RESULTS AND CONCLUSIONS
THE FIRST PHASE OF THE NEPP PROJECT

88

pearls of wisdom

NEPP
north european power perspectives

More information about the project
NEPP - North European Power Perspectives
can be find on the proejct’s homepage:
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Results and conclusions
The first phase of the NEPP project

February 2016

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NEPP
north european power perspectives

NEPP is a coherent multi-disciplinary research project focusing on the development of the electricity systems and the electricity market in Sweden, the Nordic countries and Europe with the time perspective 2020, 2030 and 2050. The research is performed by around ten well-merited researchers and analysts. The current phase of NEPP will run up to March 2016.

NEPP's goal is to deepen the insight about how the Nordic countries and the actors on the Swedish and Nordic energy markets can act to be able to - in a cost effective way and with the focus on the growth perspective – meet the expectations from the energy and climate politics in EU and the Member States, and the challenges from a changing world.

The research is charged with the task of showing how *a balanced and effective development* of the Nordic countries' and the EU's energy systems can be achieved, and how the political goals can be realised for the benefit of the society and its actors. The research should strive to identify the *success factors* for this balanced development. This can relate to the choices made in the development of the operations of electricity and energy systems, market rules, the choice of and the design of policy instruments, etc. A deeper understanding should also be gained about *the expectations* on the energy actors, politicians and the society at large, to realise various goals and development paths

More information about the NEPP project can be found at www.nepp.se.

NEPP is funded by the electricity companies, Svenska Kraftnät, The Swedish Energy Agency, and The Confederation of Swedish Enterprise. Nordic Energy Research, Swedish Smartgrid and The Royal Swedish Academy of Engineering Sciences (IVA) have contributed to the financing of some of the sub-projects. The work is supervised by a steering team which is chaired by the Director-General of The Swedish Energy Agency. Energiforsk acts as a project host.

The research and synthesis efforts in NEPP are carried out by five research teams at Chalmers University of Technology, KTH Royal Institute of Technology, Profu, Sweco and IVL Swedish Environmental Research Institute. Profu is the project leader for NEPP and Sweco is assistant project leader.

Content

NEPP's goals and tasks

NEPP's ***goal*** is to deepen the insight about how the Nordic countries and the players on the Swedish, Nordic and the North European energy markets can act to, in a cost-effective way and with the growth perspective in focus, meet the challenges that arise from the energy and climate politics in the EU and its Member States, and from the impact from the development of other external factors.

The overarching task for the research is to show how ***a balanced and efficient development*** of the Nordic and European electricity system can be achieved, and how the political goals can be realised to the benefit of the society, the customers on the electricity market, the electricity companies and the business as a whole. The research shall aim at identifying ***success factors*** that promote this balanced development. This could apply to choice of paths when developing and operating the electricity and energy system, new market regulations, the choice and design of policy instruments etc. A deeper understanding should also be sought regarding the ***expectations*** on energy actors, politicians, and the society in general in realising goals and implementing development paths. NEPP also has the ambition of contributing to a better foundation for the energy and environment-related political decisions, nationally and internationally.

A mission for NEPP is also to be a meeting place – a forum – for a fact-based discussion and dialogue between decision-makers and other energy actors from different areas and countries. The project should therefore also stimulate a constructive dialogue between researchers, politicians, authorities and players on the energy markets. Today, this forum is in full swing. We would gladly welcome this forum to continue to operate and we hope that the discussion around the themes NEPP is working with will go on. The project management is also asked by the funders to plan for a continuation of the project.

Multidisciplinary research and analysis

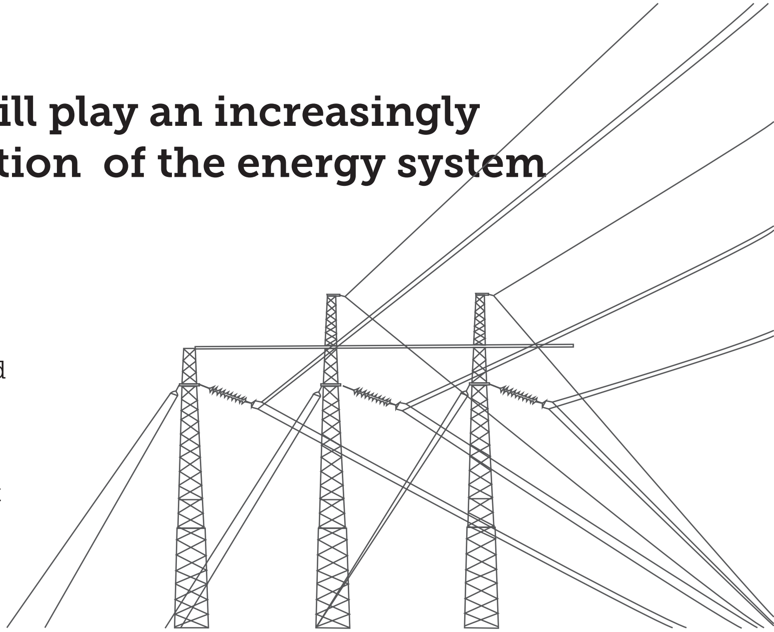
Energy and environment system analysis is best done in a multidisciplinary context. Analysing energy and environment systems is a delicate task that requires cooperation between different scientific disciplines. This, not least, since the questions generally involve technology, environment, economics and, not to forget, social structure and human interaction. In NEPP we have had a broad anchorage in the different scientific disciplines in the project as well as through the cluster of cooperating projects which constitutes NEPP.

An established forum with a long history – from Nordleden to new NEPP

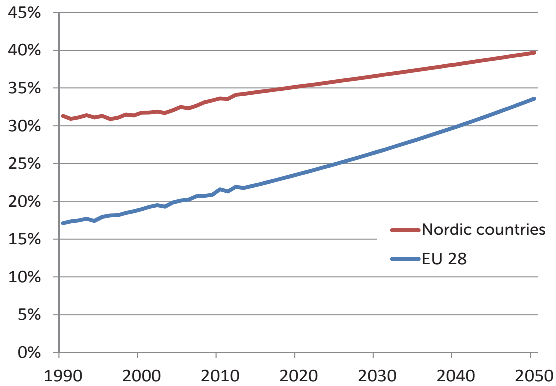
NEPP (North European Power Perspectives) and its predecessors NEP (Nordic Energy Perspectives) and Nordleden has been a central and policy-related research platform since the mid-90s, on which the energy branch with its enterprises, the ministries, the authorities, academia, and the research companies have cooperated under the supervision of Elforsk/Energiforsk and the Swedish Energy Agency. The research projects have all the way through been focusing on current – yet long term – research topics, have been multidisciplinary and neutral, and have had a close dialogue with politicians and other central decision-makers in the energy systems. The projects have acted internationally and nationally, regarding the research as well as interested parties. NEPP's predecessors involved the whole energy system (and had a supply perspective), whereas NEPP so far has had a narrower electricity focus, at the same time as the research has been widened to cover the entirety (from supply to demand, from electricity system to electricity market).

1 The electricity system will play an increasingly central role in the transition of the energy system

Electricity and the electricity system play – and are expected to play – an increasingly central role in the transition of the energy systems in Sweden, the Nordic countries, and in Europe. The share of electricity of the total final energy demand increases. In the Nordic countries, the share of electricity has increased from slightly above 30% in 1990 to almost 35% in 2012. In the EU, the share of electricity has grown even faster , from about 17% in 1990 to 22% in 2012. The share of electricity has steadily grown, year by year, with a few exception, in times of economic slowdown as well as in times of economic growth.



The share of electricity of the final energy demand is expected to continue to grow. NEPP's analyses, as well as the EU energy scenarios, indicate a doubling of the electricity share in EU between 1990 and 2050. This would correspond to a level of about 27% by 2030 and close to 35% by 2050. The growth is also expected to continue in the Nordic countries and electricity is projected to reach a share of 37% by 2030 and around 40% by 2050.



The electricity share of the final energy demand in the Nordic countries and in the EU. The graph shows the historical development from 1990 to 2012, and the projected develomment, based on the synthesis of several different energy demand scenarios, for the period up to 2050.

The Nordic electricity system is well prepared to meet the future challenges and uncertainties (on the different pathways included in NEPP's energy system scenarios). As opposed to the electricity system for the EU as a whole, the electricity system in Sweden and in the Nordic countries is characterised by an electricity generation associated with low greenhouse-gas (GHG) emissions and a high share of renewable energy sources. Electricity demand has previously, in a historic perspective, increased steadily in all Nordic countries, but have in recent years stagnated (even though the share of electricity has continued to grow, as mentioned above). This has, together with increased support of renewable electricity expansion, led to a surplus of electricity and a significant net export of electricity to our neighbouring countries during the last three to four years.

The different energy system scenarios should be viewed having the historical development and current situation in mind. The Nordic electricity system might therefore contribute to solutions in other countries through an increased electricity export and an increased electricity use in other sectors . However, this prerequisite that nuclear power is not phased-out before reaching its technical lifetime.

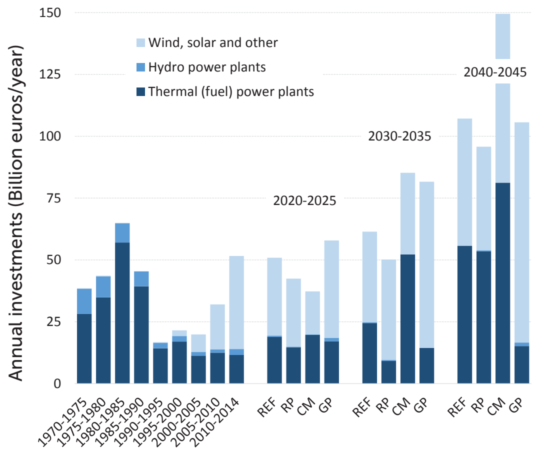
The uncertainties and challenges for the electricity systems in other parts of Europe are much larger. Many European countries have, already in the years to come, large climate commitments that will be difficult to fulfill. If we compare the uncertainties and challenges that the EU climate and energy targets put on the electricity systems in the UK and in Continental Europe by Year 2030, with the corresponding challenges facing the Nordic electricity system, the difference is significant. Our analyses show that even in a longer time perspective (up to Year 2050), the challenges will be huge regardless of which means of power production that will be predominating.

<table>
<tr><th>Challenges/uncertainties 2030</th><th colspan="2">Continental Europe and the UK</th><th colspan="2">The Nordic countries</th></tr>
<tr><td>Renewable energy (increased share)</td><td colspan="2">VERY LARGE challenge</td><td colspan="2">No/Moderate challenge</td></tr>
<tr><td>Reduction of carbon dioxide</td><td colspan="2">VERY LARGE challenge</td><td colspan="2">No/Moderate challenge</td></tr>
<tr><td>Capacity management</td><td colspan="2">LARGE challenge</td><td colspan="2">Moderate challenge</td></tr>
<tr><td>Transmission / distribution networks</td><td colspan="2">LARGE challenge</td><td colspan="2">Moderate challenge</td></tr>
<tr><td>Profitability for thermal power</td><td colspan="2">LARGE challenge</td><td colspan="2">LARGE challenge</td></tr>
<tr><td>Electricity market development</td><td colspan="2">LARGE challenge</td><td colspan="2">Moderate challenge</td></tr>
<tr><td>Nuclear power (country specific)</td><td>LARGE challenge</td><td>Moderate challenge</td><td>LARGE challenge</td><td>Moderate challenge</td></tr>
<tr><td>CCS (technology and acceptance)</td><td colspan="2">VERY LARGE challenge</td><td colspan="2">No/ Moderate challenge</td></tr>
<tr><td>Electricity demand development</td><td colspan="2">Moderate challenge</td><td colspan="2">Moderate challenge</td></tr>
<tr><td>"Cables" Nordic countries – Continent/UK</td><td colspan="2">LARGE challenge</td><td colspan="2">LARGE challenge</td></tr>
</table>

The energy and climate politics in the EU and its Member States is the factor with the largest impact on the development of the electricity system. The GHG target for 2020 is already achieved, but fulfilling the commitments for renewables by 2020 is still a big challenge for many (large) European countries, not for Sweden and the Nordic countries though. The targets for 2030 will have an even more profound impact on the electricity systems, even in the Nordic countries.

The amount of renewable electricity included in the Swedish and the Nordic electricity system the next 10-15 years will be determined solely by our own politics. In the long run, after 2030, our scenarios show a demand for relatively large quantities of wind power (and even solar power), but in the short perspective, the demand is considerably smaller. Neither EU expectations, nor electricity shortage, motivate more of renewables in the short term, only the national political demands do.

The transition of the European electricity system requires large yearly investments all the way up to 2050, at the same levels as during historical peak years. All our scenarios show that the investments in the electricity systems on "the Continent", will reach levels the coming 10-20 years, which are of the same magnitude as the historical top records, and in some of the scenarios the investments will be even larger after 2030.



Investments in electricity generation capacity in the EU – historical and future (four NEPP scenarios: Reference; Regional Policy; Climate Policy; Green Policy) (Billion euros/year)

For Sweden to reach the EU renewable energy target for 2030, no additional renewables are needed. We achieved our goals for 2020, as given by the EU renewable directive, already a few years ago. If the given EU objective for 2030 of a 27% share of renewables is distributed among the Member States using a similar burden sharing approach as done for the 2020 target, we will, within a couple of years also reach this objective.

Demands on a very high share of renewable electricity production will push down the system price of electricity to low levels, which will imply that:

- **Investments in wind and solar power will require support for a long time,** even with a continuous strong technological development of wind and solar power that reduces costs.
- **The price of electricity will remain low in the short perspective, 5-10 years, regardless of which scenario we study.** This goes for the system prices as well as the retail prices.
- **The price of electricity for end-users will rise in the long term.** In scenarios with high climate ambitions, the retail prices as well as the system price will rise in the long run. In scenarios with high ambitions regarding renewables, the system price might rather decrease further, but the total price for end-users including costs for subsidies and support will rise.

Four plus four plus three scenarios

We have formulated four main scenarios, with different assumptions regarding the future development of the world surrounding the energy systems. We have also performed a comprehensive sensitivity analysis.

We have analysed the following main scenarios:

- **Reference scenario:** A scenario with extrapolations of the current ambitions.
- **Green Policy:** One overall goal – renewables: Very massive and rapid (and one-sided) investments in renewables in all sectors.
- **Climate Market:** One overall goal – the climate: A one-sided focus on greenhouse gases, with a relatively challenging climate target.
- **Regional Policy:** An effort with three equally important and binding goals: efficiency, renewables and climate/GHG.

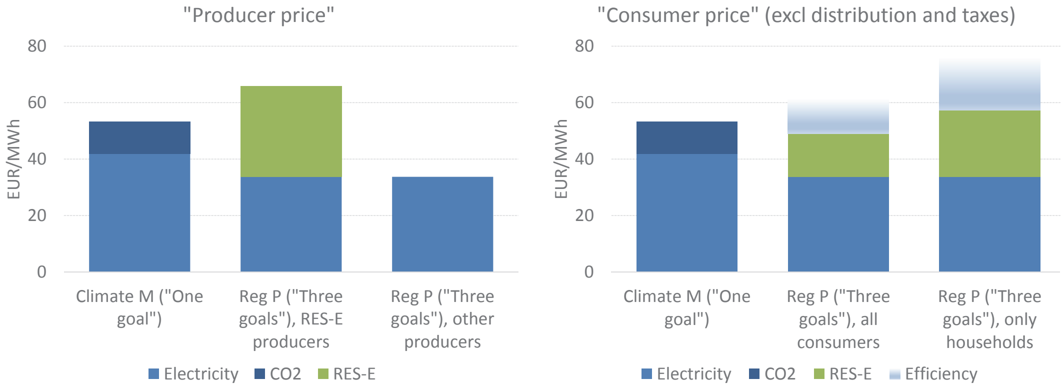
Four scenarios have also been analysed for the development of the electricity market:

- **Energy only:** A continued development of the current electricity market.
- **Capacity markets:** The current energy-only market is supplemented with a electricity capacity market.
- **Nodal pricing scheme:** A division of the electricity markets into smaller regional markets.
- **Increased regulation:** A significant increase of the policitcal control of the electricity market.

