Universität Stuttgart
Institut für Energiewirtschaft und
Rationelle Energieanwendung (IER)

Fraunhofer
ISI

Analysis of different transformation pathways for the energy intensive industry on the basis of exergy analysis

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A CASE STUDY OF THE GERMAN PAPER INDUSTRY

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Project for the Federal Environmental Agency (Umweltbundesamt, UBA)

- Project: FKZ 3716 41 112 0

- Consortium

Lead:

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Institut für Energiewirtschaft und
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Partner:

Fraunhofer ISI

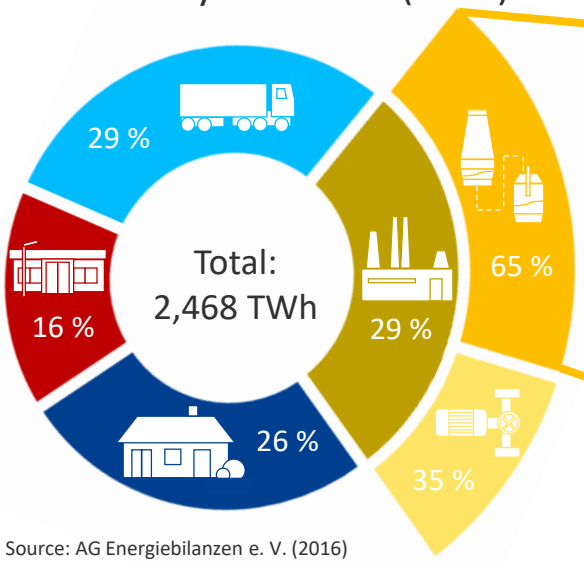
Introduction and Objective

Introduction and Objective

The German industry had a share of 29 % of final energy consumption in 2015.

FINAL ENERGY CONSUMPTION IN 2015

- Industry: 716 TWh (29 %)



Source: AG Energiebilanzen e. V. (2016)

ENERGY INTENSIVE INDUSTRY

- Considered sectors:

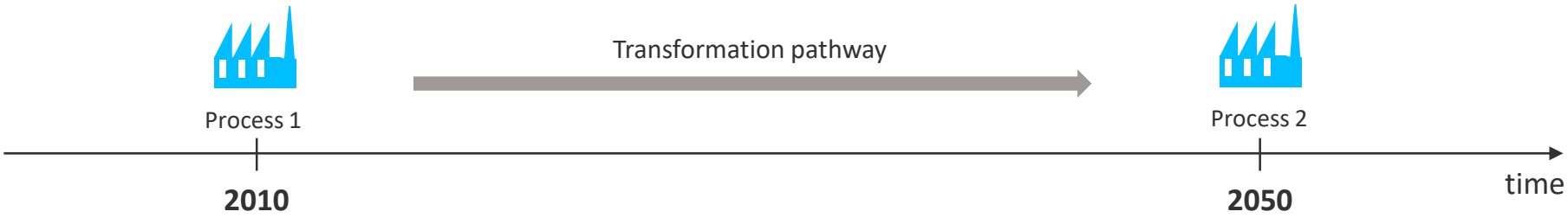
- Steel industry (158 TWh)
- Chemical industry (171 TWh)
- Cement industry (28 TWh)
- Paper industry (66 TWh)
- Glass industry (18,5 TWh)

- The **German industry** is of **particular importance** when trying to reach the proclaimed energy efficiency goals.
- In an increasingly energetically efficient system, the sole consideration of the **energy efficiency as** an **indicator** for further efficiency improvements **might be questioned**.
- The **main objective** of this project is to **examine** the **decarbonisation pathways** of selected **processes of the German industry** with an **exergy analysis**.

Method

Method

The exergy analysis of Germanys industry is conducted for the current situation and for 2050.



Indicators for the evaluation of different transformation pathways

Energy | **Exergy** | Greenhouse gas emissions | Energy costs

Exergetic efficiency

$$\eta_{IN} = \frac{\sum \dot{E}_U}{\sum \dot{E}_{IN}}$$

- The exergetic efficiency equals the ratio of exergetic benefits (chemical exergy of main products) and exergetic effort.

Degree of external losses

$$\varepsilon_{D,ext} = \frac{\sum \dot{E}_L}{\sum \dot{E}_{IN}}$$

- The external degree of loss corresponds to the ratio of external exergy losses and the exergetic effort.

