EUROPEAN
pathways
NEWSLETTER FROM »PATHWAYS TO SUSTAINABLE EUROPEAN ENERGY SYSTEMS«

2015:December

Emission targets are out of reach without a massive technological shift in the Europe's basic industries

page 7

Filip's column

The content of this newsletter reflects the variety of possibilities for transforming energy systems analysed within the Pathways research programme. We are all experiencing the large shift in the energy and electricity markets. Some ten years ago when the Pathways research programme was initiated, it is my impression that energy companies, the research community and politicians all had a rather clear picture on what the future would bring such as increasing emission allowance prices, increased fuel prices and strong development in technologies (e.g. carbon capture and storage). At present, little of that has happened. Instead we see a European electricity market with low wholesale prices, low EU-ETS allowance prices and almost no investments in thermal generation in Europe. Although this may be seen a bit depressing at first sight, there seems to be large possibilities in renewable electricity generation (RES-E). There has been a strong development in RES-E and a pressing question is how this can be integrated into the energy system, but also how further deployment of RES-E can be financed in a cost-efficient way. These are key issues of the studies within the Pathways programme and, as stated in previous newsletters, we continuously develop our modelling toolbox to be able to evaluate the effects from RES-E generation under different scenarios.

There are also interesting links between the deployment of RES-E and the transportation system. We are therefore happy about the newly initiated cooperation with the Norwegian Public Roads Administration. Within this cooperation we investigate prospects from electrifying the E39 coastal highway in Norway. The initial work confirms that there are significant possibilities from an electrification of the E39, as explained on page 4. I am very much looking forward to the continued work in this project where we study the dynamics of the transport work on the road, which should have important implications for how road infrastructures can interact with the electricity generation system, especially when it comes to integration of intermittent electricity generation. Yet, to what extent the vehicle infrastructure will be transformed is much governed by the international markets and it is difficult for local regions to act independently as is discussed in another regional project reported in this newsletter (page 5).

There are great potentials for improving the energy system in many areas. One such area is the European heating market where Halmstad University has developed and applied a methodology which can estimate the potential of heat recovering via district heating. It is shown that there is at least a three-fold directly feasible expansion potential for district heating in the European city areas, as explained on page 3.

This newsletter also gives three examples of what we can envision from the transformation of the electricity system: On page 8, results from an analysis of the transmission system show that there will be new congestion patterns in the European transmission system as a result of expansion of wind and solar power capacities. This is due to the low marginal costs of electricity at times of high output from these technologies. We also investigate how buildings can provide flexible loads for the electricity systems and modelling shows that managing the space heating and hot water heating loads provide the potentials of demand response (DR), i.e. to shift to shift load in time (page 9). Finally, page 10 summarises recent results on how wind power allocation can contribute to efficient use of wind power in a future Europe with a high share of variable renewables in the electricity system.

Sweden is known for being in the forefront when it comes to environmental issues. Yet, in some areas Sweden is definitely facing significant challenges to comply with targets to reduce carbon emissions as formulated by the European Commission and the Swedish government. This is illustrated in a recent PhD thesis by Johan Rootzén. The work identifies emission pathways for the European and Nordic energy intensive industry up to Year 2050. As stated on page 7, there is an urgent need to demonstrate and implement carbon capture and storage and other carbon dioxide mitigation technologies if any chance to comply with the targets on emission cuts.

Finally, I am proud of the recent book from the Pathways programme, which summarises the result during the period 2010 to 2013. We have sent out the book to a large number of decision makers in Sweden and Europe and we have got a very positive response on the book. We still have additional copies so please do not hesitate to contact us (see address on page 6) for a copy.

In summary I think this newsletter reflects that there are many possibilities to mitigate climate change. I can only hope that the result from the COP meeting in Paris will be that politicians and other decision makers active on the energy markets create conditions so it becomes possible to harvest all possibilities to transform the energy system, including the ones given this newsletter.

I hope you will enjoy reading this newsletter!

Prof. Filip Johnsson
Research leader of the
Pathways programme

The potential of district heating in future Europe

To what extent can district heating contribute to improved energy system efficiency and reduced CO_2 emissions in a future Europe? This is a question that Pathways researcher Urban Persson has investigated in his doctoral thesis work. The main motivation of suggesting a large-scale implementation of district heating as a structural energy efficiency measure originates essentially in the predicament that a majority of European buildings today remain highly dependent on fossil fuels to provide energy needed for space heating and hot water preparation. At the same time, vast annual volumes of rejected excess heat from European power plants and industries are mainly neglected and lost unutilised to the ambient surroundings. Thus, an extended recovery and utilisation of such secondary energy assets could realistically replace significant shares of current fossil fuels in the building stock.

