

Impacts of Electric Vehicles - Deliverable 3

Assessment of the future electricity sector

Report

Delft, April 2011

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Further information on this study can be obtained from the contact person Huib van Essen.

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Summary

Electric Vehicles (EVs) are a promising technology for reducing the GHG (greenhouse gas) emissions and other environmental impacts of road transport. It is important for EU policy makers to get an overview of the possible impacts of the introduction of Electric Vehicles. Therefore DG CLIMA commissioned CE Delft, ICF and Ecologic to carry out a study on the potential impacts of large scale market penetration of EVs and Plug-in Hybrid Electric Vehicles (PHEV) in the EU, with a focus on passenger cars and light commercial vehicles. This study includes an assessment of both the transport part (e.g., composition of vehicle fleet) and electricity production and the impacts on well-to-wheel GHG emissions, pollutant emissions, other environmental impacts, costs, etc. This report is the third deliverable of this project and provides an overview of the electricity sector and the potential interaction with EVs and PHEVs.

A review of current EU and Member State policies revealed a considerable interest in promoting renewable energy sources in the electricity sector. However, the results are still far from alleviating the overall dependency of EU Member States on energy imports and vast differences exist between the Member States. Moreover, electricity grids, i.e., both transmission and distribution grids vary considerably in terms of resilience to external pressures. Some Member States regularly experience power outages of considerable duration (mostly in Eastern Europe and the Mediterranean), while other systems perform much better (mostly in Western Europe).

The IPM model and the PRIMES baseline scenario were used to depict the expected future electricity market in the EU. The analysis finds that in a scenario without EVs, both the total electricity demand and the peak demand in the EU will rise by 22% between 2010 and 2030. The share of renewable capacity will grow from 26% in 2010 to 42% in 2030. Of this capacity increase 70% will be from wind, 6% biomass and 18% solar. By 2030 almost half of the capacity mix is composed of renewable (primarily wind) and nuclear capacity. This explains why peak prices increase significantly over time, especially after 2015, while base load and off-peak prices remain almost constant. Given the high share of renewable energy sources, our modelling results show a 10% CO₂ reduction between 2010 and 2030.

The impact of EVs on the absolute increase in electricity demand will be small. Even a complete electrification of the European fleet would result in an additional demand of about 10-15%. Electricity generation constraints are therefore unlikely to be a major issue, even with a high market uptake of EVs.

Regarding the interaction of Electric Vehicles with the current EU ETS, the overall effect will be a net reduction of GHG emissions because the overall emissions of the electricity sector are capped. For a modest EV uptake, we could identify no significant price signal in the emissions allowance market and thus no distortions to competitiveness.

Within the electricity sector, given the propagation of renewable energy sources, Electric Vehicles are both an opportunity and a threat. Intermittent energy sources such as wind and solar are difficult to coordinate with existing power generation capacities and with load curves. Already now, negative energy prices can occur at peak wind generation times that very often do not coincide with peak load periods. For times with high load and low wind



intensity, sufficient back-up generating power has to be available, reducing the overall system efficiency, i.e., increasing the cost per kWh. If uncontrolled EV charging is added to this already challenging situation, then this can have effects both at the distribution and at the generation level. Small scale EV introduction (up to 5% of the fleet) will not pose a significant threat to mature distribution grids. In Member States with weak electricity infrastructure, however, even small scale EV introduction can cause local power-outages if charging is uncontrolled.

Controlled charging – or smart charging – will allow a much greater number of cars in the system without local overload. Moreover, smart charging will allow load balancing both at sub-station and at the grid level, particularly with charging at peak wind supply times, thus easing the integration of large scale intermittent electricity sources such as off-shore wind energy. The total storage capacity of EVs is, however, quite limited and other forms of storage technology – such as pump storage or compressed air are more cost-effective.

In the medium-term, there is only a very small likelihood of EVs operating as batteries for the electricity grid, i.e., feeding back energy at peak demand times. Still, smart charging will allow EVs to penetrate the market with higher growth rates than the electricity generating capacity needs to grow, since it can make use of off-peak over-capacities. Nevertheless, under current legislation, EV owners would be able to charge whenever and wherever they want to, calling for a strong price incentive through dynamic tariffs.

Charging can be segmented into three categories: household connections, fast charging and battery swap systems. A major obstacle in Europe is that most car owners do not own a garage but park their car at the curb. This requires a multitude of capital intensive public charging stations. Given the immense investment needs and low electricity prices, no viable business concept has emerged so far. Especially swap stations seem to have a particularly low return on investment. A look into the mid-term future reveals that induction charging might become a safe and user-friendly solution to charging EVs. Current charging stations are either free or at least highly subsidised by either electricity providers or car manufacturers. Future business models might charge rather for the parking space than for the electricity.

At the time, three standards for connecting EVs to charging stations (power plug) compete for worldwide recognition: one from the American SAE, one from the European/international IEC and the Japanese CHAdeMO. Even though all players (i.e., manufacturers, industry associations) insist that they support a uniform standard, allowing any vehicle to charge at any station, also reducing the total number of charging stations needed. The outcome of this race for an international standard is still widely open. A common standard is expected in 2017.

Monitoring of EV electricity consumption – being relevant both for the accounting of the use of renewable energy in transport and the GHG emission targets in transport – can best be done through data from smart metering supplied by electricity providers. On board monitoring is less cost-effective.

Fuel taxation is currently a major income source to finance road infrastructure. Hence, it will be paramount to replace lost income through other revenues. Separate and smart metering would allow for a differentiated taxation of different electricity uses, collected indirectly through the electricity bill. The standardised power plug for EV charging, incompatible with other outlets, would prevent tax evasion.



EVs are relevant to a number of EU policies, most notably the Fuel Quality Directive (FQD) and the Renewable Energy Directive (RED). EVs can contribute to the reduction of carbon intensity of transport fuels as required under the FQD and can help achieve the set target of 10% renewable energy sources in transport by 2020. Both cases require a more detailed accounting of EV electricity consumption.





1 Introduction

1.1 Introduction to the project

Electric Vehicles (EVs) are a promising technology for drastically reducing the environmental burden of road transport. More than a decade ago and also more recently, they were advocated by various actors as an important element in reducing CO₂ emissions of particularly passenger cars and light commercial vehicles as well as emissions of pollutants and noise.

At the same time, EVs are still far from proven technology. There exist many uncertainties with respect to crucial issues like:

- The battery technology (energy capacity in relation to vehicle range, charging speed, durability, availability and environmental impacts of materials).
- Well-to-wheel impacts on emissions.
- Interaction with the electricity generation.
- Cost and business case of large scale introduction.

For EU policy makers, it is important to get a reliable and independent assessment of the state of the art of these issues in order to develop targeted and appropriate GHG reduction policy for transport. Therefore DG CLIMA commissioned CE Delft, ICF and Ecologic to carry out a study on the potential impacts of large scale market penetration of EVs in the EU, with a focus on passenger cars and light commercial vehicles. This study includes an assessment of both the transport part (e.g., composition of vehicle fleet) and electricity production and the impacts on well-to-wheel GHG emissions, pollutant emissions, other environmental impacts, costs, etc.

In this study three types of EVs are distinguished:

- Full Electric Vehicles (FEVs) that have an electric engine and no internal combustion engine (ICE).
- Plug-in Hybrid Electric Vehicles (PHEVs) that have both an ICE and an electric engine, with a battery that can be charged on the grid.
- Electric Vehicles with a Range Extender (EREVs) that have an electric engine and an ICE that can be used to charge the battery and so extend the vehicle's range. The battery of an EREV can be charged on the grid.

The results of the study should help the Commission with developing GHG policy for transport, in particular in the field of EVs and in relation to the wider EU transport policy and EU policy for the electricity sector.