Three scenarios are formulated for the Swedish electricity demand development.

- **High outcome scenario**
- **Reference scenario**
- **Low outcome scenario**

The pricing on the electricity market is heavily influenced by how policies are designed. The balance between the three comprehensive European energy-political goals – reduce the GHG emissions, increase the share of renewables and reduce the energy consumption – is to a high degree influencing the pricing on the electricity market. If the CO_2 goal is the guiding and overarching principle, the prices on the EU ETS market will be distinctly higher than today, provided the goals being ambitious enough. The producer prices of electricity will then rise accordingly. If rather the renewable goal and/or the efficiency goal are guiding, it is quite likely that the demand for emission allowances will be relatively low, with lower producer prices of electricity as a result. The aid to renewables and efficiency improvement will then instead cover a large part of the new investments. This might in turn be transferred to electricity customers in the form of, for example, electricity certificates or white certificates. In such a case, the difference in end-customer price (energy part) between the customers that are contributing to the financing of the aid and those that are not, can be huge.



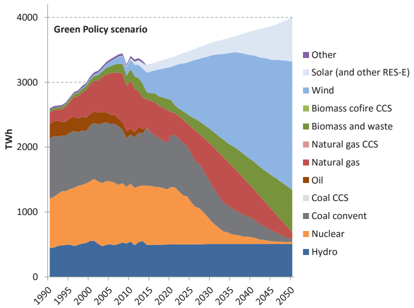
A large part of the current thermal power plants in Europe might be phased out the next coming decade. For reasons of age, roughly half of Europe's thermal power plants might be phased out by 2030. If we add newer installations, e.g. gas power plants, which today are struggling with profitability problems, the next coming 10-15 years might involve a massive decommissioning of thermal power plants across Europe. The rapid expansion of renewable electricity generation brings huge challenges regarding regulating power and reserve capacity. Thus, the price-lowering effect the expansion of renewables has had on the electricity market might be outbalanced by a price-driving effect, with very high prices during short periods, which is the result of decommissioning thermal capacity.

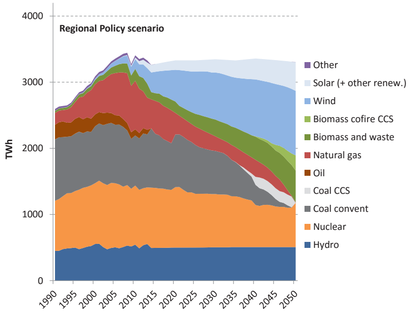
The expansion of renewable electricity generation in Europe

In more or less all of the NEPP scenarios, the renewable electricity generation in Europe is expanding massively. The differences between the scenarios are mainly level and speed of the expansion. But, there are large differences in the share of renewables between different regions. A large increase of the transmission capacity between countries and regions is needed. The expansion is most of all driven by European and national energy and climate policies, and the technological development.

In scenarios with much of renewable electricity generation in EU, particularly wind power will contribute to the large expansion. When it comes to new investments, land-based wind power is dominating. In Europe today, there is a very large potential for a continued expansion even when considering alternative land use. The great challenge is rather how to best integrate the variable electricity generation into the electricity system.

As a consequence of the large challenges associated with the variability there might be a point in, if possible, pushing the balance towards more controllable renewable electricity generation such as biofuel-based power and hydropower, provided expansion is allowed.





In scenarios with a very aggressive general European expansion of renewable power generation, some regions will occasionally have a significant power surplus and at other occasions a large need of import. Having favourable wind conditions, the countries around the North Sea and to some extent those surrounding the Baltic Sea, will probably, from cost efficiency reasons, form a future "electricity surplus region", provided that a major part of the current production capacity will still be available.

Electricity capacity is expanded faster than electricity production and electricity demand. The European electricity energy demand is expected to grow by 0-50 % up to 2050 compared with today, depending on scenario. At the same time, the installed capacity is expected to increase by 50-100 %.This will make heavy demands on grid expansions.

The expansion of variable renewable electricity generation will increase the demand of new controllable back-up capacity. Considering the low degree of utilisation, it is reasonable to expect that a significant part of such a capacity will consist of gas turbines. An advantage with gas turbines is that they have a small "visual impact", since they can easily be integrated in the existing infrastructure. However, the low degree of utilisation might discourage many of the potential investors. They are likely to be run using fossil fuels, which also might be seen as a negative factor.

A strong pan-European driving force and a big enough difference in electricity prices are required to get a large export of electricity and a massive expansion of transmission capacity. The size of the Nordic electricity export is determined mainly by 1) the strength of the common European energy and climate politics, 2) the development of the electricity demand, and 3) the future of the Swedish nuclear power.

Investments in new nuclear power and CCS will, without other support, require significantly higher prices of electricity than what we have in Europe today and in the near future. Such a development will particularly call for a considerably higher CO_2 price than today. A shifted balance in the climate policies, with a stronger focus on the emission allowances system, and less focus on aid systems for renewable electricity generation could work in this direction.

The development potential for CCS is (probably) in the foreseeable future connected to the basic industry. Some of the sub-sectors in the electricity intensive industry has no real alternatives for a substantial reduction of emissions, whereas power generation to a larger extent is able to shift from coal and natural gas to renewables (and nuclear power), as an alternative to CCS.

For more information:

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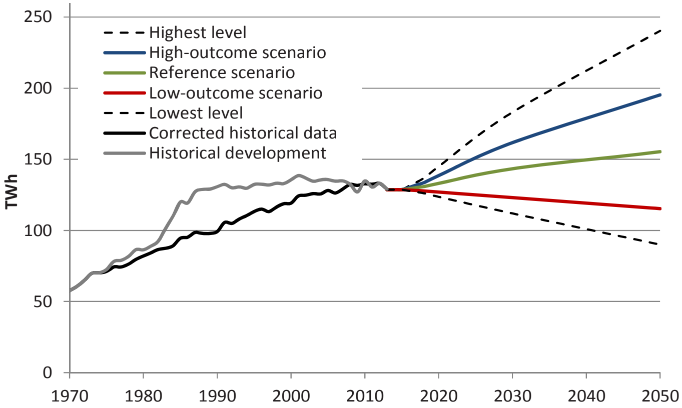
Filip Johnsson, Chalmers

Further reading:
- *Femton slutsatser om Elsystemets utveckling i Norden och Europa* (www.nepp.se)
- *European Energy Pathways – Towards a Sustainable European Electricity System* (www.energy-pathways.org)

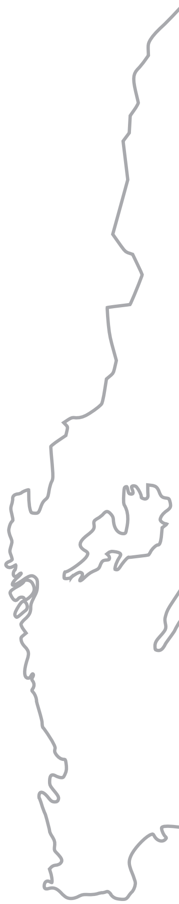
2 Electricity demand in Sweden - future developments

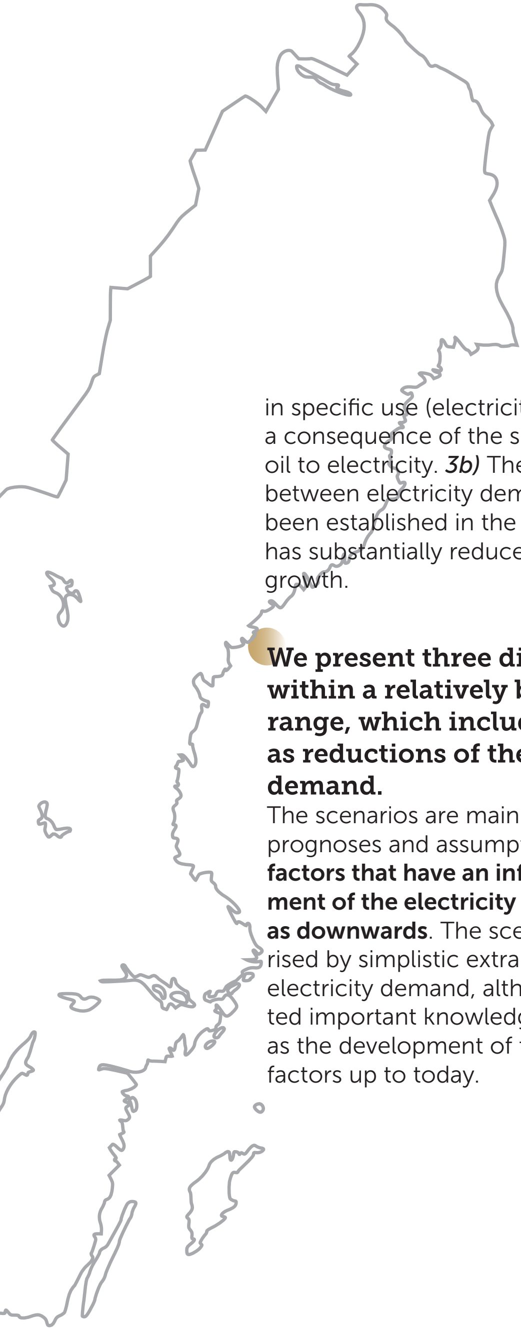
The electricity demand in Sweden has, more or less, remained at the same level of 130-140 TWh per year since the late 1980s. Prior to that, the electricity demand increased by 4-5 percent per year.

Four simultaneous processes, in different end-use sectors, explain the observed slowdown in electricity demand growth. Without these processes, the electricity demand would instead show a rather even yearly growth from the 1980s up to the financial crisis of 2008. The following processes have, together, led to a stabilisation of the electricity demand for 25-30 years: ***1a)*** In the 1980s and 1990s, electric heating in buildings (direct-acting electricity and electric boilers) increased significantly, and at a pace much faster than during prior years. This pushed the growth of electricity demand upwards. ***1b)*** Since the turn of the century, heat pumps have been installed, at a large scale, for heating purposes in buildings, and this has, in turn, had a declining effect on electricity demand. ***2a)*** During the 1980s, the electricity demand also increased rapidly in the district heating sector; but ***2b)*** in the late 1990s this demand decreased once again. ***3a)*** During the 1980s up to the mid-1990s, the electricity demand in the industry sector increased, both in total number as well as



Electricity demand in Sweden. The historical development is illustrated by two curves: the actual electricity demand (grey line); and an "alternative" or corrected demand curve (black line) where the four processes during the last 25-30 years (as described in the text above) are substituted with a more even development. For the future development up to 2030 and 2050, the figure shows the different scenarios of the NEPP project. The scenarios are based on official projections and assumptions regarding the developments of approximately ten factors that have high influence on the development of the electricity demand. We have also, in the figure, indicated a "highest" and a "lowest" level, showing the outcome if all factors co-vary.





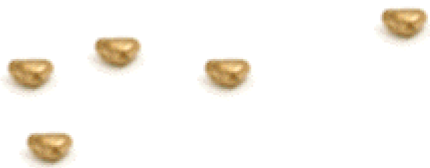
in specific use (electricity per value of output), as a consequence of the significant conversion from oil to electricity. *3b)* Thereafter, a "decoupling" between electricity demand and production has been established in the industry sector, which has substantially reduced the electricity demand growth.

We present three different scenarios, within a relatively broad outcome range, which include increases as well as reductions of the future electricity demand.

The scenarios are mainly based on official prognoses and assumptions regarding **some ten factors that have an influence on the development of the electricity demand, upwards as well as downwards**. The scenarios are not characterised by simplistic extrapolations of the historical electricity demand, although we have incorporated important knowledge from the history, as well as the development of the different influential factors up to today.

4a) Within the forest industry sector, the electricity-intensive mechanical pulp production increased rapidly during the 1980s. *4b)* This production growth declined during the 1990s, and after the turn of the century, mechanical pulp production has levelled off and during the last years even declined.

Since the financial crisis of 2008, the global economy has slowed down with a significant impact on the demand for electricity. We have seen a declining electricity demand, particularly in the industry sector. Our reference scenario includes – at least to a certain extent – a (global) recovery of the economy in the decade ahead, which will act as a driving force for a (partial) "recovery" of the last 5-7 years of decline in electricity demand.



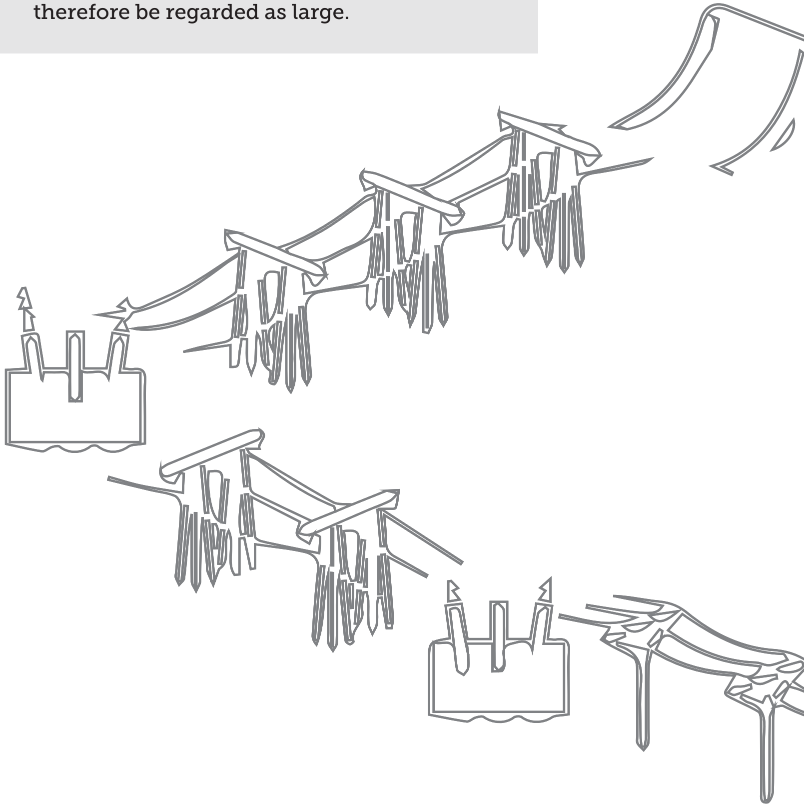
The energy efficiency improvement is the single most influential factor on the electricity demand, and its rate is predicted, in all scenarios, to gradually increase compared with today. The average annual improvement rate has, during recent decades, been 2-3%, but in the scenarios, we apply an increased rate of 3-4% per year for the period from today up to 2050.

The development of the electricity demand will still be significantly influenced by the economic development, but a continued decoupling implies that this influence will slowly be less significant in the future. However, the NEPP results show that the annual electricity demand difference between a low economic growth (an annual GDP growth of less than 1.5%) and a high economic growth (an annual GDP growth of 2.5%) will still be as large as 15-20 TWh in Year 2030 and 25-35 TWh in Year 2050.

Structural changes and technology shifts have affected demand historically, will affect demand in the future, but are difficult to predict. It is likely that we, also in the future, will see structural changes and technology shifts in the end-use sectors, but which, when, and what impact these will have on the electricity demand are, however, very difficult to predict.

