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Assessment of the potential for CO_2 capture in European heavy industries

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ABSTRACT

This study aims to assess the role of CO_2 capture and storage (CCS) technologies in reducing CO_2 emissions from the European industry sectors. Emphasis is here placed on three branches of industry with promising prospects for CCS; mineral oil refineries, iron and steel, and cement production. A relatively small number (~270) of large installations (>500 000 tCO_2/year) dominates emissions from these three branches. Together these installations emit 432 MtCO2/year, 8% of EU's total greenhouse gas emissions. If realizing the full potential of emerging CO_2 capture technologies some 270-330 Mt CO_2 emissions could be avoided annually. Further, several regions have been singled out as particularly suitable to facilitate integrated CO_2 transport networks. The best matches between sources and sinks are currently found in regions bordering the North Sea.

INTRODUCTION

Over the last decade the EU has implemented a range of policies aimed at combating climate change. Even though the trend vary across member states and between sectors the EU have managed to decrease the overall greenhouse gas (GHG) emissions by 7.7% between 1990 and 2006 [1]. However, to meet the targets of a 20-30 % emission reduction by 2020 and a further reduction of 50-80 % by 2050 compared to the 1990 levels, extensive additional efforts obviously need to me made. In the European Commission's climate change and energy package [2] which was introduced in January 2008 and passed through the European Parliament in December the same year, a number of legislative proposals were put forward aimed at facilitating further emission reductions beyond the commitment period under the Kyoto protocol (2008-2012). Two central components of this package are a strengthening and expansion of the EU Emission Trading Scheme (EU ETS) and a regulatory framework for the promotion and development of CO_2 Capture and Storage (CCS) technologies.

The EU ETS was introduced as a mean to allow the EU member states to achieve compliance with their commitments under the Kyoto Protocol as cost effective as possible. In its present shape the scheme covers CO_2 emissions from large stationary sources in the energy and industrial sectors; combustion installations, oil refineries, coke ovens, iron and steel plants, and industries manufacturing cement, lime, glass, ceramics, and pulp and paper [3]. Collectively these installations are responsible for more than 40 % of the EU's total GHG emissions.

To realise the goals of further, extensive, emission cuts beyond 2020 the European Community has agreed to increase the efforts to deploy CCS technologies [4]. To support this development the EU has set out to provide economical incentives and to develop a legal framework for CCS. From 2013, CO_2 capture, transport and storage installations will be incorporated in the EU ETS. To help stimulate the construction and operation of commercial demonstration projects 300 million emission allowances in the new entrants reserve will be set aside. Between 2013 and 2016 the Member States will also be allowed to use revenues from the EU ETS to support the construction of highly efficient power plants, including power plants that are capture ready.

In a number of reports [5,6] CCS has been recognized as one of several key options in a portfolio of mitigation actions to combat global climate change. So far most of the attention has been directed towards the application of CCS technologies in fossil fuelled power plants. The aim of the assessment presented in this paper is to provide a first estimate of the potential for CO_2 capture in European industry sectors and to identify regions that could facilitate deployment of integrated CO_2 transportation networks. This study adds on to an earlier investigation of the potential for CCS in the European electricity generation system [7]. The finding of these two studies will later be used in a more thorough assessment of the potential for a ramp-up of a large scale CCS infrastructure in Europe.

METHODOLOGY

This assessment is based on the current constitution of the European energy intensive industry sectors. A database covering all industrial installations included in the EU ETS has been established (the main features of this database will be presented below).
The analyses have been limited to three branches, mineral oil refineries, iron and steel, and cement manufacturers. The potential capture sources have been identified and the potential for CO_2 capture has been estimated through a number of steps:

- Only very large point sources have been assumed suitable for CO_2 capture. Here, 0.5 Mt CO2/year is arbitrarily chosen as representing an emission level which will give CO_2 avoidance costs that would make capture economically viable.

