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#1/2012

Filip's column

This newsletter gives examples of ongoing analysis of different sectors with respect to possibilities and challenges in reducing CO_2 emissions. Examples are given from industry, the building and heating sector, from work on how to transform the transmission network ...

cont'd on page 2

Prof. Filip Johnsson
Project manager of
the Pathway project

Pathways to Sustainable European Energy Systems is a project within THE AGS The Alliance for Global Sustainability

Mission impossible?
- prospects for radical reductions of CO_2 emissions from large stationary emission sources

Our analysis confirms that EUs short-term goal for GHG emission reduction in the sectors covered by the EU emission trading system, that is a 21% reduction by 2020 compared to 2005, is attainable with abatement measures already available. However, despite optimistic assumptions regarding the potential for, and implementation of, available abatement strategies within current production processes, our analysis shows that these strategies will not be sufficient for the power and industry sector to comply with EUs more stringent reduction ambitions in the medium- and long term.

This study assesses the prospects for CO_2 emission abatement in the four major CO_2 emitting activities in the EU stationary sector by applying scenario analysis. The analysis covers power and heat generation, petroleum refining, iron and steel, and cement manufacturing, in EU27 and Norway. An important element of the analysis has been to consider how factors such as age structure, fuel mix, activity levels, demand structure and the types of production processes applied contribute to facilitating or hindering the shift towards less emission-intensive production.

read more on page 3

Modelling energy demand for 2050 in the EU building stock

A modelling work which examines three different scenarios for efficiency of energy end uses for the EU 27 building stock to 2050 is carried out. Summarising results it can be said that EU goals on energy savings and CO_2 emissions can be met in both the so-called Market and Policy scenario by focusing on minimum efficiency construction standards for new built dwellings, end-use efficiency applied at the useful energy level, conversion efficiency standards for final energy to useful energy and fuel switching. These measures can contribute to meeting EU goals on renewables and direct CO_2 emissions if combined with efforts on the supply side. When compared to other studies, which are usually more detailed, similar results have been found.

read more on page 5

European solar market

The second phase of the Pathways project include a more detailed mapping of the growing solar power industry, with focus on CSP (concentrated solar power) and PV (photovoltaics). Since cost is definitely one of the most important drivers of future development, and solar energy costs are strongly linked to global expansion, this cannot be done without a global outlook.

read more on page 6

Filip's column

This newsletter gives examples of ongoing analysis of different sectors with respect to possibilities and challenges in reducing CO_2 emissions. Examples are given from industry, the building and heating sector, from work on how to transform the transmission network and deployment of solar technologies as well as from work with assessing transport and storage infrastructure for CCS. These are all important sectors and technologies necessary to be developed if to be able to reach required emission reductions up to the year 2050. Until then, it is not a choice of technologies and measures but rather the need for all available options, which is one of the key messages from the Pathways project.

I am very happy that the co-operation with DG-JRC is working very well. This co-operation is very stimulating and we hope to be able to intensify our common work in the near future. We have recently submitted some joint abstract to the next International Conference on Greenhouse Gas Control Technologies, to be held in Kyoto next autumn. A key issue in the co-operation is to make an analysis which shows the requirements and challenges of establishing an integrated European infrastructure for large scale deployment of the CCS technology. Although CCS is an important mitigation option (the alternative is to leave the fossil fuels in the ground), there is a challenge in establishing efficient systems for transport and storage, from the technical, public acceptance and legal points of view. This newsletter exemplifies work on the transport infrastructure work.

The building sector is an important sector which offers significant possibilities for reducing the energy use and thereby the associated CO_2 emissions. Yet, success in implementing these measures depends on numerous decisions required to be taken by many actors in the society, not at least by house owners both in private households and in housing companies. As basis for designing policy measures to realise efficiency potentials, it is important to analyse the effect of different measures on the existing building stock since, in Europe, most buildings are, so to speak, already built. In doing this there is a need to apply both a bottom-up analysis of energy efficiency measures, which typically will identify the cost-efficient measures but neglecting other "transaction-cost" related barriers, and a top down analysis (econometric analysis) which gives an indication which measures can actually be expected to be implemented under various energy-price scenarios. This newsletter gives example of both types of analysis.