$\dot{E}_{IN}$: Incoming exergy flows $\dot{E}_U$: exergetic benefits
$\dot{E}_L$: external exergy losses $\dot{E}_D$: internal exergy losses

Degree of internal losses

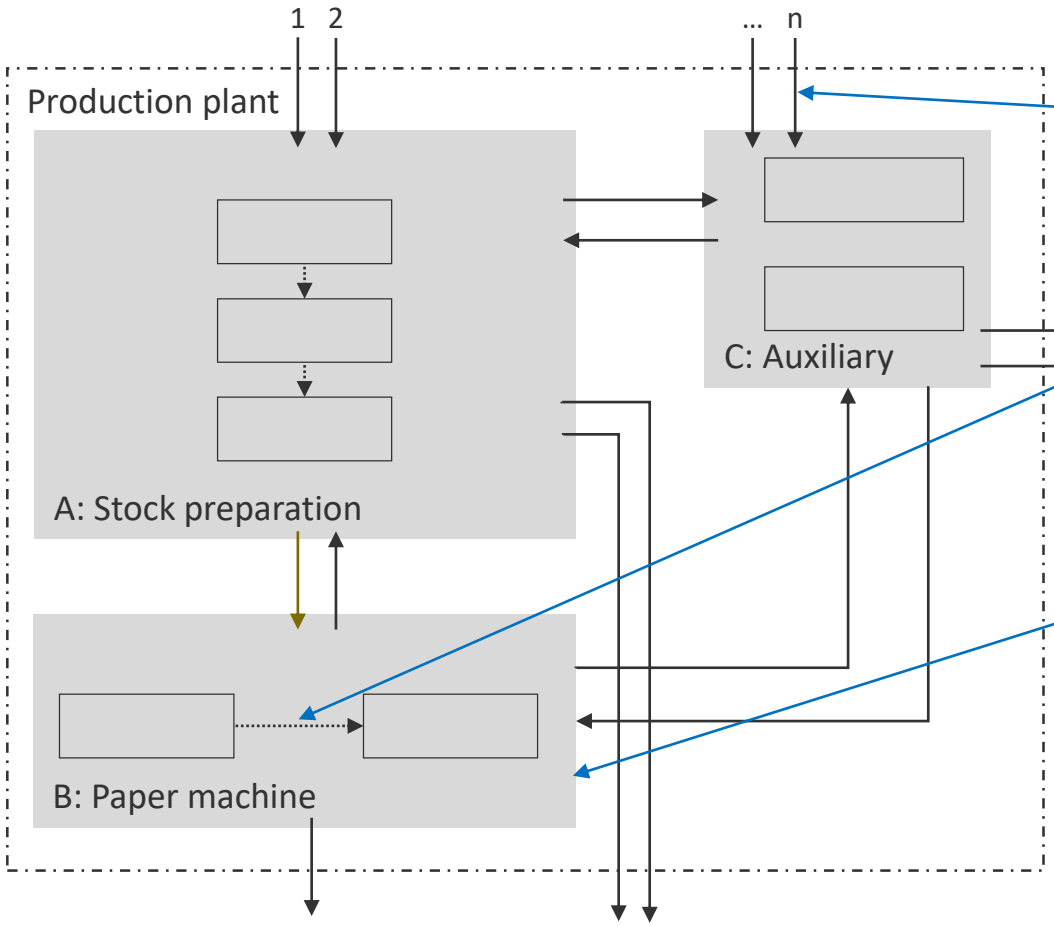
$$\varepsilon_{D,int} = \frac{\dot{E}_D}{\sum \dot{E}_{IN}}$$

- The degree of internal loss corresponds to the ratio of internal exergy losses and the exergetic effort and is calculated by subtracting the usable exergy as well as the external losses from exergy expenditure.

$$\dot{E}_D = \sum \dot{E}_{IN} - \sum \dot{E}_U - \sum \dot{E}_L$$

Method

Generic flow diagram of a production plant



External structure:
Flows (energy, material) that either enter or Leave the system boundary.

Internal structure:
Flows do not leave the system boundary.

Blackbox:
Only those flows are considered, which leave the system boundary of the blackbox (input or output).

