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NEWSLETTER FROM »PATHWAYS TO SUSTAINABLE EUROPEAN ENERGY SYSTEMS«

#2/2012

Filip's column

It is now less than 40 years left until the CO_2 emissions in the developed world must have been reduced to almost zero if limiting global warming to 2°C. This of course also requires substantial emission reduction in part of the developing world, ...

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Prof. Filip Johnsson
Project manager of
the Pathways project

A new PhD dissertation:
"Reducing Carbon Dioxide Emissions from the EU Power and Industry Sectors"

and a new Licentiate thesis:
"Reducing Carbon Emissions From Natural Gas-fired Power Plants"

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Happy summer!

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

Modeling and analyzing abundance of gas in EU's electricity sector

The market for natural gas has recently seen a significant price reduction for most explained by additional supply of unconventionally extracted natural gas (shale gas). This can contribute in a positive direction with respect of meeting European CO_2-emission targets for 2020 and onwards, especially since CCS technologies have met opposition, legal barriers as well as delay in demonstration projects. The question is to what extent the system can rely on gas as major player in the power supply when proposed European (EU) climate targets more or less prescribes a carbon neutral power system by mid-century.

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Abundance of natural gas
- increased supply of shale gas

Modeling abundance of gas is based upon the apparent large resource base of conventional and unconventional natural gas and the implications this may have for natural gas prices in combination with the large uncertainties both regarding future emissions regimes and investments in CCS.

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Characterization and modeling of the EU building stock

The demand side is the driver of the energy system and efficient energy use in the building stock is a key issue in attempts to reach climate and energy goals in the EU. In developed regions, such as the EU, most buildings are already built, which means that the main challenge in the coming decades is to improve the existing building stock.

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Solar PV technology assessment

Currently, solar photovoltaics (PV) constitute a small, but increasing, share of the EU electricity production mix. Hence, it will be of increasing importance to consider the intermittent nature of PV electricity production. Here, the intermittency on an hourly basis is analyzed and the difference in production pattern between different solar PV technologies is also investigated.

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Filip's column

It is now less than 40 years left until the CO_2 emissions in the developed world must have been reduced to almost zero if limiting global warming to 2°C. This of course also requires substantial emission reduction in part of the developing world, especially in the economies where a major part of our consumer products are produced. At the same time there are vast resources and reserves of fossil fuels in these economies as well as elsewhere. This imposes a tremendous challenge for transformation of the global energy system and, therefore, mapping and understanding the fossil fuel markets have been an important task throughout the Pathways project. This newsletter illustrates on-going analysis of the natural gas market which has recently seen a significant reduction in natural gas price due to additional supply of unconventional (shale) gas. It is not obvious what will be the consequence of this with respect to the possibilities for mitigating greenhouse gas emissions. It may help and it may result in an enhanced lock-in in natural gas based power generation (and possibly also in other sectors such as heating and transport). In the Pathways project we are analysing the natural gas market with respect to both the international fuel market and the impacts on the European power generation system (see pages 3 to 5).

Another important and expanding research topic is large scale integration of intermittent power generation. Here, we have for some time been developing a methodology for assessing the integration of large amounts of wind power generation as illustrated in previous newsletters. As seen on page 6 in this newsletter we have now also started to investigate the intermittent nature of photovoltaics (PV) electricity generation. The current work analyse the intermittency on an hourly basis, taken into account the difference in production pattern between different solar PV technologies and using detailed meteorological data. As discussed on page 6, there are significant differences in output between different PV technologies.

I am glad to announce that all our abstracts submitted to the next International Conference on Greenhouse Gas Control Technologies, to be held in Kyoto next autumn have been accepted. This includes a paper which will present our joint work with DG-JRC on the analysis on requirements and challenges of establishing an integrated European infrastructure for large scale deployment of the CCS technology. I am also happy of the two theses which were presented during the last period of the project, one written by Erik Pihl on different ways to reduce CO_2 emissions from natural gas fired power plants and the other by Johan Rootzén on CO_2 emissions from the European power and industry sectors (see page 7).

Finally, I wish you all a nice summer!

