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NEWSLETTER FROM »PATHWAYS TO SUSTAINABLE EUROPEAN ENERGY SYSTEMS«

#2/2013

Filip's column

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Prof. Filip Johnsson
Project manager of the Pathways project

Pathways to Sustainable European Energy Systems is a project within

THE AGS
The Alliance for Global Sustainability

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Public attitudes to climate change and carbon mitigation

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Strategies for wind power allocation in Europe

The electricity generation system in Europe is moving towards CO_2-free technologies, where wind and solar power are likely to form a large part of the generation. The intermittent nature of these sources can be compensated for on the generation (dispatchable plants), transmission and demand sides. In addition, geographical allocation of wind and solar plants can be deployed to facilitate large-scale penetration of variable generation into the energy system.

Lina Reichenberg investigates strategies for cost-effective integration of large amounts of wind power into the European energy system with a focus on geographical allocation.

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Filip's column

In order to analyze the possibilities and challenges of large-scale deployment of wind and solar power in Europe, there is a need to have a powerful modelling toolbox. This newsletter presents recent development of our modelling package which we now think have the necessary features required to evaluate the effects from intermittent generation under different scenarios. It should be kept in mind that the current installation of renewable electricity generation technologies in Europe as a whole is currently small compared to what is required to meet climate and renewable targets beyond 2020. It is therefore important to analyze how large amounts of especially wind power can be integrated into the system and we have started to do so, as also described in some of the previous newsletters.

This newsletter also shows some important work related demand side management both in industry and with respect to possibilities to use thermal storage in district heating networks. Although Demand Side Management (DSM) is a "hot topic" today, there is rather little known on what it can deliver and at what cost, especially with respect to the participation from industry. We have initiated some work in the area and this newsletter exemplifies from two Master thesis works. One thesis investigated the potential role of DSM measures in the Swedish industry by conducting in-depth analyses of the electricity use in key industries. The results indicate a large potential of DSM capacity in the Swedish industry, which could facilitate large-scale integration of intermittent electricity generation. Yet, current electricity prices do not provide sufficient incentives for implementing this potential, but additional economic compensation is needed. The other thesis has analyzed optimal dispatch of heat production technologies in a district heating network (with and without the possibility of thermal storage) for different scenarios. This includes a future outlook when electricity generation system is assumed to include a high share of intermittent electricity generation. The topic is of high relevance since it can be assumed that with higher and more volatile electricity prices, there will be an increased electricity generation in CHP units. Our future activities will put more focus on DSM and demand side response as means to facilitate large-scale integration of intermittent electricity generation. I am very excited to see the answers from these studies – and I hope you are too!

I wish you all a nice summer!

Prof. Filip Johnsson
Project manager of the
Pathways project

Sustainable Use of Energy Carriers in the Kattegat / Skagerrak (KASK) Region

Photo from http://kask-energy.eu

Recently, a new EU Interreg project has started. The aim of the project is to study how improved energy efficiency and large-scale integration of renewable energy can contribute to economic and environmentally sustainable development of the Kattegat-Skagerrak region (KASK). The project will include detailed studies of how to improve energy efficiency in key industries and in the existing building stock. It will also investigate the possibilities and impact of integrating wind power in the region. The project has several connections with the Pathways project and will give information on the importance of local conditions such as is expected to be obtained from the detailed mapping of land availability for siting of wind power which is currently carried out in the KASK project.

Possible pathways for the KASK region will be studied using the present energy system as starting point. The pathways will be evaluated in the short (2020), medium (2030) and long term (2050).

The project is organized with Chalmers as lead partner and Tel-Tek as project coordinator. In addition there are several other partners involved. More information is available at http://kask-energy.eu.

Interreg IVA
ÖRESUND – KATTEGAT – SKAGERRAK

Assessing the value of thermal storage in a district heating system

In a recent Master thesis work, the value of thermal storage in a district heating system is explored. The optimal dispatch of heat production technologies is investigated for different scenarios, including a future outlook when the electricity generation system is assumed to include a high share of intermittent energy sources. In this work, the district heating system of Borås is used as a case study. It is shown that thermal storage present in the district heating provides added value, for example, by reducing heat production costs, enhancing the use of base-load units and decreasing the operation of peak-load units.