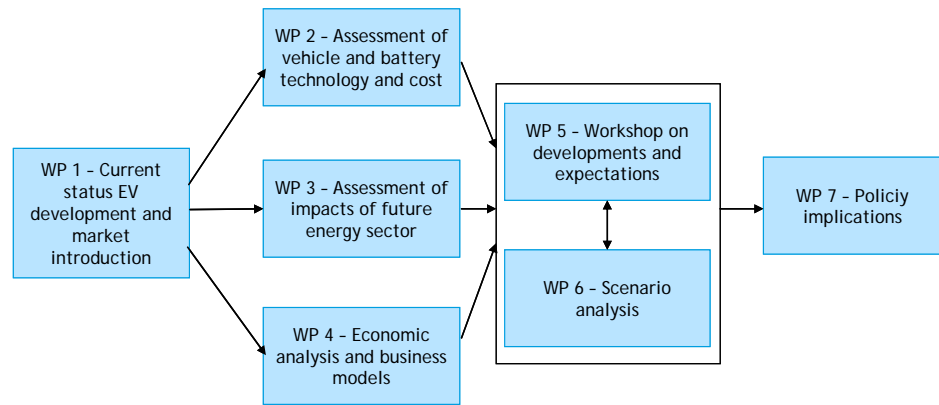
The project is organised around seven work packages (WPs):

- WP 1 Current status of EV development and market introduction.
- WP 2 Assessment of vehicle and battery technology and cost.
- WP 3 Assessment of impacts on future energy sector.
- WP 4 Economic analysis and business models.
- WP 5 Workshop on developments and expectations.
- WP 6 Scenario analysis.
- WP 7 Policy implications.

The following graph (Figure 1) gives an overview of the main interactions between the various WPs. The approach for each WP is explained in the following paragraphs.



Figure 1 Project overview



The results of this project are presented in five deliverables: Deliverables 1 to 4 presenting the results of WP 1 to 4 and a final Deliverable 5 with the results of WP 5, 6 and 7. In addition there is a summary report, briefly summarizing the main results of the entire project.

This report is the third deliverable of the project and includes the results of WP 3. The results of this Work Package will feed in the scenario analysis of WP 6.

1.2 Structure of this report

This report assesses the future electricity sector, building on available data.

The objectives are in particular to analyse the future energy sector for the years 2010, 2020, 2030 and 2050 and the constraints it could have on the introduction of EVs and PHEVs, but also potential opportunities that arise from the introduction of EVs and PHEVs. Opportunities can arise from an increase in system efficiency, being defined as less input per output such as fuel per kWh. The focus will be on development until 2030.

Chapter 2 summarises EU electricity sector policy. Next Chapter 3 presents the electricity sector forecasts based on the PRIMES reference scenario¹.

Chapter 4 discusses the influence of Electric Vehicles on the development of the future electricity mix and the resulting environmental performance, including considerations on the interactions with the EU ETS. In the same chapter, we will explore how Electric Vehicles can achieve positive impacts on renewable energy generation.

¹ The PRIMES model simulates repeatedly a static market equilibrium for energy supply and demand for EU Member States. PRIMES is owned by the European Commission and maintained by the National Technical University of Athens' E3M-lab.

Chapter 5 examines the overall grid capacity for Electric Vehicles, determining the limitations for EV market penetration, including three exemplary case studies. Furthermore, we will discuss various charging options, including costs and financing of the infrastructure. Chapter 6 covers the monitoring and tracking of EV energy consumption. Chapter 7 discusses options for EV electricity consumption monitoring and taxation. The final chapter lists the main conclusions regarding the interaction between the future energy sector and Electric Vehicles.





2 Policy overview

This chapter gives an overview over EU and Member State energy policy developments with a special focus on renewable energies.

2.1 EU energy policy

In 2006 work began on an energy plan to transform the EU into a low-energy economy and to ensure the stability, competitiveness and sustainability of the energy it consumes. The EU energy framework seeks to meet shared energy challenges of the Member States with a common strategy and coherent external energy policy. Moreover, the European Commission seeks to establish the EU as a frontrunner for tackling climate change and reducing greenhouse gas emissions. It uses a core set of energy strategies and policies consisting of the European strategy for sustainable, competitive and secure energy, the Energy Policy for Europe, the European Energy Programme for Recovery, and the Energy Security and Solidarity Action Plan.

The EU energy policy framework supports the use of market-based and financial instruments as well as research and innovation to achieve its goals. A key element of the EU's energy framework is the 20-20-20 targets, established under the EU Climate and Energy Package (CARE). The targets include reducing EU greenhouse gas emissions by at least 20% below 1990 levels, the use of renewable energy sources for 20% of EU energy consumption and reducing primary energy use by 20% compared to projected levels through an increase in energy efficiency.

The **Renewable Energy Directive 2009/28/EC** was established to promote the increased use of renewable energy use. The Directive aims to ensure that the EU will meet its 2020 goals and reach a 20% share of energy from renewable sources and a 10% share of renewable energy specifically in the transport sector.

The EU funds electricity and gas infrastructure projects and contributes about € 25 million annually to research. In addition, the EU seeks to foster relations with international partners to enhance its energy goals and to contribute to research and understanding in the area of energy supply. Furthermore, EU efforts include participation in the European Energy Community (EEC) comprised of the EU and a number of third countries, provides a **cooperative framework for the European region** to rebuild its energy network and ensure stability

The legal framework underscores that energy policy is a major concern for European politics and affects Europe in many ways: energy security, economic competitiveness, climate change and other aspects of sustainable development. A more detailed review of EU energy policy is included in Annex B.



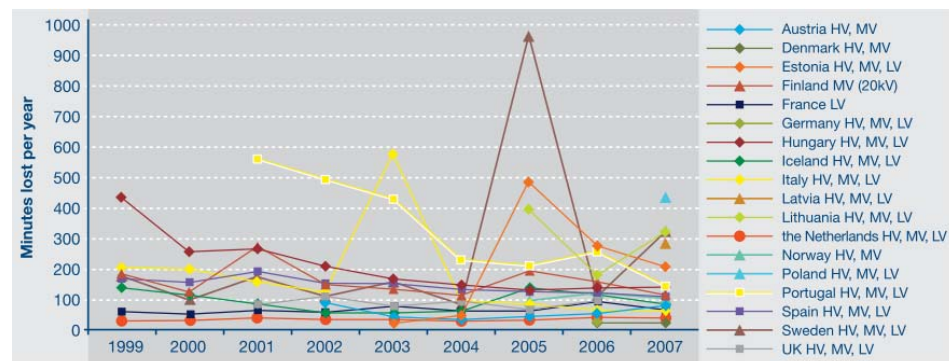
2.2 Member State energy policy and grid quality

In this section, we summarise the trends in energy policies and quality of the electric grid in various EU Member States with a special focus on renewable energies. An assessment of the electricity policy per member state is provided in 0. The information on energy policy is based on EREC fact sheets, while information on grid quality is derived from CEER (2008). The Member States represent both the key economic players in the EU and a diverse geographical and cultural mix: Austria, Belgium, Denmark, France, Germany, Netherlands, Poland, Spain and the United Kingdom.

It can be seen that most Member States make very rapid progress towards higher shares of renewable energies, although considerable differences prevail, ranging from under 2% (UK) to almost 30% (Austria).

Supply quality shows a very mixed picture. Some Member States are very vulnerable to natural hazards (Sweden) or have inherent grid stability issues (Lithuania, Latvia, Hungary, but also Spain, Portugal and Italy). These countries may lack the necessary infrastructure to support EV introduction. Only very few countries have a power system that is resilient enough to ensure grid stability, when additional high volume users are added to the system. A more detailed analysis of three case study Member States follows in Chapter 5.

Figure 2 Unplanned interruptions including all events, minutes lost per year 1999-2007



The voltage level (LV, MV, HV) is related to where the incidents occur. The French values in the figure are lower than the reality.

Source: CEER, 2008.

A more detailed overview of the respective electricity sectors can be found in Chapter 3.



