EcoGrid dk

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Steps toward a Danish power system
with 50% wind energy

EcoGrid.dk Phase I
WP3: International Scenarios

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Table of Contents:

Executive Summary

Abstract

The report documents the work carried out in work package 3 of EcoGrid.dk phase 1, and lays out scenarios for the development in market areas surrounding Denmark, mainly Germany, Norway and Sweden. The main scenario drivers are international market cooperation and environmental focus. The analysis shows that the challenges of increasing Danish wind power capacity from 3GW to 6 GW, as is the target put forward by the Danish Energy Strategy, depends on the developments in neighbouring countries. It is likely that there will be an increased need for technical reserves and system services in all scenarios, and it is likely that Denmark will need system services from surrounding markets. To what extent such reserves can be supplied by neighbouring markets, and the competition for balancing and system services, depend on market developments and investments in infrastructure. Increasing infrastructure capacities is a challenge in itself, given issues related to costs, public opposition and international obligations. The study points to the need for further scenario-based system and market studies in phase 2 of the EcoGrid.dk project.

Background and objective

The Danish power system is facing new challenges related to the new Danish energy policy with the goal of increasing the use of renewable energy to 30% of overall energy consumption by 2025. The official documents indicate that in order to reach this target, wind power should cover 50% of electricity demand in 2025.

The goal of the EcoGrid.dk research programme is to develop long term technologies and market solutions for power systems with increased share of distributed generation and renewable energy sources while maintaining the reliability of supply. As Denmark is an integrated part of the Nordic and Northwest European power system, the challenge must be seen against an international background.

The target for our work is to set the scene for the market areas surrounding Denmark. The degree of trading possibilities, physical and organizational, and the demand and supply of system services in the larger context is the main focus of the scenarios. The question is to what extent the challenge posed by the doubling of wind capacity differs with different assumptions about the development in surrounding market areas. Denmark has extensive interconnection capacity and electricity exchange with its neighbouring countries. This means that the Danish strategy for system development and the challenges thereof crucially depend on the developments in the adjacent market areas, particularly regarding markets (supply and demand) for balancing power, reserves and other ancillary services. The scenarios focus on the Nordic market and Germany, although more general (EU) market trends are also addressed.

Problem statement

Danish wind capacity is set to double from 3GW to 6GW in 2025. To what extent and how are the system challenges of increased wind power generation influenced by developments in market areas surrounding Denmark?

Approach: The Energinet.dk long-term scenarios

The overriding task of WP3 is to help broaden the picture of what future Energinet.dk should prepare for, where the doubling of Danish wind power capacity is but one component. This task is addressed by analysing the developments in surrounding areas under different market and regulatory scenarios. This study complements the scenario study carried out by Energinet.dk, and forms an important part of the basis for choosing market measures and system architecture solutions for the future Danish energy system. In order for the project and work package to be as relevant to planning processes as possible, the long-term scenarios for Denmark developed by Energinet.dk in 2007–2008 were taken as the starting point. The scenarios developed in the EcoGrid.dk project are developed with assistance from representatives from Energinet.dk, but are a result of independent choices by the WP3 project team.[1]

It is important to keep in mind that the EcoGrid.dk project task is to analyze the challenges faced by Energinet.dk if wind power capacity in Denmark is increased to 50% by 2025. In the Energinet.dk scenarios the share of wind power in Denmark varies between scenarios, and in some scenarios the share of wind power is higher than 50%. This is not in accordance with the basis of the EcoGrid.dk project objective, and the Danish scenarios as such have not been analyzed by WP3.

A few international characteristics will have significant influence on the future operation of power systems and electricity markets in Denmark. Among the most important characteristics are:

- International organization of energy markets including cross border trade
- EU in a more or less active role
- National self-sufficiency or common backup capacity
- Sufficiency of transfer capability in terms of frequency of congestion in grids and interconnectors
- Preferred energy technologies, particularly wind deployment and the role of nuclear power and CHP
- Demand development, particularly the incentives and potentials for demand response in different sectors

The four scenarios have four different combinations of these characteristics.

Short description of the international scenarios

The challenges to the operation and development of the electric transmission system in Denmark constituted by a doubling of wind capacity from 3 GW to 6 GW in 2025 have to be seen in an international context. Thus far, it has been observed that the development of wind power and more decentralized generation in the Danish system would not have been possible without access to international markets. The international markets provide an outlet for overflow generation when there is a lot of wind, back-up power when there is little wind and access to rapid regulation power, especially from the

[1] The WP3 project team consists of Berit Tennbakk and Franziska Sinner from Econ Pöyry, Paul-Frederik Bach, Kenneth Karlsson from Risø DTU, Anders Kofoed-Wiuff from EA Energianalyse and Thomas Ackerman from Energynautics.

hydro-based systems, when wind power generation falls or increases rapidly. Since the early 1990ies there has been a more or less constant trend towards increased integration and increased market based exchange between the Nordic countries, with Nord Pool as the common power exchange, and between the Nord Pool area and the continental markets (Poland, Germany and Netherlands). A study of the challenges of increasing wind power capacity in Denmark has to take the international context into account.

The analysis of the market areas surrounding Denmark has taken the Energnet.dk scenarios as the starting point. Building on the general stories and trends described in these scenarios, consistent scenarios for Germany, Norway and Sweden are developed. The main driving forces in the scenarios, following Energinet.dk's scenario matrix, are international cooperation and environmental focus. The scenarios are consistent in terms of the overall scenario drivers as laid out by the Energinet.dk scenarios. The internal consistency in terms of balance between supply and demand and the general energy and capacity balance in the whole area cannot be properly checked without a system or integrated model approach. This has not been the scope of the Phase 1 of the project and will hopefully be followed up in Phase 2.

Greenville

"International focus, environment – a highly focused concern"

The main drivers in this scenario are a concern for the consequences of climate change and common European carbon emission reduction targets. EU is playing a very active role in promoting and supporting green technologies and markets constituting a level European playing field.

The main characteristics of Greenville are high deployment of RES-E generation and reduced market share of thermal power, strong international markets and increased trade.

Economic growth is strong, but there is an increased emphasis on energy conservation. Electricity demand is more or less stabilized, even though electricity demand in the transport sector increases. In all market areas surrounding Denmark wind power capacities are expanded. Both Germany and Sweden becomes increasingly dependent on imports from other market areas as nuclear power is phased out and little thermal power is built. Since Denmark will probably have little to offer in terms of balancing power and reliable energy supply, Germany and Sweden are likely to turn to other neighbours for exchange options. Norway becomes a net exporter of electricity (and certificates) and will be interested in interconnector expansions to all other market areas, including Denmark. Denmark will however compete with UK, Germany and Sweden for access to the regulation resources offered by Norwegian hydro power.

Grønnevang

"National focus, environment – a highly focused concern"

The main drivers of this scenario are increasing environmental concern combined with a desire for local self-sufficiency. The global energy market is perceived to be unreliable and the prices are volatile. EU has failed in the development of a common energy policy and in the implementation of strong energy markets. There is strong public support for renewable energy, but countries chose different solutions in accordance with different national challenges and opportunities.

Medium economic growth and a strong focus on energy efficiency, where the estimated efficiency improvement potential is fully realized, imply that electricity demand is reduced significantly, even though electricity demand from transport increases. Wind deployment in Germany is high and there is an emphasis on finding solutions internally, e.g. in the form of demand side flexibility. There is less reliance on imports, but on the other hand, Germany does not have much flexibility to offer either. They have enough problems to cope with on their own, and Energinet.dk probably has to shield the Danish system against disruptions from the German system. On the other hand, the scenario may hold opportunities for Nordic cooperation. Norway is likely to invest in some wind power and small-scale hydro, but there will be less competition for Norwegian balancing services. Solutions may be found in Denmark-Norway- South Sweden as a more integrated balancing area.

The main challenge for Norway will be to find outlets for its power surplus. In this scenario, even Sweden has a surplus. Electrification of North Sea oil/gas installations may be able to absorb some of the surplus. Offshore electrification and expansion of Norwegian wind power may however imply more frequent internal bottlenecks in Norway, and more competition for regulating capacity from the domestic system in Norway.

Blueville

"International focus, environment – a less focused concern"

The main drivers of this scenario are security of energy supply and mobility of goods and persons as conditions for a strong European economy. EU plays a leading role in organizing a strong European market (including a market for balancing power), in the development of European energy resources and in providing a diverse range of channels for energy imports from countries outside EU. Nevertheless a high dependence on imported gas forms an Achilles' heel to European economy. The utilization of local energy sources and the conversion of energy must meet strict rules for the protection of the local environment.

High economic growth and only limited focus on energy efficiency, means that electricity demand increases significantly in Blueville. Electricity is not used to a larger extent in the transport sector. In this scenario, there is substantially less wind power generation in the areas surrounding Denmark, although there is some growth in renewables, including small-scale hydro and biomass CHP. There is likely to be a fair supply of balancing services (relative to green scenarios) and resources are likely to be shared. In Germany nuclear is phased out at a slower pace, and new capacity comes to some extent in the form of new CCGT. There is even room for biomass CHP and sufficient new gas power capacity to maintain the energy balance. Norway is a net exporter and transmission capacities are expanded to Germany and the UK. Sweden expands nuclear and biomass and imports from Finland, and in Norway more gas power is built.

In addition, access to balancing resources from international markets should be easier. It is likely that international balancing markets develop, and a higher probability that the infrastructure will be expanded to support market based trade and system needs (based on common economic rationale).

Blåvang

"National focus, environment – a less focused concern"

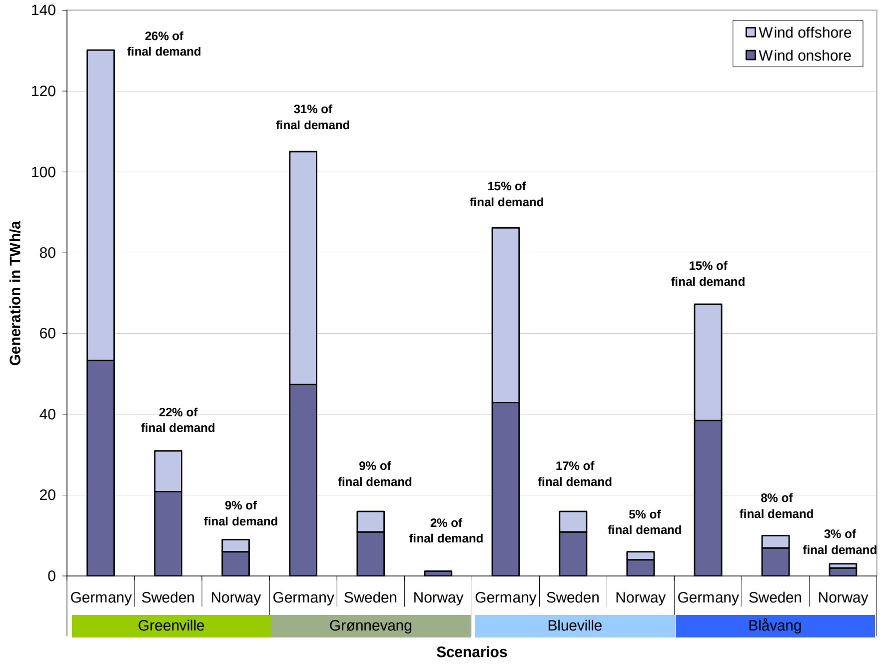
The main drivers in this scenario are preservation of national security and identity. The European populations feel that too much influence has been given to EU. Therefore the national parliaments have withdrawn important responsibilities from EU, and meticulous border control has been restored. Bi- and trilateral cooperation between countries occurs.

Economic growth is assumed to be low in this scenario and there is no particular focus on energy savings. The countries surrounding Denmark all look inwards to find solutions domestically. Germany develops a diversified capacity mix, but there is no market coupling between EEX and Nord Pool. In this scenario, Denmark should look to the North for cooperation on balancing needs. Both Norway and Sweden has a significant generation surplus, and a new interconnector to UK is established (to ease wet year challenges). A Nordic balancing market may be continued, but on the basis of strong obligations to be able to cope with domestic problems and (bi- and trilateral) long-term commitments. The demand for transit of the power surplus in the north (Norway and Sweden) to the continental markets, particularly Germany, is likely to be high.

Summary of annual generation, demand and trade in 2005 and 2025, all scenarios, per country. TWh/year

in TWh/year		**Greenville**	**Grønnevang**	**Blueville**	**Blåvang**
	2005	2025	2025	2025	2025
Germany					
Final demand	508,87	491,17	344,47	596,59	463,57
Gross generation	*556,22*	*509,02*	*376,68*	*617,56*	*517,06*
Net generation	500,60	458,12	339,01	555,80	465,36
Net exports	**-8,27**	**-33,06**	**-5,45**	**-40,79**	**1,79**
Sweden					
Final demand	136,65	144,07	95,02	177,35	129,19
Gross generation	*152,21*	*153,55*	*113,06*	*186,48*	*171,75*
Net generation	136,99	138,19	101,75	167,83	154,57
Net exports	**0,35**	**-5,88**	**6,73**	**-9,52**	**25,38**
Norway					
Final demand	112,66	98,33	64,76	127,29	98,55
Gross generation	*125,92*	*143,81*	*131,04*	*140,83*	*136,37*
Net generation	113,32	129,43	117,94	126,75	122,73
Net exports	**0,66**	**31,11**	**53,18**	**-0,54**	**24,18**

Summary of total wind deployment in 2025 all scenarios. TWh/year



Conclusions

The scenarios describe a set of very different outcomes in the electricity markets surrounding Denmark, and each scenario poses different opportunities and challenges with regard to the operation and development of the Danish electricity transmission system. Thus far, it has been observed that the development of wind power and more decentralized generation in the Danish system would not have been possible without access to international markets. The international markets provide an outlet for overflow generation when there is a lot of wind, back-up power when there is little wind and access to rapid regulation power, especially from the hydro-based systems, when wind power generation falls or increases rapidly and on short notice. Given the differences between the scenarios, it is clear that the international contribution to the costs and challenges associated with a doubling of the wind power capacity from 3 GW to 6 GW by 2025 will profoundly vary between scenarios.

The main challenges that Energinet.dk should assess in an international context are:

- Availability of balancing services from neighbouring areas (depends on flexibility in surrounding areas and transmission capacity)
- Peak load capacity (need for additional capacity – taking power balance and transmission capacity into account)
- Competition for peak load and balancing capacity (e.g. will Netherlands or Germany pay more for Norwegian flexibility than DK?) How are balancing resources allocated? At what cost may balancing resources be provided from international markets?
- Demand for transit (compensation for transit)? Impact of increased transit and increased domestic wind power generation?
- International obligations and how they influence the choices and solutions?
- Market design options. How do market design issues affect the impact and scope of market coupling and how balancing resources may be shared?

Some challenges occur in all scenarios, however to varying extents:

First of all there the **need for balancing capacity and technical reserves** will increase in all systems. Today the share of wind power capacity varies between the countries in the “Danish area”. In all scenarios it must be expected that the share of wind power will increase. The increase is largest in the green scenarios which also are the scenarios that correspond best with the current ambitious plans for wind power deployment. Accommodating further increase in wind generation in the power system is likely to be more demanding than the accommodation of the wind power developed so far. For Denmark this has mainly to do with ample transmission capacity and little competition for the balancing resources of Norwegian hydro power. The problem is amplified particularly in Grønnevang by the reduction in demand. This increases the probability that central power stations, which are important domestic providers of system and balancing services will be phased out. Hence, new balancing capacity and technical reserves must be found from other internal sources and/or provided by imports.

Second, the demand for transfer capability in Denmark is likely to increase, as power balances shift and the basis for trade increases. Currently there is growing public resistance against new transmission lines and political provisions that new transmission capacity must be cables. Add and long lead-times in decisions and construction to this picture, and there is a real possibility that the occurrence of internal bottlenecks in Denmark will increase. Hence, Energinet.dk should be prepared for a future with high and shifting loads in the system and **increased bottlenecks**. This enhances the system security challenges. The demand for transfer is likely to be largest in the "vang" scenarios due to development of large surpluses in the combined Norwegian and Swedish systems. The Blueville scenario seems to represent the least challenging scenario because of a smaller wind power deployment in neighbouring areas and a more balanced trade picture. But transit through Denmark is likely to increase even in this scenario.

Wind power generation increases in all scenarios, although the variation is substantial. The highest wind deployment is found in the Greenville scenario where up to 100% utilization of the potential (according to the Green-X database) is utilized in some countries. In the other scenarios utilization factors vary between countries from 15% up to 75%. Increasing wind power generation will increase the price volatility in the wholesale market. This problem will be amplified if there is a shortage of transmission capacity.

So what promising *solutions* to the challenges can be identified?

Although some challenges regarding grid expansion are identified, increased interconnector capacity with neighbouring countries and establishment of common market solutions could alleviate the situation. But expansion of interconnector capacity will and development of common market solutions will be easier in the "ville" scenarios than in the "vang" scenarios. Working for **implementation of international conventions and "standardized" solutions** for the decision basis to construct new interconnectors, including cost and income allocation, transit issues and market coupling solutions, should be a prioritized activity for Energinet.dk in the years to come.

Reinforcement of grids and interconnectors is likely to be necessary and an important part of a cost effective solution to balance the system without reduced service to domestic markets. It will be a major challenge in some scenarios to analyze and negotiate investments and utilization of interconnection capacity. The system operators are not supposed to maximize profit, but to increase transfer capability up to the optimal limit to the societies concerned. In pursuing this objective, the TSOs may be caught in a squeeze between international obligations, need for (negotiated) international solutions, political resistance against curtailment of wind power capacity and public opposition against overhead lines.

In the "ville" scenarios, which are characterized by market solutions and international cooperation, there is likely to be more transmission capacity and more common market solutions. However, in the Greenville scenario, Denmark will to a larger extent have to compete with other countries for the balancing resources. In the "vang" scenarios, countries emphasize national solutions. In both these scenarios there is a strong case for **Nordic cooperation** – in Blåvang because of a lack of market coupling with Germany, and in Grønnevang because there will be less international competition for balancing resources from Norwegian hydro, and at the same time, extensive wind deployment in north Germany poses an increasing threat to Danish system security.

The energy balance, and hence the total available capacity (import/export situation) also varies between scenarios. In Grønnevang particularly, it is hard to imagine how the international energy balance will develop if the dramatic reduction in demand is not matched by reductions in generation capacity. It is not likely that Denmark will be a net exporter in all scenarios, and it may be necessary for Denmark to **reduce its export dependency** (overflow situations must be expected to occur more frequently with a doubling of wind capacity). Particularly, the load factors, and hence, the profitability of the central units is likely to decline, and they may not be commercially viable. The central units are important suppliers of vital system services which then have to be replaced by other sources. This is an important issue which should be investigated further in Phase 2 of the project, where the international scenarios and the development of the Danish system should be analyzed in an integrated manner – preferably using market models to quantify, e.g., trade flows and capacity balances.

The potential for **demand response** as a source of balancing services has been assessed as well. The incentive for demand response is linked to the price variability and volatility in the market. The potential for demand response depends on technical solutions on the demand side, for example the availability of plug-in hybrid cars and the amount of heat pumps in the system. It also depends on the overall demand *level*. This means that in the Grønnevang scenario the incentive for demand response may be high because of price variations and high peaks, whereas the potential may be low due to the decline in electricity consumption. It is difficult to assess whether demand response resources are better utilized if short-term price signals are passed on to consumers, or by administrative regulations and 2-way communication solutions. It may be easier to activate demand response related to predictable variations in prices than in response to unpredictable responses (volatility) – with respect to contracts, transaction costs and technical solutions.

Recommendations for phase 2

As mentioned above, phase 2 of the EcoGrid.dk project should take an integrated approach when it comes to the further development of the scenarios. To fully understand the challenges and possible solutions it is necessary to put Denmark into the picture. The detailing of the scenarios can only be further developed in synergy with the consistency check that an integrated analysis offers. An integrated market and system analysis has to be carried out to further understand the investment incentives, price impacts (level and structure), trade and transit implications, etc. An integrated system and market analysis would also constitute the basis for the choice of measures – both market measures and technical solutions – that show the most promise in terms of costs and potential to contribute to solving the wind power expansion challenge.

Specific topics which should be investigated further in phase 2 include:

- Quantification of balancing resources available from other market areas (flexibility and transmission capacity), as well as in the Danish system
- Peak load capacity (need for additional capacity – taking power balance and transmission capacity into account)
- Competition for peak load and balancing capacity (e.g. will Netherlands or Germany pay more for Norwegian flexibility than DK?) How are balancing resources allocated? Alternatives and price formation?
- Demand for transit? (Compensation for transit?)

- International (system security) obligations?
- Cost allocation for new interconnections?
- Overall cost perspective on solutions: What is the cost efficient answer to the challenge in the different scenarios – taking market dynamics (e.g. investment incentives) into account?

Scenario issues, second phase:

- Market design in an international context (it is no use for Denmark to introduce market design that cannot be shared with neighbours, cf. gate closure and market coupling)
- Transit costs and payments – prospects for interconnections; Availabilities, investments, priority issues?
- International obligations, interactions and restrictions. What restrictions and obligations will apply to Energinet.dk as a system operator, and how will these interact with the options and opportunities.
- Market structure – market dynamics. Who will be active in the market in the future, how will they react to different market and regulatory incentives?

1 Short introduction

1.1 Project description

1.1.1 Overall goal of the EcoGrid.dk project

The overall goal of the EcoGrid.dk research programme is to develop new long term technologies and market solutions for power systems with increased share of distributed generation and renewable energy sources while maintaining the reliability of supply.

The programme will focus on identification and evaluation of new architectures and structures for the power system and development of new solutions for enhanced customer participation and pioneering concepts of system control and operation. The EcoGrid.dk programme will cover research and development activities within related areas, and the programme shall initiate and coordinate these activities.

EcoGrid.dk will look for global solutions with reference to the Danish power system and the new Danish energy policy with the goal of at least 30% renewable in the overall energy system in 2025 and indications that wind power can cover 50% of electricity demand in 2025.

1.1.2 Work package 3: International scenarios

The objective of the work package is to establish a set of common scenarios to understand future market potentials in the surroundings of the Danish transmission system. Denmark has extensive interconnection capacity and electricity exchange with its neighbouring countries. This means that the Danish strategy for system development and the challenges thereof crucially depend on the developments in the adjacent market areas, particularly regarding markets (supply and demand) for balancing power, reserves and other ancillary services. The scenarios will focus on the Nordic market and Germany, although more general (EU) market trends will be addressed.

1.2 The work process in the work package

After the project was started, it came to the knowledge of the work package leader that a scenario process had been carried out in Energinet.dk already, focusing on scenarios for the development of the Danish energy sector. A meeting was held with the scenario group in Energinet.dk to sort out the relationship between the Energinet.dk scenarios and the international scenarios developed in the EcoGrid.dk project.

Since the Energinet.dk scenarios have been developed to form a basis for their long-term strategy work, and the purpose of the EcoGrid.dk project is to contribute to the long-term challenges of integrating much more wind in the Danish system, it was decided to take the Energinet.dk scenario stories as the starting point for the EcoGrid.dk scenarios as well.

The WP3 work group has consisted of

- Anders Kofoed-Wiuff, EA Energianalyse
- Anne-Franziska Sinner, Econ Pöyry
- Ashenafi Alemu Yesus, Energinet.dk
- Berit Tennbakk, Econ Pöyry
- Kenneth Karlsson, Risø DTU
- Paul-Frederik Bach
- Thomas Ackermann, Energynautics

The WP3 work group has held five workshops in which the international scenarios have been developed. Anders Bavhøj Hansen from Energinet.dk has assisted the group with the understanding and discussions about the scenario drivers.

The WP has been lead by Berit Tennbakk from Econ Pöyry. Econ Pöyry has also had the overall responsibility for the report, for the description of the current market situation in the relevant market areas, and for the quantifications of the supply side of the scenarios. Risø DTU has conducted the demand assessments and EA Energianalyse the assessment of demand side flexibility. Energynautics have in particular submitted input on the wind and transmission capacity estimates. Paul-Frederik Bach has contributed particularly on the impacts for Energinet.dk assessments.

The resulting international scenarios presented in this report are the results of the common work in the work group. Inputs from stakeholders have also been collected – foremost through a group work session on the midterm project meeting in November 2008. The final editing of the report has been done by the project leader, who also holds the responsibility for remaining errors and misinterpretations of inputs.