Prof. Filip Johnsson
Project manager of the Pathway project

Attended workshops and conferences

Filip Johnsson held an invited key-note speak - *Development and Challenges of CCS* - at the International Energy Workshop, June 19-21 in Cape Town, South Africa. He also had a presentation of *Impact of the German nuclear phase out on European electricity supply* (a paper co-written with Mikael Odenberger and Thomas Unger).

In June, Lina Reichenberg attended the UK Energy Research Council's (UKERC) International Energy School. This is a week-long event, gathering about 100 PhD students from all over the world for a combination of seminars and project work aiming at a broader understanding of energy research including technical, physical, social, economic, environmental, and business aspects of energy systems.

Up-coming events

Emil Nyholm will participate at the 9th International Summer Academy "Energy and Environment" organized by the Institut für Klimaschutz, Energie und Mobilität in Greifswald in Germany. This is an interdisciplinary and intergenerational forum for young researchers and professionals working on energy and/or environmental issues. This year's topic of the conference is "Energy Transitions: Expansion and Integration of Renewable Energy Sources".

Eoin Ó Broin and Daniella Johansson will both present their research at the 7th Conference on Sustainable Development of Energy, Water and Environment Systems to be held in Ohrid, Macedonia in the beginning of July.

Recently published research papers

Pihl, E. , Kushnir, D., Sandén, B. and Johnsson, F. (2012). *Material constraints for concentrating solar thermal power*. Energy(in press).

Johansson, D. ; Rootzén, J. ; Berntsson, T. and Johnsson, F. (2012). *Assessment of strategies for CO_2 abatement in the European petroleum refining industry*. Energy. 42 (1) s. 375-386.

Ó Broin, E. ; Göransson, A. ; Mata, É. and Johnsson, F. (2012). *Modelling Energy demand to 2050 in the EU Building Stock – a bottom-up analysis* Proceedings of World Sustainable Energy Days conference, 29th - March 2nd 2012 , Wels, Austria

Medina Benejam, G.; Mata, É. ; Sasic Kalagasidis, A. and Johnsson, F. (2012). *Bottom-up characterization of the Spanish building stock for energy assessment and model validation* Retrofit 2012 Conference, 24 - 26 Jan 2012, Manchester, UK.

Modeling and analyzing abundance of gas in EU's electricity sector

The market for natural gas has recently seen a significant price reduction for most explained by additional supply of unconventionally extracted natural gas (shale gas). This can contribute in a positive direction with respect of meeting European CO_2-emission targets for 2020 and onwards, especially since CCS technologies have met opposition, legal barriers as well as delay in demonstration projects. The question is to what extent the system can rely on gas as major player in the power supply when proposed European (EU) climate targets more or less prescribes a carbon neutral power system by mid-century.

The development of the European electricity generation system over the next decades is explored for a "Storyline" characterized by good prospects for future supply of natural gas (for example shale gas as a new and substantial contributor to the gas market). Moreover, estimated initial cost for CCS (or other barriers) has increased, which obviously puts more pressure on the power sector when it comes to meeting emission reduction targets for 2020 and onwards. A fixed gas-to-coal price ratio of 2.0, 2.5 and 3.0 is analyzed. This text focus is on the effects on future investments in the electricity supply system. On page 4 the analysis is extended to include the impact in terms of gas consumption in EU.

Implications of shale gas – CCGT vs CCS

The analysis shows that a decreased gas price, relative coal, during a long period of time naturally increases the competitiveness of gas (see Figure 1). This is especially prominent in a carbon constrained world where a price on carbon acts with leverage advantageous for gas technologies (higher efficiency and lower carbon intensity in gas than in coal). Thus, a low natural gas price could provide a cost efficient, in terms of marginal costs on electricity as well as marginal cost of CO_2 abatement, bridge to meet targets by 2020 with the aid of fuel shifting from coal to low cost gas. In addition, the updated costs for CCS amplify the role of such fuel shift. In the longer perspective it is noteworthy from the analyses that under these conditions also gas CCS could play an important role in the eventuality of a gas-to-coal price ratio below 2.5.