I am also very happy that the fruitful co-operation with the project North European Power Perspectives. Several working meetings have been held during spring which makes us confident for an efficient joint work for the remaining part of the year.

Prof. Filip Johnsson
Project manager of the Pathway project

New PhD thesis

Johanna Jönsson defended her PhD thesis at Chalmers on January 20, 2012. The title of her thesis is "Analysing different technology pathways for the pulp and paper industry in a European energy systems perspective". The thesis shows insights and results regarding general integration opportunities in different types of existing mills and assesses economic performance and global CO_2 emissions assuming different future developments of the European energy market. The research has also addressed factors that influence the potential for industry-wide implementation of different pathways.

Past events

Energiutblick 2012

Jan Kjärstad held a presentation at the conference "Energiutblick 2012" (Nordic Energy Outlook) hosted by the Swedish Energy Agency on March, 15. He discussed demand and supply of conventional and non-conventional fossil fuels (oil, natural gas and coal). His presentation also included the current state, trends, and what implications the large fossil fuel resources may have on the work to mitigate climate change.

The second Chalmers Energy Conference, held March 28-29 2012

Chalmers Energy Conference is a forum for researchers and stakeholders in industry as well as governmental organizations involved in shaping tomorrow's energy system. The overall theme of the conference 2012 was "Electricity for tomorrow".

The conference was a two-day event with plenary talks as well as parallel sessions on the following areas:

- **Renewable power generation and grid integration** - wind, solar and ocean energy
- **Electrification of road transport** - vehicles and powertrains, electromobility, energy storage
- **Next generation nuclear power**
- **Fusion** - technologies and challenges
- **Smart grid**
- **Shaping the future** - policy instruments, business models

Mission impossible?

- prospects for radical reductions of CO_2 emissions from large stationary emission sources in the EU

Our analysis confirms that EUs short-term goal for GHG emission reduction in the sectors covered by the EU emission trading system, that is a 21% reduction by 2020 compared to 2005, is attainable with abatement measures already available. However, despite optimistic assumptions regarding the potential for, and implementation of, available abatement strategies within current production processes, our analysis shows that these strategies will not be sufficient for the power and industry sector to comply with EUs more stringent reduction ambitions in the medium- and long term. This suggest that to realize the goals of further, extensive, emission reductions, efforts to develop, and deploy, low carbon production processes must be intensified.

Explore the limits for CO_2 abatement

This study assesses the prospects for CO_2 emission abatement in the four major CO_2 emitting activities in the EU stationary sector by applying scenario analysis. The analysis covers power and heat generation, petroleum refining, iron and steel, and cement manufacturing, in EU27 and Norway. An important element of the analysis has been to consider how factors such as age structure, fuel mix, activity levels, demand structure and the types of production processes applied contribute to facilitating or hindering the shift towards less emission-intensive production. While some abatement strategies are applicable in all branches, i.e., fuel switching and energy efficiency improvements, the specific scenario generation approach has been adjusted to reflect the conditions in respective branch. The general methodological approach involves:

1) A thorough description and characterization of the current industry structure
2) Assessment of key factors and trends relevant to future CO_2 emissions in each branch
3) Scenario analysis; exploring the prospects for short- and long-term CO_2 emission reductions with the emphasis on the role of existing production processes and abatement options.
4) Impact analysis; including a discussion of the relevance and possible implications of the scenario outputs.

The overall aim has been to explore the limits for CO_2 emission abatement within currently dominating production processes.

Emission reduction mainly in the power sector

In total, five emission scenarios have been generated, two scenarios exploring future CO_2 emissions in the power and heat sector, and, one scenario for each of the other industry sectors studied. An important assumption in the scenario generation is that for the power sector emerging low carbon technologies (i.e., CCS and RES) are included as available options when the existing generation technologies are retired. In contrast, in the iron and steel and cement industries, retired production capacity is replaced with new production capacity in line with the dominating technological designs albeit with improved performances in terms energy efficiency and CO_2 intensity (i.e., technological options that deviate from the existing processes have not been considered). The analysis indicate that in the refining industry possible new investments are assumed to be directed towards desulfurization units or advanced conversion units, no new investments in primary refining capacity takes place. In the short-term, overall CO_2 emissions are reduced by 19%, from 1715 $MtCO_2$/year in 2010 to 1392 $MtCO_2$/year in 2020. A major share of the emission reduction up to 2020 occurs in the power sector and is achieved through replacing retired fossil capacities with new efficient gas fired power plants and an increase in the renewable capacity (i.e. biomass and wind).