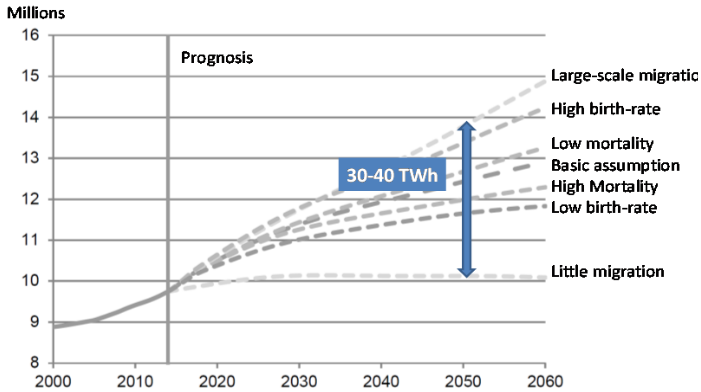
Uncertainty in projections

Former projections/scenarios for the development of the electricity demand have shown a fair precision in the time perspective up to 10-15 years, but have shown a limited precision in the more long-term perspective of 30-35 years. This is probably true also for our scenarios. The uncertainty of the projected electricity demand in Year 2030 and beyond should therefore be regarded as large.



SCB (Statistics Sweden) has during 2015 revised their population growth projection *upwards* by 0.5 million inhabitants for 2030 and by 1 million for 2050, since their previous projection (2012). ***This adjustment alone*** increases the electricity demand by up to 5 TWh by 2030, and by 5 10 TWh by 2050. In the main projection from 2015, SCB predicts a future population in Sweden of 11.4 million people by 2030 and 12.4 million by 2050. This can be compared with the current population of 9.8 million. The figure below shows SCB's different population projections. If we look at the total impact from the population growth on the future electricity demand, it will account for an increase of, at least, 10-15 TWh by Year 2030 and 20-25 TWh by Year 2050 (in the main alternative of SCB's projections and also in our reference scenario). If we compare the outcomes when applying the highest and lowest of SCB's population projections, this will result in a difference in electricity demand of 30-40 TWh in Year 2050.

SCB's most recent population projection (published in May 2015) for the development up to 2060 as given for a "main scenario" (basic assumptions) and for six alternative scenarios. The difference in electricity demand between the lowest and the highest projection corresponds to 30-40 TWh in Year 2050.



Energy efficiency improvements take place in all sectors, and they are to a large extent "autonomous", i.e. not driven by a pronounced efficiency improvement policy (not directly policy driven). The driving forces behind most of the efficiency improvements are rather economic, technological and structural (even if these three driving forces to a certain extent are influenced by political decision, e.g. taxes, norms and support to technology development and research). Our scenarios are based on the assumption that economic, technological and structural driving forces will continue to be strong, or even stronger over time, in industry as well as in the housing, service and transport sectors.

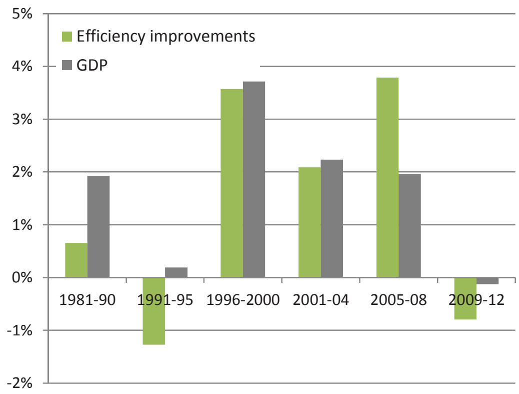
The electricity demand in the service sector continues to grow but not as fast as previous. The increase of household electricity declines entirely. . The electricity demand in the service sector (i.e. business electricity in premises and property electricity in premises and dwellings) has increased by 3-4 %/year since the 1970s. This is a result of, e.g., the population growth, the GDP development and the rise of standards. There has, however, at the same time been a "decoupling" as a consequence of an even larger efficiency improvement, and in all of our scenarios we assume a continued significant efficiency improvement rate.

Result

Efficiency improvement is (much) more pronounced in periods of economic growth than in periods of recession. The correlation is distinct, and in periods of slow economic growth, efficiency improvement is instead very moderate (close to zero).

Improved energy efficiency in electricity use (excluding space heating and hot tap-water heating) in the residential and service sector as well as a large part of the industrial electricity use are mainly taking place in connection with replacement of machines and equipment. The new equipment, e.g. household appliances, is usually more energy efficient than the old equipment. These equipment replacements are primarily done during periods of economic prosperity. In periods with low economic growth, less replacements are occurring which explains the lower level of efficiency improvement.

Energy efficiency improvements for heating purposes, on the other hand, do not show the same correlation to economic growth and business cycles.



Yearly change of GDP and yearly energy efficiency improvements of electricity use in the residential sector (household electricity). If efficiency improvements are compared to the economic term "household expenditures" instead of GDP, a similar result is attained. (Source: NEPP analyses)

Examples of future "jokers": the transport sector, district heating, and IT.

A large-scale introduction of electric vehicles will the electricity demand increase significantly. Under discussion today is also the possibility to use electricity during low-price periods to produce district heating, but high tax rates currently limit the profitability for this. In the IT sector data centres are planned and constructed at several locations, and these centres are very electricity intensive.

The electricity demand for heating declines significantly in all scenarios. In the ongoing project "Heating market Sweden" (see next page), possible developments of the Swedish heat market are analysed by looking at four different heat market scenarios. All of these scenarios are characterised by a decreased electricity demand in spite of an increasing market share of electric heating in several of the scenarios. This is due to a continued heat pump expansion, a decreasing heating demand (as a result of increased energy efficiency in existing buildings and the implementation of low energy requirements in new buildings), and that new, more efficient, heat pumps replaces direct-electric heating, electric boilers and/or older, less efficient, heat pumps.

The industry's electricity demand is expected to start growing again in parallel with the presumed economic recovery, internationally and nationally, but demand is assumed to grow slowly. Electricity demand in the pulp and paper industry will not increase at all in our reference scenario. The future development for the industry is, however, still difficult to predict. We have, together with subject-matter experts and branch representatives, looked at the factors influencing the electricity demand in different industrial branches. Our analyses show a relatively large possible outcome range for the future electricity demand in industry.

There are possibilities to influence the electricity demand politically, even if this influence is rather *indirect* than *direct*. It is probably easier (through political decisions) to influence the demand upwards than downwards.

The EU Energy Efficiency Directive will have a rather limited impact on the development of the electricity demand. Less than a tenth of the efficiency improvement of the electricity demand in the reference scenario is a result of measures related to the Directive.

For more information:

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Further reading:
- *Tjugo resultat och slutsatser om elanvändningen i Sverige* (www.nepp.se)
- *Scenarier för den framtida elanvändningen* (www.iva.se/publicerat)

NEPP has had a close cooperation with the project **”Värmemarknad Sverige”** (Heat Market Sweden), which is a multidisciplinary research project about the Swedish heat market.

• **The heat market is worth 100 billion SEK and 100 TWh per year.** The costs of end use energy comprise 75 % of the turnover, and the costs associated with the heating installations account for 20 %. Taxes are a bit more than a fourth of the total turnover, and VAT and electricity tax are the largest of the taxes.

• **Single-family houses is the largest sub-market, in SEK as well as in TWh.** They represent approximately 40 % of the energy demand, and more than half of the turnover in SEK. Multi-family houses account for 30 % of the energy demand and a bit more than a fifth of the turnover, while premises account for 25 % of the demand and approximately a sixth of the turnover..

• **District heating is dominant measured in TWh, and electric heating and heat pumps – measured in SEK.** District heating represents a bit more than half of the total heating demand, whereas electric heating and heat pumps together account for a third. District heating is the largest means of heating in multi-family houses and premises, but the electrically based technologies are largest in single-family houses. Electric heating and heat pumps represent 45 % of the total turnover in SEK, while district heating represents 40 %.

• **A tougher competition can be expected on the heat market.** District heating, heat pumps, electric heating and biofuels are dominating the market today. Heat pumps are challenging electric heating, but also district heating to an increasing extent. But, the strategic advantages of district heating (cogeneration, waste heat, waste incineration and unrefined fuels), together with a high heat density and an established infrastructure, gives it a continued strong competitiveness in urban areas. The project´s scenario analysis shows market shares for district heating by 2030 in the interval of 45-55 %, and for heat pumps 25-35 % (to be compared with the current share of a bit more than 50 % for district heating and a good 20 % for heat pumps). Electricity demand for heating will decline even in the scenarios with an increased market share for electricity based heating, e.g. heat pumps.

• **It is likely that we will see a continued reduction of the heating demand.** The population is expected to grow by almost 20 % up to 2050. With an unchanged area standard (m2 per person), the heated area will increase accordingly. Still, energy efficiency improvements and a low demand in new properties are expected to result in lower volumes on the heating market. The total heating demand in dwellings and premises might by 2050 end up in the interval of 60-90 TWh (70-90 TWh by 2030) (to be compared with the demand today of approximately 90 TWh/year).

3 Electricity capacity in a new focus when the arena is redefined

A new arena for the electricity capacity is now drawn up, as a consequence of the increasing amount of intermittent power. The current challenges with the winter peak and the wet year/dry year variations are accompanied by new challenges with variable and hard-predicted fluctuations throughout the whole year. It is thus, the variations in generation that create these challenges for the electricity system, not the variation on demand.

A massive expansion of renewable electricity is now taking place in Sweden and many other countries. The large share of wind and solar power brings specific challenges. Since neither solar, nor wind power is controllable, and since they also fluctuate considerably, the question is how the electricity system is going to be balanced. The Nordic countries have a big advantage compared with the other European countries, in having a relatively large volume of controllable hydropower. To what extent hydropower (and the transmission grid) can even out variations in demand and in other generation is of uttermost importance, since it will have a huge impact on the price and thereby all other investments on the electricity market, in the Nordic region and by our trading partners.

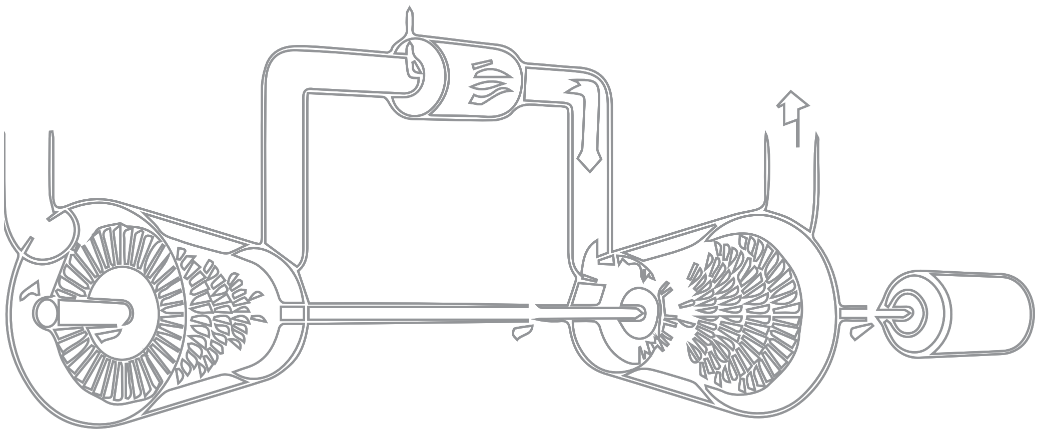
Simplistically speaking, during the hours with sufficient regulating capacity, the price variations will be small. The profitability of investments in demand flexibility and in other means of generation will be poor, whereas the profitability of grids and international connections will be good. On the other hand, during the hours with insufficient regulating hydro power capacity, the price volatility will be high and other, more costly, resources will be needed to help regulating the system. During these periods our neighbours cannot rely on import from the Nordic countries.

Balancing generation and demand will be a greater challenge than it is today. The variations in the future net demand (demand minus variable power) will be much larger than the demand variations for which the system is designed today. Hours with plenty of power will rapidly be replaced by hours with power shortages. The system must be dimensioned correctly and designed to be adjusted swiftly. The unreliable prognoses for wind power also make the planning horizon shorter.

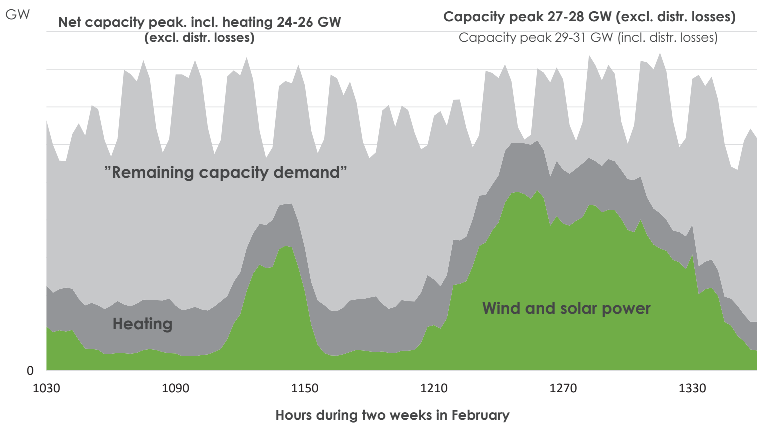
It is probably the producers that will face the largest challenge. The introduction of renewable power with special aid, which is mainly intermittent in its character, crowds out other production and creates, at least initially, a price pressure on the market. This undermines the economy of the existing controllable power plants, and it also means that it will take longer time until the renewable technologies can be funded without state aid. The largest challenges for the backbone grid operators is to expand the grids at the required rate. There is a significant risk that the renewable power will be trapped in some regions.

From a regulating perspective there are three overarching challenges:

- The first one is to create the right **economic conditions for the controllable production that really is needed.**
- The second is to create **incentives that result in effective investments in the grids.**
- The third is to create the **incentives necessary for the potential of demand flexibility to be unlocked.** Smart grids is about, amongst other things, letting the customers contribute positively to the balancing of the electricity system, thereby reducing the need for controllable generation and grid expansion.



The capacity challenge is all about matching production to demand. The development of the production, rather than the demand will represent a growing challenge! When the balance between production and demand is stretched, we see high prices of electricity. Hitherto, high prices have been associated with a large electricity demand. In a future with an increasing amount of variable power, the high prices will be related to a large demand as well as to a small production from wind and solar power.



A schematic illustration of the capacity demand in Sweden during two weeks in February in 2050 (the grey and green fields added), and the part of demand covered by wind and solar power during these weeks (green field). In the figure the remaining demand of capacity (not covered by wind and solar power) is subdivided into electric heating (dark grey) and other demands (light grey).

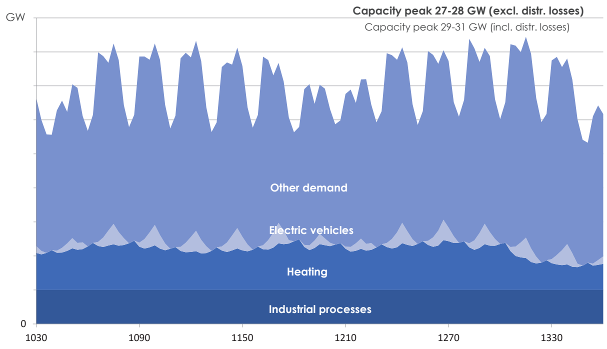
The demand for controllable generation capacity, in the figure called "the net capacity peak", will be 24-26 GW by 2050. This means, if these preliminary results are correct, that our need for **available controllable generation capacity** (in addition to wind and solar power) **will be at least of the same magnitude as today.**

Also, a future electricity system with much of wind and solar power will need to handle rapid and large variations in generation, which will require very high flexibility in controllable generation and in demand.

Result

A smoother electricity load curve: Electric heating and electric vehicles will define the peaks. The capacity demand from electricity use will mainly change in parallel with the development of the (electricity) energy demand. In our electricity demand scenarios, the total capacity demand will, during the winter, decline somewhat in relative terms (i.e., in relation to the development of total energy demand). This is due to a decreased heating demand, which will level out the load and reduce the winter peaks compared to today. In the scenarios including a large-scale introduction of electric vehicles, we might instead experience an increased diurnal load variation unless “intelligent loading strategies” could reduce the diurnal variation significantly.