Impact on prices on electricity and EU ETS

A gas-to-coal price ratio of around 3 gives a marginal electricity cost of around 65 €/MWh up to around 2040, which is similar results as for the ratio applied in in the original Pathways scenarios (i.e. a ratio of 3-4). A reduced gas-to-coal price ratio gives a lower absolute gas price, and thus, resulting in lower electricity prices until 2020 indicating new gas CCGT on the build margin. The results for marginal CO_2 abatement costs show similar trends as the development of the electricity price. This indicates fuel shifting from coal to gas as the marginal abatement measure until around 2020 whereas marginal costs are higher than the original scenario during the later period reflecting conventional gas being replaced with gas CCS as the marginal measure compared

to conventional coal being replaced with coal CCS in the original scenario; bear in mind the lower carbon intensity of gas technologies compared to corresponding coal technologies. It should be kept in mind that fuel prices as well as price development in the pathways original scenarios reflect a situation not affected by the economic recession beginning of 2008 and also do not take into account the prospects of cost efficient shale gas, which is the object of this study. In addition, costs for CCS, for capture as well as transportation and storage, are based on earlier work (ENCAP and early estimates on transportation and storage) and which reflects economical maturity already from the first implementation, and hence, provides a large and rapid employment of CCS technology (from year 2020 when it is assumed to be available).

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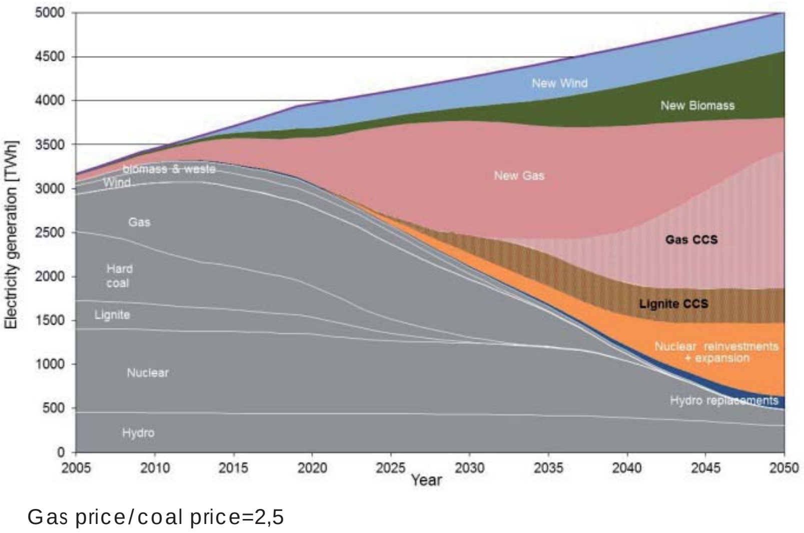

Figure 1. Development of the European electricity generation system. Shown is the Market scenario under influence of a reduced gas price (relative original) by fixing the gas price relative the coal price by the factor 2.5.

Abundance of natural gas
– increased supply of shale gas

Modeling abundance of gas is based upon the apparent large resource base of conventional and unconventional natural gas and the implications this may have for natural gas prices in combination with the large uncertainties both regarding future emissions regimes and investments in CCS. Modeling results showed a large increase in gas based generation in EU under the Market scenario if the natural gas to coal price ratio was held at 2.0 through to 2050 with natural gas consumption in the power sector doubling by 2021 and more than tripling by 2050. A forthcoming analysis of results will further focus on market dynamics with respect to the natural gas price and gas supply side aspects, and with regard to the power sector, siting issues.

Modeling gas abundancy and delayed CCS

After COP 15 in Copenhagen and COP 16 in Cancun, there are significant uncertainties with respect to a global post 2020 GHG emission mitigation regime. It is clear that one of the key mitigation options, CCS, will require large up-front investments and that CCS may not reach a commercial mature stage until well after 2020, considering the lead times for development and the large upfront investment requirements in combination with uncertainties in the post 2020 climate mitigation policy.

At the same time, more than 110 GW coal based power plant capacity in the EU is older than 30 years indicating substantial replacement requirements over the next two decades while switching from an old coal plant to a new gas fuelled combined cycle will offer considerable near-term CO_2-emission reductions. Investment cost for a new gas CCGT is less than half the investment cost for a new coal plant and the construction time is also considerably shorter for a gas CCGT.

Substantial conventional gas resources together with potentially significant unconventional gas resources may lead to natural gas becoming increasingly competitive underpinning a large expansion in gas based power while at the same time not compromising security of supply. Yet, a large scale deployment of natural gas based power generation – in addition to the large deployment which occurred during the last decades – may lead to a lock-in effect and possibly be negative for security of supply due to reduced fuel diversification.

