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Renewable electricity in Europe

Current state, drivers, and scenarios for 2020

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Abstract

The European Union has the target to increase the share of renewable energy sources (RES) in its gross final consumption of energy to 20 % by 2020 (9.2 % in 2006). Besides electricity, primary energy consumption includes heating, cooling, and transportation. Increasing RES in transportation is more costly than in electricity generation, and hence the share of renewable energy sources in electricity generation is likely to be significantly higher than 20%. It has been estimated, that the RES share in electricity sector could be around 35 % in 2020.

A significant part of the new renewable electricity (RES-E) capacity will be wind power and photovoltaics (PV). The output from these is variable, and not dispatchable in the traditional sense. Increasing wind and PV generation presents vast challenges to the power market and electricity grid. The keys to integrate variable generation to the grid are adequately interconnected electricity markets and smarter grids with more flexible demand.

Currently, each Member State has a separate support scheme for RES-E. The instruments can be divided between investment support and operating support (price subsidies, green certificates, tender schemes, and tax reductions for the production of electricity). Feed-in tariffs are the most prevalent support mechanism.

Largest addition in the NREAPs is expected from wind power generation. Wind power could exceed hydropower generation in 2016-2017. High growth is also expected in solid biomass-based electricity generation and PV. NREAP scenarios were compared against four other sources, which had quite similar expectations.

Preface

One of the central drivers for future Smart Grids is increasing variable renewable power generation. This study describes the status and historical development of the EU renewable power sector. Different scenarios and projections for renewable electricity are compared, and the implications of the new variable power generation capacity on the electricity grids and market are studied.

This research report has been prepared as apart of the Finnish Energy and Environments Competence Cluster’s (Cleen) research program “Smart Grids and Energy Markets”. The research resulting in this study was done by VTT Technical Research Centre of Finland.

30.4.2011

Authors

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List of abbreviations

AC	Alternating Current
CSP	Concentrated Solar Power
DC	Direct Current
EU	European Union
HVDC	High Voltage Direct Current
MS	Member State
MSW	Municipal Solid Waste
NREAP	National Renewable Energy Action Plan
OECD	Organisation for Economic Co-operation and Development
PV	Photovoltaics
RES	Renewable Energy Sources
RES-E	Renewable Energy Sources – Electricity
TSO	Transmission System Operator
VarRE	Variable forms of renewable energy

1. Introduction

The European Union has the target to increase the share of renewable energy sources (RES) in its gross final consumption of energy to 20 % by 2020 (9.2 % in 2006). Besides the electricity sector, primary energy consumption covers heating, cooling, and transportation. Increasing RES in transportation is more costly than in electricity generation, and hence the share of renewable energy sources in electricity generation will be significantly higher than 20%, if the target for the year 2020 is achieved. It has been estimated, that the RES share in electricity sector would be around 35 % in 2020.

The EU has a long-term target to keep the global warming less than 2 degrees compared to pre-industrial level. This target would require the EU to cut the emissions by 80-95 % by 2050. By 2050, virtually all electricity generated should come from carbon-neutral sources. Thus, the share of RES in electricity generation will increase even more pronouncedly after 2020.

A significant part of the new RES-E capacity will be wind power and photovoltaics. The output of these electricity production forms is variable, and not dispatchable in the traditional sense. Increasing wind and photovoltaic generation presents vast challenges to the power market and electricity grid. The keys to integrate variable generation in to the grid are adequately interconnected electricity markets and smarter grids with more flexible demand.

This report focuses on renewable electricity generation in the EU. Firstly, the EU renewable energy policies and targets are shortly outlined in chapter 2. Chapter 3 describes the current state of renewable energy in the EU by technology. Newest data on each technology's installed capacity and electricity production is provided for wind, solar, hydro, and geothermal power as well as biomass-sourced electricity.

In chapter 4, the instruments to support the electricity generation from renewable sources are described for a selection of Member States. Reviewed countries are Germany, Spain, the United Kingdom and the Nordic countries.

Member States were required to publish National Renewable Energy Action Plans (NREAP) by the end of July 2010. These plans provide detailed roadmaps on how the Member States expect to reach the legally binding targets for 2020. They include sectoral targets, the technology mix expected to be used, and the trajectory each Member State will follow. They also include the measures and refoms that will be undertaken to overcome the barriers to develop renewable energy. In chapter 5, these plans are summarised for each RES-E technology and compared against other presented scenarios on solar and wind power development in the EU.

Finally, in chapter 6 the challenges in connecting variable renewable sources to the grid and keeping the grid stable with high penetration of variable generation are discussed.

2. The EU's renewable energy targets for electricity

2.1 RES-E targets for 2010

The EU's renewable energy policy started in 1997, when the European Commission published a white paper "Energy for the future: renewable sources of energy" (EC 1997) stating a target for the EU to double the European Union's renewable energy share of the gross domestic energy consumption to 12 % by 2010. The 1997 White Paper included a renewable energy strategy and action plan. Following legislation (Directive 2001/77/EC) set indicative national targets for electricity produced from renewable sources. The target for the whole European Union was set to 21 % of electricity consumption from renewable energy sources by 2010, and the Member States' targets ranged from Luxembourg's 5.7 % to Sweden's 60 %.

Member States are free to choose their preferred support mechanism in order to achieve their targets. Member States are also required to publish a renewable energy progress report every second year.

EU has regularly assessed how Member States are progressing towards the 2010 targets. The newest progress report shows that the EU is not likely to achieve the RES-E target in 2010 (EC 2011). Only Hungary and Germany had already achieved their targets in 2008 and a few Member States (Denmark, Ireland, Lithuania, Poland and Portugal) are still likely to achieve their 2010 targest for renewable electricity in electricity generation. Targets for RES-E by Member State and the situation in 2008 are presented in Figure 1.

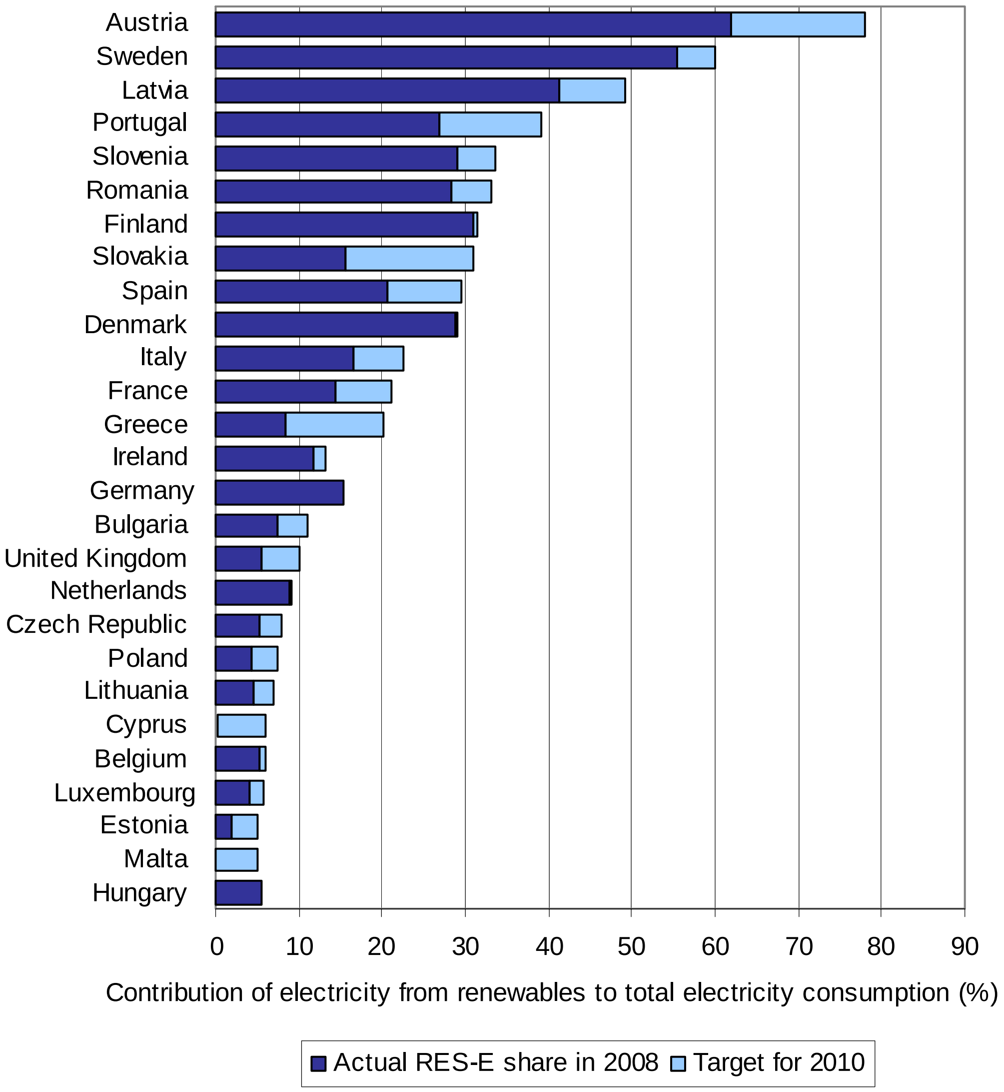

Figure 1. Actual RES-E share of electricity consumption in 2008 and the target for the year 2010.

2.2 RES targets for 2020

In 2008, the Commission proposed a new, more rigorous framework to drive forward the development of renewable energy and set new legally binding targets for 2020. The 2009 directive “on the promotion of the use of energy from renewable sources” (2009/28/EC) set mandatory renewable energy targets for each Member State and drafted a trajectory on how to reach the targets. Because each Member State has different renewable energy potential and energy mix, targets vary between Member States. EU’s overall target for renewable energy was set to be 20 % for 2020. The directive also improves the legal framework for promoting renewable electricity, requires national action plans that establish pathways for the development of renewable energy sources, creates cooperation mechanisms to help achieve the targets cost effectively and establishes the sustainability criteria for biofuels. Implementation should be done in each Member State by December 2010.

The percentual targets for RES in each Member State are shown in figure 2. The renewable energy directive did not include binding targets for electricity produced from renewable sources. However, Member States were required to publish a National Renewable Energy Action Plan (NREAP) by the end of June 2010. In these plans, the national targets for the share of energy from renewable sources consumed in transport, electricity, heating and cooling sectors for 2020 are set. NREAPs are analysed further in chapter 5.

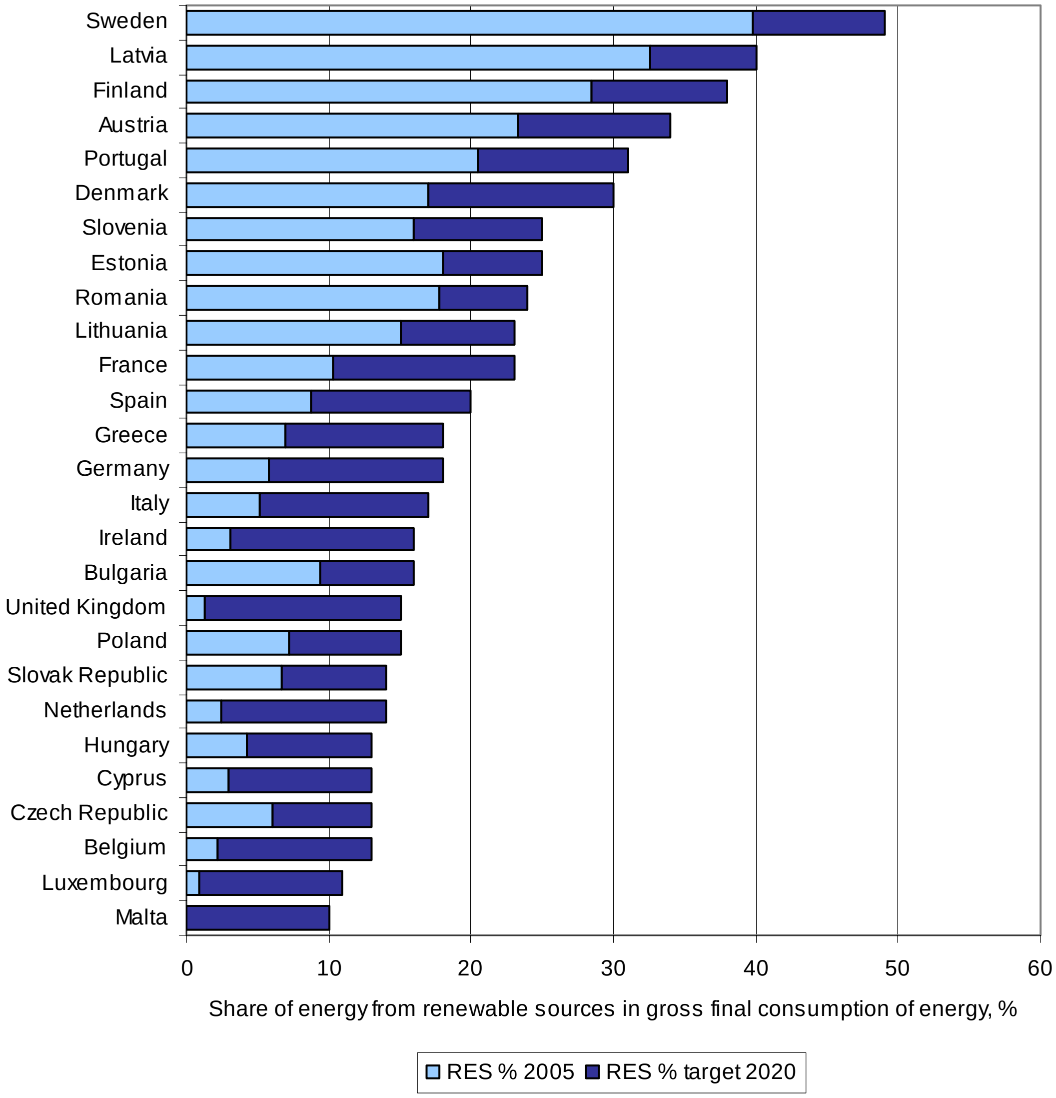

Figure 2. Share of energy from renewable sources in 2005 and targets for the year 2020.

The 20 % target for RES in 2020 covers all energy consumption including heating and cooling, transportation, and electricity generation. However, increasing RES in transportation sector is more costly than in electricity generation, and hence the share of renewables in electricity generation is expected to be around 35 % in 2020, if the 20 % target for RES is achieved.

3. Current and historical RES-E generation and capacity

In this chapter, the historical development and current state of electricity generation from renewable sources (RES-E) by technology in the European Union is described. Data is provided by Eurostat. Analysis is provided until 2008, since this is the most recent year for which data is available from the Eurostat databases.

The RES directive defines the “energy from renewable sources” as energy from non-fossil fuel sources, that is wind, solar, aerothermal, geothermal, hydrothermal and ocean energy, hydropower, biomass, landfill gas, sewage treatment gas, and biogases. This study focuses on the renewable electricity generation, and the technologies studied are

- hydropower
- wind power
- biomass-sourced electricity
- solar power (photovoltaics and concentrated solar power/solar thermal systems)
- geothermal power systems
- wave, tidal and ocean energies.

For the last category (wave, tidal and ocean energies), there is no data available on Eurostat, as these technologies are still not in commercial stage. It should be also noted, that power stations using biomass as a fuel can usually switch completely or partly to other fuels.

3.1 Summary

3.1.1 Electricity generation

The electricity generation from renewable sources in the European Union has increased from 369 TWh in 1995 to 585 TWh in 2008[1] (figure 3). Hydropower is the dominant renewable energy

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[1] Data source Eurostat, including net electricity generation – Wind turbines, Net electricity generation – Hydro power plants, Net electricity generation – Geothermal power plants, Net electricity generation – Biomass-fired power stations, Gross production from photovoltaic systems and Gross production from solar thermal systems.

source in electricity generation, accounting for about 60 % of renewable electricity in recent years. Nevertheless, the share of hydropower in renewable electricity mix has decreased significantly from about 90% in the mid 1990's as other renewable capacity has increased.

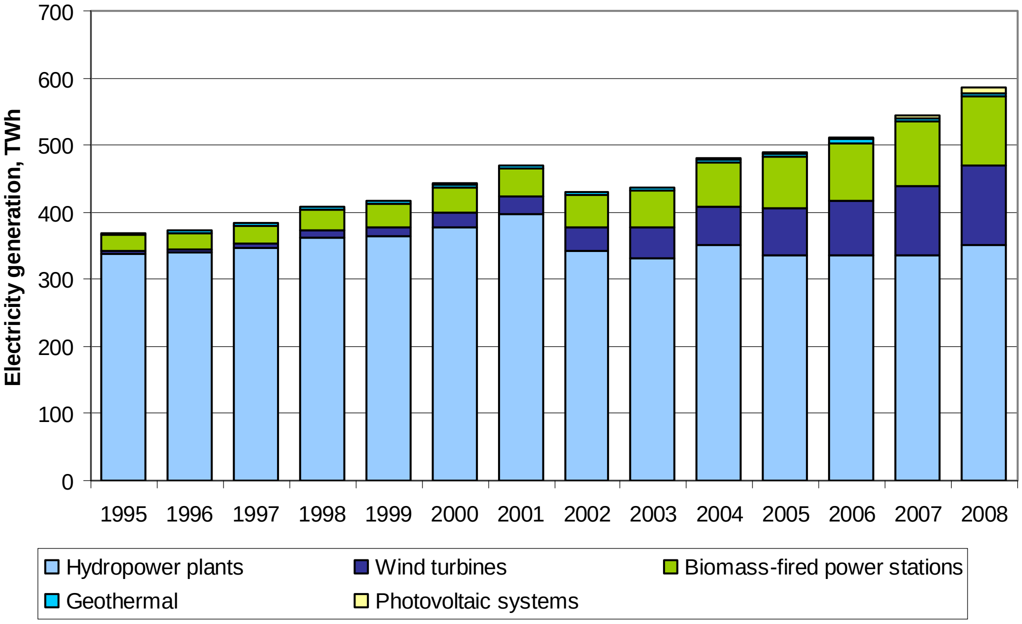

Figure 3. Electricity generation from renewable energy sources in the European Union (EU-27).

Figure 4 is an illustration of non-hydro renewables based electricity generation development in the European Union, and Figure 5 illustrates individual technologies development between 1995 and 2008. Non-hydro RES-E generation has increased from about 30 TWh in 1995 to 233 TWh in 2008. As can be seen, wind power and biomass-fired power generation dominate the non-hydro renewable power generation. In recent years, photovoltaic electricity generation has increased prolifically, but its total contribution to renewable electricity generation is still small.

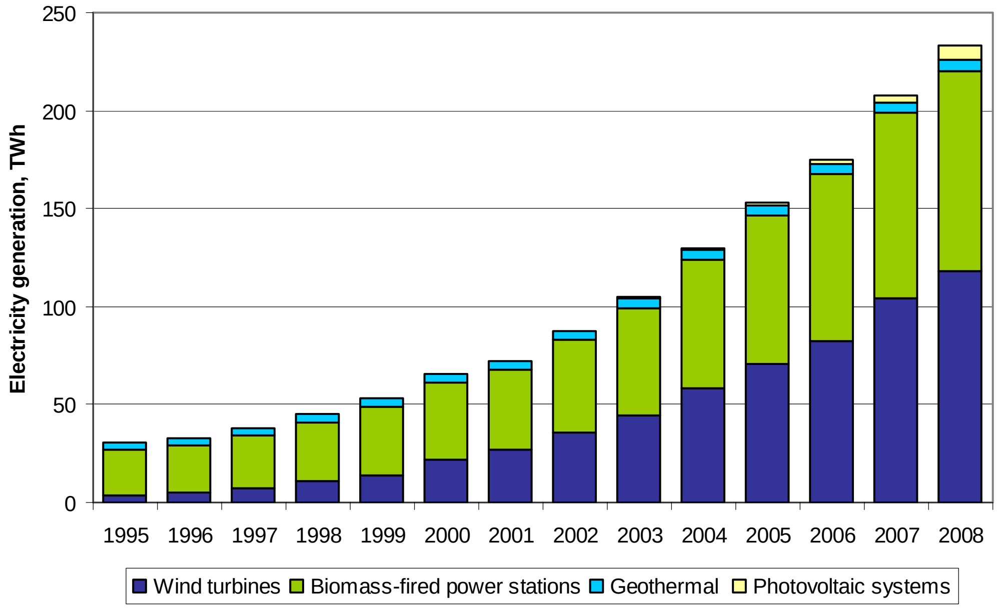

Figure 4. Electricity generation from renewable energy sources in the European Union (EU27) excluding hydropower.