Table 1 Renewable energy in nine EU Member States: consumption and targets

Country	Dependence on external energy supplies	Share of wind in renewable electricity	Share of solar in renewable electricity	Share of biomass in renewable electricity	Share of hydro in renewable electricity	Share of renewables in electricity	Share of renewables in gross final energy	European target - 2020 (final energy)	National target - 2020	Feed-in tariff	Progress to date
Austria	87.8% (2007)	N.a.	N.a.	N.a.	86.6%	65%** (2007)	28.8% (2007)	34%	N.a.	Yes	+
Belgium	77.9% (2006)	17.2% in Flanders (2008)	1.7% in Flanders (2008)	60% in Flanders (2008)	0.2% in Flanders (2008)	3.9% (2006)	3.65% (2007)	13%	N.a.	No	-
Denmark	-30% (2007)	70% (2007)	N.a.	30% (2007)	N.a.	27.9% (2007)	17% (2007)	30%	N.a.	Yes	+
France	50.4% (2007)	7% (2008)	0%	3%	86%	13% (2007)	11% (2007)	23%	N.a.	Yes	±
Germany	73% (2007)	45% (2007)	3%	28 %	24%	14% (2007) 11.5% (2006)	9.8% (2007) 7.8% (2006)	18%	N.a.	Yes	+
Netherlands	38.9% (2005)	29% (2009)	1%	66%	1%	7.6% (2007)	4% (2009)	14%	14%	No	-
Poland	18.4% (2005)	12% (2008)	0%	49%	39% (2008)	3.48% (2007)	7.2% (2005)	14%	N.a.	No	±
Spain	78% (2006)	51% (2008)	4%	4%	41%	20.3% (2007)	9% (2007)	20%	29.4% (2010)	Yes	±
UK	13% (2005)	29% (2008)	0%	33%	38%	5.16% (2007) 4.6% (2006)	1.94% (2007)	15%	N.a.	Yes	-

Data source: EREC, IEA, Eurostat and AGEB, 2010.

** Without pump storage consumption.



3 Electricity sector baseline forecasts

3.1 Introduction

This chapter provides a description of the expected future developments in EU electricity markets, based on a forecasting exercise using ICF's modelling platform and input assumptions tailored to the European Commission's Reference Scenario in the report 'EU Energy Trends to 2030-Update 2009'². Modelled in this fashion, the Reference Case described here accounts for recent developments in electricity demand, fuel and emission allowance prices and in the composition of conventional and renewable capacity and generation seen in Europe. Meanwhile, it provides a view of regional generation results to 2030 that are closely aligned with the scenario reported in the 'EU Energy Trends' document³. The following paragraph provides a brief description of ICF's power markets model used in this exercise, while more detailed description can be found in Annex C.

ICF's Integrated Planning Model (IPM[®]) determines the least-cost capacity expansion plan to satisfy future demand requirements subject to the set of technical, economic, regulatory and environmental constraints that characterise the European wholesale power markets. A unit may come online only if it is economically viable, i.e., if the net present value (NPV) of its revenue from electricity sales plus the capacity premium available to new entrants (which may arise from a separate capacity market, e.g., Ireland, or be incorporated within the electricity price) surpasses the NPV of its long-run fixed and variable costs. Hence the model makes an informed decision about future dispatch and remuneration of all options, highlighting the interdependency of electricity dispatch and capacity expansion decision.

Employing the IPM[®], the analysis of long-term developments in European power markets was conducted for all EU Member States excluding Malta and Cyprus, plus non-EU European countries connected to the integrated power grid, for a total of 32 separated but interconnected modelled national systems. For results presentation EU Member States are divided into seven regional blocks as shown in Table 2.

² EU energy trends to 2030 – UPDATE 2009, European Commission, Directorate-General for Energy in collaboration with Climate Action DG and Mobility and Transport DG, 2010 http://ec.europa.eu/energy/observatory/trends_2030/doc/trends_to_2030_update_2009.pdf.

³ The Reference Case described in the report 'EU Energy Trends to 2030 - Update 2009' was derived using the PRIMES model, another model than employed here. Due to differences in the computational methodology and the use of varying assumptions for secondary variables, the results from the two models are not expected to be identical or analogous on all levels.



Table 2 Regional description

Regional Groups	Countries
North-West Mainland Block	France, Germany, Belgium, Netherlands, Austria and Luxembourg
North-East Block	Poland, Czech Republic, Hungary and Slovakia
South-East Block	Bulgaria, Romania, Greece,
Centre-South Block	Italy and Slovenia
South-West Block	Spain and Portugal
Nordel-Baltics Block	Sweden, Finland, Denmark, Estonia, Latvia and Lithuania
UK-Ireland Block	United Kingdom and Ireland

The following sections first cover the key assumptions employed in the Reference Case, and then present the associated results.

3.2 Electricity demand and load profile

The IPM® selects generation capacity options to meet electricity demand across all hours of the year and all years of the forecast horizon, and to meet system reliability requirements specified as the minimum planning reserve capacity needed above anticipated peak electricity demand. As such, demand for power can be divided into three main components: cumulative electricity demand for the year, the hourly demand profile across all 8,760 hours of the year and peak demand (i.e., the highest realisation of hourly demand in the year).

Figure 3 below presents the Reference Case forecasts of electricity and peak demand at-busbar. Electricity demand in the EU rises an average 1% per year over 2010-2030, from approximately 3,300 TWh in 2010 to 4,000 TWh by 2030. Peak demand rises a similar 1% annually on average, from 540 GW in 2008 to 660 GW in 2030.

Figure 3 Electricity and peak demand forecast

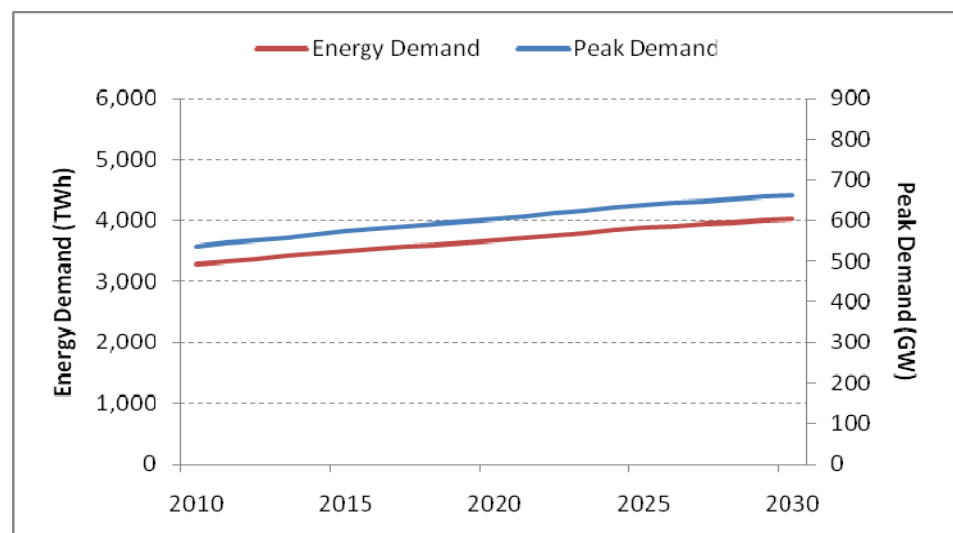
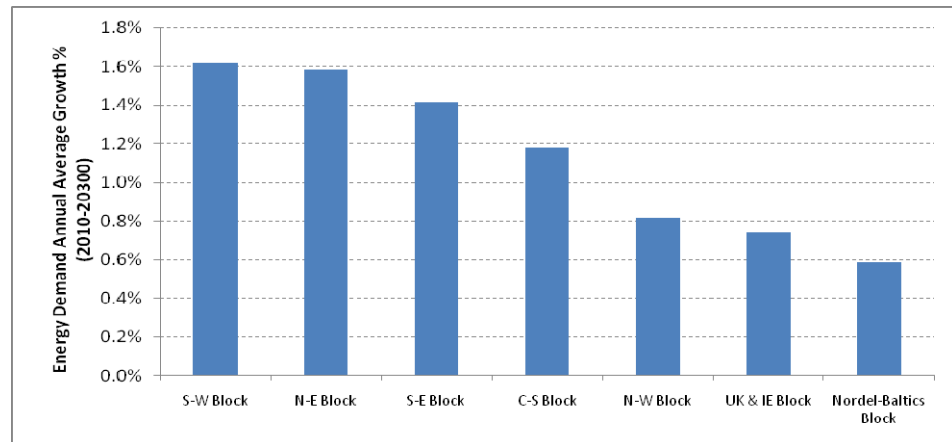


Figure 4 displays the regional breakdown of energy demand growth rates, with the Eastern regions and South-West Block (Spain and Portugal) leading the rise in demand.