Even if these loading strategies would not level out the load to any larger extent, the impact on the total capacity demand will be rather limited, and the conclusion that the total capacitydemand varies with the electric energy development is still valid. NEPP’s preliminary result will then give the peak load development seen below during a normal year in the different scenarios. The capacity peak will be between 21 000 and 33 000 MW (21-33 GW) excl. transmission losses, in the three main scenarios by 2050 (to be compared with a level of approximately 23 500 MW (23.5 GW) today).



A schematic picture of the electricity capacity demand in Sweden during two weeks in February 2050, when the peak capacity of the year is expected to occur. Please note that the subdivision of the capacity demand into sectors is preliminary.

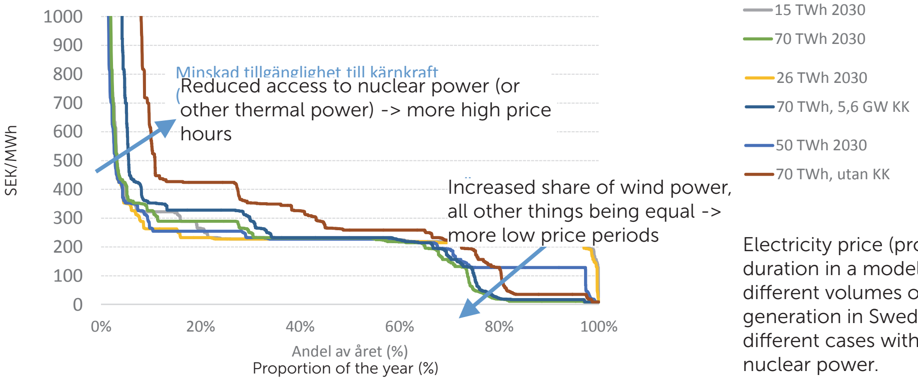
Table: Development of the electricity capacity demand (effect peaks) in NEPP’s three main scenarios for the electricity demand. The table shows the electricity capacity demand in MW during a normal year, excl. transmission losses.

MW	Low scenario	Reference scenario	High scenario
Today	23 500	23 500	23 500
2030	22 600	25 600	28 300
2050	21 400	27 300	32 900

	House-holds	Service	Heat market	District heating production	Industry	Transport
Development of the capacity demand	Like energy demand	Like energy demand	Reduced maximum peak load during winter	Like energy demand	Like energy demand	Larger diurnal variations

The more of wind power and the less of controllable thermal power generation, the larger the variations in the price of electricity.

When we introduce more of wind and solar power in the system, all other things being equal, we will see more and longer periods of low or very low prices of electricity. Also, these low price periods will occur during all seasons throughout the year, even in wintertime. This is a clear change compared with the historical picture, with low price periods mainly to be found during the summer season. If a large share of wind power is combined with a scenario where large parts of the nuclear power are phased out, the proportion of periods with high or very high electricity prices will increase. This will make the “price duration curve” over the year steeper than it is today (see figure below). The variability in generation, and thereby the price of electricity, will increase over the year.



Electricity price (producer price) duration in a model year (2030) for different volumes of wind power generation in Sweden, and for two different cases with reduced access to nuclear power.

> **”In a situation with large amounts of variable electricity generation, the price of electricity will not any longer solely be defined by the demand, but to at least to the same extent by the availability of wind (and sun). The wind power plants will generate most power when the wind is the strongest, not when the willingness to pay is the highest.”**

Matching of electricity production and electricity demand is made more difficult by som policy instruments. One example is the electricity tax, which, even with a zero-price on electricity, prevents electricity from being used. Conversely, it is illogical that electricity certificates significantly stimulates electricity production even during periods where there is no demand. The design of the electricity tax and the electricity grid tariffs rather spur ”prosumers” to adapt their consumption to minimise electricity fed into the grid which is not necessarily a strategy benefitting the system as a whole.

A choice of market system is needed to be able to handle the capacity issue in the future. To ensure a sufficient capacity to meet a high electricity demand, at the same time as the availability of wind power as well as of other power plants is low, a market system that gives strong enough incentives is needed. There are many well-functioning solutions to achieve this, but several are untested, and therefore concerns are raised regarding their consequences. Many decision-makers, from industry as well as political parties therefore want to be assured that:

- We will protect our energy-only market, and not introduce a system compensation capacity.
- We will not create a permanent capacity reserve, but decommission it in the long term
- We will not end up with extreme prices
- We will not face a capacity shortage

Unfortunately it is not possible to achieve all these goals at the same time. A choice between the market systems at hand is needed, which means a balanced choice between the defined goals. (See more about the development of the electricity market in Chapter 7.)

Complex problems require advanced and complementary modelling tools.
The NEPP project has focused on the development of the North European electricity system. The system and the related questions are very complex, and consequently require detailed and advanced modelling tools for the analysis work. In the NEPP project we have used models which analyse the long-term development up to 2050 (ELIN and TIMES-NORDIC), as well as models which in detail analyse the electricity system for single years, and down to the hour level (EPOD and APOLLO). NEPP has also worked with a broad geographical system delimitation, using tools that covers all of the European electricity system (APOLLO, ELIN and EPOD), but also with tools that in more detail focus on the electricity system and other parts of the energy system in Northern Europe (TIMES-NORDIC) or Sweden. The project has also had access to a number of more sector-specific and specialised modelling tools dealing with, for example, private production of solar power, and regional grids.

For more information:

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Further reading:
- *Beskrivning av konkreta utmaningar som det svenska elnätet står inför med anledning av den pågående omställningen av energisystemet (www.nepp.se)*
- *NEPP:s resultatblad bl.a. Vindkraften kommer att öka - men hur mycket? (www.nepp.se)*

4 The power system's regulation abilility is facing new and large challenges

Of the future changes that can be anticipated for the Swedish power system, it is the growing share of wind and solar power that creates the largest challenges for the Swedish power system. Wind and solar power have a number of characteristics that generate these challenges:

- They have a limited controllability and are dependent on the sun shining and the wind blowing.
- Wind prognoses are uncertain and reaches a high degree of accuracy only a few hours on beforehand. Solar power is partly easier to prognosticate but the thickness of the cloud-cover is hard to predict and creates large variations.
- Wind and solar power do not use synchronous machines that are directly connected to the electricity system, and thus they do not, without special solutions, contribute inertia or voltage regulation to the system.

NEPP has identified eight challenges for the future power system stability. These are mainly related to two situations: Large amounts of variable generation and a low demand; or small amounts of variable generation and a high demand. An increased share of variable generation will also lead to general challenges in all types of conditions for operations, in order to maintaining balance and reliability in the system. Overcoming these challenges is more or less difficult depending on the scenario, and they are also interdependent. The challenges are not impossible to solve, but it can in some cases be quite costly.

Challenges for future power system stability

Challenges when there are large amounts of wind and solar power and a low demand

1. Inertia

During periods when conventional production is replaced by large amounts of solar power or classical wind power, the amount of "system inertia" will be smaller, since solar and wind power plants usually do not operate with synchronous machines directly connected to the electric system. Inertia is required to fend off disturbances in the power system.

2. Load balancing

With a larger amount of wind and solar power in the system, the short term variations (seconds to hours) will be larger, which increases the need for balancing capacity. With a larger amount of wind and solar power, it will also become more frequent that only a limited number of conventional power plants are active in the system. This implies that fewer plants might have to share the load balancing burden, and that they must have enough margin to handle this.

3. Surplus situations

On sunny and windy days with a low demand, there might be a surplus situation that must be handled, especially if neighbouring markets have a similar situation and cannot absorb this surplus.

4. Transmission capacity

If large amounts of wind power is to be transmitted from northern Sweden to southern Sweden and out on the international grid, while other, synchronous, generation is more or less idling, there is a need of other reactive compensatory mechanisms to maintain the voltage level and thereby the transmission capacity in the national grid.

Challenges when there are small amounts of wind and solar power and a high demand

5. Available peak load capacity

With a larger amount of wind and solar power capacity, there will be situations with high electricity demand and low wind and solar power generation. Enough capacity is needed also for these situations.

General challenges in keeping the balance

6. Increased needs of flexibility in controllable generation and consumption

- Wind power generation can be assumed to have as large variability as the demand has today. However, the demand varies in a regular and predictable way, whereas the wind power fluctuates following a stochastic pattern. This poses a challenge to the planning of hydropower generation with patterns and volumes different to what the current river sections once were designed for.
- The physical regulation capacity and the regulatory system for hydropower are designed to handle the current regular variations in demand.
- Hydrological circumstances and water-ecological considerations in different river parts, limits the possibilities for a fast re-planning of the water regulation.
- A larger amount of intermittent wind and solar power makes it more difficult to plan the hydro power production along a river part and the usage of the transmission grid. The increased uncertainty may lead to both the generation and the transmission needing to be planned more conservatively and with larger margins.

7. Adaption of the distribution of responsibilities and of the market mechanisms
The responsibility and burden-sharing between the actors in the electricity system, with the aim to maintain the physical balance, and the market mechanisms available to support this, are all designed to fit the current needs. The increased and modified regulation needs might mean that the current models for cooperation and for the market will not be adequate. They might rather form an inefficient regulatory system.
If the responsibility to manage the increased prognosis uncertainties is assigned to the actors on the market, a development might be required towards a large part of the electricity trade being made closer to real time. An alternative is that a larger part of the load balancing is handled by the system operator and that the procurement of regulation services is extended.

8. Annual regulation
If solar power becomes a substantial part of the power system, it will call for an extended interseasonal storage, since a major part of the generation takes place when the demand is low.

For these eight challenges there are a large number of potential (partial) solutions. There are good reasons to believe that also a power system with a very large share of variable electricity generation might be well-functioning. But insight into the challenges and the ability to implement the solutions is necessary for this to happen.

An additional challenge is that we will have to manage many (or all) of the challenges at the same time. How large the eight challenges will be, will also determine the total size of the challenge.

When nuclear power is replaced by wind power, there will be a reduction of flywheel mass in the system, unless other measures are taken. Mechanical flywheel mass is needed for the stability of the system. It is primarily provided by the rotating mass in turbines and generators in the power plants. Wind power does not provide mechanical flywheel mass without special equipment. Nuclear power contributes more flywheel mass than other kinds of power, and replacing nuclear power always means a reduction of the flywheel mass in the system, no matter with what it is replaced. Synthetic flywheel mass from wind power, may potentially be an effective answer to this challenge. But, its potential requires further investigations.

We will be able to handle all the eight challenges, but implementing the solutions is a challenge per se.

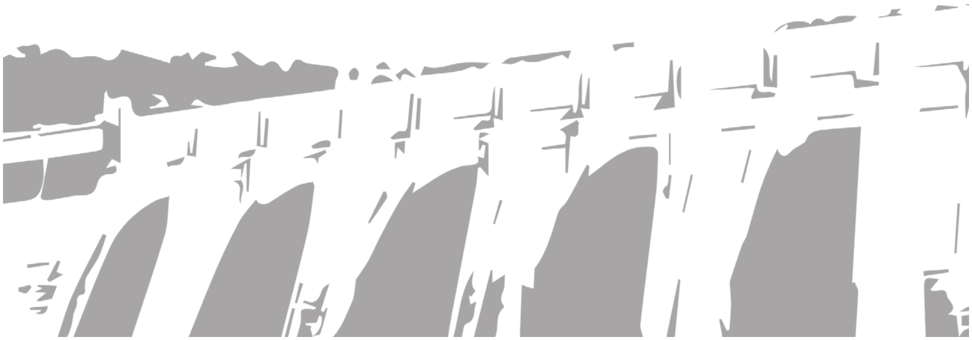
There is a large number of potential solutions for handling the eight challenges, and a power system with a large share of variable electricity generation might well work adequately. But it requires a good insight and the ability to get the solutions in place. In the table below are listed some ten examples of the type of solutions that are required. Several of them can be used to handle more than one challenge. Also, several of the solutions are interdependent. In the long term, most of the solutions will probably be needed, but this is defined by the extent and the rate of the transformation of the electric system.

Table: Examples of solutions and which challenges they relate to

Challenges/potential solutions	1	2	3	4	5	6	7	8
	Inertia	Load balancing	Surplus situations	Transmission capacity	Available peak load capacity	Increased demand of flexibility	Distribution of responsibilities	Annual regulation
Power electronics in wind power and fast regulation of HVDC connections								
Expanded regulation with nuclear power and other thermal generation, and regulated demand								
Let wind and solar energy spill when there is a lack of demand								
Reinforce the transmission grid internally and to neighbouring electricity systems								
Develop the demand flexibility and energy storage, and create incentives for the heat pumps and electric boilers in district heating								
Invest in an expanded shunt or series compensation, and in technology for the operations of backbone grids with less marginal								
Create incentives for controllable electricity generation, e.g. cogeneration, and invest in new reserve capacity, e.g. gas turbines								
Better prognoses, and the adaption of regulating capacity, regulatory frameworks, and environmental measures for entire river parts								
Review the responsibility distribution between those responsible for the system, for the balancing, and other actors								
Maintain or enhance the yearly regulating capacity in the hydropower, and develop new forms for seasonal storage								
Reduce the amount of electricity based heating (if replaced by district heating, there will be a larger foundation for cogeneration)								

Nordic hydropower is well prepared to balance a system with a large share of wind power. The variations in wind power are large capacity-wise as well as energy-wise. The electricity generation from wind power varies between close to zero and installed capacity, and the fluctuations have a varying duration, often lasting for days. There is also a high degree of uncertainty in the prognoses. To balance these variations there is a need of controllable generation with sufficient capacity, large enough reserves of energy and an adequate flexibility. The regulated river systems, mainly in Sweden and Norway, can offer exactly this: power plants with a varying degree of overcapacity, connected to enormous energy reserves in the form of water reservoirs, charged through restrained electricity generation. The overcapacity and the large volumes of the reserve, together with the hydropower's inherent capability to swiftly change its production, give a good flexibility on the timescales the balancing of large amounts of wind power requires.

Water management regulations will more and more often restrict the balancing potential of hydropower. Often, water management regulations pose a more pronounced constraint to the balancing capacity of hydropower than natural and technological restrictions. This will become more obvious as the wind power is expanded and the nuclear power is phased out. As a consequence of hydrological circumstances, measures that impose restrictions on one power station might affect the balancing power of the entire river. It is of great importance that the consequences of the measurers suggested in the national strategy for the implementation of The EU Water Framework Directive are analysed considering this, so the environmental benefits are maximised locally in the river, as well as nationally and globally.



More about hydropower

Hydropower gives by far the largest contribution to the balancing of the power system on all time scales, from second to season. The relative balancing contribution measures the co-variation between one or several power plants and the net demand. During the period of 2012 to 2014, the Swedish hydropower balanced on average 102 % of the variation of Swedish net demand within a day, 69 % of the variation between days, and 46 % of the variation during the year (seasonal scale). The value of more than 100 % diurnally implies that Sweden also exports balancing power. For a period of several days import/ export accounts for 25 % of the balancing, and on the seasonal scale nuclear power and cogeneration contribute with 35 and 20 % of the balancing capacity, respectively. Within the hourly scale and all the way down to the second scale, almost exclusively hydropower is used for manual up and down regulation, as well as for the automatic regulation services needed to maintain the grid frequency .

The 13700 MW that usually is stipulated as the maximum available capacity in the hydropower system cannot be exploited for longer periods of time. The total installed hydropower capacity in Sweden is approximately 16200 MW, whereof 13700 is regarded as available. The hydropower plants usually have a high availability, higher than 95 %, but the possibility to fully utilise the installed capacity is restricted by other factors such as water management regulations, transmission restrictions, plant-internal operational restrictions and ice conditions.