- Sector specific conditions; CO_2 capture is not applicable in all manufacturing processes. The prospects for capture depend on what production process that is utilized. The sectors have therefore been divided into different sub-categories depending on process route (e.g. integrated steel plants and mini mills).

- Plant specific conditions; the total emissions from a plant is typically the sum of several separate emission sources. The different flue gas streams differ with respect to their suitability for CO_2 capture.

- Capture technology; there are a number of alternative capture technologies that are applicable to industrial processes. The technological and economical challenges vary depending on what capture option that is chosen. To illustrate the varying potential of different industry CO_2 capture options two setups of different capture technologies have been used in the assessment. In Route A capture technologies with high capture potential and relatively high costs are assumed to dominate, in Route B capture technologies with lower capture potential but also with lower costs dominate.

Finally the geographical distribution of the emission sources has been considered. One way to limit the costs of the CCS chain would be to create capture clusters in regions with several emission sources located relatively close to each other. This would be a way to facilitate the development of integrated transportation networks. The geographical distribution of point sources, the occurrence of potential capture clusters and their location in relation to suitable storage sites have been assessed through geospatial analysis in ArcMap.

The Chalmers industry database

To analyse the possibilities and limitations imposed by the present energy infrastructure a database including facility level data on key processes and plant components related to energy use and CO_2 emissions has been established. The Chalmers energy infrastructure database has been designed to cover both the supply side and the demand side of the European energy systems [8]. The database is divided into a set of sub-databases: the Chalmers power plant database (Chalmers PP db), the Chalmers fuel database (Chalmers FU db), the Chalmers CO_2 storage database (Chalmers CS db) and the Chalmers member states database (Chalmers MS db). The databases are being continuously updated and the scope is gradually widened. As part of the study presented in this paper the database has been updated with facility level data on ~4000 industrial installations included in the EU ETS. This new sub-database, the Chalmers industry database (Chalmers IN db), includes the following features:

- Comprises EU27
- Cover industrial installations in seven industry subsectors including; mineral oil refineries, coke ovens, metal ore roasting or sintering installations, installations for the production of pig iron or steel including continuous casting, installations for the production of cement clinker or lime, installations for the manufacture of glass including glass fibre, installations for the manufacture of ceramic products, industrial plants for the production of pulp, paper or board
- Exact location of the plants; country, city, address and geographical coordinates
- Emissions and allocated emission allowances; verified CO_2 emissions and allocated emission allowances for the period 2005-2007 and allocated emission allowances for 2008-2012
- Sub-sector process classification; Installations are classified depending on type of production process, e.g. Integrated steel plants (Blast Furnaces) and Minimills (Electrical Arc Furnaces)

The primary data source has been the Community Independent Transaction Log (CITL) [9]. Other information sources include the European Pollutant Emission Register [10], the IEA GHG CO_2 Emissions database (for more details see [11]) and the Plantfacts database (described in [12]).

OPPORTUNITIES FOR CO_2 CAPTURE IN EUROPEAN INDUSTRY SECTORS

Investments in CO_2 capture technologies involve high capital costs. For CO_2 capture to be economically and technologically realistic the particular CO_2 source need to emit significant quantities of CO_2. Capture is thus likely to be applicable only for large stationary emission sources. There are a number of industrial activities that generate flue gas streams with very high concentrations of CO_2 (e.g. natural gas processing installations and ammonia and hydrogen production plants). These high concentration sources (CO_2 concentration in gas stream typically close to 100%) have been pointed out as possible early prospects for the implementation of CCS [6]. Their share of the total emissions from large stationary sources are however, low. Fossil fuelled power plants, particularly coal fired power plants, are generally thought to be most suitable for a large-scale deployment of CO_2 capture. The power sector is also where assessments of different routes for CO_2 capture have reached the furthest. A number of pilot scale demonstration projects have been initiated and several more are being planned [13]. In addition to the power sector some energy intensive manufacturing industries have been pointed out as suitable for CO_2 capture. Manufacturing of primary materials such as chemicals, petrochemical, iron and steel, cement, paper and aluminium require significant inputs of electricity, heat and steam. Fossil fuels remain the most important source of energy. Many industries have managed to lower their energy use and CO_2 emissions considerably through increased energy efficiency and through alterations in production processes and in fuel and feedstock mixes. But still, manufacturing industries account for roughly 10 % of the total CO_2 emissions in the EU. Many of these industrial sectors are now included in the EU ETS. The power and heat sector dominates the trading scheme both in terms of number of installation (>7000) and actual emissions (72% of the overall emissions covered by the EU ETS). Mineral oil refining, iron and steel manufacturing and cement and lime production together account for more than 22 % of the emissions [14]. A relatively small number (~800) of large emitters (> 0.5 Mt CO2/year) in these four sectors are collectively responsible for more than 80 % of all EU ETS emissions (~30% of EU's total GHG emissions). Figure 1 provides an overview of the distribution of CO_2 emissions between the different industry sectors in EU27.