Identification of primary target regions

Urban Persson has developed methodologies to address and assess the European potential of heat recovering via district heating. This includes methods to estimate the economic competiveness of district heating on the European heat market, to assess regional heat demands as well as to characterise and quantify the benefits of excess heat recovery. His research also provides a spatial mapping, on a European regional scale, of building heat demand and matches this against availability of excess heat, see Figure 1. This mapping identifies the current primary target regions where a large-scale implementation of district heating would be most cost effective and most suitable for expansion.

Large expansion potential

The research results clearly indicate that district heating should be able to provide cost and resource efficient heat distribution to a major share of Europe's urban residential and service sector buildings. There is at least a three-fold directly feasible expansion potential for district heating in city areas. A large scale implementation of district heat should benefit from access to abundant current excess heat availabilities and, by its utilisation, contribute to improved local and regional environments as well as to higher energy system efficiency in the European energy system. There are, however, several issues and challenges (mainly non-technical) that must be addressed in a successful transition to a more energy efficient supply structures in future Europe.

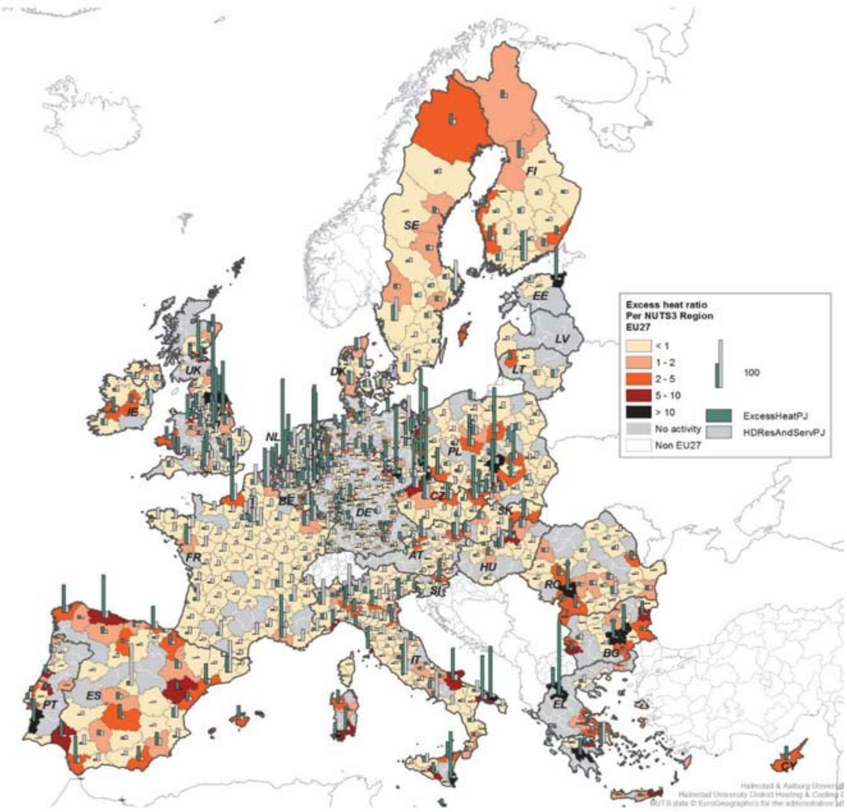


Figure 1 *Excess heat ratio per NUTS3 region in EU27. The excess heat ratio relates the excess heat availability to the heat demand of the residential and service sector in the NUTS3 region. The vertical bars in the figure compares excess heat to heat demand measured in PJ.*

Read Urban Persson's PhD thesis, **"District heating in future Europe: Modelling expansion potentials and mapping heat synergy regions"**

For further information:
URBAN PERSSON, Halmstad University

Newly initiated research project on:

The E39 as a renewable European electricity hub

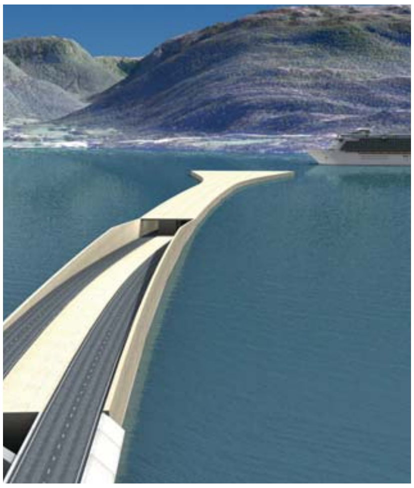


Bild: www.vegvesen.no

The Norwegian Ministry of Transport and Communications has plans for extensive investments in road infrastructure in the E39 coastal highway. The E39 runs from Trondheim along the western coast down to the southern tip of Norway, passing an area with a rapid economic development and a projected future increase in road traffic. The 150 billion Norwegian infrastructure project “Ferry-Free E39” has the goal of building new bridges and tunnels over eight fjords and a vision of climate-neutral roads with significant input from wind power and tidal power.