In a future scenario with a higher share of intermittent energy sources in the system, we are likely to experience a greater volatility in electricity prices and possibly, an even greater discrepancy in the minimum and maximum daily prices than today. A district heating (DH) system containing a combined heat and power (CHP) unit and a thermal storage unit may have the possibility to turn the volatility of electricity prices into a competitive advantage. Berna Melissa Akkaya and Dmytro Romanchenko have in their Master thesis assessed the value of including a thermal storage unit in a district heating system as a basis for discussing its optimal use and potential role in the system.

An optimization model is developed and applied

In order to assess the value of thermal storage, a mathematical-based model has been developed. The model is capable of generating an optimal operation schedule for all the units present in a district heating system, with an objective to minimize total system heat production cost. Berna and Dmytro have in the thesis applied their model to the district heating system of Borås as a case study. Different scenarios are investigated to define the optimal dispatch of heat production technologies and to assess the value of energy storage in different sets of conditions. This includes both current conditions as well as a prospective outlook assuming higher and more volatile electricity prices due to a high share of intermittent power sources in the national energy system.

Thermal storage provides added value

The modeling results based on current conditions indicate the value of having a thermal storage unit available in the system. For all cases analyzed, representing different heat demand and demand patterns, the total heat production costs decreased when thermal storage was present in the system compared to when it was not. The presence of a thermal storage unit enhanced the use of base-load units and decreased the use of peaking units, suggesting both economic and environmental benefits of thermal storage, see Figure 1. The future outlook, with higher and more volatile electricity prices, implies increased power production in CHP units. The optimal thermal-storage use strategy remains, however, similar as for the price curve seen today. For the specific system analyzed, it was concluded that the existing thermal storage unit (a hot water storage tank with a maximum capacity of 1900 MWh) is sufficient to serve as a redundancy unit in case of a breakdown of several heat producing units for up to 30 hours. However, in what way the system reacts to more extreme weather condition needs to be further researched.

The MSc thesis *Modeling and analysis of a district heating system containing thermal storage- Case study of the district heating system of Borås* is available at the Division of Energy Technology, Chalmers.

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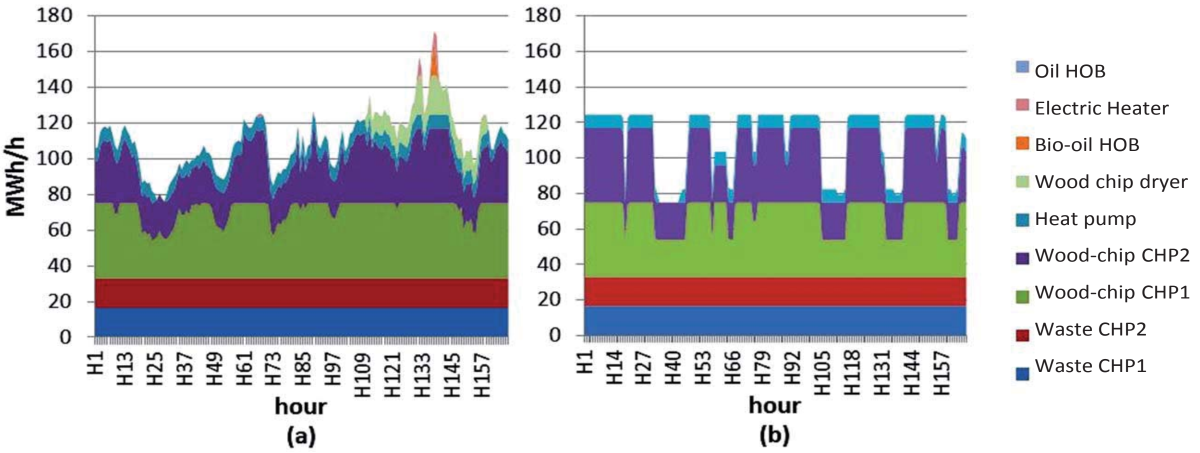

Figure 1. *Modeling results of cumulative heat production from the reference scenario (current situation) in a typical week in January for the DH system in city of Borås a) with no storage in the DH system b) with thermal storage in the DH system.*

Developments of the electricity-supply modeling package

In the Pathways project, future pathways of the entire European energy system are analyzed using a model package consisting of several sectorial energy models developed in the project (for a detailed description, see the Pathways Methods and Models book, available at www.energy-pathways.org). In the second phase of the project, there is a focus on the development of the electricity system including possible scenarios of large-scale integration of renewable, typically intermittent, energy resources. A large share of the modeling development effort has, therefore, been directed towards the electricity-supply system in order to respond to these research issues. Here we focus on some of these developments.