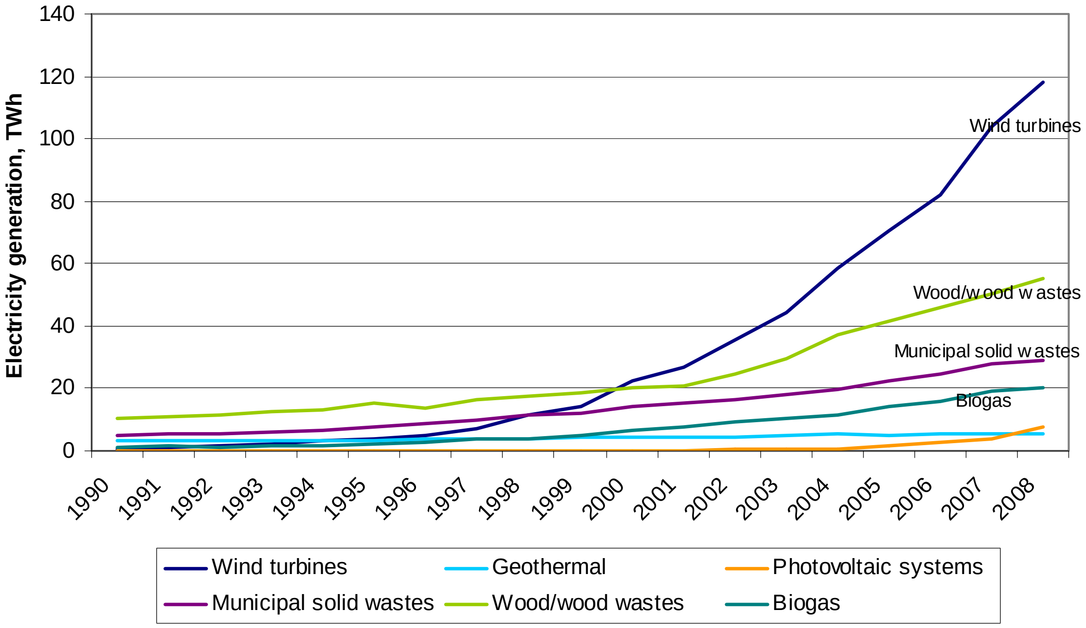

Figure 5. Electricity generation from renewable energy sources in the European Union (EU27) excluding hydropower.

3.1.2 Installed capacity

Renewable power generation capacity has doubled from around 100 000 MW in 1995 to 200 000 MW in 2008 (Figure 6). In 2008, hydropower capacity amounted to about one half of the total renewable power capacity. During the last 13 years, wind power capacity has more than 25-folded, and at present wind power dominates the non-hydro capacity mix (Figure 7). Due to a relatively small capacity factor, the share of wind power in the total renewable power capacity is more pronounced in terms of capacity than generation.

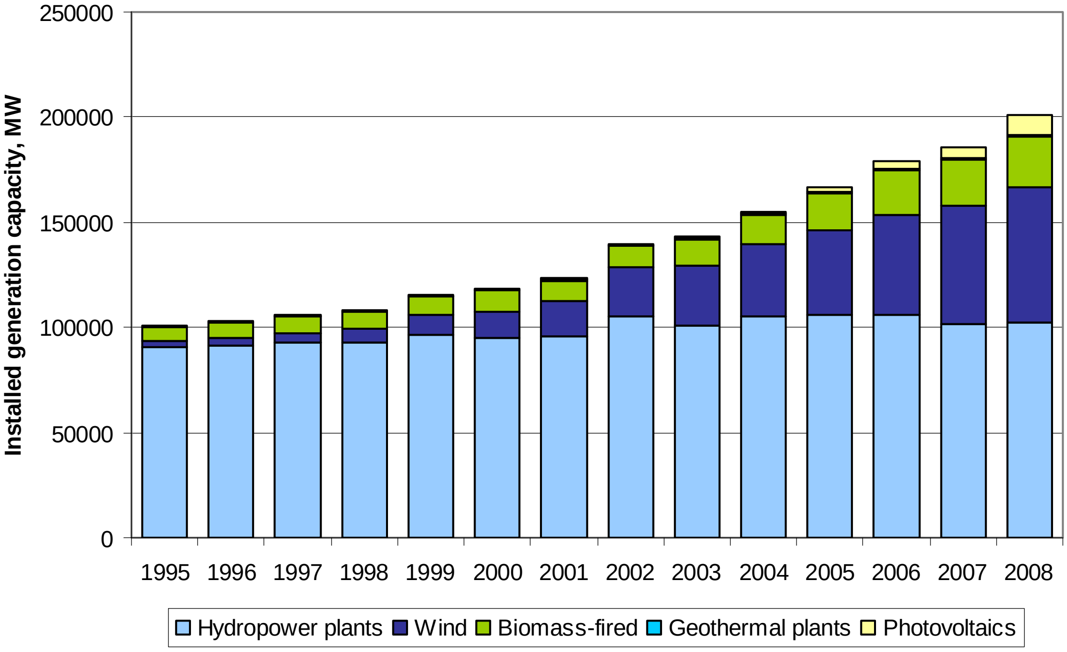

Figure 6. RES-E power generation capacity development in the European Union.

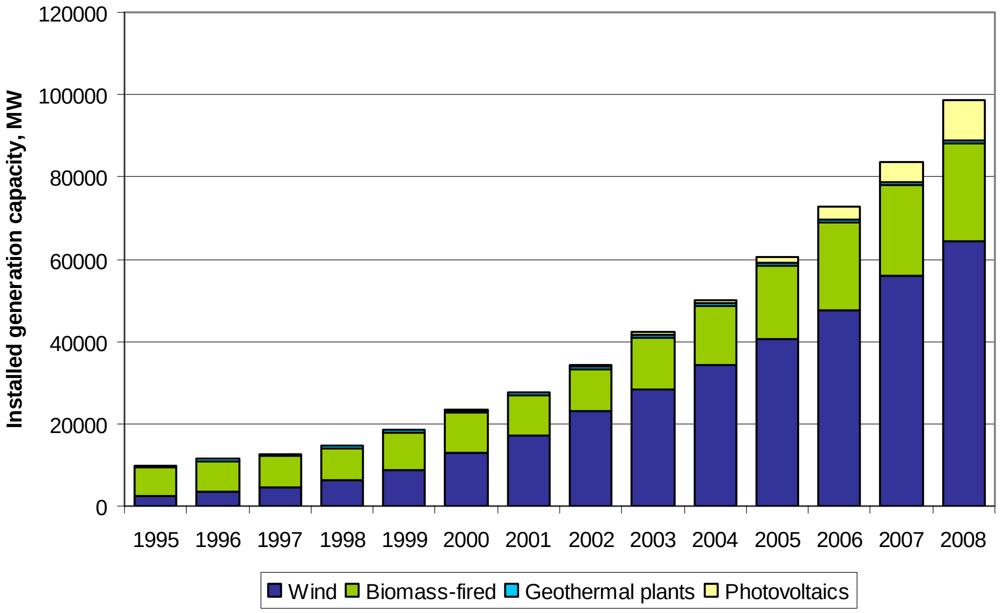

Figure 7. RES-E power generation capacity development in the European Union excluding hydropower.

3.1.3 Country profiles

In Figure 8, the renewable electricity profiles of each EU Member State are presented for the year 2008. As hydropower is the largest renewable electricity source in Europe, the countries, which have significant hydropower assets, dominate the total RES-E production as well. However, large hydropower producers Norway and Switzerland do not belong to the European Union, and thus they are not included in the graphics. Wind power production is most notable in Germany, Spain, and Denmark, while the largest countries producing electricity from biomass are Germany, Sweden, Finland, the Netherlands, Italy, and France. Only Italy has notable power generation from geothermal power plants. In Germany and Spain, photovoltaic power generation has increased in the recent years and is at present a significant source of electricity. Only Spain has solar thermal electricity generation, and the figures are still too low to show in graphics.

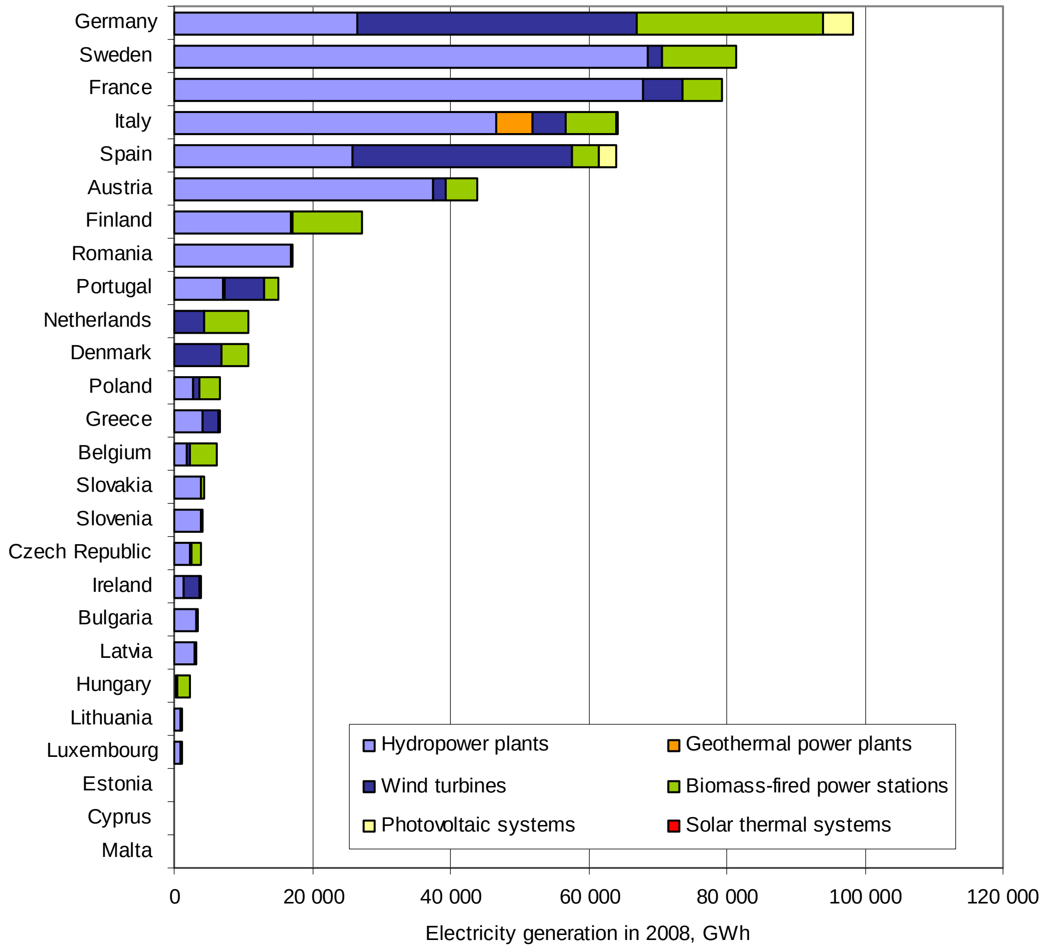

Figure 8. RES-E generation in 2008 in the European Union.

3.2 Wind power

Wind power is the single largest non-hydro renewable power generation source in the EU. Since 2000, wind power capacity has grown from 12 800 MW to 64 400 MW in 2008. Thus, wind power capacity has grown over 50 % more than estimated: in 1997 White Paper (EC 1997), wind power capacity was estimated to be 40 GW in 2010. In 2009, wind power installations accounted for 39 % of new power generating capacity installations in the EU, which makes year 2009 the second year running that more wind power was installed in the EU than any other generating technology (EWEA 2010).

In 2008, wind power generation in EU totalled 118 TWh, representing about 4 % of the total net electricity generation. Germany and Spain are the largest wind power producers, together accounting for 63 % of installed capacity. In Denmark, wind power accounted for almost 20 % of the net electricity generation, and in Spain and Portugal this figure was 10.6 and 12.8 %, respectively.

While latest Eurostat statistics cover the year 2008, European wind power statistics for the year 2010 are available from other sources. According to Eurobserver, the European Union's cumulative installed wind power capacity was 84 339 MW in the end of 2010, and wind power generation in 2010 was 147 033 GWh.

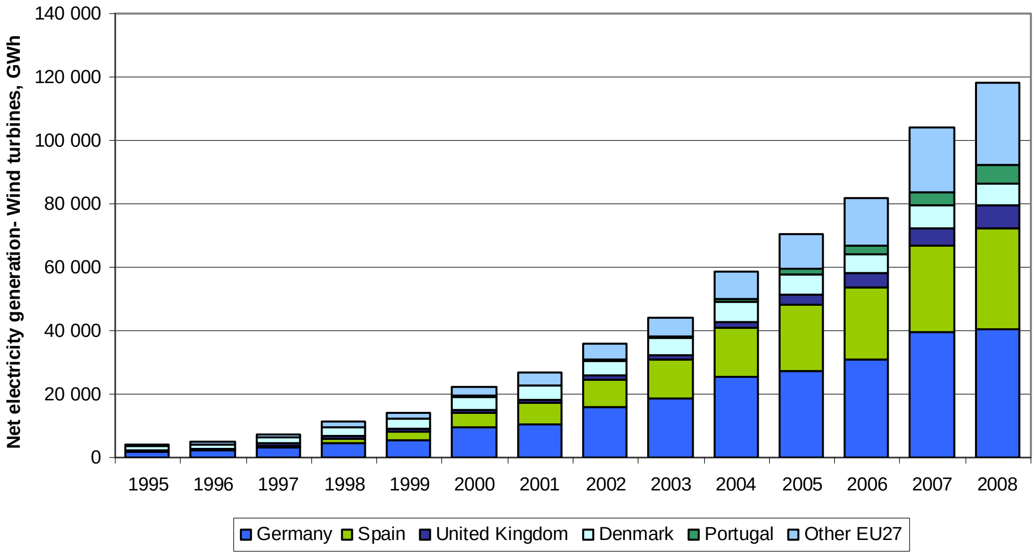

Figure 9. Electricity generation from wind power in the European Union.

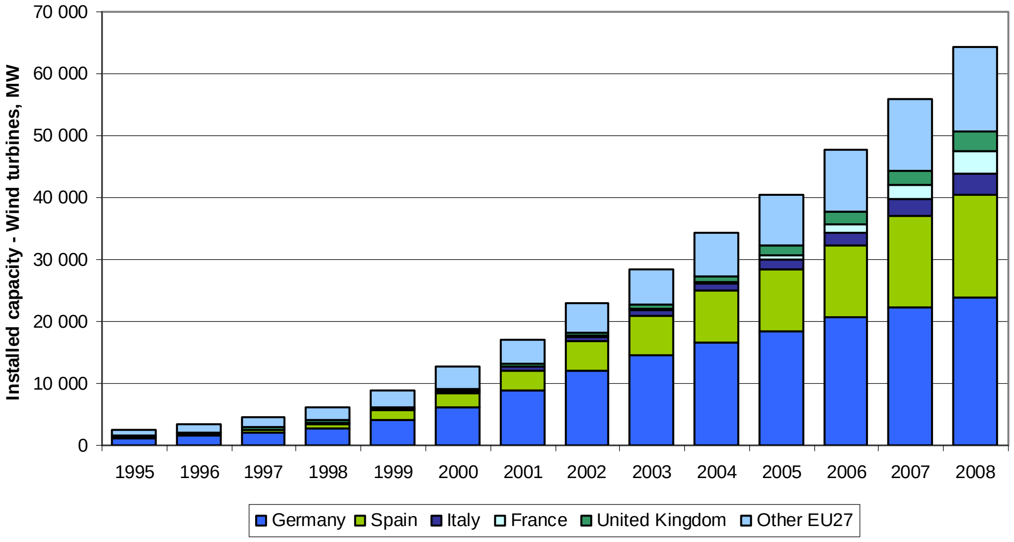

Figure 10. Cumulative installed wind power capacity in the European Union.

3.3 Biomass

The directive 2009/28/EC defines that biomass means the biodegradable fraction of products, waste and residues from biological origin from agriculture (including vegetal and animal substances), forestry and related industries including fisheries and aquaculture, as well as the biodegradable fraction of industrial and municipal waste. Biomass can be cultivated inside or outside the territory of the Community, but in both cases, it must meet certain criterias for the sustainability. It should be noted that statistics regarding biomass are somewhat uncertain. Escpecially statistics from new EU Member States are scarcer.

Biomass electricity generation is based on three fuel types: solid biomass, biogas, and the biodegradable fraction of municipal solid wastes (MSW). Biomass-fired power stations output has increased from 38.7 TWh in 2000 to 102.1 TWh in 2008, which makes biomass the second largest renewable electricity source in the EU. Germany has more than quadrupled its biomass electricity generation from 2000 to 2008. Second largest bioelectricity producer Sweden has also almost tripled its bioelectricity production, while in Finland growth has been slower. The development of the electricity production from biomass-fired power stations is illustrated in figure 11.

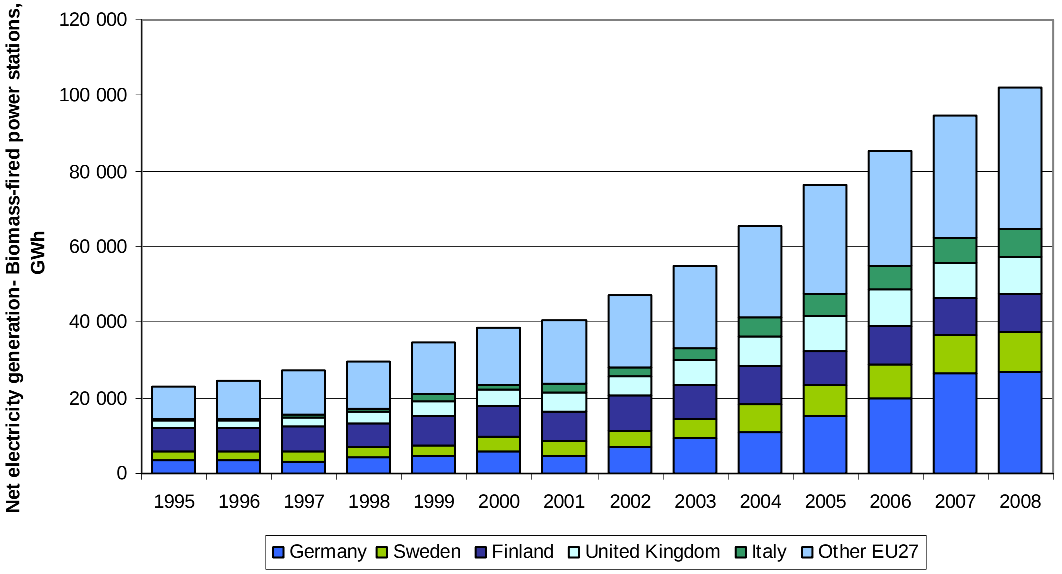

Figure 11. Electricity generation from biomass-fired power stations in the European Union.

Figure 12 illustrates the increase in biomass-fired power stations capacity from 1997 to 2008. Figures cover the whole capacity of municipal solid waste based power generation, not only the fraction that corresponds to the renewable part of MSW.

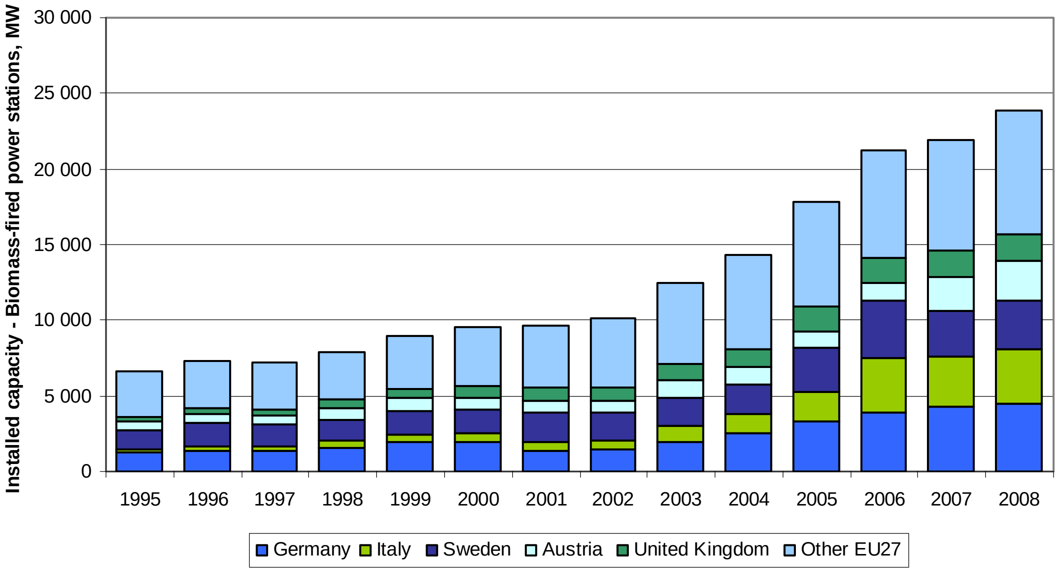

Figure 12. Cumulative installed biomass-fired power station capacity in the European Union.

