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# PERSPECTIVES ON THE POTENTIAL FOR CCS IN THE EUROPEAN PULP AND PAPER INDUSTRY

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## INTRODUCTION

The Pulp and Paper Industry (PPI), like other energy-intensive industry branches, is suitable for implementation of carbon capture and storage (CCS) since they have large on-site emissions of $CO_2$ and usually also excess heat available which can be utilised in the capture process. Further, since a large share of the $CO_2$ emissions associated with the European PPI originates from biomass, if CCS is implemented the levels of $CO_2$ in the atmosphere can be further reduced in comparison to implementing CCS only on fossil emission sources, i.e. provided the biomass is grown in a sustainable way. This fact makes CCS within the European PPI an interesting alternative.[1] This chapter assumes that world governments adopt policy measures that stimulate significant $CO_2$ reductions and the purpose of this chapter is to discuss CCS as an option for the PPI to significantly reduce its $CO_2$ emissions. The chapter gives an introduction to CCS in general and CCS in the PPI in particular. Some main opportunities and challenges are presented and discussed and an example of the potential for CCS in the European PPI is

1 See for instance ZEP, Zero Emissions Platform (2012). Biomass with $CO_2$ capture and storage.

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presented. The chapter ends with a list of main conclusions. This chapter is partly based on Johnsson et al. (2012)[2] and Jönsson and Berntsson (2012)[3].

### A SUMMARY ON CCS TECHNOLOGY

The capture and storage of $CO_2$ (often referred to as "carbon capture and storage", CCS) involves four major steps: (1) capture of $CO_2$ from large point sources, such as power plants or industrial processes, (2) treatment of the $CO_2$ for transport (compression and/or liquefaction), (3) transport of the captured $CO_2$ to a storage site, and (4) injection of the $CO_2$ into the storage site, typically a geological formation located deep underground. Current research and development includes all four aspects of CCS. However, most emphasis so far has been on the capture processes (1) due to capture being the most expensive part of the CCS chain. The additional expense of applying CCS on a power plant or industrial process originates from increased investment and operation and maintenance costs (capture technology) and costs for transportation and storage of captured $CO_2$. In addition, the capture of $CO_2$ is in most cases energy demanding, which is normally considered as an energy penalty compared to the process without capture. The energy demand can, however, be reduced if the capture process is efficiently integrated, something which can be analysed using different process integration tools (see Chapter 8). The costs discussed today are at least 50-60 EUR/ton $CO_2$ for the whole CCS chain. However, the aim is to achieve future costs for capture and storage as low as about 25 EUR/ton $CO_2$. This cost estimation is very sensitive to assumptions and to the nature of the host process which explains the substantial spread of estimates that can be found in the in literature. For CCS to be an alternative, the cost of capture, transport and storage need to be lower than the cost for emitting the $CO_2$.

The actual capture technology is by no means one single technology, rather, several options and possibilities exist. For integration of $CO_2$ capture in the PPI, the currently most significant technologies are post-combustion capture by solvents and possibly the oxy-fuel process.[4] In addition, there are other important capture technologies such as Chemical-Looping-Combustion. However, this capture technology is less mature and would require reconstruction of the boilers, making it less significant within the next 10-20 years. Post-combustion capture essentially uses a solvent to absorb the $CO_2$ from the flue gases in a scrubber, which is then stripped by boiling off the $CO_2$, which is captured, including regeneration of the solvent. The boiling off and regeneration requires heat and the captured $CO_2$ requires compression work, which result in the above-mentioned energy penalty. Examples of solvents that can be used include amines and chilled ammonia. An advantage for post-combustion capture using solvents is that it can be implemented for retrofit of existing plants. Pre-combustion capture by the oxy-fuel method can simply be described as performing the combustion in a controlled atmosphere consisting of pure oxygen and re-circulated flue gases. Here, the energy penalty stems from operation of the air separation unit required to obtain the oxygen.

2 Johnsson, F. et al. (2012). The importance of $CO_2$ capture and storage – a geopolitical discussion. Thermal Science, 16(3), pp. 655-668.

3 Jönsson, J., and Berntsson, T. (2012). Analysing the potential for implementation of CCS within the European pulp and paper industry. Energy, 44(1), pp. 641-648.