Hydropower's ability to balance incorrectly predicted wind power generation is considered as good, provided that there is a planned marginal for unpredicted up regulation when a large amount of hydropower is in operation. The largest inaccuracies in predictions – from one to a couple of hours – can already today be compared to an unforeseen outage of a nuclear power unit, and they can be expected to grow in proportion to the installed wind power capacity. Even if the most significant errors will occur only at rare occasions, there must still exist a readiness to balance them. The critical point is whether there are sufficient amounts of free capacity (on a system level), when much of the hydropower is running, i.e. the capacity issue. At the end of the day it is a matter of security of supply and the dimensioning of reserves.

Eighteen hydro power plants stand for half of the average disposable capacity in Swedish hydropower. Average disposable capacity is calculated as installed capacity multiplied by the average non-used capacity during a certain period of time. There is an obvious link between high average disposable capacity and the contribution to the balancing of the power system. In Sweden there are about 1 800 hydropower plants, whereof a bit more than 200 usually are regarded as large (>10 MW). Only 18 of these plants stand for half of the average disposable capacity on a yearly basis. However, with an increased use of hydropower for system balancing, it is no necessarily in these plants that increase will occur, but the increase will probably be covered by other plants.

Swedish hydropower capacity can be expanded if legal, environmental and economic hurdles can be overcome. There is little potential for harnessing more energy from Swedish rivers without exploiting the four free-flowing ones. However, capacity can be increased in existing stations, thus delivering more capacity during shorter periods. An expansion of the capacity in the hydropower should be carried out with a strategic approach, so that the hydropower system as a whole achieves maximum capacity to balance an electricity system with large amounts of wind power, without impairing the environment in the affected waterways. Preliminary results indicate that it is mainly the balancing capability on a multi-day horizon that should be improved to be able to persistently balance the weather systems without having to spill water.

Energy production might decrease the balancing capacity of hydropower in the wintertime. One reason why hydropower has a good balancing capability year round is that nuclear power has taken over a large part of the base-load-generation and thereby freed hydropower capacity. When the nuclear power is phased out, hydropower will probably, at least initially, partly reclaim its old role as a provider of base-load-generation. A likely scenario is then that more water will be stored from summer to winter. In NEPP:s analyses we have shown that the balancing contribution from hydropower will decrease when the water flow in the river is high and the production is large. Thus, the nuclear power decommissioning might result in a lowered balancing capability of hydropower in the wintertime, but increased capacity in the summertime.

There is no legislated accountability for specific actors and authorities to maintain adequate capacity to manage the total electricity demand. The electricity market of today is based on distributed accountabilities between the actors. Svenska Kraftnät is system accountable, with responsibility for the short term balance between demand and generation. In the longer perspective however, there is no distinct accountability defined, it is rather shared between producers, decision-makers and authorities. But, the government has partly shouldered its responsibilities by introducing legislation for a strategic capacity reserve. If the government wants to expand its accountability, this can be done by introducing capacity markets, by enhancing regulations by other means, and/or by an expansion of its authority.

District heating production on the margin is likely very costly in peak load situations. The heating demand is usually large and the price of electricity high in electricity shortage situations. This means that the cogeneration plants in the district heating system are fully utilised already under "normal" operation. Therefore, no additional electricity capacity is available when the electricity balance is stretched. If the cogeneration plants instead could be operated in power-only mode, somewhat more electricity could generated, but at the cost of losing the cogeneration plants' heat production. Thus, this heat production would have to be replaced by other production, which would be very costly. Hence, this is not a realistic scenario. It has rather, from time to time, been discussed to reduce the power generation in cogeneration plants to allow an increased heat production based on bio fuels instead of running oil-fired heat-only boilers.

The potential for cogeneration to contribute frequency regulation is limited. At circumstances when the need of frequency regulation mainly appears, i.e. when large amounts of wind and solar power are available and the electricity demand is low, the contribution from cogeneration is probably small, since the cogeneration plants, to a large extent, would not be running. However, the need for further frequency regulation might arise even at other times, and then there could be better conditions for the district heating systems to contribute through the cogeneration plants.

The district heating systems' possibility to manage "surplus" electricity is limited by a number of key factors. If the electricity "surplus situation" is the result of a low electricity demand, it is reasonable to also expect a low district heating demand. Many of the district heating systems are then supplied by very inexpensive heat production, e.g. industrial waste heat and waste incineration. This means that district heat produced by electric boilers and heat pumps would be competing with this inexpensive heat; and for the electricity demand to increase, the district heating producers must be compensated for the associated additional costs. Particularly electric boilers have relatively high heat-production costs, even with a zero price of electricity. These costs derive from electricity taxes, electricity certificates, and the variable operations and maintenance costs.

If the "surplus situation" is rather a consequence of a very large power production (i.e. large amounts of wind power available), it might occur simultaneously with a large heating demand, e.g. in the wintertime. Under such circumstances, the existing heat pumps in the district heating system are already in full use, as a consequence of low electricity prices and/or high alternative costs for district heating production. The potential to further absorb inexpensive electricity is thereby limited, at least for existing heat pumps. Electric boilers might, however, increase electricity demand additionally in such low-price situations, since they are less often fully utilised. But, this requires really low electricity prices, considering the additional costs.

The contribution from district heating to electric system stability

In the project "El och fjärrvärme – samverkan mellan marknaderna" [1], with which NEPP has collaborated, the possibilities of the district heating system to handle eight challenges in the electricity system is studied. The analysis is summarised in the form of a simple scorecard (see the table below). The assessment in the table indicate the added impact that district heating (the current system as well as a further expanded and developed system) might have on the future electric system's stability.

Challenges for the power system	Co-generation	Electric boiler/ heat pump	Other
Large amounts of wind and solar power and low demand			
- Inertia	+	0	0
- Load balancing	++	+	0
- Surplus situations	+	++	+
- Transmission capacity	+	+	0
Low amounts of solar and wind and solar power and high demand			
- Available peak load capacity	+++	+	+++
General challenges in keeping the balance			
- Flexibility in controllable generation and consumption	+	+	+
- Responsibility distribution and market mechanisms	0	0	0
- Annual regulation	0	0	+

+++: Large contribution; ++: Distinct contribution; +: Some contribution; 0: No contribution

Under the title "other" can be found, for example, increased district heating use and heat storage

1) Electricity and District Heating – Cooperation Between the Markets

For more information:

Lennart Söder, KTH; Sture Larsson, f.d. Svenska Kraftnät ;
Johan Bladh, Vattenfall

Further reading:
- *Reglering av ett framtida svenskt kraftsystem (www.nepp.se)*

Some ten energy models in close cooperation

All of the research teams which are represented in NEPP use energy models for their analyses. These are professional models that are used daily in investigations and scientific work. In NEPP we have used the models in cooperation and we have thereby been able to analyse the questions from different angels, at the same time as we have gained new insights based on the holistic perspective derived from the model cooperation in itself. It has also contributed to the quality assurance of the project results and conclusions, and thus strengthened the projects

One ambition in NEPP has been to let analyses with and without models run in parallel to improve the quality of the research. For example, the results from a series of in-depth interviews, of a workshop, or of a comprehensive statistical analysis, might be used as input when defining various calculation bases and boundary conditions for the modelling tools. Conversely, an interesting model result can be used as the input or as "test" in research that is more focused on understanding and describing different actor's choices and decisions today.

Modelling is one thing and comprehension is another!

Complex models often give complex results and answers. The usefulness of these results can best be measured by the level of understanding and insight they bring. It takes not only professional modellers, but also skilled analysts with a knowledge and understanding of the reality today and in the future. That is way the NEPP project has performed its research with a multidisciplinary approach, where the model results have been analysed, discussed and understood. This also gives more credibility to NEPP's model analyses. Similarly, the project has had the opportunity to assure the quality of the results in dialogue with the actors in the branch at steering team meetings, workshops and seminars. This way, the researchers have also been provided with valuable feedback on their model results. It is only when insights and comprehension is gained that the model results become truly useful!

The research area of variable energy generation must be handled with sophisticated model methodology

An important focus area in the NEPP project has been large-scale integration of variable renewable electricity generation such as wind and solar power. Getting a better understanding of how a massive expansion of variable renewable electricity generation will impact the other energy systems, not the least the other controllable power categories , e.g. thermal power plants, requires novel thinking regarding model methodology. To catch the sometimes very fast fluctuations, modelling down to the hour level is needed. Moreover, the operations and flexibility characteristics of different power plant types must be described in detail. Start-up costs, part load and load following properties of single specific power plants have been necessary to include in some of the modelling steps to generate the needed knowledge. Model-wise this is very complex.

5 Demand flexibility will become more important and have “new functions”

Demand flexibility is driven by high prices, today as well as in the future. But its role will partly be different in the future as the high prices can be expected to occur more frequently during a year, and for more reasons than today. This will give demand flexibility new functions.

The potential for demand flexibility is at least 4000 MW in Sweden

Our view is that demand flexibility offers a technical potential for an capacity reduction of at least 4000 MW in Sweden. This is a significant potential and is equal to almost 15 % of the maximum national capacity peak.

The potential for demand flexibility in industry is tightly coupled to price elasticity, i.e. the relation between demand and price of electricity. The potential for load reduction in Sweden is estimated to be approximately 2000 MW when the electricity price passes 200 EUR/MWh. The potential for demand flexibility among households with electric heating is estimated to be a little bit more 2000 MW, equalling 2 kW in app. 1 000 000 single-family houses. The potential is this large in this customer segment because of the possibility to use these houses' heat inertia to move the load a few hours without impacting the comfort. If a lower comfort can be accepted, the potential is even larger.

Table: The potentials for various types of demand flexibility in Sweden

Sector	Total potential (MW)
Industry	1900-2300 MW
Single-family houses with electric heating	2000-2400 MW
Shopping centres	40-50 MW
Offices	140 MW
Schools	10-20 MW
Total potential	**4000-4500 MW**

Price volatility is the strongest driving force for demand flexibility

An important basis for the implementation of demand flexibility is that the measures should be market-conforming and thereby profitable for the participating parties. To make the price of electricity useful as a control signal for adjusting the demand, price volatility is necessary, which makes it cost-effective to move load from high-load periods to low-load periods.

The potential might increase in the future

In a longer perspective also other kinds of demand flexibility might come into play, e.g. moving load through adjusting the timing for electric vehicle charging, or adapting the use of household appliances based on differences in price between different points in time.

Demand flexibility also has a balancing effect on electricity price

Demand flexibility will lead to a levelling out of the electricity price by cutting the peaks, but also by raising the price during low-load periods. An increased demand flexibility will thereby reduce the price volatility. In this way, promoting demand flexibility will - paradoxically enough - also counteract the incentives for a further increase of demand flexibility. Thus, there might be a balance that limits how much demand flexibility that is really lucrative.

Time-differentiated network tariffs can be an effective control signal for demand flexibility in households

The current prices of electricity do not vary enough to give sufficient incentives for demand flexibility for an electrically heated single-family house. But, with time-differentiated network tariffs more than 500 SEK/year can be saved. This saving is also predictable, which makes investment decisions easier.

Demand flexibility will also give a lower energy demand

An increased demand flexibility will also lead to an improved energy efficiency. The field studies that have been made show energy savings of around 10 - 15 %, when customers become aware of their consumption and optimise their heat supply. The reduced demand might be the prime incentive for investing in demand flexibility.

However, the current network regulations do not give incentives for demand flexibility

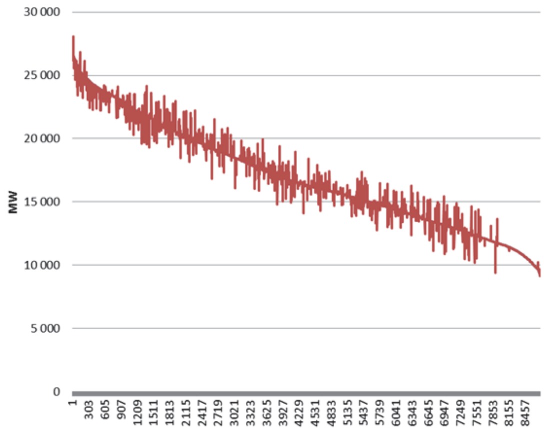
The network regulations do not today give incentives for minimising losses or costs against the upstream network . The network operator therefore has no incentives to promote demand flexibility. The requirement for equal tariffs in adjacent areas, together with the requirement for tariffs being non-discriminatory, might prevent local benefits of demand flexibility from becoming realised.

Time-differentiated network tariffs

Today several network operators offer time-differentiated network tariffs which makes it profitable to move load from high-load periods to low-load periods. These tariffs give, already today, stronger incentives than the variations of the electricity price do and will also bring a predictability that makes it easier for customers to invest in control equipment. At the same time a market is opened up for energy services enterprises. Then, nothing is stopping actors from beginning to act after the electricity prices also if, and when, they become more volatile. Time-differentiated network tariffs will probably also give the right signals for the system and they might encourage behavioural changes that are beneficial to the local network as well as the system as a whole.

Demand flexibility should be adapted to net demand

The figure shows load duration curve where a scenario with and one without demand flexibility are superimposed. With a low demand there is no heat load to move, and therefore, there is no real demand flexibility. But more or less throughout the year, there is down and up regulation; and the peak load is actually higher in the scenario with demand flexibility than in the scenario without. The reason is that demand flexibility responds to price signals, and that electricity price peaks do not necessarily coincide with the highest electricity demand. This is particularly obvious in a system with large amounts of wind power. If wind power generation is high at the same time as the demand is high, the prices might well be low (not high, as today). Then, net demand is the dimensioning factor rather than the peak load.



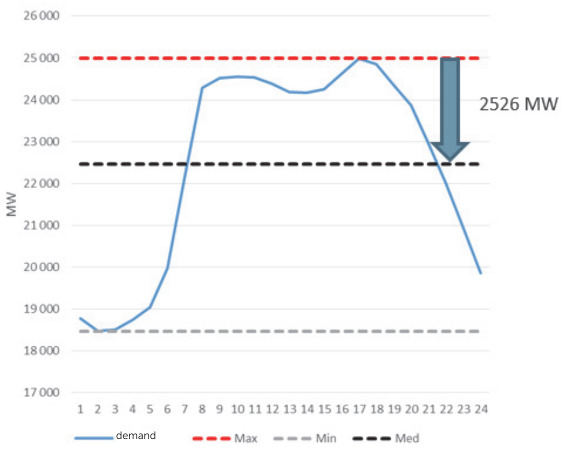
The impact of demand flexibility on the peak load in a scenario with large amounts of wind power

Demand flexibility should not be confused with generation

Demand resources are typically available "a number of hours" and are lacking the duration of the production resources. Demand resources are also dependent on a load that can be reduced when they are going to be used. Therefore, demand resources cannot directly be compared to production resources.

Demand flexibility with returning load has a limited potential for cutting capacity peaks

If demand flexibility is used only for moving load within a day, the potential is limited by the difference between the peak load and the daily average load (with a maximum demand flexibility, the load will be flat and equal to the daily average load). For the day with the highest demand during a year, this implies a potential of approximately 2 500 MW, even if the potential for demand flexibility during individual hours will be higher.



Demand in Sweden January 13th 2014 (the day with the highest load in 2014). If the load is levelled out completely, the maximum reduction will be 2526 MW

It is desirable to have demand flexibility already on the spot market

Demand flexibility can be distinguished into two different types depending on the price signal the customer is responding to. Demand Response (DR) means that the customer simply responds to the spot prices that are published at 13.00 the day before and adapt their electricity use accordingly. The upside of this type of price control is that it can be automated using simple and relatively inexpensive technology. The downside is that it can – with a high penetration – result in the price fluctuations being moved rather than smoothed out. Demand Side Management (DSM), on the other hand, means that the demand flexibility is invited already on the spot market the day before, based on the estimated flexibility the customer can contribute with on the market. The impact by the demand flexibility on the price is thereby explicitly included in the market clearance on the day-ahead market. This alternative leads to equilibrium prices and increased socio-economic benefits, and is therefore attractive from a system perspective. The drawback is that this procedure is more complicated and probably requires that an aggregator, e.g. an electricity trader, is allowed to control the load on behalf of the customer.

