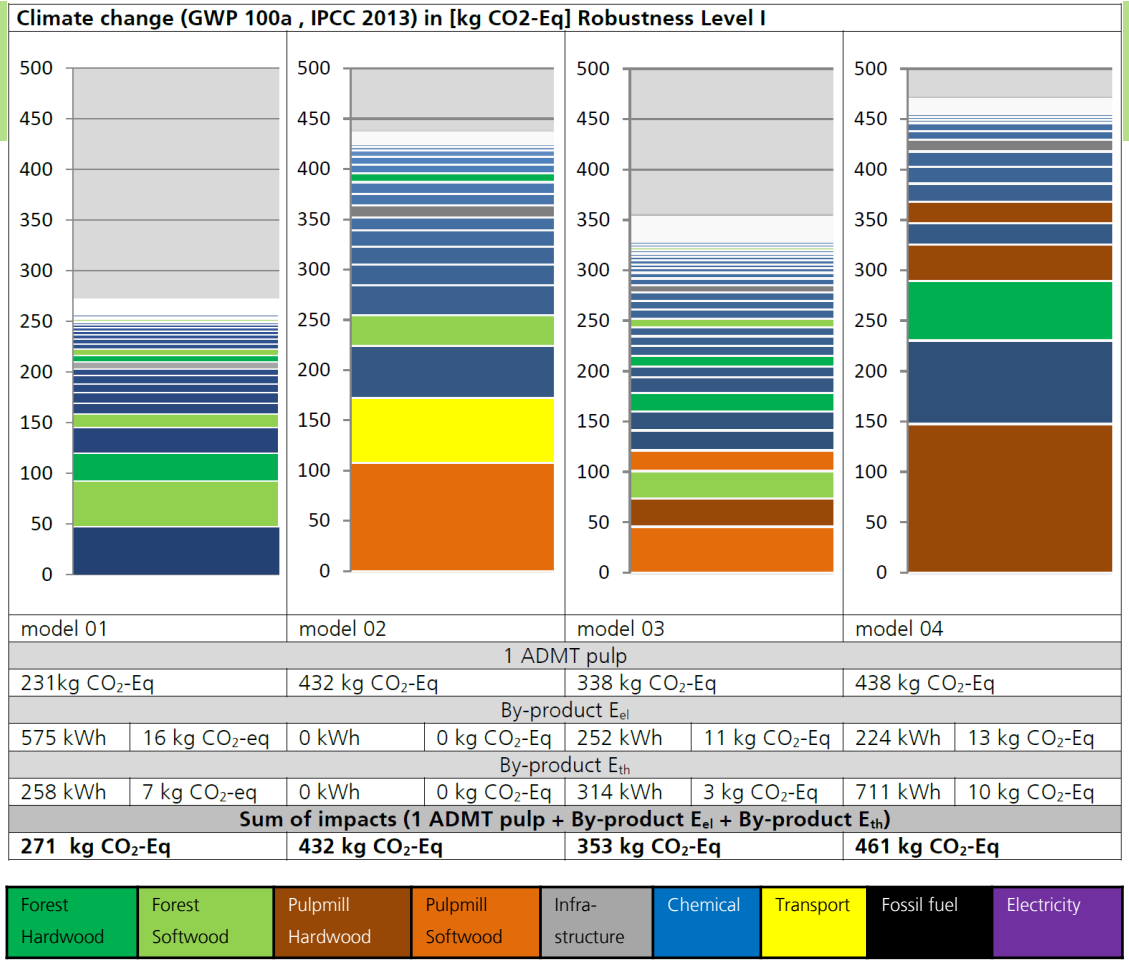
Main results

Global Warming Potential



Compared to average pulp mills that also use the ECF or TCF production process, model 01 achieves a reduction in emission of CO_2 -eq.

Methodical background:

The impact category **Climate Change** is showing the Global Warming Potential. In unit of kg CO_2 equivalents is expressed the radiative forcing of all relevant greenhouse gases such as methane, laughing gas and others that are released in the analysed artificial processes.
The actual known numbers for radiative forcing in the Earth's atmosphere related to relevant time horizons 25, 100 and infinite years stem from periodical reports by the Intergovernmental Panel on Climate Change (IPCC).

In this study, the 100-year time horizon is expressed as CO_2 equivalent per functional unit. Robustness factor I means the most reliable analysis.