4 Introducing the oxy-fuel process would, however, demand much more reconstruction of the boilers compared to post-combustion capture.

Based on a review of recent studies (IASKS 2012[5], GeoCapacity[6], NPD 2012[7], EC 2012[8], Kjärstad et al.[9, 10, 11]) some conclusions can be drawn regarding the current stage CCS technology, opportunities and challenges. First, there is probably more than sufficient storage capacity in Europe to store most of the emissions from large-scale sources for several decades. There is now an urgent need to gain experience in $CO_2$ injection and $CO_2$ storage. However, most CCS projects in Europe with storage in onshore reservoirs have been abandoned due to fierce local opposition. At the same time, projects with offshore storage have met little or no opposition. By far most of the identified offshore storage capacity in Europe is located in the North Sea. It is clear that CCS requires political commitment and a renewed willingness to go forward with research, development and demonstration. Since no emitters are willing to invest billions in developing a technology that only might be useful after 2020, investors will require financial security and possibly even full funding of the first large-scale demo-projects. Finally, failure to implement CCS will require close to complete phase-out of fossil fuels if stringent $CO_2$-emission reduction targets are to be met.

## CCS PLANTS – GLOBALLY, WITHIN THE EU AND IN THE SWEDISH PPI

Large-scale CCS is already taking place at some sites in the world; in Norway more than 13 million tonnes (Mt) of $CO_2$ has been injected into an aquifer in the North Sea (Utsira) while injection into the Tubåen formation in the Barents Sea has been stopped due to rapid pressure build-up around the injection well. The projects in Norway separate $CO_2$ from natural gas so that the natural gas can be marketed, i.e. the cost of capture would have had to be carried anyway and since Norway has a substantial tax on $CO_2$-emissions from the offshore industry, it is more cost efficient to store the $CO_2$ than to emit it. Also, since 2004 0.6 Mt of $CO_2$ per year has been stripped from natural gas produced from the In Salah gas field in Algeria followed by injection into an aquifer. In the US, $CO_2$ has been injected into oil fields to enhance recovery (so-called EOR – Enhanced Oil Recovery) for several decades and in 2010, there were more than 120 $CO_2$ EOR projects injecting more than 60 Mt $CO_2$ annually of which 13 Mt from anthropogenic sources. The by far largest $CO_2$ project in the world, the Gorgon project in Australia, is under construction and is projected to separate between 3.4 and 4.0 Mt of $CO_2$ per year from natural gas and inject it into an aquifer.

However, within the European Union several CCS projects under development have been abandoned during the last few years. In particular, out of the six CCS projects receiving a combined financial support of one billion euro from the EU under the EEPR (European Energy Program for Recovery), at least two projects have either been shelved or deferred indefinitely; the Hatfield IGCC in the UK and

5 IASKS (2012). Fossil Fuels: Climate Change and Security of Supply. International Journal of Sustainable Water and Environmental Systems, 4(1), pp. 79-87.

6 Geocapacity Project.

7 NPD (2012). Norwegian Petroleum Directorate.

8 EC (2012). Energy Roadmap 2050. European Commission.

9 Kjärstad, J. et al. (2011). Establishing an integrated CCS transport infrastructure in northern Europe - Challenges and Possibilities. Paper presented at the GHGT10 Conference in Amsterdam.

10 Kjärstad, J., et al. (2011). CCS in the Skagerrak-Kattegat-region - Assessment of an intraregional CCS infrastructure and legal framework. Paper presented at the GHGT10 Conference in Amsterdam.

11 Kjärstad, J., et al. (2012). Modelling large-scale CCS development in Europe – linking techno-economic modelling to transport infrastructure. Paper presented at the GHGT11 Conference in Kyoto.

the Jänschwalde project in Germany. Since we are already in 2013, it appears likely that only a handful of the twelve targeted CCS plants in Europe will become operational in 2015 as envisioned by the European Commission.[12,13] This is critical since there is an urgent need to move the development into demonstration of large-scale capture units so that these can be tested, further developed and improved in order to reduce cost.

Today, $CO_2$ is captured from the flue gases at two Swedish pulp and paper mills, M-real Husum and StoraEnso Nymölla. The captured $CO_2$ is, however, not transported and stored as pure $CO_2$ but chemically bound in the production of PCC (precipitated calcium carbonate).