3.4 Solar power

3.4.1 Photovoltaic systems

In recent years, the installed capacity of photovoltaic systems has increased fast. In 1990's, annual photovoltaic production did not exceed 0.1 TWh. Since the turn of the century, both capacity and generation have been growing rapidly, and photovoltaic electricity production totalled 7.4 TWh in 2008. In 2008, 56 % of the installed capacity was in Germany, 35 % in Spain and 5 % in Italy, and the shares of generation were 60 %, 35 % and 3 %, respectively. Photovoltaic electricity production development is illustrated in Figure 13 and capacity development in Figure 14.

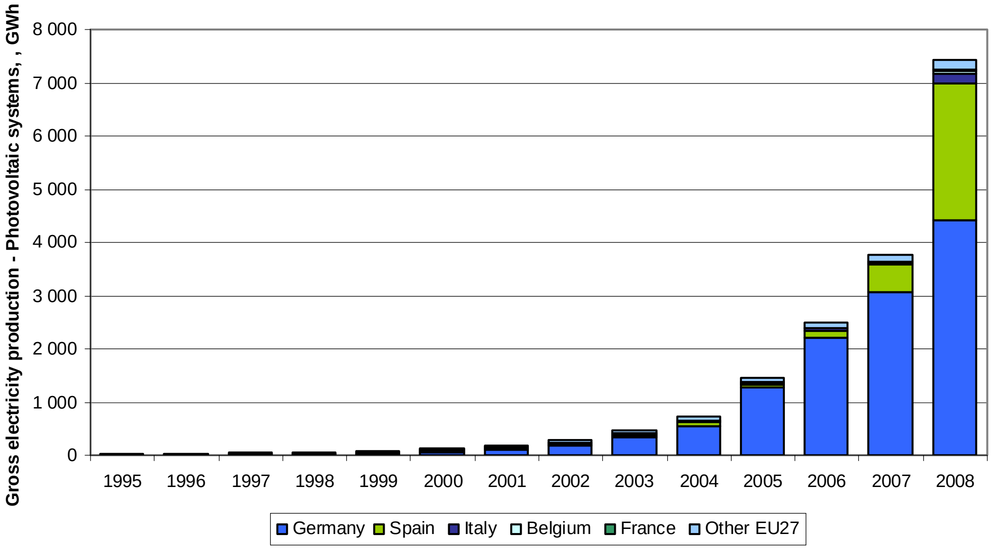

Figure 13. Electricity generation from photovoltaic systems in the European Union.

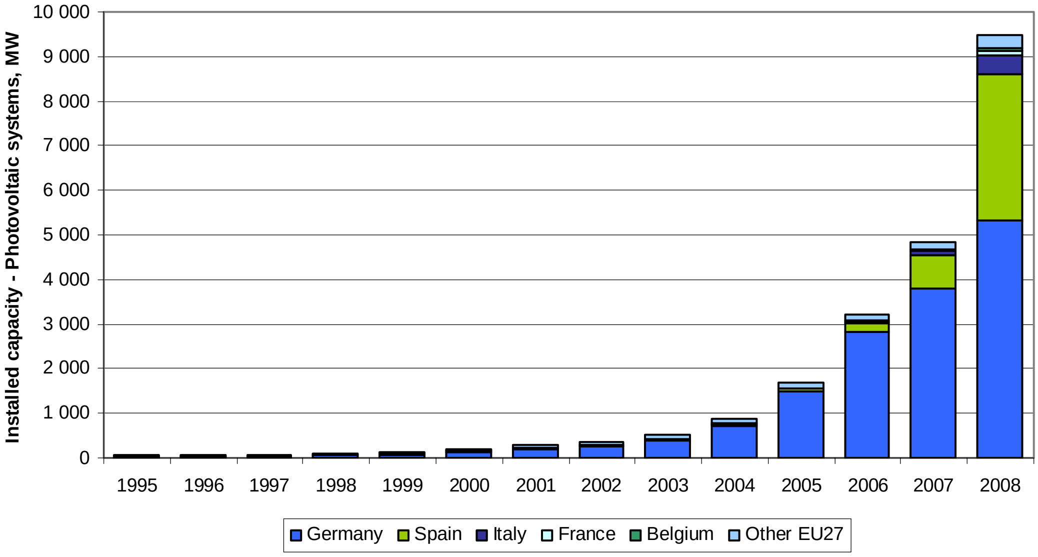

Figure 14. Cumulative installed photovoltaic system capacity in the European Union.

3.4.2 Concentrated solar power

The European Union’s installed capacity of solar thermal systems was 11 MW in 2007 and 61 MW in 2008. All the reported capacity was in Spain. Eurostat has not published electricity generation figures for solar thermal power.

3.5 Hydropower

The installed capacity of hydropower stations has grown steadily in the EU over the past fifteen years. In 1995, the installed capacity was 90.8 GW and in 2008, it was 102.3 GW. While the installed capacity shows little annual variation, hydropower production varies from year to year due to hydrological conditions. The annual average hydropower production in the EU is about 350 TWh. When counting renewable electricity shares, Eurostat normalises hydropower production to average conditions.

Besides the countries belonging to the European Union, Norway and Switzerland also have signficatn hydropower assets. In 2008, Norway's hydropower capacity was 29 700 MW, larger than any single European Union Member State's hydropower capacity. In the same year, Switzerland's hydropower capacity was 15 300 MW.

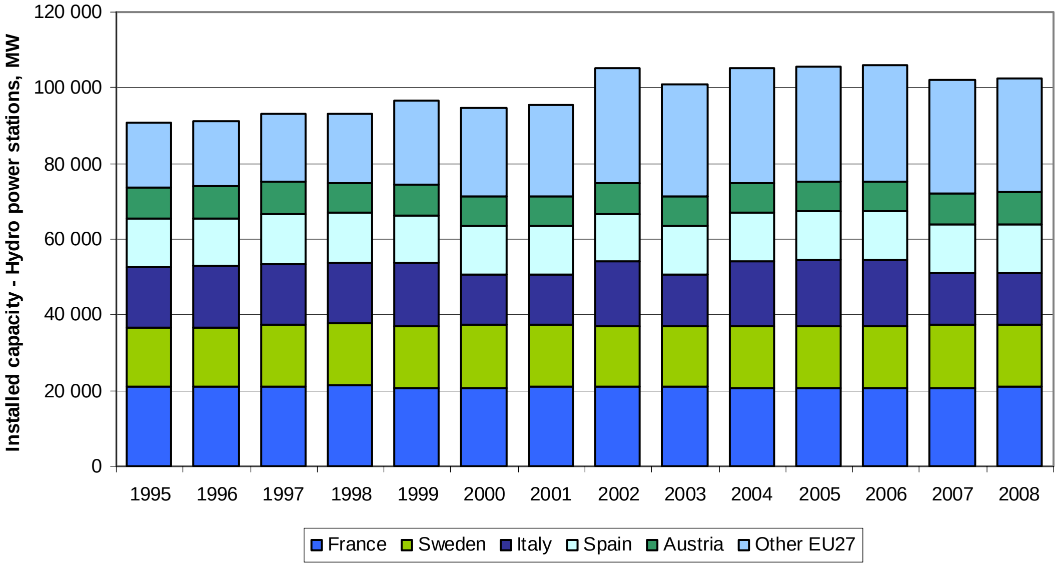

Figure 15. The installed capacity of hydropower stations in the European Union.

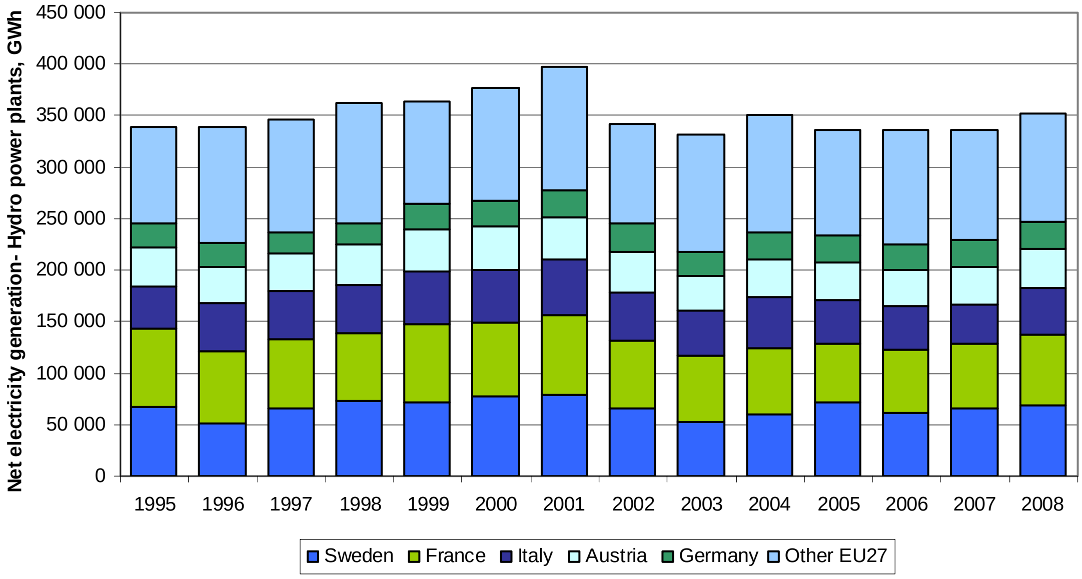

Figure 16. Electricity generation from hydropower plants in the European Union.

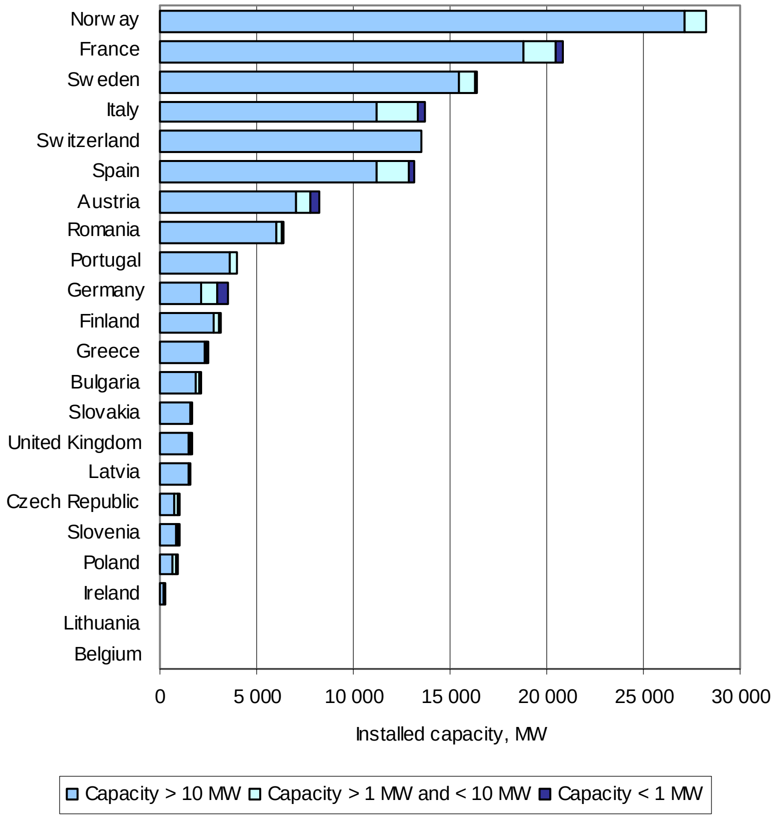

Figure 17. Cumulative installed hydropower capacity in 2008. Countries with smaller than 50 MW capacity have been exluded (Estonia, Denmark, the Netherlands, Luxembourg, and Hungary).

3.6 Geothermal energy

In 2008, the total installed capacity of geothermal power plants in the European Union was near 700 MW. Over 96 % of the installed capacity is in Italy, while there are also some small applications in Portugal and Austria. Greece had a 2 MW geothermal power plant capacity until 1999, but since then the installed capacity in Greece has been removed. The total power production from geothermal power plants was 5.4 TWh in 2008.

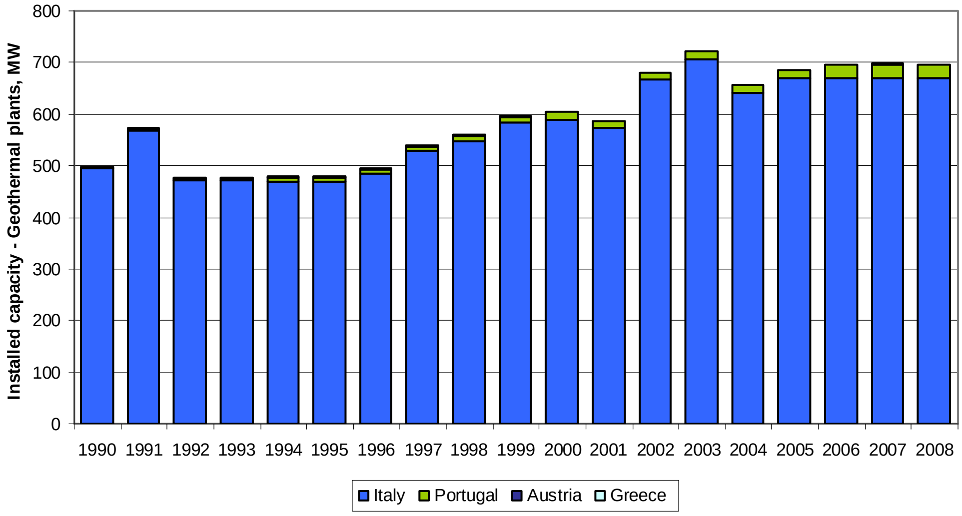

Figure 18. Cumulative installed capacity of geothermal power plants in the European Union.

4. Renewable electricity support schemes

This chapter describes the current subsidy schemes for renewable electricity in selected countries, which are Germany, Spain, the UK, and the Nordic countries. National currencies have been converted to euros using the average exchange rate for the year 2010.

4.1 Introduction to support schemes

The European Union's Member States are required to support electricity from renewable sources. Currently, there is a different support system in each Member State, ranging from tax-exemptions to feed-in tariffs. These different support schemes have been developed because support is linked to other national priorities such as regional development and employment and because national electricity markets are still different.

The market-based instruments which can be used to promote renewable electricity can be divided between investment support (capital grants, tax exemptions or reduction on the purchase of goods) and operating support (price subsidies, green certificates, tender schemes, and tax exemptions or reductions on the production of electricity) (EC 2008). Generally, operating support (support per MWh) is far more important than investment support.

Operating support instruments can be further divided to quantity and price based instruments. **Quantity based instruments** fix a quantity of renewable electricity to be produced. These include (EC 2008):

- **Quota obligations**, which in 2008 were used in seven Member States. Under a quota obligation, government imposes an obligation on consumers, suppliers, or producers to source a certain part of their electricity from renewable energy. This obligation is usually facilitated by tradable green certificates. Renewable electricity producers sell the electricity at the market price, but they can also sell green certificates, which they receive for the production of renewable electricity.
- Under **tendering,** a tender is announced for the provision of a certain amount of electricity from a certain technology source, and the bidding should ensure that the cheapest offer is accepted. This method has been successfully used in Denmark for the development of offshore wind power projects.

Price based instruments fix a price to be paid for renewable electricity (EC 2008):

- In 2008, **feed-in tariffs and premiums** were used in 18 Member States. Feed-in tariffs and premiums are granted to renewable electricity producers for the electricity they feed into the grid, and they are usually technology-specific. Feed-in tariffs take a form of a total price per unit of electricity paid to the producers whereas the premiums are paid to the producer on the top of the electricity market price. Premiums introduce competition among the producers in the electricity market, while feed-in tariffs do not. Both are normally granted for a period of 10 to 20 years. In addition to the level of the tariff, the long duration decreases the market risk faced by investors.

- **Fiscal incentives** can be for example tax exemptions or reductions. In 2008, these were the main support scheme in two Member States. Producers of renewable electricity are exempted from certain taxes in order to compensate the unfair competition they face due to external costs in the conventional energy sector.

Renewable energy resource potentials and technology costs vary between Member States. Thus a single support instrument is seldom sufficient to develop renewable energy sources available in one country. Most of the Member States apply many support schemes simultaneously.

4.2 Denmark

Danish government's policy is, that by 2020, Denmark will be a green, sustainable society and the country will be among the three most energy efficient countries in the OECD (Klima- og energiministeriet 2010). Denmark has a target of 30 % renewable energy by 2020. The government's long-term energy-political vision is that Denmark will ultimately become independent of fossil fuels.

Financial support for electricity generation based on renewable energy is stated in Act No. 1392 of December 2008 on the Promotion of Renewable Energy[2]. Support is given in the form of price subsidies for wind turbines, biogas etc., biomass, and other RE installations.

4.2.1 Wind turbines

Generally, wind power producers receive a subsidy of 25 øre/kWh (3.36 c/kWh[3]) for electricity generation that corresponds to generation during the first 22 000 full load hours after connection to the grid. This subsidy does not apply to offshore wind turbines according to tender and domestic wind turbines. There is also a 2.3 øre/kWh (0.31 c/kWh) compensation for balancing costs for wind turbine electricity.

The Promotion of Renewable Energy Act also contains a **scrapping scheme** for old wind turbines. According to the scheme, a scrapping certificate can be earned by replacing old, inappropriately situated wind turbines with new, more efficient turbines. With turbines connected from 21 February 2008 or later, the price subsidy is 8 øre/kWh (1.07 c/kWh) for electricity generation corresponding to

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[2] http://www.ens.dk/en-US/Info/Legislation/Energy_Supply/Documents/ Promotion%20of%20Renewable%20Energy%20Act%20-%20extract.pdf

[3] Average exchange rate for 2010: DKK 7.4473 (Bank of Finland)

12 000 full load hours for twice the installed effect of the dismantled windmills (Klima- og energiministeriet 2010).

Offshore wind power projects are subsidised through tender procedure. The Danish Energy Agency announces a tender for a specific, geographically defined area. Applicants submit quotations for the price at which bidders are willing to produce electricity in the form of a fixed feed-in tariff for a certain amount of produced electricity. The winning price will vary from project to project, since local conditions are different.

Domestic wind turbines with an installed effect of 25 kW or less are awarded a subsidy for electricity supplied to the electricity network. The turbines need to be connected to their own consumption installation. The combined subsidy and market price make up 60 øre/kWh (8.06 c/kWh) (Klima- og energiministeriet 2010).

The Promotion of Renewable Energy act contains also four new schemes to promote the development on wind turbines on land: loss of value to real property due to the erection of wind turbines, local citizens' option to purchase wind turbine shares, a green scheme to enhance local scenic and recreational values and a guarantee fund to support financing of preliminary investigations etc. by local wind turbine owners' associations.

4.2.2 Biogas

The subsidy for electricity produced by installations that use biogas, gasified gas produced from biomass, Stirling motors, and other special electricity generation installations which use biomass as a source of energy is in combinations with market price 74.5 øre/kWh (10.00 c/kWh). If these generators use these sources of energy in combination with other fuels, a price subsidy of 40.5 øre/kWh (5.44 c/kWh) is given for that part of the electricity produced using biogas (Klima- og energiministeriet 2010).

4.2.3 Biomass

For the electricity produced by the burning of biomass, there is a subsidy of 15 øre/kWh (2.01 c/kWh). This subsidy applies for installations that use solely biomass and installations that use a combination of biomass and other types of fuel (Klima- og energiministeriet 2010).