Figure 4 Electricity demand annual average growth rate (%) by regional blocks



The long-term electricity needs of the EU are expected to increase, as they have on average historically. In other words the key elements of electricity demand growth (e.g., new roles for electricity, etc.) remain present despite the occurrence of the recent economic downturn, and new capacity deployments will need to keep pace. The key factors affecting demand growth over time and across Europe are:

- A slow growth in demography in most countries.
- Changes in the composition of the European economy; turn towards a services-based economy and growth in the residential sector.
- Demand side management (DSM) and energy efficiency improvements.
- Demand elasticity in response to rising electricity prices.
- New roles for electricity (e.g., heat pumps, Electric Vehicles in the long term).
- Growth in power demand during cold spells (most of Europe) or heat spells (Southern Europe).

Energy efficiency improvements are a main driver against future demand growth. Since 2007 the EU has had an indicative objective to harness its potential for energy demand abatement and increase efficiency by 20% by 2020 compared to BAU projections. This would effectively return the EU to its 1990 consumption levels. Demand elasticity and the move to a service-based economy are other factors curbing the pace of growth, particularly in the industrial and commercial sectors, with CO₂ prices affecting both developments.

Further discussion of demand assumptions appear in the 'EU Energy Trends' report.

Demand for electricity fluctuates across regions, by time of day and across the days of the year, forming varying hourly load profiles. ICF has employed the historical hourly load profiles for the modelled regions, as reported by ENTSO-E and by transmission system operators if otherwise available. Modelling the hourly load shapes included adjustments to reflect the changes over time of the projected energy and peak demand. The relationship between hours within the year however was retained unchanged over time, in other

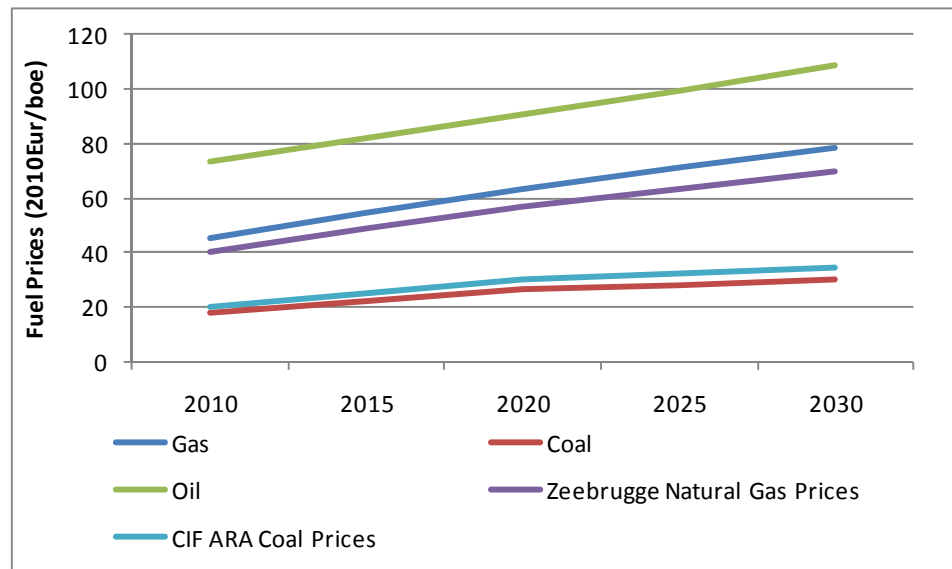
words having peaks and troughs vary in amplitude but occurring at the same time of year.

Fuel prices

The fossil fuel price assumptions employed in this modelling exercise were based on the global price trends presented in the 'EU Energy Trends to 2030 - Update 2009' report previously cited. The report includes a description for the basis for the forecast.

The global forecasts were first translated into European hub prices - specifically at Zeebrugge for natural gas and Amsterdam Rotterdam Antwerp (ARA) for hard coal - by preserving the time trends of the original study and commencing them at actual average hub prices for 2010 to date, as reported by Platts Media. In the case of natural gas, the resulting assumptions were slightly below those employed in the original 'EU Energy Trends' study of 2009. For both gas and coal, prices increase at an annual average rate of 3%, in 2010 real terms. The assumptions for the fuel prices are shown in Figure 5 below.

Figure 5 Fuel price assumptions (EU)



Prices for the fuels as delivered at the plant gates, for the countries studied, took the hubs' commodity prices, plus ICF data on historical spreads with other hubs, international and internal transport prices and relevant tariffs.

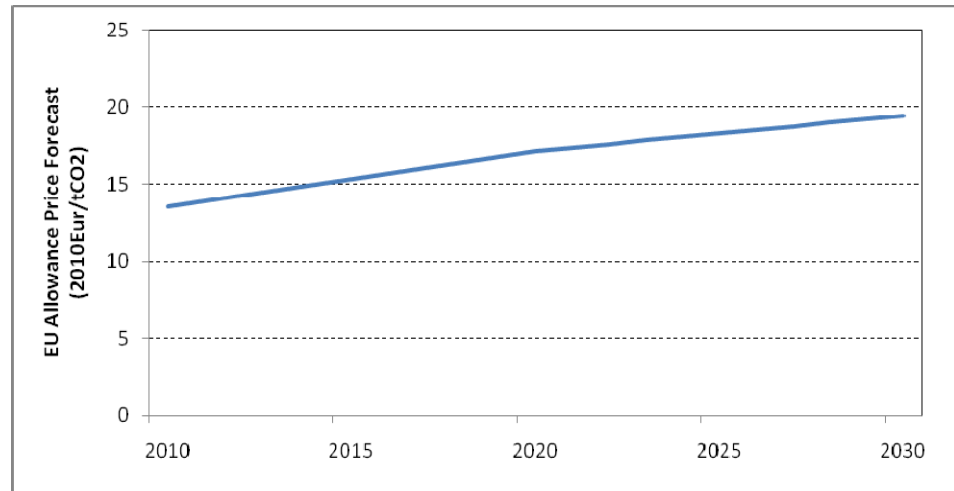
EU allowance price forecasts

The EU allowance (EUA) forecasts are taken from the Reference Scenario in the 'EU Energy Trends' report previously mentioned. Details on the basis for the forecast are presented as part of the scenario description for the 2009 report. Most importantly, the scenario considers that a 20% reduction in GHG emissions relative 1990 levels is achieved by 2020. Post-2020 prices continue to rise albeit at a slower pace to meet longer term emission reduction goals. Of note, the forecast also assumes the attainment of the 20% target for the share of renewables in meeting 2020 energy consumption. The price forecast for the EUAs employed in the EU Emission Trading Scheme reflects these achievements.



As shown in Figure 6, the forecast has EUA prices rising to 15 €/tCO₂ in 2015, 17 €/tCO₂ in 2020 and reaching 19 €/tCO₂ in 2030.