Industry would not comply with reduction targets

The estimated aggregate CO_2 emission reduction potential, over the period 2010-2050, amounts to approximately 1180 $MtCO_2$ per year, corresponding to a 70% reduction. The result of the scenario analysis estimates the potential of annual CO_2 emission reductions in 2050 to amount to approximately 1180 $MtCO_2$ for the studied sectors. This corresponds to a 70% reduction compared to year 2010. Assuming a massive deployment of emerging low-carbon technologies (i.e CCS, onshore & off-shore wind and solar power), the estimated CO_2 emissions from the power sector would be in line with EU's roadmap for 2050 (a 95% emission reduction in the power sector). However, despite the extensive measures assumed to be implemented, the results indicate that the industry sectors would fail to comply with EU's CO_2 reduction ambitions (an 85% reduction in these sectors by 2050) which suggests that currently available abatement strategies will not be sufficient to meet these targets. Figure 1 shows the estimated abatement potential in the industry sector relative an aggregate business as usual scenario (i.e. frozen technology and fuel mix).

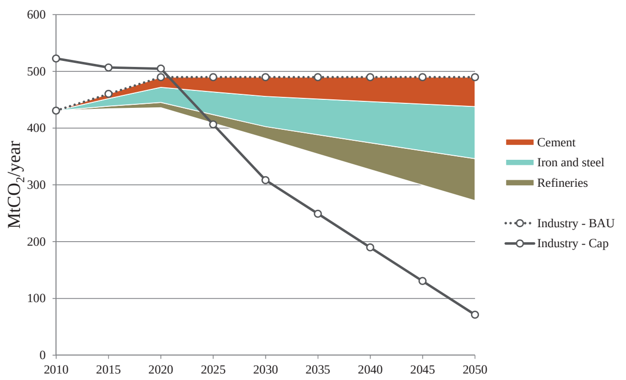

Figure 1. The estimated abatement potential in the industry sector (relative an aggregate business as usual scenario) as well as the emission cap in the industry sector, corresponding to an 85% reduction by 2050.

For further information:
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Modelling energy demand for space and water heating in the EU residential sector

Econometric modeling of energy use for space and water heating for four EU countries has been performed. The results show that despite the counteracting influence of increasing affluence and larger floor areas, higher energy prices can lead to reductions in total energy use for space and water heating in all the countries examined.

Econometrics used to model energy use

The case of the total stock of dwellings (existing and new built) between 2005 and 2050 is examined individually for France, Italy, UK and Sweden. Energy demand for space heating was decomposed as follows:

E=population *x* floor area/capita *x* energy use/floor area

Econometrics is used to model floor area per capita and energy use per floor area (Unit Consumption). Three different scenarios of future energy prices (corresponding to annual energy price changes of 0%, 2%, and 3%) are used to estimate how the factor Unit Consumption will develop to 2050. One scenario of future income (an annual increase of 1.93%) is used to estimate the development of Floor Area per capita up to 2050. The results for Unit Consumption and Floor Area per capita are combined with future estimations of population to calculate total energy demand in dwellings to 2050.

Price increase explains half of the reduction

The modelling reveals an increase in floor area demand in each country to 2050. On the other hand, Unit Consumption decreases from about 130 - 180 to 65 - 120 kWh/m^2 depending on the price scenario. In the high price scenario, these figures represent approximate average annual demand decreases of 1.5% (See Figure 1).