2 Overview of the Energinet.dk scenarios[2]

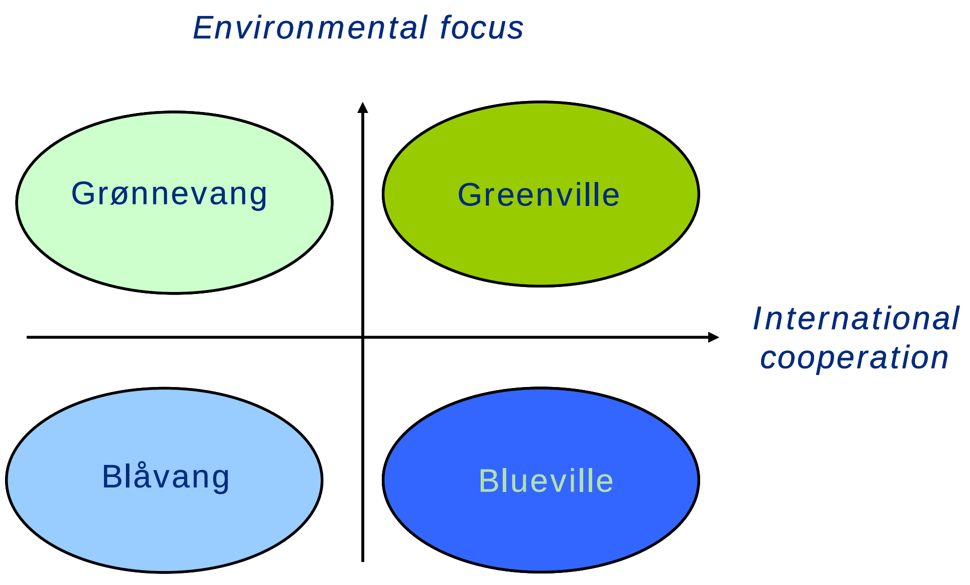
2.1 The scenario matrix

The Energinet.dk scenarios are built in relation to two basic uncertainties for the future:

- The degree of international cooperation on energy policy issues and markets generally. The extremes (for Denmark) are:
  - National focus: Energy policies are national, use of domestic resources and local solutions, self-sufficiency and independence.
  - International focus: Energy policies are international and challenges and opportunities are handled in international fora, European cooperation on foreign policies.
- The degree of environmental focus in Denmark. The extremes are:
  - High environmental focus: Environmental issues are emphasized and regarded as a growth factor, a positive attitude towards paying for environmental benefits, externalities internalized in the energy sector.
  - Lower environmental focus: Environmental issues focussed to a lower extent, environmental issues not the most important for investment decisions.

The scenarios axes are shown in Figure 2.1 below.

Figure 2.1 Energinet.dk scenario matrix



[2] The chapter is a summary and translation of the presentation of scenarios in ”Scenariorapport, fase 1 – Arbejdspapir” as interpreted by the EcoGrid.dk WP3 project group.

When working with the international scenarios we have not tried to follow the Danish scenarios in detail, but rather to construct stories that are consistent with the spirit of the scenarios. A lot of drivers will be common for Denmark and the surrounding areas, e.g.,

- A strong and unified EU or not
- An international climate agreement or not
- Confidence and functionality of markets
- Common infrastructure policy
- Available technologies

Below we give a short general description of the Energinet.dk scenarios for Denmark as they are presented in publications from Energinet.dk.

2.2 The four Danish scenarios

2.2.1 Greenville

"International focus, environment – a highly focused concern"

The main drivers in this scenario are a concern for the consequences of climate change and common European carbon emission reduction targets. EU is playing a very active role in promoting and supporting green technologies and markets constituting a level European playing field.

New international climate policy and carbon market agreements have followed the Kyoto protocol and Denmark has high income from exports of environment technology. The internal market in the EU functions well and regulations take the form of harmonized economic incentive regulation. Security of supply and competitiveness of the European economy are less prioritized than environmental concerns. There is a common European TSO, a common regulatory framework, and a reliance on market based instruments. External costs are internalized through taxes and levies.

Energy conservation is popular in among the public and it is an explicit goal to reduce the energy intensity of the economies (energy use/GDP ratio). New standards for electric appliances have been adopted. The transport sector has gradually become less oil dependent, by a transfer to more gas, electricity and biofuels.

Electricity generation has transformed away from fossil fuels to generation based on renewable energy sources. All coal fired generation capacity has been closed, and some of the capacity has been replaced by gas fuelled CHP capacity. There is also a substantial increase in micro CHP based on biomass.

The internalization of environmental costs has not hurt the economies. There is a positive investment climate and relatively high GDP growth.

2.2.2 Blueville

"International focus, environment – a less focused concern"

The main drivers of this scenario are security of energy supply and mobility of goods and persons as conditions for a strong European economy. EU plays a leading role in organizing a strong European market (including a market for balancing power), in the development of European energy resources and in providing a diverse range of channels for energy imports from countries outside EU. Nevertheless a high dependence on imported gas forms an Achilles' heel to European economy. The utilization of local energy sources and the conversion of energy must meet strict rules for the protection of the local environment.

There has been a growing concern about the dependency of Russian gas in Europe, and security of supply concerns are at the top of the energy policy agenda. New common framework conditions for energy markets have been adopted, and regulations take the form of harmonized economic incentives across the Union. The security of supply issue is dealt with as a common problem which needs a common solution. The energy sector is consolidated and mergers take place across borders. It is easy for foreign companies to invest in the energy sector, although the infrastructure remains publicly owned and a European TSO is established. Transmission bottlenecks are reduced through investments in new capacity and removal of trade barriers.

A common European gas exchange is established, where even Russian gas is traded.

Energy conservation is one of the most important policy goals to increase security of supply. This is accomplished through new standards for electric appliances and voluntary agreements with large energy users.

2.2.3 Grønnevang

"National focus, environment – a highly focused concern"

The main drivers of this scenario are increasing environmental concern combined with a desire for local self-sufficiency. The global energy market is perceived to be unreliable and the prices are volatile. EU has failed in the development of a common energy policy and in the implementation of strong energy markets. There is a strong public support for renewable energy, but countries chose different solutions in accordance with different national challenges and opportunities.

When it comes to R&D there is successful international cooperation, e.g. on fuel cells and technologies which allow large-scale deployment of renewable capacity. On the implementation level NIMBY opposition hampers capacity developments. In Denmark, no overhead cables are allowed. Renewables capacity is to a large extent offshore wind.

There is little confidence in the market and market coupling comes to a halt. Gas continues to be traded on long-term physical contracts. Gas exports from Denmark are restricted.

There is a high focus on energy efficiency, and a shift away from oil in the transport sector. However, there is a mixed fuel situation with oil, gas, electricity and bioethanol in the transport sector.

Coal is banned in Danish electricity generation (in 2015) and the electricity system is increasingly decentralized.

2.2.4 Blåvang

"National focus, environment – a less focused concern"

The main drivers in this scenario are preservation of national security and identity. The European populations feel that too much influence has been given to EU. Therefore the national parliaments have withdrawn important responsibilities from EU, and meticulous border control has been restored. Bi- and trilateral cooperation between countries occurs.

The environmental focus is mainly on local and regional issues. An international climate agreement is in place, but there is no agreement on common means. There is little confidence in the market because of effect shortages and rolling blackouts. Additional capacity is procured through public auctions, and in the end a responsibility of the TSO. Market coupling between Nord Pool and EEX is not established. Energy conservation is in focus for security of supply reasons. Common standards for electric appliances were only adopted gradually. In the transportation sector however, common vehicle requirements were adopted and cars are fuelled by a mix of oil, electricity and bio ethanol.

Offshore wind power capacity is increased and onshore mills are replaced by larger ones. The coal fired central units are kept but refurbished with increased efficiency. In addition some small-scale CHP on gas and biomass are established.

2.3 Relevance for the EcoGrid.dk project

The Energinet.dk scenarios have a time horizon up to 2030, slightly longer than the focus of the EcoGrid.dk project which is 2025, the same horizon as the wind target set by the Danish government. Hence, the international scenarios cannot be directly adapted to the Energinet.dk scenarios.

It is important to keep in mind that the EcoGrid.dk project task is to analyze the challenges faced by Energinet.dk if wind power capacity is increased to 50% by 2025.

In the Energinet.dk scenarios the share of wind power in Denmark varies between scenarios, and in some scenarios the share of wind power is higher than 50%. This is not in accordance with the basis of the EcoGrid.dk project objective.

In our scenario work we have used the general stories as developed by Energinet.dk, and worked out what would be the reasonable development in surrounding market areas, given the common drivers described by the Energinet.dk scenarios. Our task has not been to evaluate the Energinet.dk scenarios, although some feedback and inputs have been given to Energinet.dk in the course of the project meetings.

When using the international scenarios in the further work in Energinet.dk, the Danish scenarios should hence not be used – they should be adapted to the object of study in the EcoGrid.dk project. The target for our work is to set the scene for the market areas surrounding Denmark. The degree of trading possibilities, physical and organizational, and the demand and supply of system services in the larger context is the main focus of the scenarios. The question is to what extent the challenge posed by the doubling of wind capacity differs with different assumptions about the development in surrounding market areas.

3 Overview of markets surrounding Denmark

In this chapter we give an overview of the current situation and prospects in the power market areas surrounding Denmark. A more detailed description is found in Appendix 1.

3.1 Electricity production and energy supply

The domestic fuel mixes in the power supply differ substantially between the countries (see Figure 3.1 below).

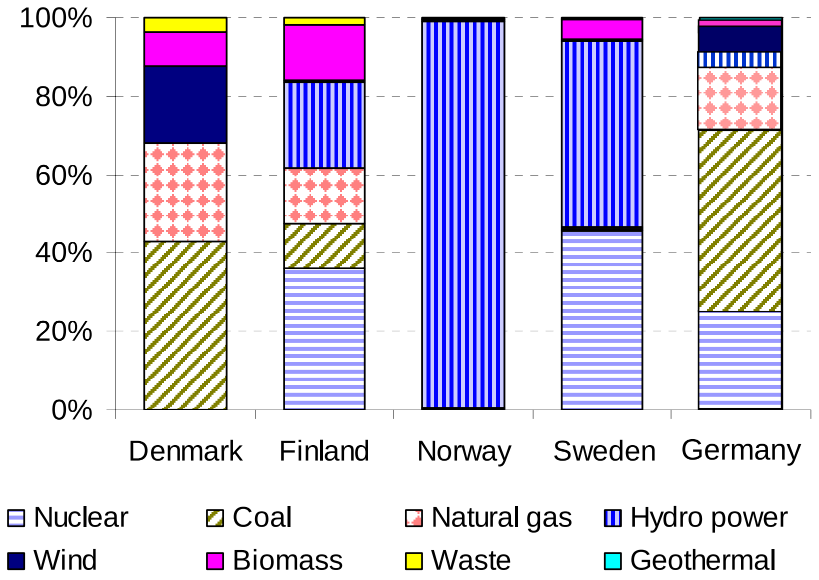
Nuclear, coal, natural gas and wind energy are the main energy resources for power generation in Germany. Security of supply and import dependency are major concerns as domestic gas resources are depleted, domestic hard coal is expensive and lignite resources are limited. A political consensus has resulted in a nuclear phase out act. Wind power capacity has increased rapidly over the last 5–10 years, and is set to continue to increase. Never-the-less it is expected that a major share of future power generation must be based on imported coal and gas.

Norway is a major producer of oil and natural gas and the third largest net exporter of oil & gas in the world (account for 25% of EU natural gas imports). However, only 1% of the total Norwegian energy consumption is based on natural gas (one natural-gas based electricity plant under construction onshore and four more granted licenses). The Norwegian power supply system is dominated by hydro power, mainly large scale hydro power stations with substantial reservoir capacity. The potential for large scale hydro generation is largely exploited or conserved. However, Norway has large potentials for wind power and small scale hydro, and policy targets are ambitious. New gas power is also an option, but must currently be built with carbon capture and storage facilities.

Sweden has no petroleum resources and only 1% of the total Swedish energy consumption is based on natural gas. The Swedish power system is mainly based on hydro and nuclear power. Sweden has large biomass resources and the utilization of biomass in district heating and CHP plants has increase in recent years, particularly since the introduction of the Electricity Certificate trading scheme. There are also ambitious targets for wind power both on and off shore.

Finland has a differentiated fuel mix. Also the electricity generation is diversified and based on coal, nuclear and hydro resources. Imports from Russia are massive (~11.5 TWh/a) and stable. Finland is also characterised by a very high rate of combined heat and power (CHP) in industry and for district heating. Finnish CHP, both in industry and for district heat, is characterised by very high energy efficiency. Finland has so far not gone for ambitious wind power targets.

Figure 3.1 Relative fuel mix in Nordic and German power generation, 2005



Source: Nordel 2005; PROGNOS Energiscenarios 2030

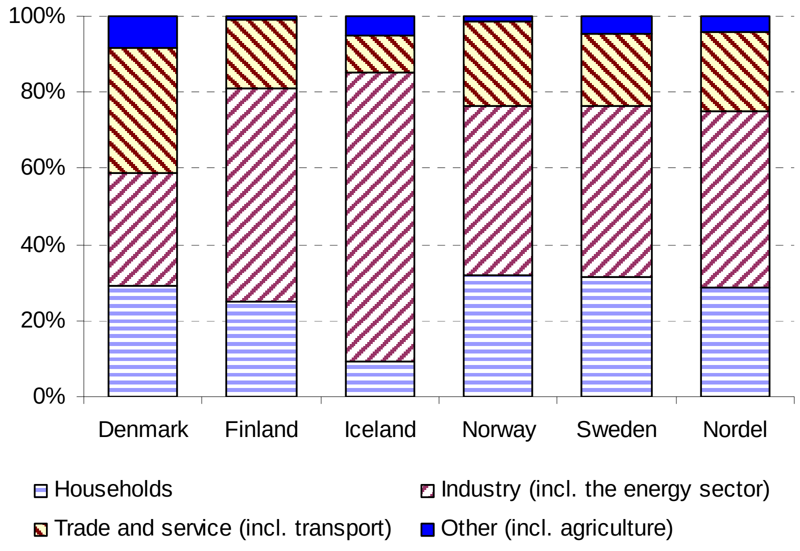
3.2 Electricity consumption

The electricity consumption constitutes a very large part of the net energy consumption in the Nordic countries.

The distribution of electricity consumption per sector and country (relative shares) is shown in Figure 3.2. For the Nordic countries in total (the Nordel area) the industry accounts for almost half of the electricity consumption and the household and service sectors counts for 29% and 21% respectively.

In Denmark, the service sector has a relative large share (33%) compared to the other countries (10–22%). This has to be compared with the relatively small electricity consumption per capita in Denmark, the fact that there is almost no power intensive industries in Denmark and that the use of electrical space heating is limited.

Figure 3.2 Relative net consumption of electricity in 2005



Source: Nordel 2006

3.3 Renewable energy targets and support schemes

In 1997 the European Union started working towards a target of a 12% share of renewable energy in gross inland energy consumption by 2010, representing a doubling of the contribution from renewable energies compared to 1997. In 2001, the EU Member states (MS) adopted voluntary targets to be reached by the latest in 2010 (Directive 2001/77/EC). The overall EU target for renewable consumption in 2010 corresponds to a 21% share of renewable *electricity* (RES-E) consumption in the EU by 2010. This 12% target is not likely to be met. Based on current trends, the share of renewable energy in the EU will not exceed 10% by 2010.

In 2007 the EU adopted a mandatory target to increase the EU share of renewable energy to 20% of the gross energy consumption by 2020 (EU COM(2007)1). All countries are affected by the EU directives, Germany, Sweden and Finland as members of the EU, and Norway through the EEA treaty. Individual targets for the Member States and national allocation plans with sub targets for the electricity, transport (biofuels) and heating sectors are yet to be determined (beginning of 2008).

In beginning of 2008 a new proposal of the Directive on the promotion of the use of energy from renewable sources has been presented by the Commission (COM(2008) 30 final). It is seen as a roadmap towards harmonised support systems for renewable energy. The 2008 Directive defines the following mandatory targets for 2020 in Table 3.1.

Table 3.1 *Renewable energy shares in 2005 and targets in 2020 for the Nordic countries*

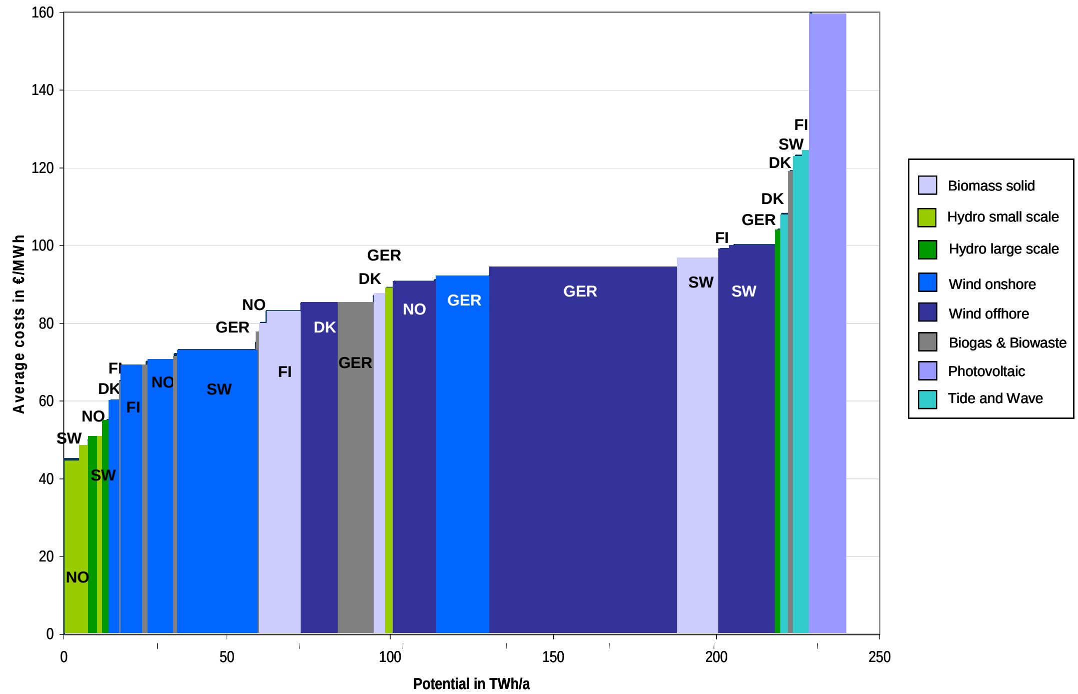
	Share of energy from renewable sources in final consumption of energy (2005), %	Share Renewables in the final energy demand by 2020, %
GER	6,6	18
FIN	28,5	38
SWE	39,8	49
NOR	51	n/a

Source: COM (2008) 30 final

3.4 Future cost and potentials of RES-E production

The expected potentials and costs for renewable power generation (RES-E) can be seen in the figure below. It shows long-term cost developments of RES-E as forecasted by the Green-X model.[3] Costs are adapted endogenously on the basis of technology-specific learning rates.

Figure 3.3 *Production costs and potentials for future RES power technologies - year 2020*



Source: Green-X model, 2005

[3] Source: www.green-x.at; In the Green-X model the calculation of generation costs for the various generation options is done by a somewhat complex mechanism, internalised within the overall set of modelling procedures. Thereby, band-specific data (e.g. investment costs, efficiencies, full load-hours, etc.) are linked to such general model parameters as interest rate and depreciation time.

The potential supply of energy from each technology is described for each country analysed by means of dynamic cost/resource curves. In dynamic cost curves the costs and the potential for electricity generation/demand reduction change over time. However, the data on future potentials and costs is based on recent expectations. Therefore, the data is afflicted with high uncertainty and consequently should be considered very carefully. Nevertheless, it gives an indication of future costs levels, i.e. to reach specific RES-E targets. It also shows the differences of conditions in the countries.

In the production hierarchy Norwegian small scale hydro is the cheapest RES production technology having production costs of 45 €/MWh. The most expensive RES-E technology is photovoltaic having production costs of more than 160 €/MWh. The physical production potentials amount to nearly 140 TWh per year which is equivalent to about 1/3 of actual electricity consumption in the Nordic countries. The main part of the potential is wind power and solid biomass.

Compared to the recent price level on the Nord Pool spot market of 40 €/MWh (2007) there is an incentive only to invest in Norwegian small and large scale hydro. Norwegian "biogas and biowaste" is on the edge of incentives.

If the huge potential for on shore wind power has to be realised, a price level of nearly 80 €/MWh is required. This price level will yield an incentive to invest in on shore wind power in all Nordic countries, and to increase RES-E generation by nearly 60 TWh per year. According to the data wind power is cheapest in Norway, followed by Denmark, Finland and Sweden. The assessments made above only take into account the pure on site production costs. Taking into account also the costs of the electricity system will reduce the potentials.

3.5 Power exchange

Currently the Nordic countries constitute one market in the sense that electricity is traded at the common exchange Nord Pool. The Nordic electricity market is quite well organized with Nord Pool's spot market on the top of bilateral contracts and extensive financial trade.

At Nord Pool, one Nordic system price is calculated, but in practice there are often bottlenecks in the system. The main bottlenecks are handled by splitting the market into different price areas, usually following national borders (although Norway and Denmark are divided into two or more price areas).

Some rules differ between the Nordic countries, for instance on internal congestion management. The transmission grids are controlled by national system operators in all four Nordic countries. The TSOs in Denmark, Norway and Sweden (Energinet.dk, Statnett and Svenska Kraftnät) are fully state owned, whereas the Finnish state owns only 12% in the Finnish TSO, Fingrid. The Nordic system operators have a long tradition for cooperation organized in Nordel.

Although bottlenecks are often observed, there is substantial transmission capacity between the market areas. Trade flows are determined by available capacities and price differences.

Norway has an interconnector (opened in 2007) to Netherlands, Sweden has interconnection to Poland and Finland to Russia and Estonia (opened 2006).

For some years the German electricity market was less organized than the Nordic market, but now the German power exchange, EEX, has developed a broad range of services to market players in Germany. The cross border trade with Germany is still less efficient than between the Nordic countries, but further improvements have been agreed upon and full market coupling is set to be implemented in September 2008. The transmission grids in Germany are owned by 4 regional system operators, which are subsidiaries of the 4 largest generating companies: EON, RWE, Vattenfall and ENBW.

Germany has interconnectors to both Danish market areas and to Sweden. There are also initiatives looking at interconnectors directly between Germany and Norway. Germany is also closely linked with other neighbouring countries to the west (Netherlands), south (France, Switzerland) and east (Austria, Czech Republic).

After several cable faults the NorNed interconnector was ready for exchange of energy between Norway and Netherlands in May 2008. The Dutch power exchange, APX, will be a significant hub in Europe. The coordination between Nord Pool and APX is supposed to be more efficient than the cross border trade with Germany has been so far, but because of the TLC (Trilateral market coupling) process between Netherlands, Belgium and France, trade on NorNed is currently handled through explicit auctions.

Transmission system operators (TSOs) on the European continent coordinate their activities within UCTE (Union for the Co-ordination of Transmission of Electricity). All European TSOs meet in ETSO (European Transmission System Operators).

The European Union considers the competition in the European electricity market to be in-sufficient. The following problems have been identified:

- Most wholesale markets remain national in scope, with high levels of concentration in generation, which gives scope for exercising market power
- Vertical integration of generation, supply and network activities, which reduces the incentives to trade and for new companies to enter the market, has remained a dominant feature in many electricity markets
- The low level of cross-border trade is insufficient to exert pressure on (dominant) generators in national markets
- There is a serious lack of reliable and timely information (transparency) in the electricity wholesale markets that is widely recognized by the sector
- Price formation is complex, and many users have limited trust in the price formation mechanisms.

EU has shown a particular interest in the German electricity market.

There is still a potential for improvements of the trading conditions for market players in Denmark. New interconnectors and further development of the national and international trading arrangements hold out prospects of improvements in the near future.

4 Detailed scenario descriptions

In this chapter we summarize the detailing of the scenarios for the market areas surrounding Denmark. The main focus is on Germany, Norway and Sweden, but even the situation in Finland is commented in some sections. The focus of the work has been to explore developments in the areas surrounding Denmark taking into account that different scenarios will imply different solutions, and that national circumstances and history will affect developments in the countries differently. As far as it has been possible, we have tried to quantify supply and demand side characteristics, including interconnector developments. A final quantification of the scenarios will however require an integrated model approach, where even Denmark is put into the equation.

4.1 Overall generation capacities

Generation capacities are developed using a two step approach. Future RES-E capacity levels are based on potentials derived from the Green-X renewable power generation database containing data for potentials as well as cost analyses. (See footnote 3 for reference and Appendix 1 and 4 for details.) Capacity levels have been calculated by applying technology specific load factors to the power generations presented by Green-X.

Fossil fuel capacities have been derived from historical data. The year 2005 builds the base. The base year's capacity levels are derived directly from the Platts database[4]. Starting at the year 2005, capacities are developed along a timeline, until 2025. According to the age structure of the power plant fleet, retirements and already known new capacity investments have been considered.

All data given for the scenarios refer to the year 2025. The capacity and generation mix for each scenario has been investigated by country for Germany, Sweden and Norway.

In all countries, the Greenville scenario shows the strongest focus on renewable capacity extension. Hereby the wind capacities, on- and offshore take centre stage in Greenville.

The Blueville scenario does present the "gas scenario" where most countries significantly extend gas power capacities.

Nuclear capacities are neither part of Greenville nor of Grønnevang.

In all countries, existing large hydro power capacities are only increased due to increase in system's and turbine's efficiency. No additional investments in large hydro power are assumed.

[4] http://www.platts.com/Analytic%20Solutions/energyadvantage/index.xml

4.2 Power generation

The basis for all scenarios is generation levels in 2005. Generation levels for fossil based generation are in turn based on actual capacities in 2005 plus appropriate load factors. In all scenarios, renewable power generations have been defined first. This has been done according to the countries' overall potential in renewable power generation.