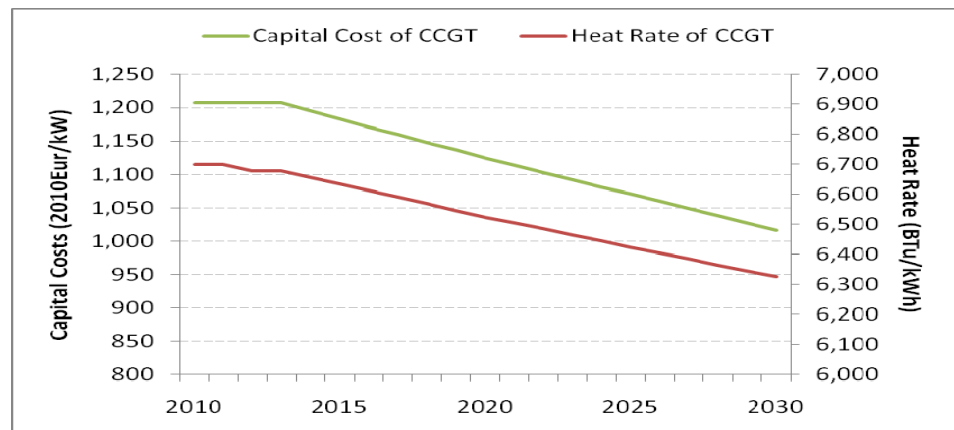
Figure 6 EU allowance price forecast (2010 €/tCO₂)



Technological and cost improvements in generating technology

The efficiencies and cost structures of newly built units depends on the generation technology and the online year. Capital costs decrease over time for most technologies in line with assumptions on improvements in technology cost containment. Figure 7 shows the capital costs for combined cycle gas turbines, which in real 2010 terms decline from approximately 1,200 €/kW in 2010 to just over 1,000 €/kW by 2030. Figure 7 also shows that heat rates are also assumed to decline over time as the technology advancements make the generation process more efficient.

Figure 7 Average combined cycle costs and heat rate assumptions (EU)



Other technologies undergo similar trends, but unconventional renewable technologies may receive feed-in tariffs and other forms of subsidies that alter their capital costs. The assumption is that as CO₂ prices rise, such non-emitting technologies will become economical and subsidies will be lifted when capital costs are competitive with conventional thermal units.



Lastly we assume lead times for planning and construction of ten years for nuclear, five years for coal and off-shore wind, three years for CCGTs and one to two years for other technologies. Hence certain build types are unavailable in the short-term.

3.3 EU capacity and generation mix

Figure 8 presents the forecasted capacity mix of the EU power system.

The forecast presents a system undergoing a rapid growth in unconventional (i.e., non-hydro) renewable units: 340 GW are added by 2030, with 70% of this capacity being wind-based, 6% biomass-fired and 18% solar, in line with the information gathered from the Reference Scenario of the 'EU Energy Trends' report previously mentioned. The substantial increase in renewable capacity is required to meet the 2020 target set by the European Commission for 'green' power, and to meet growing demand to 2030. The largest share of the renewable capacity deployment occurs in the Western European regions, with more than 200 GW coming online over the study horizon in the combined North-West Mainland, South-West and UK-Ireland Blocks.

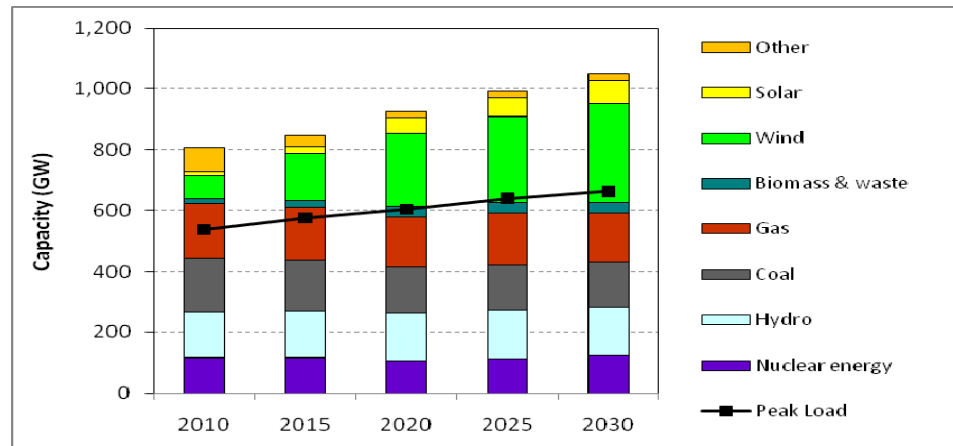
Hydro and gas-fired units retain fairly constant capacities on the system over the study horizon, with a gain of 10 GW for the former and a loss of 10 GW for the latter. However, inefficient oil/gas based turbines plus coal-fired and nuclear units compose the majority of retiring capacity. In the EU, retirements of these capacity types over the period total 58 GW, 32 GW and 31 GW, respectively.

Nuclear additions in the UK-Ireland and Centre-South Blocks (specifically the UK and Italy) offset the decommissioning predominantly in the North-West Mainland Block (Germany and Belgium) according to the assumptions that the analysis followed, and as a result the nuclear fleet retains its approximately 115 GW share.

The coal fleet retirements are distributed more heavily in the North-West Mainland and UK-Ireland Blocks as slow demand growth couples with renewable energy deployments and the burden of the Large Combustion Plant Directive (LCPD). The Directive causes unscrubbed coal-fired facilities to face the cumulative costs of retrofitting scrubbing technology or of limited operating hours, cumulated to the CO₂ emission costs.



Figure 8 EU capacity mix forecast (GW)

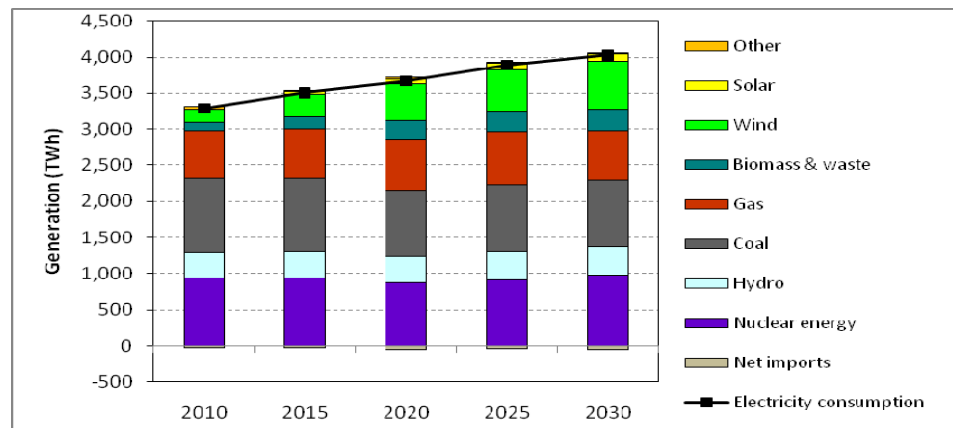


In a similar fashion to Figure 8 above, Figure 9 shows the EU generation mix forecasted over the study horizon.

The EU system undergoes shifts over the study horizon that include foremost the decline in conventional coal and gas, from 50% of the market in 2010 to 40% in 2030, to the benefit of unconventional renewable energy. Renewables account for 19% of generation in 2010, but hold 32% of total in 2020 and 36% by 2030. The largest share of renewable generation comes from wind, which contributes to 5% of generation in 2010 growing to 17% by 2030. Other non-conventional renewable technologies (e.g., biomass, solar) show significant growth but, following the assumptions replicated as part of this analysis, they represent still a small share of total dispatch.

Nuclear generation grows roughly 4% over 2010-2030, but its share of total falls from 28 to 24% as energy demand growth increases more rapidly.