For more information:

Saara Hollmén, Magnus Lindén, Johan Bruce, Sweco

Further reading:
- *Planera för effekt! Slutbetänkande från Samordningsrådet för smarta elnät* (www.swedishsmartgrid.se)
- *NEPP:s internal reports (www.nepp.se)*

6 Smart grids – a development that has been going on for a long time

For an electricity system to be functioning at all, a continuous balance between demand and supply is required. For electric devices to work satisfactory it takes, more than a continuous balance, a voltage in the grid that varies within reasonable limits. With these prerequisites as a basis, our electric system has developed over more than 60 years. The ambition has been to create a system as economically efficient as possible under the present technological and legal conditions.

The balancing of the system and the voltage regulation can be done in many different ways, and some examples of system solutions are:

- Flexible power plants (power plants that have the capability to adapt to demand variations and (unwanted) variations in other power plants)
- Power plants which produce the most when demand is high, e.g. hydropower with large reservoirs, and cogeneration plants
- Transmission to other areas, which evens out the total need for regulation and increases the number of power plants that can be engaged
- Flexible electricity demand
- A powerful distribution grid (low impedances, high voltage, large areas in power lines)
- Voltage regulation in adjustable transformers
- Voltage regulation in solar cells and wind power plants
- Auxiliary equipment (SVC, Static Var Compensation) that is installed and controls the voltage

"It is not about the control measure being "smart" itself, it is rather the consequence of the measure that should be smart."

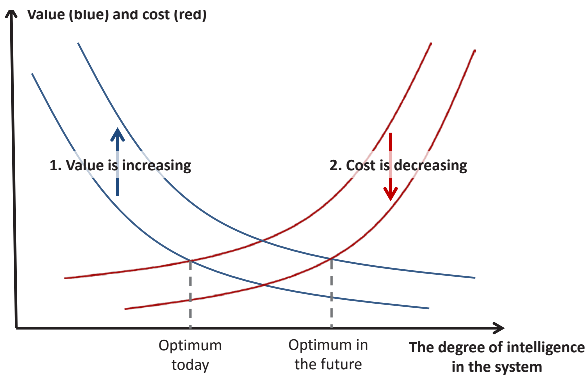
In the power system, it is possible to continuously measure several quantities, e.g. voltages, transmission, generation and demand. This information can then be used for various kinds of decision making. The aim of the decisions is to, as efficiently (smart) as possible, control the generation, demand and transmission, in a way that helps the electricity system comply with the requirements for economic efficiency and reliability. Control means switching on and off breakers, regulation in various components etc. It is not about the control measure being "smart" itself, it is rather the consequence of the measure that should be smart.

Thus, the development towards a "smarter" grid is something that happens gradually and is today primarily driven by the development in the electronics area. Moreover, the demands on society to supply secure and cost effective electricity increase. A greater element of intermittent generation also means a higher pressure on the distribution system and new demands for regulation, which gives further incentives for finding the most cost efficient solutions.

"Smart" grids is all about using more IT in the power system, so that the infrastructure can be exploited closer to its maximum technical performance. Technically, it is possible to measure everything everywhere in the system with a resolution level of seconds, and control every household appliance, but it would be very costly. The value of an extreme degree of measurement is also questionable, which is illustrated by the fact that the value declines the more you get. But, all the evidence suggests that we will see more of smart solutions in the future, since:

1. The value is increasing: We will in the future see more of variable electricity generation, e.g. wind and solar power, which requires more control. With the liberalised market there is a higher pressure on costs.
2. Costs are reduced: This goes for costs for measuring, controlling, transferring, as well as processing the information.

Also, the society's dependency on a functioning electricity system is increasing, which leads to a need to minimise the risks of errors, to reduce the consequences of the errors that still occur, and to rapidly correct the errors.



Smart grids is not a revolution, but an evolution

Collaboration with the Swedish Coordination Council for Smart Grid

In December 2014, the Swedish Coordination Council for Smart Grid submitted their action plan for smart electricity grids *("Planera för effekt!")* to the Swedish Minister of Energy. NEPP contributed during 2013 and 2014 with 10 out of 26 supporting reports, which have worked as a facts base for the council, and they also refer to all of the NEPP reports in the action plan.

Below is a short description of these reports. The results and the conclusions from the reports are described in several different chapters in this document. (See references below).

Description of the specific challenges facing the Swedish electricity grid as a result of the ongoing transformation of the energy system.
NEPP analysed, early in the work of the council, the challenges facing the Swedish electricity system as a result of the ongoing transformation of the energy system, with amongst other things a large share of intermittent electricity generation (See Chapters 3 and 4).

Analysis of the effect of different changes in regulatory frameworks, division of roles and market models that might contribute to a better utilisation of demand flexibility.
(See Chapters 4, 5 and 7).

Conditions and driving forces for different types of electricity consumers to adapt their consumption patterns and reduce their electricity demand. The report clarifies the role demand flexibility might play on the future electricity market. Focus is on the short term demand flexibility with a duration from 1 to 3 hours. (See Chapter 5).

Expectations on the future electricity grids – smart grids. How smart grid applications might contribute to decreasing the investment needs in the grids given a massive introduction of electric vehicles and distributed generation.

A detailed scenario analysis and quantification of the council's four scenarios. The study elucidates the effects on the electricity and energy system level in the future scenarios created by the council, and includes quantitative estimations based on NEPP's own scenarios. (Results from NEPP's own scenarios are presented in Chapter 1).

Assessing the contribution from smart grids to fulfill energy and climate targets

How the development of the European power system affects the need for smart electricity grids in Sweden. The development of the power system outside of Sweden will have a large impact on our needs for smart grids. Our analysis identifies some ten important factors and areas that will influence the future development.

An overall view of the technology development and applications in key areas, which make new demands of the grid development – electric vehicles, wind power, solar cells and energy storage

Technology for smart grids for the electricity grids themselves. Survey and demand analysis. A review of the technological solutions that can be integrated in the future smart grids.

Analysis of the societal driving forces behind the smart grids.
See next pages.

Analysis of what drives the development of smart grids

One of the tasks for the Coordination Council for Smart Grid was to analyse which factors that contribute to the development of smart electricity grids in different sectors of the society. An important part of this work was an expert seminar with a dual purpose:

- To identify what it is in the society that drives the development of smart electricity grids.
- To understand how these societal changes affects the need for, and the usefulness of, smart grids.

Below, a sample of the topics discussed at the seminar are presented:

”**Internet of things”**, connecting machines, people and networks in larger systems. New conceptual models to be communicated to customers/users will be required, but new business opportunities will be created. The challenge is not technology in itself, rather how fast we can develop practices for interacting with the surrounding world through ICT (Information and Communication Technology).

The society of today is more online and interconnected, and is more complex and has more actors than it used to, which can contribute to its resilience capacity, but it might also make the society more vulnerable and thereby less resilient. Resilience in the context of the society and the society’s infrastructure can be seen as the resistance to change/disturbance/external influence, but it can also be explained as the capability to recover and reorient. Resilient infrastructure is formed by robustness in the systems, as well as by redundancy and flexibility.

The future healthcare, where patients can be attended/treated in their homes using e-health solutions, will pose high expectations on robust electricity systems, and availability both regarding IT and electric systems. Healthcare of today has become more complex, not the least because of the many actors under one roof. The concept of e-health, roughly ”IT in health care”, is a player in the shaping of this reality, where a large number of actors are expected to cooperate. In parallel with the customer-driven IT technology, we now see a more patient-driven healthcare. Patients with their own equipment for, e.g., long-term measurement of blood pressure or ECG confront the healthcare with new questions. How should the healthcare system meet the expectations and demands from patients doing more and more of their own research? Patients and other stakeholders have new expectations today compared to how it used to be.

The consumers of tomorrow are raised with IT, digital media and devices, in a way that is totally different from previous generations, and this might influence what they in the future will expect from, e.g., the electricity companies. The age at which Swedish youth/children are starting to use IT is declining rapidly, and half of the 2 to 3 years olds have come in contact with internet. Which services will this generation expect as adults?

We don’t know what is going to drive the next technology shift. ”For example, Spotify revolutionised the music industry in a way nobody could predict, and a whole branch collapsed”. One uncertainty is the future development of energy storage; will this impact the future of the electricity companies?

Many components in smart grids require that data can be exchanged between different interested parties, which is complicated by the lack of standards and principles for this kind of cooperation. A related issue is storing and managing the extremely large amounts of data resulting from the collection of an increasing number of measured values.

A development path that seems unlikely today, but which would have a dramatic effect on the electricity system and the electricity companies, is if the customers partly, or fully, separate themselves from the regular electricity grid. Maybe we will see 12 V systems with private electricity generation in solar cells and storage of electricity in batteries?

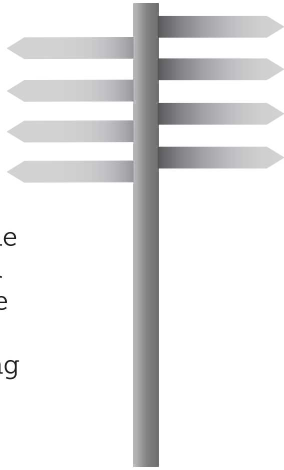
Is the ”quality” of our electricity too high?
Would it be possible, as a customer, to choose what best fits ones need (with an alternative pricing). One development option could be a differentiation of the electricity delivery with one part payed for as top-rate, but another part bought as second-rate, e.g. with the agreement that the supplier might pause delivery during (short) specified periods. Thus, the supplier can avoid purchasing electricity the hours with extremely high prices, and thereby be able to sell electricity less costly. The customers would then have to accept to postpone washing, and reduce their heating during short periods, without great sacrifices.

For more information:

Håkan Sköldberg, Profu ;
Lennart Söder, KTH

Further reading:
- *Planera för effekt! Slutbetänkande från Samordningsrådet för smarta elnät* (www.swedishsmartgrid.se)
- *NEPP:s underlagsrapporter* (www.nepp.se

7 The Power market is at a crossroads



There is a need for a redesign of the European power market. The market design of today – based on an energy-only market – will not necessarily deal adequately with large amounts of renewable electricity generation. The low marginal costs of renewable generation will reduce the price on the electricity market, making conventional generation unprofitable. There are concerns that this could - without some form of intervention - lead to underinvestments in conventional power capacity.

An energy-only market will have difficulties to deliver needed investments in generation. Energy-only markets have some disadvantages. Generators are expected to recover their fixed costs during a small number of hours when generation capacity is scarce. This is not always politically feasible. Capacity mechanisms are suggested as an answer to this problem. Also demand-flexibility is brought forward as a possible solution.

Europe is moving towards a centrally planned power market. A large majority of all new capacity introduced in recent years is based on subsidies rather than market based payments. Up to now, this has been especially true for renewable generation, but it is becoming true also for conventional and nuclear power. The UK is an example of a market that is becoming increasingly more centrally planned, with long term contracts for renewables and nuclear power, and a capacity market for conventional generation. Another example is France, where a part of the nuclear power generation is traded with regulated tariffs.

Capacity markets will lead to increased investments. The introduction of a capacity market will mean yet another revenue stream for the generators in addition to the payment for energy. Uncertainty, and thereby risk, will be less which lead to lower capital costs. If a capacity market is introduced in a country, it might result in distorted investment incentives in neighbouring countries, so that investments are transferred to the area with a capacity market. This can, in turn, lead to a decreased security of supply in the neighbouring countries.

Capacity markets will lead to lower wholesale prices. The increased capacity, which is a result of a capacity market, will lead to lower wholesale prices. If the capacity mechanisms are unevenly distributed, the price effects will spill over to neighbouring countries. For the end consumers, the lowered energy price is balanced out by the payment for capacity.

The cost of capacity markets will increase once new investments are needed. The capacity price on a capacity market is expected to cover the fixed costs that are not covered by revenues from the energy market. In a capacity market where the demand can be met by existing generation, the price should be capped by the fixed operation and maintenance costs. If new capacity is needed, also the capital costs to cover the investment must be included, which results in a considerably higher capacity price.

The choice between a strategic reserve and a capacity market is dependent on how often it is expected to be used. Capacity systems can either be targeted or market-wide. Targeted capacity mechanisms, as the Swedish strategic reserve, are well suited for peak load plants that are only needed for a few hours every year to handle occasional load peaks. These installations have a limited impact on the market and they are relatively inexpensive. Market wide capacity systems, e.g. the capacity markets that have been implemented on the Continent, are well suited for capacity that is expected to be used frequently, e.g. to handle fluctuations in wind power. These systems will have a major impact on the electricity market and can be quite costly.

Including interconnectors in a capacity mechanism is far from simple. The implementation of national capacity markets in Europe might lead to distorted cross-border competition. Therefore, there are discussions about whether it is feasible to rely on import in scarcity situations, and how national capacity mechanisms could incorporate contribution from generators outside the national borders. Several different models are proposed where it is either generators in neighbouring areas or the interconnectors that are incorporated. In both models the major topic of discussion is about who carries the accountability for non-delivery.

Locational marginal pricing will allocate transmission capacity more efficiently, but lead to less liquidity on the market. In a market with nodal pricing, a full network model is used to simultaneously establish both dispatch volumes and prices at each injection and exit node, taking into account not only the bids from the market participants but also the resulting flows. The price at each node will vary not only depending on costs of generation electricity, it will also reflect the costs associated with transmission constraints and transmission losses. Nodal pricing is considered to encourage a more efficient use of the network. As an effect of the increased complexity with many nodes, the market will be less liquid. In US, nodal complexity is simplified by aggregating nodes into trading hubs.

For more information:

Johan Bruce, Andrea Badano, Sweco

Further reading:
- *Ten statements about The future Power Market Design* (www.nepp.se)
- *Facts sheets from NEPP; for example: Capacity mechanisms : revived interest in capacity mechanisms throughout Europe in the face of high volumes of intermittent generation* (www.nepp.se)

8 Politics and the economic development are the factors that influence the electric system the most

The future energy and climate politics of EU and its Member States, and the economic development (GDP growth) are the external factors with the most pronounced impact on the development of the electricity system, in the short as well as in the long perspective.

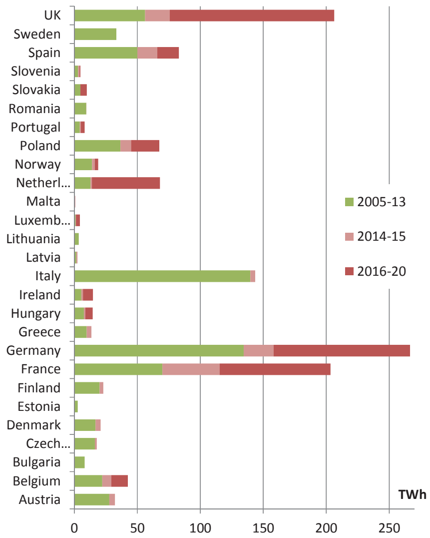
For most countries, the biggest challenges are the EU-common goals for GHG reduction, renewable energy and energy efficiency. A couple of countries, e.g. Sweden, Denmark and Germany have, beyond this, defined their own more far-reaching goals. Germany has also decided to phase out all nuclear power (2012), and nuclear power decommissioning is always on the political agenda also in Sweden, particularly now when several power companies have decided to go for an early retirement of several nuclear power units.

The finance crisis 2008, and the continued weak economic development in the EU thereafter, has had a major impact on the energy demand. The yearly increase of the total energy demand we had before 2008 was replaced by a yearly decline after the finance crisis. Also the electricity demand has decreased.

The EU is well on the way to achieving its 20% targets for 2020, but there are still some uncertainties. The climate target for EU-28 for 2020 is already reached, since GHG emissions are already reduced by a bit more than 20 % (up to 2013) compared to the level in 1990. The 20% renewables target is within reach, and the current share of 15% (in 2013) is exceeding the defined interim targets. However, a large number of the EU Member States are falling behind, and this might jeopardize the target achievement for 2020 (see next page). Also the target for an energy efficiency improvement by 20% from 2005 to 2020 is reachable, and we are so far more than half the way (12% in 2013). However, a fast economic recovery within the EU would make it more difficult to attain this target for 2020.