Legend
External structure — Internal structure — Blackbox

Case-study for the German paper industry

Case-study for the German paper industry

Consideration of the German recycled-fibre-based paper mills

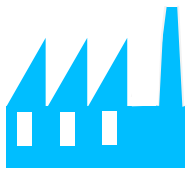
INDUSTRY STRUCTURE

- NACE 17.1 Manufacturing of pulp, paper and paperboard in 2010[1]:
  - Production: 22,7 mio. t Paper/a
  - FEC[2]: 72.42 TWh/a
  - CO_2-Emissions: 18,717,883 t

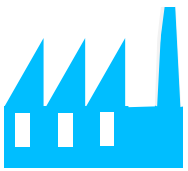
PRODUCTION OF PACKAGING PAPER

- Scope: Recylced-fibre-based paper mills[4]
  - Integrated mills with deinking
  - Integrated mills without deinking
  - Integrated Cartonboard mills

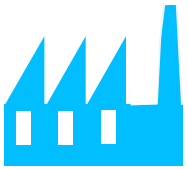
Newsprint and printing Paper



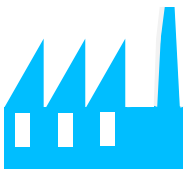
LWC/SC paper[3]



Tissue paper



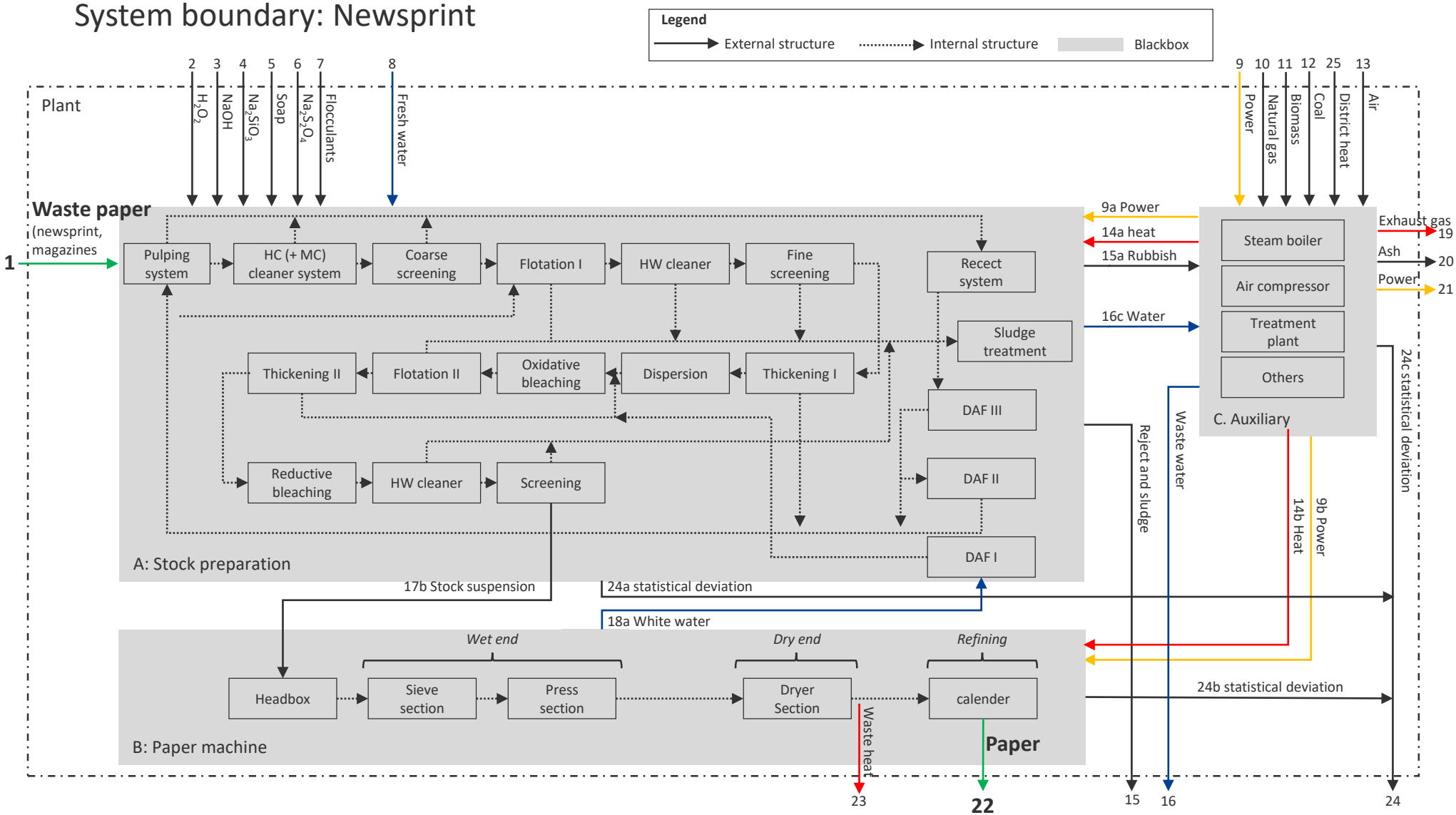
Packaging Paper and board



[1] Umweltbundesamt (2014)
[2] FEC: final energy consumption[PJ]
[3] LWC/SC: light weight coated/super-calendered paper
[4] European Comission (2015): Best available Techniques Reference document for the production of Pulp, Paper and Board

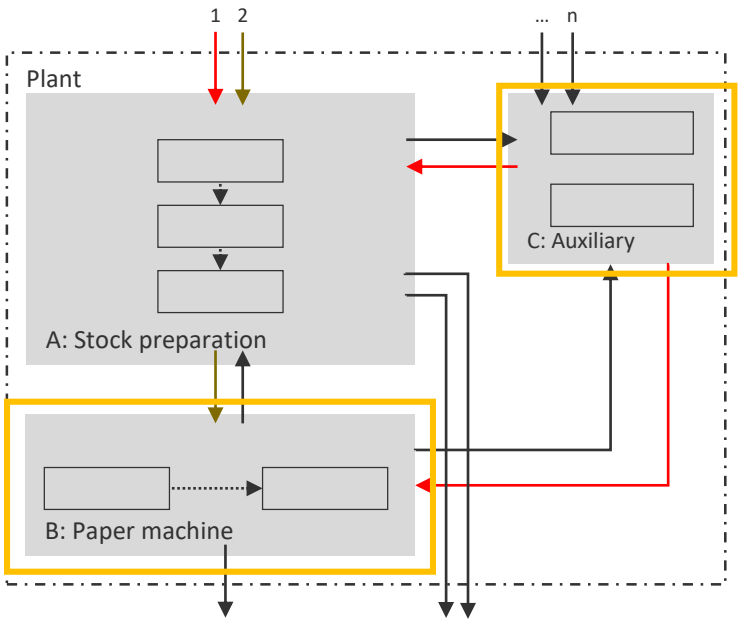
Case-study for the German paper industry

System boundary: Newsprint



Case-study for the German paper industry

Transformation pathway



B: Paper machine

Currently it is not clear which technology will prevail until 2050. Nonetheless different studies suggest a **reduction of process heat demand** for the **paper drying** by **20%.**

