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Towards a Sustainable European Energy System – The Role of the Pulp and Paper Industry

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In this paper a methodology for analyzing the potential for and effect of implementation of different technology pathways within the pulp and paper industry, developed by the Heat and Power Technology research group at Chalmers University of Technology, is presented. The methodology assumes detailed research and is based on bottom-up thinking. To exemplify its usefulness two studies applying the methodology are summarized. All in all, it can be concluded that the presented methodology enables integration of the different research projects, connecting research on different system levels with each other, which in turn gives the research group the possibility to better answer questions regarding the development and future role of the pulp and paper industry on a higher system level whilst still considering important characteristics of individual technologies and/or mills.

1. Introduction

The pulp and paper industry (PPI) is currently in a transition situation – where it is no longer only producing pulp and/or paper but also producing additional products which can increase both the mill profitability and the overall mill energy efficiency – thereby transforming mills into biorefineries. Depending on the development of the energy market, this transformation can also contribute to a reduction of the global CO_2 emissions. For the kraft PPI, earlier studies have shown that there are many technologies and system solutions – hereafter denoted technology pathways – which enable energy efficient production of additional value products such as materials, chemicals, transport fuels, electricity and/or district heating (Jönsson et al., 2012; Pettersson and Harvey, 2010). Another alternative is to integrate carbon capture and storage (CCS) by utilizing the steam/heat surplus to cover the energy demand in the carbon capture processes (Hektor and Berntsson, 2007).

All in all, for the PPI there are many technology pathways possible. Several parameters, technical as well as economic, influence if and when these technology pathways will, or can, be implemented. Some of these parameters are site-specific, like the configuration and age of the process equipment, others depend on the surrounding energy and transport infrastructure and future energy market prices and costs for emitting CO_2. Thus, from a future perspective, it is not clear which technology pathway is the most profitable one or which pathway gives the lowest emissions of CO_2 due to uncertainties in the future value of different energy products and the formation of future policy schemes. This can lead to uncertainty for the PPI regarding the choice of technology pathway(s). Consequently, to be able to

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estimate the potential for different technology pathways on a European level and thus estimate the future role of the European PPI an approach, connecting results from detailed technology studies to the actual European PPI stock, and also to a higher systems level is necessary.
The aim of this paper is to describe the developed approach for analyzing the potential for implementation of different technology pathways within the PPI. Further the aim is to give examples of results for different pathways obtained by applying the approach to previous and on-going research at the Heat and Power Technology research group at Chalmers University of Technology.

Due to the nature of this paper, most references are to papers from the Chalmers research group. There are, however, numerous papers on process integration and energy efficiency in the pulp and paper industry on e.g. the mill level. Two recent examples are Mateos-Espejel et al. (2010) on Kraft pulp mills and Ruohonen and Ahtila (2009) on mechanical mills.

2. Description of the methodological approach

In order to be able to elucidate the potential for, and effect of, implementation of different technology pathways within the PPI two main questions need to be addressed:

- In the future, which is the most profitable pathway(s) and which pathway gives the largest reductions of CO_2?
- Can all mills implement all of the different studied pathways?

In order to be able to answer the first question, the impact on the different pathways' economic performances and CO_2 emissions consequences by the future development of the energy market and different policy schemes need to be studied. To be able to answer the second question, the effect of, or limitations due to, external preconditions, such as geographical location and existing and new infrastructure, need to be studied for different sub-sectors of the pulp and paper industry.

To be able to give as accurate answers as possible for these two questions knowledge and data on different system levels are needed. Such knowledge is currently produced by many different research projects at the Heat and Power Technology research group at Chalmers University of Technology where the research is carried out on four different system levels, see Figure 1. Apart from the technology research at the four different system levels, method focused research is also carried out within the fields of energy market scenarios and optimization under uncertainty, as further described in the subsequent text.

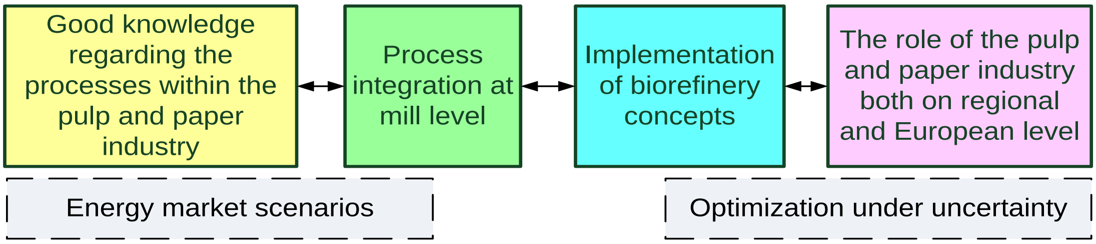

Figure 1: The four system levels for research on which the developed approach is based

Good knowledge regarding the processes within the pulp and paper industry
At this system level research regarding the improvement and development of pulp and paper processes is performed. For example, since previous process integration studies has shown beneficial results if the black liquor is evaporated to higher dry solid content, experimental research regarding the effect of this on the heat transfer (Johansson, et al., 2009) and the scaling (Gourdon, et al., 2008) is

performed in an research falling film evaporator. During the year 2010 a cracker for catalytic cracking of lignin is also taken into operation.