4.2.4 Other types of renewable energy installations

Solar energy, ocean and wave power or other renewable energy sources apart from biogas and biomass receive a subsidy so, that the subsidy combined with the market price of electricity makes up 60 øre/kWh (8.06 c/kWh) for the first 10 years after network connection and 40 øre/kWh (5.37 c/kWh) the following ten years. If these installations combine renewable energy with other sources, the subsidy is 26 øre/kWh (3.49 c/kWh) for ten years and 6 øre/kWh (0.81 c/kWh) for the following ten years. For other energy sources, the price subsidy is 10 øre/kWh (1.34 c/kWh) for 20 years from network connection (Klima- og energiministeriet 2010).

4.3 Finland

Finland's national target for renewable energy is 38 % of the final consumption of energy by 2020. This requires an estimated increase in renewable energy of 38 TWh. On 1 January 2011, Finland introduced a new subsidy scheme (feed-in tariff scheme[4]) for the production of electricity based on wind power, biogas, and wood-based fuel. The scheme seeks to increase electricity production based on wind power by 6 TWh and that based on forest chips utilised as fuel by 22 TWh.

Through the feed-in tariff scheme, electricity producers receive support for a period of twelve years to cover the difference between actual production costs and electricity market price.

4.3.1 Wind power

The target price for electricity production by wind power is 83.5 €/MWh. The feed-in tariff equals the target price minus electricity market price (feed-in tariff premium mechanism). If the market price is higher than target price, no feed-in tariff is paid. However, until 2015 the target price is set to be higher, 105.30 €/MWh, on the basis of which the feed-in tariff will be paid for a maximum of three years. The nominal output capacity of wind power plants admitted to the feed-in tariff scheme should be at least 500 kVA. Wind turbines which are not eligible for the feed-in tariff will continue to receive a fixed subsidy of 6.90 €/MWh (TEM 2010).

4.3.2 Wood chips and other energy from wood

The bulk of the forest energy growth should be achieved using small-sized wood and stumps, but the harvesting costs are currently too high for energy undertakings to afford. In order to increase forest energy, a three-part aid package has been introduced:

- **Energy subsidies for small sized wood**: Harvesting small-sized wood is supported, if the wood is used for energy purposes.
- **Support for electricity production from wood chips (feed-in tariff):** In Finland, wood competes against other fuels in electricity production. When the price of carbon emissions permits is low, wood's competitiveness against fossil fuels is poor. The effect of fluctuations in the price of emission permits is stabilised by linking electricity production support to the price of emission permits, which guarantees the competitiveness of forest energy in relation to peat. From January 2011, electricity produced from wood chips receives a feed-in tariff. The tariff is 18 €/MWh, when the price of emission permit is 10 €/ton. If the price of emission permit rises over 23 €/ton, the feed-in tariff is 0 €/MWh.
- **Feed-in tariff for small CHP plants**: The heat loads of municipalities and industry can be used more effectively by replacing heat boilers with CHP-units. Because the cost of electricity generated by small CHP plants is higher than the market price, these units are sup-

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[4] Laki uusiutuvilla energialähteillä tuotetun sähkön tuotantotuesta 1396/2010
http://www.finlex.fi/fi/laki/alkup/2010/20101396

ported by feed-in tariff. The target price for the small CHP-units using wood fuel is 83.5 €/MWh, and the feed-in tariff equals the target price minus the electricity market price. In CHP production, a heat premium of 20 €/MWh is paid for the electricity produced from wood fuel. The maximum feed-in tariff paid per year is limited to 750 000 for any one plant. The increase of electricity generation with these units is estimated to be relatively small, some 0.2 TWh (TEM 2010).

The nominal output of forest chip and wood fuel powered plants admitted to the feed-in tariff scheme should be at least 100 kVA. For wood-fuel powered plants, the maximum limit for nominal output is 8 MVA.

4.3.3 Biogas

In 1 January 2011, a feed-in tariff scheme for electricity generated from biogas was introduced. The target price for biogas-sourced electricity is set to 83.5 €/MWh. The feed-in tariff equals the target price minus electricity market price. In CHP production, a heat premium of 50 €/MWh is paid. The nominal output of biogas plants admitted to the feed-in tariff scheme should be at least 100 kVA.

4.4 Germany

Between 1990 and 2009, the share of renewable energy in energy supply in Germany has increased from 2 % to 10 % in final consumption of energy (Germany 2010). Electricity generation from all renewable energy sources has more than quintupled, from 17 TWh in 1990 to over 93 TWh in 2009. In 1990, hydropower and traditional use of wood dominated the renewable energy production. At present, more advanced technologies are used, and Germany has a mix of wind, biomass, geothermal energy, and photovoltaic systems in the electricity sector.

The share of electricity from renewable sources in gross final consumption of energy will, according to the scenario with additional efficiency measures, increase in the period 2005-2020 from 10.2 % to 38.6 %. This corresponds to an increase of electricity production from renewable sources from 62 TWh in the base year 2005 to 217 TWh in 2020. In electricity sector, renewable energy is developed mainly by feed-in tariffs through Renewable Energy Act[5] (*Erneuerebare-Energien-Gesetz*, EEG). This measure began in April 2000 as a follow-up regulation to the Electricity Feed Act of 1991. The EEG has had amendments in 2004 and 2009, and the next revision is planned in 2011. CHP is also encouraged through Combined Heat and Power Act (KWKG). This measure began in April 2002, and was revised in January 2009.

Tariff levels are defined by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU 2008). Tariff and sample degression rates for hydropower, landfill gas, sewage gas, pit gas, biomass, geothermal energy, and wind power are introduced in table 1. These tariffs apply for

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[5] http://www.erneuerbare-energien.de/files/english/pdf/application/pdf/eeg_2009_en_bf.pdf

the period 2009 to 2018. Installations first commissioned prior to 2009 are subject to older legislation so that different rules apply.

Table 1. Germany's feed-in tariffs for hydropower, landfill gas, sewage gas, pit gas, biomass, geothermal energy, and wind power.

	Subsidy rate (ct/kWh)	**Degression (rate in %)**	**Duration of tariff payment (years)**	**Bonuses**
Hydropower				
New installations up to 5 MW	up to 500 kW: 12.67 500 kW-2 MW: 8.65 2 MW-5 MW: 7.65	No	20	-
Modernised/revitalised installations of up to 5 MW	up to 500 kW: 11.67 500 kW-5 MW: 8.65	No	20	-
New and modernised installations above 5 MW	up to 500 kW: 7.29; up to 10 MW: 6.32; up to 20 MW: 5.80; up to 50 MW: 4.34; above 50 MW; 3.50	1.0	15	-
Landfill gas, sewage gas, pit gas				
Landfill gas	up to 500 kW: 9.00 500 kW - 5 MW: 6.16	1.5	20	Technology bonus of 1.00 or 2.00 ct/kWh if innovative procedures are applied that benefit the environment
Sewage gas	up to 500 kW: 7.11 500 kW - 5 MW: 6.16	1.5	20	
Mine gas	up to 1 MW: 7.16 1 MW - 5 MW: 5.16 above MW: 4.16	1.5	20	
Biomass*	up to 150 kW: 11.67 150 - 500 kW: 9.18 500 kW - 5 MW: 8.25 5 MW - 20 MW 7.79	1.0	20	Bonus for electricity from energy crops, innovative installation technology, CHP bonus
Geothermal energy	up to 10 MW: 16.00 above 10 MW: 10.50	1.0	20	Heat use, technology bonus, early bird bonus
Wind power				
Onshore**	Initial tariff paid for five years: 9.20 Basic tariff: 5.02 System services bonus: 0.50 Repowering bonus: 0.50	1.0	20	
Offshore	Initial tariff: 13.00 Early bird bonus: 2.00 Basic tariff: 3.50	until 2014: 0.0 from 2015: 5.0	20	

*Installations with a capacity of more than 5 MW are only eligible when operating on CHP mode

** The higher initial tariff period is extended by two months for each 0.75 per cent of the reference yield by which the yield of the installation falls short of 150 per cent of the reference yield.

Where tariffs vary depending on output levels, they are determined separately for each share of an installation's output, which falls between the relevant threshold values. For other than wind and solar energy, the output of an installation will not be deemed to be its effective output, but rather the ratio of the total kilowatt-hours fed into the grid in the calendar year in question to the total number of full hours for that calendar year (BMU 2008). An example for wind energy installation near the coast which produces 150 % of the reference yield in a period of five years starting with commissioning is presented in table 2. The installation meets the requirements for the services bonus and is commissioned in 2010.

Table 2. Germany's feed-in tariff for wind power – sample calculation for onshore installation for the higher initial tariff (five years).

Sample tariff for wind power	**2010**	**2011**
Higher initial tariff	9.11	9.02
System services bonus	+ 0.50	+ 0.49
Remuneration	= 9.66 c/kWh	= 9.5 c/kWh

The amended Renewable Energy Sources Act prescribes a two-stage reduction in feed-in tariffs for electricity from solar energy. Reductions apply from 1 July 2010 and 1 October 2010.

In Germany, a dynamic degression for the solar energy feed-in tariffs is applied. Degression depends on the annual installed capacity increase in Germany. As a rule, there is a 9 percent degression rate, but the degression rate may be higher or lower depending on the installed capacity in the previous year (BMU 2008).

Tariffs for electricity from solar radiation are presented in table 3 (installations attached to or on top of buildings). Tariff rates for own consumption are possible values only, and an average household electricity price of 20 c/kWh is assumed for calculations. The difference between the tariff rate for direct consumption plus avoided costs for household electricity and the tariff rate for the respective installation attached to or on top of buildings leads to an incentive of 3.6 c/kWh for own consumption up to 30 %, and above 30 %, there is an incentive of 8 c/kWh (BMU 2008).

Table 3. Germany's feed-in tariffs for solar energy (installations attached to or on top of buildings).

	January 2010	**July 2010**	**October 2010**	**2011**
up to 30 kW	39.14	34.05	33.03	28.74
30 - 100 kW	37.23	32.39	31.42	27.33
100 - 1000 kW	35.23	30.65	29.73	25.86
from 1000 kW	29.37	25.55	24.79	21.56
own consumption				
up to 30 kW	22.76	17.67	16.65	12.36
from 30 % own consumption	22.76	22.05	21.03	16.74
30 - 100 kW	0.00	16.01	15.04	10.95
from 30 % own consumption	0.00	20.39	19.42	13.33
100 - 500 kW	0.00	14.27	13.35	9.48
from 30 % own consumption	0.00	18.65	17.73	13.86

In Germany, there are two regulations governing the **priority use** of installations producing electricity from renewable energy sources. According to EEG, grid operators are required to purchase, transmit and distribute preferentially the total amount of electricity from renewable energy sources (Germany 2010). Renewable electricity generators do not have an active participation in the electricity markets, but they can sell the electricity produced monthly to third parties.

4.5 Norway

Norway is not a member of the European Union, and thus the country has no binding targets for renewable energy in 2020. Norway has Europe's highest hydropower production, and hydropower covers about 98.5 % of electricity production. However, Norway has also an excellent wind power potential. Current target for an increase in renewable electricity production and energy efficiency is 30 TWh annually compared to 2001 by 2016.

In January 2011, Norwegian Water Resources and Energy Directorate (NVE) had 21 600 MW of wind power projects on the table, corresponding to an annual wind power production of 66 TWh. In recent years, actual annual wind power production in Norway has been around 1 TWh annually.

Norwegian state-controlled enterprise Enova manages the support scheme for wind power construction. The most cost efficient projects as determined based on an 8 per cent rate of return, estimated power production potential and forward power prices will receive state support (Mondaq 2010).

Norway and Sweden have long negotiated on a common green certificate market. In 2009, the countries signed an agreement on the common market, which is to begin functioning on 1 January 2012. The new system is expected to generate 26.4 TWh by 2020, each country financing 13.2 TWh[6].

4.6 Spain

In Spain, electricity generation using renewable energies is considered Special Regime production in the terms laid down in the Electricity Sector Law 54/1997[7]. The Special Regime is based on a system of direct support to production. The scheme has proven to be highly effective in the development of electricity using renewables (Gobierno de España 2010). The Special Regime applies to almost all renewable electricity generation techniques with few exceptions, mainly large-scale hydropower.

In Spain, the generation of electricity from renewable sources is promoted through feed-in tariffs and a premium system. The remuneration paid for electricity generation using renewable energies is established by Royal Decree 661/2007[8] of 26 May 2007. This decree regulates electrical energy pro-

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[6] http://www.regjeringen.no/en/dep/oed/press-center/Press-releases/2010/norway-and-sweden-agree-on-a-common-mark.html?id=627396

[7] http://www.boe.es/aeboe/consultas/bases_datos/doc.php?coleccion=iberlex&id=1997/25340

[8] http://www.boe.es/aeboe/consultas/bases_datos/doc.php?coleccion=iberlex&id=2007/10556

duction under the special regime and defines the legal and economic regime for electrical energy and cogeneration plants and plants that use renewable energies and waste as raw material. The tariffs and premiums are defined so that they afford a reasonable return on investment taken in account the specific technical and economic aspects of each technology, installed capacity and the date operation commenced, in all cases using criteria of system economic sustainability and efficiency (Gobierno de España 2010).

Owners of installations producing electricity using renewable energies may choose, for periods of at least one year, between two alternatives:

- Regulated tariff sale, different for each technology or
- Sale on the open electricity market. Remuneration is the price on the organised market (of freely negotiated price) supplemented by a specific premium for each technology area.

Premiums vary based on hourly electricity market prices. If the electricity price is low, the remuneration scheme guarantees a floor price meaning that the owner of a renewable installation can be assured a minimum return. The system has also a ceiling premium payment: if electricity market price is higher than this ceiling, no premiums are paid. Spanish tariff and premium levels for year 2010 are presented in tables 4 – 6.

Table 4. Spain: remuneration levels for solar and wind power and electricity generation from geothermal, wave, tide, hot dry rocks, ocean thermal, and marine currents in force during 2010.

2010	**Two options for electricity sales**			**Option A**	**Option B**		
Group	**Subgroup**	**Rating**	**Timing**	**Regulated tariff c/kWh**	**Reference premium c/kWh**	**Ceiling c/kWh**	**Floor c/kWh**
Solar	Photovoltaic	P < 100 kW	First 25 years	46.59			
			Thereafter	37.27			
		100 kW < P < 10 MW	First 25 years	44.17			
			Thereafter	35.34			
		10 < P < 50 MW	First 25 years	24.31			
			Thereafter	19.45			
	Solar thermal processes		First 25 years	28.50	26.87	36.39	26.87
			Thereafter	22.80	21.50		
Wind	Onshore		First 25 years	7.75	3.10	8.99	7.54
			Thereafter	6.47			
	Offshore				8.92	17.35	
Geothermal, wave, tide, hot dry rocks, ocean thermal, and marine currents			First 25 years	7.29	4.07		
			Thereafter	6.89	3.24		

Table 5. Spain: remuneration levels for hydroelectric and electricity generation from biomass in force during 2010.

2010	Two options for electricity sales			Option A	Option B		
Group	**Subgroup**	**Rating**	**Timing**	**Regulated tariff c/kWh**	**Reference premium c/kWh**	**Ceiling c/kWh**	**Floor c/kWh**
Hydroelectric		P < 10 MW	First 25 years	8,25	2,64	9,01	6,90
			Thereafter	7,43	1,42		
		10 MW < P < 50 MW	First 25 years	**	2,23	8,46	6,47
			Thereafter	***	1,42		
Biomass	Energy crops	P < 2 MW	First 25 years	16,81	12,67	17,59	16,30
			Thereafter	12,47			
		P > 2 MW	First 25 years	15,51	11,16	15,96	15,10
			Thereafter	13,06			
	Agricultural or garden waste	P < 2 MW	First 25 years	13,30	9,16	14,08	12,79
			Thereafter	8,97			
		P > 2 MW	First 25 years	11,37	7,02	11,84	10,98
			Thereafter	8,53			
	Forestry waste	P < 2 MW	First 25 years	13,30	9,16	14,08	12,79
			Thereafter	8,97			
		P > 2 MW	First 25 years	12,51	8,16	12,97	12,10
			Thereafter	8,53			

** The amount of the tariff will be: (6.6 + 1,2 * x ((50 - P) / 40)) x 1.0605

*** The amount of the tariff will be: (5.94 + 1.080 x ((50 - P) / 40)) x 1.0605

Table 6. Spain: remuneration levels for electricity generated from manures, biofuels or biogas and biomass from industrial installations in force during 2010.

2010	Two options for electricity sales			Option A	Option B		
Group	**Subgroup**	**Rating**	**Timing**	**Regulated tariff c/kWh**	**Reference premium c/kWh**	**Ceiling c/kWh**	**Floor c/kWh**
Manures, biofuels or biogas	Biogas from rubbish dumps		First 25 years	8,45	4,47	9,48	7,87
			Thereafter	6,89			
	Biogas generated in digesters	P < 500 kW	First 25 years	13,83	10,81	16,23	13,07
			Thereafter	6,89			
		P > 500 kW	First 25 years	10,24	6,59	11,67	10,10
			Thereafter	6,89			
	Manures		First 25 years	5,67	3,74	8,81	5,40
			Thereafter	5,67			
Biomass from industrial installations	Biomass from agricultural installations	P < 2 MW	First 25 years	13,30	9,16	14,08	12,79
			Thereafter	8,97			
		P > 2 MW	First 25 years	11,38	7,02	11,84	10,98
			Thereafter	8,53			
	Biomass from forestry installations	P < 2 MW	First 25 years	9,82	5,68	10,60	9,30
			Thereafter	6,89			
		P > 2 MW	First 25 years	6,89	2,53	7,34	6,47
			Thereafter	6,89			
	Biomass from black liquor installations	P < 2 MW	First 25 years	9,82	5,94	10,60	9,30
			Thereafter	6,89			
		P > 2 MW	First 25 years	8,46	3,88	9,52	7,93
			Thereafter	6,89			

4.7 Sweden

Sweden’s energy vision is that in 2050, the country will have a sustainable and resource efficient energy supply with no net emission of greenhouse gases into the atmosphere (Regeringskansliet 2010). The Swedish Parliament has decided that in 2020 the proportion of renewable energy will be at least

50 % of the total energy usage. This target is one percentage point higher than the official binding target. The target for renewable electricity generation is an increase of 25 TWh compared with 2002.

4.7.1 Electricity certificates

In Sweden, the main support scheme for electricity generation from renewable sources is electricity certificates. The scheme was introduced on 1 May 2003[9]. The certificate scheme provides support for a maximum of 15 years. The producers of electricity from renewable sources receive certificates according to their production. By selling their electricity certificates, the producers receive an additional income from their electricity generation.

The scheme includes hydroelectric power, solar energy, wave energy, geothermal energy, biofuels, and electricity produced in cogeneration plants using peat.

Demand for certificates is created when all electricity suppliers and certain electricity consumers are obliged to purchase electricity certificates corresponding to a specific proportion (quota) of their electricity sales or consumption. The amount of electricity certificates that suppliers must purchase will increase annually as the quota successively increases. On April 1 of each year, the quota-bound suppliers submit electricity certificates for cancellation corresponding to their quota obligation (Regeringskansliet 2010).

If the quota-bound electricity supplier/consumer does not cancel in accordance with his quota obligation a quota obligation fee will be payable. The fee (quota obligation charge) is 150 % of the volume-weighted average of the certificate price during a period from 1 April of the cancellation year to 31 March the following year inclusive.

The certificate price and trade volume development is illustrated in figure 20. During 2010, the average price[10] was SEK 295 (33 €) per certificate. The system has no floor or bottom price.

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[9] Lagen 2003:113 om elcertificat (the Electricity Certificates Act)

[10] Average exchange rate for 2010: SEK 9.5373 (Bank of Finland)

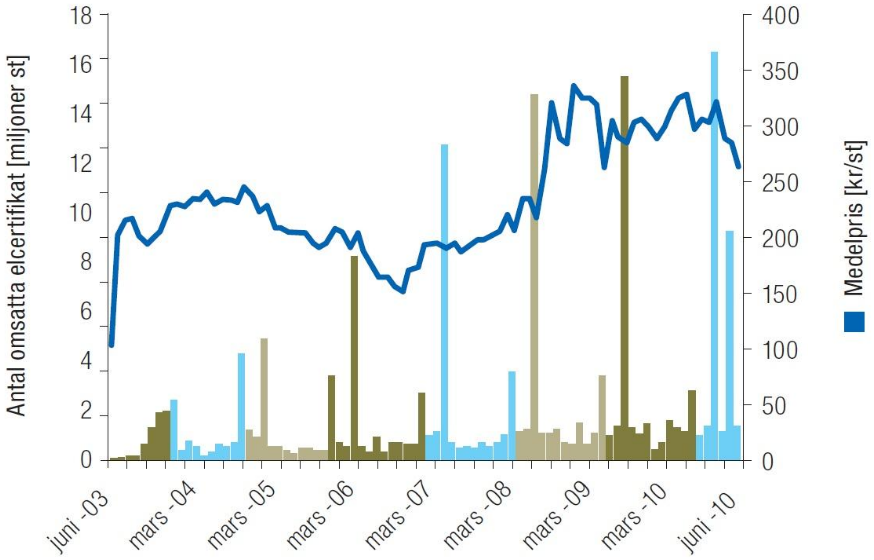

Figure 19. Average price and monthly trade volume for electricity certificates in Cesar –system from June 2003 until June 2010 (Swedish Energy Agency 2010).