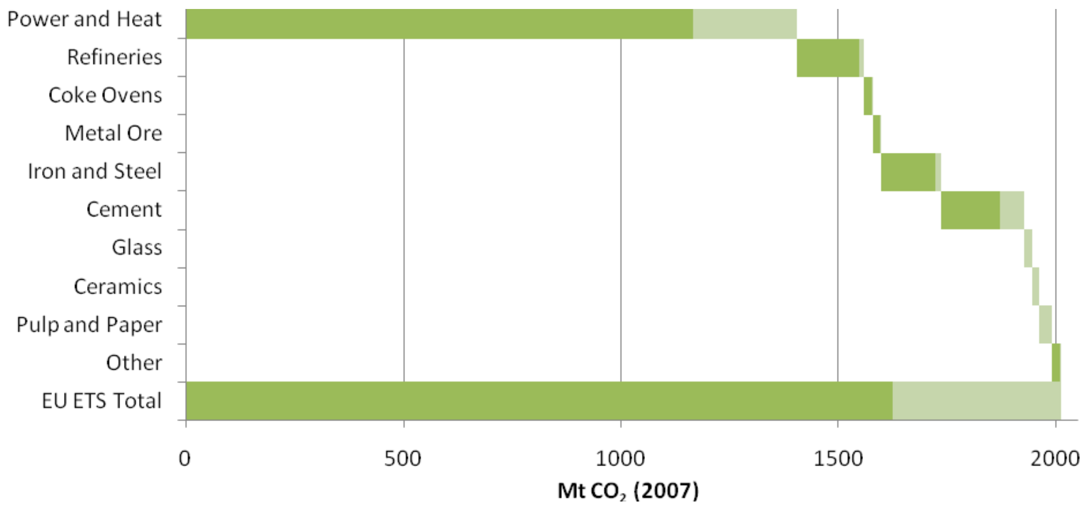

Figure 1. Sectoral breakdown of the EU ETS. Large emission sources (>0.5 Mt CO_2/year) share of sectors total emissions, dark blue, and smaller emissions sources (<0.5 Mt CO_2/year), light blue. A relatively small number of large emitters dominate the overall emissions of the trading scheme [9].

In theory it would be possible to apply CO_2 capture at all of these large point sources. In practice, however, opportunities for capture vary across sectors and between individual plants. Important for the prospects for CCS for a given point source are:

- The possibility to limit the costs associated with CO_2 capture. The cost of CO_2 capture depends primarily on the properties of their flue gas streams and the flue gas flow. CO_2 typically represent only a small portion of the flue gas.
- Location in relation to other large CO_2 emission sources and to storage sites, i.e. to facilitate integrated transportation networks to suitable storage sites.
- The prospects of applying CO_2 capture without disrupting the core production processes.

There are several methods to separate and capture CO_2 in industrial processes. Capture technologies are often divided into three main categories:

- Pre-combustion processes, where carbon is separated from the fuel before combustion.
- Post-combustion processes, where CO_2 is removed from the flue gas.