In the scenarios, renewable capacities are derived from the Green-X generation potential.[5] The basis for the potentials analysis is 2005 power generations. Green-X estimates the additional potential of renewable power production which can be added until 2025. The database describes the potential supply of energy from each technology for each country analysed by means of dynamic cost-resource curves. Dynamic cost curves are characterised by the fact that the costs and the potential for electricity generation can change each year. However, the data on future potentials and costs are based on recent expectations. Therefore, the data is afflicted with high uncertainty and consequently should be considered very carefully. Nevertheless, it gives an indication of future potentials. It also shows the differences of conditions in the countries considered in the scenario analysis.

During the development of the scenarios, we have come to the assessment that the Green-X figures are very much at the high end of future renewable power potentials and may in some cases overestimate potentials. However, it seems to be the best source of recent data currently available, and in which the countries' potentials are assessed by the same approach. Hence Green-X data for different countries should at least be comparable.

The Green-X potentials on the renewable power generation is energy source specific and given in TWh/a. The basic assumption is that the full Green-X potentials are exploited in the Greenville Scenario (in some cases, figures has been adapted a bit; see table below). Furthermore, according to the scenario descriptions and demand projections, the power generations for the other scenarios have been developed. Hereby, power generations have been calculated by defining the utilisation rate of the total potential.

[5] Norway is not included in Green-X. The used figures on Norwegian renewable power potentials reflect the Norwegian governmental targets on renewable power resources for the year 2010. These figures may not reflect the total potential for RES-E within Norway. Nevertheless, due to lack of better data and sources, these data has been used in the further quantification of Norwegian generation volumes in the scenarios.

Table 4.1 Utilisation rates for renewable power generation potential for each scenario

	Greenville	Grønnevang	Blueville	Blåvang
Germany	100% of Green-x potential (wind: 75% of potential)	Windpower: 75% of potential other sources: 50% of potential	75% of potential	50% of potential
Norway	100 % of own estimated potential	15% of potential	50% of potential	25% of potential
Sweden	100% of Green-x potential (but no add. hydro large scale)	50% of potential	Wind power: 50% of potential other sources: 75% of potential	30% of potential

All potentials (in TWh) derive from Green-X (see Chapter 3.1) but have been adjusted in some cases: Usually, Green-X data seem to be on the optimistic side, they are therefore used fully in the Greenville Scenario. RES-E expansion in the other Scenarios is then adjusted in accordance to the scenario descriptions.

The thermal power power generations have been calculated by applying a load factor on capacity levels for 2025. So, first, 2025 capacities have been developed according to the scenario descriptions, then a load factor has been applied which resulted in the generation figures (in TWh). In the development of capacities until 2025, life-time expectations, plus all known plans for extension and closure of capacities have been taken into account.

4.2.1 Germany

In all scenarios Germany keeps its diversified generation mix consisting of renewable generation, hard coal and lignite based generation as well as generation from natural gas. Of the existing capacities in 2005, about 13 GW hard coal capacity, 10 GW lignite capacity and 8 GW natural gas capacity will be retired before 2020. This basically applies in all scenarios, although in Grønnevang and Blåvang we assume that these capacities are retired a bit earlier than in the other scenarios, and replaced by new capacity for securing supply.

In Greenville, Blueville and Blåvang, Germany's hard coal based power generation does include all already decided investment decisions. Additionally, in Blueville and Blåvang hard coal generation volumes are developed further in order to meet overall demand. In Grønnevang, due to decreasing demand, hard coal based power generation is significantly lower than in the other scenarios.

The actual power generations for these energy sources differ between the scenarios. In Greenville and Grønnevang, the focus is very much on RES-E generation. Germany's Greenville Scenario presents the highest utilisation rate of renewable energy sources of all the scenarios. Wind energy is the dominating renewable energy source in power generation, constituting about 90% of the expected RES-E potential from 2005 to 2025 is exploited. In Greenville, 75% of the overall wind potential, given by Green-X, is utilised both on- and offshore. In addition, it is assumed that large hydro power generation increases due to better efficiency of turbines.

In comparison to Greenville, the Grønnevang scenario utilises the same power generation of wind power but only 50% of Greenville's potential for the remaining energy sources. In Blueville 75% of the volume in Greenville is utilized and in Blåvang only 50%.

Blueville includes large extensions of gas power generation whereas Blåvang is the only scenario where we assume that some nuclear generation is kept in the year 2025.

New hard coal and natural gas capacities are added in all Scenarios. But the number of newly installed GW varies in each Scenario. New lignite capacity is only added in Blueville and Blåvang.

The scenarios' power generations per energy source in 2025 have been changed compared to 2005 volumes as follows:

Greenville

There is a significant increase in renewable generation; in fact it is 4 times higher than in the base year. Nuclear is not accepted in the Greenville world and is phased out according to plan. Coal generation is kept constant since about 24% of existing capacities' are phased out due to age, but at the same time about the same generation volume (70 TWh) is deriving from new investments. Generation based on lignite is reduced by 60% and gas power generation in increased by 40%. Total power production is reduced by ca. 10%.

Grønnevang

There is a more than doubling of RES-E power generations, and nuclear is phased out according to plan. Even generation based on fossil fuels is reduced; gas by 5%, hard coal by 40% and lignite by 60%. Total power generation is decreased by ca. 30%.

Blueville

Even in this scenario RES-E generation is doubled. Given current policies and targets, it is likely that substantial volumes of wind capacity will be developed in Germany, even in this scenario. Nuclear power is phased out according to plan and to a large extent replaced by gas power generation, which is tripled. Hard coal generation is reduced by 25% and lignite by 50%. Total power generation is increased by ca. 20%.

Blåvang

RES-E volumes increase even in this scenario, mainly based on national policies focusing on security of supply and utilization of domestic energy sources. Because of security of supply concerns, nuclear phase out is delayed and only 50% of capacity decommissioned by 2025. Hard coal and lignite generation is reduced because capacity is phased out according to age, hard coal generation declines 17% and lignite generation 20%. On the other hand gas power generation increases by 20%. Total power generation in 2025 is decreased by ca. 7%.

Figure 4.1 *Power generation capacity in Germany in 2005 and 2025, all scenarios. GW installed.*

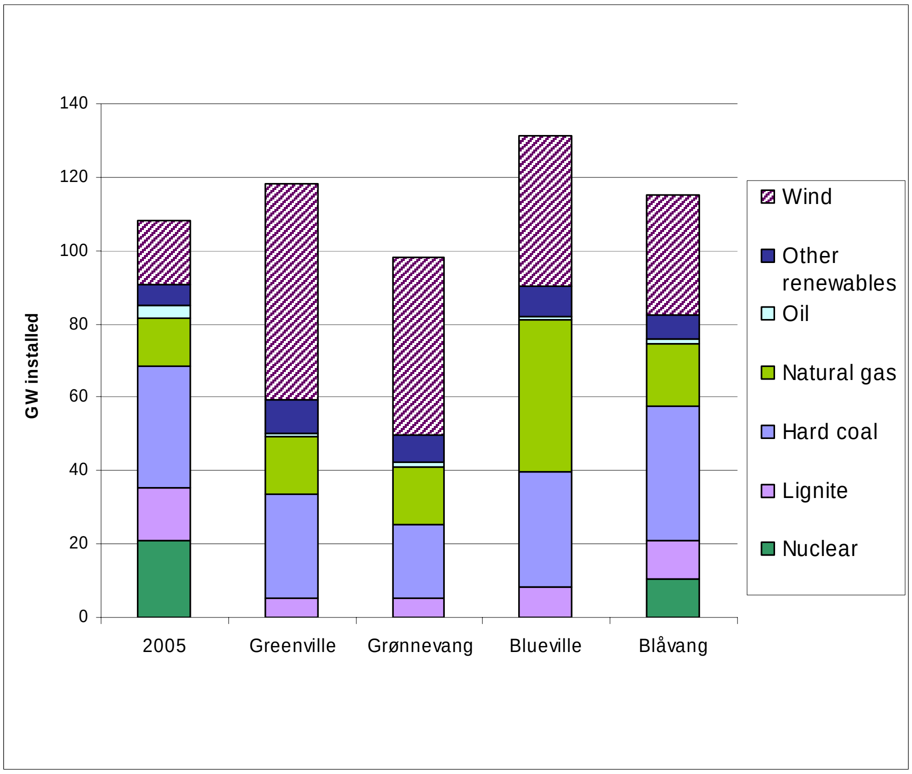
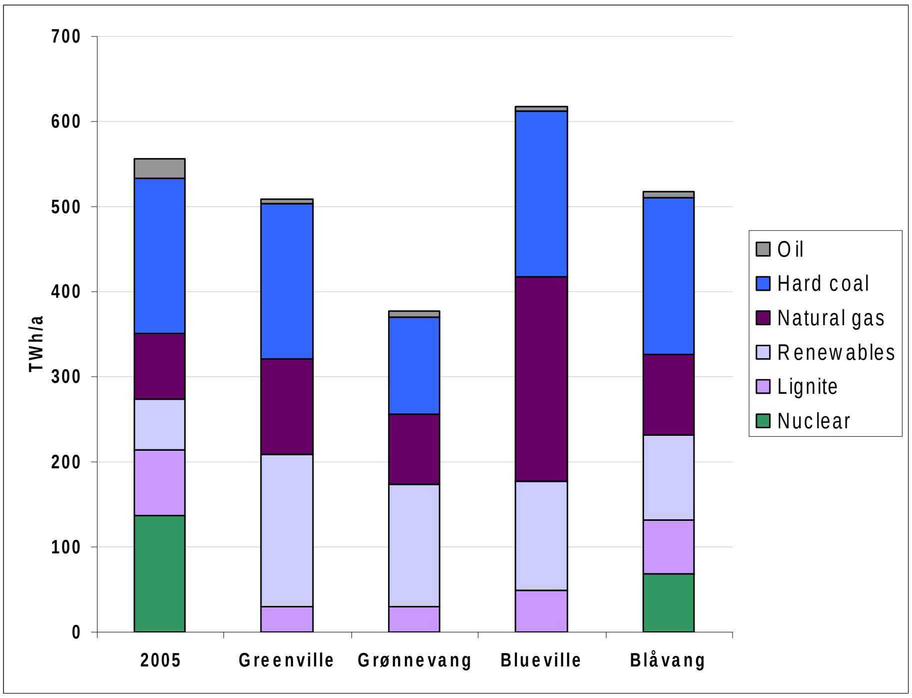


Figure 4.2 *Power generation in Germany in 2005 and 2025, all scenarios, TWh/year (gross)*



4.2.2 Norway

Large-scale hydro power continues to constitute the basis for Norwegian power generation in all scenarios. Basically, the 2005 power generation by large-scale hydro power sources is kept constant in the two scenarios: Greenville and Grønnevang. This is due to environmental concerns of new large scale hydro installations. Nevertheless, small-scale hydro does develop and increases in both scenarios by about 1 TWh. In Blåvang and Blueville large-scale hydro power generation is increased due to improvements in system and turbine efficiency. According to the Norwegian Water Resources and Energy Directorate there is a potential for technology improvement in existing hydro power turbines up to 0.8 TWh/a.[6] This potential is utilised in both scenarios, Blueville and Blåvang. Additionally, due to higher power demand, in Blueville small-scale hydro power is also developed and contributes about 2 TWh in 2025.

Beside hydro power generation, in all scenarios, wind and natural gas power generation differ.

Norway's additional renewable power potential is based on small scale hydro power and wind power. Greenville is Norway's wind scenario, with a strong focus on utilising Norway's wind power potentials. Hereby, Greenville shows the biggest increase in power generations. Wind power increase from 0 to 12 TWh in 2025. Even in Blueville there is some focus on wind generation, although additional gas power is also introduced. Blåvang and Blueville represent the scenarios with strongest natural gas generation increase.

In the Grønnevang scenario, only 15% of Greenville's RES-E potential is exploited because demand decreases strongly. However, in Blueville 50% of the RES-E potential is utilized and in Blåvang 25%.

In Norway, fossil power capacity relates almost exclusively to new natural gas power. In all scenarios, gas power capacities increase according to policy plans. From 2008 onwards, a new CCGT plant of a total capacity of 0.42 GW is online. Furthermore, in 2010, a second plant, a CHP facility of 0.28 GW will produce power by burning natural gas. In Greenville and Grønnevang it is assumed, that in 2013, both plants will implement carbon capture and storage (CCS), which reduces the plants' efficiency by 10%. In addition to already planned investments, it is assumed that one more gas power plant of 0.42 GW capacity will be built and start operation in 2015 in Blåvang and Blueville.

[6] See http://www.nve.no/modules/module_109/publisher_view_product.asp?iEntityId=8721

The generation mix changes from 2005 until 2025 as follows:

Greenville

Hydropower generation stays at the same levels as in the base year. Other RES-E generation increases by 900% although from a low level in the base year. Gas power is introduced, but only according to what is currently decided (and to some extent built), i.e. a total of 4 TWh. Total generation increased by 10%

Grønnevang

RES-E generation increases by only 1% because export opportunities are limited. Hydro generation stays at the same level as in the base year. Again, no additional gas power is introduced besides the 4 TWh already in place or decided. Total generation increased by 4%.

Blueville

Hydro power generation is increased by 2.3 % and other RES-E generation (mainly wind) by 500%. Gas power is expanded slightly, to 7 TWh compared to the base year. Total generation increased by 12%

Blåvang

As hydro power is kept at the same levels as in the base year and demand growth is moderate in this scenario, Norway does not need a whole lot more capacity for security of supply reasons. Gas power is assumed to be expanded somewhat and RES-E generation (excl. hydro) is moderately developed, resulting in a 255% increase in (other) RES-E generation (mainly wind). Total generation increases by 7%.

Figure 4.3 *Power generation capacity in Norway in 2005 and 2025, all scenarios. GW installed.*

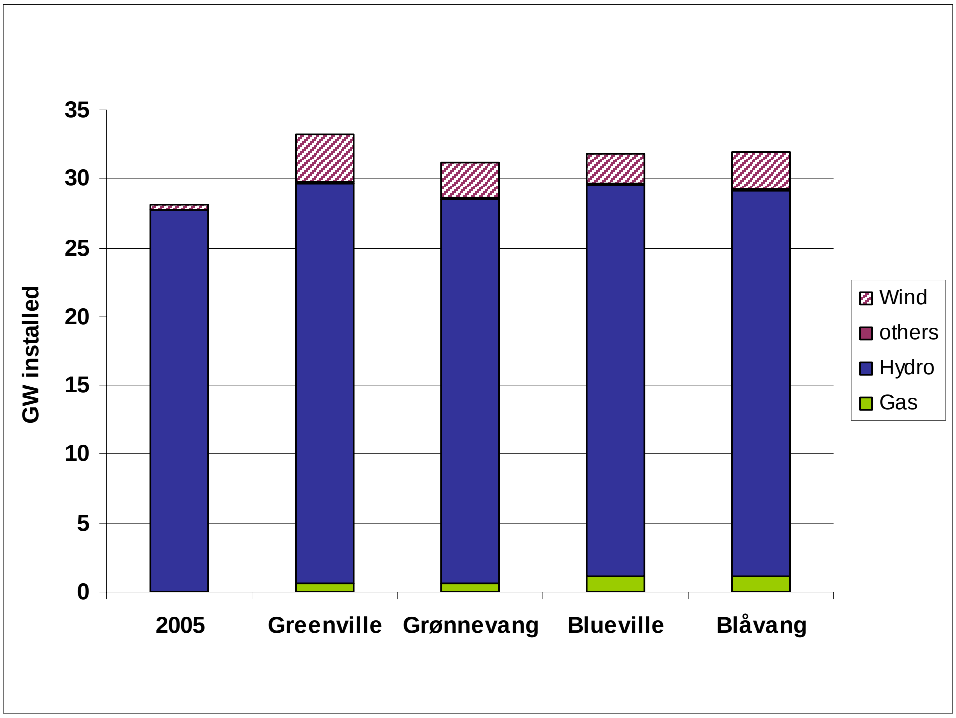
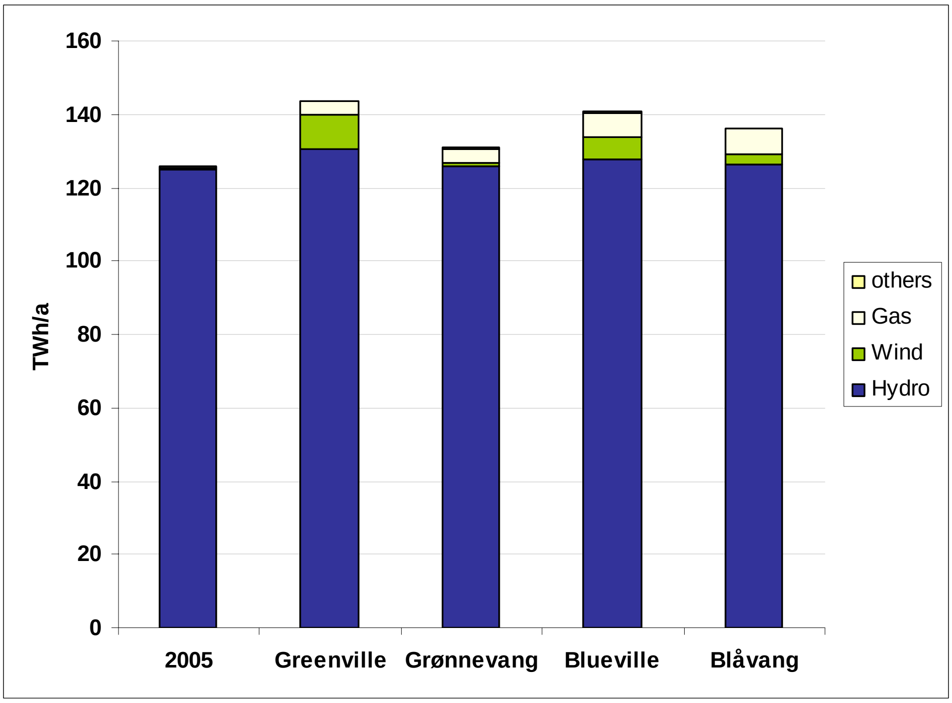


Figure 4.4 *Power generation in Norway in 2005 and 2025, all scenarios TWh/year (gross)*



4.2.3 Sweden

The difference between the scenarios for Sweden is very much associated with the development in nuclear power generation, in addition to natural gas generation and RES-E generation.

Nuclear capacities are phased out until 2025 in both Greenville and Grønnevang. In the other scenarios nuclear capacities are increased. In Blueville, one nuclear plant of 1500 MW is added to the in 2005 existing capacity. In Blåvang, a smaller unit plant of 1000 MW installed capacity is added to the existing capacity.

Furthermore, the scenarios differ in terms of gas power capacities. In Greenville, and Blueville, gas capacities are increased. In Grønnevang and Blåvang, gas capacities decline from 2005 onwards.

With regard to RES-E generation, hydro power generation stays constant in all scenarios, i.e., at the base year level of 72 TWh. Hence, the main changes occur in the development in wind and bio energy power generation. The Greenville scenario shows extensive utilisation (100%) of the wind power potential given by Green-X. This results in an increase of onshore generation by 20 TWh and offshore by 10 TWh. In Grønnevang, except of the wind potential, all remaining RES-E potential is utilised 75%. Hence, biomass power generation increase by nearly 8 TWh/a.

In Grønnevang and Blueville, the wind potential is only utilised by 50%, Blåvang realizes 30% of the total wind and RES-E potential.

There is no extension of hydro large scale power generation in any of the scenarios.

Greenville is Sweden’s wind scenario. Blueville and Blåvang both include nuclear power generation whereas in Greenville and Grønnevang, all nuclear generation is phased out in 2025.

In all Swedish scenarios, coal power capacities are kept relatively constant. This capacity is mainly used as back-up and peaking capacity.

The generation mix in the Swedish scenarios changes from 2005 until 2025 as follows:

Greenville

RES-E generation except hydro is expanded substantially, from 5 TWh in the base year to 45 TWh in 2025, an increase of 800%. Hydro power is not expanded as potentials are fully exploited or conserved. Nuclear power is phased out and gas power increases from 1.1 TWh in the base year to 6.7 TWh in 2025. Total generation is reduced by 7%.

Grønnevang

Hydro generation stays constant and other RES-E generation increases from 5 TWh to 25 TWh, an increase of 400%. Nuclear power is fully phased out and gas power is reduced to 0.42 TWh. Total generation decreases by 27%

Blueville

RES-E generation except hydro is expanded from 5 TWh to 28 TWh, an increase of 460%. Both nuclear and gas power generation is expanded as well; gas power capacity increase by 40% and nuclear capacity by 20%. Total generation increases by 23%.

Blåvang

RES-E generation except hydro increases moderately from 5 TWh to 18 TWh (260%). Nuclear capacity is also increased somewhat, by 12%, and gas power capacity by 35%. Total generation increases by 13%.

Figure 4.5 *Power generation capacity in Sweden in 2005 and 2025, all scenarios. GW installed.*

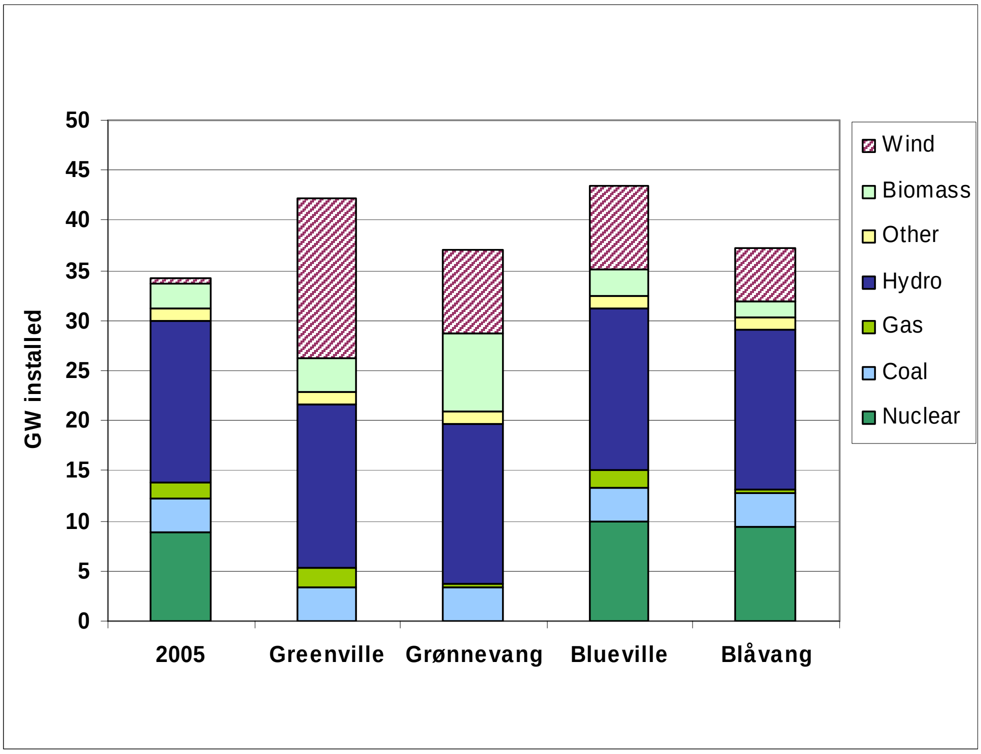
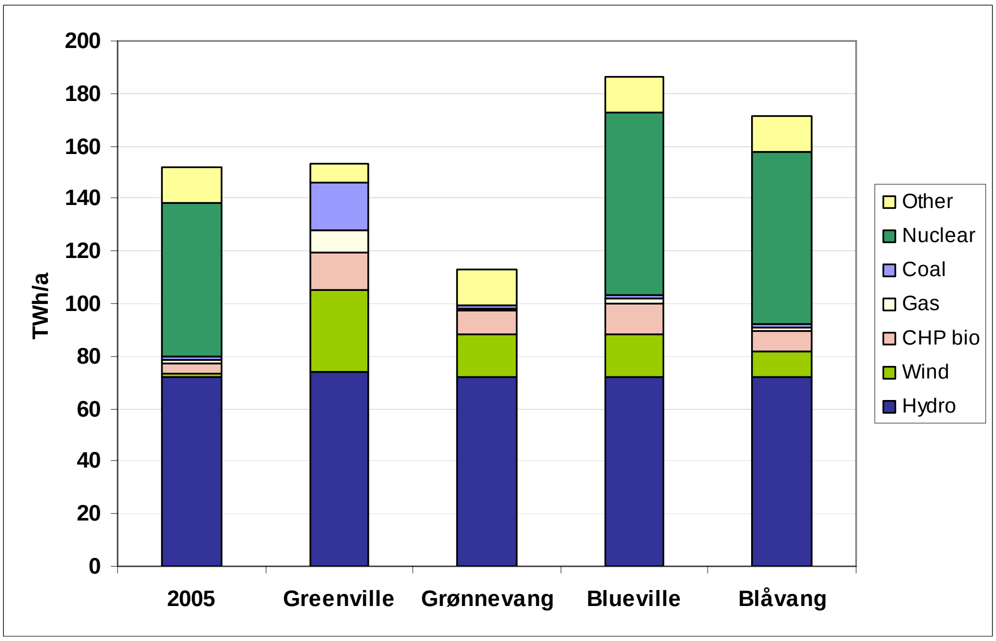


Figure 4.6 *Power generation in Sweden in 2005 and 2025, all scenarios TWh/year (gross)*



4.2.4 Balancing resources on the supply side

In most of the scenarios and for most of the considered countries, wind power replaces conventional thermal power generation from 2005 to 2025. This applies very much in Greenville and Grønnevang, and especially in Germany and Sweden. Hereby, the intermittency of wind may create system problems when wind power is used to supply a high proportion of total energy demand. Wind power generation is highly variable in the short term. Because instantaneous electrical generation and consumption must remain in balance to maintain grid stability, this variability can present substantial challenges when large amounts of wind power are to be incorporated into a grid system. Intermittency and the non-dispatchable nature of wind energy production (although wind power can be regulated *down*) can raise costs for regulation, incremental operating reserves, and (at high penetration levels) could require additional energy demand management systems or storage solutions. In addition, fluctuations in load and allowance for failure of large generating units require thermal reserve capacity that can also regulate for variability of wind generation.