## DOES CAPTURING BIOGENIC $CO_2$ GENERATE NEGATIVE EMISSIONS?

CCS implemented on biomass fuelled (biogenic) processes (Bio Energy Carbon Capture and Storage, BECCS), e.g., sugar cane-based ethanol mills, chemical pulp mills and biomass-fired power plants, can provide the possibility to reduce atmospheric levels of $CO_2$. This is usually referred to as negative $CO_2$ emissions or as carbon negatives. However, there are several challenges for BECCS that remain to be resolved for it to play a major role in the energy system. For example, it is likely that capturing $CO_2$ from biomass fired processes will be more expensive compared to implementation in large scale coal fired power plants, due to economies of scale for biomass fired plant that are limited by biomass fuel logistics as well as technical aspects in the actual process design, e.g., the maximum steam temperature (determining the plant efficiency) may have to be limited to avoid alkali related high temperature corrosion on heat transfer surfaces. In addition, it should be noted that net negative emissions can only be achieved when more greenhouse gases are sequestered than are released into the atmosphere. Until CCS has been applied to all fossil fuelled power plants and all other $CO_2$ emissions have been curbed, the total net global $CO_2$ emissions will not be negative.

From the year 2013, (fossil) $CO_2$ capture, transport and storage installations will be incorporated in the European Union emission trading scheme (EU ETS). Capture and storage of $CO_2$ from combustion of biomass has not yet been incentivised through the ETS. However, it is expected that inclusion of the concept of carbon negatives will be required to meet the stringent long-term emission reductions proposed by for instance the EU. For the discussion of CCS in the PPI in this chapter it is assumed that in future policy schemes captured and stored $CO_2$ originating from sustainably produced biomass is granted the same economic compensation as $CO_2$ originating from fossil fuels.

## CCS IN THE PULP AND PAPER INDUSTRY

The PPI is energy-intensive and has large on-site emissions of $CO_2$. Consequently, the $CO_2$ emissions in the PPI are associated with only a limited amount of geographical sites, i.e. mills. Furthermore, previous research has shown that for the chemical kraft PPI (sulphate process), there are many technologies and system solutions which can reduce the process steam demand, yielding a heat surplus

12 Reuters (2012). UK won't get EU cash for carbon storage: EU sources. Press release dated November 11, 2012.
13 NER300.

and thus enabling energy-efficient production of additional added-value products such as materials, chemicals, transport fuels, electricity or district heating. In this way the mill is transformed into a biorefinery (see e.g. descriptions of different biorefinery concepts in Chapters 2 and 6). Another alternative is to integrate carbon capture (CC) by utilising the heat surplus to (fully or partly) cover the heat demand in the carbon capture processes. This way the cost and energy efficiency of the concept is improved.[14] Previous research has shown that compared to other options for using surplus steam, CCS gives much larger reductions of global $CO_2$ emissions and is economically comparable to more proven technology alternatives – such as increased electricity production in condensing turbines – if the economic value of capturing $CO_2$ is high.[15] The potential for carbon capture and storage (CCS) in the industry sector and the potential for formation of industrial capture clusters have previously been discussed.[16] However, analyses of the potential for CCS in the industrial sector usually do not include the PPI since the $CO_2$ emissions in this sector to a large extent are biogenic.

## OPPORTUNITIES AND CHALLENGES FOR IMPLEMENTING CCS IN THE PULP AND PAPER INDUSTRY

CCS, being an emerging, capital intensive technology requiring large scale implementation, shares some of the policy challenges described for biomass gasification in Chapter 12. In addition, the following opportunities and challenges are important to take into account when discussing CCS in the PPI:

*A significant part of the emissions in the PPI are biogenic.* As previously mentioned, the fact that the $CO_2$ emissions in the PPI to a large extent are biogenic provides both an opportunity and a challenge. An opportunity since in the long term perspective if the addition of fossil $CO_2$ to the atmosphere is reduced (by e.g. CCS on fossil emission sources) implementing CCS also on biogenic sources could contribute to slowly “decarbonising” the atmosphere. However, it provides a challenge since all existing regulations and policy instruments (ETS etc.) in the area include only fossil $CO_2$, limiting the economic incentives for investments in capturing biogenic $CO_2$.