A self-sufficient energy hub

Maria Taljegård is analysing conditions for the E39 as a self-sufficient energy hub and possibly also as a part of the European electricity system. She will, together with her colleagues within the Pathways programme, use the European electricity investment model (ELIN) and the dispatch model (EPOD) to investigate how an electrified E39 can interact with the electricity generation system, including import and export of electricity to neighbouring regions. The future role of E39 in the energy system will depend on investments in transmission capacity (e.g. to the UK and to continental Europe) as well as demand side management in industry and buildings.

The annual road traffic volumes for E39 has been estimated to 2,600 million vehicle kilometres, which corresponds to 6% of the Norwegian road traffic volumes. The yearly energy use for road transport along E39 is currently around 3 TWh. There are large geographical variations in the traffic intensity along E39, from less than 1,000 to more than 70,000 vehicles on an average day. Such work should, on an average, not be a problem to supply with electricity, but with respect to peaks and variations in the transportation work it might put challenges to the electricity system.

Electrification of the E39

The current CO_2 emissions from the road transportation on E39 are estimated to 0.7 Mton per year. In order to reach low or zero emissions in the future, a transition to electricity or hydrogen is most likely needed. An electrification of E39 could imply electric cars, fuel cells, and conductive or inductive charging from the road (e.g. overlines or ground-level supply). The estimation of CO_2 emissions reductions, when electrifying E39, depends on the technologies applied, and the time perspective. Also it is not obvious how to account for CO_2 emissions, which will depend on whether a marginal or average perspective of increased demand for electricity is applied and whether a short or a long term time frame is considered. In this project, a first assessment of the transportation work and its implication for different prime-mover technologies have been carried out with respect to load profiles and impacts on CO_2 emissions. Detailed model studies of the European and Nordic electricity systems will be performed in order to further investigate the (climate) impact of an electrification of E39.

Minor influence on annual electricity balance

In a regional (the E39 region) perspective, electrifying the transport sector will have a minor influence on the total use of electricity when considering the yearly average, as can be seen from Figure 2. The electricity generation in the E39-region (consisting of six counties) is 60-75 TWh per year, depending mainly on if it is a wet or a dry year; and the electricity use in the region is around 50 TWh per year. However, there might be significant local and time variations in the potential power demand, which could impose a challenge on the electricity system in the form of specific power peaks, and this will be further studied in project. The transformation of both the transportation sector and the electricity system offers potentially interesting links with possibilities for integrating the generation and use of electricity so as, for example, make better use of variable renewable electricity generation such as wind power.

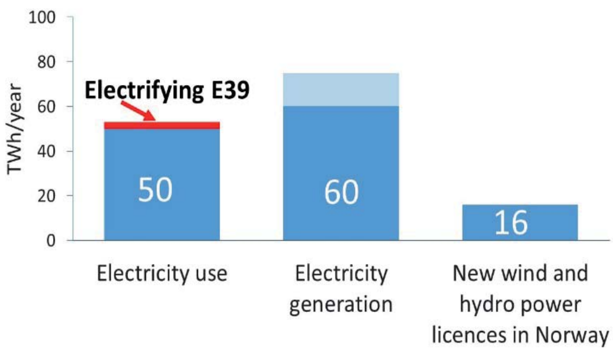


***Figure 2** Annual electricity balance (in TWh) in the E39 region showing current electricity use and the estimated added demand from an electrification of the E39. As comparison, the two vertical bars to the right show the electricity generation in the region and the approved additional renewable installations in Norway.*

For further information:
MARIA TALJEGÅRD, Chalmers University of Technology

Decarbonising the transport sector in the Swedish Kattegat/Skagerrak region

What possibilities does the transport sector in the Swedish Kattegat/Skagerrak (KASK) region have to comply with stringent climate targets? A scenario has been developed showing that it is possible to reach zero CO_2 emission by Year 2050 by implementing measures to reduce energy demand and by switching from fossil fuels to non- CO_2 emitting fuels such as biofuels and electricity. This scenario indicate the opportunities, as well as the challenges, of decarbonising the transport sector of the region.