One major challenge with wind power is that it will not produce at all in hours when there is no wind, and it is not possible *a priori* to know when this will happen. Since no wind can occur in high load and peak load periods, the power system has to get sufficient peak capacity from other sources in order to avoid black-outs or rationing in high load/low wind situations.[7] Hence, the supply/demand balance in the scenarios should not only be checked in terms of energy balances, but also in terms of capacity balances. Can the countries' peak demand be supplied by controllable capacities including all fossil fuel, nuclear and biomass combined heat and power capacities? Or is additional regulation/peak capacity needed? As an assumption, hydro power is only considered to be available at 80 % of its capacity. All solar and wind power capacities are counted as intermittent power.

Peak demand in Germany, in the year 2005 was at a level of 82527 MWh/h.[8] In Sweden, peak demand was at a level of 25800 MWh/h.[9] Due to the dominance of large-scale hydro with reservoirs in Norway, and the corresponding high installed capacity, we do not consider the capacity balance in Norway further.

Taking the 2005 peak demand values as the basis, in both green scenarios, Greenville and Grønnevang, controllable power capacities in Sweden can actually cover this 2005 peak demand value (see table below). Here, no growth factor is applied to the 2005 peak demand. But also in Greenville, where actual demand is increased by 5% compared to the year 2005, controllable power capacities can meet this demand.

Taking into account the reductions in demand in Greenville and Grønnevang, even Germany will be able to cover peak demand by its controllable power capacities. Nevertheless, especially the Greenville scenario may present a challenge for Germany in regard to balancing the huge amount of wind energy entering the system.

[7] Additional capacity may also be found on the demand side, i.e. by reductions in demand. See section 4.3.6.

[8] Source: UCTE, Statistical yearbook 2005, September 2006 Edition, chapter 2 page 110

[9] Nordel, Annual Statistics 2005: http://www.nordel.org/content/Default.asp?PageID=213

This has been calculated without the assumption of any security margin which is usually between 10 and 15% of installed capacity (n-1 rule). Applying a security margin of 15% which would require a 15% higher installed capacity than peak demand, both Sweden and Germany would not present enough controllable power capacity to cover the peak demand plus the security margin. Hence, the conclusion is that additional peaking capacity and/or demand response resources must be developed.

Table 4.2 Peak demand in 2005 compared to controllable power generation and intermittent power generation in Greenville and Grønnevang

	Greenville			Grønnevang	
	Peak demand 2005	Controllable Power	Intermittant power	Controlable Power	Intermittant power
	GWh/h	*GW installed*	*GW installed*	*GW installed*	*GW installed*
Germany	82.53	82.14	59.43	76.88	39.11
Sweden	25.80	28.11	16.08	25.09	8.32

4.3 Demand development

In the construction of a consistent storyline for the development of the energy system in the countries around Denmark, the development in energy demand is a main component. While the Energinet.dk scenarios focus on the future power system, most emphasis is put on the demand for electricity, but demand for transport, heating and process energy is also considered.

The frame for the demand scenarios can in short be described in the following bullet point:

- The so-called STREAM model is used for describing energy demand scenarios in the countries around Denmark (see appendix 2)
- The demand scenarios take economic growth and development in energy efficiency into account
- For each country demand scenarios are described for each of the treated futures: Greenville, Blueville, Grønnevang and Blåvang.

4.3.1 The STREAM model in short

STREAM for Denmark was developed in cooperation between:

- The Danish TSO (Energinet.dk)
- The major Danish power producer (DONG Energy)
- Consultants EA Energy Analyses Ltd.
- Risø National Laboratory for Sustainable Energy, Technical University of Denmark.

STREAM has been further developed to cover all EU-27 countries.

Each country can be modelled individually or in groups of countries.

Characteristics

- It includes the whole energy system (in this case we only look at the demand side)
- It is fast to use (changing of scenarios during a meeting)
- It is publicly available – transparent.

4.3.2 Demand drivers

The main drivers for future energy demand in the scenarios are divided on the different storylines are shown in Table 4.3.

Table 4.3 Energy demand drivers for the different scenarios

	GDP growth	Increased outsourcing	Flex demand	End use RE share	Energy efficiency	Transport
Greenville	High (+1%)*	Yes	High	High	Middle (step 1)	El.,H2,bio vehicles
Blueville	High (+1%)*	Yes	Middle	Moderate	Weak (ref.)	Gas vehicles
Grønnevang	Medium (+0%)*	No	High	Very high	Strong (step 2)	El.,H2,bio vehicles
Blåvang	Low (-1%)*	No	Middle	Moderate	Weak (ref.)	Electric vehicles

* Change according to the EU Commission DG Tren baseline scenario

Energy demand in 2025 is modelled for each country for four sectors:

- Tertiary
- Industry (incl. agriculture)
- Households
- Transport

As a reference the sector-wise economic growth is taken from the EU Commission DG Tren scenarios running until 2030. In high growth scenarios 1% is added to the DG Tren growth and in low growth scenarios 1% is subtracted. In scenarios with increased outsourcing the growth in industry is lowered 1% and goods transport lowered 0.5%, while the tertiary sector is increased by 0.5%.

Table 4.4 shows the used economic yearly growth rates in each scenario. Greenville and Blueville are high growth scenarios. Grønnevang is medium growth following the DG Tren assumptions and Blåvang is a low growth scenario.

Table 4.4. Economic growth in each country for each storyline divided on sectors (p/g = person transport/goods transport)

Growth percentage per year		DG Tren	Greenville	Blueville	Grønnevang	Blåvang
Norway	Industry	1.9	2.9→1.9	2.9→1.9	1.9	0.9
	Tertiary	2.4	3.4→3.9	3.4→3.9	2.4	1.4
	Household	2.2	3.2	3.2	2.2	1.2
	Transport p/g	1.4/1.3	1.9/1.8-1.3	1.9/1.8 -1.3	1.4/1.3	0.9/0.3
Finland	Industry	1.6	2.6→1.6	2.6→1.6	1.6	0.6
	Tertiary	2.0	3.0→3.5	3.0→3.5	2.0	1.0
	Household	1.6	2.6	2.6	1.6	0.6
	Transport p/g	1.0/0.2	1.5/0.7-0.2	1.5/0.7-0.2	1.0/0.2	0.5/-0.3
Sweden	Industry	2.3	3.3→2.3	3.3→2.3	2.3	1.3
	Tertiary	2.1	3.1→3.6	3.1→3.6	2.1	1.1
	Household	1.8	2.8	2.8	1.8	0.8
	Transport p/g	1.2/1.4	1.7/1.9-1.4	1.7/1.9-1.4	1.2/1.4	0.7/0.9
Germany	Industry	1.2	2.2→1.2	2.2→1.2	1.2	0.2
	Tertiary	1.6	2.6→3.1	2.6→3.1	1.6	0.6
	Household	1.2	2.2	2.2	1.2	0.2
	Transport p/g	1.4/1.4	1.9/1.9-1.4	1.9/1.9-1.4	1.4/1.4	0.9/0.9

4.3.3 Energy savings/Energy efficiency

Three different levels of energy savings are used in the scenarios. The basis development assuming a continuation of present policies is called “Reference”. “Step 2” represents maximum realizable energy saving potentials and “Step 1” is defined as 50% of “step 2”.

All these saving potentials are based on the background material to Danish Energy Saving Act.[10] This is due to the lack of data within this field for the four countries. This means that we assume equal saving potentials within each sector and end use service in the four countries as in Denmark.

All the scenarios are assumed to realize at least what is called the “Reference” level of energy savings or a weak focus on savings. Scenarios with middle effort on energy savings include on top of the reference level of savings, the savings listed under “Step 1” (e.g. middle saving in electricity in tertiary sector is 28% + 15% = 43%).

With a strong effort within savings should be understood the reference level plus the Step 2 level (e.g. strong saving in electricity in tertiary sector is 28% + 30% = 58%).

Table 4.5 Energy savings per sector and use

Percentage saving compared to today’s level	Energy form	Efficiency improvement in basis Reference, %	Additional savings in scenarios Step 1, %	Additional savings in scenarios Step 2, %
Tertiary	Electricity	28	15	30
	Heating	15	13	25
Industry	Energy intens.	16	17	34
	Other	13	19	38
Residential	Electricity	28	14	28
	Heating	25	13	25

4.3.4 Transport sector

In all scenarios a general average efficiency improvement for all types of vehicles at 30% compared to the average today is assumed.

In the Greenville and Grønnevang scenarios 10% of the person transport work is moved from car to bus, train and bike. And 5% of the goods transport is moved from trucks to trains.

[10] Mainly the report "Faglig baggrundsrapport - Handlingsplan for en fornyet indsats - Energibesparelser og marked", Udkast december 2004, from the Danish Energy Agency.

Greenville

In Greenville in 2025 10 % of the transport work in cars is covered by electric vehicles, 10% by plug-in hybrids, 10% by biofuels and 2% by hydrogen.

In transport work by buses 5% is covered by electric vehicles, 10% by biofuels and 10% by hydrogen.

For trucks and vans 10% of the transport work is covered by electric vehicles, 10% by biofuels and 5% by hydrogen. The remaining part is covered by diesel.

Grønnevang

In Grønnevang 15% of the transport work in cars is covered by electric vehicles, 10% by plug-in hybrids, 10% by biofuels and 2% by hydrogen.

10% of the transport work in busses is covered by electric vehicles, 15% by biofuels and 10% by hydrogen.

For trucks and vans 10% of the transport work is covered by electrical vehicles, 10% by biofuels and 5% by hydrogen. The remaining part is covered by diesel.

Blueville

In Blueville in 2025 10 % of the transport work in cars is covered by natural gas vehicles and 10% by biofuels.

30% of the transport work in buses is covered by natural gas, 10% by biofuels and the remaining by diesel.

For trucks and vans 5% of the transport work is covered by biofuels and the remaining part is covered by diesel.

Blåvang

In Blåvang in 2025 10 % of the transport work in cars is covered by electrical vehicles and 10% by biofuels.

10% of the transport work in busses is covered by natural gas, 10% by biofuels and the remaining by diesel.

For trucks and vans 5% of the transport work is electric vehicles and 5% by biofuels and the remaining part is covered by diesel.

4.3.5 Resulting annual power demand in each country in 2025

First we will give some general comments on the resulting electricity demands in 2025 for all the countries, focusing on the differences between storylines.

Greenville

Greenville has high economic growth, though to some extent reduced in the industry sector due to outsourcing of energy intensive production. At the same time the environmental focus in the scenario and the increased use of renewable energy means that a big potential for energy savings has been harvested, supported by EU policy. The level of savings includes savings up to “Step 1” as defined in the previous section.

The combination of economic growth, energy savings and increased use of electricity in the transport sector yields electricity demand more or less at the same level as in the base year 2005.

Grønnevang

Grønnevang has medium economic growth combined with a strong focus on renewables, energy savings and local solutions. Measures and legislation concerning energy savings at the EU level has been supplemented by additional initiatives in the four countries. All the countries are assumed to implement energy savings at the level of “Step 2”, which is more or less the maximum realizable saving potential.

In the transport sector electricity is used directly in electric vehicles, but also to produce hydrogen and biofuels.

The demand for electricity in the Grønnevang scenario is significantly lower than in the base year and almost half of the demand in the Blueville scenarios.

Blueville

Economic growth in Blueville is at the same level as in Greenville, but there is no specific focus on renewables and the level of implemented energy savings follows the “Reference” level, also interpretable as continuing the polices already implemented today and otherwise current trends.

This leads to increased power demand compared to the base year mainly in the industry and tertiary sector.

Blåvang

In Blåvang low economic growth and a weak focus on energy savings (“reference” level) are assumed. This gives the countries relative high energy intensity, but due to the low economic growth electricity demand ends up pretty close to the level in the base year.

Figure 4.7 Electricity demand Germany in 2005 and 2025, all scenarios. TWh/year

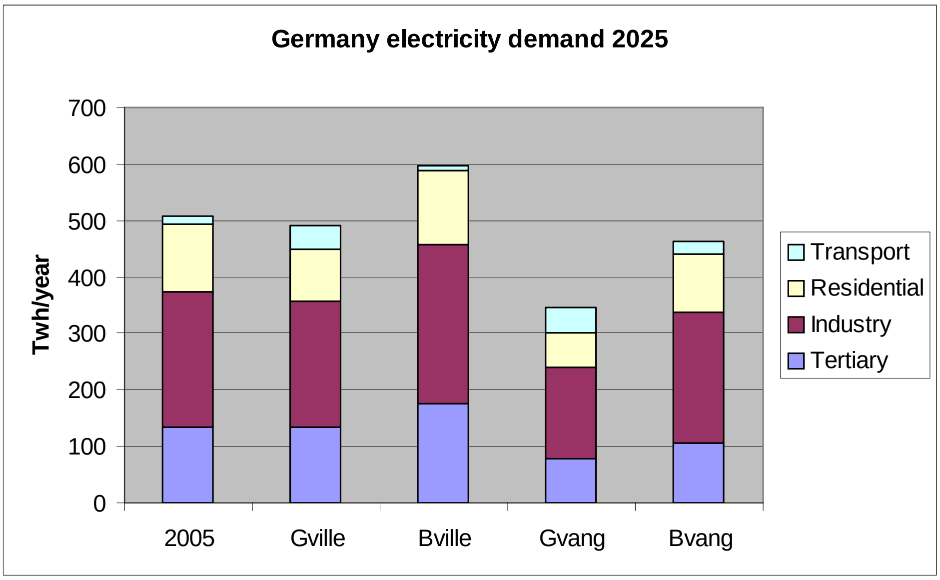


Figure 4.8 Electricity demand in Sweden in 2005 and 2025, all scenarios. TWh/year

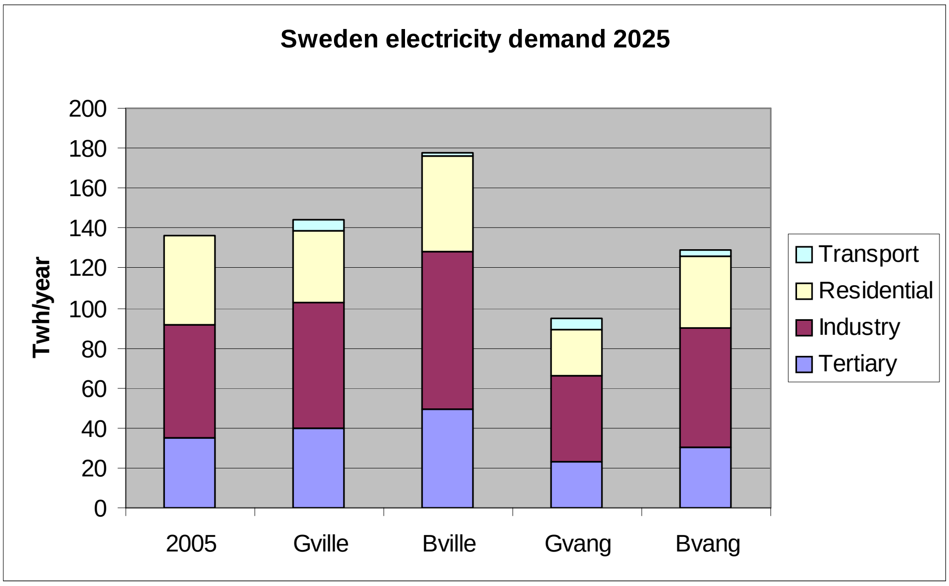


Figure 4.9 Electricity demand in Finland in 2005 and 2025, all scenarios. TWh/year

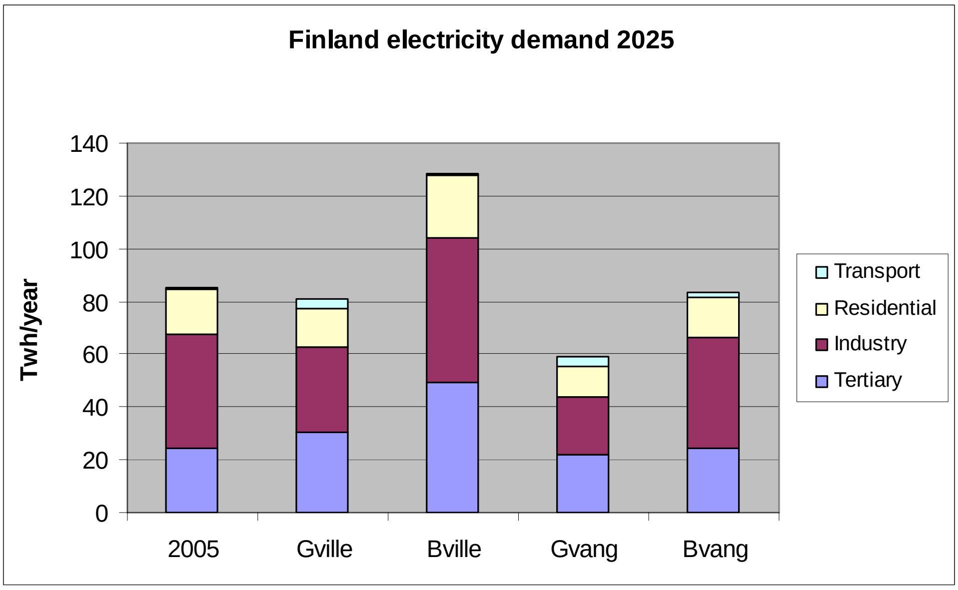
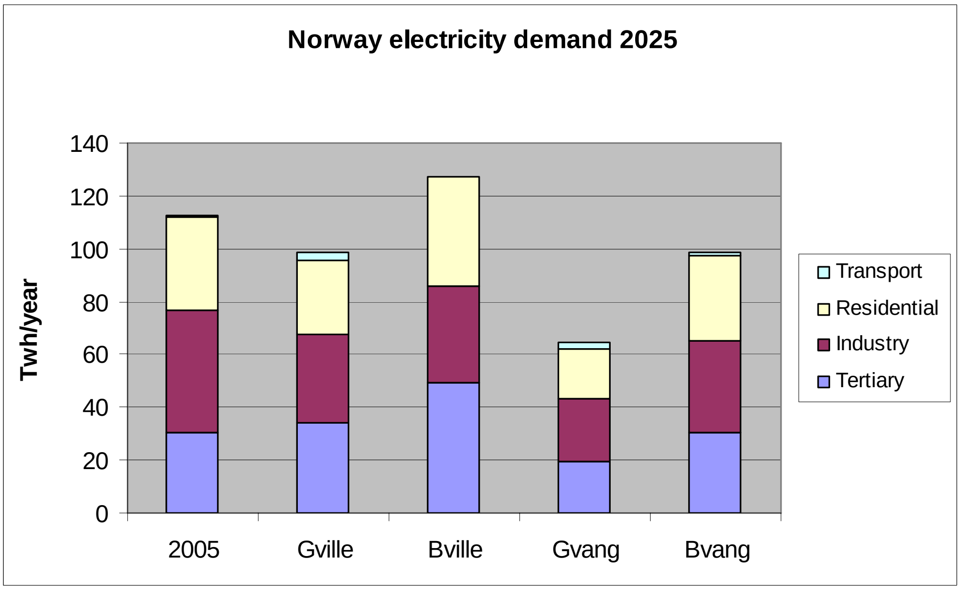


Figure 4.10 Electricity demand in Norway in 2005 and 2025, all scenarios. TWh/year



For more detailed results from each country please consult Appendix 4.

The power of economic growth and efficiency improvements can be studied by comparing the scenarios. Although the Blueville and Blåvang scenarios have the same low effort within energy savings, Blueville ends up with a demand for electricity which is 30% higher than Blåvang. This is mainly due to a 2% higher economic growth per year.

The Greenville scenario has high economic growth (as in Blueville), but due to almost full utilization of the energy saving potential, then Greenville electricity demand can be held at the same level as today.

Grønnevang has a medium economic growth and the same level of savings as Greenville. This leads to a decreasing demand for energy. If Grønnevang in addition had low economic growth, as in Blåvang, then electricity demand would be around 50% lower than it is today!

Future demand for energy is very sensitive to the economic development and development in efficiency. This is why we need different scenarios to embrace the span of possible future levels of demand.

4.3.6 Demand response potentials

Demand response can be defined as consumers increasing or reducing consumption as a response to prices or to the needs of the electricity system. Demand response typically involves peak-load reductions, but demand response could also imply an increase in electricity consumption as a response to very low electricity prices or a means of providing balancing power. The activation of back-up potentials at the end-user level, as a response to prices or incentives, is also often defined as demand response.

For a number of reasons demand response is mentioned as a prerequisite for a well-functioning electricity market. Demand response reduces the risk that the day-ahead market fails to clear, it stabilizes electricity prices, it reduces demand for expensive peak power capacity and it limits the possibilities of market players to exert market power.

Moreover, in electricity systems with high shares of wind power, demand response can be an important means to increase the value of electricity when wind generation is high, and to balance fluctuations in wind generation.

The sources of demand response are manifold. Until now industrial facilities have been the most important suppliers of demand response, primarily energy intensive processes such as metal smelting. In the longer term, as more advanced metering systems are installed at households and among smaller companies, an additional potential can be expected here. Electricity consumption, which is connected to some sort of heating/-cooling storage, for example electric heating or refrigerators, can be expected to hold the greatest potentials as consumption here can be increased or decreased for shorter or longer periods without affecting the comfort of consumers significantly.

In this respect using electricity for heating in connection with district heating systems holds considerable promise in view of increased wind power integration. Electricity could either be converted to heat using electric boilers, which is a fairly cheap technology, or by heat pumps, which convert electricity to heat with a significantly higher efficiency. Heat pumps are more costly to invest in however. Since most district heating systems in Denmark are supplied by CHP plants, have access to back-up boiler capacity and have significant heating storage capacity (approx. 8 hours of heat consumption), such solutions could allow for very flexible electricity consumption – which may provide upwards as well as downwards regulation services.

Looking 10–20 years ahead the transport sector may offer another important source of demand response. If commercialized, electric vehicles and plug-in hybrid electric vehicles will have the flexibility of charging when it is beneficial for the electricity system, or serving as “batteries” for the electricity system when prices are high or the system is strained. Electrolysis plants converting electricity to hydrogen could hold a similar potential, and even large facilities producing biofuels – and using electricity as in input – could be assumed to respond in a flexible way to electricity prices and system demands.

Although there is little doubt that flexibility exist on the demand side, it may be a considerable challenge to activate demand response. This challenge is mainly related to the communication of price signals to end users within a relevant (sufficiently short) time frame, and the actual cost of demand response. The first challenge may be solved by introducing innovative contracts to end-users, but must probably be done in combination with automatic two-way communication meters in order to be effective. The second challenge is the actual costs associated with demand response, of which transaction costs may play a significant role. Both the market instruments and the actual potential (and cost) of end-user response may vary between the scenarios. We assume that these potentials are exploited in further detail in WP 4.

Demand response in the EcoGrid.dk scenarios

The level of demand response developed in the EcoGrid.dk scenarios is likely to differ from scenario to scenario. The main driver for demand response is a market characterized by a high frequency of very low or very high prices – or a combination of both. Moreover, the price signals must be passed on to end-users. In addition, system operators and regulators have a role with respect to promoting demand response through for example promotion of technology solutions, tariffs, acquisition of reserves and balancing power and taxation.

Among the four EcoGrid.dk scenarios the incentives for developing demand response are expected to be strongest in the Grønnevang scenario. Wind power, which has a high focus in this scenario, can be expected to yield a price picture with many low prices, when the wind is peaking and high prices when it is calm. Moreover, the scenario focuses on local solutions to deal with this including the utilization of wind in the transport sector and for heating via heat pumps. On the other hand electricity consumption within industries and households is lower compared to in any of the other scenarios – as a response to energy efficiency measures – and this reduces the technical potential for demand response here.

Greenville also has a strong impetus for wind power, but this scenario to higher degree uses international trade of power as a means of integrating wind power. This can be expected to reduce the incentives for demand response as the higher level of trade will smoothen out prices. On the other hand, solutions are expected to be more market-based in the Greenville scenarios, making it more likely that price-signals will be passed on to end-users.