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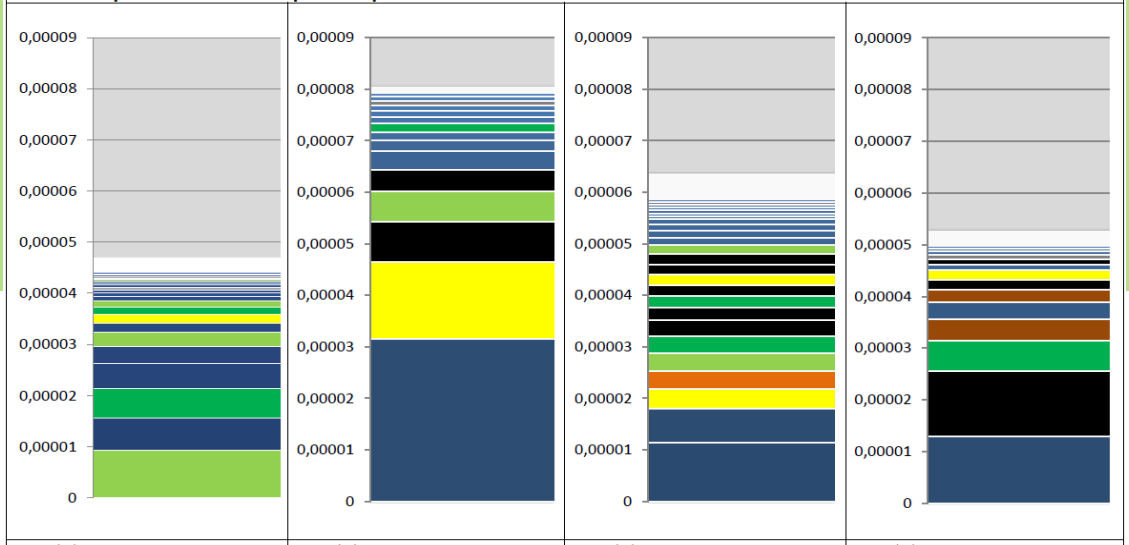
Main results

Ozone Layer Depletion

Ozone depletion, ozone depletion potential (ODP), Robustness Level I



model 01		model 02		model 03		model 04	
1 ADMT pulp							
4,27E-05 kg CFC-11-Eq		8,033E-05 kg CFC-11-Eq		6,071E-05 kg CFC-11-Eq		4,989E-05 kg CFC-11-Eq	
By-product E_{el}							
575 kWh	2,79E-06 kg CFC-11-Eq	0 kWh	0 kg CFC-11-Eq	252 kWh	2,03E-06 kg CFC-11-Eq	224 kWh	1,47E-06 kg CFC-11-Eq
By-product E_{th}							
258 kWh	1,25E-06 kg CFC-11-Eq	0 kWh	0 kg CFC-11-Eq	314 kWh	6,3E-07 kg CFC-11-Eq	711 kWh	1,16E-06 kg CFC-11-Eq
Sum of impacts (1 ADMT pulp + By-product E_{el} + By-product E_{th})							
4,68E-05 kg CFC-11-Eq		**8,03E-05 kg CFC-11-Eq**		**6,34E-05 kg CFC-11-Eq**		**5,25E-05 kg CFC-11-Eq**	

Forest Hardwood	Forest Softwood	Pulpmill Hardwood	Pulpmill Softwood	Infra-structure	Chemical	Transport	Fossil fuel	Electricity

The potential for ozone layer depletion is at a comparably low level for all ECF based mills.

In comparison, the average mills using the TCF process show a high potential to deplete the ozone layer. The higher impact on the ozone layer results from the higher nitrogen oxide emissions of the energy-intensive TCF bleaching chemical production.

Methodical background:

In this study, the impact category **Ozone Depletion Potential** is expressed in kg CFC-11-equivalents of ozone layer-depleting molecules like nitrous oxide and hydrocarbons, which are strongly related to summertime circulations in the southern hemisphere of the Earth, observed by the World Meteorological Organization (WMO). These molecules rise into the Stratosphere and are exposed to high UV energy, reacting catalytically to the decomposition of ozone molecules. Robustness factor I means the most reliable analysis.