*The development of the EU ETS.* Presently the majority of $CO_2$ emissions from the stationary energy system in Europe are regulated in the EU ETS. The EU ETS has clearly defined emission targets to be achieved by the year 2020 and is believed to be a key instrument also after this year in forthcoming policy within the EU. However, emissions have been regulated in so called trading periods, where the first (2005-2008) and second have ended (2009-2012), to even out annual variations from for example temperature and hydro power generation fluctuations. In the beginning of the third trading period (2013-2020) price in the EU ETS is about ~8 EUR/ton $CO_2$, which is far too low to have an impact on the development of CCS. The reason for such a low price can partly be explained by over allocation of emission permits as well as the possibility to use international credits in the EU ETS.

14 Also mills without a steam surplus can be transformed into a biorefinery and/or implement CCS but with weaker economic performance (see Chapter 6).

15 Jönsson, J., et al. (2012) Comparison of options for utilization of a potential steam surplus at kraft pulp mills–Economic performance and $CO_2$ emissions. International Journal of Energy Research, DOI: 10.1002/er.2905.

16 See e.g. Rootzén, J., et al. (2011) Prospects for $CO_2$ capture in European industry. Management of Environmental Quality, 22(1), pp. 18-32.

The result is an excess of about 1-1.5 billion emission allowances, corresponding to 1-1.5 billion tonnes (Gt) of $CO_2$, in the beginning of trading period three.[17] Thus, without further actions prices are expected to remain low until after 2020.

The EC communication "Energy Roadmap 2050" describes possible pathways for the EU energy system indicating almost full $CO_2$ emission reduction from the electricity generation sector, which at present is the majority of all emissions in the EU ETS. If put into practice, such a zero net $CO_2$ emission electricity system is estimated to correspond to $CO_2$ prices in the range of 100 EUR/ton $CO_2$ for the period 2030 and beyond.[18] At these $CO_2$ price levels the PPI and other process industry sectors might very well become interested in CCS as $CO_2$ abatement technology.

*Efficiency gains through potential heat integration and integration with other biorefinery concepts.* The potential for heat integration of the capture process is one reason why CC is of interest for the PPI. Previous research has shown that process steam savings can be made with thermal integration of a CC unit. This way the capture cost is reduced and the CC-concept can become more profitable.[19] Finally, it could be interesting to combine CC and lignin extraction at a mill since some of the captured $CO_2$ could then be used in the lignin separation process (see Chapter 6 for further reading on lignin extraction and other alternative biorefinery concepts in the PPI) and thus eliminate the need to buy more expensive $CO_2$ on the market.

*The largest reductions of $CO_2$ emissions compared to other technologies for utilisation of mill excess heat.* If the PPI is to contribute to significantly to reduction of global $CO_2$ emissions, CCS is the technology that by far provides the largest reductions compared to e.g. other possible technology options to utilise potential steam and heat surplus. However, even though the process can be efficiently integrated, the future economic performance of the technology is highly dependent on the development of the price for emitting $CO_2$ (including potential benefits received for capturing biogenic $CO_2$) as well as other energy market prices.

*High investment costs.* Investments in $CO_2$ capture technologies are associated with high capital costs. Since CCS is a non-commercial technology the estimated costs are highly uncertain. This contributes to making the future economic performance of the technology hard to predict. Furthermore, the energy cost for capture is also significant and can thus not be neglected. Hence, for $CO_2$ capture to be economically and technically realistic the source of $CO_2$ needs to be large enough and the energy heat demand of the capture process should preferably be possible to integrate with other processes at the capture site. As previously stated, when capturing $CO_2$ in the PPI the potential for heat integration gives a possibility to reduce the heat demand that has to be provided by primary energy and thus improve the economic performance.

17 SWD (2012). COMMISSION STAFF WORKING DOCUMENT. Information provided on the functioning of the EU Emissions Trading System, the volumes of greenhouse gas emission allowances auctioned and freely allocated and the impact on the surplus of allowances in the period up to 2020, 234 final.