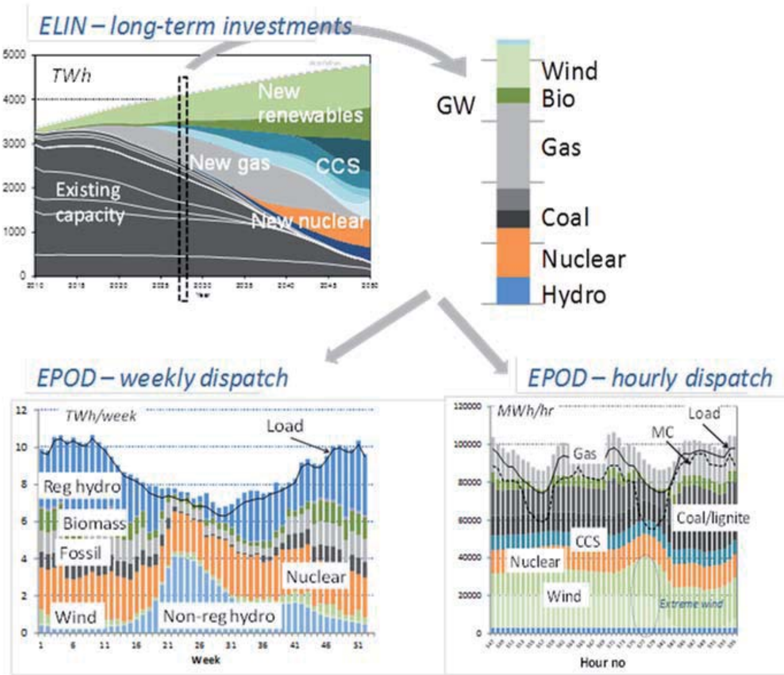

Figure 1. *The ELIN model optimizes the long term investment strategies for the electricity supply sector. The results are thereafter analyzed in detail with the short-term dispatch model EPOD.*

The electricity-supply modeling package

The two main models applied to the electricity-supply sector are ELIN and EPOD (see Figure 1). The ELIN model is a long-term dynamic optimization model which describes the present generation system derived from the Chalmers power plant database and an extensive basket of new technologies which are to meet the changes in future demand as existing capacity comes of age or becomes unprofitable. The short-term dispatch model EPOD analyzes in detail a specific year based on the capacity (existing and new) obtained in a preceding ELIN model run. The dispatch analyses may be conducted weekly, diurnal or hourly. Findings from the EPOD analyses concerning the feasibility and efficiency of the system are fed back into ELIN in order to improve the setup of that model.

Regionalization of ELIN/EPOD

Included in the ELIN/EPOD package is a regionalization, i.e. Member States are further divided into 50 intra-national regions (see Fig. 2) composed of a specified set of NUTS2 areas. The regions are defined by major transmission bottlenecks, as seen today and in the near future. Thereby, intra-national as well as international grid issues may be handled. The refined regionalization also provides means to investigate allocation of renewable power, such as wind and solar power, where production often is highly dependent on geographical siting.

Renewable power generation

Research activities in the Pathways project provide detailed mappings of wind and solar resources including, for instance, production profiles, estimates on potentials and covariance of wind and PV electricity generation depending on geographic allocations (see p 8 and Newsletter 2013:1). These findings are linked to the electricity-supply model package. For example, there are eight different investment classes for onshore wind power implemented in the ELIN model. Each class corresponds to different wind availability with an upper limit on the amount of capacity, the potential that the class can host for a specific NUTS2 area. Thus, a step-wise cost supply curve with individually sized steps for each NUTS2 area is generated. So far, for offshore wind power there is one investment class per NUTS2 area applied. Moreover, each NUTS2 area has a unique wind generation pattern corresponding to a production profile. For solar power, four investment classes, with technology dependent generation patterns, are implemented. All this

Figure 2. *The subdivision of EU-27, Norway and Switzerland into 50 individual regions in the ELIN/EPOD model package. The regions are linked through interconnector capacities.*

yields hourly production profiles, which are used as key inputs to the EPOD model.