What will be required to transform the road transport sector of the Swedish KASK region (i.e., the Västra Götaland and Halland counties) as to comply with targets aiming at having a CO_2-emission-free national transport sector by 2050? On a national level, different roadmap studies (for example realised by the Swedish transport administration, Elforsk and SOU) have indicated possibilities to reduce fossil fuel consumption in the national road transport system by 80% up to 2030 (relative to 2010) as well as to reach zero overall GHG emissions in 2050, which basically implies a complete phase-out of fossil fuels within the national transport sector. However, what will this entail as the national results are brought down and assessed on a regional level? This question is analysed in a recent study where relevant pathways for the transport sector of the Swedish KASK region are developed.

A Sweden in miniature

The metropolitan region of Göteborg make up a large part of the Swedish KASK region regarding, for example, population and transport demand. As typical for metropolitan regions in Sweden, the share of vehicles using other than conventional fuels, such as petrol and diesel, is higher in the studied region compared to a national average. However, distinctly different from the other metropolitan regions, there is a currently a relative large dependence of cars in terms of commuting to and within the Göteborg region. The Swedish KASK region also show parallels to the national average with regard to car ownership per capita and fuel consumption as well as with regard to terrain, road characteristics and in terms of population density and can, thus, broadly be described as a Sweden in miniature. Based on these regional prerequisites and assessments of technology development, possibilities to behaviour changes and transformation rates, a scenario is derived showing how the road transport sector in the region can be transformed from a fossil fuel dominated system to a system with zero CO_2 emissions by 2050.

Reaching zero CO_2 emissions

The developed scenario of the transformation up to 2050 is compared to a base scenario where transport demand in the region is assumed to increase from approximately 20TWh in the base year (2007) up to 29TWh in 2050 and no other changes are assumed to take place in the current vehicle mix. To reduce CO_2 emissions there are two main groups of measures: reducing the energy demand for transportation; and switching from fossil fuels to a non-CO_2 emitting fuel. Figure 3 shows the result with the regard to energy consumption in the Swedish KASK region. The height of each bar gives the energy demand in the base scenario while actual demand (in the developed scenario) is given by the combined fuel use (that is, fossil fuels plus renewables plus electricity). The difference between the two scenarios indicates the reduced energy demand resulting from actions such as reduced transport demand, shift in mode of transportation (moving, for instance, from private to public transportation), increased vehicle efficiency, and efficiency increases resulting from fuel switching (for example when switching from petrol to electricity). Through implementation of the different measures, the CO_2 emission from the transport sector is reduced by 80% by 2030 (or even by 85% if comparing to the base scenario). The demand of energy for transportation in the region is then about 11.5 TWh and is to a major part supplied by biofuels (6.4 TWh). It is, however, assumed that it is not possible to further expand the biofuel use after 2030. To reach a zero-emitting system in 2050, fossil fuels are completely phased out through increased electrification and an assumed further increase in vehicle efficiency. The total energy demand for transportation in

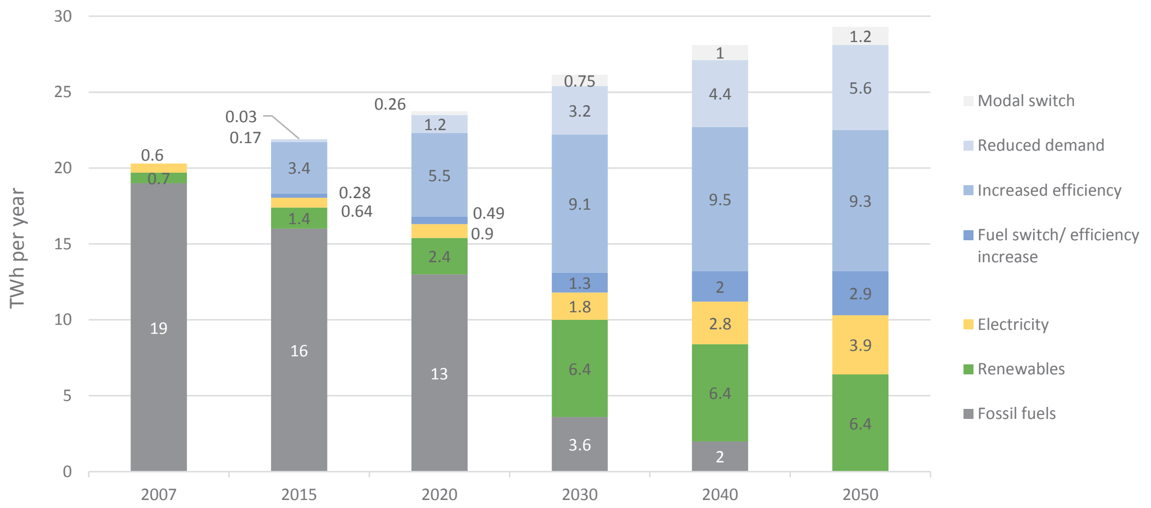


***Figure 3** Estimated annual energy consumption up to 2050 in a scenario towards zero-CO_2 emissions in the transport sector of the Swedish KASK region. Demand in a base scenario is given by the height of each bar while the blue parts of each bar indicate different measures applied to reduce energy demand.*