4.7.2 Wind power

The Swedish Parliament has decided on a national planning framework for wind power that corresponds to 30 TWh by 2020, of which 20 TWh will be on land and 10 TWh will be offshore. Besides electricity certificate system, wind power has additional support systems (Regeringskansliet 2010).

Since 2007 municipalities, county administrative board, regional autonomous bodies, and municipal cooperative bodies have been able to apply for **aid for planning initiatives for wind power**. The system aims to provide resources for spatial planning in order to create the conditions for further expansion of wind power. Under normal circumstances, aid is provided at 50 % of the total cost of the planning initiative.

The market introduction of wind power is supported by **wind pilot aid**. Aid is provided for pilot projects in order to reduce the costs of establishing new wind power plants and to increase knowledge of the effects of establishment in certain environments. Aid is provided for technology development, market introduction and environmental impact studies.

4.7.3 Support for photovoltaic cells

Solar photovoltaic cells receive governmental support[11]. The aid applies to all types of solar photovoltaic cell systems connected to electricity grids. The contribution is 60 % (55 % for large commercial enterprices) and applies to the entire solar photovoltaic cell installation, including material and labour. All types of applicant may apply for aid. The maximum amount of aid is SEK 3 million per

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[11] Förordningen (2009:689) om statligt stöd till solceller (Ordinance concerning government support for solar photovoltaic cells).

building. The total amount that has been allocated for aid is SEK 100 million (11.2 million euros) during 2009 and SEK 50-60 million (5.6 – 6.7 million euros) for 2010 and 2011. The aid is valid from 1 July 2009 until 31 December 2011 (Regeringskansliet 2010).

4.8 United Kingdom

United Kingdom has traditionally based its energy production on domestic fossil fuels. Compared to many other Member States, the UK is starting from a very low level of renewable energy production. The UK promotes renewables in electricity sector with Renewable Obligation Certificates, and is going to establish a system of feed-in tariffs (UK 2010).

Renewable Obligation (RO) system started in 2002 and the support is available to 2037 (2033 in Northern Ireland). The system is intended primarily for large-scale renewable electricity generation by professional energy companies. RO-system is the main support system, while feed-in tariff system is planned for small-scale operators. The UK's **feed-in tariff** system is designed for households, communities and small busineses investing in projects up to 5 MW. The system was introduced on 1 April 2010, and will close to new entrants in 2021, although these new entrants will be eligible for 20 years support. There are also plans for feed-in tariffs for large-scale generators alongside RO-system (UK 2010).

4.8.1 The Renewables Obligation

The Renewables Obligation[12] provides support for renewable electricity generating stations, including Combided Heat and Power (CHP) plants fuelled by biomass and crops, and CHP plants fuelled by energy from waste. Since the introduction, the RO has tripled the level of eligible renewable electricity generation (from 1.8% in 2002 to 5.4 % in 2008). In the RO system, electricity suppliers are obliged to source a specified and annually increasing proportion of their annual sales to customers from renewable sources, or pay a penalty. Suppliers demonstrate their compliance with the RO by presenting Renewables Obligation Certificates (ROCs). Generators are issued with ROCs for every megawatt hour of eligible renewable electricity they produce. Different technologies receive different numbers of ROCs/MWh. Renewable electricity generators can sell their ROCs to suppliers or traders to receive a premium on top of the wholesale price of their electricity (UK 2010).

The level of the obligation for 2009/2010 obligation period is 9.7 ROCs/100 MWh. This increases incrementally to 15.4 ROCs/100 MWh. There are no technology specific targets. The amounts of ROCs received from electricity generation using different technologies are presented in Table 7.

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[12] The Renewables Obligation Order 2009 was made under the Electricity Act 1989, and it applies to England and Wales. Scotland and Northern Ireland have their own Renewables Obligation acts or articles.

Table 7. The UK: Renewables Obligation Certificates for different generation technologies.

Generation type	ROCs/MWh	Generation type	ROCs/MWh
Hydro-electric	1 *	Pre-banded pyrolysis	1
Onshore Wind	1**	Standard gasification	1
Offshore Wind	1.5***	Standard pyrolysis	1
Wave	2	Advanced gasification	2
Tidal Stream	2	Advanced pyrolysis	2
Tidal Impoundment – Tidal Barrage	2	Anaerobic Digestion	2
Tidal Impoundment - Tidal Lagoon	2	Co-firing of Biomass	0.5
Solar Photovoltaic	2****	Co-firing of Energy Crops	1
Geothermal	2	Co-firing of Biomass with CHP	1
Geopressure	1	Co-firing of Energy Crop with CHP	1.5
Landfill Gas	0.25	Dedicated Biomass	1.5
Sewage Gas	0.5	Dedicated Energy Crops	2
Energy from Waste with CHP	1	Dedicated Biomass with CHP	2
Pre-banded gasification	1	Dedicated Energy Crops with CHP	2

* In Northern Ireland 2 - 4 ROCs/MWh for installations under 1 MW. In Scotland, tidal stream receives 3 ROCs and wave 5 ROCs

** In Northern Ireland onshore wind under 250 kW 4 ROCs

*** 2 ROCs subject to meeting specific criteria from 1 April 2010

**** Small-scale PV 50 kW or below in Northern Ireland receives 4 ROCs per MWh

The auction price of ROCs can be found through third party trading sites[13]. The buyout price (which has to be paid by suppliers unable to provide a Renewables Obligation Certificate) forms the upper limit of the ROC auction price. For 2009/2010, the buyout price was £37.19/MWh (44.10 €/MWh).

4.8.2 The feed-in tariffs

The UK’s feed-in tariff scheme is designed to increase small-scale low carbon electricity generation. The support is intended for individuals, householders, organisations, businesses, and communities, who have not traditionally engaged in the electricity market. In 2020, this scheme is expected to support over 750 000 small-scale low carbon electricity installations. The UK has a central scenario of 30 % electricity from renewables sources by 2020. The contribution of FITs is estimated to be 1.6 % of electricity consumption (6 TWh) in 2020 (UK 2010).

The feed-in tariff system provides support for 10, 20, or 25 years depending on technology. The scheme began in 2010 and will close to new entrants in 2021. Tariff levels are presented in table 8.

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[13] For example, http://www.e-roc.co.uk/index.htm

Table 8. The UK: Feed-in tariff levels and tariff lifetimes for the period 1.4.2010 – 31.3.2013.

Technology	**Scale**	**Tarif level for new installations in period (p/kWh)**			**Tariff lifetime (years)**
		1.4.2010 - 31.3.2011	1.4.2011 - 31.3.2012	1.4.2012 - 31.3.2013	
Anaerobic digestion	< 500 kW	11.5	11.5	11.5	20
	> 500 kW	9.0	9.0	9.0	20
Hydro	< 15 kW	19.9	19.9	19.9	20
	15 - 100 kW	17.8	17.8	17.8	20
	100 kW - 2 MW	11.0	11.0	11.0	20
	2 MW – 5 MW	4.5	4.5	4.5	20
MicroCHP pilot*	< 2 kW*	10*	10*	10*	10
PV	< 4 kW (new build)	36.1	36.1	33.0	25
	< 4 kW (retrofit)	41.3	41.3	37.8	25
	4-10 kW	36.1	36.1	33.0	25
	10-100 kW	31.4	31.4	28.7	25
	100 kW-5 MW	29.3	29.3	26.8	25
	Stand alone system	29.3	29.3	26.8	25
Wind	< 1.5 kW	34.5	34.5	32.6	20
	1.5-15 kW	26.7	26.7	25.5	20
	15 - 100 kW	24.1	24.1	23.0	20
	100 - 500 kW	18.8	18.8	18.8	20
	500 kW - 1.5 MW	9.4	9.4	9.4	20
	1.5 MW - 5 MW	4.5	4.5	4.5	20
Existing microgenerators transferred from the RO		9.0	9.0	9.0	to 2027

* Note the microCHP pilot will support up to 30 000 installations with a review to start when the 12 000th installations has occurred

5. Outlook for the EU’s renewable electricity generation in 2020

The EU Member States were required to publish National Renewable Energy Action Plans (NREAPs) in 2010. These plans include RES-E targets by technology for the year 2020. In this chapter, the NREAPs are first analysed in terms of the projected electricity production. Then these plans are compared to other forecasts and scenarios on renewable electricity generation in the European Union. The comparison will focus on wind and solar power.

5.1 Summary of the National Renewable Energy Action Plans

Article 4 of the renewable energy Directive (2009/28/EC) required the Member States to submit National Renewable Energy Action Plans (NREAP) to the European Union by 30 June 2010. These plans provide detailed roadmaps of how each Member State expects to reach its legally binding 2020 target for the share of renewable energy in their final energy consumption. By the end of the year 2010, all 27 Member States had published their National Renewable Energy Action Plans. In the following, a summary of these plans for the RES-E production is presented.

Figure 20 and Figure 21 show the summarised projected trajectory for different renewable electricity generation techniques. In the first figure, each Member State’s estimation of the total contribution (gross electricity generation) expected from each renewable electricity technology have been summarised to reach an estimate for the whole European Union. RES-E generation is expected to almost double from 653 TWh in 2010 to 1 217 TWh in 2020. The sectoral targets for 2010 and 2020 are presented also in Table 9. Largest addition is expected in wind power production. Onshore wind power production is projected to more than double between 2010 and 2020, while offshore wind power production is projected to increase from 9 TWh in 2010 to 134 TWh in 2020. High growth is also expected in solid biomass-based electricity production (78 TWh between 2010 and 2020) and photovoltaics (63 TWh). Hydropower production will increase only slightly.

Figure 21 illustrates the projected trajectory for individual RES-E production technologies. In 2020, wind power will be the single largest RES-E production technique, if the projected trajectory is realised. Wind power production will exceed hydropower production in 2016-2017. In terms of GWh’s, solar and biomass-sourced electricity will experience more modest growth. Hydropower production will increase only slightly. Geothermal, wave, tidal and ocean energies’ share of the total RES-E production will be only around 1 % in 2020.

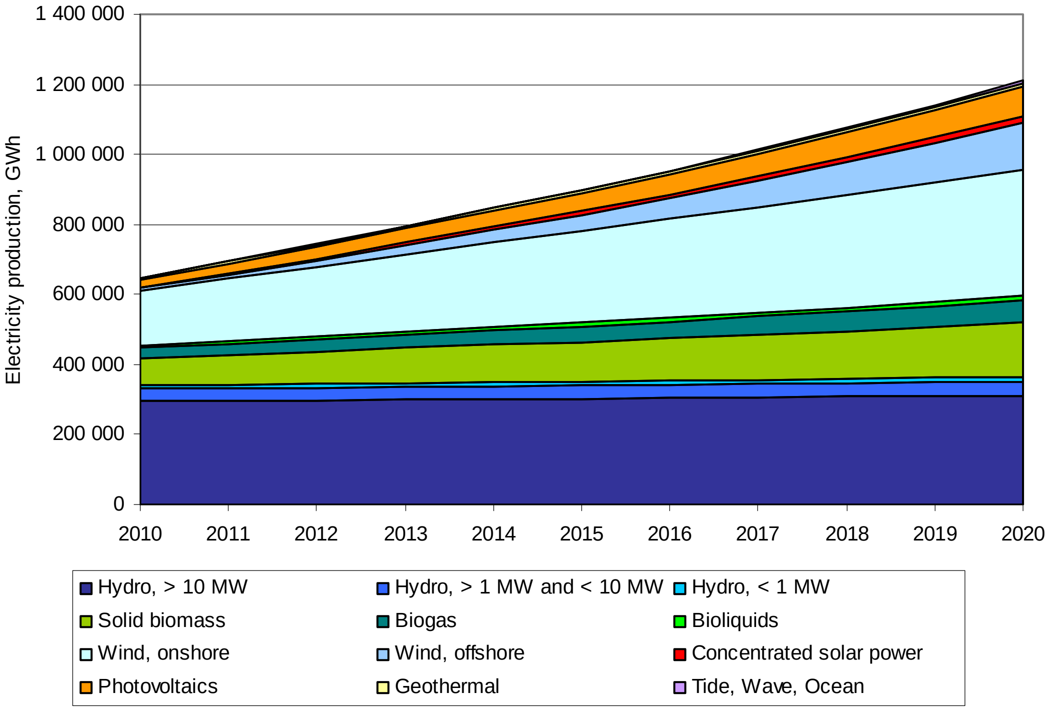

Figure 20. Projected trajectory of RES-E production for EU27 based on NREAPs.

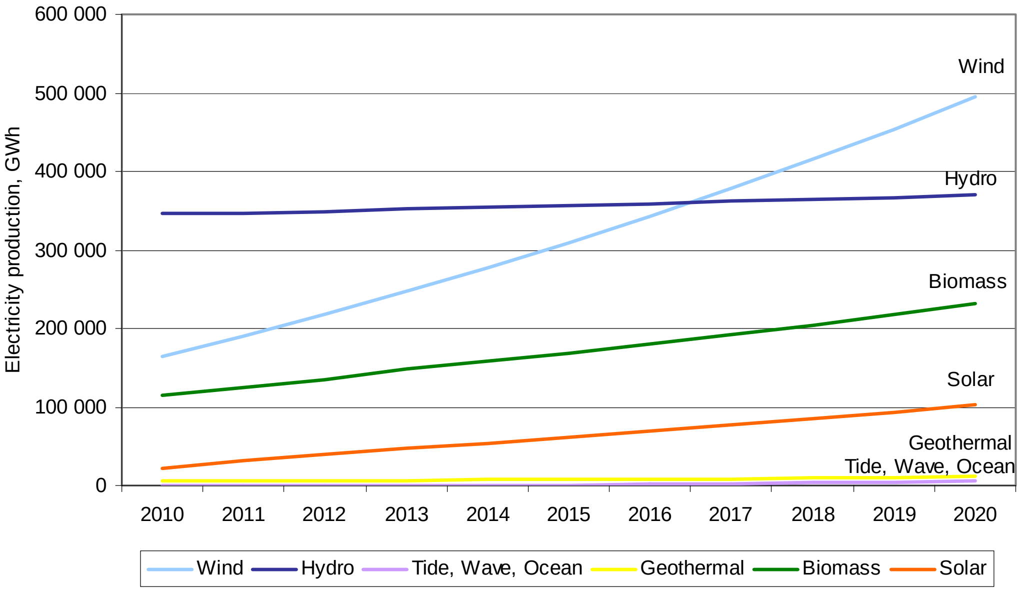

Figure 21. Individual RES-E technologies' projected trajectory for EU27 based on NREAPs.

Table 9. Summary of the NREAPs: renewable energy sources in electricity production for the years 2010 and 2020[14].

TWh	2010	2020	Difference between 2010 and 2020
Hydro, < 1 MW	11	12	2
Hydro, > 1 MW and < 10 MW	34	40	6
Hydro, > 10 MW	296	312	15
Hydro, pumped storage	23	32	9
Hydro total*	**346**	**370**	**24**
Wind, offshore	9	134	125
Wind, onshore	156	361	205
Wind total	**165**	**495**	**330**
Biogas	29	64	35
Bioliquids	9	13	4
Solid biomass	77	155	78
Biomass total	**114**	**232**	**118**
Concentrated solar power	1	20	19
Photovoltaics	20	83	63
Solar total	**21**	**103**	**82**
Geothermal	**6**	**11**	**5**
Tide, wave, ocean	**1**	**6**	**5**
Total RES-E	**653**	**1 217**	**564**

* Some countries include pumped storage in total hydro, some do not.

In 2020, the total RES-E production for the European Union is estimated to be 1 217 TWh based on NREAPs. This RES-E production represents 34 % of the projected gross final electricity consumption in 2020 (3 530 TWh).

Projected RES-E shares by Member State are illustrated in figure 22. If the NREAPs are realised, Austria, Sweden, and Latvia will have the largest RES-E shares in 2020. In all of these countries, large part of RES-E production is hydropower.

Figure 23 illustrates the projected variable power production (wind and solar) shares of the total consumption in 2020. For the whole European Union, wind power's share of the total consumption is projected to be 14 % and solar power share 3 %. Variable generation shares vary considerably between countries and electricity market areas. Ireland has the largest projected wind power share of 37 %, followed by Denmark (31 %), Greece (25 %), and Spain (21 %). Large solar power shares are projected in Spain (8 %), Germany (7 %), and Greece (5 %).

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[14] As some Member States include pumped storage in the total hydropower production and others do not, the total for hydropower does not match the sum of individual categories.

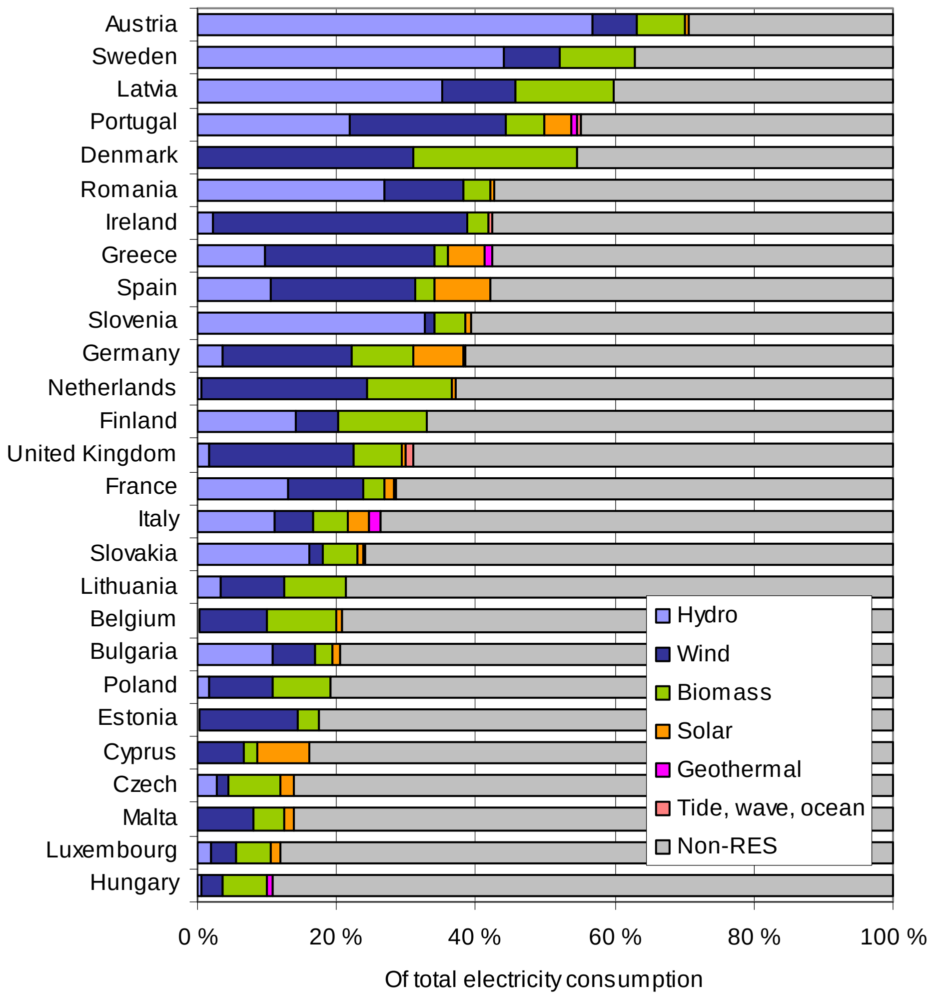

Figure 22. Projected RES-E shares of the total projected gross final electricity consumption in 2020.