Figure 9 EU generation mix forecast (TWh)



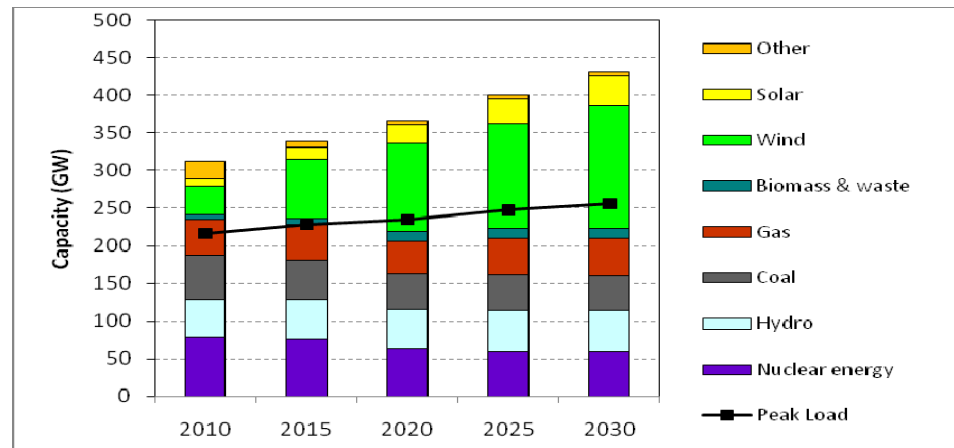
3.4 Regional capacity and generation mix

North-West Mainland Block:

France, Germany, Belgium, Netherlands, Austria and Luxembourg

As mentioned above, large renewable deployments were forecasted for the European grid, with the majority occurring in Western European regions which take on high renewable targets. As shown in Figure 10, approximately 170 GW of renewable capacity are added in the North-West Mainland Block between 2010 and 2030, 120 GW of which is assumed to be wind capacity.

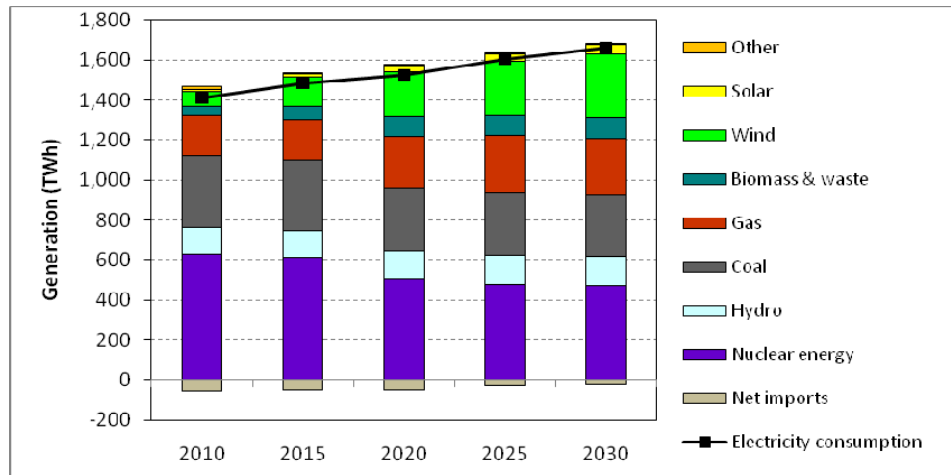
Figure 10 North-West Mainland Block capacity mix forecast (GW)



With rising CO₂ prices and the LCPD affecting mostly coal-fired units, efficient gas units act as the new entrant of choice in the mid-term, with approximately 4 GW of combined cycles added to the system by 2030, replacing about 12 GW of coal retiring by 2030. Roughly 31 GW of inefficient gas/oil peaking units also retire with the increasing CO₂ prices, renewable capacity builds and new combined cycle plants. Germany and Belgium are expected under the assumptions employed to decommission much of their nuclear fleet over the coming decade, which leads to over 20 GW of capacity retiring by 2025.

Figure 11 shows the generation mix for the region. Renewable generation increases from 18 to 37% by 2030. Conventional thermal generation is displaced by renewable generation, but retains a 35% share by 2030.

Figure 11 North-West Mainland Block generation mix forecast (TWh)



North-East Block: Poland, Czech Republic, Hungary and Slovakia

The North Eastern Block is dominated by coal capacity. Nuclear capacity increases its presence in the mix, adding over 6 GW by the end of the horizon. Renewable capacity additions also sum to 6 GW, most of which are from wind and biomass (Figure 12).

Figure 12 North-East Block capacity mix forecast (GW)

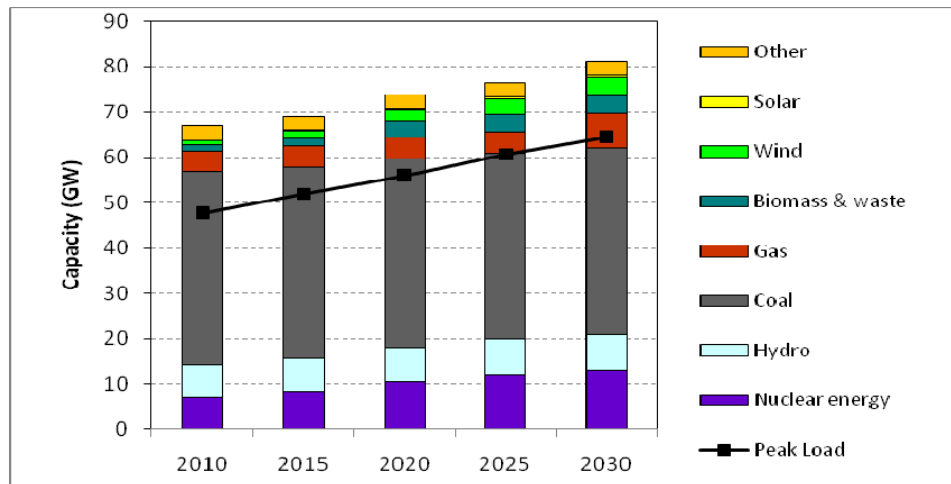
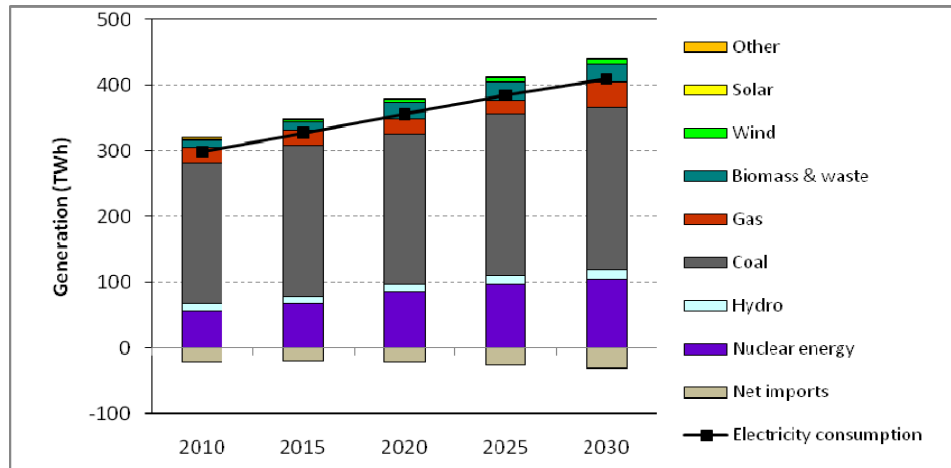


Figure 13 shows that coal generation composes 72% of the total mix in the near term, and retains a dominant 60% share by 2030. Biomass-fired dispatch more than doubles over 2010-2030, and nuclear generation sees a larger increase in absolute terms, from 56 TWh to 105 TWh over the same timeframe.



Figure 13 North-East Block generation mix forecast (TWh)



South-East Block: Bulgaria, Romania and Greece

As shown in Figure 14, the capacity mix of the South-East Block is dominated mainly by coal followed by nuclear. Over the forecast horizon there is an increase in nuclear and unconventional renewable capacity, adding up to approximately 3 GW and 15 GW by 2030, respectively. Most of the renewable additions come from wind, approximately 8 GW, while 6 GW of coal retire by 2030.