It may be that DR will be activated using more command and control measures in Grønnevang than in Greenville. A priori it is not possible to say which will realize the largest potential or involve the lowest costs.

In the two blue scenarios wind power – and its effect on market prices – is not as strong a driver for developing demand response. Nevertheless, Blåvang can be assumed to have a higher level of demand response than Blueville due to its focus on local solutions. Contrary, Blueville, is likely to see a high technical potential within households and industry, since this scenario has the highest general electricity demand. Given the description of the configuration of the Blueville scenario above (see summary in next section), the need for DR seems to be less pronounced in this scenario than in the other three.

Table 4.6 provides an overview of the expected incentives to develop demand response in Denmark's neighbouring countries in the four scenarios as well as an estimate of the potentials within four different categories: households, industry, electricity for heating and transport.

Table 4.6 Preliminary estimate of the incentives and potentials for demand response in Denmark's neighbouring countries

	Grønnevang	Greenville	Blåvang	Blueville
Expected market incentive to develop DR ("price picture")	Very strong	Strong	Medium	Medium
Estimated potential Households (appliances)	Low	Medium	Medium	High
Industry	Low	Medium	Medium	High
Electricity for heating	High	Medium	Medium	Medium
Transport	High	High	Medium	Low

4.4 Transmission and trade

The following analysis of developments in the energy balance and the needed infrastructure development was performed without a detailed system analysis, hence the infrastructure data used for the scenarios must be viewed as first assessments mainly. In order to make a real quantification, an integrated market and system analysis must be performed, and other market areas, most notably Denmark, must be put into the equation. Main drivers for capacity expansion will be energy exchange, market coupling, policy focus and (international) demand and supply of balancing resources.

4.4.1 Energy balances

The table below summarizes the energy balances per country and scenario, based on the projections for investments in different technologies and demand development above.

Table 4.7 Net imports in 2005 and 2025, all scenarios, per country. TWh/year

in TWh/year		Greenville	Grønnevang	Blueville	Blåvang
	2005	2025	2025	2025	2025
Germany					
Final demand	508,87	491,17	344,47	596,59	463,57
Net generation	*556,22*	*509,02*	*376,68*	*617,56*	*517,06*
Gross generation	500,60	458,12	339,01	555,80	465,36
Net exports	**-8,27**	**-33,06**	**-5,45**	**-40,79**	**1,79**
Sweden					
Final demand	136,65	144,07	95,02	177,35	129,19
Net generation	*152,21*	*153,55*	*113,06*	*186,48*	*171,75*
Gross generation	136,99	138,19	101,75	167,83	154,57
Net exports	**0,35**	**-5,88**	**6,73**	**-9,52**	**25,38**
Norway					
Final demand	112,66	98,33	64,76	127,29	98,55
Net generation	*125,92*	*143,81*	*131,04*	*140,83*	*136,37*
Gross generation	113,32	129,43	117,94	126,75	122,73
Net exports	**0,66**	**31,11**	**53,18**	**-0,54**	**24,18**

As can be seen from the table, there are significant variations in the energy balances depending on scenario.

Compared to the situation in 2005, Germany's deficit increases in the "ville" scenarios, whereas the situation is more balanced in the "vang" scenarios, which have a weaker focus on trade.

The Swedish situation is mainly affected by the nuclear situation: In the Blue scenarios, nuclear capacity is expanded, creating a surplus of 25 TWh in Blåvang where demand contracts. In the Green scenarios nuclear is phased out and there is a higher penetration of renewables, particularly in Greenville, more or less making up the balance. Demand developments indicate never-the-less that Sweden will import in Greenville and export in Grønnevang.

Norway is a net exporter in all scenarios except Blueville. The balance is mainly explained by the differences in demand development between the scenarios. In

Grønnevang Norway has a surplus of more than 50 TWh in years with normal precipitation.

4.4.2 Assessment of infrastructure developments per country and scenario

Greenville

Increasing trade and international markets, partly to exploit the renewable resources where the potential is greatest, will result in the need for new transmission capacity. In particular, increasing net exports from Norway is likely to require interconnector capacity expansions transmission lines until 2025. Possible expansions include plus 1200 MW to Denmark and plus 1200 MW to Sweden as well as a new line to GB (plus 800 MW) as well as directly to Germany (plus 600 MW).

Sweden is set to be a net importer in Greenville, but not by a very large annual volume. Increasing wind capacity may require additional balancing resources, which may be supplied by Norway (up to 1200 MW plus) and Poland (plus 600 MW). In addition, increasing trade between Scandinavia and Germany may require new transmission lines between Sweden and Denmark (plus 600 MW) and directly between Sweden and Germany (plus 600 MW).

Denmark's role as transmission corridor between Scandinavia and Germany will increase. Excess wind generation capacity in South Sweden/Norway will be exported to Denmark and further to Germany, which will increase its dependency on imports. During certain extreme situations new CCGT in North Germany may be used for balancing wind power in South Sweden/East Denmark. Possible expansions include 1200 MW new transmission capacity to Germany (600 MW from Jutland and 600 MW from Zealand) as well as 1200 MW to Norway and 600 MW to Sweden.

Grønnevang

In Grønnevang demand declines substantially in all countries. Germany and Sweden are however reasonably balanced because nuclear capacity is phased out, but Norway develops a huge surplus in 2025. Norway does not have old conventional thermal capacity to phase out. Expansion of interconnector capacity cannot be ruled out in this scenario, but will probably not be prioritized by the countries. As international markets are rather weak, national solutions rather than developments of new transmission lines are prioritized. However, Norway will have to look for markets to export the surplus or ways to increase demand, e.g. power intensive industry or powering off-shore oil installations from land.

Wind power expands, however, so it could be necessary to increase interconnector capacity to balance the wind. Interconnectors will to a larger extent be seen as tools for system services, and a smaller proportion may be kept open to market based trade, i.e., the system operators may reserve large shares of capacity for short-term balancing services. Although new interconnectors may not be needed, Denmark is still likely to play a role as a transit country, and with more intermittent power generation in the systems around, the variation in trade flows may pose an increasing threat to the Danish system.

New interconnector capacity may be plus 600 MW to Sweden, plus 600 MW to DK, plus 1600 MW to Germany, plus 1600 MW to the Netherlands and plus 1600 MW to GB.

Blueville

Blueville is the only scenario with a strong increase in demand, which results in increased import demand from Germany and Sweden and reduced exports from Norway. In fact, Norway is balanced in normal years in this scenario. This means that there is likely to be easier for a Danish surplus to be exported to neighbouring areas, and that the demand for transit through Denmark is likely to be smaller than in the other scenarios. Renewable generation development is limited, and hence transmission capacity is not needed to balance fluctuating generation resources over a larger geographical area to the same extent as in the Green scenarios. Hence, the need for new transmission capacity is likely to be limited to the 600 MW between Norway and Sweden already planned for 2012; plus a 300 MW line between Sweden and Denmark as well as between Denmark and Germany.

Blåvang

Even though trade is not assumed to play a significant role in Blåvang, Norway and Sweden are both significant net exporters, mainly due to reduced demand because of the strong energy efficiency efforts. This assumption may of course be challenged in view of the resulting energy surplus. If demand does indeed decline as assumed, Norway and Sweden will need more interconnector capacity as an outlet for the surplus. The most likely expansions are Norway-Germany (plus 600 MW) and Norway-Denmark (600 MW plus), plus strengthened connections between Sweden and Denmark (600 MW). However, Germany is assumed to be in balance in this scenario, and the export must find other markets, e.g. UK, Netherlands or even Italy. Since strengthening of interconnector capacity is not likely to be prioritized in this scenario because of a lack of market solutions and international agreement, it is likely that solutions to the surplus situation must be found domestically.

4.4.3 Implications for Denmark

From the point of view of Denmark, the Greenville scenario implies increased exports from Norway and Sweden and increased imports to Germany. Although expansion of interconnector capacity to other markets can be imagined, this indicates increased demand for transit through Denmark and for increased transmission capacity. In Grønnevang the combined surplus of Norway and Sweden increases even more, but the import demand from Germany is reduced. If Denmark also has a significant surplus in this scenario, it will be an important challenge for the Nordic area to find outlets for this surplus. In Blueville all surrounding areas are importers, so clearly there will be a demand for exports from Denmark, but even a general demand for increased investments in conventional capacity. In Blåvang the Nordic surplus is again a huge challenge, not least since other countries are looking at domestic solutions and trying to be balanced in this scenario. Since markets and trading solutions are not prioritized in this scenario, it is also likely that Denmark will not have a strong obligation to transfer power from North to South in this scenario, and will be in a strong negotiation position towards Norway and Sweden. It is also likely that the competition for regulating and balancing resources will be weaker in Blåvang.

5 The international context and challenges for Energinet.dk

Work package 3 is an analysis of the present market conditions in Denmark's neighbouring countries and of four possible future market conditions selected in a scenario study. The purpose has been to detect the implications of alternative future international developments for Energinet.dk.

5.1 The essential characteristics

The Danish government has set targets for the use of renewable energy by 2025. Wind energy shall cover 50% of the electricity demand. The new generation pattern will have a direct impact on system balancing, market performance, system security and local grid design. Available capacity of transmission grids and interconnections must be shared between increasing demands for balancing services, technical reserves and commercial trade. A number of measures must be implemented in order to maintain appropriate standards within these areas.

Some of the new measures will depend heavily on access to reserves and other services in neighbouring countries. However the availability of such services will depend on long term trends in European societies. The scenarios describe some alternative trends which may substantially affect energy markets and power systems.

A few international characteristics will have significant influence on the future operation of power systems and electricity markets in Denmark. Among the most important characteristics are:

- International organization of energy markets including cross border trade
- EU in a more or less active role?
- National self-sufficiency or common backup?
- Sufficiency of transfer capability in terms of frequency of congestion in grids and interconnectors
- Preferred energy technologies, particularly the role of nuclear power and CHP
- Incentives for decommissioning and investments in central generation capacity
- Incentives for investing and operating peaking/regulating capacity
- Demand development
- The flexibility on the demand side.

The four scenarios have four different combinations of these characteristics. Some of these are summarized above.

Other characteristics may also affect the challenges for the development of the energy systems, and thus, indirectly, the challenges posed by integration of large quantities of wind power in the Danish and Northwest European electricity system. Such characteristics include:

- Market structure, e.g., dominance of a few large European energy utilities, and possible impacts of market power
- The role of TSOs/national or regional TSO responsibilities
- Dependency of energy imports, particularly natural gas

It has not been possible within the framework of EcoGrid.dk phase 1 to explore all these characteristics for each of the scenarios. We do however recon that the presented scenarios offer a good basis for further exploration of these characteristics in phase 2.

5.2 Implications for Energinet.dk – preliminary assessment

The Danish power system is an integrated part of the Nordic and Northwest European electricity system. Hence, the wind power challenge cannot be fully assessed without reference to the developments in adjacent market areas. Work package 3 – International market scenarios – explores the developments in the closest market areas, Germany, Norway and Sweden, and provides a starting point for a comprehensive study of future configurations of the system as a whole, or more precisely, of the Danish system as an integrated part of the larger power system. It is a starting point only, because it describes some of the pieces of the jigsaw puzzle. The next stage would be to put the pieces together and study the integrated situation. Hence, the assessment presented here is preliminary because the full picture is not described yet.

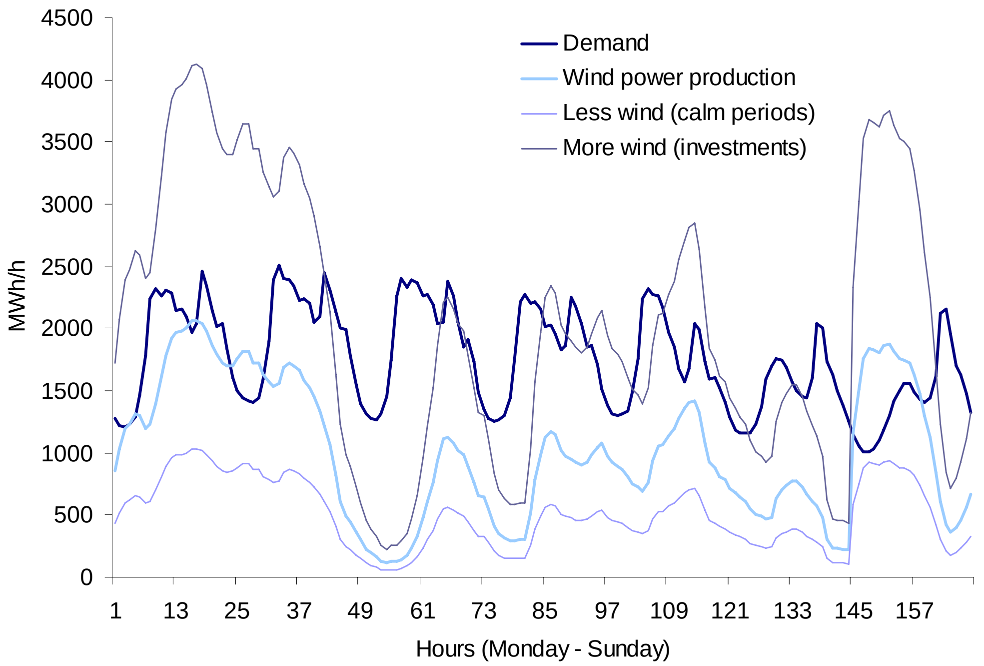
The EcoGrid.dk project is based on the condition that renewable energy by 2025 must cover 50% of the electricity demand in Denmark. Energinet.dk is already facing challenges related to the relatively large share of wind power in the system. “It is hard to imagine how the actual Danish power system could be balanced without access to international markets” (WP2 report: Requirement Analysis).

It is estimated that about 3 GW new balancing capacity will be required in order to achieve a 50% wind energy share. Sources of balancing services can be:

- Neighbouring countries
- New domestic measures
- Curtailment of wind power.

To illustrate the magnitude of the challenge, take a look at Figure 5.1. The figure shows an example of hourly wind power variations for a week in Jutland today (light blue curve), compared to total (hourly) demand (dark blue curve). For the same wind profile, a doubling of the wind power capacity will yield wind power generation as shown by the thin blue line (labelled More wind (investments)). As we can see, wind power generation may exceed demand by up to 2 GW in some hours, while in others wind power generation is almost 0 whereas demand is up to 2.5 GW. Hence the system should be prepared to export a surplus of up to 2 GW and to cover a shortfall of 2 GW.[11]

Figure 5.1 Example of wind power generation with double capacity in West Denmark



The EcoGrid.dk projects (EcoGrid.dk and EcoGrid.EU) will explore different market and technical measures to balance wind power generation. To put it in a simplified way, technical measures define the potentials for system balancing whereas regulations and market measures define to what extent the potentials can and will be utilized. Given the challenge at hand (as illustrated in Figure 5.1) it is probable that it will be necessary – and definitely cost efficient – to get provisions of balancing services (including outlets for surplus generation or overflow) from other market areas. It cannot however, be ruled out that it will be necessary – and again cost efficient – to curtail wind power generation to maintain the system balance. This means that the benefit of increased wind power capacity is declining with increased quantities, i.e., one should expect wind capacity load factors to decline over time even if wind conditions are the same. Such a result may not be a major system challenge, but it will certainly be a political challenge.

[11] With a 1% increase in peak demand per year, demand may increase to about 2.9 GW by 2025 which will reduce the overflow problem somewhat. Demand may however increase significantly less, and significantly more, especially with increased use of electricity in transportation. (See demand predictions in section 4.3.)

In summary, the main challenges identified in the scenarios are:

- Investments in new interconnector capacity – allocation of costs and benefits
- Availability of balancing services from neighbouring areas (depends on flexibility in surrounding areas and transmission capacity)
- Peak load capacity (need for additional capacity – taking power balance and transmission capacity into account)
- Competition for peak load and balancing capacity (e.g., will Netherlands or Germany pay more for Norwegian flexibility than DK?) How are balancing resources allocated?
- Increased demand for transit through Denmark will pose its own challenges for system development and operation, in addition to the challenges of accommodating increased domestic wind capacity. Will costs be shared or borne by the Danish system?
- International obligations: To what extent can Denmark (and other countries) rely on imports of system and balancing services?

Increased need for balancing capacity and technical reserves in Denmark will cause increased demand for transfer capability, including international interconnections and domestic grid enforcement. It is not unlikely that there will be general resistance against new transmission lines and very long construction periods in all North European countries, with frequent congestions and price volatility in the wholesale market as a result.

The transfer capability will be available to both balancing service and to the wholesale market. In case of congestion the reduced capacity must be shared. If the transmission capacity available to for regular spot exchange is reduced, it may lead to increased price volatility and distorted competition.

Reinforcement of grids and interconnectors will be necessary in order to balance the system without reduced service to domestic markets, and particularly if balancing capacity is to be supplied from neighbouring countries – which is likely to be necessary. It will be a major challenge in some scenarios to analyze and negotiate the interconnection capacity. The system operators are not supposed to maximize profit, but to increase transfer capability up to the optimal limit to the societies concerned. In pursuing this objective, the TSOs may be caught in a squeeze between international obligations, need for (negotiated) international solutions, political resistance against curtailment of wind power capacity and public opposition against overhead lines.

Appendix 1: Electricity generation in the market areas around Denmark: Current situation and policy trends

Germany

Electricity generation mix

The German government has a challenging energy policy agenda. It has decided to phase out nuclear power and it has established ambitious targets to reduce greenhouse gas emissions. While it is not yet clear how nuclear power will be replaced, it is fact that energy efficiency and conservation, co- generation and renewables, as well as fossil fuels, play a significant role in Germany's energy supply. To ensure that these policies are cost-effective, their development and effectiveness are closely monitored.

The German government wishes to maintain a significant coal-based electricity generation capacity to avoid over-dependence, and associated supply and price risks, on imported energies. The policy for hard coal is also closely related to social, regional and employment policies. Because of its poor competitiveness, domestic hard coal receives a significant, but declining (run out in 2015), amount of subsidies. Lignite production does not receive subsidies. Lignite power plants, however, are currently protected by legislation prohibiting new entries in the eastern part of Germany.

Germany is the second largest European natural gas market after the United Kingdom. These are the only European countries that have fully liberalised their gas markets. In 2000, gas consumption reached 88 bcm, representing a 21% share of primary energy supply. The supply base is diverse, with domestic production accounting for 22% of the supply, and preparations are under way to establish a gas-trading hub in Bunde, near the Dutch border. Currently there are about 750 companies operating in the German gas sector, but there is a trend of consolidation and mergers among gas companies, and between gas and electricity companies.

Germany will gradually phase out nuclear power by closing down plants when they reach an average of 32 years of operation. Nuclear power now covers 30% of electricity generation and 13% of total primary energy supply. The negotiated agreement between the government and nuclear utilities to phase out nuclear power entails no direct cost to the government and provides industry with some level of certainty and flexibility in implementation. The national energy policy implications of the decision are significant. The magnitude of these implications makes it essential that necessary corrective action is taken and at the right time. The government thus needs to be well informed of developments in this area at all times, which will require a continuous assessment process. The nuclear phase-out policy will not relieve government and industry in the near future of the responsibilities they now carry for the ongoing nuclear programme. Competence in the nuclear sector will need to be maintained for decades. The ways and means for managing and disposing of radioactive materials will have to be maintained and developed, and nuclear power plants will need to be decommissioned safely.

In 2000, the share of renewables (including hydro-power) in primary energy supply was 3.4% and in electricity generation 7.3%. The Renewable Energies Act of April 2000 aims to double the share of renewables in total energy supply by 2010 compared to 2000 levels. The national policy on renewable energy is embedded in a European framework, according to which Germany should generate 12.5% of its electricity from renewable energy by 2010. This target expected to be already reached in 2007.

Renewable energy technologies have deployed rapidly in Germany since 1990 largely as a result of energy policies adopted by the German government and the European Union. In Germany, 8 % of the country's final energy consumption has been provided by renewable energy sources in the year 2006. In the same year, the share of renewable energies in total electricity consumption was 12%. As much as 6% of each sector's energy demand, in heat supply and road traffic is provided by renewable energy sources. Of Germany's renewable energy sources for electricity generation, more than 60% derives from windpower, hydropower and solid biomass.

Developments in share of renewable energy sources in German energy supply

	1998	1999	2000	2001	2002	2003	2004*	2005*	2006*
Final energy consumption (FEC)	%								
Electricity production (as % of total GEC)	4.8	5.5	6.3	6.7	7.8	7.9	9.3	10.4	12.0
Heating supply (as % of total heating supply)	3.5	3.5	3.9	3.8	3.9	4.6	4.9	5.4	6.0
Fuel consumption (as % of total road transport)	0.2	0.2	0.4	0.6	0.9	1.4	1.9	3.8	6.6
Share of RES in total FEC	**3.1**	**3.3**	**3.8**	**3.8**	**4.3**	**4.9**	**5.5**	**6.6**	**8.0**

Source: Communication from the Government of the Federal Republic of Germany to the Commission of the European Communities[12]

During the 1990s, wind power was greatly developed in Germany. As the sites suitable for hydro-power and onshore wind are becoming limited, Germany has announced ambitious targets for developing offshore wind power. Renewable energy is supported by both direct subsidies and feed-in tariffs; the latter were introduced by the Renewable Energy Sources Act in 2000, and are in effect indirect subsidies. The level of these indirect subsidies was approximately €1 billion in 2001, and this annual expenditure is likely to grow as more renewable energy capacity is installed. According to the Act (EEG), grid operators have to pay fees for electricity from renewable energy sources. The difference between fees and the market price for electricity from traditional sources is apportioned to consumers via their electricity bills as EEG apportionment. The different types of renewable energy sources receive different fees based on the cost of electricity generation. The progress report states that in some sectors it is necessary to adapt the amount of fees.

[12] Reporting obligation in accordance with Article 3(3) of Directive 2001/77/EC; 23 October 2007

Onshore wind power

At the end of 2006 there were around 18,685 wind turbines for electricity generation in Germany, with a capacity of around 20,600 megawatts. Thus in 2006, wind energy once again made the biggest contribution to electricity generation from renewable energies.

Offshore

Since the space for setting up new installations for wind energy on land is becoming increasingly scarce, a trend has meanwhile set in to develop the major potential for energy generation at sea. Operating offshore wind parks can minimise impacts on the landscape and on the environment.

The Federal Government considers it to be a realistic assumption that wind parks will generate a capacity of 20,000–25,000 megawatt by 2025/2030. If these figures are reached, 15% of the current electricity demand in Germany could be covered by wind turbines installed at sea.

Biomass

The Renewable Energy Sources Act also promotes electricity generation from biomass. Biomass is defined as renewable raw materials such as wood but also plant and animal wastes. Within the framework of the Renewable Energy Sources Act, the Biomass Ordinance of 2001 regulates what substances and technical procedures can be used and what environmental requirements have to be met. Additional measures such as the market introduction programme for renewable energies give support to increasing the energy exploitation of biomass, in particular for heat production.

Solar energy

Promoting renewable energies has also led to an increased electricity supply from solar energy and, at the same time, has stimulated the labour market.

There is also an increased use of solar heat with a total of about 8 million square metres of installed solar collectors in 2006.

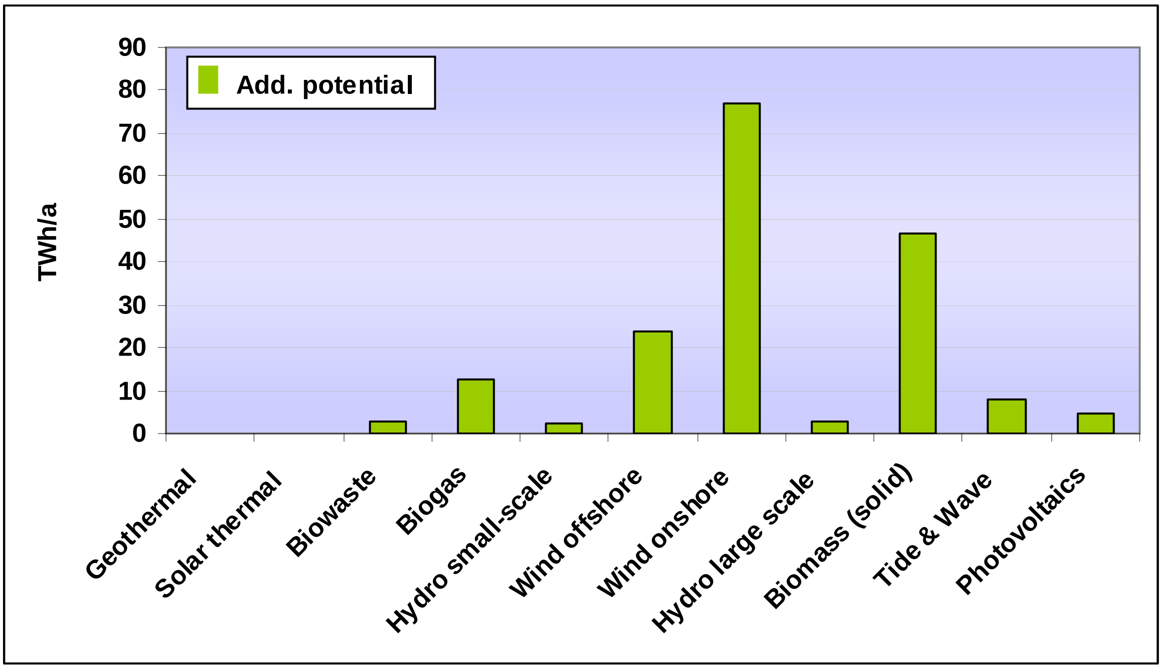
Policy trends

The German's government goal is to increase the share of renewables in gross electricity consumption by 2010 to at least 12.5%. The medium-term objective for the Federal Government is to increase the share of renewable energies in electricity provision to at least 20% and in primary energy consumption to 10% by 2020. In the long term, i.e. by the middle of this century, around half of the energy supply is to be met by renewable energies.