The hydropower resource is subdivided into regulatable and non-regulatable hydropower. Depending on hydropower type, generation is defined and limited by output capacity, inflow profile and total yearly output. Nordic hydropower is, in addition, modeled with regional reservoir constraints. To formulate these constraints, the allocation of hydro power resources is based on a full year model run with weekly resolution. Using a model run rather than data has the advantage of allowing the model to distribute the hydropower resource in time differently compared to today based on changes in the rest of the electricity generation system. An increased wind power generation may for example be unevenly distributed over seasons and geographic areas and change the optimal use of the hydropower resource.

Cycling costs for thermal generation

Responding to large amounts of varying power generation from intermittent energy sources will put new requirements on flexibility of the thermal power generating units present in the electricity system. The need for an approach to account for costs to vary the production level is evident. Therefore, cycling costs for thermal generation has been introduced in the EPOD model by including minimum load levels and start-up times. This reduces the ability of saving fuel (and costs) between hours of production by sudden large reductions in output.

A result of introducing cycling costs is exemplified in Figure 3. This is a case representing high penetration of wind power (40%) by 2020 in Northern Poland. This is a region with high wind potential. Currently, however, wind contributes only marginally to the electricity generated in that region. The results indicate that wind power production may significantly replace coal-based power. At the same time gas based power is increased, even though the marginal costs of coal power is, in general, lower than the marginal costs of gas power. Including cycling costs and assuming that gas power has superior cycling properties will, thus, add relatively more costs to the operation of coal power plants. Since an increased penetration of wind power will lead to increased cycling of thermal power plants, model results indicate that such a development may promote the use of flexible units such as gas power. Such a conclusion does, however, rest on the assumption that the marginal cost of gas power is not too high compared to the marginal cost of coal power.

Stability constraints in the transmission system

The electricity transmission system suggests both opportunities as well as challenges for the large-scale integration of renewable energy sources. The regionalization of ELIN/EPOD into 50 regions, where the borders are chosen to represents major bottlenecks in the European transmission system, enables a further analysis of these issues. The EPOD model is designed to be able to account for stability constraints as a part of the dispatch optimization, or for post-optimization analysis of congested lines. Stability constraints are included by applying DC load flow analysis; i.e. each region presented in Figure 2 has a variable phase angle and transmitted power over a connection is given by the phase angle difference between the regions in question. This means that the interdependencies of active power flow between regions in a meshed synchronous system are taken into account.

In addition to above mentioned developments of the electricity-supply model package, there is a continuous development and updating of the databases providing input data of the existing generation system to the model as well as the economic and technical descriptions used by the models.