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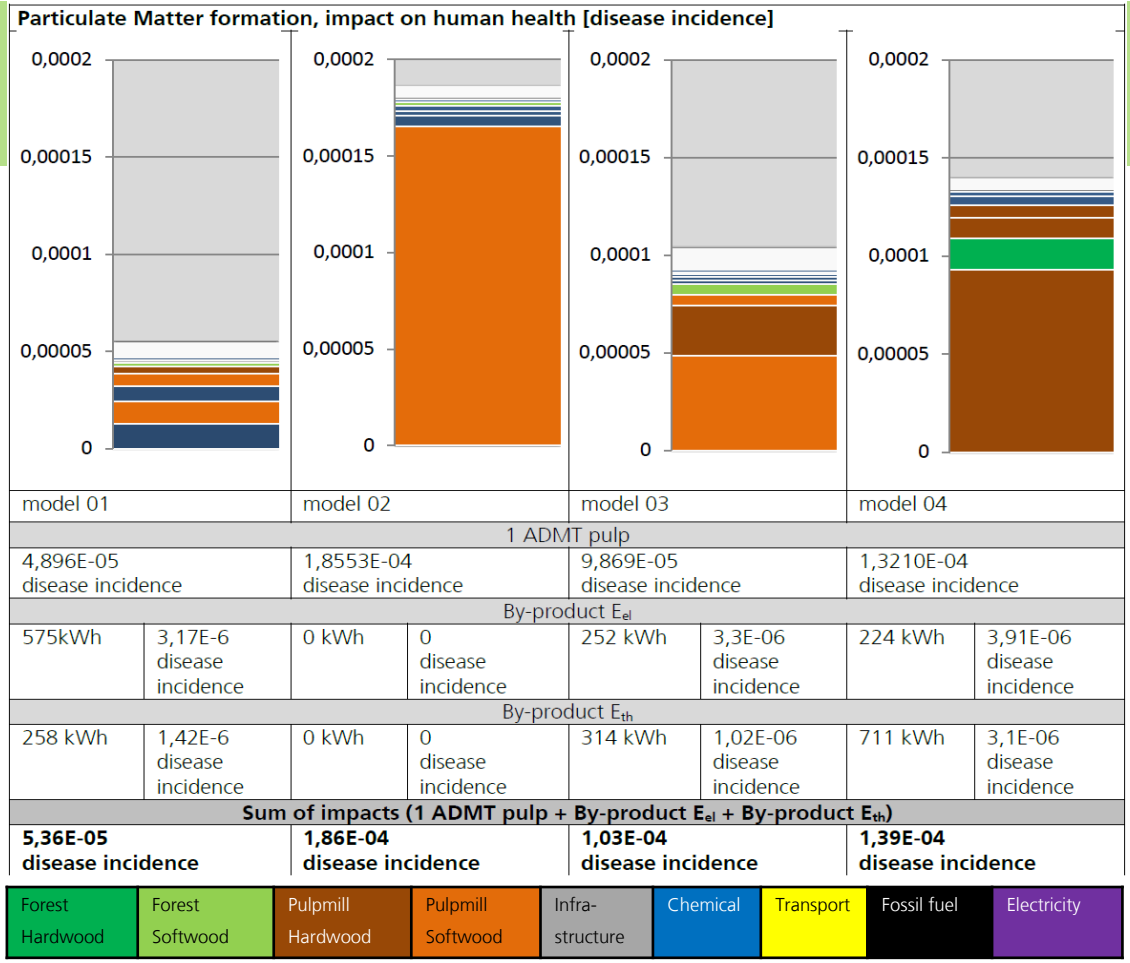
Main results

Fine Dust



The low emission of particulate matter from model 01 in comparison to the modelled average pulp mills with ECF and TCF bleaching contributes to better air quality

Methodical background:
Particulate Matter is fine dust described in the aerodynamic diameters of $PM_{0.2}$, $PM_{2.5}$ and PM_{10}, to reflect the complex mixture of organic and inorganic substances in fine dust. The distinction between primary and secondary PM provides information about the formation under natural conditions or induced by artificial activities. They are robust, measurable with particle counters and can be found indoors and outdoors with different retention times in the atmosphere. The characterisation model to describe the relation between PM and disease incidences was developed by the Society of Environmental Toxicology and Chemistry (SETAC) as a member of UN Environmental Programme (UNEP). The disease incidence is the unit in this indicator for environmental impact related to diseases caused by PM concentrations (disease incidences/kg $PM_{2.5}$) because the impact of $PM_{2.5}$ on human health was well understood.