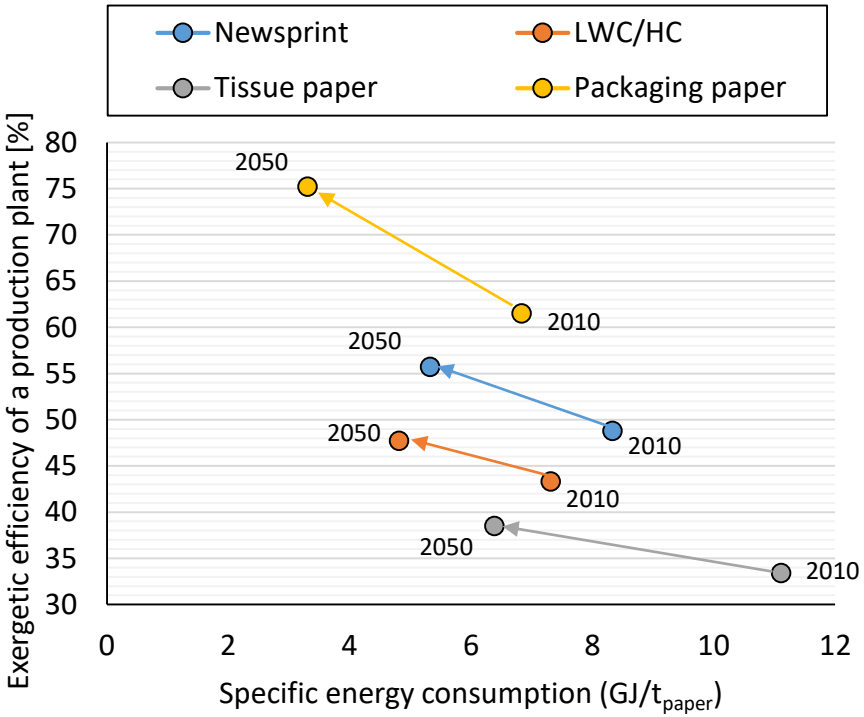
C: Auxiliary

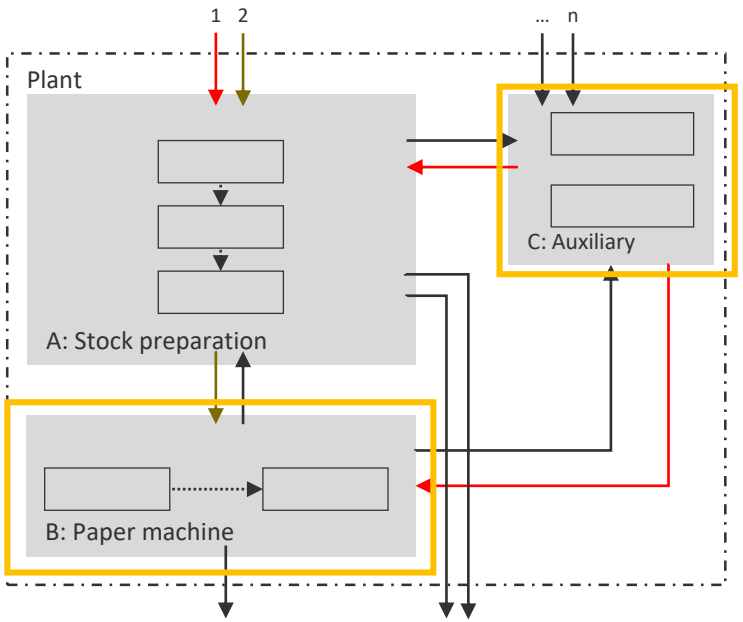
Heat pumps are already available which supply heat up to temperatures of 110 ° C. Recent research suggests that by 2020 **temperatures up to 160°C** can be achieved through the use of **high-temperature heat pumps** with new refrigerants and compressors (Wolf 2017). This would allow the use of heat pumps for heat supply in the paper industry.

Within the scope of this study we assume that until 2050 it will be technically possible to use high-temperature heat pumps for the supply of process heat for the paper drying. In this case the exhaust air from the dryer (about 70°C) can be used as the heat source.

Case-study for the German paper industry

Development of the exergetic efficiency of a production plant





Energetic analysis

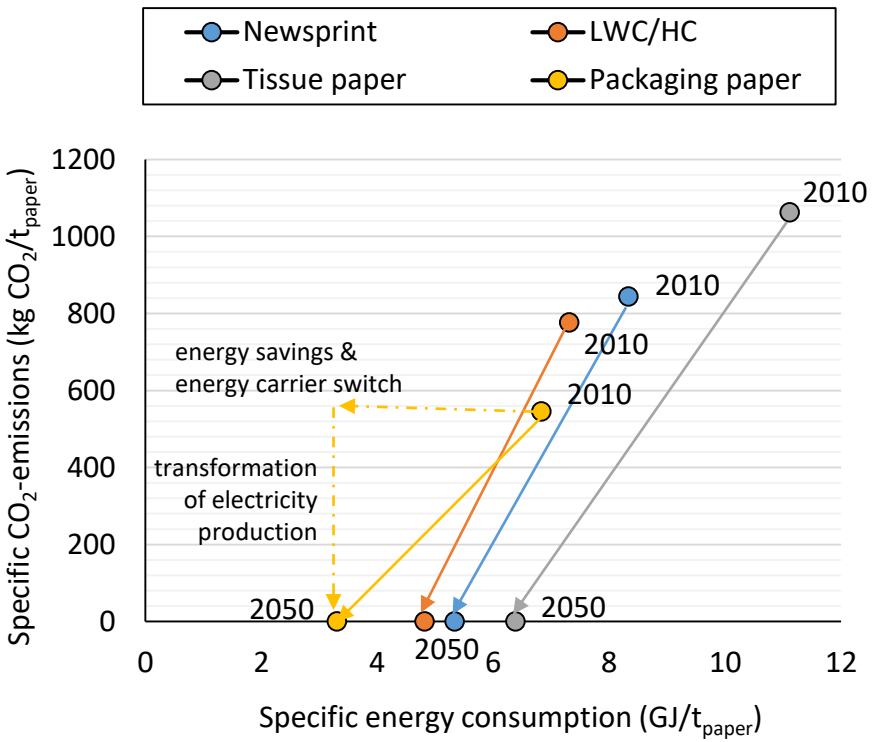
Reduction of specific energy consumption by **34.2 – 51,6 %** through efficient drying techniques and the use high-temperature heat pumps.