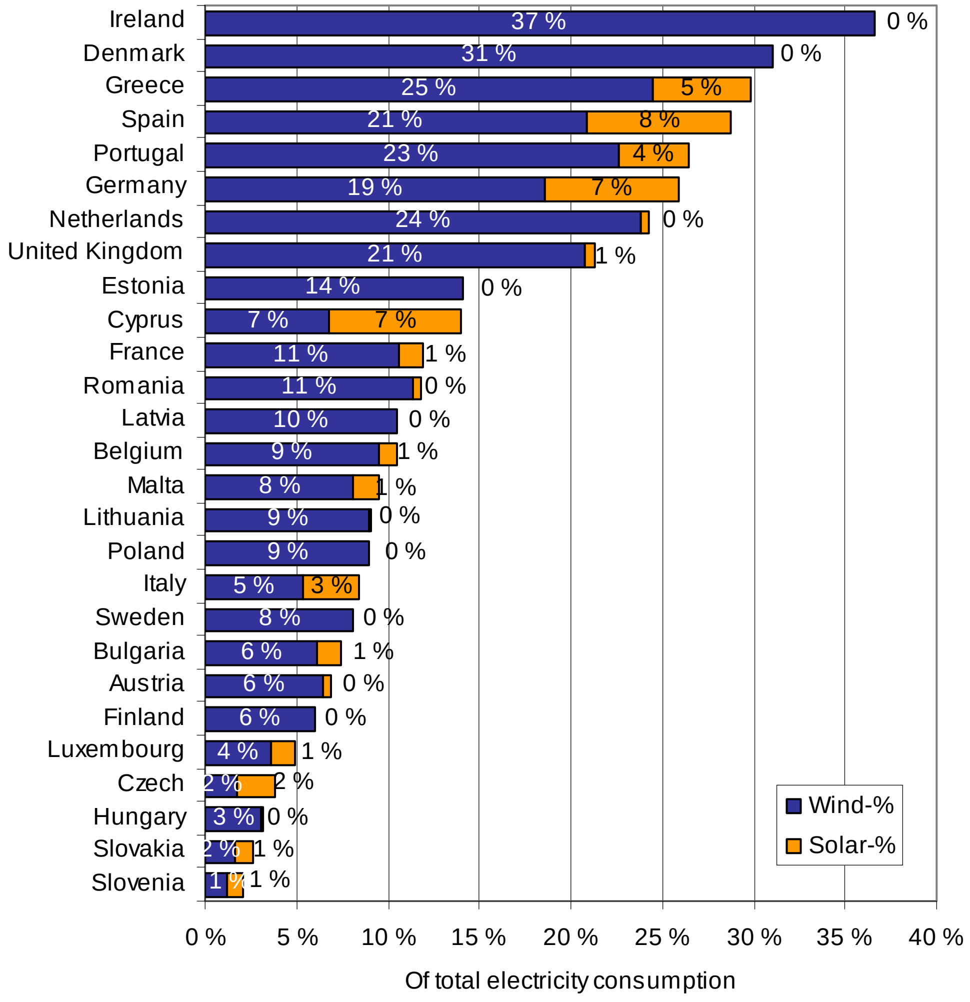

Figure 23. Projected wind and solar power shares of the total projected gross final electricity consumption in 2020.

5.1.1 Wind power

According to the Eurostat statistics, wind power production totalled 118 TWh in the EU in 2008. In NREAPs, this figure is forecasted to increase to 165 TWh in 2010, and then triple to 495 TWh by 2020. This figure represents 14 % of the projected total gross final electricity consumption in 2020. If the projected trajectory is realised, wind will be the largest source of renewable electricity in 2020, exceeding hydropower by more than 100 TWh/year.

For the year 2010, NREAP plans for wind power capacity seem to be in line with actual wind power capacity. The targeted wind power capacity in 2010 is 84.9 GW, and according to the European Wind Energy Association EWEA, the installed wind power capacity in the European Union was 84.1 GW in the end of 2010.

Figure 24 illustrates the projected wind power additions between 2010 and 2020 by country. Onshore wind power production is projected to increase by 205 TWh and offshore production by 125 TWh.

Largest additions in wind power production are expected in Germany, United Kingdom, Spain, France, and the Netherlands. These countries are already large wind power producers. Germany, United Kingdom, France, and the Netherlands expect to increase their offshore wind power production significantly.

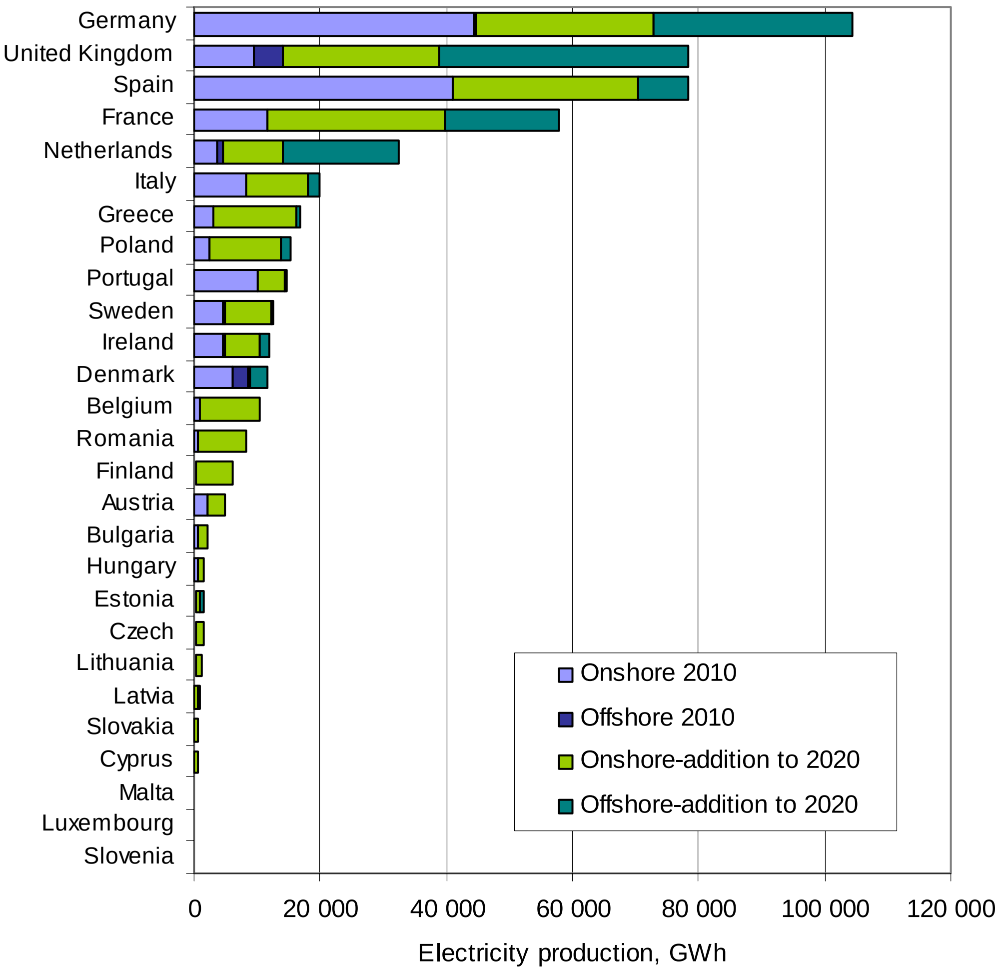

Figure 24. Summary of the National Renewable Energy Action Plans – wind power[15].

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[15] Belgium and Finland have not specified the division between onshore and offshore wind power. In this graph, all wind power in these countries is assumed onshore although both countries have coastline.

5.1.2 Biomass

In 2005, EU27 electricity production from biomass was 102 TWh. According to the NREAPs, biomass-sourced electricity production is forecasted to increase to 114 TWh in 2010, and then double to 232 TWh in 2020. Figure 25 illustrates the projected biomass-sourced electricity production additions between 2010 and 2020 for EU27. Electricity production from solid biomass is projected to increase by 78 TWh, electricity production from biogas by 64 TWh and from bioliquids by 4 TWh.

Largest additions in biomass-sourced electricity are expected in Germany, United Kingdom, France, the Netherlands, and Italy. The largest additions by technology are

- **Solid biomass**: largest increase in the United Kingdom (15 TWh), which accounts for 23 % of the total increase in solid biomass-sourced electricity. Other large additions in solid biomass-sourced electricity are expected in France (9 TWh), Germany (7 TWh), Belgium (7 TWh), and Sweden (6 TWh).
- **Biogas**: largest additions in Germany (10 TWh), Italy (4 TWh), the Netherlands (4 TWh), and Poland (4 TWh). Electricity production from biogas in projected to decrease by 1.3 TWh in the United Kingdom.
- **Bioliquids**: additions only in Italy (3 TWh), Finland (660 GWh), and in Portugal (353 GWh). Other Member States do not expect additions to electricity production from bioliquids.

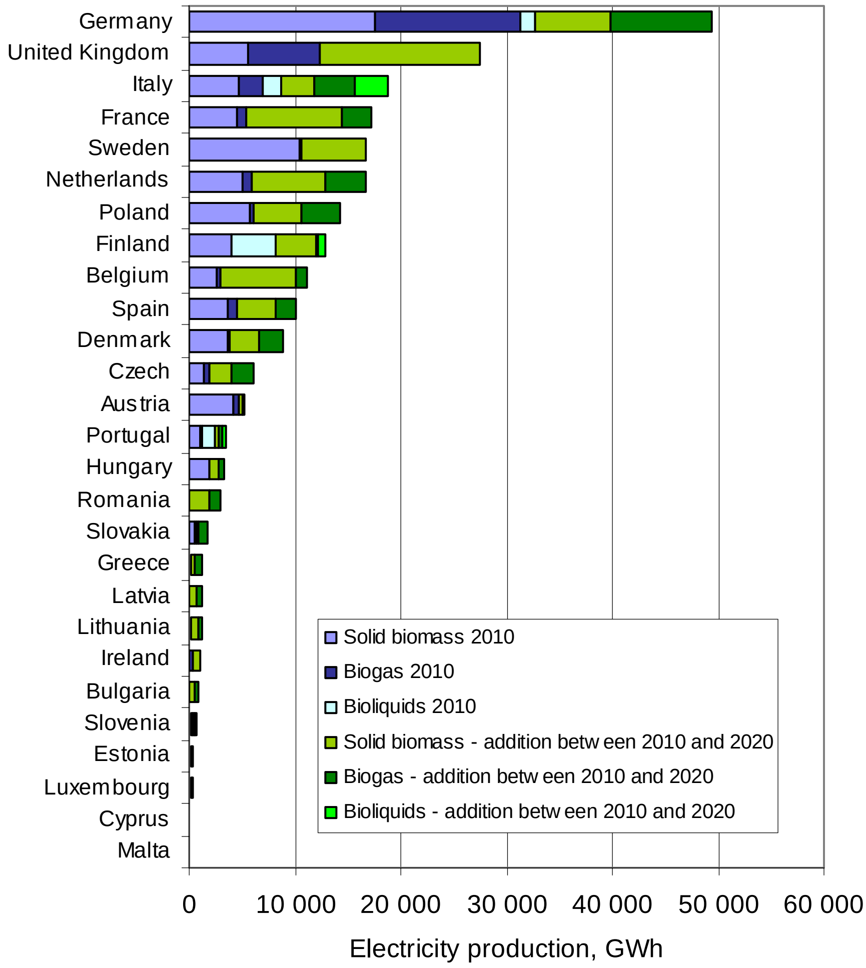

Figure 25. Summary of the National Renewable Energy Action Plans – electricity production from biomass.

5.1.3 Solar electricity

In EU27, solar electricity production totalled 7.4 TWh in 2008. This electricity was almost solely produced in photovoltaic systems. Member States aim to increase solar electricity production to 21 TWh in 2010 and further to 103 TWh in 2020.

Between 2010 and 2020, largest additions in solar electricity production are expected in Germany (41 TWh), Spain (30 TWh), Italy (11 TWh), and France (7 TWh). In Spain, concentrated solar power production is expected to increase by 14 TWh, while in other Member States, CSP is projected to produce significantly smaller amounts of electricity in 2020. Other countries rely on photovoltaic systems.

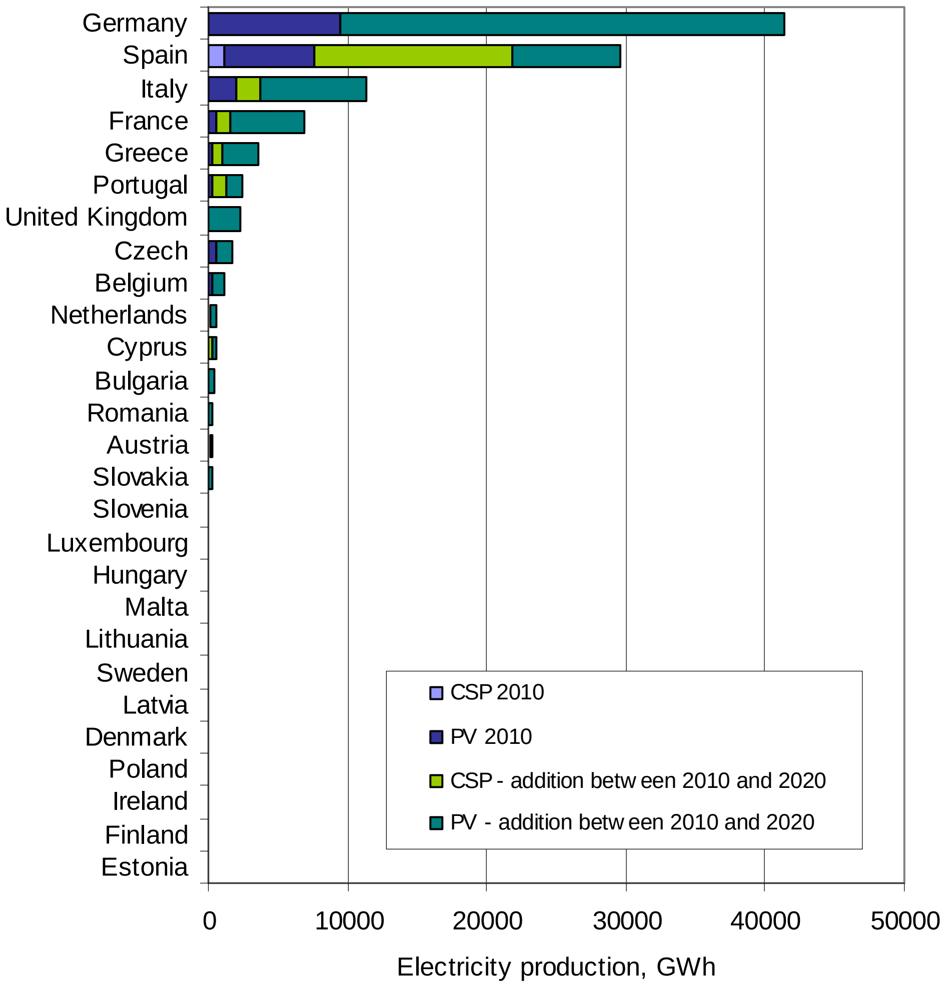

Figure 26. Summary of the National Renewable Energy Action Plans – solar electricity.

5.1.4 Hydropower

Hydropower production varies from year to year depending on hydrological situation. In 2008, the total EU27 hydropower production was 352 TWh according to Eurostat statistics. For 2010, the targeted hydropower production is 346 TWh according to NREAPs. Large-scale hydropower dominates with a production of 296 TWh, while small-scale hydropower production is expected to be 45 TWh.

Electricity production from large-scale hydropower is projected to increase to 370 TWh by 2020. Largest additions in large-scale hydropower production are expected in Spain (4.5 TWh), Portugal (3.6 TWh), Austria (3.1 TWh), and Romania (2.6 TWh). Two countries, Sweden and Italy, expect large-scale hydropower production to decrease by 3.2 TWh (Sweden) and 3.0 TWh (Italy).

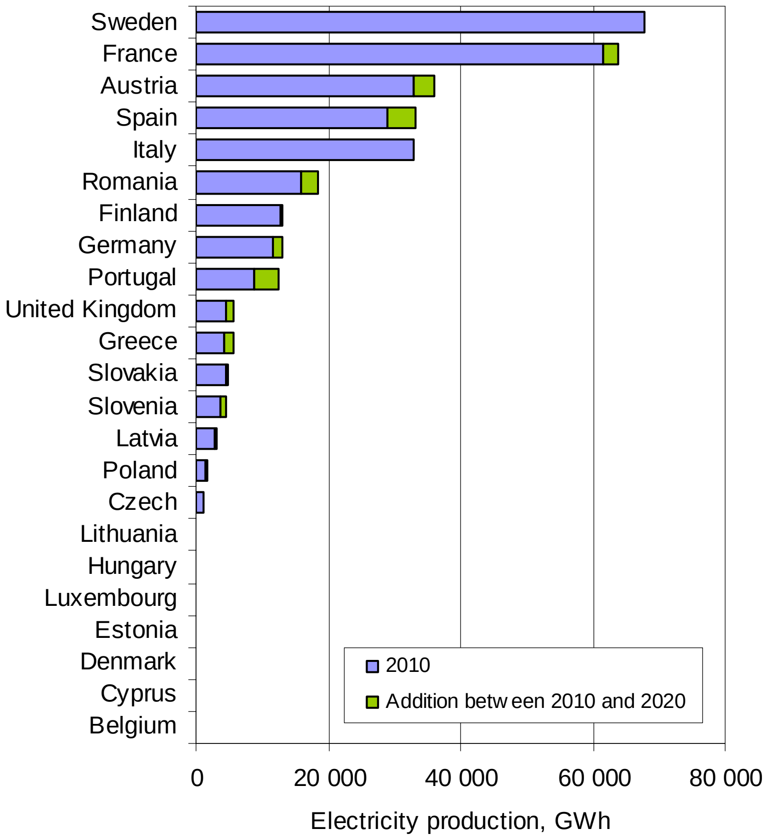

Figure 27. Summary of the National Renewable Energy Action Plans – large-scale (> 10 MW) hydropower. In Sweden and in Italy large-scale hydropower production is expected to decrease by 3.2 TWh (Sweden) and 3.0 TWh (Italy).

Small-scale (< 10 MW) hydro power production is projected to be 45 TWh in 2010 and increase to 53 TWh by 2020. Largest addition is expected in Italy (2.9 TWh).

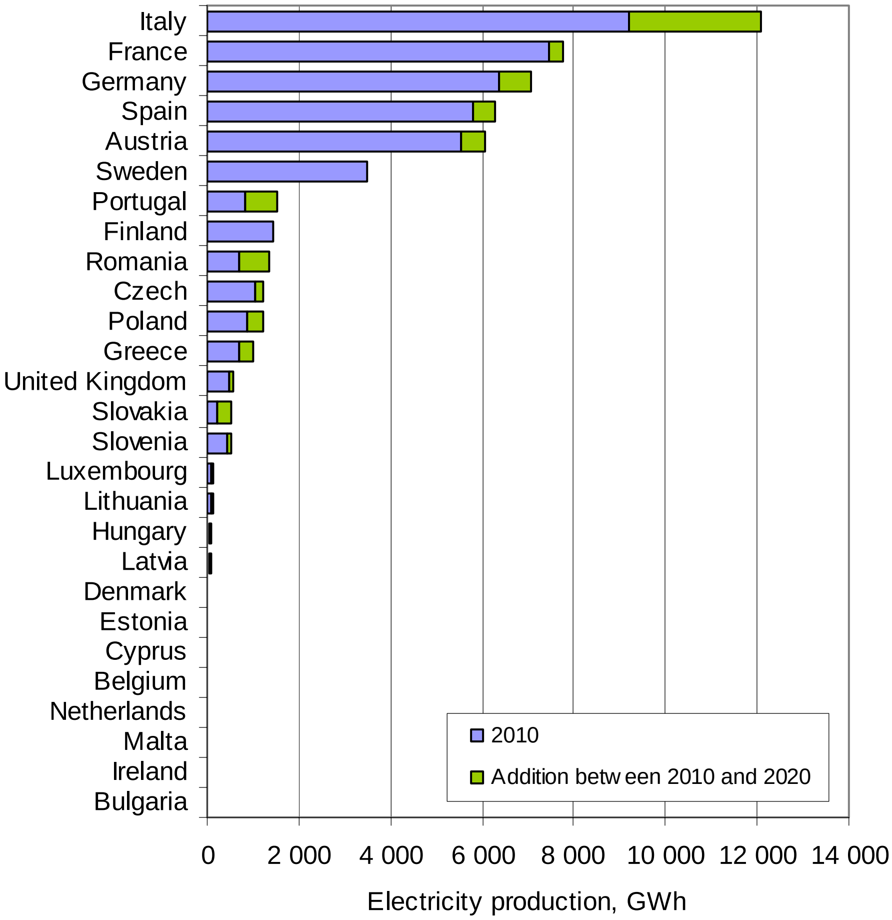

Figure 28. Summary of the National Renewable Energy Action Plans – small-scale (< 10 MW) hydropower.