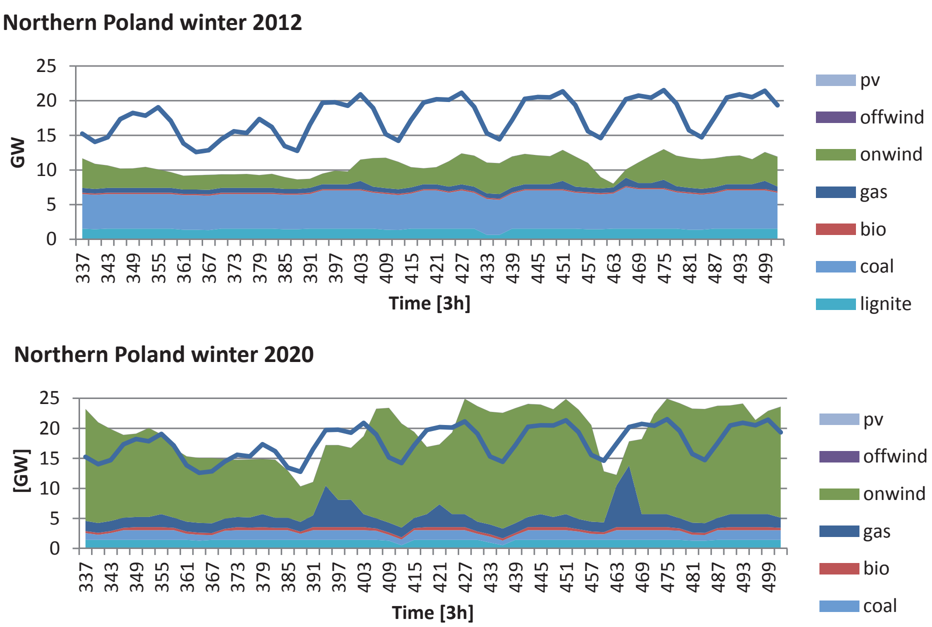

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Figure 3. *Modeling results for the region Northern Poland when cycling costs are included. Upper panel corresponds to the present system. In 2020 (lower panel) it is assumed that the region have a 40 % share of wind power installed. The difference between demand (blue line) and supply is balanced by import from or export to surrounding regions.*

Demand Side Management in Swedish Industry

Soran Esmailnajad and Jens Sundquist have in their Master thesis investigated the potential role of Demand Side Management (DSM) measures in the Swedish industry by conducting in-depth analyses of the electricity use in five key industries. The results indicate a large potential of DSM capacity in the Swedish industry, which could facilitate the large-scale integration of intermittent energy sources. However, current electricity prices do not provide sufficient incentives for implementing this potential, but additional economic compensation is needed.

In their thesis, Soran and Jens have explored the possibility for the Swedish industry to modify their electricity load pattern by implementing Demand Side Management (DSM) measures. Cost reductions are often the main motivation for applying DSM, but other incentives are to reduce peak generation capacity, to increase reliability of the system, and to reach environmental targets.

The electricity use by the Swedish industry corresponded in 2010 to 36% of total electricity consumption in Sweden, where the dominating electricity-intensive industrial sectors are: the pulp-and paper industry; the steel and metal industry; and the chemical industry. In fact, the pulp and paper industry make up for almost half of total industrial electricity consumption in Sweden. This indicates the potential impact a change of the load pattern in the industrial sector may have on the energy system.

Analysis of five key industries

A survey of the specific electricity use in industry was conducted by collecting data from literature, statistical sources and directly from companies. Five key industries, representing the main three electricity-intensive industrial sectors, were selected for in-depth analysis of the DSM potential, focusing on Load shedding and Load shifting. A step-by-step method was applied for each case to specify and classify the electricity load and determine potentials for load shedding and load shifting. This includes compiling load-duration curves and distributing total consumption over the different sub-processes where the loads are categorized either as a batch or a continuous process and the load cycle shape is determined. The restrictions and limitation for each load is accounted for before the potential for load shedding and load shedding, respectively, is calculated and evaluated. Figure 1 illustrates a possible response to changes in electricity price in the loads of a steel and metal industry investigated.

A large DSM potential exist in the Swedish industry

The survey and case study analyses show that the Swedish industry is very heterogeneous regarding their production characteristics and electricity use. Even for the same production category and industrial branch, similar processes differ in demand and pattern. This indicates the need of an analysis for each specific case. However, specific case studies may be used to estimate, at least roughly, the DSM potential of similar processes and highlight interesting areas of application. The results from the specific analyses suggest a DSM potential of around 250 MW for the five industries investigated in this thesis. They indicate a large potential of DSM capacity for the aggregated Swedish industry, and especially in the Mechanical pulp-and paper industry. In spite of these significant DSM potentials, the analyses show that current electricity prices are not sufficient to provide economic incentives for the Swedish industry to modify their load patterns. This implies that there is need for additional economic compensation to engage the industry to respond to, for example, a deficit on the electricity-supply side.

The results of the Master thesis project provide important input for further research in the Pathways project. The MSc thesis *Demand Side Management in the Swedish Industry* is available at the Division of Energy Technology at Chalmers.