- Oxyfuel combustion, where fuel is combusted in oxygen (mixed with recirculated flue gas) instead of air creating a more or less pure CO_2 stream in the off gases.

In principle most of these technologies are applicable to the industrial processes in focus of this study. Post combustion capture through chemical absorption could be applied to almost all industrial processes [15]. Process specific capture technologies could, however, provide more cost effective options. A summary of the assumptions made on possible capture options in the three sectors assessed here are presented in Table 1. In the following sections the challenges associated with CO_2 capture in each sector will be described more thoroughly.

Table 1. Summary of the capture options considered in this study

Source type	Targeted flue gas stream	CO_2 concentration in gas stream[d] (% by gas volume)	Capture technology	Cost per tonne of CO_2 captured (€/t)	Average recovery rate (% of plants total CO_2 emission)
Mineral oil refineries[a]	Furnaces and boilers	3-13	Oxyfuel combustion	~30	65
	CHP Plant + Catalytic cracker		Post combustion capture	~45	80
Integrated steel plants[b]	Blast furnace	20	Top Gas Furnace Recycling	~20	70
Cement plants[c]	Precalciner	14-33	Oxy combustion	~34	50
			Post combustion capture	~60	80

[a] Estimations based on [6,16,17].
[b] Estimations based on [6].
[c] Estimations based on [18]
[d] CO_2 concentrations in dominating flue gas stream in conventional production processes.

Refinery sector

Mineral oil refining involves several production steps, crude oil is purified, separated, transformed into a wide array of petroleum products. A modern refinery typically consists of an integrated network of separate processing units. Most flue gas emissions result from the generation of heat and electricity. The furnaces and boilers that feed the different sub processes are fuelled by a mix of petroleum coke, still gas (by products in the refining process), petroleum fuels and natural gas. Energy use and CO_2 emissions vary depending on what type of crude oil being processed and on the mix and quality of the final products.

The total CO_2 emissions from a refinery are thus a sum of several emission sources of varying size. The flue gases from these different sources have different properties and are differently

well suited for CO_2 capture. As indicated in Table 2 process heaters and steam boilers are responsible for the major share of the CO_2 emitted from a typical refinery. There are two main options to target the CO_2 emissions from furnaces and boilers; either CO_2 is separated from the flue gases through chemical absorption (post combustion capture) or heaters and boilers are converted to oxyfuel operation with CO_2 capture [16].
To decrease the quantity of electricity bought from external suppliers some European refineries have invested in combined heat and power (CHP) plants covering almost all of the electricity demand and a large share of the internal heat demand. If targeting the CHP flue gas and the off-gas from the catalytic cracker ~80% of the direct CO_2 emissions from the refining process could be covered [17]. It is technically possible to expand the scope of the capture to include other sub-processes, increasing the overall CO_2 abatement potential, but this would also increase the cost.

The iron and steel sector

The iron and steel industry is highly energy intensive and the production of crude steel is associated with significant CO_2 emissions. The sector has a complex industrial structure, but two production routes dominate the global production [6]:

- Integrated steel plants; the most common production route. Involves a series of interconnected production units (coke ovens, sinter plants, palletising plant, blast furnaces/basic oxygen furnaces, continuous casting units). Processing iron ore and scrap to crude steel. Coke, derived from coal, function both as fuel and reducing agent.

- Mini-mills; where scrap, direct reduced iron and cast iron is processed in electrical arc furnaces to produce crude steel.