this system would in this case be just above 10 TWh. Thus, demand is halved compared to the base year and almost cut by two-thirds compared to the base scenario. In the analysis, only end-use emissions from the transport sector are accounted for, and electric vehicles are, thus, assumed to be zero-emitters. However, in a broader energy systems perspective, consideration must be taken to how electricity is produced when determining the net climate benefit of from electricity in the transportation system.

National and international efforts are required

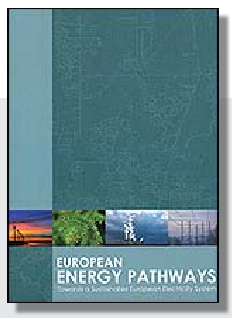
The scenario analysis shows that to reach strict climate targets in the transport sectors, all measures are needed, both with respect to fuel usage and to reduction in demand for transportation fuel. To accomplish such a significant transformation of the transport sector will require strong and long term policy measures as well as participation by all citizens. The latter will require significant shifts in norms and values among the public, which in turn will require a clear political leadership. However, neither the Swedish KASK region itself nor Sweden, have governance over all actions required. This, since the technical development of more efficient vehicles is typically carried out to meet requirements on international markets and it is unlikely that car manufacturers will develop vehicle technologies only for the Swedish market. Therefore it is crucial that there is a clear and long term policy on a Swedish as well as on the EU level with regard to ambitions to reduce CO_2 emissions from the transport sector. If not, it cannot be expected that the KASK region (nor Sweden) will meet the target of a decarbonised transport sector.

For further information:
HÅKAN SKÖLDBERG & EBBA LÖFBLAD, Profu;
JAN KJÄRSTAD, Chalmers University of Technology

New Book

The second book reporting on the progress and results of the Pathways research programme is released. This book has an explicit focus on the transformation of the electricity system and presents and discusses the results obtained from comprehensive analyses of various options to reduce significantly emissions of CO_2 from the system over the coming decades. The book covers key areas such as the *long-term development of the European electricity-supply system* and *large-scale integration of renewable electricity*, but it also provides in-depth studies relating to both the resource-side as well as the demand-side of the electricity system.

EUROPEAN ENERGY PATHWAYS – Towards a Sustainable European Electricity system



For more information see: www.energy-pathways.org

A copy of the book can be order from:
Marie Iwanow at the Division of Energy Technology at Chalmers University of Technology.

Emission targets are out of reach without a massive technological shift in the Europe's basic industries

"There is an urgent need to demonstrate and implement carbon capture and storage, CCS, and other carbon dioxide mitigation technologies", says Pathways researcher Johan Rootzén, who recently presented his doctoral thesis at Chalmers University of Technology.

The targets for lower emissions of carbon dioxide from Europe's basic industries are out of reach, without urgent introduction of innovative carbon dioxide mitigation technologies. Researchers at Chalmers University of Technology draw this conclusion after several years of research into carbon-intensive industry in Europe.

"While this will involve major investments in primary production, our results suggest that there will only be marginal impacts on costs and prices in the end-use sectors."

The debate about how to reduce emissions of carbon dioxide often focuses on emissions from generation of electricity and transport. Johan Rootzén has researched another major source of emissions: energy-intensive heavy industry in Sweden and EU, such as oil refining, and production of cement and steel.

Making production more energy efficient and changing to fossil free fuels are two of the alternatives which are often mentioned, but when it comes to the production of cement and steel, it is only possible to tackle a limited amount of emissions with these measures, due to the method of production. One way to reduce emission would of course be to reduce production, but major investments in housing, infrastructure and renewable energy are foreseen over the coming decades which are likely to result in a continued high demand for bulk products like steel and cement.

"There is a lack of strategy from political actors about how emissions from these industries should be reduced, even though these industries are responsible for a tenth of emissions of carbon dioxide in Europe and nearly 20 percent in Sweden", says Johan Rootzén. "At the same time Sweden and the EU have a target in which emissions should be almost zero by 2050."

"The clock is ticking", says Johan Rootzén. "Plants within heavy industry have very long lifespans, so implementation of new technology and new solutions take a long time. There are only a few investment cycles left to year 2050. If the EU is serious about reducing emissions by 80-90 percent by 2050, then the issue of how to finance the development and implementation of innovative process technology must be brought to the table now." In Chalmers' Division of Energy Technology, like many other universities and institutes in the world, different technologies for mitigation of carbon dioxide emissions, including carbon dioxide capture and storage, have been developed over the years. A number of questions on how these technologies can be implemented remain. It is especially urgent to establish large-scale demonstration of the entire CCS chain; capture, transport and storage.