Different scenarios assuming a natural gas to coal price ratio (GCR) of 2.0, 2.5 and 3.0 are therefore modeled and analyzed as also described on page 3 of this newsletter.

Gas consumption potentially rising from 130 bcm in 2009 to 445 bcm in 2050

Figure 1 shows resulting gas consumption up to 2050 in six modeled scenarios, Market Pathway (blue) and Policy Pathway (red) with a GCR of 2.0, 2.5 and 3.0 (the Market Pathway and

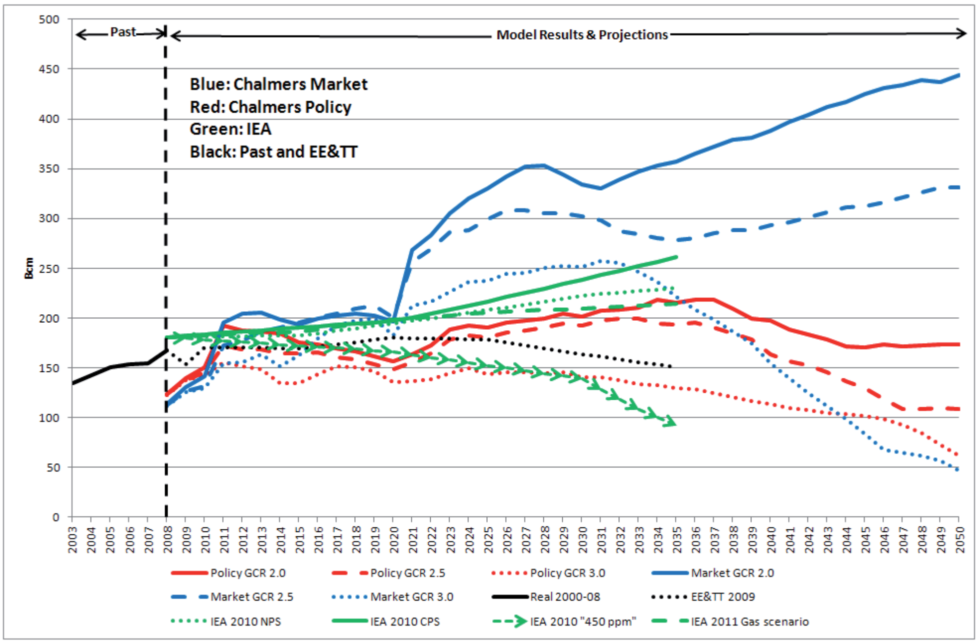

Figure 1: Chalmers modeled gas consumption up to 2050 in six scenarios assuming abundance of gas and delayed CCS along with projections up to 2030 from IEA (from WEO 2010: the New and Current Policy scenarios, NPS and CPS, the 450 ppm scenario; and from WEO 2011: the gas scenario) and EE&TT (the 2009 study).

the Policy Pathway is further described in Newsletter - special issue 2011). Included in Figure 1 are also four projections up to 2030 from IEA's World Energy Outlook and from the European Energy and Transport Trends to 2030.

As can be seen from Figure 1, only the Market 2.0 and 2.5 scenarios lead to a substantial increase in gas consumption. The Market 2.0 scenario implies more than a doubling from current levels by 2021 and more than a tripling by 2050. Six countries account for almost 80% of total gas consumption in the power sector in 2050; Italy, Germany, UK, Luxembourg, Hungary and the Netherlands. Most remarkable is the consumption level reached in Luxemburg, up from less than 1 bcm in 2008 to a peak of 48 bcm requiring almost 40 GWe gas based capacity (as opposed to 0.4 GWe being on-line in 2008). Between 2009 and 2027, gas based capacity in EU (plus Norway) increases from 219 GWe to 470 GWe indicating an average annual net addition of 14 GWe. This should not however represent a problem, as, for instance, 15 GWe gas based capacity was installed in 2005 while some 13 GWe was installed both in 2004 and 2010.