The level of Unit Consumption calculated in this work for 2050 is quite different from the passive house standard (30 kWh/m^2). Annual price increases that would be necessary to reduce Unit Consumption below 30 kWh/m^2, are 10 - 20 %. Given that the 3% annual increase in energy prices is historically high for a period of 45 years, this suggests that additional policy measures and regulations will be needed to achieve such targets. While the energy price has a significant impact on energy demand in the scenarios for all the countries, it is noteworthy that even the scenarios with zero increases in energy prices show considerable reductions in Unit Consumption. The reason for this is the impact of the time trend coefficient, as included in the regressions for Unit Consumption. The time trend coefficient captures gradual changes in Unit Consumption over time that cannot be attributed to changes in prices or climate (e.g., technology progress and legislation). Although about half of the total reduction in Unit Consumption is attributed to the time parameter does not mean that this reduction occurs “by itself” as time passes. Non-price policy measures have certainly affected the gradual energy efficiency improvements seen in the past and they are also indirectly incorporated into the time trends of the scenarios (see Figure 1).

France and Sweden can meet goal of 1 % per annum decrease in demand

Figure 1 presents model results and compares the change in overall energy demand for the four countries and three price change scenarios studied. As can be seen the demand falls in all scenarios, except in the case of the 0 % price change scenario for Italy and UK. A hypothetical political goal of 1 % savings per year from 2005 to 2050 would be met for France and Sweden but not for Italy and UK.

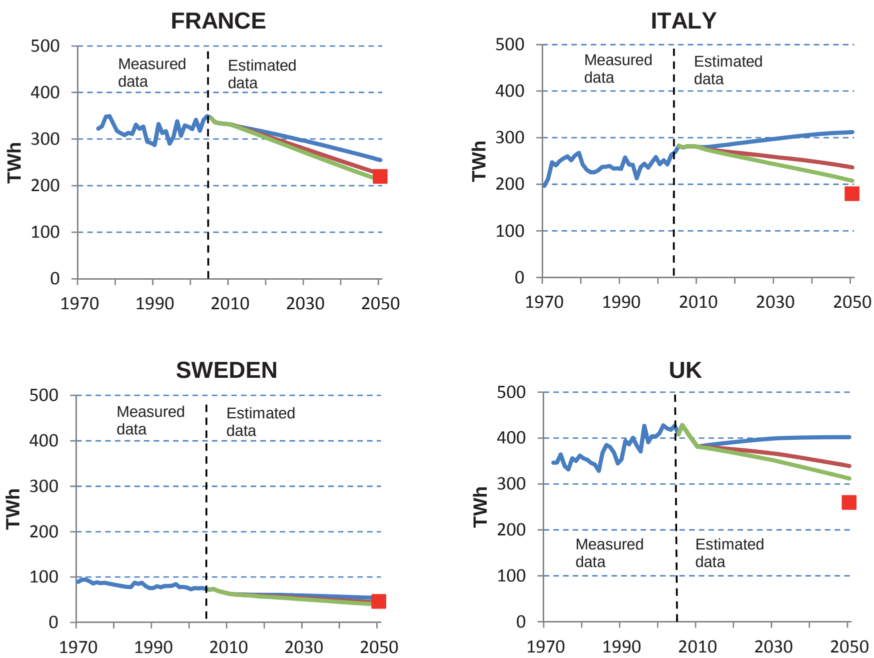

Figure 1 : Scenarios for total energy demand for space and water heating for France, Italy, Sweden, and the UK from 2006 to 2050. The results for each country differ based on three annual price change scenarios (0%, 2%, and 3%). The point on the graph reflecting a hypothetical 1% per year reduction in demand between 2006 and 2050 is indicated by the red box.

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Modelling energy demand for 2050 in the EU building stock
- a bottom-up analysis

A modelling work which examines three different scenarios for efficiency of energy end uses for the EU 27 building stock to 2050 is carried out. Summarising results it can be said that EU goals on energy savings and CO_2 emissions can be met in both the Market and Policy scenario by focusing on minimum efficiency construction standards for new built dwellings, end-use efficiency applied at the useful energy level, conversion efficiency standards for final energy to useful energy and fuel switching. These measures can contribute to meeting EU goals on renewables and direct CO_2 emissions if combined with efforts on the supply side.