Process integration at mill level

At this system level the aim is to investigate how the thermal energy demand can be decreased through improved process integration. Apart from traditional process integration improvements such as using Pinch analysis to identify and solve pinch violations (Axelsson, et al., 2006) novel approaches and methodological developments are also performed, e.g. the development of advanced curves (Nordman and Berntsson, 2006) and the concept of process integrated evaporation where the evaporator partly uses high temperature excess heat instead of steam (Algehed, 2002).

Implementation of different biorefinery concepts

Increasing the process integration at a mill gives potential for integration of different biorefinery concepts since the increased process integration leads to a decreased steam demand and the steam no longer needed in the processes can be used in another way, e.g. in a biorefinery process. Also, to thermally integrate the mill processes and the biorefinery processes is a key issue. However, in order to be able to compare alternative biorefinery options with each other (both their economic performance and their effect on the global CO_2 emissions) it is important to evaluate them with respect to the future energy market. At the Heat and Power Technology research group, such system aspects are studied for many different biorefinery concepts, e.g. black liquor gasification with production of biofuels or electricity (Pettersson and Harvey, 2010), extraction of lignin (Olsson, et al., 2006), the conversion of an old pulp mill into an ethanol plant (Fornell and Berntsson, 2009), and carbon capture and storage (Hektor and Berntsson, 2007).

The role of the pulp and paper industry on both a regional and European level

The research performed at this system level aims at bringing together knowledge from the underlying system levels with characteristics for the existing PPI stock in Europe, giving a broader understanding of where and how different technology pathways can be implemented. The research follows the methodology presented in Section 2.1 and an example of a study performed on this system level is presented in Section 3 with the example of CCS as a pathway (Jönsson and Berntsson, 2010).

Energy market scenarios

The future economic performance, as well as the global emissions of CO_2, associated with different technology pathways is dependent on the development of the energy market. To depict different possible future energy market conditions an energy market scenario model has been developed (Axelsson, et al., 2009). The scenarios, given as output from the model, are combinations based on different fossil fuel price levels and different CO_2 emission charge levels. A benefit of using these scenarios, that reflect the strong connection between different energy market parameters, is that a packaged sensitivity analysis of the energy market prices is conducted. Using the energy market scenarios, it is easy to compare the economic performance and the global CO_2 emissions effect of different competing pathways.

Optimization under uncertainty

Uncertainties regarding the future energy market prices and policy schemes strongly influence the investment decisions made by companies in energy-intensive industry sectors such as the PPI. To be able to analyze and show robust investment alternatives, regardless of the above described uncertainties, and to be able to illustrate potential risks for technology lock-in a methodology for optimization of investments under uncertainty has been developed (Svensson, et al., 2009). The methodology combines the research groups' deep understanding of process integration, gained from previous research at different system levels described above, with stochastic programming and is primarily aiming at aiding decisions makers in industry.

2.1 Methodological approach to combine knowledge and results from different system levels

To be able to fully benefit from the knowledge gained on the different system levels a systematic approach is needed which combines results from studies on different system levels and consequently assesses the overall potential for different pathways whilst considering characteristics of each mill. Such an approach has been developed by researchers working on the fourth system level described in the text above (Jönsson and Berntsson, 2010). The developed approach is based on:

a) Previous research in the form of model mill studies and cases studies regarding process steam savings and the effect of different technology pathways on the energy balance for different types of mills
b) Technical and geographical data for the European pulp and paper industry
c) Data for the infrastructure surrounding the European pulp and paper mills
d) Previous research regarding the future development of the energy market (energy market scenarios)

Consequently, the approach assumes previous, detailed research and is based on bottom-up thinking. An overview of the approach is presented in Figure 2. A more thorough description of the different parts of the approach, represented by the boxes in Figure 1, can be found in Jönsson and Berntsson (2010).