The Environmental Minister recently pointed out that the 2010 target for increasing the use of renewable energies was already met in the middle of 2007: "We can and must raise the bar for the 2020 target. The share of renewable energies in total electricity consumption should increase to at least 20%. This is the only way in which we can make a significant contribution to reaching the ambitious EU target agreed upon in March during the German EU Presidency." By 2030 the share should have risen to at least 45%. So far, the EEG lays down that the share has to increase to 12.5% by 2010 and to at least 20% by 2020.

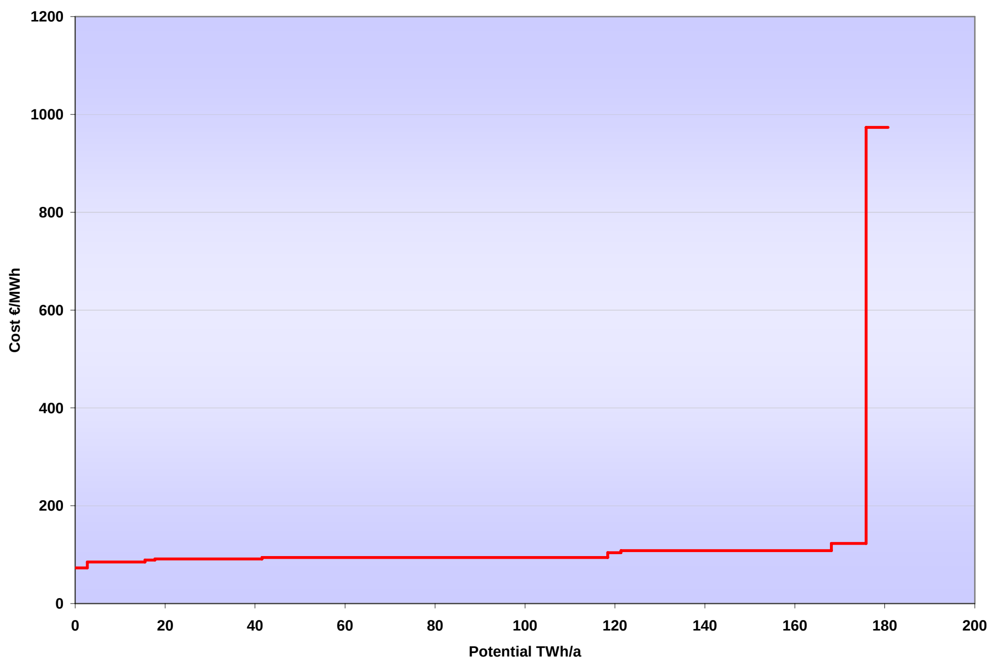
Costs and potentials

Future potential for renewable power generation in Germany



Source: www.green-x.at

Marginal costs of future renewable power generation in Germany



Source: www.green-x.at

Conclusion

The successes of renewable energy in Germany over the past decade must be balanced with other considerations. For example, some community and environmental groups are mounting opposition to the continued expansion of wind power installations because of their impacts on the landscape and bird populations, due to the noise generated by wind turbines, and due to concerns regarding the transparency of the siting and permitting processes for new wind plants. Increasingly, suboptimal sites have been developed for renewable energy production as the highest quality (and lowest cost) sites both onshore and offshore have been exploited. Also, Germany's gas, coal, and electric power industries have objected to mandates for the purchase of more expensive renewable power and to the subsidies granted to renewable producers. In addition, the accelerated deployment of renewable energy technologies in Germany has paralleled a sharp decline in investment in energy research and development by the German government, prompting concerns that early deployment of renewable technologies may come at the expense of future generations of energy technologies. While renewable energy is likely to make further gains in Germany in the near- to mid-term, domestic growth of renewable energy may be slowed in the longer term by political pressures and technological limitations.

Energy security is an important issue for Germany as the country has limited indigenous energy resources. Moreover, the decision to gradually phase out nuclear power by 2025 will increase Germany's reliance on imports of coal and natural gas, which currently represent 27% and 78% of demand for these fuels. Germany will also continue to depend heavily on imported oil, at about 40% of its total primary energy supply. To address these energy security issues, Germany is focusing on the development of domestic fuels and renewables, energy end-use efficiency, and on good relations with energy exporting countries.

Norway

Electricity generation mix

In Norway, electricity is supplied almost exclusively from hydro power. District heating production only amounts to roughly 2.5 TWh annually and is dominated by solid waste incineration. Since the turn of the century the share of bio fuels has increased significantly both in relative and absolute numbers.

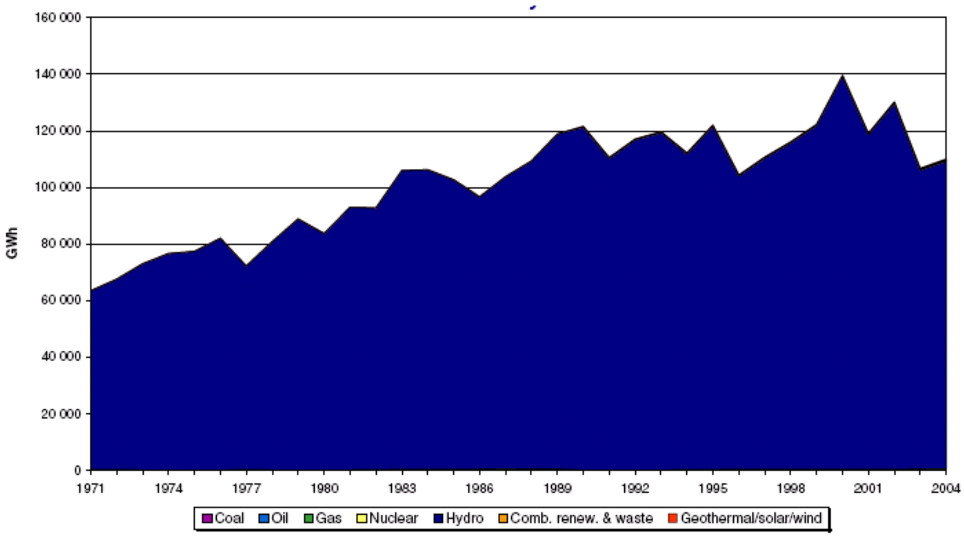
In Norway 99% of total electricity production is hydropower (normal precipitation year production is 121 TWh, installed capacity 28300 MW in 1000 large and small plants) which is equal to 50% of total energy consumption. The total large scale hydropower potential is 205 TWh with an additional small-scale potential of 25 TWh.

Hydropower has been utilised widely in Norway. State- or county owned companies have build most of the (large scale) plants before the liberalisation in the early 1990'ies. Since the investment cost were financed though these companies, only the running and operational costs had to be covered by the sale of electricity. Therefore, these plants can run without the subsidies.

For other renewables support for renewable energy sources was given in the form of investments subsidies during the 1990'ies. Norway still has large unused hydropower resources. However, utilization of the remaining hydro resources is highly controversial due to nature conservation concerns. Special simplified concession rules apply to small-scale hydropower (less than 10 MW).

Wind energy was introduced as a renewable energy alternative in the 1990 (NVE, 2005)13. The first projects were pilot projects, and the process to licence the first large projects commenced in 1997/98. By the end of 2005, wind power capacity had grown to 280 MW.

Norway's electricity generation by fuel, 1971–2004



Source: IEA, 2006

Support schemes

Currently, 99% of the electricity produced in Norway is hydropower. Renewables other than conventional hydro are referred to as "new renewables", and include solar, wind, wave and biomass. The supply from new renewables is relatively small in Norway, given the availability of cheap clean hydro-generated electricity that in the past could easily cover Norwegian energy requirements, including space heating. In particular, the use of electricity for space heating has delayed the development of biomass resources for heat production, which plays a major role in other countries such as neighbouring Sweden.

Solar plays a very minor role in Norwegian energy supply owing to the northerly location of the country.

During the 1990ies support for other renewable energy sources was given in the form of investments subsidies. Special simplified concession rules apply to small-scale hydropower (less than 10 MW).

Wind energy was introduced as a renewable energy alternative in 1990 (NVE, 2005)[14]. The first projects were pilot projects, and the process to licence the first large projects

[13] Vindkraft I Norge – status januar 2005.

[14] Vindkraft I Norge – status januar 2005.

commenced in 1997/98. By the end of 2005, wind power capacity had grown to 280 MW.

In 2002, Enova SF was established, a government agency that administers support to energy efficiency and renewable energy projects. Enova also administers the support scheme to promote infrastructure for domestic supply of natural gas.

In early 2000, the government planned to establish a green certificate market joint with Sweden. However, the negotiations were terminated in the beginning of 2006, just before the system was to be launched. In autumn 2006, a new support scheme for renewable electricity based on feed-in tariffs was announced; this scheme was planned to come into force from January 1, 2008, but has been postponed. The feed-in tariffs are differentiated between technologies:

- Bio fuelled CHP: 10 øre/kWh
- Wind power: 8 øre/kWh
- Small-scale hydro: 4 øre/kWh

In the mean time, Enova has announced an auctioning procurement process in order to fulfil the 2010 wind power target (see below). The first auction closes in September this year, and a new one will be announced next year. Only projects with a valid concession can bid into the auction. On the other hand, there is no upper limit to the subsidy any one project can receive.

Furthermore, (rights based) investment support is given to:

Wind: Investment subsidy granted to additional, cost-effective projects bigger than 1,5 MW. The maximum level of subsidy is currently 25% of the total investment.

Others: Solar space and water heating, and projects that combine solar heating with other energy sources except electricity can get an investment subsidy up to 25% of cost

Tax exemption:

Renewable projects are not paying CO_2 tax. All power production smaller than 99 kW capacity is exempt from the electricity tax. Hydropower projects smaller than 1 MW are exempted from the investment tax of 28%. Biofuels are exempt from both fuel tax and CO_2 tax.

Policy trends

The present goal for Norway is to achieve 12 TWh of energy conservation and energy production by *new* renewable energy within 2010. Of this, at least 4 TWh must be district heating based on new renewable energy sources, waste heat or heat pumps, and at least 3 TWh wind power.

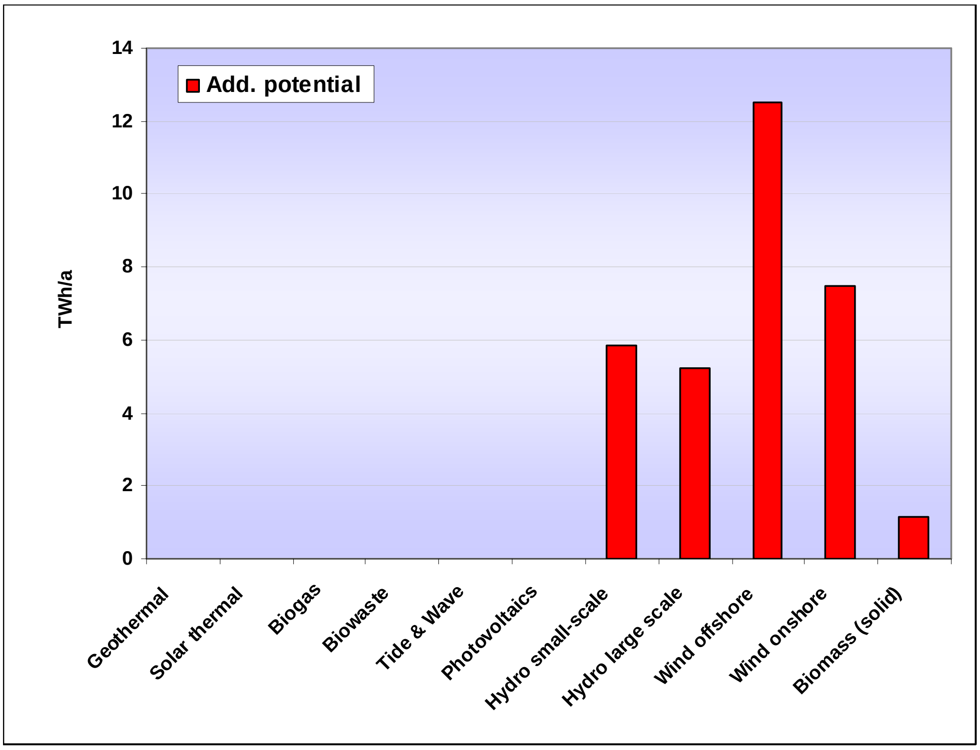
The government has chosen to support new renewable sources of energy as a means to increase available electricity generating capacity in Norway in a way that is environmentally advantageous and fits well with the existing energy system. The overall target for renewable electricity production in Norway is 90% in 2010.

One other target is to reduce the use of mineral oils for heating by 25% in the first commitment period under the Kyoto Protocol (2008–2012) compared to the average use during the period 1996–2000. To achieve this, measures such as grant support and taxation changes to encourage greater exploitation of biomass and methane from the agricultural sector for energy purposes have been introduced. Support is also given for making greater use of waste as a source of energy to replace fossil fuels than is currently the case in Norway, thereby reducing the quantity of biodegradable waste that is land-filled and leading to methane emissions in the future.

Norway is positive about developing micro- and mini-hydropower plants because they usually have a smaller environmental impact and are used as a local energy resource. By simplifying licensing agreements small hydropower could be a relatively easy and environment-friendly way of adding capacity to the Norwegian electricity system

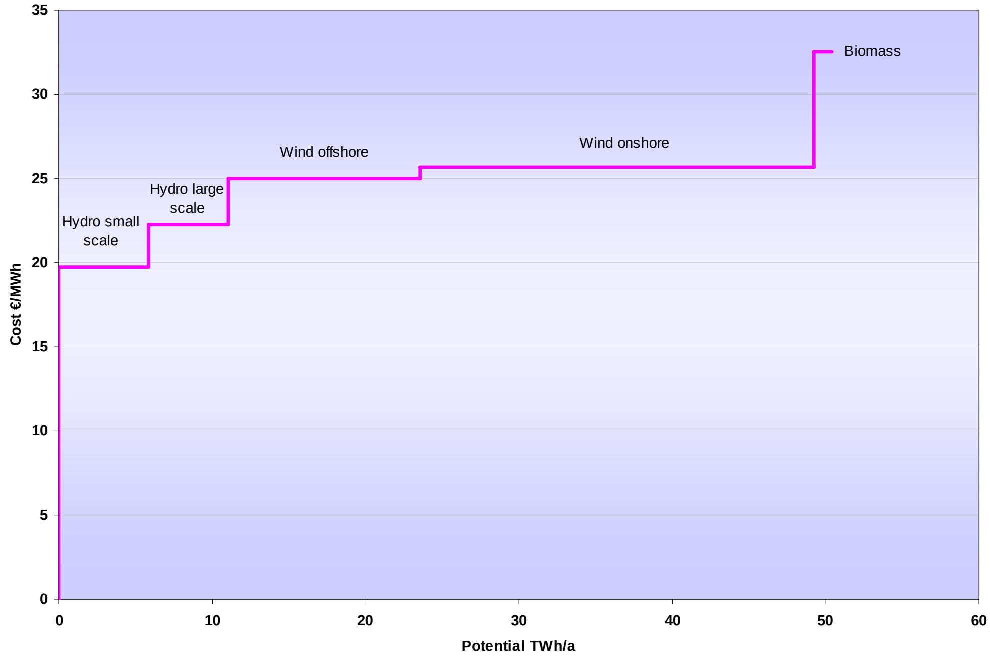
Costs and potentials

Future potential of renewable power production in Norway



Source: www.green-x.at

Marginal cost of future renewable production in Norway



Source: www.green-x.at

Sweden

Electricity generation mix

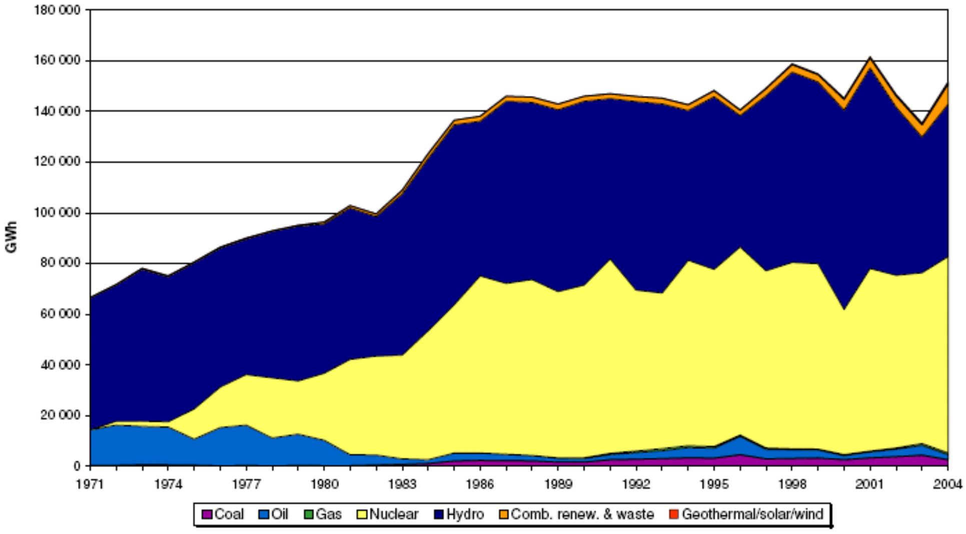
In Sweden 40–50% of the total electricity production comes from hydropower (around 67 TWh in normal years), around 50% from nuclear power and only 7% from other sources (of which half is biomass).

Despite rising industrial output, the use of oil has fallen from more than 70% of the total energy supply in 1970 to around 30% today. This is mainly due to diversification of fuels and more efficient use of energy. See figure below.

The share of renewable energy sources in the Swedish energy system has increased rapidly during the past decade, from 22% of the total energy supply in 1994 to 28% today. Biomass accounts for the greater part of the increase. Wind energy has increased from negligible in 1994 to almost 1 TWh today.

Sweden has an extensive district heating sector. District heating accounts for about 40% of the heating market in Sweden. The change in the fuel mix has been dramatic. Compared to 1970, when oil was the main fuel, oil accounts for only a few percent today. More than 62% of district heating fuel today is biomass. The proportion of bio energy used in the Swedish energy system has steadily increased from a little over 10% of the total energy supply in the 1980's to about 16% or 100 TWh in 2004. Most of the increase has been is attributable to industry and district heating plants. The bio fuels used in the Swedish energy system consist mainly of wood fuels, black liquors and tall oil pitches, and ethanol.

Sweden's electricity generation by fuel from 1971 to 2004



Source: IEA, 2006

Policy measures

Prior to 1991 there was no support for renewables in Sweden. In 1991, several support schemes for renewable energy were introduced, including wind power, bio-fuelled power and solar heat. The support schemes were mainly designed as investment subsidies, e.g., 4,000 SEK/kW for bio fuelled power and 15% of total investment costs for wind power. In July 1994 an environmental bonus was added to the wind power subsidy. The bonus was designed as a production subsidy (per kWh) and it equalled the electricity consumption tax.

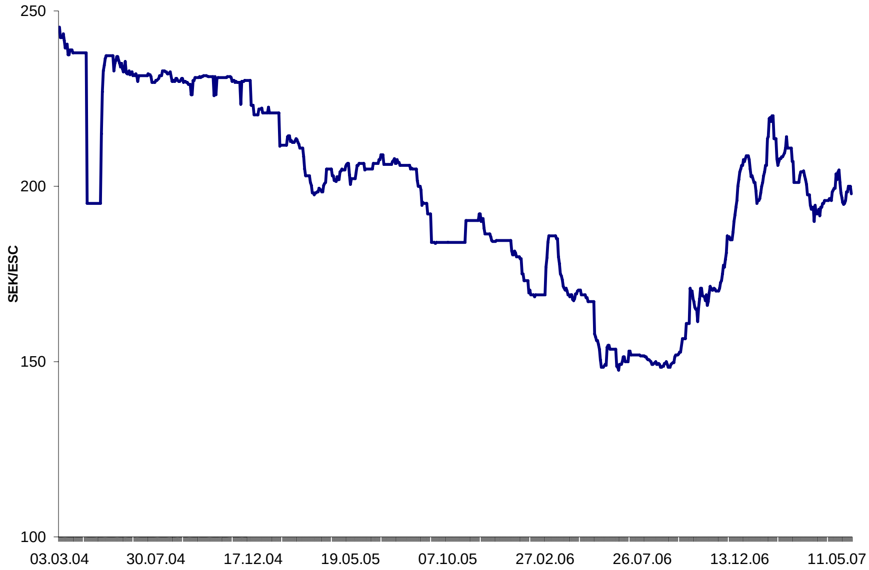
In May 2003 a green certificate system was introduced. This scheme includes all renewable electricity generation (new as well as existing). Demand for electricity certificates has become mandatory through a quota obligation, i.e. a certain share of the electricity consumption (excluding industry) has to be supplied from "certified" renewable energy generation. The quota obligation will be gradually increased to achieve the Swedish target of additional 10 TWh electricity from renewable energy sources in 2010 compared to the level in 2002, and 17 TWh in 2016. The supply demand based settlement mechanism, guarantees a price up to 2007: for each type of technology: 1,45 € cent/kWh

Wind power

The environmental bonus for wind power was not removed, but will be gradually phased out. Basically, it is a tax reduction, which will be decreased each year until 2009 when it should be completely phased out. On-shore wind power is not entitled to the environmental bonus after 2008, but off-shore wind power will receive the bonus until 2009.

In 2003 the Swedish Energy Agency introduced a program for support to technology development in connection with market introduction of large scale off-shore wind power and for installations in the arctic region. The aim with the programme is to stimulate the market, achieve cost reductions and develop knowledge about environmental effects. During the period from 2003 to 2007 the budget is 38 million Euro. The Parliament has recently also agreed to extend the programme with another 5 years until 2012 and has approved another 38 million Euro to the programme.

Price development of green certificates in Sweden



Source: Nord Pool.no

The electricity certificate scheme has led to a significant increase in support for electricity based on bio-fuels.

Policy outlook

The objective of the Swedish Government's energy policy is to secure a reliable supply of electricity and other forms of energy at internationally competitive prices, both for the short and the long terms. Sweden has decided that an energy policy should create conditions for efficient and sustainable energy use, as well as a cost-effective Swedish energy supply with minimum negative impact on health, the environment and the climate. It should also facilitate the transition to an ecologically sustainable society. To achieve this, global cooperation is required.

It is uncertain if Sweden's future electricity mix will be based on nuclear power or not. Recent political signs indicate the opinion of an extension of nuclear capacities. On the other hand, in reality, technical problems accumulated and supported again the rather negative image of nuclear technologies. However, regarding Sweden's ambitious CO2 reduction targets, nuclear could be solution for fossil free electricity generation in future. Nevertheless, Sweden has defined quantified targets for renewables:

- An additional 10 TWh electricity from renewable energy sources in 2010 compared to the level in 2002, and 17 TWh in 2016
- Wind power: A national target: wind power production of 10 TWh/a by 2015
- Bio energy: Future investments in bio energy are planned.

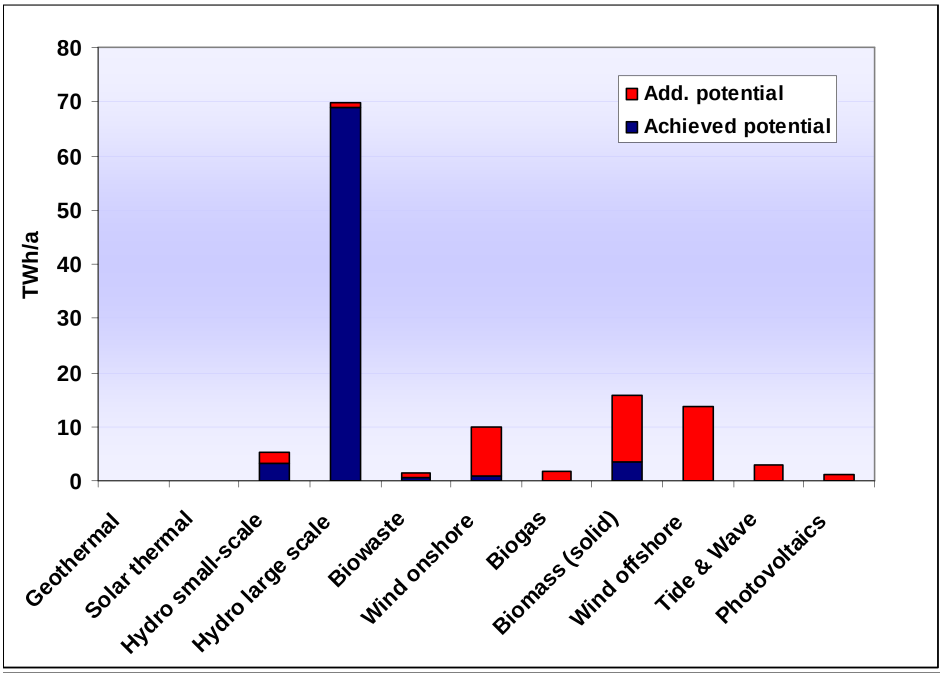
Even though, wind energy today accounts for less than one percent of the electricity production, the potential for wind energy is substantially larger. The expansion rate for wind energy has increased rapidly during the past few years. A national target has been set for creating the conditions for annual wind power production of 10 TWh by 2015.