Measures outside building envelope are important

Figure 1 shows the impact that the individual contributions of the four categories of efficiency measures applied in this work have on final energy demand in the residential sector in the Market scenario. For 2050 the four categories contribute the following proportions of total savings: Minimum efficiency construction standards for new built dwellings (21%), End-use efficiency applied at the useful energy level (40%), Conversion efficiency for final energy to useful energy (25%), and Fuel switching (14%). The contribution of new building standards obviously takes a long time to have an impact considering the low annual construction rate. In addition the importance of measures not concerning the building envelope, i.e., conversion efficiencies and fuel switching is emphasised as they contribute nearly 40 % of savings. Improvements in conversion efficiency on its own makes a significant contribution to savings not to mention the useful heat energy generated in heat pumps not shown in the graph. The graph would suggest that both end-use efficiency at the useful energy level and conversion efficiency should be the priority target of measures. Similar results are found in the Policy scenario, except that in this scenario there are greater savings from end-use efficiency.

The results for 2020 for the Market and Policy scenarios show reductions in CO_2 emissions greater than 10% on 2005 levels in both scenarios. The results for 2050 show a reduction in emissions of over 90% compared to year 1990. Thus, the EU targets for 2020 and aspirations for 2050 would clearly be met. Although the amount of renewables in the energy carrier mix in buildings is not much over 50 % in 2050, direct CO_2 emissions from buildings are nearly eliminated. This shows that either the Market and the Policy scenario are adequate pathways to EU CO_2 reduction goals although they are heavily dependent on complimentary action on the supply side.

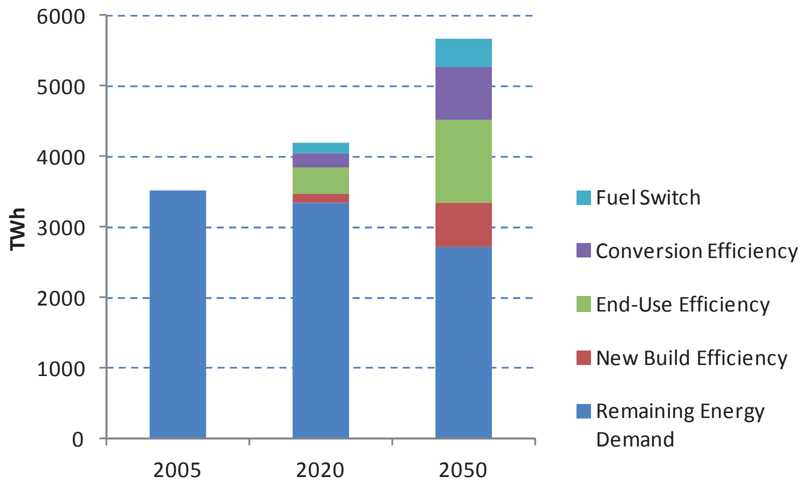

Figure 1 : Baseline and Market scenarios in 2020 and 2050 for the EU 27 showing contribution of individual measure categories to energy use reduction.

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New licentiate thesis:

Modelling energy demand in the buildings sector

Eoin Ó Broin

In the on-going effort within the EU to tackle greenhouse gas emissions and secure future energy supplies, the buildings sector is often referred to as offering a large potential for energy savings. The aim of this thesis is to produce scenarios that highlight the parameters that affect the energy demands and thus potentials for savings of the building sector. Top-down and bottom-up approaches to modelling energy demand in EU buildings are applied in this thesis.

The thesis is available from eoin.obroin@chalmers.se, or by phone: +46 31 772 14 50

European solar markets
- with a global outlook

The second phase of the Pathways project include a more detailed mapping of the growing solar power industry, with focus on CSP (concentrated solar power) and PV (photovoltaics). Since cost is definitely one of the most important drivers of future development, and solar energy costs are strongly linked to global expansion, this cannot be done without a global outlook.

Market expansion

The European solar markets are growing at paces that have to be viewed as unprecedented. In one year, 2010, the installed capacity of PV increased by more than 120%, an addition of 13 GWp. Within the Pathways project a detailed mapping of the European and global solar power capacity has been performed. The Chalmers power plant database now includes all larger (>10 MW) CSP plants and most PV installations >5 MWp.