Exergy analysis

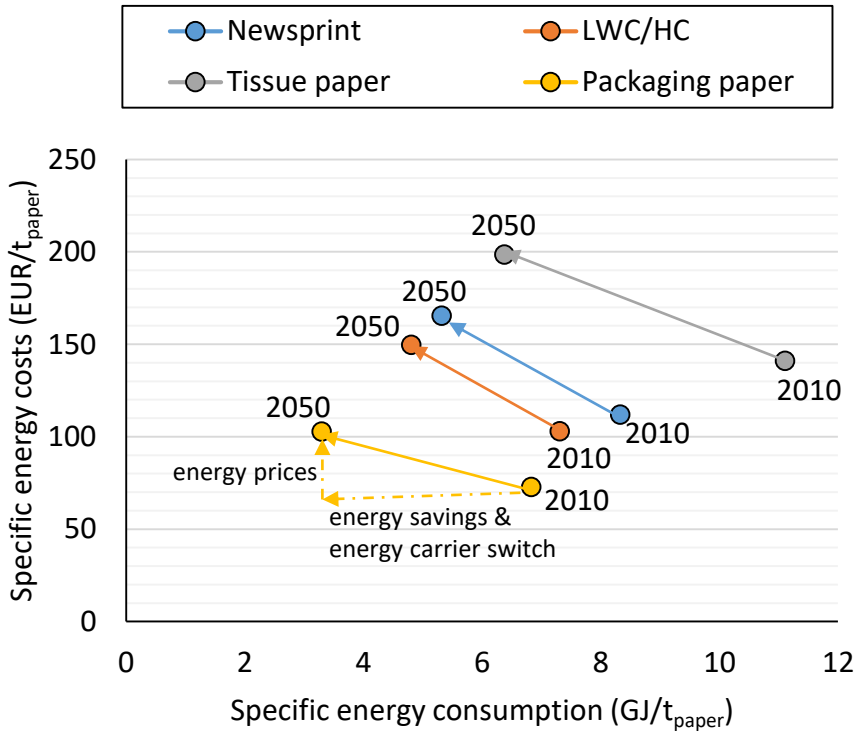
The results of the exergy analysis show that the main source of exergy is lost when high value energy carriers (e. g. natural gas) are used to produce low pressure steam for the paper machine.

Case-study for the German paper industry

Development of the economic and ecological indicators



Assuming that the process heat demand is reduced by 20 % and completely supplied using high-temperature heat pumps the specific CO_2-emissions of paper production can be completely eliminated.[1)]



Changing from fossil fuels to electricity leads to an increase of the specific energy costs due to the higher costs of electricity compared to fossil fules.[2)]

1) e_{EL} = 0 kg CO_2/MWh_{el}, based on Umweltbundesamt (2014)

2) P_{el_2010} = 19,8 EUR/MWh, P_{el_2050} = 31,1 EUR/MWh, $P_{fuel\text{-}avg\_2010}$ = 8,2 EUR/MWh, $P_{fuel\text{-}avg\_2050}$ = 12,17EUR/MWh, P_{CO2_2010} = 13,0 EUR/t_{CO2}, P_{CO2_2050} = 76,0 EUR/t_{CO2} based on Bubeck (2017)

Conclusion

Conclusion and next steps

Conclusion:

- Assuming that **high-temperature heat pumps** will reach temperatures of >150 °C as described in several studies, producing **greenhouse gas-neutral paper** from recycled fibers will be **technically possible** (assuming the electricity production is CO_2-neutral by 2050).
- The results of the **exergetic analysis** show, that in terms of exergy the **focus** should **not only be on the production system** itself **but also** focus on the **process heat supply system** as most of the exergy destruction is located their.

Next steps:

- Analysis of the remaining industry sectors:
- Analysis of future options for sector integration:
  - energy-related integration (e. g. inter-company heat integration)
  - material-related integration

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