5.1.5 Geothermal power systems

Electricity production from geothermal power stations totalled 5.5 TWh in 2005. The total production is projected to increase to 6.0 TWh in 2010 and further to 10.4 TWh in 2020. Figure 29 illustrates the situation in Member States that had included at least some geothermal power production in their NREAP.

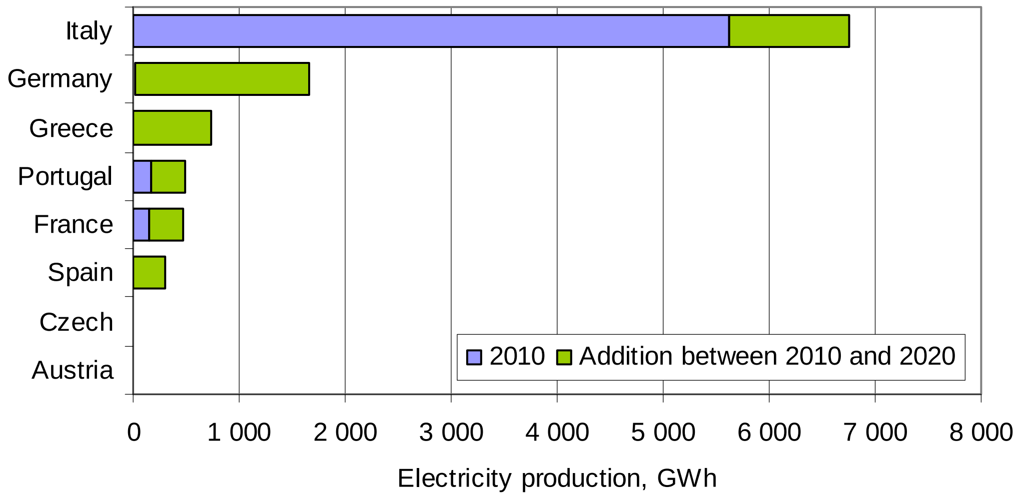

Figure 29. Summary of the national Renewable Energy Allocation Plans – electricity production from geothermal power systems.

5.1.6 Tide, wave and ocean energies

According to the National Renewable Energy Action Plans, only France produced electricity from tide, wave and ocean in the year 2005. This production totalled 0.5 TWh. In 2010, tide, wave, and ocean power production is expected to be still 0.5 TWh. By 2020, the production is expected to increase significantly compared with current production levels. United Kingdom, France, Portugal, Ireland, Spain, and Italy plan to produce electricity in these systems, and the total projected electricity generation is 6.0 TWh in 2020. Figure 30 illustrates the situation in Member States that had included tide, wave and ocean-sourced power production in their NREAP. Italy's production is expected to be 0.005 TWh in 2020.

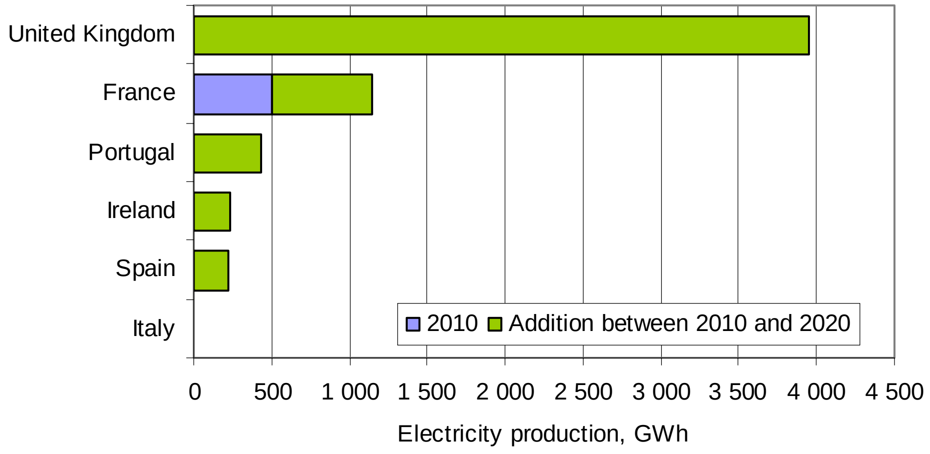

Figure 30. Summary of the National Renewable Energy Action Plans – electricity production from tide, wave and ocean power.

5.2 Comparison of NREAPs to other RES-E scenarios

In recent years, many different organisations have published their views on how the EU could transform to a low carbon economy. Some of these are long-term scenarios focusing on the year 2050, while some are more detailed forecasts for the closer future. In this chapter, different scenarios for wind and solar power production in the EU are compared.

Usually publications include at least two scenarios. *Baseline scenario* determines the development under current trends and policies already adopted. This scenario serves as a baseline, to which other scenarios can be compared. Baseline scenario should not be considered as a forecast. *Climate policy scenarios* include new policies, which have not yet been adopted by the time the scenario is made.

The analysis focuses on scenarios published in 2009 and 2010. Economic concept has greatly changed in recent years. The global downturn, which started in autumn 2008 led to falling fuel and electricity prices, and electricity consumption showed negative growth rates in year 2009. Since then, medium and long-term outlooks have been revised with new energy consumption figures. Especially the figures for the next couple of years have been changed. Analysed scenarios are presented in the following:

EU energy trends to 2030 – update 2009 by European Commission (EC 2010)

This report includes two scenarios: a baseline scenario and a climate policy scenario called “reference scenario”. The scenarios have been derived with the PRIMES energy system model by a consortium led by the National Technical University of Athens. The scenarios give detailed data for each 27 Member States. The study has been commissioned by the Directorate General for Energy in collaboration with the Directorate General for Mobility and Transport.

World Energy Outlook 2010 by International Energy Agency (IEA 2010)

Annually published World Energy Outlook includes projection of energy demand, production, trade, and investment, fuel by fuel and region by region to 2035. In the 2010 edition, three different scenarios were presented. “Current policies” scenario serves as a baseline scenario, “New Policies Scenario” anticipates future actions by governments to meet the commitments they have made to tackle the climate change and growing energy insecurity, and “450 Scenario” is a pathway with the objective of limiting the global temperature increase under 2° C. The study has been prepared by the International Energy Agency.

Ten-year network development plan 2010-2020 by European Network of Transmission System operators for Electricity (ENTSO-E 2010)

The European transmission system operators published their first community wide network development plan in 2010. The first publication was a pilot project, where new RES-E generation was forecasted as a bottom-up approach based on individual forecasts made by national TSOs.

RE-thinking 2050. A 100 % Renewable Energy Vision for the European Union by European Renewable Energy Council (EREC 2010)

The study presents an ambiguous vision for a 100 % renewable energy system by 2050 for the European Union. The report focuses on economic potential of renewable energy. The RES-E figures for electricity supply are projections of EREC's member associations, which include for instance European Wind Energy Association (EWEA), European Photovoltaic Industry Association (EPIA), and European Solar Thermal Industry Federation (ESTIF).

Power Choices. Pathways to Carbon Neutral Electricity in Europe by 2050 by Union of the Electricity Industry (Eurelectric 2010)

This report is based on a greenhouse gas reduction goal of 75 % across the entire EU economy. Power Choices study uses the PRIMES energy model. In Power Choices –scenario, the EU power sector's carbon intensity falls by almost 95 % from 2005 to 2050.

In the following, above mentioned wind and solar power production scenarios are compared to the actual generation in the years 2000-2008 and summaries of the NREAPs. Shorthands for the scenarios are

- NREAP: Summary of the National Renewable Energy Action Plans
- EU: EU Energy Trends to 2030 - Update 2009
- IEA: World Energy Outlook 2010, where 'a' refers to New Policies –scenario and 'b' to 450 scenario
- ENTSO-E: Ten-Year Network Development Plan 2010-2020
- EREC: RE-thinking 2050. A 100% Renewable Energy Vision for the European Union
- Eurelectric: Power Choices. Pathways to Carbon Neutral Electricity in Europe by 2050

5.2.1 Wind power

Figure 31 includes the actual wind power production during 2000-2008 and different projections for the years 2020 and 2030. In the EU, wind power production totalled 118 TWh in 2008. Newest production estimates for the year 2010 are available from Eurobserver, which estimates the wind power production in 2010 to be 147 TWh. The projected wind power production in 2020 varies between 399 TWh (EU Energy Trends 2030, baseline) to 525 TWh (EU Energy Trends, climate policy scenario). The summarised NREAP wind power production is 495 TWh.

For the year 2030, EREC gives the most optimistic wind power production scenario (833 TWh). Lowest value, 586 TWh was found in the IEA's baseline scenario.

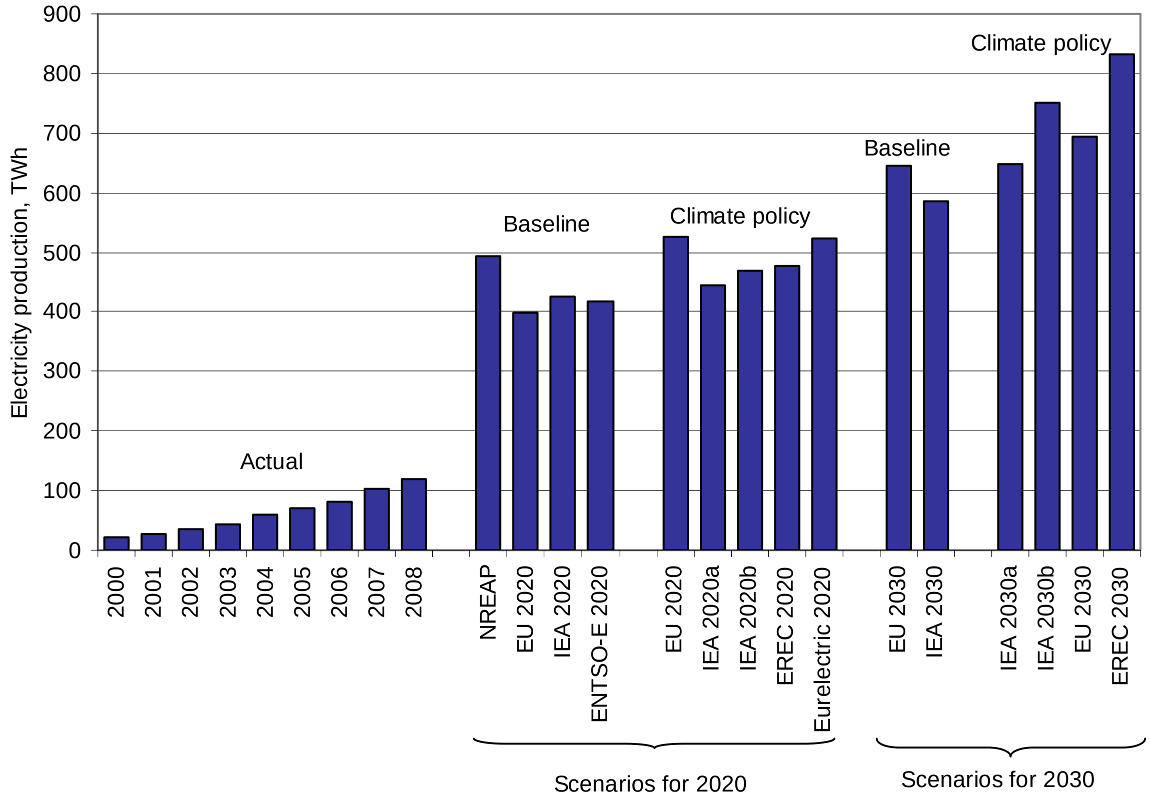

Figure 31. Actual wind power production in the years 2000-2008 and scenarios for 2020 and 2030 in the European Union.

5.2.2 Solar power

According to Eurostat statistics, solar power production has grown from 4.5 TWh in 2000 to 5.4 TWh in 2008. For the year 2020, different scenarios of solar power production vary a lot. Lowest value can be found in ENTSO-E's TYNDP, which gives a value of 24 TWh. Second lowest value is almost twice larger, 46 TWh in EU's baseline scenario. Largest value, 223 TWh by EREC, is also significantly larger than any other projection. The summarised NREAPs give a solar power production of 103 TWh in 2020.

Projections for 2030 range from 75 TWh (EU baseline) to almost 700 TWh (EREC). EREC's figure is significantly larger than any other projection.

In IEA's scenarios, CSP's share of the total solar power output varies between 21-30 % in year 2020 and is about 30 % in 2030. EREC publishes also the division between CSP and PV. For both 2020 and 2030, CSP's share of the total solar power production is 20 %.

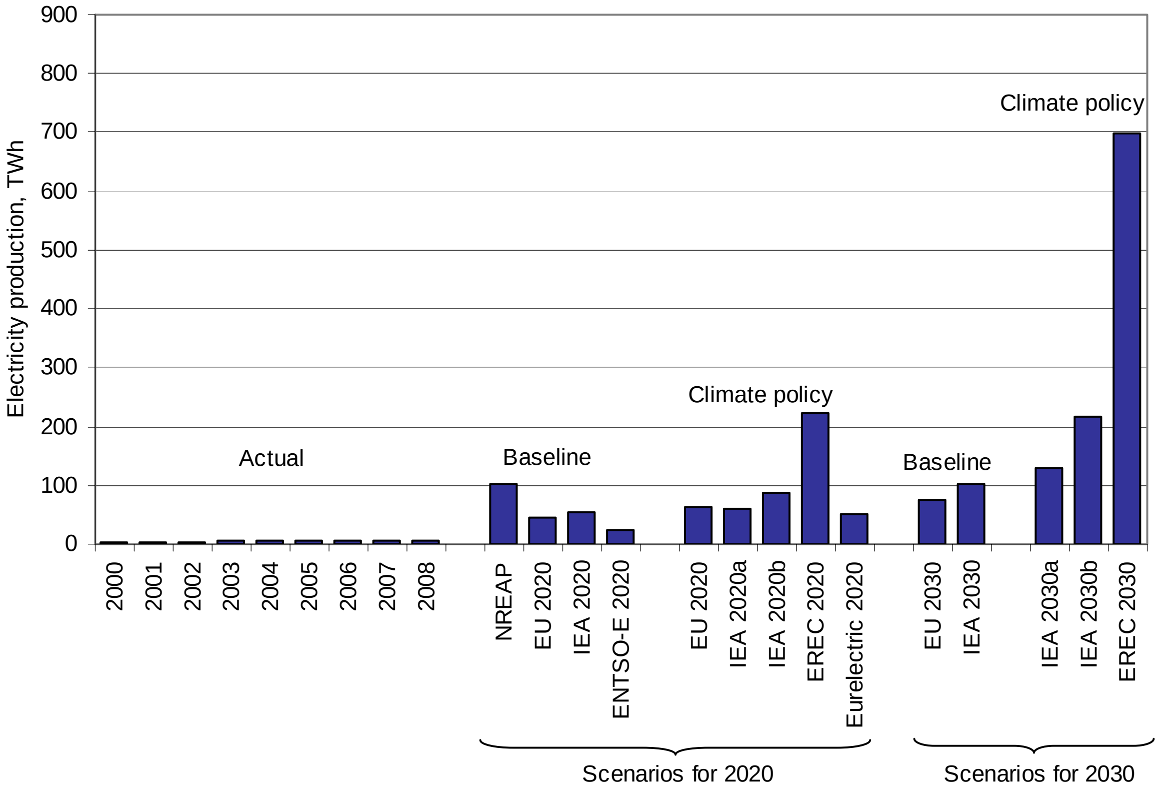

Figure 32. Actual solar electricity production in the years 2000 and 2008 and scenarios for 2020 and 2030 in the European Union.

6. Market and grid integration issues

Wind power and photovoltaics (PV) are not dispatchable forms of power generation in the traditional sense. They can generate electricity only when the energy source is available. This creates two related challenges for the power system: the production varies and it has a considerable forecast error. Same issues are to a lesser extent manifest in tidal (only variability), wave, run-of-river hydropower, and concentrating solar thermal without heat storage, but these are not considered further in this chapter. Other forms of renewable power (biomass, reservoir hydropower, and geothermal) should not have significant integration issues as they can be integrated into the existing operational structures.

Rest of the power system has to accommodate the variation from the variable forms of renewable energy (varRE). Large part of electricity demand is already variable and hence the variability in varRE generation will add to the existing variation. Small amounts of varRE will not be a problem for the system as the system is already capable of handling variation. However, as the penetration of varRE increases, it will first start to influence and then to overshadow the existing demand variation. Power systems are not necessarily equipped to deal with increased variation. It will require specific measures to keep system reliability at high level and to minimize the economical impact of additional variation. These measures are discussed in this chapter (see more in Holttinen et al 2009).

Forecast errors will increase in a similar manner. Currently electricity demand has a prediction error and conventional power plants sometimes fail to produce according to the schedules that are decided before the actual system operation. The forecast error in varRE can be considerable especially in the operational time scale where day-ahead markets usually close 12-36 hours before the hour of operation. This chapter discusses different means to cope with the increase in forecast errors.

The chapter also summarizes the challenges associated with connecting varRE to the grid and keeping the grid stable with high penetration of varRE.

6.1 Variability decreases with increasing area

One power plant, be it wind power turbine or a PV panel, can have large fluctuations in output over short time scales. However, as more and more power plants of this kind are connected together through the power grid, there is very significant smoothing of the variation. Variation is defined here as per unit variation, which means change in the production divided by the installed capacity. This is measured as a step change over a certain time scale. The smoothing effect is due to decreasing correlation as the distance between production sites grows.

The variation in PV will get smaller as the size of the area grows (Wiemken et al 2001, Murata et al 2009, Mills and Wiser 2010). One source of variation is due to clouds passing over the PV array. Variations due to cloud cover changes are not correlated over longer distances in shorter time scales, since the same cloud will not pass over multiple sites simultaneously. It is therefore smoothed out as can be seen from Figure 33. In longer time scales a large cloud can move or develop over multiple sites within the analyzed time scale. Another source of variation is due to diurnal cycle in the solar insolation. This is naturally highly correlated even over longer distances.

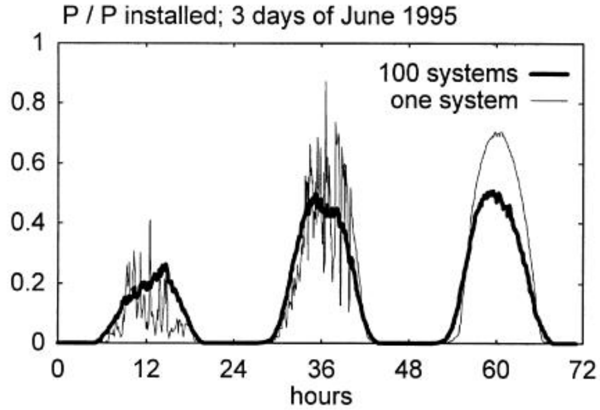

Figure 33. Variation of PV production in Germany during three days. The figure shows how the variation is smoothed when the output from multiple PV systems is analysed instead of only one system. Data based on 5 minute averages. Reprinted from Wiemken et al 2001.

Wind turbines experience changes in production due to wind turbulence and gusts. These are not correlated over longer distances and therefore they are smoothed out with increasing area and number of turbines (Wan 2005). On the other hand, most wind power production is based on pressure gradients present in the synoptic scale weather systems. This creates correlations in production over longer time scales even in a large area. However, wind farms dispersed over a large geographical area (e.g. a country) are located under different parts of the synoptic weather system and therefore the correlation decreases as distance grows (Figure 34). In addition, some winds are due to local weather phenomena and can be uncorrelated with the synoptic weather system pressure gradients (for further discussion of wind meteorology, see Petersen et al 1998). If wind power is concentrated in a relatively small area, there can be a relatively fast change in production when a weather front passes over the area (e.g. Wan 2005).

The lack of correlation leads to smoothing in the production, which can be depicted with a duration curve as in Figure 35. In a duration curve, the average hourly productions of the year are sorted in a descending order. A single site or turbines from a single country have a higher range of possible outputs than wind turbines that have been spread out over a whole continent (Kiviluoma and Lu 2010). However, in practice smoothing will be limited by the constraints in transmitting the power from production sites to load centers as well as market barriers to take advantage of the existing transmission.