Germany has for many years been the leading market for solar energy in Europe and the world. The cumulative capacity was 17.4 GW at end 2010, up 7.4 GW from 2009. Spain has shown a very strong growth in solar power – in particular PV – after attractive feed-in tariffs were put in place by the 2007 Royal decree. The PV tariffs were restricted, leading to relatively modest PV capacity additions in 2010, while CSP tariff levels were unchanged and there was continued increase by 450 MW in 2010 (and at least another 300-400 MW in 2011). The strongest rising market in solar power appears to be Italy. In 2010 it was number two in Europe in new capacity additions (see Table 1). There are indications that for 2011 Italy has surpassed Germany on new installed power by tripling or even quadrupling the rate of installation from last year.

The growth in solar power is to a very large degree governed by the scale and levels of support mechanisms. In Spain, the main limit to expansion has clearly been set by how many new projects that have been provided with feed-in tariffs. There are however some other factors that play in as well. One of the major obstacles reported from the USA is difficulties in obtaining transmission right. There have also been delays in projects (Ivanpah solar park) due to environmental protection issues.

Table 1 Top solar countries in Europe [Eurobserv'er 2011 and Chalmers Power Plant Database 2012].

Country	2009 capacity (MW_p)		2010 capacity (MW_p)	
	PV	CSP	PV	CSP
Germany	9 960	<10	17 400	<10
Spain	3 440	410	3 810	860
Italy	1 160	<10	3 480	<10
Czech rep.	463	0	1 950	0

Cost curve analysis and support mechanisms

The costs of solar power have gone down considerably since the first PV panels in the 1950s-60s (about a hundred times) and since the first CSP power plants in the 1980s. Historical cost developments of PV as well as CSP have shown typical learning curve patterns with estimated learning rates of 20% for PV and 14% for CSP, indicating the cost reduction per doubling of cumulative installed capacity. The CSP technology has historically had a cost advantage over PV, but the reduction in PV has been strong and costs are now comparable for the two technologies. PV is, thus, a strong competitor to CSP in markets where the potentially better dispatchability that CSP offers has low value. In the future, PV will likely benefit further from a higher learning rate and an established industry. However, CSP has the benefit of being at an earlier stage of its learning curve and can thus accomplish capacity doubling (and hence cost decreases) with smaller investments.

Solar-fossil hybrids as pathways

With increasingly hard cost competition from PV, solar thermal power technologies, such as CSP, need to develop unique advantages in order to win market shares. One interesting option is to hybridize with other thermal power, such as fossil fuel plants. This type of integration gives solar power at low costs and could provide a pathway to faster development of solar technologies, in particular in markets with low economic support levels.

ISCC (Integrated Solar Combined Cycle) hybrids have been a focus of a study carried out within the Pathways project, in a cooperation between Chalmers and KTH. The study has evaluated the potential for solar hybrids based on available existing combined cycle natural gas plants (with Spanish conditions as a test case), and performed techno-economic optimization of ISCC plant layout. The optimization was performed with genetic algorithm routines coupled to detailed thermodynamic models in the commercial heat balance program Ebsilon. Genetic algorithms work by principles of trial and error, varying a set of input parameters for the thermal model randomly within set bounds, then narrowing the bounds by "learning" which parameter value combinations that give the best results (best trade-off between two objectives). It is suggested that costs of solar power (i.e. the extra output of power from the plant that can be attributed to the solar field) are significantly below that of stand-alone solar plants. A deepened study of the case is to be finished by spring 2012.

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Role of electricity transmission and interconnectors

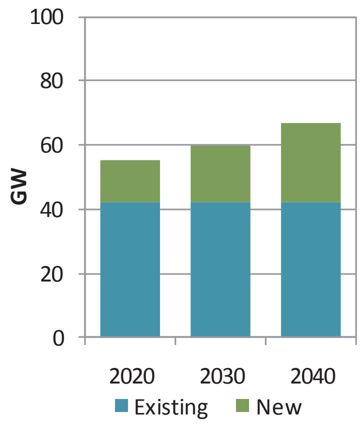
New interconnectors will play an important role in the ongoing processes of integrating the European electricity markets and handling the increase in renewable and intermittent sources of electricity production, such as wind power. The strengthening of the European electricity infrastructure has been identified as an area of priority in a recent communication by the European Commission. Within the Pathways project, an integrated modeling approach for addressing the complexity of generation and grid planning issues is applied, and the need for new interconnector investments across the EU has been estimated to almost 30 GW by 2030.