Figure 14 South-East Block capacity mix forecast (GW)

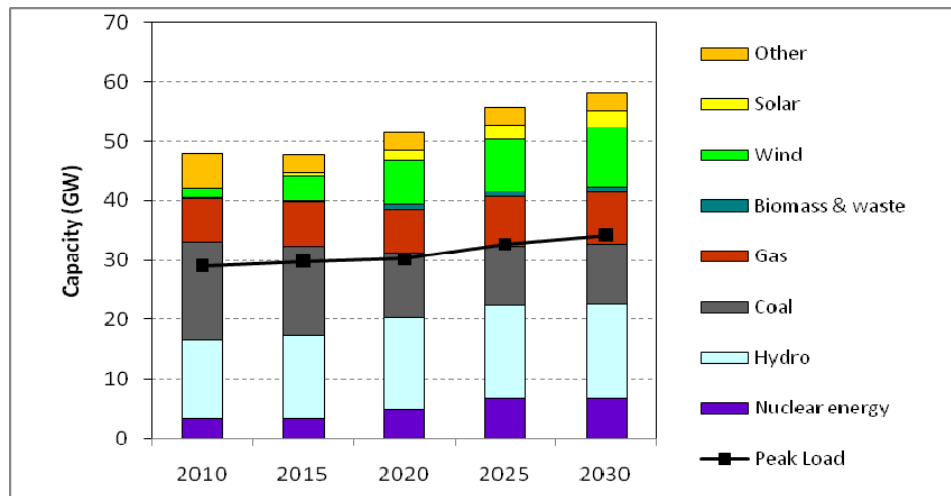
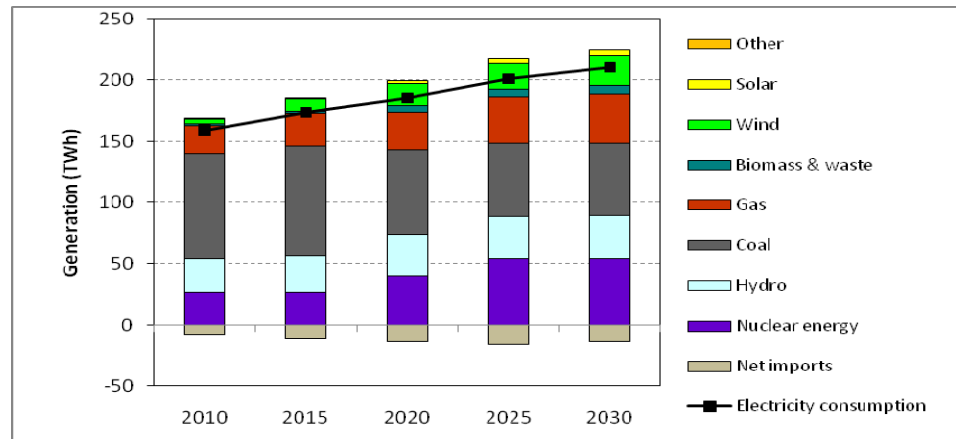


Figure 15 displays the South-East Block's generation mix. Coal, nuclear, hydro and gas together contribute to approximately 97% towards the generation mix of the South Eastern Block in 2010. We observe that over the forecast horizon nuclear and renewable (mainly wind) generation increases displace coal and gas from the supply stack, whose share in the generation mix reduces from 65% in 2010 to approximately 44% in 2030.



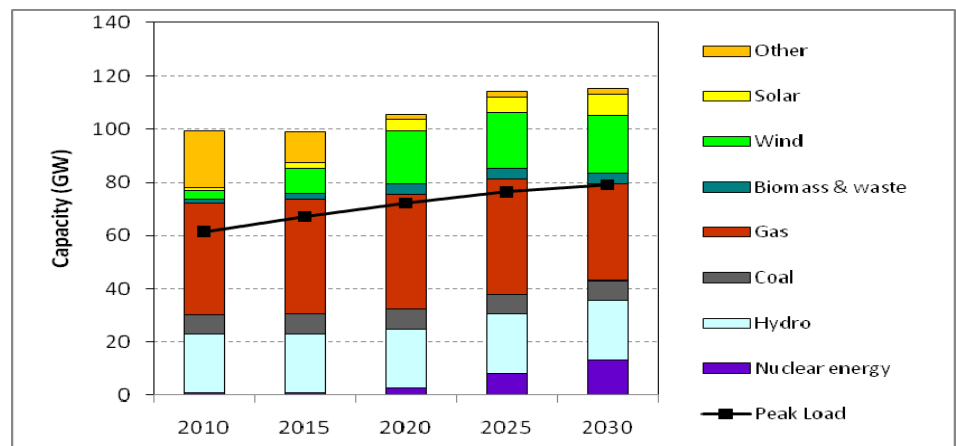
Figure 15 South-East Block generation mix forecast (TWh)



Centre-South Block: Italy and Slovenia

Gas dominates the capacity mix of the Centre-South Block, contributing approximately 68% of total in 2010 but then falling to approximately 46% by 2030. Approximately 20 GW of inefficient steam units are retired between 2010 and 2030, while 28 GW of renewable capacity and 12 GW of nuclear capacity are added over the same period. Wind capacity increases more than six folds by 2030 (Figure 16).

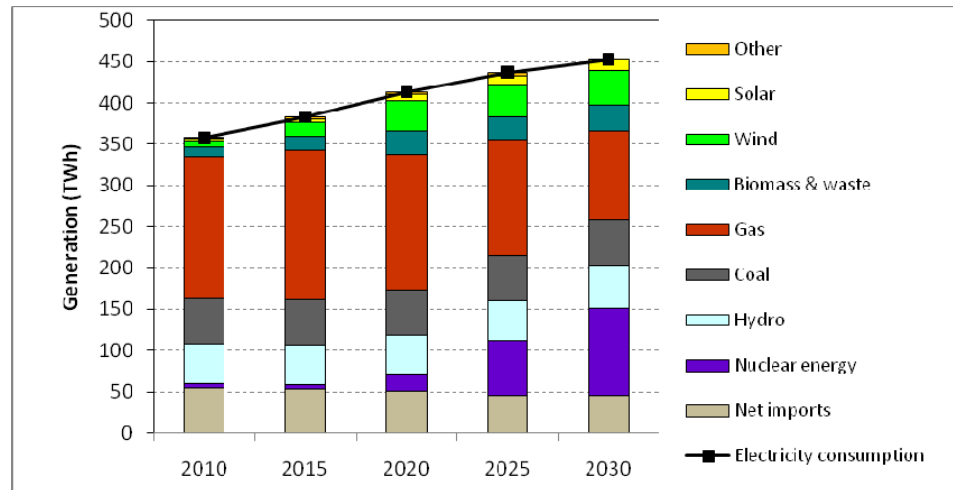
Figure 16 Central South Block capacity mix forecast (GW)



As shown in Figure 17, the majority of the generation mix is composed of gas units, contributing approximately 48% of the near-term dispatch, then falling to approximately 24% by 2030. Gas generation over the forecast horizon is displaced by nuclear and renewable generation in the long-term. Renewable generation increases from 19% in 2010 to approximately 30% in 2030, while nuclear generation increases from approximately 2% to approximately 23% over the period.



Figure 17 Central South Block generation mix forecast (TWh)



South-West Block: Spain and Portugal

As Figure 18 displays, the South-West Block has a balanced capacity mix in 2010 with gas holding a 27% share, while 47% comprises of hydro and unconventional renewable capacity. Renewable capacity's contribution increases from 47% in 2010 to 77% in 2030, and the growth is mainly in the form of wind additions reaching 54 GW by 2030. There are a further 17 GW of solar additions. Approximately 6 GW of inefficient steam units retire on an economic basis by 2030, and 3 GW of nuclear units decommission.