Johan Rootzén

"It is easy to say that we should achieve zero emissions, but this requires that we take the issues seriously and are given the opportunity to demonstrate new technologies; CCS as well as other mitigation options. There are indeed question marks concerning CCS, and large investments are required in CCS as well as in other measures. Yet, if society decides not to try then we limit the room for manoeuvring in the future. Our research suggests that without a shift in technology then refineries, steel and cement industries alone are going to be the source of up to a quarter of the emissions in 2050", says professor Filip Johnsson who has been leading the Chalmers research.

In his thesis, Johan Rootzén also concludes that a shift in technology to a less carbon intense production of steel and cement would only have a marginal effect on the final price of a car or a house, despite the large invest-ments required in the production step of the primary materials. This is because the cost of these materials is such a small part of the cost of the final product.

He now hopes that he and his colleagues' research will lead to politicians in both Sweden and Europe taking the decision to pave the way for CCS and other mitigation technologies, which could seriously reduce emissions from energy-intensive industry.

"This is one of the major critical issues we must deal with. The choice of path that we make in Sweden and Europe can, of course, only affect the global development so much. But we, who have to a large extent built up our industries and economies on coal, oil, steel and cement have, in my opinion, a responsibility to lead the way and develop measures which can show the rest of the world that it is possible to achieve ambitious emission reduction targets", says Johan Rootzén.

TEXT: CHRISTIAN LÖWHAGEN

Read Johan Rootzén's thesis: **"Pathways to deep decarbonisation of carbon-intensive industry in the European Union - Techno-economic assessments of key technologies and measures"**

For further information:
JOHAN ROOTZÉN, Chalmers University of Technology

Changing roles for the transmission and distribution networks

To combat anthropogenic climate change, it is clear that the European power sector will have to undergo a comprehensive overhaul to significantly reduce its CO_2 emissions. However, climate change is not the only issue, and other environmental problems as well as other concerns, such as security of supply, spur initiatives to reduce our dependence on fossil fuels and develop renewable energy sources for electricity production. Variable renewable power generation, in the form of wind and solar power, is currently growing quickly and is likely to play an even greater role in a future energy system. This implies that in the future, the supply side could become the main source of variability in the electricity system. Thus, whenever, for example, wind power generation increases or decreases, the surrounding system must adapt to maintain the balance. One possibility to handle the increased variability in supply, but also to access renewable power generation sites as well as to integrate distributed generation, is by using the electric grids differently compared to today.

Potential system benefits

In his research, Joel Goop studies how the usage of transmission and distribution grids change as the levels of variable renewable electricity generation increase. The variations in the supply could be reduced by trading across a geographical area, or to access existing flexible assets and, for example, use Nordic hydropower to manage variations in continental Europe (see, for example, Pathways Newsletter #3/2013). Distribution grids may also play an important role in integrating new renewable generating capacity. Since wind and solar power can be installed as relatively small units, they can be located in proximity to consumers, through distributed generation. This allows potential system benefits, such as reduced grid losses, and also enables close integration with DSM systems and local storage, although it could also impose new requirements on distribution systems.

New congestion patterns

The results of the modelling show that new congestion patterns arise in the European transmission system as a result of expansion of wind and solar power capacities, due to the low marginal costs of electricity at times of high output from these technologies. This is illustrated in Figure 4 where a “traditional” peak-load congestion pattern is compared to a new peak-wind congestion pattern. The research by Joel Goop and his collegues also shows that such peak-wind congestion may be difficult to handle with alternative variation management strategies, such as demand-side management (DSM), whereas for peak-load congestion, DSM may be an alternative to grid capacity expansion. Moreover, a rapid expansion of solar power generation within Europe could have a significant impact on marginal costs of electricity and could cause significant congestion during sunny seasons if its geographical distribution is uneven. It is, however, found that distributed solar power can help to reduce losses if the locations of new installations are optimised to maximise local consumption.