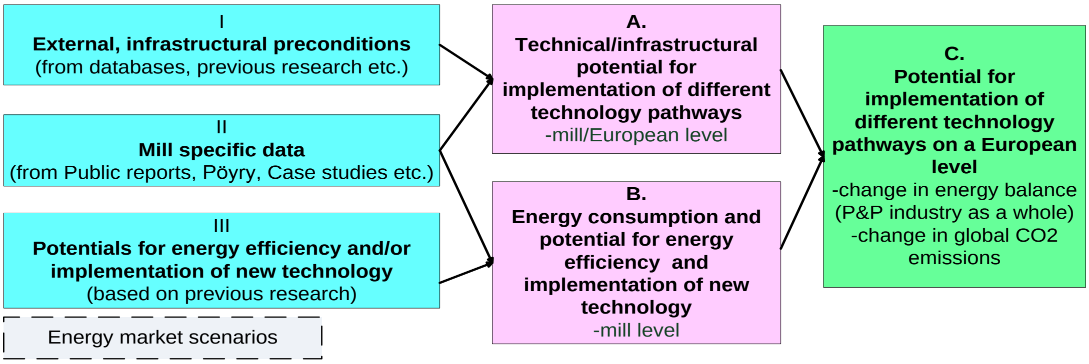

Figure 2: An overview of the suggested approach (Jönsson and Berntsson, 2010)

3. Examples of results from previous research using the presented approach

In the subsequent text two examples of studies based on the developed methodology are presented. The two studies each highlight one of the questions stated in the aim, where the first study aims at elucidating the economic performance and global CO_2 emissions associated with different technology pathways for six future energy market scenarios and the second study aims at showing for which mills in Europe CCS could be implemented assuming different developments of the expansion of CCS infrastructure.

3.1 Comparison of options for utilization of excess steam and debottlenecking the recovery boiler at kraft pulp mills (Jönsson, et al., 2012)

In the study, the trade-off, in terms of annual net profit and global emissions of CO_2, between different technology pathways for utilization of excess steam and heat was investigated for a mill depicting a typical Scandinavian mill of today. The trade-off was analyzed for six future energy market scenarios having different levels of CO_2 charge. The technology pathways studied included lignin extraction, electricity production, CCS and black liquor gasification with production of electricity or DME. A further analysis of how different parameters such as policy instruments and investment costs affect the different technologies was also included. The results show that, generally, for reasonable levels of the biofuel support, the best economic performance among the studied technologies is given by extraction of lignin that can be priced as oil. However, if the level of support for biofuels is high black liquor gasification with DME production generally has the best economic performance among the studied options. All the studied technology cases decrease global CO_2 emissions significantly compared to not making investments. Capturing and storing CO_2 from the recovery boiler flue gases gives the highest CO_2 emissions reduction and is also an economically attractive option in scenarios with a high CO_2 charge.

3.2 Analyzing the Potential for CCS within the European Pulp and Paper Industry (Jönsson and Berntsson, 2010)

The aim of the study was to assess the potential for CCS within the European PPI. Emphasis was placed on a selection of large and competitive mills with promising potentials for CCS. Together the studied mills emit 82 Mt CO_2/y (including both biomass based and fossil emissions), compared to the total (fossil) CO_2 emissions included in the energy-intensive industries part of EU ETS of 600 Mt CO_2/y (excluding the Power and heat sector). The results show that the amount of CO_2 which can be captured heavily depends on the future expansion of CCS transport and storage infrastructure. In total, 10-99 Mt CO_2/y can be avoided (including captured emissions from the additional fuel needed to satisfy the energy demand of the capture process, thus sometimes > 82 Mt CO_2/y). Further, the results show that when adding the PPI capture potential to the potential for CCS within other energy-intensive industries, the majority of the PPI emissions are originating from kraft pulp and paper mills far away from other energy-intensive industries and potential fossil capture clusters which are mainly located in central Europe. This makes the paper mills in central Europe most suitable for implementation of CCS; however, these mills generally have much lower on-site emissions than the kraft pulp and paper mills. Thus, if the aim is to implement CCS within the PPI in order to achieve large emission reductions, it is important to consider also large biomass based emissions point sources when mapping capture clusters and deciding where to build the future infrastructure for CCS.

4. Summary and conclusions

The Heat and Power Technology research group at Chalmers University of Technology has developed a methodology for analyzing the potential for and effect of implementation of different technology pathways for the European PPI. The developed methodology builds on the knowledge gained from different research projects on four different system levels. Thus the methodology is able to address questions such as:

- In the future, which is the most profitable pathway(s) and which pathway gives the largest reductions of CO_2?
- Can all mills implement all of the different studied pathways?

In this paper the usefulness of the methodology is shown by two examples of studies applying different part of the methodology in order to answer the two questions stated above. As shown by the examples, to work in this integrated way, connecting research on different system levels with each other, gives the possibility to better answer questions on a higher system level whilst still considering important characteristics of individual technologies and/or mills.

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