Source: Wüstenhagen, S., Krombholz A. Life Cycle Assessment of fibres from bioproduct mill compared to fibres from average European and Latin American pulp mills, Fraunhofer IMWS, 2022
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Main results

Constraints

The life cycle assessment method is a multi-criteria approach to study environmental impacts.
Since the method must use assumptions and averages, as well as scientific models of varying robustness, the results are estimates.
In the following list, three most relevant limitations are given for consideration.

Limitations with regard to land use category

- For LANCA® based impact category in EF 3.0 for Land Use (Robustness Level III) challenges to further development of characterisation factors, special for changes of land use are identified: "The lack of characterisation factors to be used for reversible land transformation that already include considerations on the regeneration time." (De Laurentiis, et al., 2019)

Limitations regarding the data used

- The use of other secondary data sets, or other primary data may lead to a different assessment of the comparative evaluation.
- The results of this study only apply to the use of the primary data provided by the client for this study, and the secondary data stemming from the environmental database in release versions stated in study.

Limitations due to the choice of valuation methods

- The selection of indicators was made in consensus with critical experts.
- The procedure of the UBA for the assessment of environmental impacts was used as a guideline.

Main results

In parallel to evaluation strategy oriented to UBA method using the ordering principles of "ecological thread" and "distance to target" and "Robustness Level" the Äänekoski bioproduct mill shows advantages also, when a comparison of the impact categories from the average pulp mills (ECF and TCF bleaching) is done.

Setting a significance-threshold of 10% to ensure significance of resulting values, the model 01 shows advantages in all environmental impact categories of Robustness Level I, compared to other models:

- **Global Warming Potential (Robustness I)**
- **Ozone Depletion Potential (Robustness I)**
- **Particulate Matter (Robustness I)**
- **Human toxicity (Robustness Level III)**
- **Resource utilisation (Robustness Level III)**
- **Ecotoxicity (Robustness Level III)**

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Model 01 shows equivalent results (significance threshold 10%) in the impact categories of the life cycle assessment comparison with models 03 and 04, representing average pulp mills that also used ECF bleaching:

- **Acidification (Robustness Level II)**
- **Eutrophication (Robustness Level II)**
- **Photochemical Ozone formation (Robustness Level II)**
- **Ionising radiation (Robustness Level II)**
- **Human toxicity (Robustness III)**
- **Water user deprivation potential (Robustness Level III)**

Model 02 shows disadvantages (significance threshold 10%) in comparison to the model 01, 03, and 04 in the following impact categories:

- **Ozone Depletion Potential (Robustness Level I)**
- **Particulate Matter Formation (Robustness Level I)**
- **Acidification (Robustness Level II)**
- **Ionising Radiation (Robustness Level II)**

summary

Modern bioproduct mills, such as the bioproduct mill in Äänekoski (ECF), are showing in most of the environmental impact categories lower values compared to average pulp mills in Europe (ECF & TCF) and Latin America (ECF).

Photo: Metsä Group

Additional information

Laboratory tests on elementary flows

Effluent

- All effluent values at the bioproduct mill in Äänekoski are well below the EU limits.
- This is due to the closed water cycle in which water and chemicals are recycled and returned to the process for reuse.
- Due to the regionally good supply of surface water, water use at the Äänekoski bioproduct mill is more environmentally friendly than at mills, which partly rely on groundwater (water withdrawal potential).

Dioxine

- Extensive dioxin measurements were carried out by the Eurofins Institute in May 2022.
- These show that modern pulp mills that use ECF bleaching and whose wastewater is treated in an active sludge plant do not emit chlorinated dioxins.