Analyzing the results with respect to natural gas

Obviously, it is important to investigate whether the increased demand envisioned in for example the Market 2.0 scenario will affect natural gas prices so that demand will be dampened. Europe's own conventional gas resources are being depleted and the second largest exporter to EU, namely Norway, will have to prove up new reserves in order to maintain current export levels. At the same time, search for unconventional gas is ramping up on every continent including in Europe, for instance IEA estimates some 14 Tcm (Trillion m^3) recoverable gas throughout Europe (current production in EU is around 0.2 Tcm while consumption is 0.5 Tcm) although these figures are highly uncertain and there is also considerable local opposition to production of unconventional gas on several places in Europe. On the other hand, several significant discoveries of conventional gas worldwide over the last few years together with production of unconventional gas in other parts of the world may still lead to an abundance of gas on world markets and thus, very competitive natural gas prices. These are some issues that will be further studied in forthcoming research. The research will also investigate import infrastructure, both on EU and single member state level. Results of the scenario modeling with focus of an abundance of gas, will also be analyzed with regard to power plant site requirements, i.e how can and should the large amount of gas based power coming on-line up to 2050 be located.

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Solar PV technology assessment
- from radiation to power output

Currently, solar photovoltaics (PV) constitute a small, but increasing, share of the EU electricity production mix. Hence, it will be of increasing importance to consider the intermittent nature of PV electricity production. Here, the intermittency on an hourly basis is analyzed and the difference in production pattern between different solar PV technologies is also investigated. The production patterns based on metrological data indicate that electricity output is highly dependent on weather conditions, which emphasis the need of looking into the effects of this intermittent production. Moreover, based on the same metrological conditions a difference in output of up to 10% is seen between different PV technologies.

Description of intermittent production is needed

A future energy system will likely incorporate large amounts of energy production based on renewable sources. A few of these sources, e.g. biomass, allow a production pattern similar the currently dominating fossil and nuclear based sources. Others, on the other hand, for example for example wind, solar, wave and tidal, have a production pattern depending on conditions with less possibility to regulate. A good description of these intermittent patterns is therefore needed to analyse the effects and possibilities of a large integration of intermittent power into the current energy system.

The production pattern of solar PV can be described using meteorological time series for solar irradiance and ambient temperature, as these data through a transfer function can be transformed to a prediction of solar PV output, as shown in Figure 1.

Currently, normal distributed solar PV profiles are applied in the Pathways EPOD model to capture the intermittent output pattern. While these descriptions correspond well to sunny cloud free days as seen in Figure 1a, days of partial cloudiness do not follow the applied pattern, see Figure 1b, which indicate the need of improving the representation of PV output patterns in energy system models.

Output pattern is similar for different technologies

The shown pattern applies for standard crystalline silicon panels (C-Si) which constitutes the majority today's installed grid connected PV systems. However, the thin film technology is an emerging PV technology which compared to C-Si requires a less energy intensive manufacturing process and can also be deposited on many different substrate materials, rendering it more flexible, but a disadvantage is that it is more prone to degradation than C-Si. Two promising thin film technologies, CIS and CdTe, have described transfer functions and their output patterns can thus be described similarly to the C-Si technology. If comparing results, the three different technologies show the same pattern in their output. However, the output from the CdTe panel is higher compared to CIS and C-Si given the same irradiance and temperature. The difference varies depending on irradiance level, with higher differences at low levels which decrease as irradiance increases and is stabilised at around 7-10% when the irradiance is high enough to be of interest. However, since the output pattern is relatively similar, the significance of different technologies while studying the effect of intermittency is probably limited.

Profiles can be used to find synergies and need for storage

The pattern profiles could be applied to describe different investment classes and potentials of solar PV in energy systems models such as the ELIN model allowing for an allocation of PV production to suitable regions. Moreover, the solar profile description together with existing wind profiles (as assessed in another part of the Pathways project) and profiles for wave energy could be used to explore synergy effects when integrated in the EU energy system. Moreover, they could provide a tool for evaluating the need for storage as well as how such storage should be designed in the system.