The Swedish Green electricity trading scheme will very likely be continued in future. RES potentials and costs levels indicate that small hydro power, bio waste and wind onshore potentials will be utilised first. In addition solid biomass and wind offshore potentials are of promising size although cost levels are higher. (Compare with figures on next page)

A definite focus area of Swedish Energy policy will be the decentralized system, especially in the heating sector. Here biomass could increase its share to 100%.

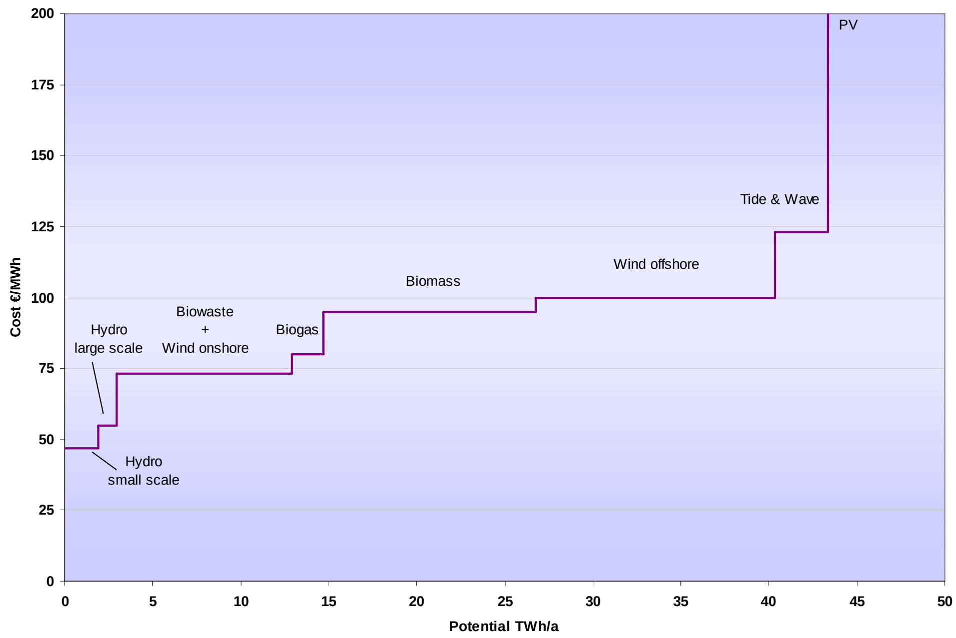
Costs and potentials

Future potential of renewable power production in Sweden



Source: www.green-x.at

Marginal costs of future renewable power production in Sweden



Source: www.green-x.at

Appendix 2: The STREAM modelling tool

The Sustainable Technology Research and Energy Analysis Model is used – in short called STREAM - was originally developed for the project the "Future Danish Energy System" carried out 2004-2007 by the Danish Board of Technology in conjunction with some of the most important Danish stakeholders in the energy sector.

The model is able to provide a quick insight of the different potential energy mixes not only for whole Europe, but also for defined regions or countries. The model allows planners, politicians, students and others to be able to create scenarios on demand. Moreover, the databases used can be periodically updated (through Eurostat for example) making this tool and the results more realistic and adaptable. Also different potential policies or projections can be incorporated providing an overview of the proposed scenario. Currently the latest version of the model is available upon request.

The STREAM model consists of three Excel spreadsheet models:

- The energy savings model
- The duration curve model
- The energy flow model.

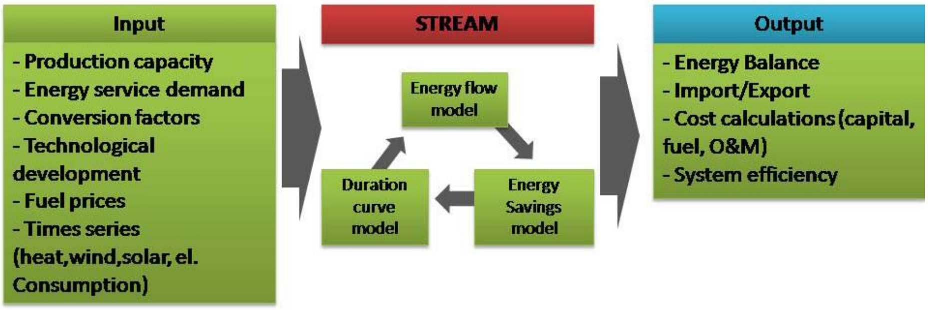
This modelling tool is rather unique due to three key elements:

- The model is developed with the purpose to enhance the complete energy flow from fuel exploration, conversion and energy use across all sectors in the society, including the transport sector. Many other models only focus on certain parts of the energy system for example the dispatching of power plants in the electricity sector and the district heating system
- The model is developed in cooperation among a university, an energy company, a transmission system operator and consultants. This gives the model a high degree of credibility and keeps focus on problem solving and results in the dialogue with other interests
- It is a relatively simple model making it possible to conduct new analyses relatively quickly – for example during a meeting. This enhances the knowledge basis for intelligent decisions.

The models are based on a bottom-up approach. This means that the user defines the input to the models. For instance, X percent wind power in the electricity sector or X percent bio ethanol in the transport sector and on this basis an output is calculated. The model does not perform an economic optimization specifying exactly which set of measures are the most advantageous to combine under the given conditions.

The *energy savings model* forms the basis for the energy products and service demand. The demand for heat and power are used in the *duration curve model*, and calculates the potential for combined heat and power taken into account the flexible demand, generation from fluctuating electricity technologies (wind, solar PV etc,) and the potential for heat pumps. The *energy flow model* combines the input and output from the two other models in the total energy system providing an overview of total energy consumption, emissions and costs of the analysed energy system.

Data on European energy systems such as available resources and projected demand for energy services are supplied from a *data aggregation module*. Input data is specified for each country in the EU but can be aggregated into regions for the purpose of modelling.



The STREAM model

Appendix 3: Energy saving potentials in different sectors

Tertiary sector:

Energy savings I Tertiary sector - natural development and additional saving potentials			
	Ref.	Step 1	Step 2
Lighting	35%	15%	30%
Cooling	15%	20%	40%
Electrical motors	12%	12%	23%
Electronics	30%	13%	25%
Pumping	35%	13%	25%
Air conditioning/ventilation	32%	24%	48%
Other use	20%	3%	5%
Electricity demand excl. heat	**28%**	**14%**	**28%**
Space heating	15%	13%	25%

Industry Sector:

Energy savings i Industry sector - natural development and additional saving potentials			
	Ref.	Step 1	Step 2
Steel	16%	17%	34%
Chemical/petrochemical	20%	18%	35%
Pulp and paper	15%	18%	35%
Sum Energy Intensive Industries	**16%**	**17%**	**35%**
Non-metallic minerals	15%	18%	35%
Food and Tobacco	15%	23%	45%
Construction	12%	19%	38%
Mining	12%	19%	38%
Machinery	10%	20%	40%

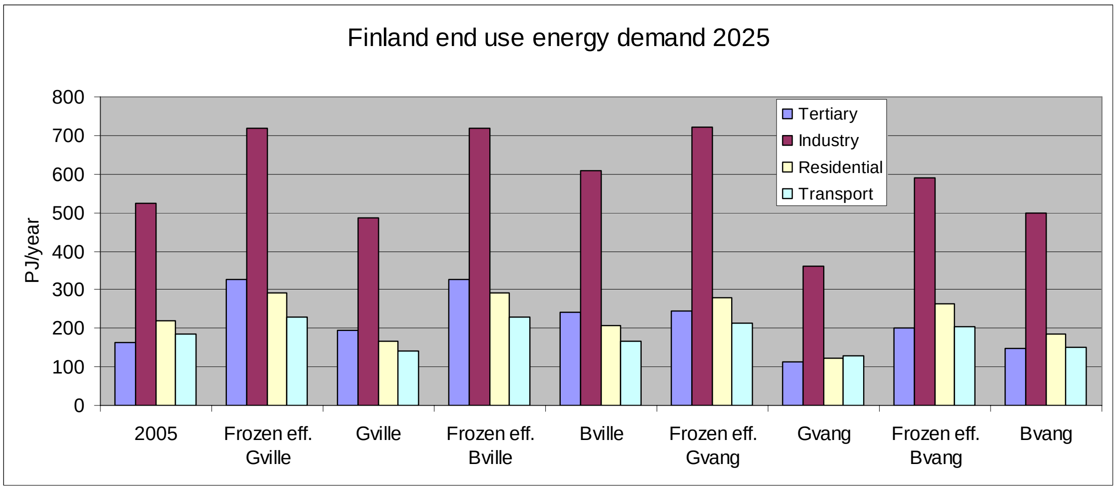
Ferrous metal	10%	20%	40%
Transport equipment	10%	20%	40%
Textiles and leather	15%	18%	35%
Wood industry	10%	13%	25%
Sum Other Industries	**13%**	**19%**	**38%**

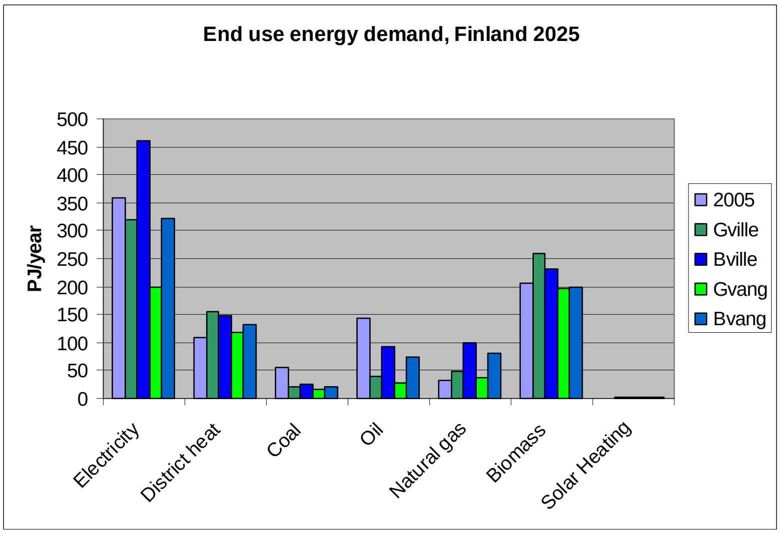
Residential sector:

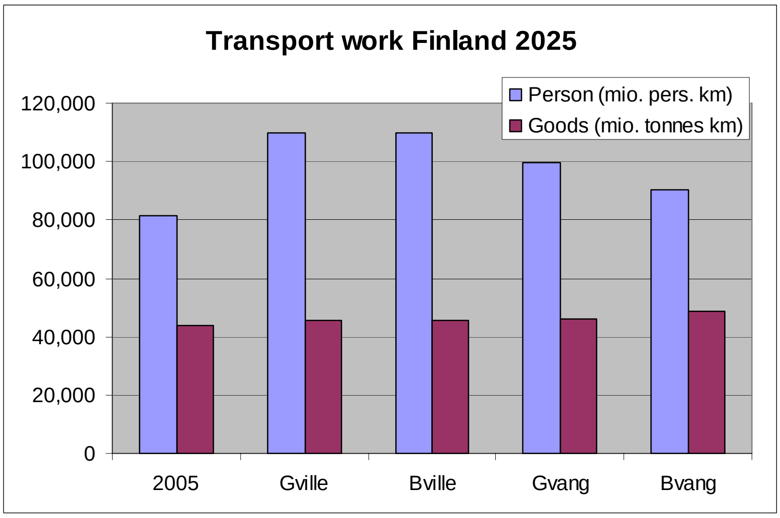
Residential sector			
	Ref.	Step 1	Step 2
Lighting	35%	20%	35%
Refrigerators/freezers	15%	8%	15%
Washing/cooking	33%	16%	33%
Standby	35%	15%	35%
Dryers	35%	18%	35%
Air-cond	30%	10%	30%
Other use	25%	13%	25%
Electricity demand excl. heat	**28%**	**14%**	**28%**
Space heating	25%	13%	25%

Appendix 4: Demand: Detailed country results

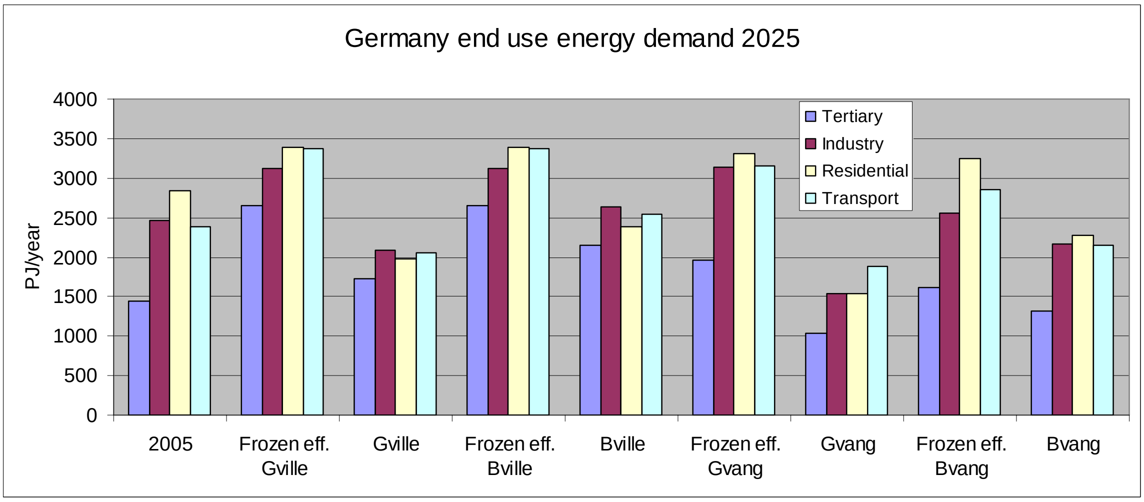
Finland

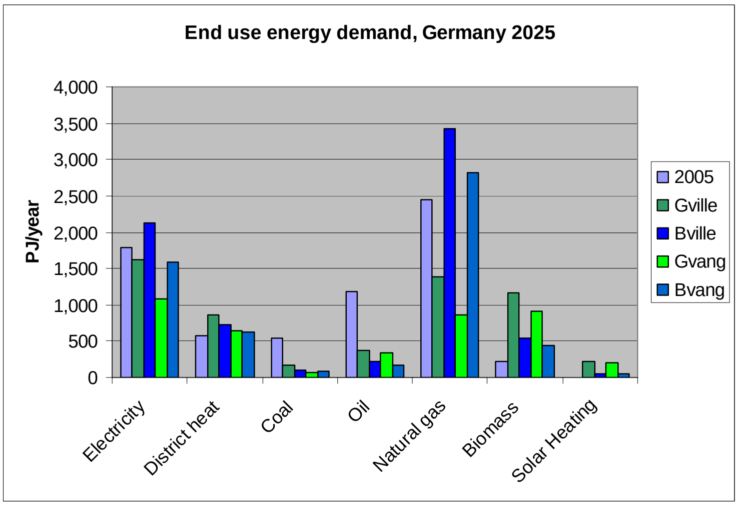


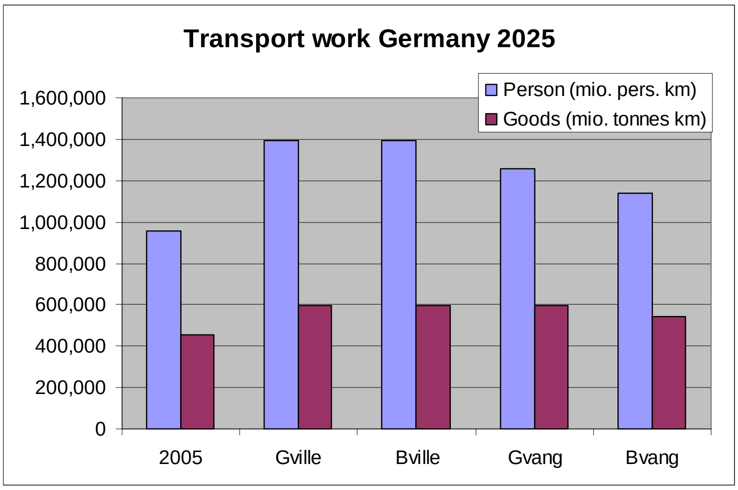



Transport work Finland 2025
Person (mio. pers. km)
Goods (mio. tonnes km)
120,000
100,000
80,000
60,000
40,000
20,000
0
2005
Gville
Bville
Gvang
Bvang

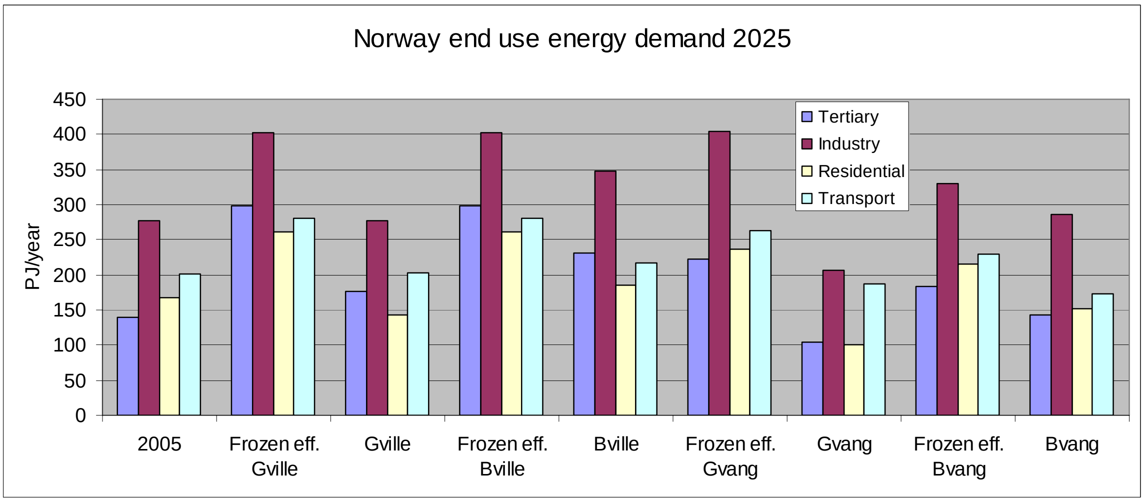
Germany

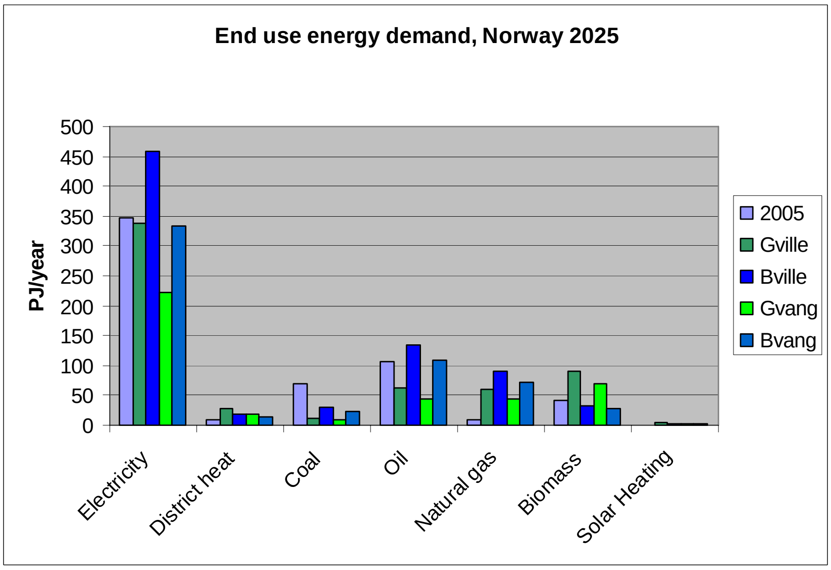

Germany end use energy demand 2025
PJ/year
4000
3500
3000
2500
2000
1500
1000
500
0
Tertiary
Industry
Residential
Transport
2005
Frozen eff. Gville
Gville
Frozen eff. Bville
Bville
Frozen eff. Gvang
Gvang
Frozen eff. Bvang
Bvang

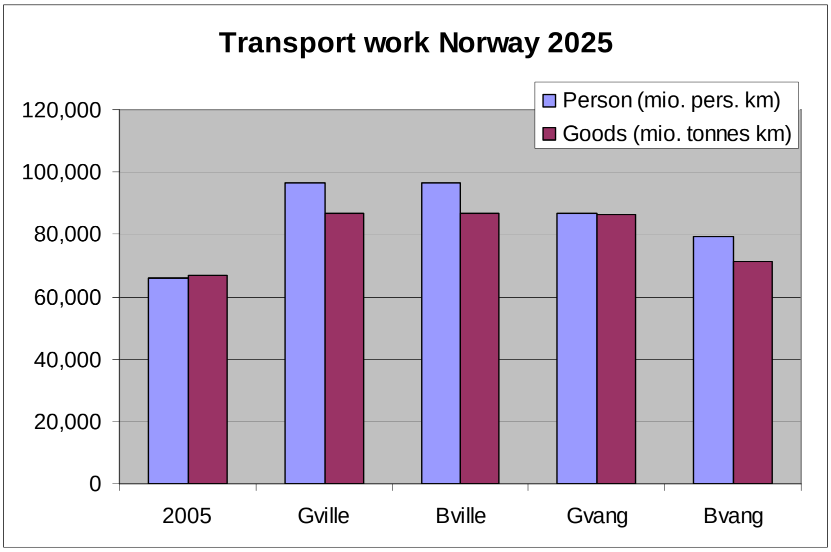

End use energy demand, Germany 2025
PJ/year
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
2005
Gville
Bville
Gvang
Bvang
Electricity
District heat
Coal
Oil
Natural gas
Biomass
Solar Heating


Transport work Germany 2025
Person (mio. pers. km)
Goods (mio. tonnes km)
1,600,000
1,400,000
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
2005
Gville
Bville
Gvang
Bvang

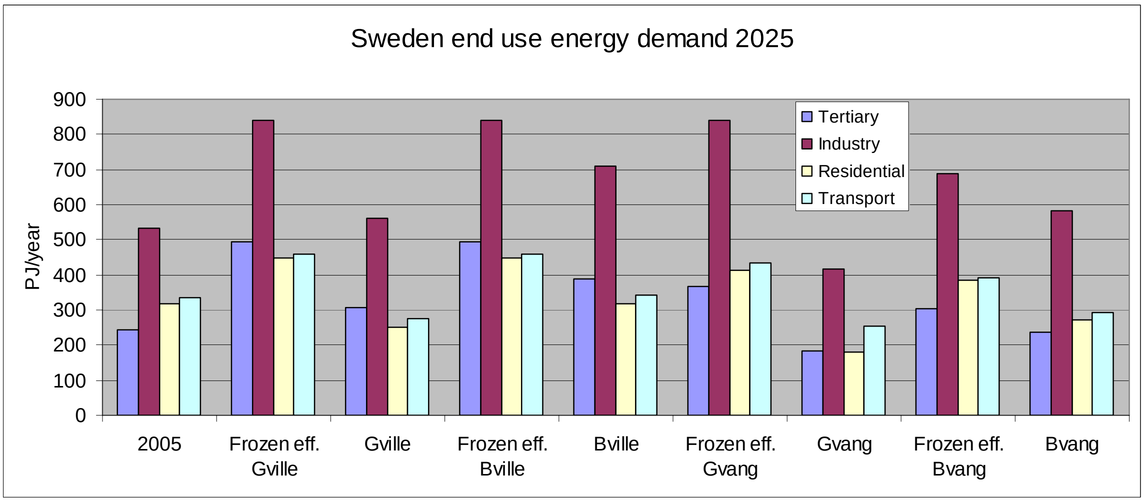
Norway

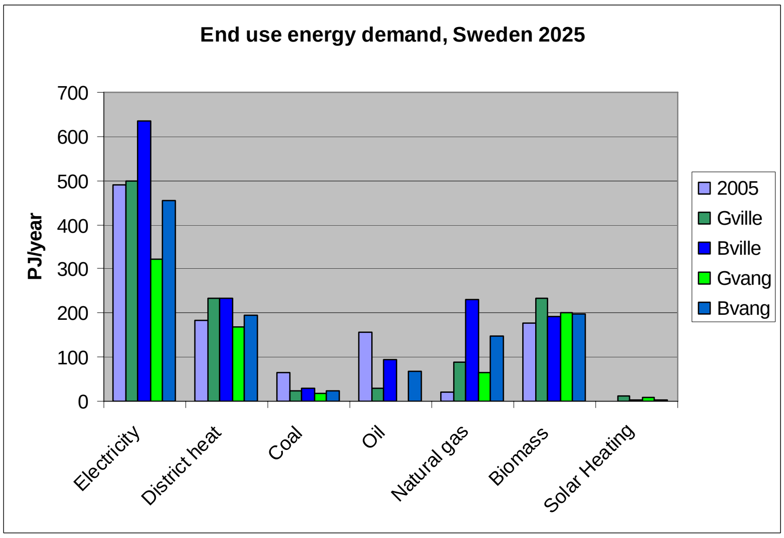

Norway end use energy demand 2025
PJ/year
450
400
350
300
250
200
150
100
50
0
Tertiary
Industry
Residential
Transport
2005
Frozen eff. Gville
Gville
Frozen eff. Bville
Bville
Frozen eff. Gvang
Gvang
Frozen eff. Bvang
Bvang