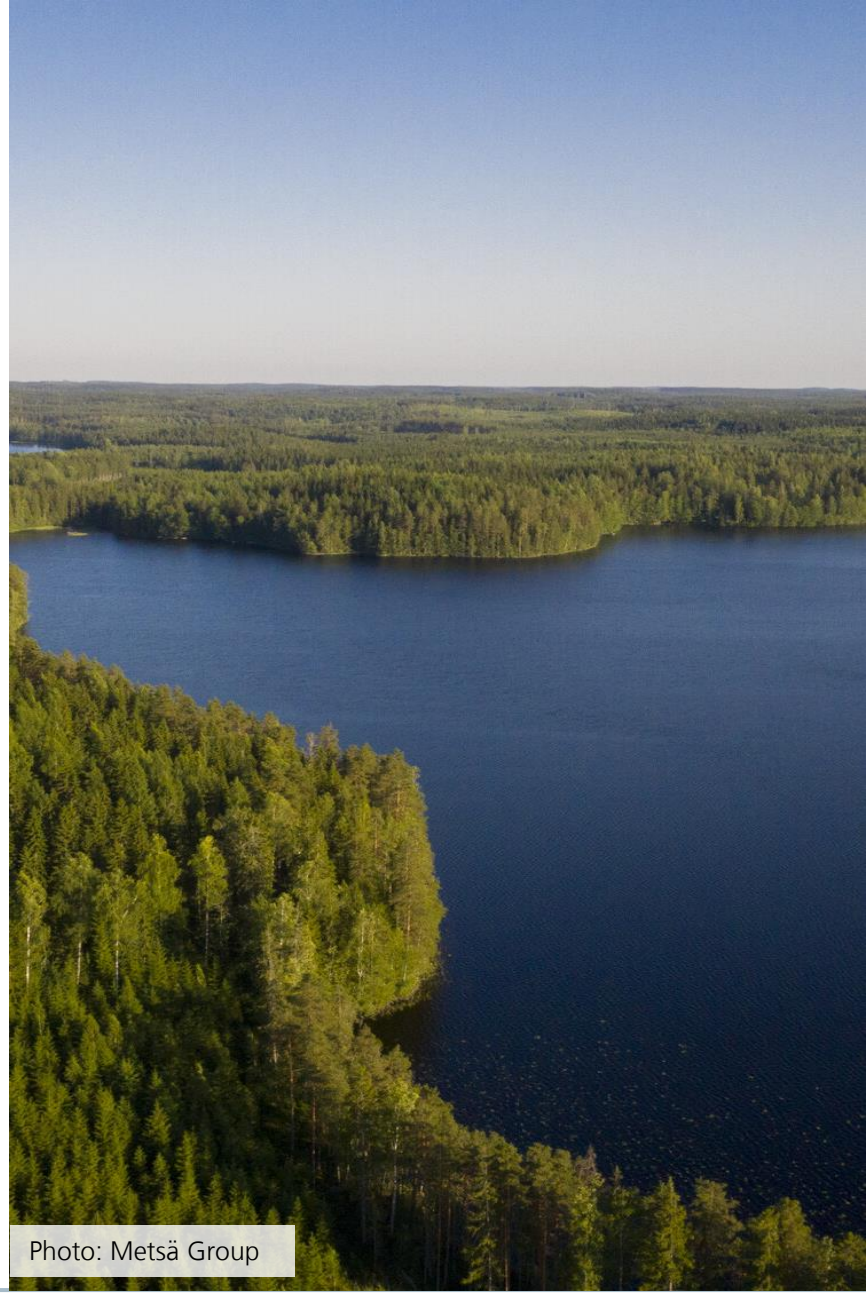

Photo: Metsä Group

Additional information

Analysing the end products

- The analysis of the end products by the Fresenius Institute showed that TCF and ECF tissue products have the lowest toxicity values (toxicity by luminescent bacteria), regardless of the OX (Organically bound halogens) or AOX (Adsorbable Organically Bound Halogens) value. *
- Only products that did not consist of fresh wood fibres, such as recycling, bamboo or grass fibres, had higher values in terms of impurities and showed partly higher toxicity values (toxicity by luminescent bacteria).

* OX and AOX are sum parameters. It does not allow any implications of the harmfulness of the effluent as such. The level of AOX indicates only the possibility for multiple chlorination. With values of AOX above 1 kg/ADMT, the probability of multiple chlorination is elevated. With values lower than 0,5 kg/ADMT no tetrachlorinated substances are created, the Äänekoski bioproduct mill has a 4 times lower AOX emission of 0,11 kg/t.

Photo: Metsä Group

Imprint

Spotlight Report - Life Cycle Assessment of fibres from bioproduct mill compared to fibres from average European and Latin American pulp mills

The study was commissioned by METSÄ FIBRE OY, Finland, on 23 March 2022, and is open accessible https://publica.fraunhofer.de/handle/publica/437013
The main contractor to carry out the study is Fraunhofer IMWS. The report was prepared on January 2023.
The study was conducted according to the requirements of the International Standard DIN EN ISO 14044.

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