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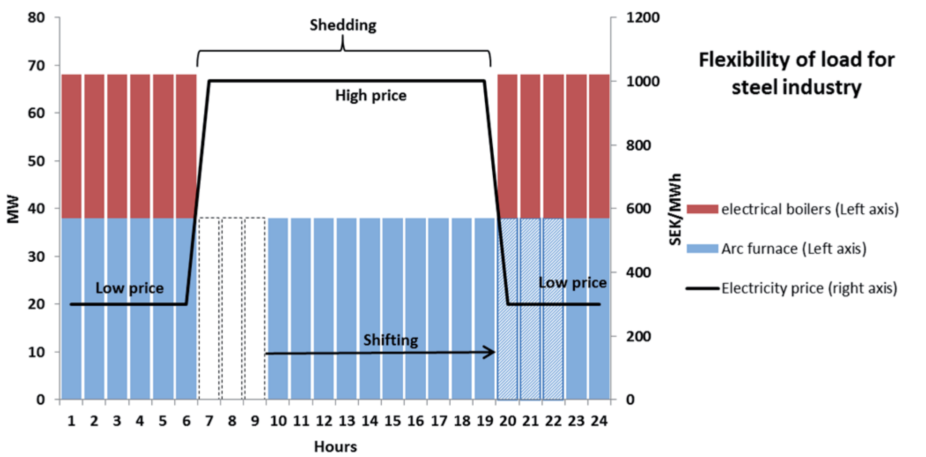

Figure 1. *Illustration of possible response to electricity price changes for the arc furnace and electrical boilers in one of the industries investigated, Steel and metal Industry A, in this thesis project (Source: Company information).*

Public attitudes to climate change and carbon mitigation

A study performed within the Pathways project shows that an increasing number of Swedes believe that a change in life style is a necessary measure in order to solve the climate problem while less people now think that technical solutions will be sufficient. This indicates an increased awareness among the public of the need for lifestyle changes, which could facilitate implementation of policies promoting environmental behavior.

Households contribute to GHG emissions through everyday energy-related behaviors, such as heating the home, electricity use, use of public transportation, and increased consumption of products and services. To cut GHG emissions and mitigate global climate change, there is a need for drastic transformation of the entire energy system which, thus, obviously involves the general public.

Exploring public opinions to understand psychological factors

The drastic cut of emissions will require strong policy measures across all sectors, including those that will directly influence consumers and their behaviors. However, the implementation of strong and sustainable policy measures requires a comprehensive understanding of what underlying mechanisms and procedures are needed for people to accept the measures and to act in environmentally benign manners. This is the aim of a joint study, within the Pathways framework, by researchers from Chalmers and the University of Gothenburg. The study explores public opinions regarding climate change and mitigation options. It also examines how psychological factors, such as attitudes, norms, preferences on new energy technology and willingness to pay, may determine energy efficient behavior. The work is part of several joint studies in which the general public has been polled in the US, the UK, Sweden, and Japan (see Chapter 20 in "European Energy Pathways", available at www.energy-pathways.org). The present study is based on two surveys performed in Sweden in 2005 and 2010.

Life style changes are highlighted

The results show a substantial shift in opinion regarding new technologies as a solution to mitigate climate change occurred between the 2005 poll and the 2010 poll. In the 2010 poll, the majority believe that lifestyle changes would be necessary whereas technologies as a solution are ranked higher in the 2005 poll, see Figure 1. Moreover, the change in opinion is also reflected by the decreased share of more skeptical statements such as we will have to ''learn to live with and adapt to a warmer climate'' and that ''global warming is a problem but Sweden will not do anything about it''. These results clearly signal a shift toward increased awareness of the gravity of the climate change problem. They also indicate that the respondents are aware of the need to contribute to mitigation of climate change by changing lifestyle.

Renewable energy and energy-saving measures are top ranked

In both polls, the areas of renewable energy and energy-saving measures were ranked as the most important mitigation options to be prioritized by the Swedish Government. These areas are likely to be considered as ''abstract'' and superordinate response alternatives. The other response alternatives address more specific targets, such as investments in public transport or energy-efficient