Figure 4 *Model results of network congestion (Above) Peak-load congestion arises due to a high load demand in central Europe while cheap available solar power exist in Southern Italy and the Iberian peninsula. There is also congestion between Scandinavia, where there is cheap hydropower, and continental Europe. (Below) Peak-wind congestion due to high wind power output in Northern Germany. The congestion is illustrated by the yellow curve in the maps. Higher marginal prices are represented by the more intense red colours.*

Read Joel Goop’s licentiate thesis **“The roles of transmission and distribution networks in integrating variable renewable electricity generation”.**

For further information:
JOEL GOOP, Chalmers University of Technology

A new role for the electricity consumer

In a future electricity system, the demand side is likely to have a more active role than it has had historically. Instead, future electricity consumers may, in part, take the role as producers and, thus, turn into prosumers. This implies an increased share of distributed generation, but also that the consumers may manage their loads through demand-side management measures. Emil Nyholm has investigated what such more active electricity consumers might entail, with special focus on assessing the technical and short term economical potential for demand response (DR), i.e., the shifting of loads in time, and the interplay between DR and distributed solar photovoltaic electricity (PV) generation in a Swedish context.

Demand respons potential

By modelling the building stock, based on an hourly energy balance, Emil Nyholm shows that there is a considerable technical potential for the DR of electric space heating in Swedish single-family dwellings. The total installed heating capacity is estimated to 7.3 GW, but all of this capacity is of course not fully available for DR at all times. The pattern of shifting varies with the actual season and time of day. Shifting time frames of up to 12 hours are possible during summer, although the maximum number of consecutive hours with a considerable reduction in load during winter is approximately 3 hours due to increased energy losses to the surroundings. The modelling results show that given the current Swedish electricity prices, up to 5.5 GW of decreased load and 4.4 GW of increased load can occur as a result of the shifting. The modelling also shows that, on an annual basis, DR shifts up to 1.46 TWh of electric heating, which corresponds to 1% of the total Swedish electricity demand.

Significant synergic effects

Emil Nyholm's research results also show that the synergic effects of DR and solar PV are significant for the DR of hydronic heating loads. The results indicate an ability to reduce yearly electricity cost for the average consumer by up to 5% depending on the size of the installation, see Figure 5. However, due to the seasonal mismatch between the hydronic load and PV electricity generation, the value of DR diminishes as the capacity of PV installations increase above 4.2 kWp for the average household (corresponding to an array-to-load, ALR, of 3 as given in Figure 5). The possibility of DR of common appliance loads, such as washing machines and dishwashers, on the other hand, shows weak potential for improving the value of a PV investment, despite the rather generous shifting time-frames allowed in the modelling.

Even though the current economic incentives for implementing DR is low given today's electricity prices, this may change in a future electricity system where more flexibility is required and therefore render a higher value (larger variations in electric prices to be expected). It should also be stressed that the modelling shows that managing the space heating and hot water heating loads provide the largest potentials of DR. It is also these measures that may entail the least behavior changes of the consumers, which indicate that the actual prospect of implementing DR and realising this potential is high.

Read Emil Nyholm's licentiate thesis: **"Demand response and distributed solar generation in the Swedish residential sector – A techno-economic evaluation"**

For further information:
EMIL NYHOLM, Chalmers University of Technology

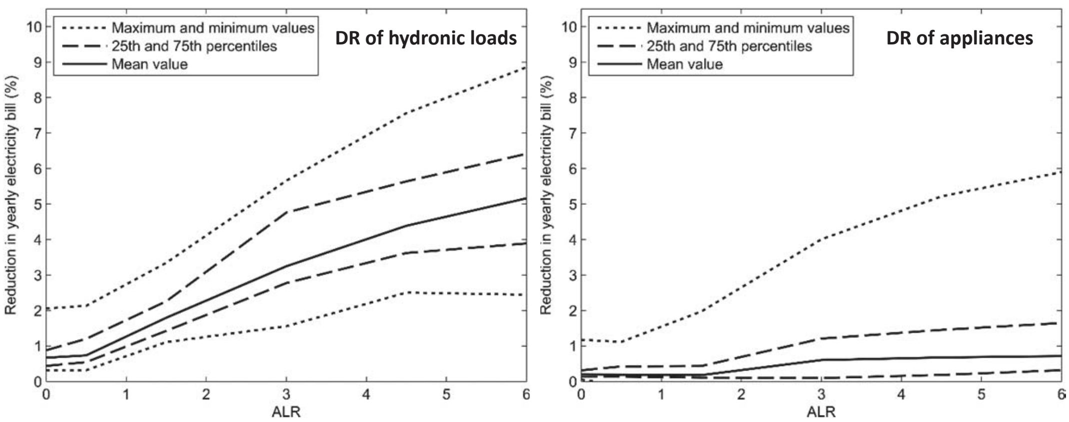


Figure 5 *Reductions in yearly electricity bill (not accounting for the investment cost of the PV panels) compared to an hourly pricing scheme for different array-to-load (ARL) ratios which represents the installed size of the PV installation. The left panel shows DR of hydronic loads and the right panel DR of appliances. Data and prices are based on actual values for Year 2007.*

System benefits for European wind power

In a future European electricity system, wind power and other variable renewables may constitute a large share of electricity production. One way of managing the inherent variability of wind power is to take advantage of the weather patterns when allocating wind power over larger areas, so that the aggregated output of wind power displays lower variation than that of a single region. This is a research area that Lina Reichenberg further explores by investigating the limits of geographic smoothing by optimising the regional allocation of wind power in Europe.