18 Odenberger, M., et al. (2013). Prospects for CCS in the EU Energy Roadmap to 2050. Energy Procedia.

19 Hektor, E. and Berntsson, T. (2007). Future $CO_2$ removal from pulp mills - Process integration consequences. Energy Conversion and Management. 48(11), pp. 3025-3033.

*Potential storage locations and infrastructure for transport of emissions.* Today, CCS is not a commercial technology and the necessary infrastructure for both transport and storage is neither in place nor definitely planned. The latest European wide assessment of storage capacity was completed in 2009 with the GeoCapacity project which, applying a conservative approach, estimated total storage capacity in 25 European countries to 117 Gt of which 96 Gt in aquifers, 20 Gt in oil and gas fields and 1 Gt in coal fields.[20] More than a third, almost 44 Gt, was assumed to be located in the Norwegian and UK part of the North Sea. It should, however, be noted that most estimates only are rough preliminary estimates, in particular with regard to capacity in aquifers. Sweden was not a part of the GeoCapacity project but the Swedish Geological Survey has done preliminary estimates of storage capacity in three aquifers in the Swedish part of the Baltic Sea. The most promising structure, Faludden, southeast of Gotland, may have a storage capacity ranging from 450 to 4,500 Mt. Two smaller and much more uncertain areas have also been identified; offshore southwest Skåne and in the southeastern part of the Kattegat Sea.[21] For the pulp and paper mills located near harbors the buildup of transport infrastructure could be facilitated since ships could be used for transport before the total transported amounts could justify the establishment of pipe infrastructure.

### AN EXAMPLE: POTENTIAL FOR CCS IN THE EUROPEAN PPI CONSIDERING THE GEOGRAPHICAL LOCATIONS OF THE MILLS

Here, the European pulp and paper industry is defined as mills located in the countries that are included in CEPI (Confederation of European Paper Industries), i.e. the countries in Europe with the highest density of pulp and paper industry. Today, the European PPI is transforming due to increased global competition and changing market demands. In this process many (small) less profitable mills are decommissioned and the remaining mills are increasing their production capacity, keeping the total pulp and paper production rather constant. This structural change implies that not all of the mills in production today will still be in production at the time when CCS will be commercially available. To account for this fact, the mills included to represent the European PPI have been chosen based on competitive strength and size; this gives a selection of 171 mills for this example.

The amounts of on-site $CO_2$ emissions from the pulp and paper mills included in this example are presented in Figure 7.1. For comparison, the total on-site emissions of $CO_2$ for all CEPI mills are also presented. As can be seen in the figure the kraft mills have much larger on-site emissions compared to the mechanical pulp and paper mills (using more electricity) and the pure paper mills (having a lower energy demand in total since no virgin fiber is processed).

20 GeoCapacity (2009). Storage Capacity. Deliverable 16, Work Package 2, EU GeoCapacity project.

21 Anthonsen, et al. (2012). $CO_2$ storage potential in the Nordic region. Paper presented at the GHGT11 conference in Kyoto, Japan, November 2012.