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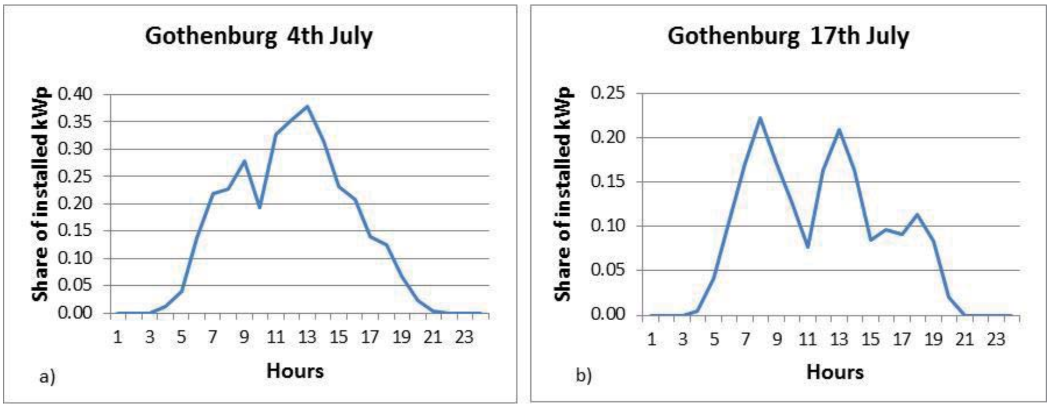

Figure 1. *Output from a C-Si PV panel expressed as share of installed kWp for a) a sunny cloud-free day (pane to the left); b) a partial cloudy day (pane to the right)*

New PhD dissertation

”Reducing Carbon Emissions From Natural Gas-fired Power Plants
– Biomass, Concentrated Solar and Carbon Capture”

Erik Pihl defended his thesis “Reducing carbon emissions from natural gas-fired power plants – Biomass, Concentrated Solar and Carbon Capture” on June 11, 2012. In this thesis, possibilities to reduce emissions from natural gas combined cycle gas turbine (CCGT) plants are evaluated. This evaluation is done from two perspectives: techno-economic analysis, and analysis of the resource and integration potentials. Included technologies are biomass and concentrating solar power (CSP), integrated with the CCGT, as well as application of post-combustion carbon capture and storage (CCS) to the gas plant.

One main conclusion is that there are potential efficiency and cost benefits of integrating biomass and solar energy with existing natural gas-fired power plants. Solar and biomass options are both found to give up to 8-13%-points better efficiency when integrated with a triple pressure CCGT plant, than corresponding stand-alone configuration. CCS in gas plants is found to have the lowest levelized cost of electricity (60-80 EUR/MWh) compared to biomass-based options (80-140 EUR/MWh) and stand-alone solar (>200 EUR/MWh). Biomass-gas hybrids are, however, found to be competitive with CCS options in terms of break-even cost of CO_2. Integrating CSP collectors with combined cycle plants will reduce the the levelized cost of electricity to almost half that of stand-alone plants (~130 EUR/MWh), nearly closing the gap to where CSP can be competitive with other low-carbon technologies.

The total economic potential for biomass power is found to be about 1,000-3,000 TWh electricity per year (TWhe/y) in the EU. Comparable figures for CSP are 2,000-3,000 TWhe/y. The EU CO_2 storage capacity is sufficient to facilitate more than 3,000 TWhe/y from natural gas CCS over a 100 year period. The European integration potential with CCGT plants is estimated to about 240 TWhe/y for biomass and 2-4 TWhe/y for concentrating solar. An analysis shows that material constraints should not be restrictive for significant growth or global capacity of the studied technologies. Integrating with existing CCGT plants can be viewed as a “low-hanging fruit” to reduce CO_2 emissions, and build capacity and develop solar and biomass technologies.

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New Licentiate thesis

“Reducing Carbon Dioxide Emissions from the EU Power and Industry Sectors
- An assessment of key technologies and measures”

Johan Rootzén has presented his licentiate thesis, “Reducing Carbon Dioxide Emissions from the EU Power and Industry Sectors - An assessment of key technologies and measures”, on May 28, 2012.