Substantial need for new interconnectors in Europe

The research conducted in the Pathways project using the ELIN model indicates that it is profitable for the European electricity system to significantly expand the interconnector capacity between the Member States, from the existing 42 GW (existing interconnector capacities are taken from ENTSO-E public online NTC values) to almost 60 GW in the Policy scenario[1)] or to 55 GW in the Market scenario[2)] by 2020. Figure 1 presents the results of the Policy scenario. It should be noted that new interconnector capacities identified are based on the economic and environmental considerations of the projects. However, such investments require substantial lead times, which are so far not fully taken into account in the modelling analyses. In further research, the technical feasibility of new interconnections capacity in terms of locations of grid connection points, network loading as well as overall system stability will be subject of detailed investigations.

An approach to evaluate the profitability of new interconnectors

The ELIN model is used to evaluate the power transmission capacity (trade) required between EU member countries for the coming 40 years. In this analysis, investments in new transmission capacity occur if they are found to be profitable. The evaluation method is similar to the ”value-based” planning method which is available in the literature. It should be noted that the methods for transmission charges differs between countries in Europe. In this study it has been assumed one common method based on locational marginal pricing. If the difference in wholesale electricity prices between the two ends of an interconnector is sufficiently large to motivate investments in interconnector capacity, these investments will be made. Consequently, the price difference will be reduced when the transmission capacity becomes increasingly available. These investments are made until the differences in electricity prices between the countries are reduced to the annualised investment costs of the interconnector capacity. As a result, the interconnector would be able to recover its investment cost.



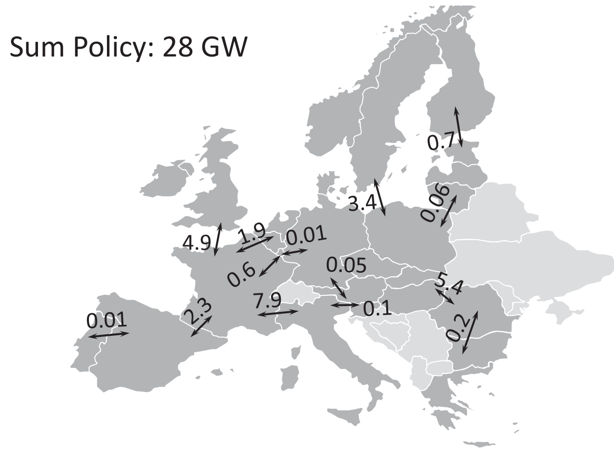


Figure 1: European interconnector capacities (the sum of net transfer capacities between EU Member States, and including Norway) in the Policy scenario in 2020, 2030, and 2040 (left), and the regional distribution of new capacity (in addition to those existing in 2010) in 2030 (right).

1) The Policy scenario reflects a future development including several specific policy measures directed towards renewables and efficiency measures.
2) The Market scenario reflects a route with few if any technology preferences, i.e. the choices of technology means to meet stated climate targets are left to the market.

For further information:
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Linking techno-economic modeling of Europe's electricity sector to large-scale CCS infrastructure optimization

The on-going collaboration with EU JRC on large-scale CCS, links CO_2-flow by country from Chalmers ELIN model to a model developed by JRC optimizing a bulk CO_2-pipeline network. JRC's work indicates more than a doubling in cost moving from onshore to offshore storage. Chalmers work shows that cost are rising substantially also when the bulk system is developed further into a detailed network. Still, specific cost is modest, about € 5.2/ton CO_2. The introduction of a minimum injection period of 45 years in aquifers indicates that large-scale CCS in Europe may require substantial offshore storage.