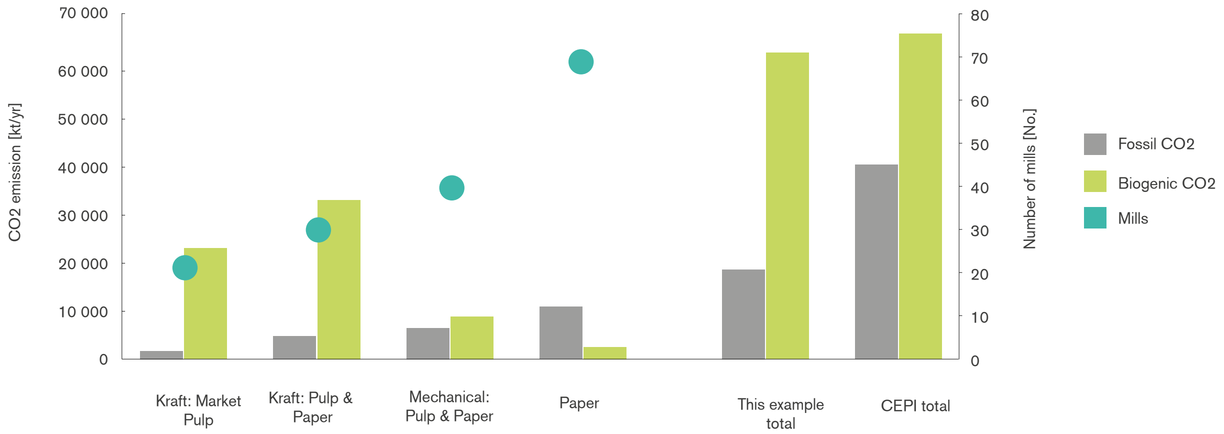


**Figure 7.1** Fossil and biogenic emissions of $CO_2$ for the mills included in the example compared to CEPI total emissions.

The geographical distribution of these $CO_2$ emissions is shown in Figure 7.2 together with an overview of where different types of mills are located. As can be seen, the regions with the highest emissions are located around the Baltic Sea (in Sweden and Finland), in the south of Spain and in the middle of Portugal (the regions with most kraft pulp and kraft pulp and paper mills).

Today, CCS is not a commercial technology and the necessary infrastructure for both transport and storage is neither in place nor definitely planned, as described earlier in this chapter. It is thus hard to predict which plants will have the most favorable preconditions for implementing CCS. To address this task, a reasonable approach could be to assume the following:

- Infrastructure is most likely to be developed first in proximity to sites with many large point sources, hereafter denoted capture clusters.
- Depending on how the biomass-based $CO_2$ is viewed from a mitigation point of view, it can be assumed that infrastructure will first be built around large fossil point sources or around large point sources regardless of the origin of the emissions.
- It is reasonable to assume that mills with larger emissions will have a larger potential for profitable introduction of CCS compared to mills with small emissions.