Apart from these two dominating production routes there are several newer iron making processes compatible with CO_2 capture.
Nearly 60% of the steel produced in EU27 is produced through the integrated route (coke oven, blast furnace, basic oxygen furnace). The rest is produced in electric arc furnaces and a very small fraction (~0.3%) in open hearth-furnaces [19].
The opportunities for CO_2 capture in the steel production chain vary both depending on process and on feedstock. In the integrated steel production route there are three main process gas flows, coke oven gas (COG), blast furnace gas (BF gas) and basic oxygen furnace gas (BOF gas) [20]. These gas flows typically serve as fuel feedstock throughout the entire chain of production. The largest flow of CO_2 in a conventional integrated steel mill is generated in the blast furnace (see Table 2 below).
Recovery of CO_2 from the BF gas has been recognized as a feasible option for capture in the steel industry [6]. If applying current end-pipe-technologies to existing blast furnaces ~30% of the overall CO_2 emissions from a conventional integrated steel plant could be recovered. Capture could be applied to other gas flows in the production process but costs are likely to be higher, since volumes and concentrations are lower. Efforts are being made to develop new steel making processes that could facilitate further CO_2 emission reductions. The Ultra-Low CO_2 Steelmaking (ULCOS) programme have identified a number of process technologies that combined with capture could reduce CO_2 emissions with at least 50 % compared to current best routes.
One of the most promising opportunities for CO_2 capture in the steel industry would be to replace or retrofit conventional blast furnaces with Top Gas Recycling Blast Furnaces (TGR-BF). In a TGR-BF the CO_2 is separated from the BF gas and the remaining, CO rich, gas

stream is recirculated into the furnace. The CO would then function as reducing agent lowering the demand for coke. If simultaneously replacing preheated air with pure oxygen the BF gas stream would be free of N_2 simplifying CO_2 capture. It has been estimated that 70% of the CO_2 emitted from an integrated steel plant could be recovered if TGR-BF with CO_2 capture were to be introduced [6].

The cement sector

In a cement plant calcium carbonate ($CaCO_3$) and different forms of additives are processed to form cement. The raw material feedstock typically consists of calcareous deposits, such as limestone, marl or chalk. The manufacturing involves three main production steps [21]:

- Raw material preparation: mining, grinding and homogenising of raw material.
- Clinker burning: the raw material is gradually heated and finally burned at a peak temperature around 1450^{o}C. At around 900^{o}C the calcination takes place and CO_2 is released from calcium carbonate. As the temperature rises the clinkerisation begins. Calcium oxide reacts and agglomerates with silica, alumina and ferrous oxide, forming cement clinker.
- Cement preparation: grinding and mixing of clinker and additives.

Cement production is very energy intensive. Significant amounts of electricity are used to power both the raw material preparation and the cement clinker grinding and large quantities of fuels are needed in the clinker burning process. The clinker production is the most energy intensive production step, it accounts for more than 70% of the total energy consumed [22]. There are two basic types of cement clinker production processes, wet or dry, and a number of different kiln types. Energy intensities vary depending on choice of production route and on kiln technology [21]. In Europe around 90% of the production is based on dry processes and most plants use rotary kilns [23].
Almost all of the direct CO_2 emissions from the cement production come from the clinker burning process. Roughly 60% of the CO_2 emissions originate from the calcination, the remaining CO_2 emissions are related to fuel combustion [23] In modern cement plants fuel is inserted in two stages: in the precalciner where the raw material is preheated and calcided (>90% of the calcinations takes place in the precalciner) and in the rotary kiln where the clinkerisation occurs [18,23].
Two options for CO_2 capture in the European cement industry have been considered here; post combustion capture and oxy-combustion (in precalciner) with capture [18].
Post combustion capture could be applied utilizing the same basic principles as being developed for coal fired power plants. It has been estimated that 95% of the CO_2 emissions from a cement plant could be avoided if post combustion capture is introduced. The regeneration of the CO_2 capture solvent would, however, require additional generation of steam thus increasing the overall CO_2 emissions slightly.
Oxy-combustion with CO_2 capture could be applied both in the precalciner and in the kiln but by targeting the precalciner only the impacts on the clinkerisation process could be minimized. Around 50% of the CO_2 from a cement plant could be captured using the oxy-combustion precalciner setup.