The overall objective of the work presented in this thesis is to provide a technology-based perspective on the feasibility of significant reductions in CO_2 emissions in the EU power and industrial sectors, with the emphasis on expected turnover in the capital stock of the existing infrastructure. Three sectors of industry are included: petroleum refining; iron and steel production; and cement manufacturing. The analysis is based on a thorough description and characterization of the current industry infrastructure and of the key mitigation technologies and measures in each sector. The work provides a comprehensive assessment of the roles of technologies and measures that are commercially available today, as well as those of emerging technologies that are still in their early phases of development. The results show that the EU goal for emissions reductions in the sectors covered by the EU ETS, i.e., 21% reduction by 2020 (as compared to Year 2005 levels), is attainable with the abatement measures that are already available. However, results indicate that the targeted levels of 2050 will be difficult to achieve unless a major breakthrough in low-carbon process technologies materializes within the period (see Newsletter 2012:1). The results also illustrate how large-scale implementation of CCS in industrial settings might contribute to significantly reducing CO_2 emissions from heavy industries in the EU. Taken together, these studies highlight the importance of, in parallel with the implementation of measures to meet the short-term (2020) reduction targets, accelerating efforts to develop new zero- or low-carbon technologies and processes that would enable significant reductions in emissions in the long term (2050).

For further information:
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Characterization and modeling of the EU building stock

The demand side is the driver of the energy system and efficient energy use in the building stock is a key issue in attempts to reach climate and energy goals in the EU. In developed regions, such as the EU, most buildings are already built, which means that the main challenge in the coming decades is to improve the existing building stock.

To develop energy efficient strategies for building stocks, there is need for simplified methodologies and tools for assessing different options and selecting the best option. Thus, within the Pathways project, Erika Mata has developed a methodology and a so-called bottom-up model, the ECCABS model, to assess energy saving measures (ESM) and CO_2 mitigation strategies in building stocks. The net energy demand is calculated for a number of buildings, representative for the building stock and the model also generates results in terms of delivered energy, associated CO_2 emissions, and the cost of implementing different ESM. The results are thereafter extended to an entire buildings stock in a country.

The building stock modeling has been validated against the Swedish residential stock, for which the results of the modeling are in agreement with the statistical data. Using the model to assess a number of ESM reveals that the energy usage of the Swedish residential sector can be reduced by 55% and the associated CO_2 emissions can be reduced by 63%, with most of the ESM being cost-effective.

The applicability of the methodology is investigated for EU countries

The applicability of the methodology to define archetype buildings and the use of the model for countries with another climate and a larger building stock than Sweden is now being investigated. This is done within the scope of different Master of Science theses performed at Chalmers University of Technology, and the countries studied initially are Spain, France, the United Kingdom and Germany. These countries stand for about 55% of energy consumption in the residential sector of EU-27.

The Spainish building stock

Georgina Medina applied the model on Spain (i.e. a south-European country) to analyze the energy demand and also included the non-residential sector in the analysis. The building stock is here represented by 120 archetype buildings (defined by building type, climate zone, and period of construction). The application of the model to Spain was found generally appropriate since energy demand obtained (181 TWh for the residential sector and 91 TWh for the non-residential sector for the year 2005) is close to data given in international statistics.

A sensitivity analysis also confirmed that the heat transfer coefficient of the building (U-value) and the hot water demand are the main parameters influencing the final energy demand.

The French building stock

A similar study to characterize the French building stock is performed by Josep Maria Ribas. It is here concluded that 54 residential buildings and 45 non-residential archetype buildings are needed to characterize the building stock. The calculated annual final energy demand for the residential sector is about 435 TWh and for the non-residential sector 179 TWh, which is slightly less than corresponding values provided by official statistics.

The UK building stock

Reza Arababadi executes a case study of the energy use in buildings in United Kingdom. Results indicates that the methodology of using archetype buildings (in this case about 250 buildings) is also suitable for describing the UK building stock, and the annual final energy demand results (579 TWh for the residential sector and 77 TWh for the non-residential) are also in the same range as statistics. There is however a scarcity of data for non-residential building, which is a common problem for all countries investigated, and this could explain that the model results for this sector show a slightly larger deviation compared to statistics, but satisfactory to validate the model.

The German building stock

Artur Bauer and Sohejl Wanjani are carrying out a study of the German building stock which also constitutes the largest amount of buildings in EU. From the data collected it has been possible to describe the residential sector with about 120 different archetype buildings. However, although large efforts were made no data was found describing the German non-residential sector. Modeling results indicate an annual final energy demand of 625 TWh for the residential sector, which shows high consistency with official energy statistics.

The different case studies indicate that the methodology and the ECCABS model, despite being developed for Sweden, are also applicable for other countries and conditions, and is thus, suitable when analyzing energy efficient strategies for building stocks in an European context.

For further information:

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