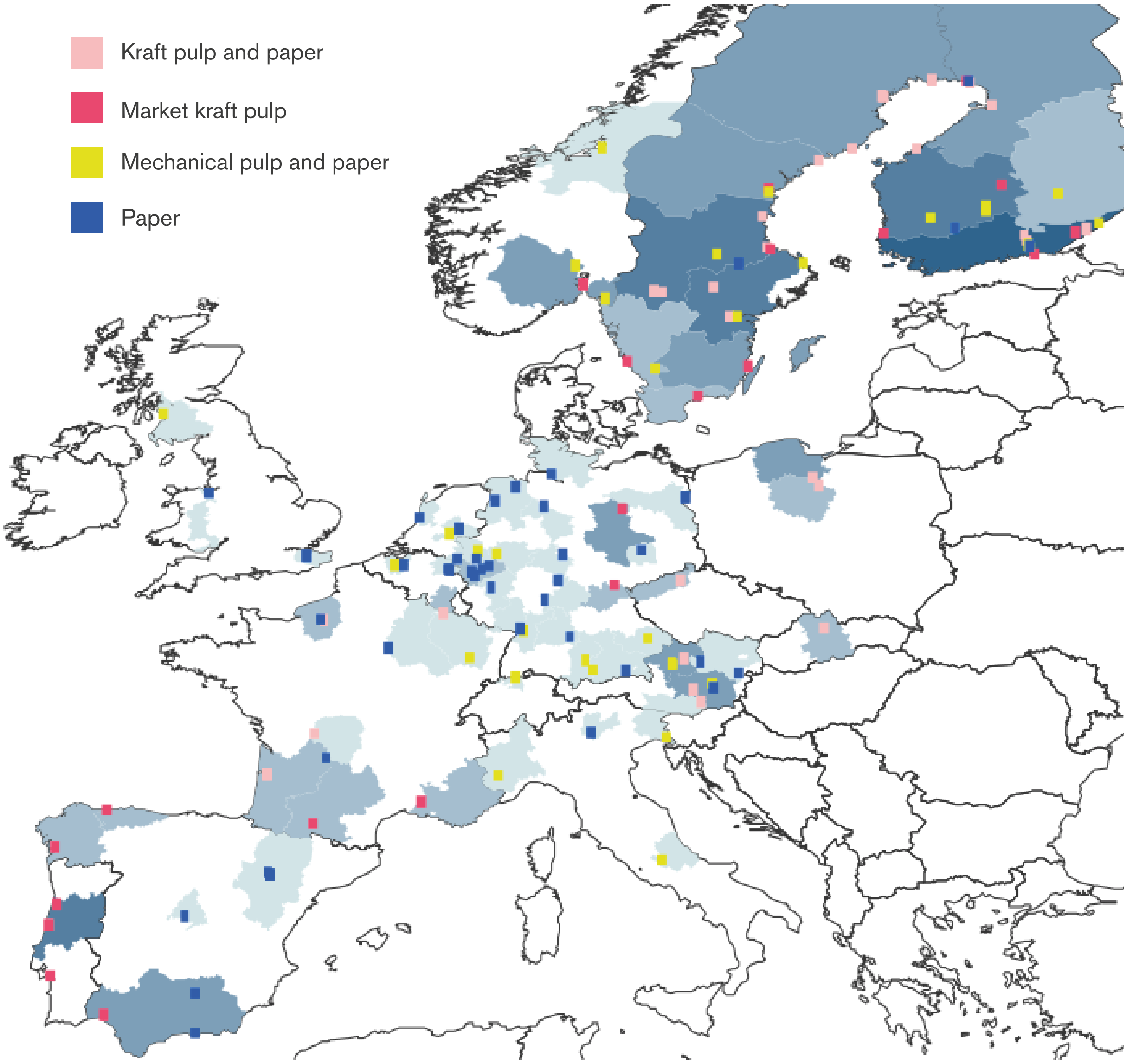


**Figure 7.2** The geographical distribution of on-site $CO_2$ emissions from the European PPI. The colored squares represent individual mills (emitting >0.1 Mt $CO_2$/yr). Regions colored in blue have a high density of emissions; the darker the color, the higher the emissions. Figure originally presented by Jönsson and Berntsson (2010)[22].

The geographical positioning of the pulp and paper mills included in the work on which this example is based in relation to the geographical positioning of other energy-intensive industries, power plants and capture clusters is displayed in Figure 7.3.

22 Jönsson, J., and Berntsson, T. (2010). Analysing the potential for CSS within the European pulp and paper industry. Proceedings of the 23th International Conference of Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems, ECOS, 2010, Lausanne, Switzerland, June 14-17, pp. 676-683.