Table 2: Breakdown of CO_2 emissions from industrial production processes

	Source	Fraction of CO_2 emissions
Refineries[a]	Furnaces and boilers	65%
	Regeneration of cat. cracker catalyst	16%
	Power (55% imported)	13%
	Other sources	6%
Integrated steel plants[b]	Coking plant	5%
	Sinter plant	10%
	Blast furnace	65%
	Other sources[a)]	20%
Cement plants[c]	Pyroprocessing (in precacliner and rotary kiln)	>80%
	Other sources	<20%

[a] Based on [24]. Other emission sources include flaring, methane steam reforming, effluent processing and incineration.
[b] Estimations based on [25,26]. Other emission sources include palletising plant, continuous casting, basic oxygen furnace, rolling and finishing, oxygen plant and power plants.
[c] Estimations based on [18]. In a modern cement plant a majority of the CO_2 emissions occur in the precalciner (~60%).

RESULTS

Mapping the large point sources

In total 270 installation have been identified as large emission sources (>0.5 Mt/year). 89 refineries, 33 integrated steel plants with 74 blast furnaces in operation and 148 cement plants. Together these installations emit over 430 $MtCO_2$/year, more than 8% of EU's total GHG emissions. Consequently changes in each single plant could have significant effects on the overall GHG emissions of the European Union. The occurrence of large emission sources vary considerably between EU member states. Five countries, Germany, Spain, United Kingdom, Italy and France stand out as having both large overall emissions and many large emitters. The heavy industries share in the total GHG emissions also vary across member states. Large industry point sources typically accounts for between 8-12% of the total GHG emissions (12 countries fall into this category). In the Czech Republic, Denmark, Ireland, Poland, Slovenia large industry emission sources contribution to the total GHG emissions are smaller, in these countries their share is less than 5%. In Slovakia the contribution is much larger, three large industries are responsible for more than a quarter of the total GHG emissions. In Estonia, Latvia and Malta there are no industries with emissions exceeding 0.5

Mt CO_2/year. This situation may affect the priority given to industry CO_2 capture in the different member states.

Potential for industry CO_2 capture

If realizing the full potential of the CO_2 capture technologies considered in this study 60-75% of the emissions from large industry point sources could be avoided (see table 3.). In Route A post combustion capture technologies dominate in the refinery and cement sectors and conventional blast furnaces are replaced with Top gas recycling blast furnaces in integrated steel plants. In Route B refinery furnaces and boilers are converted to oxyfuel operation, oxy combustion is applied in cement plant precalciners and Top gas recycling blast furnaces with CO_2 capture dominate the steel sector. The mitigation potential is significantly larger in Route A where approximately 330 Mt CO_2 would be captured annually, compared to roughly 270 Mt CO_2 per year in Route B. The cost associated with CO_2 capture would, however, most likely be higher in Route A than in Route B. These estimations should be seen as illustrations of the potential role of CO_2 capture in large industry point sources, i.e. a first estimate.

Table 3. Potential for CO_2 capture at large industrial emission sources in EU.

Industry sector	CO_2 emission captured (Mt CO_2/year)	
	Route A	Route B
Mineral oil refineries	116	94
Integrated steel plants	106	106
Cement plants	107	67
Total	329	267

Distribution of emission sources

As illustrated in Figure 2 the large industry point sources are unevenly distributed over the European continent. By aggregating industry CO_2 emissions on regional level (the Nomenclature of territorial units for statistics, NUTS regions, has been used to represent the regions of the EU) 23 regions with more than one large industrial point source and where emissions from large industrial point sources exceed 5Mt CO_2/year, have been identified (highlighted in green and dark green). The aggregated emission from large industry point sources in these regions amounts to approximately 200 Mt CO_2/year. Furthermore, based on the relative distance of the individual point sources and the emission density of these sources 22 regions have been singled out as possible capture clusters (dashed contours).