Allocation strategies

Different wind power allocation strategies will provide different system benefits, and in her work, Lina Reichenberg has studied allocations that yield:

- A high average output
- A smooth output, in which increments within the time span of 3-24 hours have been minimised
- An output that avoids low output
- An output in which wind power covers the maximum load within the region where it is produced

Capacity factors above 30%

The research results indicate that, while high average output (thus, explicit allocation to windy spots) is only favoured in one of the optimisation strategies, also allocations that result from optimising the other system benefits tend to display a high capacity factor (around 30% compared to 34% when allocating for high output), given the assumptions applied. Thus, considering that the present allocation has an average capacity factor of 20%, there are potentially large benefits to be gained from optimising geographic allocation. Figure 6 compares an optimised allocation (here based on high average output) to the present allocation of wind power in Europe.

Results also indicate that avoiding low output and smoothing the output give rise to similar allocations, i.e., there is virtually no trade-off between these two goals. If instead the objective of wind power allocation is to cover a maximum load within a region, this results in an allocation with high penetration levels of wind power, up to 60% of annual load, in windy regions. Taken together, the results from Lina Reichenberg's research highlight that wind power allocation can contribute to efficient use of wind power in a future Europe with a high share of variable renewables in the electricity system.

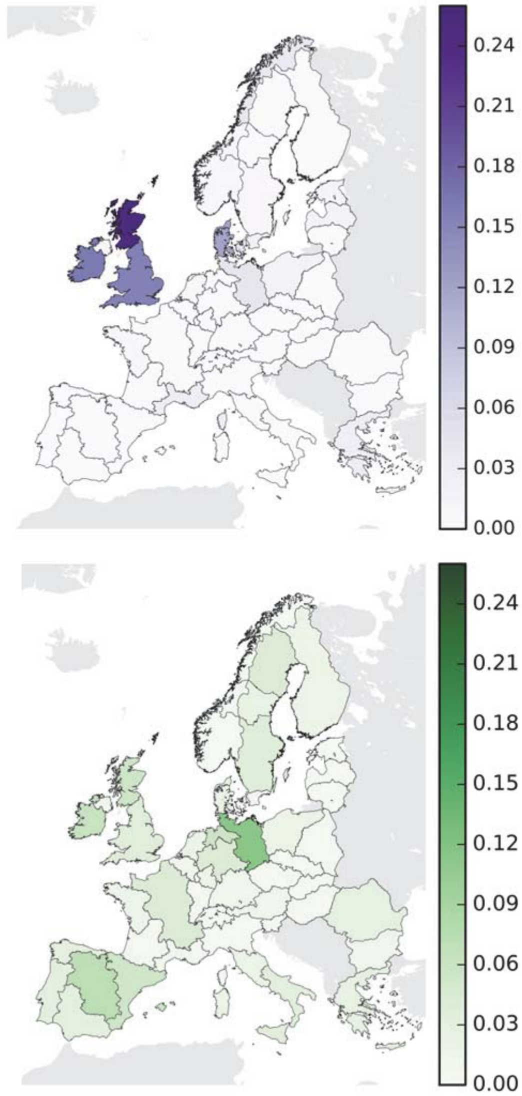


Figure 6 *Shares of total installed capacity for: a) the High-output strategy; and b) the present allocation case. In a) the total installed capacity is 250 GW, while for the present allocation (b) the installed capacity of 136 GW is taken from the Chalmers Power Plant database*

Read Lina Reichenberg's licentiate thesis: **"System benefits for the European wind energy system - The effect of optimizing geographic allocation"**

For further information:
LINA REICHENBERG, Chalmers University of Technology

The Pathways research programme

This newsletter reports on the progress and results from the research programme "Pathways to sustainable European energy systems". The main objective of the research programme is to conduct a comprehensive analysis and assessment of the long term transition of the European energy system towards significantly reduced CO_2 emissions in Year 2050. This development follows the roadmap towards a competitive low-carbon economy set out by the European Commission. The focus of the research is on the transformation of the electricity system with links to relevant sectors such as the heating and transportation systems.

pathways TO SUSTAINABLE EUROPEAN ENERGY SYSTEMS

More information about the Pathways research programme:
www.energy-pathways.org