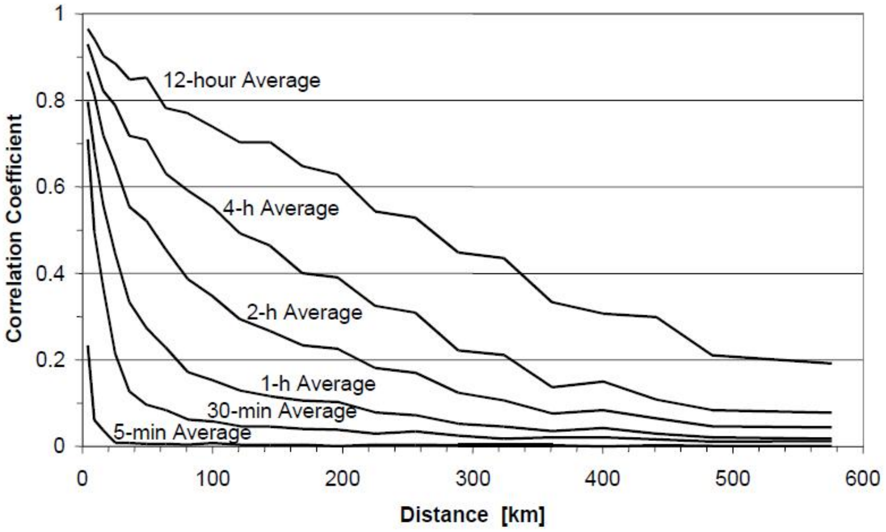

Figure 34. Correlation coefficient of Δp for different time scales over a varying distance (reprinted from Ernst et al 1999).

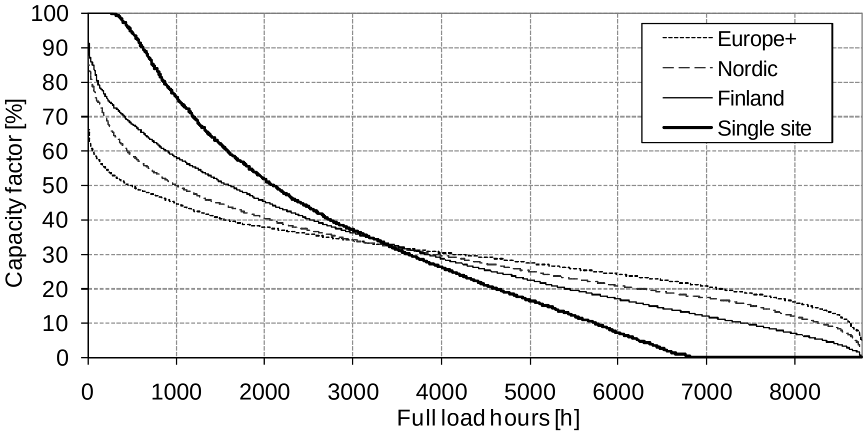

Figure 35. Approximate duration curves for wind power at different spatial scales. The time series have been scaled with an exponent to match the capacity factor of about 30%. Europe+ refers to Europe and parts of North Africa.

6.2 Integration of power markets

Smoothing of variable production over longer distances is one reason to integrate power markets. Market integration will also decrease the costs of operating the power system, as production from cheaper conventional power plants in one country can replace more costly production in another country. Furthermore, the provision of ancillary services across borders is usually less expensive than providing those separately country by country. VarRE will increase the need for some ancillary services.

However, it is challenging to integrate power markets. First, there are winners and losers and losers tend to resist change. Existing producers often lose if prices fall due to market integration. Power systems also include natural monopolies, which might in principle be indifferent towards change, but in practice, it could take a while before they embrace the change. Market integration will also influence monetary flows between the countries. Second, the existing practices and legislations have to be reconciled, which can be difficult.

Third, operation of larger systems gets increasingly complex and the stability of the power system might be increasingly at risk. Preventive measures can alleviate the problem, but blackouts are caused by unexpected events and larger systems might be more prone to those. One particular challenge associated with variable production is that power flows in a large meshed grid will be difficult and slow to calculate. If certain lines are expected to get overloaded further calculations are necessary to find an operating strategy that will relieve the problem. This has to be done before the operation.

6.3 Super grids

There have been proposals to increase the amount of long-distance transmission lines radically in order to integrate markets and facilitate the transmission of mainly renewable generation to load centers. However, power losses increase as distance grows. This is especially true for AC transmission, which is the backbone of current high voltage grids. High voltage DC (HVDC) lines would have much lower losses and therefore have been proposed to form the backbone of the super grid. However, technology for meshed HVDC grids is immature and there is no experience how it would be operated. At least it would be possible to point inject power from a distant resource location to the midst of the AC system with a HVDC line.

In Europe there is discussion of building a super grid to connect offshore wind power as well as Northern African solar and wind resources to consumption areas, which are mainly located in central Europe (e.g. Desertec, Friends of the Supergrid). Figure 36 shows an example of a super grid configuration. The discussion is backed by some tentative research, which indicates that using the better resources at a distance is more economic than using poorer resources closer to consumption (Giebel et al 2005, Czisch and Schmid 2004, Kiviluoma and Lu 2010). Discussion is ongoing in the US as well, where several large studies have been performed analyzing the costs and benefits of trunk lines for varRE integration (DoE 2008, Corbus *et al* 2010, Lew *et al* 2010).

Figure 36. Concept of a “EUMENA Supergrid” based on HVDC power transmission as “Electricity Highways” to complement the conventional AC electricity grid, as developed by TREC in 2003. The symbols for power sources and lines are only sketching typical locations. Reprinted from Desertec Foundation 2009.

6.4 Wind power will affect operational reserves

If electricity consumption were to be perfectly known beforehand, and power plants and power lines would not fail from time to time, there would be no need to keep reserves. Everything could be scheduled beforehand and the system would run smoothly. As this is not the case, power system operators have to prepare to meet the forecast errors, variations within the market period, and occasional failures in power plants and in transmission lines. This is achieved with reserves, which are divided into many categories depending on their intended use. In here, simplified terms are used for reserve categories – the actual names and contents vary between power systems.

There is a reserve for a sudden large failure (contingency reserve). Contingency reserve has to react quickly to restore the balance between supply and demand. Changes in varRE output spread over a large area are not as dramatic as they occur in the time span of several hours. This can still lead to quite fast ramps at high penetrations, but contingency reserves are not used to deal with these. Instead, varRE will affect 1) the operating reserves that correct for the variations within the market period and 2) for the accumulating deviation arising due to forecast errors in demand as well as varRE.

The first line of operating reserves operates automatically and they need to be relieved in the case that the error stacks up in one direction. In the Nordic power system, the relief is achieved through a market based stack of offers from power plants and managed consumption. This is called balancing power. It usually takes a while (5-15 minutes for thermal units) to bring the new capacity online and therefore there has to be enough automatic operational reserves. Increased forecast errors lead to a need to increase the automatic operational reserves. It is also important to ensure that the market will provide a large enough stack of balancing power that can compensate for the sometimes rather large errors in varRE production over the time scale of power system operations.

6.5 Forecast errors can spur changes in market design and reserve structures

Wind power forecasts are used in power system operations in power systems where the share of wind power is considerable. Forecasts are used by wind power producers to make as informed bids as possible and by TSOs to ensure sufficient reserves. Forecasting tools have improved considerably and are likely to improve further (for review see Giebel *et al* 2011). On the average, the forecasting tools give decent predictions of wind power output in the day-ahead time range (root mean squared error between 5-15% of installed capacity depending on the forecast method, region, and regions size; Porter and Rogers 2009). However, at large wind power penetrations forecast error can add up to considerable MWs. There are also rare events with very large forecast errors and these can cause challenges for the system operation (e.g. Atienza 2009).

The forecasts have a smaller error if the predicted wind output is low and if the time horizon of the forecast is just few a hours (see Figure 37 and Figure 38). Both of these have important implications.

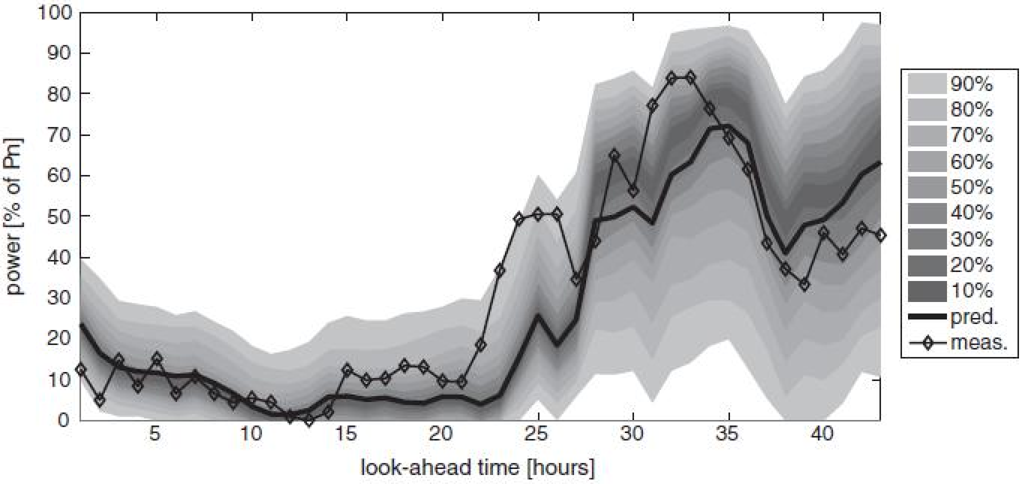

Figure 37. Example of probabilistic predictions of wind generation. (Reprinted from Pinsen *et al* 2009)

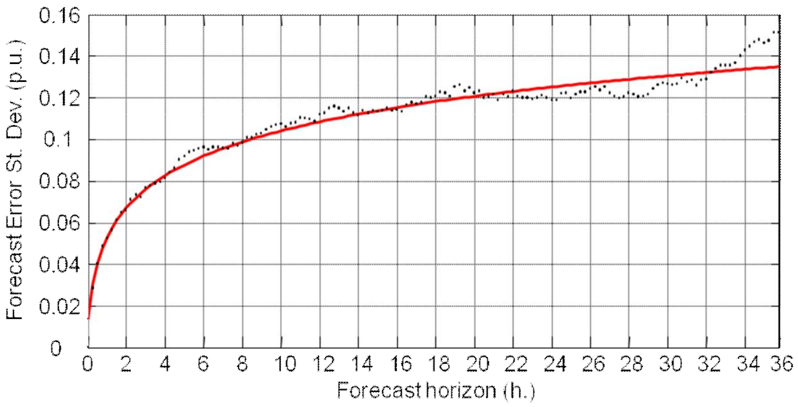

Figure 38. Normalized standard deviation of wind power forecast error for 12 GW installed capacity versus forecast horizon. (Reprinted from Gibescu et al 2009)

In current system operation practice, operational reserve requirements are usually kept constant. That constant is deemed enough for secure operation of the system. If wind power variability and forecast errors are treated in the same way, it will lead to large reserves requirements once the wind penetration is high. However, large variations and/or errors are not possible most of the time and it would be a waste of resources to upkeep unnecessary reserves. Therefore large wind penetration should lead to **dynamic reserve allocation** especially for the slower reserve categories. Reserve requirement should depend on the possible variation and forecast errors in wind and load as well as possible power plant or transmission line trips, and it should vary from hour to hour.

Another implication is that the day-ahead market will have a large forecast error in comparison to the situation one hour or two hours ahead of operation. Hence, **intra-day markets** with a short gate closure time become more beneficial and can decrease the need for reserves induced by wind power considerably. Balancing market can achieve the same thing, but the requirement to provide the power in 10-15 minutes can mean considerably higher costs than if there is one hour to start-up. Efficient intra-day market should also enable slower units to lock in a generation plan according to the start-up/ramping times of the unit. Wind forecast errors will have such a large impact on the slower reserve categories that it could be worthwhile to rethink how the reserves and markets are organized in a given system. Optimal configuration is also influenced by the amount and types of units in the system. For instance, a hydro system has very different capabilities than a thermal system. New market designs together with high varRE penetration would also promote investments in new flexible units or increasing the flexibility of existing units.

6.6 Connecting to the grid

In some parts within the European power systems, the lack of long-distance transmission capacity is becoming the key issue in integrating large amounts of wind power. This is taking place especially in the regions where the best sites are far from consumption. For PV the challenge is more in the distribution grids, although in some countries distribution grids are also an issue for wind power.

6.6.1 Distribution grids may not be adequate

Most PV and a portion of wind power have been connected to distribution grids. For wind power this has taken place especially in rural areas where higher voltage levels have not been available or when the wind farm size has been too small to warrant connection to a higher voltage level.

Distribution grids have been originally designed to transmit power from transmission grids to small-scale consumers. Large scale penetration of varRE in distribution grids will require new equipment for network control and protection to cope with the change from one-directional to bi-directional power flow (see Ehara 2009 and Coster et al 2011 for further information).

Several problems can take place when generation is connected to the distribution grid. In areas with low demand, overvoltage may occur, which can shorten lifetime of some equipment. Overvoltage can be mitigated by limiting the output from varRE, controlling reactive power, or by storing part of the produced electricity. Poor design of independently connected PV systems can lead to voltage imbalance issues. Harmonics are in principle possible, but can be prevented with proper equipment. Wind farms can also cause sudden dips in voltage, if a large amount of generation suddenly trips out of the distribution grid.

At high penetrations, varRE can overload either the distribution lines or distribution grid components. This can be prevented either by limiting varRE capacity or by upgrading the distribution grid. It can also be more cost effective to curtail peak production than to re-enforce the grid.

6.6.2 Connecting multiple varRE resources over time

Especially for wind power, the best resource areas are likely to get the bulk of the wind capacity. This will lead to problems in designing grid connections for multiple wind farms. A single wind farm might not warrant a connection to a higher voltage level, but further development in the same area can lead to a situation where a larger connection would have been beneficial in the first place. In addition, the necessary reinforcements in the transmission grid should be shared. Therefore, early planning is crucial. However, there will be risks associated with the uncertainty of future projects. It becomes important to agree who bears the risks and benefits of this uncertainty and to plan what is the best plan for transmission build-up from the overall perspective.

6.7 Other grid issues

In the past wind turbines have been equipped with protections that disconnect the turbine from the grid if changes in the frequency or voltage are significant enough. This has created challenges for the system operation, when a large amount of wind production has tripped when there has been a fault in the grid. This can be mitigated, since most new turbines are equipped with low voltage ride through capabilities, which mean that wind turbines can withstand certain faults in the grid. In addition, they could provide services to bring voltage and frequency back to the normal operating range. The new requirements have been included in the grid codes of power systems where the wind power penetration has been increasing. However, older wind turbines can still operate according to the former requirements.

Frequency deviations due to faults are normally arrested by inertial and governor responses of the conventional generators. When wind power production displaces conventional generation, the frequency control capability decreases. 10-20% wind power penetration means some days of situations where the share of production is high (50-100%). In these situations, a fault could cause an extreme dip in the system frequency. Wind turbines could provide some inertia to the system. The possible contribution is dependent on the rotating mass and speed of the rotor. However, this cannot be replenished at will after it has been exhausted, as is the case with conventional generators using governor response. To avoid loss of load, there has to be enough upward reserves that can support frequency before the frequency drop is too large. This is less of a problem in large systems where the inertia is naturally larger than in smaller systems, which rely on a few conventional generators at times of high wind power production.

7. Summary and conclusions

RES-E targets

The European Union has the target to increase the share of renewable energy sources (RES) in its gross final consumption of energy to 20 % by 2020 (9.2 % in 2006). Besides electricity sector, primary energy consumption covers heating, cooling, and transportation. Increasing RES in other sectors, e.g. transportation is more costly than in electricity generation, and hence the share of renewable energy sources in electricity generation will be significantly higher than 20 %, if the target for the year 2020 is achieved.

The EU has a long-term target to keep the global warming less than 2 degrees compared to pre-industrial level. This target would require the EU to cut the total greenhouse gas emissions by 80-95 % by 2050. By 2050, virtually all electricity generated should come from carbon-neutral sources. Thus, the share of RES in electricity generation will increase even more pronouncedly after 2020.

RES-E historical development and current state

In 2008, the electricity generation from renewable sources in the European Union totalled 585 TWh. Historically, hydropower has dominated the renewable electricity generation, and hydropower’s share of the total renewable electricity production has been around 60 % in the recent years. As almost all of the EU’s economically and technically exploitable hydropower capacity has already been built, hydropower production varies from year to year almost solely depending on hydrological conditions. Hydropower capacity has been more or less stable.

Non-hydro renewable power production has grown substantially. In 1995, non-hydro RES-E production totalled 30 TWh, and in 2008, this figure was 233 TWh. Wind power (118 TWh in 2008) and biomass-sourced electricity (102 TWh in 2008) comprised 95 % of the non-hydro RES-E generation in 2008. Of these two, wind power capacity and production have grown more sharpishly. Other RES-E technologies were still marginal on EU level in the year 2008: photovoltaics power generation was 7 TWh, geothermal power systems 5 TWh and solar thermal systems 16 GWh of electricity in 2008.

RES-E support schemes

The European Union Member States are required to support electricity from renewable sources. Currently, there is a different support system in each Member State, ranging from tax exemptions to feed-in tariffs. The market based instruments which can be used to promote electricity can be divided in between investment support (capital grants, tax exemption or reduction on the purchase of goods) and operating support (price subisidies, green certificates, tender schemes, and tax exemptions or reductions on the production of electricity). Generally, operating support (support per MWh) is far more important than investment support.

RES-E support schemes were studied for selected countries specifically Germany, Spain, the UK, and the Nordic countries. This report describes supporting schemes as they are today. Historically, supporting schemes have often been redefined when technologies have developed and costs decreased. Support mechanisms have also been developed to be more market oriented, and as RES-E generation shares increase, RES-E generators have been obliged to participate in the electricity market.

RES-E scenarios

In 2010, the EU Member States were required to publish National Renewable Energy Action Plans (NREAP). These plans provide detailed road maps on how the Member States expect to reach the legally binding targets for 2020. According to these plans, the RES-E generation is expected almost to double from 2010 to 2020 from 653 TWh in 2010 to 1217 TWh in 2020. Largest addition is expected in wind power production, which was projected to be 495 TWh in 2020 (147 TWh in 2010). High growth is also expected in biomass-based electricity production (78 TWh between 2010 and 2020) and photovoltaics (63 TWh). Hydropower production is expected to increase moderately (24 TWh). Ocean and geothermal energies will also experience moderate growth, if NREAPs are realised.

According to NREAPs, wind power production’s share of the total consumption in 2020 will be 14 % for the whole European Union. Solar power’s share will be around 3 %. The projected variable generation shares will vary a lot between countries and electricity market areas. Largest shares of variable generation (wind and solar power) are projected for Ireland (35 %), Denmark (31 %), Greece (30 %), Spain (29 %), and Portugal (29 %).

NREAP plans for wind and solar power were compared to other scenarios and forecasts of RES-E production in the European Union. Wind power production projections for the year 2020 ranged from 399 TWh to 525 TWh. Lowest values were in baseline figures, which are not forecasts for the future. Climate policy scenarios were roughly in line with the NREAP figure (495 TWh in 2020).

Projections for solar power varied greatly. Lowest value for solar power production in 2020 was 24 TWh (ENTSO-E). Second largest value was almost twice as large, 46 TWh, and the largest projection was significantly larger than any other projection, 223 TWh (EREC).

Grid and market integration

Wind power and photovoltaics (PV) are not dispatchable forms of power generation in the traditional sense. They can generate electricity only when the energy source is available. This creates two related challenges for the power system: the production varies and it has a considerable forecast error.

Rest of the power system has to accommodate the variation from the variable forms of renewable energy (varRE). Large part of electricity demand is already variable and hence the variability in varRE generation will add to the existing variation. Small amounts of varRE will not be a problem for the system as the system is already capable of handling some variation. However, as the penetration of varRE increases, it will first start to influence and then to overshadow the existing demand variation. Power systems are not necessarily equipped to deal with so large variation. It will require specific measures to keep system reliability at high level and to minimize the economical impact of additional variation.

Incorporating large amounts of varRE will require changes to current operational practices in order to achieve economic efficiency while maintaining reliable system operation. The factors influencing the system operation and possible ways to mitigate the impacts of variability and prediction errors have been summarized in chapter 6. The market design should be reconsidered, integration of markets and additional transmission lines become more beneficial, and capabilities of varRE power plants to provide some system services become important.

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