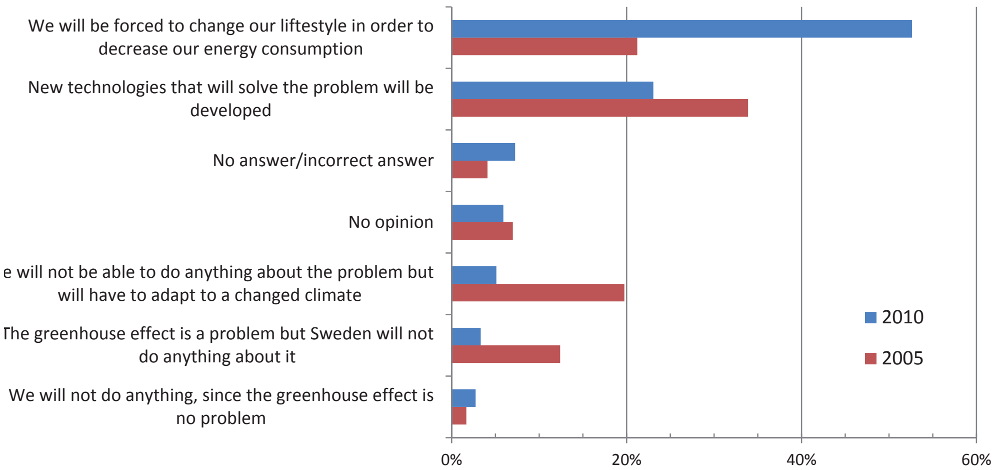

Figure 1. *Swedish respondents' were asked to choose only the option that corresponded to their opinion of how Sweden should address the issue of climate change in 2005 and 2010.*

buildings, and are thus most likely to be viewed as more concrete and subordinate options. This is in line with other research which has shown that it is easier for people to hold a positive attitude toward a nonspecific area, such as ‘‘the environment’’, rather than admitting a specific behavior, such as reduced car use, in favor for the environment. These aspects must obviously be considered when designing and communicating policies.

Increased awareness could pave way for stricter policies

The findings of this study show that there is an increase in awareness of the need for changing lifestyle among citizens to cope with climate change. Yet, to transform the increased awareness to action requires policies, but this increased awareness among the public may constitute a foundation for acceptance of the implementation of more strict policy measures instead of relying on voluntary and more ‘‘softer’’ policies such as information. It can be concluded that policy recommendations have to take a psychological perspective, predominantly with respect to changing behavior (e.g., attitudes and abilities), although it is equally important to target demographic factors, such as level of income. Therefore, it is essential to consider household energy use from several perspectives.

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Strategies for wind power allocation in Europe

The electricity generation system in Europe is moving towards CO_2 free technologies, where wind and solar power are likely to form a large part of the generation. The intermittent nature of these sources can be compensated for on the generation (dispatchable plants), transmission and demand sides. In addition, geographical allocation of wind and solar plants can be deployed to facilitate large-scale penetration of variable generation into the energy system. Lina Reichenberg investigates strategies for cost-effective integration of large amounts of wind power into the European energy system with a focus on geographical allocation.

The work presented here investigates strategies for cost-effective integration of 250 GW of wind power into the European energy system with a focus on geographical allocation. Three allocation strategies are investigated with the aim to: 1) maximize capacity factor of aggregated output (allocation to windiest sites), 2) maximize Conditional Value at Risk (CVaR) and minimize intra-period changes of aggregated output (dampen variation in the aggregated wind power output) and 3) maximize regional load coverage from wind power.

The allocation is determined by a multi-objective optimization model with detailed weather data and regional load data for EU 27, Norway and Switzerland. Europe is divided into 52 regions, designed to mirror the limitations in transmission capacity.

Wind power is built where it is windiest

Strategy 1 leads to large wind power installation in UK and Ireland, and northwest continental Europe. The region with the highest relative production (load/wind power production) produces as much as eight times its annual load. This means that instant production may be even higher, compared to the load, since both wind power production and load vary in time. The capacity factor of the aggregated output is 33.4 % and aggregated production is heavily dominated by the wind conditions in and around the UK, and, thus, there are large variations in wind production. Figure 1 (left panel) shows the time series of the aggregated output according to this strategy.

Dampened variation of the aggregated wind power output

Strategy 2 benefits from the complementary nature of geographically dispersed wind power, by allocating (and building away bottlenecks) so as to minimize the probability for a low output in aggregated wind power production. The aggregated time series for this strategy is presented in Figure 1 (right panel), and the capacity factor is 25.6 %. The allocation becomes quite dispersed, but with a bias towards windy regions.