The joint project with the EU JRC on CCS infrastructure can be divided into three distinct steps;

1) Chalmers ELIN model provides annual CO_2-flow by fuel and country as part of modeling Europe's electricity sector.
2) JRC develops cost optimized bulk pipeline system for Europe based on data provided by ELIN model.
3) Chalmers develops a detailed CCS network based on the above steps and on the Chalmers databases of CO_2-sources and sinks.

Offshore storage gives double cost

In the second step, JRC develops a cost optimized bulk pipeline system for Europe based on the Policy scenario, both for a case where on-shore storage in aquifers is assumed to be allowed as well as for a case when it is assumed not to be feasible. In total some 15.2 Gt CO_2 is transported to storage sites between 2020 and 2050 as envisaged by the Policy scenario in Pathways 1. If onshore storage in aquifiers is not allowed, the total investment increases from € 14 billions to € 29 billions.

Designing a detailed network requires accurate geographical information

The third step, which is ongoing, applies the information provided by the two first steps along with Chalmers databases on power plants and CO_2 storage sites to develop a detailed collection and distribution system. Figure 1a shows how Chalmers initially envisioned distribution of aquifers in Germany based on earlier information while Figure 1b shows the actual distribution as provided later by Greenpeace based on work performed by BGR (Bundesanstalt für Geowissenschaften und Rohstoffe). The black dots and lines in Figure 1a shows CCS plants and distribution pipelines respectively while red circles show large gas fields and light yellow circles denote aquifers. In Figure 1b, the collection system is shown as blue dashed lines while the distribution system is shown as red dashed lines. In Figure 1b, aquifers are shown as green circles with size depending on storage capacity and where the largest aquifers are able to store around 300 Mt if a conservative approach is being applied on storage capacity, i.e. 6.3 Gt aggregated for all German aquifers.

The collection and distribution network will add significantly to cost

The different distribution of storage sites or, more importantly, storage and injection capacity as shown in Figures 1a and 1b have a significant impact on the design of the network but still relatively modest impact on specific cost. Investments were actually reduced by € 1 billion in the system to the right, from € 10.3 to € 9.3 billion. However, the detailed German system will alone require investments corresponding to two thirds of the entire European bulk system as calculated in the second step.

Large-scale CCS in EU likely to require offshore storage

Another factor that strongly affects the work in the third step is the application of an upper limit on annual injection capacity in an aquifer. This is a highly reservoir specific parameter which is usually not known. In this study, after discussion with leading geologists, it was decided to apply a minimum injection period of 45 years. This implies, in the modeling, that large amounts of CO_2 had to be exported from, among others, Belgium, Germany and Italy, to large aquifers in the Paris basin and in Poland. This is, however, questionable due to issues such as public acceptance and real storage capacity. Therefore, if France and Poland for some reason cannot (or will not) store large amounts of foreign CO_2, the risk is that offshore storage is the only remaining option for large-scale CCS in EU, with significantly higher distribution cost.

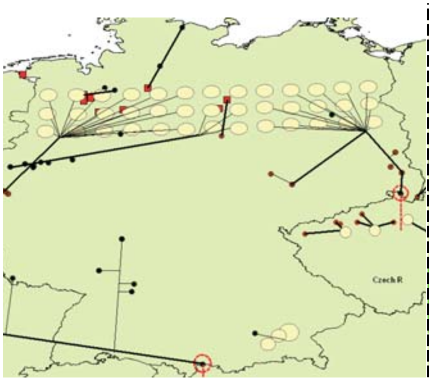

Figure 1a

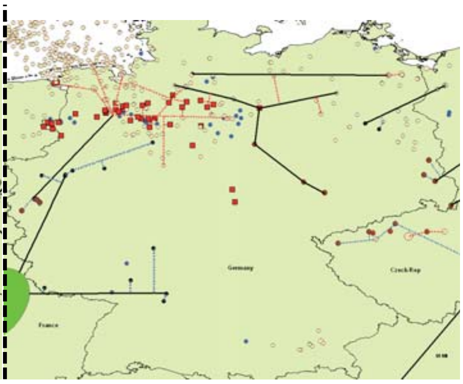

Figure 1b

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