Several of the large EU Member States must accelerate their investments in renewables considerably, if the EU target of a 20 % share of renewable energy by 2020 is to be attained. The share of renewable energy has steadily grown in the EU for a long time. In 1990, the share was 6 %; in 2005, it was 8-9 %; and in 2013, 15 %. Therefore, the prospect of achieving the target of having a 20 % share in 2020, looks relatively promising.

It is, however, crucial that countries such as the UK, France and the Netherlands reach their goals. They have only achieved a mere third of their targets between 2005 and 2013, i.e. halfway through in time. Germany, which is often regarded as a forerunner, was, in 2013, only halfway to their target.



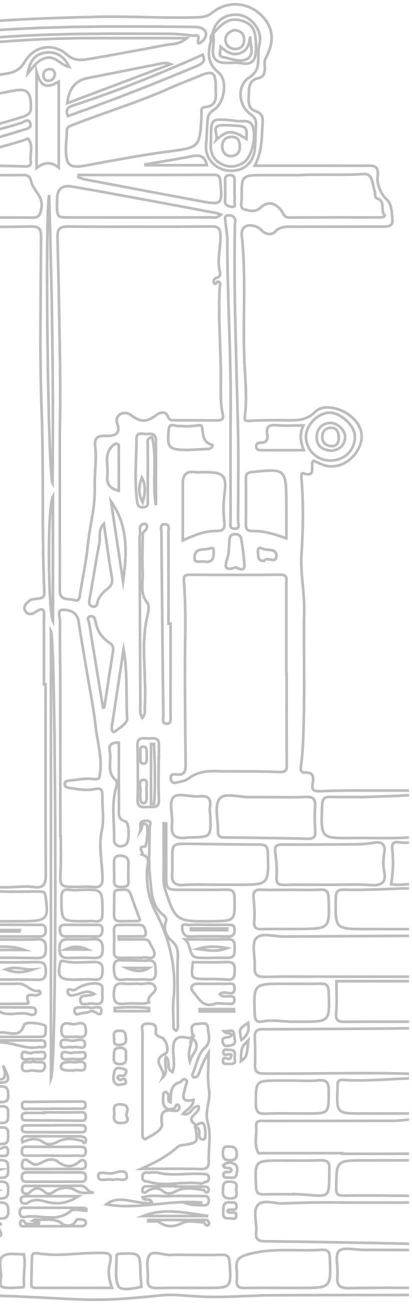
The renewable goal for the EU Mamber States. Several large countries are still far from achieving their targets

The weak GDP development in the EU after the financial crises contributes significantly that targets can be reached. It explains at least two thirds of the reduction of primary energy consumption, which implies an energy efficiency, in the EU, of 12 % (in 2013). Together with the economic recession in Eastern Europe after the collaps of the USSR in the 1990s, the financial crisis also explains about a third of the reduction of GHG emissions.

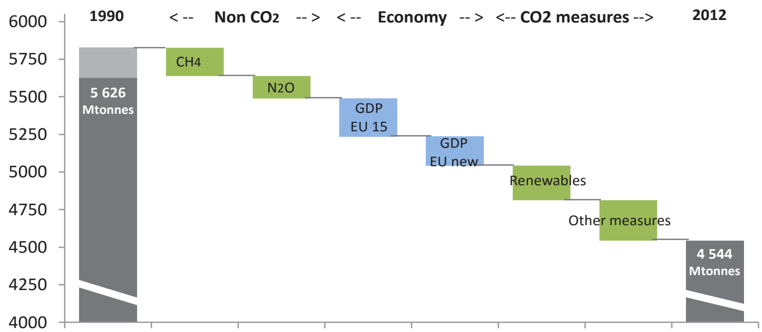
The GDP development has less impact on the renewable target

The target for renewables is specified as a proportion of the renewables in final energy consumption (total energy consumed by end users). The numerator is, thus, the amount of renewable energy and the denominator is the amount of final energy consumption. The proportion (share) will grow when the amount of renewable energy is increased, as well as when the amount of "final energy" is decreased. But, it is worth noting that a one-percent increase of the numerator, or a one-percent decrease of the denominator, will not result in a one-percent increase of the share of renewables. It will rather result in an increase by a bit more than a tenth of a percent given the current renewable share of approximately 15%.

For this reason, we can see that the share of renewables will only increase by slightly more than 1 % if the amount of "final energy" is reduced by 10 % by 2030, for example as a consequence of an economic slowdown. Neither has the historical decline in energy use after the economic crisis in 2008 had any major influence on the increase of the observed share of renewables. The increase from 8 -9 % in 2005 to 15% in 2013, can mainly be explained by the large investments in renewables (the numerator, renewables, has in this case increased by 55 %, from a bit less than 100 to 155 Mtoe, and the denominator, final energy, has decreased by approximately 10 %, from 1200 to 1100 Mtoe).



Three principal factors explain at least three quarters of the GHG reduction in the EU between 1990 and 2013. The downturns in GDP in the early 1990s and during the financial crisis in 2008 and the following years, investments in renewable energy, and measures taken to reduce methane and nitrous oxide emissions, are the three principal factors behind a very large part of the GHG emissions reductions between 1990 and 2013.



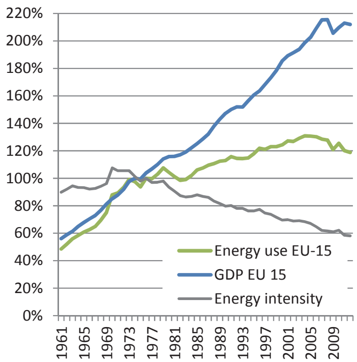
A schematic view of the main factors behind the reduction of GHG emissions in EU-28. The reduction is related to an emission level extrapolated from the emission level in 1990, according to a Business-as-Usual scenario.

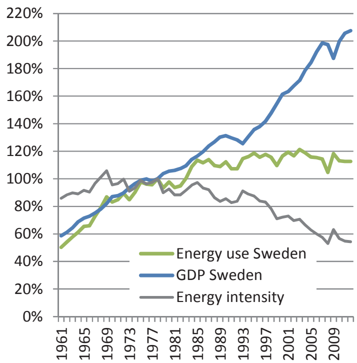
The electricity sector has contributed to the transformation of the energy system in the EU, and the CO_2 emissions stemming from electricity generation have been reduced significantly. However, all of this reduction has occurred in Eastern Europe; the emission reduction in Western European electricity generation is small. Sweden, in contrast, has had low emissions during the whole period of 1990–2012.

The emissions of methane and nitrous oxide have so far been reduced twice as fast as the CO_2 emissions, but the current scenarios predict a slower reduction up to 2030 and 2050. In percentage terms, both the methane and the nitrous oxide emissions have been reduced by approximately 35 %, which is twice as much as the 17 % reduction of CO_2 emissions. The emission reductions mainly derive from the agriculture sector, waste management, fuel extraction/fuel management and in the industry. The development of methane and nitrous oxide emissions in Sweden is similar to that in the EU as a whole.

Sweden is the country in the EU with the lowest level of GHG emissions related to the GDP, and this has been the case for the whole period of 1990-2012. This apply for the CO_2 emissions, the (combined) "non-CO_2" emissions and the total GHG emissions. Every year, since 1990, we have had by far the lowest level of total GHG emissions per GDP. In average we have had every year since 1990, 25 % lower emission levels than the runners-up among the EU countries, Denmark and France, and 35 % lower levels than the EU average. The figures for the CO_2 emissions are similar to that of the totals, which is logical since CO_2 is the dominating GHG. More surprisingly, we also have, related to the GDP, the lowest (combined) emissions of the other five GHGs (dominated by methane and nitrous oxide). For these "non-CO_2" gases we have had, since 1990, an emission level that has been 45 % lower than EU-28 (on an average) and 15 % lower than the second best EU Member State, Austria.

The "decoupling" between energy and GDP is a relatively modern phenomenon, and the preceding period with "coupling" was not very long either. Before "coupling", we had a period we could call "pre-coupling", with energy intensities at levels several times higher than today. The energy use has increased with the GDP development, in Sweden as well as in the EU (Western Europe), since the late 19th century. The "decoupling" did not appear until the oil crisis in the 1970s. The development after the "decoupling" has been similar in Sweden and in the EU, with a continued GDP growth at the same rate as before (until the financial crisis) but with only a small increase in energy use. Thus, the energy intensity has gradually declined to the current level, approximately 60 % of the intensity in the 1970s. Obviously the economy has become much more energy efficient.





The EU Commission exaggerates the political influence on energy efficiency improvements

The EU Commission:
"After a hesitant start, Europe's energy efficiency policy is now delivering. Framed by the 20% savings target for 2020, there is steady momentum at European and at national level... ...The Commission considers that it is appropriate to maintain the existing momentum and propose an ambitious efficiency target of 30% (2030)."

Source: EU Commission Document SWD(2014) 255 final

The EU Commission states, in documents that form the basis for the 2030 objectives, that it is convinced that the main cause to the observed reductions in energy demand is the implemented energy efficiency policy, and not the economic recession. This conviction is based on comprehensive analyses that – which is noteworthy – indicate the opposite, namely, that the main cause is the economic recession. The NEPP analyses also conclude that recent years' energy demand reductions are mainly explained by the economic slowdown.

The current recession might raise false hopes about a swift goal achievement

In the EU parliament there is an ongoing discussion about increasing the goal for energy efficiency improvement in EU by 2030, from 27 % to 40 %. At the same time, the Swedish government wants to raise the ambition in the EU ETS, and to increase the climate goal in the EU to a level beyond the 40 % reduction of GHG emissions to 2030, that the EU has stipulated. They argue that we need to act more aggressively to achieve the necessary climate adaption, and refer to the fact that we have already reduced the emissions as well as the energy consumption in EU more and faster than expected. But, they do not mention that a significant part of the explanation why we are further ahead than expected is to be found in the finance crisis and the recession, and an increasingly better economy is not accounted for when arguing for a tightening of the goals. This might raise false hopes about a rapid goal achievement even in the future, something that might prove hard if Europe's economy recovers and we get a sustainable period of economic prosperity.

For more information:

Bo Rydén, Profu ; Filip Johnsson, Chalmers

Further reading:
- *"Did-you-know-that"-sheets. Facts sheets from NEPP, available at:* www.nepp.se
- *Fem myter om energin och klimatet och tio utmaningar för Sveriges, Nordens och Europas el- och energisystem* (www.nepp.se)

9 The challenges to reach the climate targets of 2030 and 2050 are very large

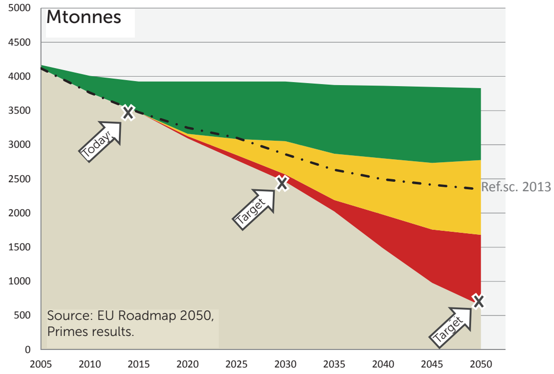
The challenges in the transformation to a climate neutral energy system in Sweden, the Nordic region and the EU are huge, so huge that it can be argued that the likelihood to fully succeed in the transformation to 2050 is low. Even a more moderate rate and scope would be challenging. Industry and transport are the sectors with the largest and most challenging transformation in Sweden.

The challenges are roughly the same in all scenarios. The challenges to reach the climate targets of 40% by 2030 and of 80-90% by 2050 are roughly of the same magnitude, regardless of which path (scenario) is chosen; and the challenges for Sweden and the Nordic region are of the same order as for EU as a whole.

The largest challenges in the transformation are namely the large scope (80-90%) and the fast pace (only 35 years left to 2050) of the required emission reductions. To manage this, all measures are needed, and therefore, the choice of scenario – the path – will be of less importance.

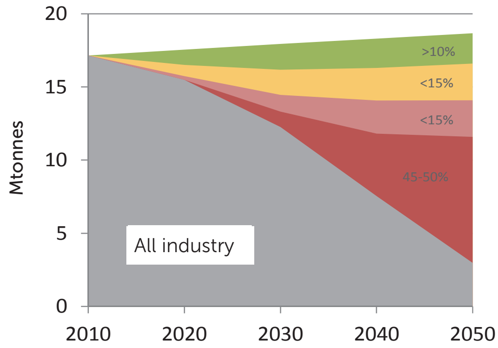
Germany has the highest emissions of CO_2 per capita.
Of the six large countries in the EU-28, Germany has the highest levels of CO_2 emissions per capita, more than 30 % higher than the EU average. The current (2012) emissions of CO_2 in the EU amount to 7.5 tonnes per capita. This apply for the EU-28 (as a whole) as well as for the average of the six large EU countries (Germany, France, United Kingdom, Italy, Spain and Poland). However, the CO_2 emissions in Germany is 10 tonnes per capita, more than 30 % higher than the EU average. In Poland, which has the second highest CO_2 emission of the six large countries, the emission is 8.5 tonnes per capita.

The CO_2 emissions must be reduced much more than what has been done so far, in all sectors. Hitherto, a large part of the GHG emissions has been achieved by "non CO_2" abatement measures, and as a consequence of the economic downturn. For the period up to 2030, it is reasonable to assume that the reduction of methane and nitrous oxide will slow down and the economic growth will start to recover. This results in growing demands for CO_2 emission reductions in all sectors. We must the next 15 years – if the 2030 target is to be reached - most certainly achieve a CO_2 reduction in the EU that is at least twice as large as what has been accomplished the last 25 years (from 1990 up to now). And we must go on in this speed for yet another 20 years to also reach the target for 2050.



The challenges in reducing the CO_2 emissions in the EU-28 by 2030 and 2050. The challenges have been evaluated using the NEPP project's scorecard methodology. (The EU's reference scenario is included as comparison.)

The challenges in the transformation of the industry are very large. A sector-wise analysis of the Swedish industry reveals that - with conventional measures - only a 5 - 10 % reduction of CO_2 emissions is possible in sectors such as refineries/chemistry and the cement industry. To go further, totally novel actions must be taken, e.g. CCS and a shift of raw material. This might involve a radical structural change with very uncertain profitability as a consequence. Also the iron and steel industry, and the mining industry, are facing significant challenges, whereas the challenges are more moderate in the transformation of the pulp and paper industry.



Challenges in reducing CO_2 emissions in the Swedish industry as a whole. The challenges have been evaluated using the NEPP project's scorecard methodology.

MEASURES FOR REDUCTION OF EMISSIONS

Green:	Current technology and measures, moderate costs
Yellow:	Current technology and measures (BAT), comparatively high costs and/or process changes
Light red:	Current or new technology and measures close to commercialisation, requiring massive investments and/or process changes
Red:	New technology and measures, currently in the R&D stage

For more information:

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Further reading:
- *NEPP mid-term report* (www.nepp.se)
- *NEPP Progress Report, Part 2* (www.nepp.se)

The challenges in transforming the transport sector are very large. The Swedish target of having a fossil-fuel independent vehicle fleet by 2030 is very ambitious. This target cannot be reached without powerful measures and the transformation must start right away. At the same time, it is obvious that the Swedish ambition of a rapid transformation of the transport system is not in line with the EU's ambitions. The EU's roadmap stipulates instead a very modest transformation up to 2030, approximately 20 % CO_2 reduction, and rather indicate the period between 2030 and 2050 as the main period for the transformation of the transport sector in the EU.