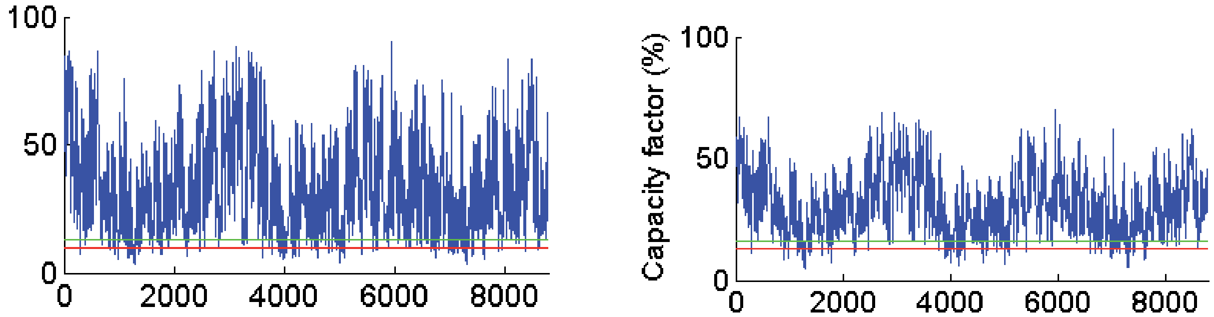

Figure 1. *Time series of aggregated wind power output (capacity factor). **Left**: Allocation for maximizing capacity factor (Strategy 1), **Right**: Allocation which dampens aggregated output variation (Strategy 2). The time series are on a 3-hourly resolution over three years. The yearly variation is visible in both time series, with three winter peak periods.*

Wind power allocation according to regional load

Strategy 3 is a strategy for a non-integrated European future with limited electricity trade between regions, i.e. momentary excess wind production has no value in the model. Thus, this strategy maximizes the sum of the wind power that can be used within the same region where it is generated. This strategy leads to an uneven distribution of penetration levels for wind, where windy regions may reach a total wind production of up to 65 % of the demand, while regions with less favorable wind conditions lack wind power. Figure 2 shows the modeling results for Strategy 3 in terms of share of total wind power (250 GW) installed in each region.

The modeling of the different strategies shows that using geographical allocation, the aggregated output can be modified so that the output essentially varies between 15 % and 60 % of installed capacity (to be compared with the wind-power variation of a country which typically varies between 0 and maximum output). There is a trade-off between high capacity factor and system benefits, but Strategies 2 and 3 also favor windy sites. This entails that it is possible to get system benefits, while keeping the capacity factor high. There was a certain overlap between the allocations in Strategies 2 and 3, indicating that it would be possible to allocate wind power for the present system with limited transmission, while getting system benefits with integration at a later stage.

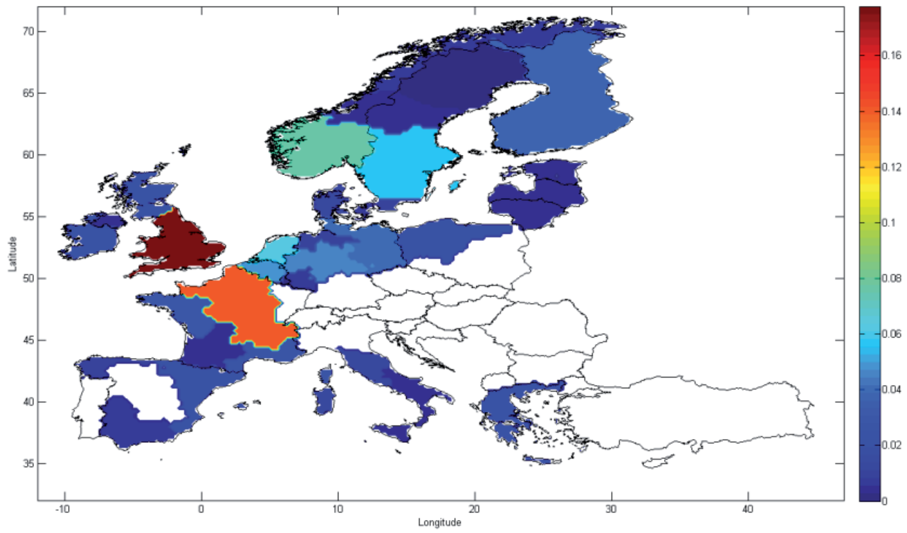

Figure 2. *Modeling results of the share of total wind power (250 GW) installed in each region for Strategy 3 (wind power is allocated to maximize regional load coverage from wind power).*

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