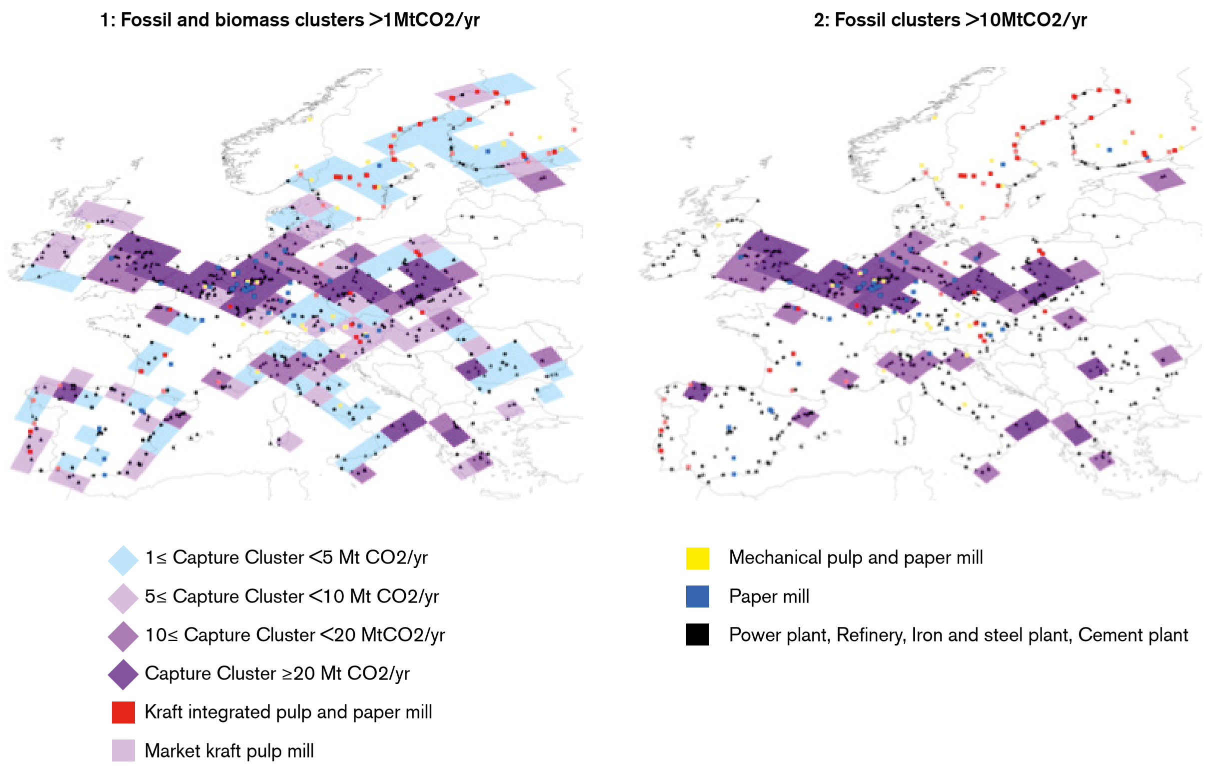


**Figure 7.3** The geographical distribution of the European PPI in relation to other large industrial point sources and power plants emitting $CO_2$. Possible capture cluster areas are represented by colored squares (150 × 150 km). Adapted from figure first presented in Jönsson and Berntsson (2012).[23] The underlying map and the data for other heavy industries and power plants were compiled by Rootzén et al.[24]

As can be seen in Figures 7.2 and 7.3, most of the large emitting kraft pulp and paper mills are located on the eastern coast of Sweden and in Finland, far away from most of the largest fossil capture clusters created by other energy-intensive industries and power plants. The most beneficial geographical positions in terms of close proximity to potential capture clusters and potential storage sites in the North-Sea[25] are held by paper mills in central Europe. These mills have, however, much smaller on-site emissions compared to the kraft mills. On the other hand, it should also be noted that most Swedish and Finnish sources are located along the coast which will facilitate the build-up of a cost efficient CCS infrastructure with minimum impact on the environment since ships can be utilised to transport the $CO_2$ initially when volumes are on the rise. Also, a location close to the coast will provide easy access to cooling water for the capture and compression processes.

## CONCLUDING REMARKS

Of the total on-site $CO_2$ emissions from the PPI a large part is biogenic. A third of the mills are responsible for about 75% of the emissions. Consequently, implementing CCS in the European PPI will lead to capture of mainly biogenic $CO_2$. To

23 Jönsson, J., and T. Berntsson (2012), Analysing the potential for implementation of CCS within the European pulp and paper industry. Energy, 44(1), pp. 641-648.

24 Rootzén, J., et al. (2011), Prospects for $CO_2$ capture in European industry. Management of Environmental Quality, 22(1), pp. 18-32.

25 Assuming storage in closed aquifers, mineralization of the $CO_2$ could be another option, however that technology need a major breakthrough before being possible to commercialise in large scale.

make CCS in the PPI a viable option it is therefore critical that capture of biogenic $CO_2$ is granted the same financial support as capture of fossil $CO_2$.

If CCS is to be introduced on a large scale in order to reach substantial $CO_2$ emission reductions within the European PPI, the emission intensive Scandinavian kraft PPI must be included. If this is done, up to around 60 Mt $CO_2$ per year could be captured. This is more than the total amount of fossil $CO_2$ emitted per year in Sweden (presently around 50 Mt $CO_2$ per year).

The amount of $CO_2$ that can be captured from the European PPI depends heavily on the expansion of transport infrastructure. While the Swedish and Finnish PPI's from one point of view have beneficial location along the coast which may facilitate the build-up of a CCS infrastructure, they are located far away from Europe's major emission clusters. The results from the example provided in this chapter show that when matching the PPI capture potential with the potential for CCS within other energy-intensive industries and the power and heat sector, the $CO_2$ emission intensive kraft PPI holds a very poor geographical position compared to potential large capture clusters and storage places. This is especially true if only the largest capture clusters are considered. Due to this poor matching between $CO_2$ sources and potential $CO_2$ sinks and transport infrastructure, it can be argued that for the European PPI, CCS has an up-hill road in order to be a viable, large scale alternative for reduction of $CO_2$ emissions.