A fossil fuel free transport system

Commissioned by Elforsk and Swedenergy, in a parallel project with which NEPP cooperated, a roadmap was worked out in 2012 for a fossil free transport system in Sweden by 2030. The purpose of this work, carried out in a broad collaboration with around 40 organisations, was to show which measures, choice of paths, decisions, and policy instruments, that are required for the transformation. Here, selected examples of results from this work is presented:

- **It is possible to reduce the use of fossil fuels by up to 80 % compared with today**, if the transformation starts immediately and very powerful policy instruments are implemented. But, succeeding in this is a big challenge. The public "FFF Investigation" and The Swedish Transport Administration draw the same conclusions in their analyses.

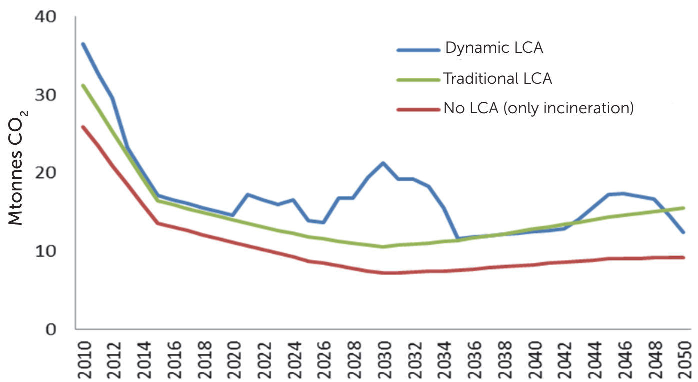
- **All types of measures are needed.** Achieving such a large and fast transformation of the transport system requires that all measures are considered and used. More efficient vehicles and fuel shifting are not sufficient. Also transport demand reductions, which can be accomplished by planning the society more transport efficient, and changing to more energy efficient types of transportation will be necessary.

- **Electrification of private cars as well as of heavy duty vehicles is of vital importance to the transformation of the transport system.** Through its energy efficiency as a fuel and, also due to, to the possibility to radically reduce the use of fossil fuels also in the electricity generation, electricity is considered as being of great significance to the transformation of the transport system in the entire EU. In the roadmap for Sweden, 2.5 TWh of electricity is expected to be used in the private car fleet by 2030, corresponding to app. 1 million electric vehicles. "Pure" electric vehicles as well as hybrids. Electric engines in the roadmap also introduced in heavy duty vehicles, and by 2030 the total electricity demand in the transport sector has increased from 3 TWh today to almost 9 TWh. The biggest hurdles for a large introduction of electric vehicles today is the pricing of the vehicles, the current limitations in battery capacity and the lack of an infrastructure for charging. If we follow the development for electric vehicles to 2050, the roadmap shows a volume of a further 7 TWh of electricity for light and heavy vehicles together. The total electricity demand would then add up to app. 15 TWh/year.

10 An extended climate analysis provides new insights, and strengthen NEPP's results and conclusions

The climate impact is dominated by the emissions from incineration

In a lifecycle perspective the climate impact from the Nordic electricity system is dominated by GHG emissions from incineration in condensing and cogeneration power plants. In all of the scenarios these emissions are reduced, from an already low level (seen in an international perspective). Emissions from e.g. auxiliary energy , and extraction and transport of fuels amount to 20 % of the total emissions today – and in a longer perspective up to 40 % - depending on scenario, technology and period in time (see figure). When in time the emissions occur also makes a difference on the climate impact. Traditional lifecycle analysis does not take this into account and the climate impact in the near future is underestimated, which can be seen in the figure below.



The figure shows the results from calculations of CO2 emissions from the NEPP scenario Green Policy in three different ways:

1) Lifecycle perspective considering when in time the emissions occur (blue line = dynamic LCA-calculation),
2) Lifecycle perspective in the traditional way (green line = traditional LCA)
3) Without lifecycle perspective (red line = only emissions from incineration)

Dual benefits from recovery of methane from landfills
CO_2 constitutes the dominating source of GHG emission from the energy sector. Small amounts of methane, nitrous oxide, and fluorinated gases also make a contribution. Methane emissions originate from, for example, landfills, and thus the recovery of landfill gas might both reduce the emissions of a powerful GHG and replace the use of fossil fuels for energy purposes.

But, the largest methane reduction in energy recovery is associated with waste incineration since waste is then combusted rather than deposited.

The timing perspective is important when evaluating the biofuel's climate performance. Today, biofuels are often appreciated as climate neutral since the CO_2 emitted when they are burnt once was absorbed by the growing biomass. But, the use of biofuels does have an impact on the climate, for example through its effect on the biogenic carbon deposits and emissions from auxiliary energy. Moreover, it will bring forward the emission of biogenic CO_2 as the biomass is combusted rather than degraded in nature. This timing perspective changes the climate performance for biofuels significantly. The NEPP results show that regardless of time horizon, branches and tops are better than stumps, which in turn are better than coal.

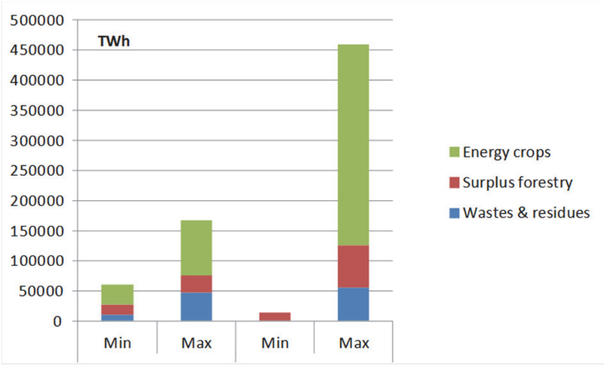
The climate neutrality of biofuels is today questioned by many, but policy instruments for renewables might make them competitive. We have, in NEPP, in a special model study, analysed what would happen if also the CO_2 emissions from the biofuels were included in the emission allowances trading schedule. The model results show, not surprisingly, that it then will be (somewhat) more difficult to reach the climate goals in Sweden and the Nordic countries. We will also see an effect on the development of the energy system, but this effect is relatively moderate, since the electric certificate system and the renewable energy directive will still give a significant stimulation to the use of biofuels. The use will however not reach the same level in these scenarios as in the base scenarios (where biofuels are assumed to be climate neutral). Instead the use of, for example, wind power and heat pumps will increase. The price of electricity as well as the price of CO_2 and the electric certificate price will rise, which also stimulates the energy efficiency improvement a bit more .

The global bioenergy potential is large

The global biofuel resources might - in the long run - become very large, and is, in reality, no barrier to a growing share of biofuels. The environmental assessment of biofuels in the future and their potential role in the energy system pose more substantial restrictions.

Different assessments of the global biomass potential show a very large variation, between 0 to 600 EJ by 2050 (0 - 450 000 TWh), depending on which assumptions are made. Land availability for energy crops, population growth, vegetarian or animal diet, yield per hectare, use of agricultural waste, and intensity of forestry are all factors with impact on the biomass potential. The global biomass potential can be compared with the total global primary energy supply of 550 EJ in 2008 which is by 2050 expected to grow to 600 - 1040 EJ.

In the assessments showing the highest potentials, the largest biomass shares derive from "farmed" biofuels, i.e. energy crops, whereas the potential of forest fuels is more limited. The global biomass potential can also be compared with the current (Year 2012) demand of biomass for energy purposes which amounts to 53 EJ. Of this, 34 EJ is traditional firewood combusted in more primitive types of equipment. 6 EJ are used for generation of electricity.



Apparently, on a global level there are sufficient biomass resources to stabilise the CO_2 emissions. This is evident if biomass-potential assessments are matched against demand scenarios that aim to stabilise CO_2 levels in the atmosphere within the interval of 440 - 600 ppm by 2100. These scenarios show a global biomass demand for energy purposes of a bit more than 100 EJ.

There is yet no real established international market for biofuels. In 2010, the total international biofuel trade amounted to 0.3 EJ, of which 2/3 was intra-European trade.

For more information:

Jenny Gode, Lars Zetterberg, IVL ; Mattias Bisaillon, Profu

Further reading:

- *Climate impact of long-term energy scenarios - Dynamic calculations* (www.nepp.se)

References

Theme reports:

”15 slutsatser om Elsystemets utveckling i Norden och Europa”. (2015)

”Ten statements about The future Power Market Design”. (2015)

”20 resultat och slutsatser om Elanvändningen i Sverige”. (2015)

”Reglering av ett framtida svenskt kraftsystem” (2016)

”Elsystemets utveckling i Norden och Europa”. (2016)

”The future Power Market Design”. (2016)

Synthesis reports:

”NEPP mid-term report” (2012) *(includes 5 internal reports)*

”Executive summary of NEPP mid-term report” (2012)

”Tolv påståenden i halvtid” (2012)

”Progress Report, Part 1”. (2013) *(includes 10 internal reports)*

”Progress Report, Part 2”. (2013) *(includes 15 internal reports)*

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”Beskrivning av de konkreta utmaningar som det svenska elnätet står inför med anledning av den pågående omställningen av energisystemet” (2013)

”Förutsättningar och drivkrafter för olika typer av elkunder att justera förbrukningsmönster och minska sin elförbrukning i dag och i framtiden” (2013)

”Utmaningarna i klimatomställningen inom industrin och transportsektorn” (2013)

”Hur utvecklingen av kraftsystemet utanför Sveriges gränser påverkar behovet av smarta elnät i Sverige (2013)

”Översiktlig bedömning av teknikutveckling och tillämpning inom nyckelområden som ställer nya krav på att elnäten utvecklas – elfordon, vindkraft, solceller och energilagring” (2013)

”Analysera effekten av olika förändringar i regelverk, rollfördelning och marknadsmodeller som kan bidra till att utnyttja möjligheterna till efterfrågeflexibiliteten bättre” (2014)

”Analys av vad i samhällsutvecklingen som driver utvecklingen av smarta nät” (2014)

”Bedömning av det bidrag som smarta elnät kan ge för att uppfylla energi- och klimatmål” (2014)

”Fördjupad scenarioanalys och kvantifiering av rådets fyra scenarier (2014)

”Krav på framtidens elnät – smarta nät. (2014)

”Teknik för smarta elnät för själva elnäten. Kartläggning och behovsanalys” (2014)

”Climate impact of long-term energy scenarios – Dynamic calculations” (2014)

”På väg mot en elförsörjning baserad på enbart förnybar el i Sverige. En studie om behov av reglerkraft och överföringskapacitet”(2014)

”Reglering av ett framtida svenskt kraftsystem, del 1” (2014)

”5 myter om energin och klimatet och 10 utmaningar för Sveriges, Nordens och Europas el- och energisystem”. (2014)

”Studie av sannolikhet för hög elförbrukning, effektbrist, effektvärden och höga elpriser ”(2015)

”Elanvändningen i Sverige 2030 och 2050” (2015)

”Reglering av ett framtida svenskt kraftsystem, del 2” (2016)

Result sheets:

”Nordic Energy Technology Perspectives (Nordic ETP)”

”Evaluating the Customer’s Benefits of Hourly Pricing based on Day- Ahead Spot Market optimization

”Stochastic Model of Electricity Retailer Incorporating Aggregated Electric Vehicle Charging Uncertainity”

”An Extended OPF Incorporating Multi-Terminal VSC-HVDV and Its Application on Transmission Loss Evaluation”

”Wind Power Capacity Credit Optimization”

”Model Analysis of Alternative CO_2 Emission Coefficients of Solid Biomass ”

”Increased power export from Sweden to Germany due to nuclear phase out policy - transmission network considerations”

”Linking techno-economic modeling of Europe’s electricity

sector to large-scale CCS infrastructure optimization ”

”Abundance of natural gas - increased supply of shale gas”

”Four main scenarios - a proposal”

”Prospects for radical reductions of CO_2 emissions from large industrial emission sources in the EU”

”Capacity mechanisms : revived interest in capacity mechanisms throughout Europe in the face of high volumes of intermittent generation”

”Different time scales for studies of power system performance

”Wind power in Ireland and USA - workshop report”

”Impact of the German nuclear phase-out - models results”

”Wind energy will grow - but how much?”

”The development of European electricity supply under climate-policy constraints”

”Market rules for electricity trade between Nordic countires and the continent, including legal preconditions for Merchant links”

”The role of electricity transmission and interconnectors”

”Increase in Nordic electricity export towards 2030 – selected results from recent studies”

”Hydro power as a balance resource - for increasing amounts of wind power: possibilities and limitations”

In swedish:

”Betydelsen av elöverföring mellan och inom länder”

”Kapacitetsmekanismer - stora volymer av intermittent produktion leder till ökat europeiskt intresse för kapacitetsmekanismer”

”Hur utvecklingen av kraftsystemet utanför Sverige påverkar vårt behov av smarta elnät”

”Ökad nordisk elexport till 2030 : - en syntes av resultat från genomförda studier”

”Marknadsregler för elhandel mellan de nordiska länderna och kontinenten, inklusive lagstiftning och för privatägda transmissions-ledningar”

”Vindkraften kommer att öka - men hur mycket?”

”Did you know that?”

Result sheets (available at: www.nepp.se/reults.htm)

- Three principal factors explain at least three quarters of the greenhouse gas reduction in the EU between 1990 and 2013
- The emissions of methane and nitrious oxide have so far been reduced twice as fast as the carbon dioxide emissions, but the current scenarios predict a slower reduction up to 2030 and 2050
- The electricity sector has contributed to the transformation of the energy system in the EU, and the carbon dioxide emissions from the electricity generation have been reduced significantly. All of this reduction has happened in Eastern Europe, the emission reduction in Western European electricity generation is small - (but Sweden,in contrast, has had low emissions during the whole period of 1990–2012)
- Several of the large EU Member States must accelerate their investments in renewables considerably, if the EU target of a 20 % share of renewable energy by 2020 is to be reached
- To reach the EU’s target for renewables for 2030, Sweden will not need more renewable energy than what Sweden has, if the burden is shared the same way as for the target for 2020
- Of the six large countries in EU 28, Germany has the largest emissions of carbon dioxide. France is on top among the six largest countries, when it comes to (the total amount of) the other five greenhouse gases
- Sweden is the country in the EU with the lowest level of greenhouse gas emissions related to the GDP, and this has been the case all the way from 1990-(2012). This goes for the CO_2 emissions, the (combined) ”non-CO_2” emissions and the total greenhouse gas emissions
- Europe’s economy has recovered from every GDP decline the last 150 years. If the future is guided by the past, we will see a full recovery even from the current fall in the GDP
- The ”decoupling” between energy and GDP is a relatively modern phenomenon, and the preceding period with ”coupling” was not very long either. Before “coupling” we had a period we could call ”pre-coupling”, with energy intensity at levels seve-ral times what we have today

NEPP – A research cluster in a broad collaboration

NEPP’s research is performed in close collaboration with several international and national research projects active in NEPP´s focus areas. The project is also a resource for governmental investigations, councils, and commissions. Below are listed projects and activities with which NEPP has collaborated in its first phase:

- Swedish Smartgrid (set up by the government)
- Nordic ETP 2013, and 2016 (led by IEA and Nordic Energy Research)
- IEA Wind – Task 25 (a cooperation between 25 countries and organisations led by IEA)
- The Nordic Wind Integration Research Network – NWIN (with contribution from Nordic Energy Research)
- Vägval el (led by IVA, The Royal Swedish Academy of Engineering Sciences)
- Market Design and EFORIS (electricity market programme led by Elforsk and Energiforsk respectively)
- Pathways to Sustainable European Energy Systems (An international project led by Chalmers University of Technology)
- Capacity Markets in Europe: Impacts on Trade and Investments (A collaboration project led by Sweco)
- El och fjärrvärme – samverkan mellan marknaderna (a Fjärrsyn project led by Profu)
- Värmemarknad Sverige (a collaboration project led by Profu)
- Roadmap för ett fossilbränsleoberoende transportsystem (a collaboration project led by Swedenergy and Elforsk)

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