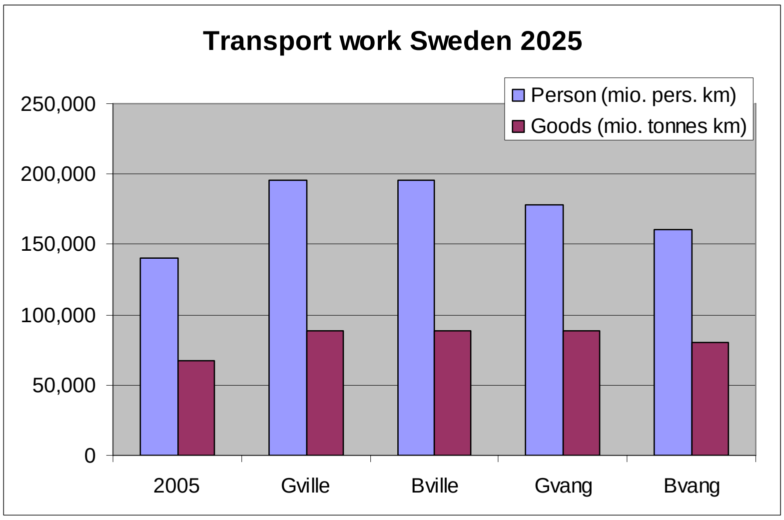

End use energy demand, Norway 2025
PJ/year
500
450
400
350
300
250
200
150
100
50
0
2005
Gville
Bville
Gvang
Bvang
Electricity
District heat
Coal
Oil
Natural gas
Biomass
Solar Heating


Transport work Norway 2025
120,000
100,000
80,000
60,000
40,000
20,000
0
Person (mio. pers. km)
Goods (mio. tonnes km)
2005
Gville
Bville
Gvang
Bvang

Sweden


Sweden end use energy demand 2025
PJ/year
900
800
700
600
500
400
300
200
100
0
Tertiary
Industry
Residential
Transport
2005
Frozen eff. Gville
Gville
Frozen eff. Bville
Bville
Frozen eff. Gvang
Gvang
Frozen eff. Bvang
Bvang


End use energy demand, Sweden 2025
PJ/year
700
600
500
400
300
200
100
0
2005
Gville
Bville
Gvang
Bvang
Electricity
District heat
Coal
Oil
Natural gas
Biomass
Solar Heating

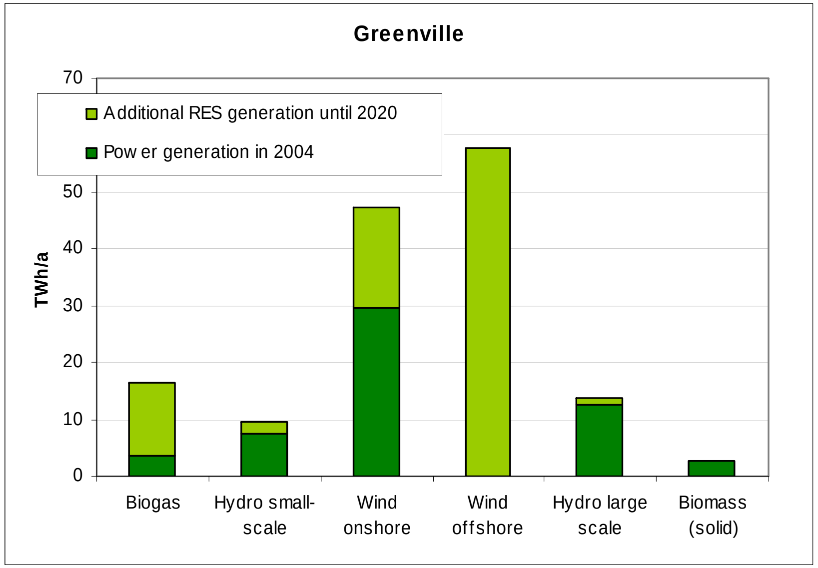

Transport work Sweden 2025
250,000
200,000
150,000
100,000
50,000
0
Person (mio. pers. km)
Goods (mio. tonnes km)
2005
Gville
Bville
Gvang
Bvang

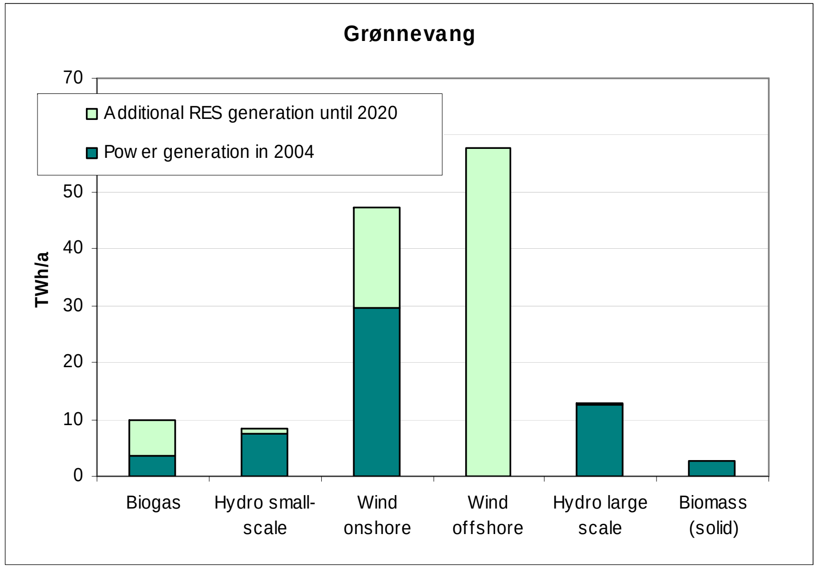
Appendix 5: Supply: Detailed scenario results

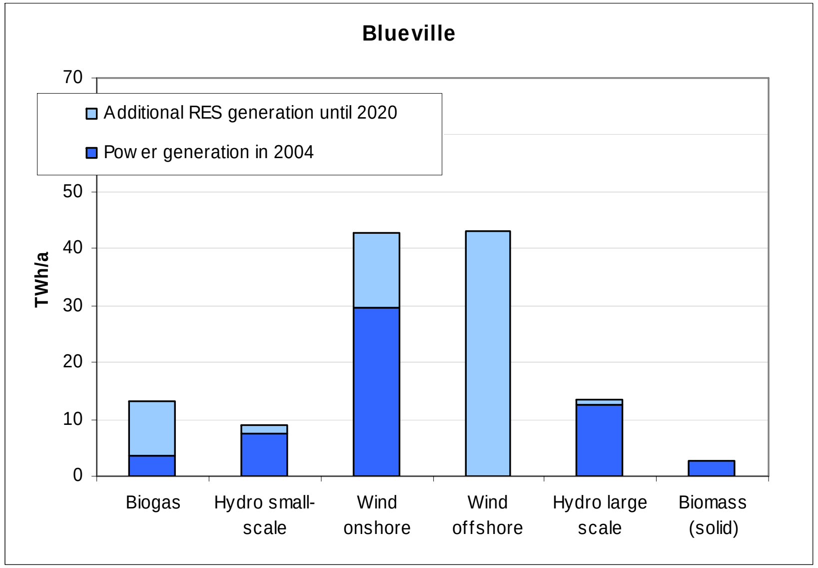
Detailed RES-E capacity by country and scenario

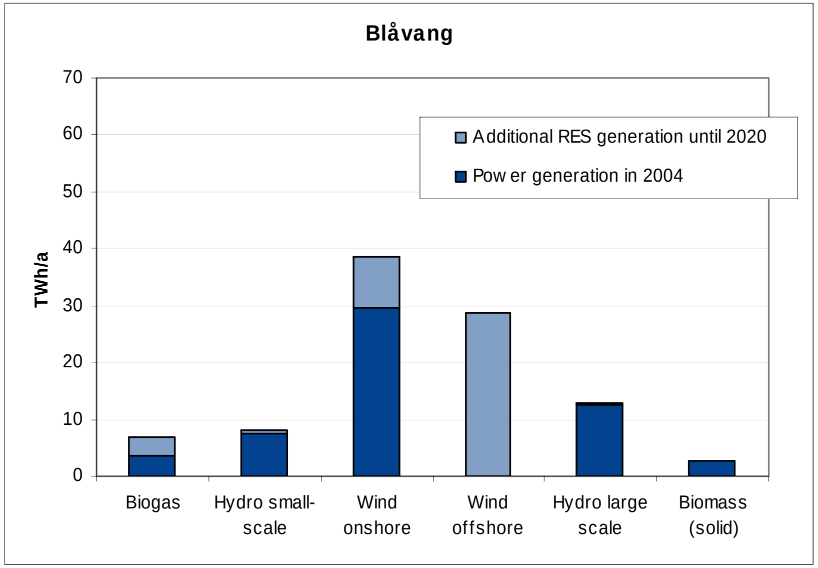
The exact power generations for renewable power production in the different countries and scenarios can be seen below. It has been distinguished between different energy sources and technologies: wind power, on- and offshore, hydro power, large scale and small scale, solid biomass and biogas.

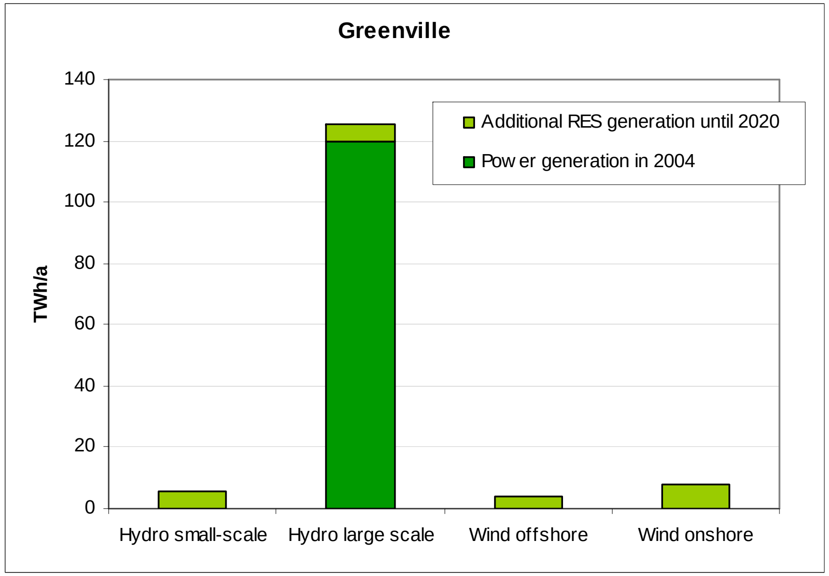
Germany

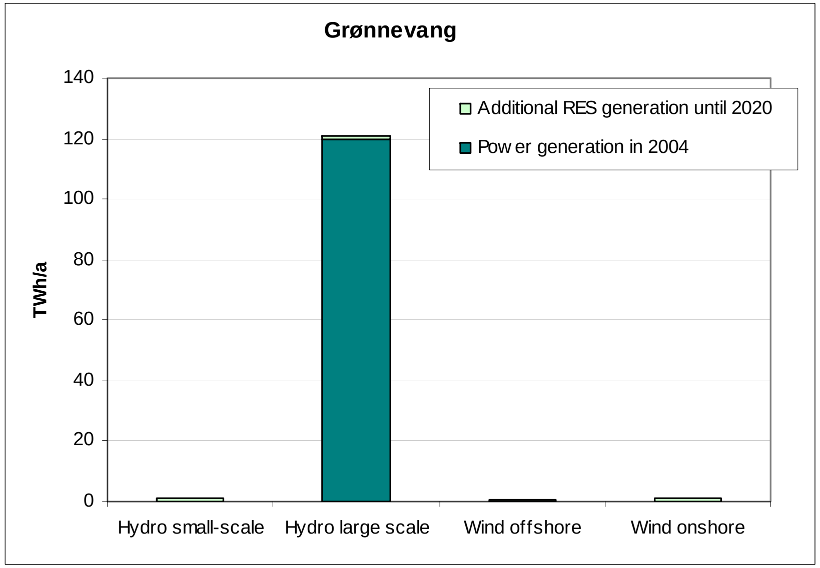

Greenville
Additional RES generation until 2020
Pow er generation in 2004
TWh/a
70
50
40
30
20
10
0
Biogas
Hydro small-scale
Wind onshore
Wind offshore
Hydro large scale
Biomass (solid)


Grønnevang
Additional RES generation until 2020
Pow er generation in 2004
TWh/a
70
50
40
30
20
10
0
Biogas
Hydro small-scale
Wind onshore
Wind offshore
Hydro large scale
Biomass (solid)

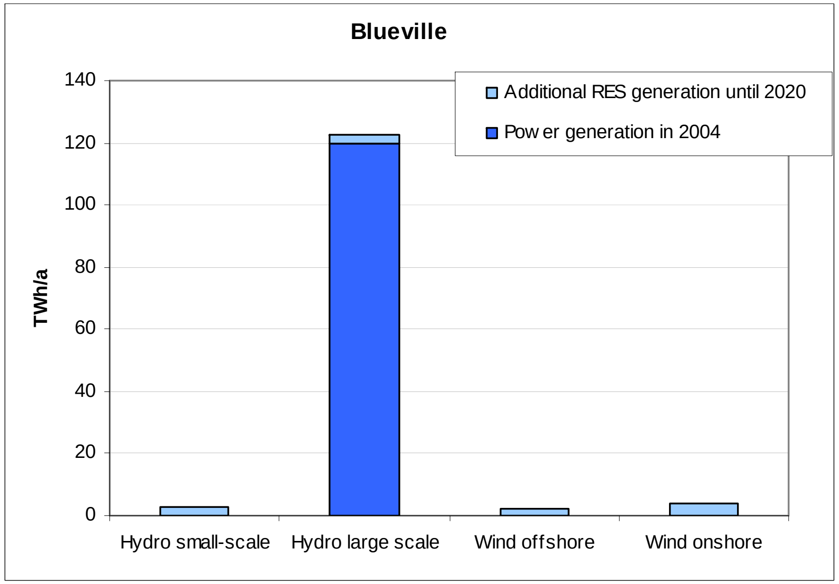

Blueville
Additional RES generation until 2020
Pow er generation in 2004
TWh/a
70
50
40
30
20
10
0
Biogas
Hydro small-scale
Wind onshore
Wind offshore
Hydro large scale
Biomass (solid)

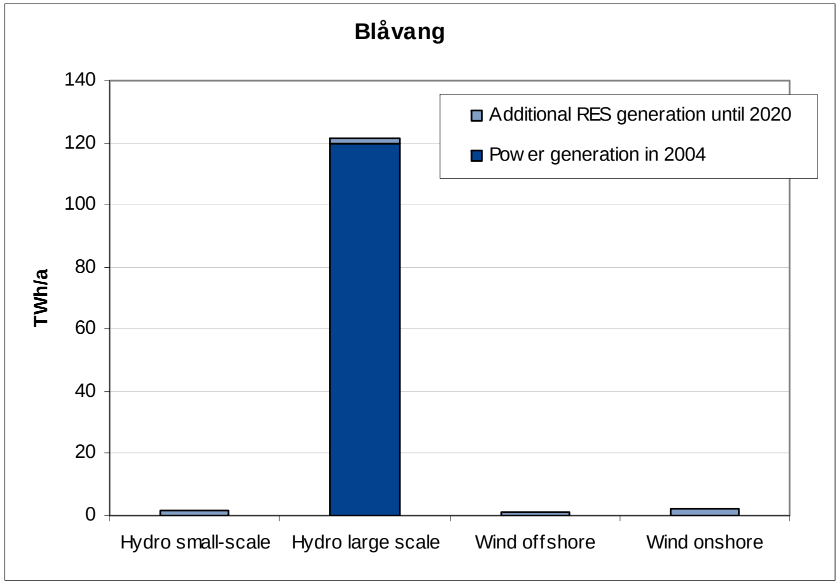

Blåvang
Additional RES generation until 2020
Pow er generation in 2004
TWh/a
70
60
50
40
30
20
10
0
Biogas
Hydro small-scale
Wind onshore
Wind offshore
Hydro large scale
Biomass (solid)

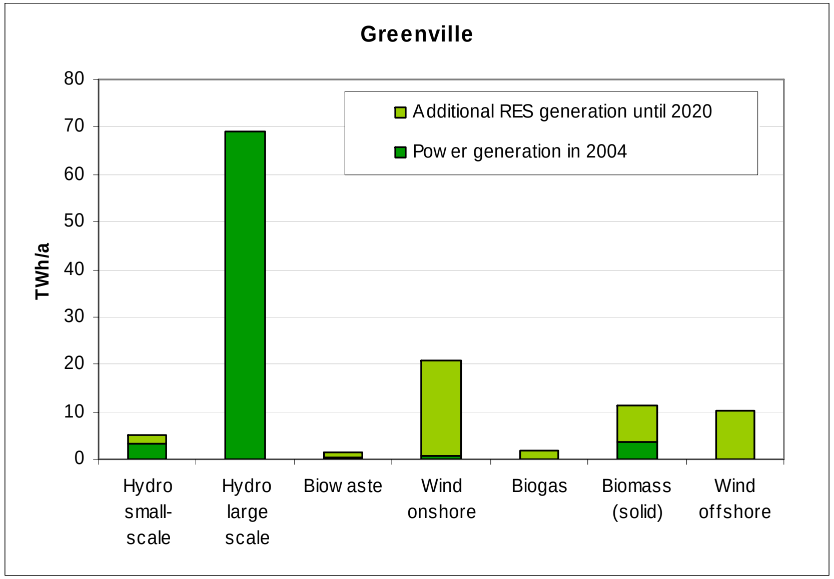

Greenville
140
120
100
80
60
40
20
0
TWh/a
Additional RES generation until 2020
Pow er generation in 2004
Hydro small-scale
Hydro large scale
Wind offshore
Wind onshore

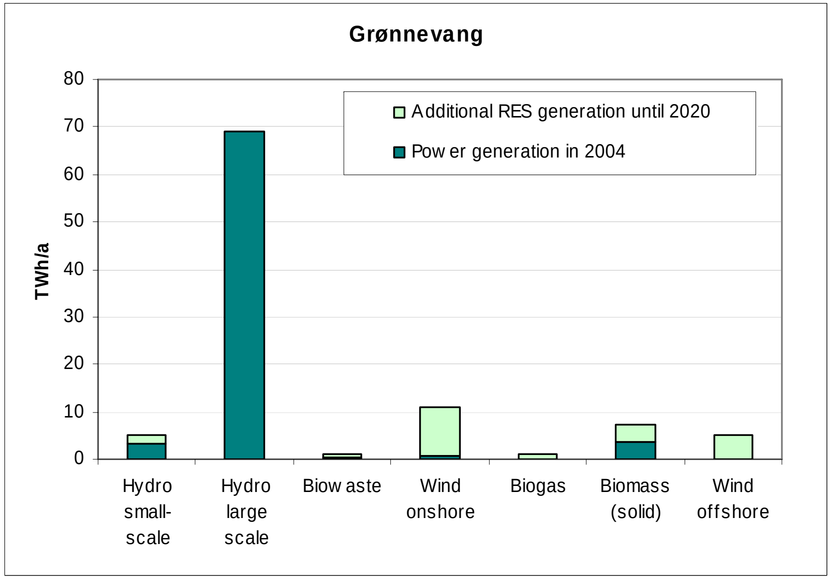

Grønnevang
140
120
100
80
60
40
20
0
TWh/a
Additional RES generation until 2020
Pow er generation in 2004
Hydro small-scale
Hydro large scale
Wind offshore
Wind onshore

Norway

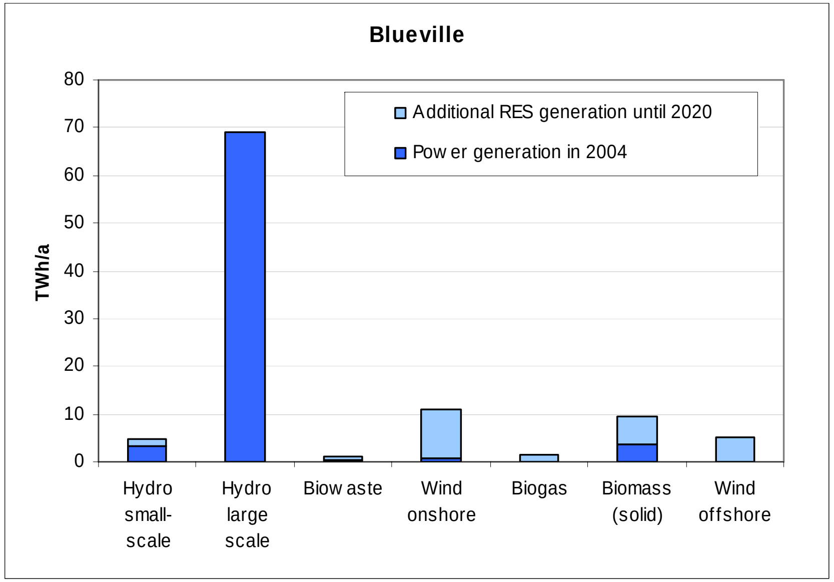

Blueville
140
120
100
80
60
40
20
0
TWh/a
Additional RES generation until 2020
Pow er generation in 2004
Hydro small-scale
Hydro large scale
Wind offshore
Wind onshore

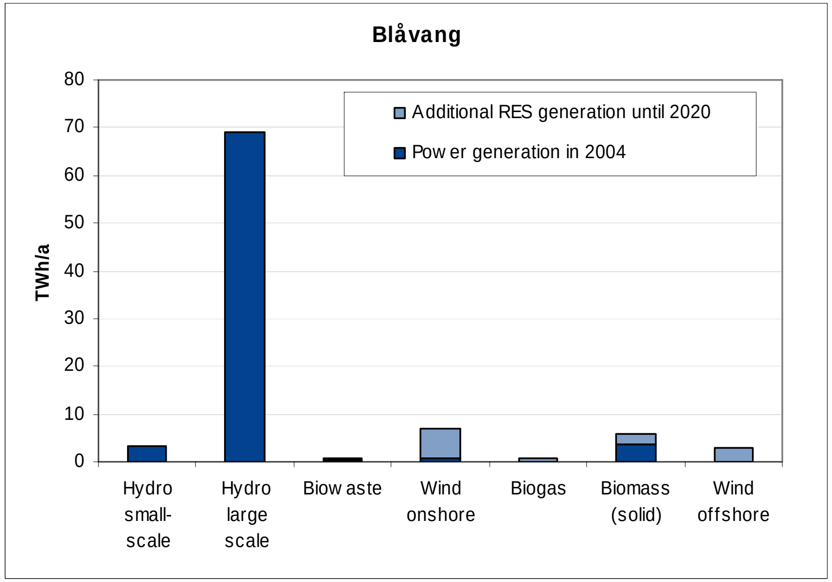

Blåvang
140
120
100
80
60
40
20
0
TWh/a
Additional RES generation until 2020
Pow er generation in 2004
Hydro small-scale
Hydro large scale
Wind offshore
Wind onshore


Greenville
Additional RES generation until 2020
Pow er generation in 2004
TWh/a
80
70
60
50
40
30
20
10
0
Hydro small-scale
Hydro large scale
Biow aste
Wind onshore
Biogas
Biomass (solid)
Wind offshore


Grønnevang
Additional RES generation until 2020
Pow er generation in 2004
TWh/a
80
70
60
50
40
30
20
10
0
Hydro small-scale
Hydro large scale
Biow aste
Wind onshore
Biogas
Biomass (solid)
Wind offshore

Sweden


Blueville
Additional RES generation until 2020
Pow er generation in 2004
TWh/a
80
70
60
50
40
30
20
10
0
Hydro small-scale
Hydro large scale
Biow aste
Wind onshore
Biogas
Biomass (solid)
Wind offshore


Blåvang
Additional RES generation until 2020
Pow er generation in 2004
TWh/a
80
70
60
50
40
30
20
10
0
Hydro small-scale
Hydro large scale
Biow aste
Wind onshore
Biogas
Biomass (solid)
Wind offshore