To limit the costs of CO_2 capture, transport and storage, clusters need to be matched with suitable storage sites. Potential storage sites are unevenly distributed across EU. Most member states have identified geological structures that could be used for CO_2 storage but the accuracy of the estimated storage potential varies. The potential for geological storage of CO_2 in EU has been assessed in the GESTCO and GeoCapacity projects [28]. The GESTCO project covered 7 EU member states and Norway. In the following GeoCapacity project the geographical coverage has been expanded to include totally 25 European countries (including 20 EU member states and 5 neighboring countries). Potential storage sites include saline aquifers, hydrocarbon fields and unminable coal seams (however, coal seams have a limited storage potential and storage can be technologically challenging). The saline aquifers are thought to have the largest storage potential but more detailed analysis is needed to determine site specific capacities. Even though the storage potential is lower, depleted hydrocarbon fields have the advantage of being relatively well explored, the geology has often been carefully examined and the fields have proven capable of retaining fluids and gases for very long time periods. The best matches between industry emission clusters and potential storage sites are found in regions close to the North Sea; in the eastern part of the United Kingdom, northern France, Belgium, Netherlands and in north-western Germany.

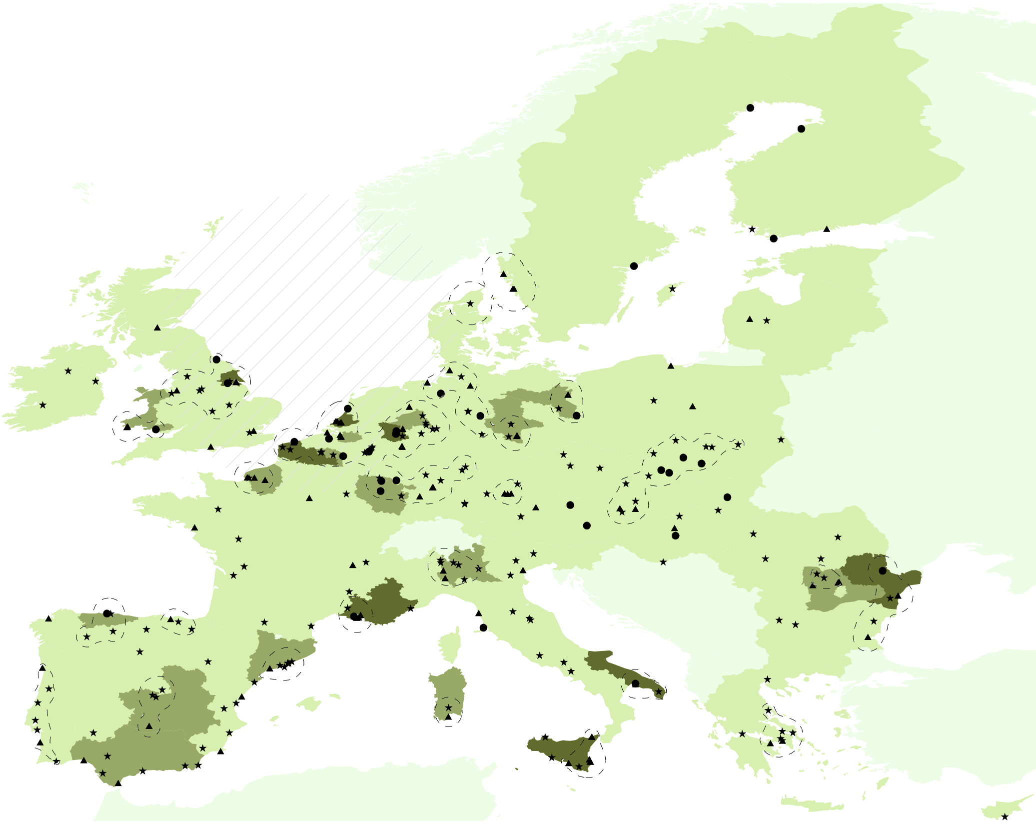

Figure 2: Geographical distribution of large point sources (>0.5 Mt CO_2/year) in the European industry sectors. Triangles denote refineries, circles integrated steel plants and stars cement plants. Regions where emissions from large industry point sources exceed 5Mt CO_2 annually are highlighted in green and dark green. Areas with dashed contours represent regions with high densities of large point sources (possible capture clusters).The underlying map was compiled using data from [29].

DISCUSSION

There are several examples of studies in the literature exploring the potential for CCS and matching CO_2 sources and sinks on national, regional and global level (e.g. [20,30,31,32,33]). It has been shown that through application of CCS technologies CO_2 emissions from large stationary sources could be lowered considerably. Most studies cover major emission sources in both power and heat sector and industry. Here, emphasis has been placed solely on CO_2 emission sources in heavy industries. This assessment shows that by adapting a relatively small number of large emission sources in the European industry sectors for CO_2 capture a significant reduction in total EU CO_2 emissions could be achieved. Yet, many challenges need to be addressed before CCS can be seen as a viable option for CO_2 emission mitigation in industry. Issues like costs, public acceptance, legal aspects of CO_2 transport and storage and the choices made on policy level will be crucial both for the scale and rate of the diffusion of CCS.

All of the industrial sectors assessed here involve complex production processes. If CO_2 capture is going to be applicable to industry, capture technologies that do not interfere with the core processes need to be developed. Post-combustion capture could generally be applied without negative impacts on the production processes, but the associated costs are generally high. More process specific capture technologies, with lower costs, are being explored (e.g. oxy-fuel combustion in refinery furnaces and boiler, TGR-BF in integrated steel plants and oxy-combustion processes for the cement industry). But still, deployment on commercial scale seems to be at least one decade away. Much development work remains both when it comes to the economical and process related aspects of CO_2 capture technologies. And even with these pieces in place retrofitting of the existing plant stock and investments in new capture ready plants will take time.

The estimations of the potential for industry CCS presented in this paper are based on a rather simplistic approach and they are only to serve as illustrations of the potential role of CO_2 capture in the heavy industry sectors. The present industrial structure has been used as a reference point for the estimates. The capital age of the existing industry plant stock and its implications for the deployment rate of CO_2 capture has not been considered. CO_2 emissions from industry sectors are assumed to remain relatively constant. Increases in CO_2 emission from industry due to increased production are assumed to be outweighed by other CO_2 mitigation measures than CCS. Further, it should be noted that the assumptions made here about CO_2 capture costs are rather speculative. The industry CO_2 capture projects currently being set up will provide valuable insights on both the technical and economical aspects of industry capture. Most likely, there will be significant development in both policy setting (e.g the future development of the EU ETS and other policy instruments related to climate change mitigation and energy use) and in technology the coming decades which would alter the prerequisites for the deployment of CCS technologies. Examples of planned industry demonstration projects include; a post-combustion capture installation connected to a new refinery CHP plant in Mongstad (Norway) [17] and the introduction of two TGR-BF's, one mid-sized and one full scale, at the integrated steel plants in Eisenhüttenstadt (Germany) and in Florange (France) [34].

As stressed above, the geographical distribution of major CO_2 point sources and their location in relation to suitable storage will have implications for the potential roll-out of a CCS infrastructure. A transportation infrastructure for large quantities of CO_2 will require an extensive network of pipelines. CO_2 transportation costs could be lowered in regions with many large point sources if the different utilities could share the efforts of constructing and operating transport networks. The synergy effects could become even greater if efforts where coordinated across sectors (i.e. between actors in the power and heat sector and in the various industry sectors) and member states.

CONCLUSION

A first estimate of the potential for CO_2 capture in European industry sectors show that considerable emission reductions could be achieved if targeting large point sources in some of the most emission intensive sectors (i.e. mineral oil refineries, integrated steel plants and cement plants). The analysis also shows that opportunities exist in several regions to lower the total costs of the CCS value chain if efforts to develop CO_2 transportation networks where to be coordinated. The best matches between sources and sinks are currently found in regions bordering the North Sea

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