Figure 18 South Western Block capacity mix forecast (GW)

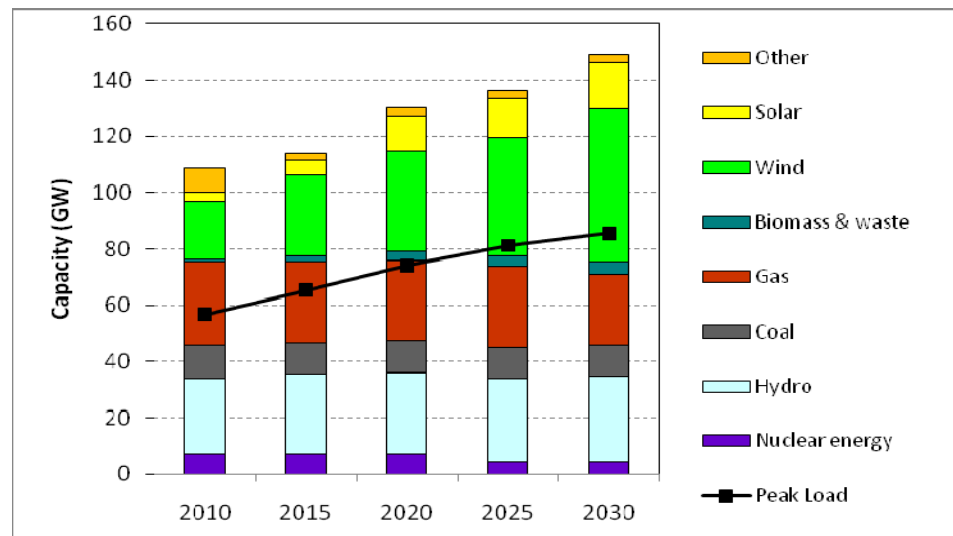
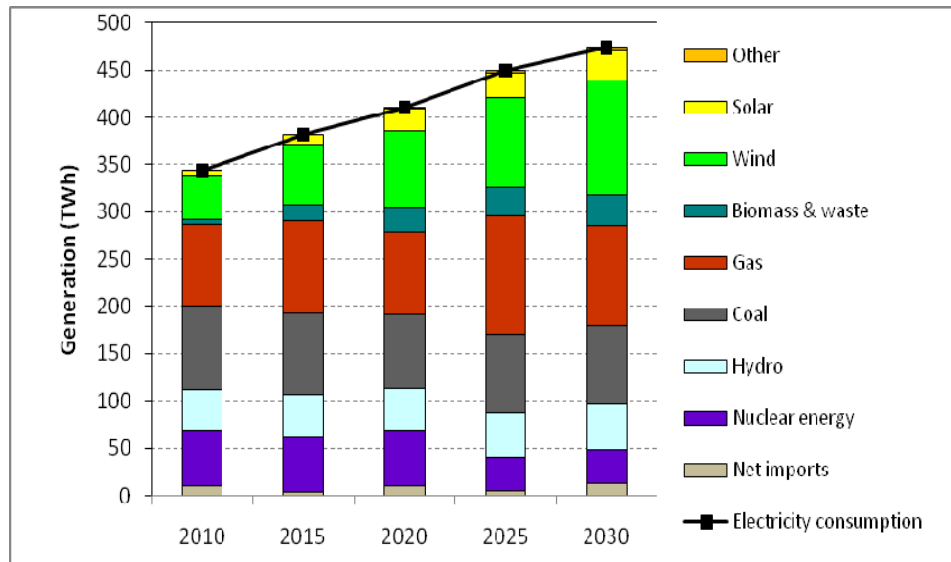


Figure 19 presents the region's associated generation mix predominated by conventional coal and gas. The fuels' share of the market averages 52% in 2010 and falls to 41% by 2030. Generation from unconventional renewable sources triples by 2030.



Figure 19 South Western Block generation mix forecast (TWh)

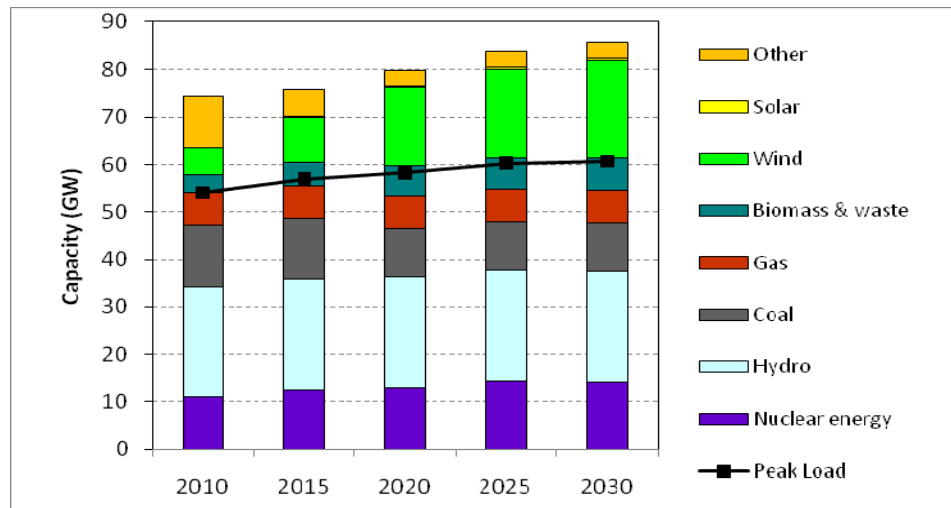


Nordel-Baltics Block:

Sweden, Finland, Denmark, Estonia, Latvia and Lithuania

Conventional resources namely coal, gas and nuclear, form approximately 56% of the capacity mix in the near-term, which over time is supplanted by renewable capacity additions to 2030. 15 GW of inefficient steam and coal-based capacity retire by 2030. There are 19 GW of renewable capacity additions in the Nordel-Baltics Block, of which approximately 15 GW are wind additions (Figure 20).

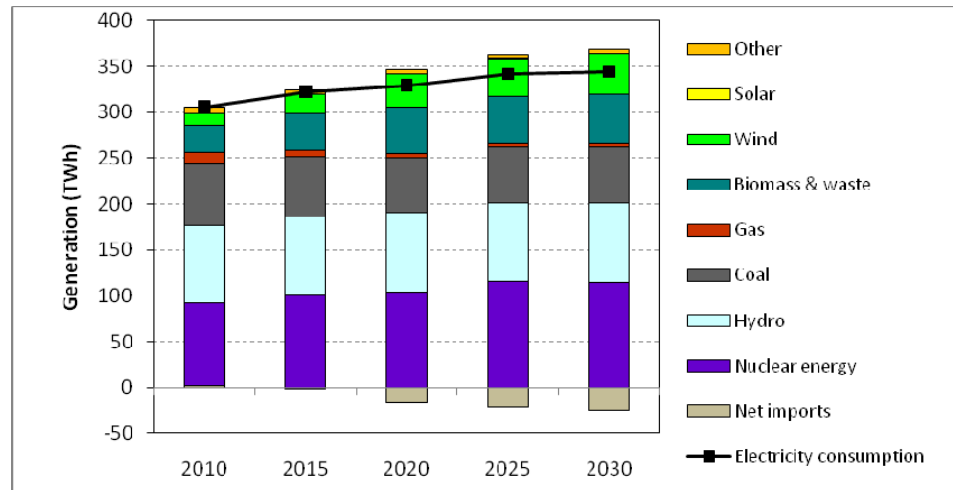
Figure 20 Nordel-Baltics Block capacity mix forecast (GW)



Coal, nuclear and hydro each contributes 25% of the generation mix in the near term. Nuclear units' proportion of total generation increases to 33% by 2030 and holds the largest share of the market, by fuel type. Renewables as a whole, including hydro, hold 41% in 2010 and 54% in 2030. Wind and biomass contribute 12 and 15% shares in the generation mix by 2030, respectively (Figure 21).



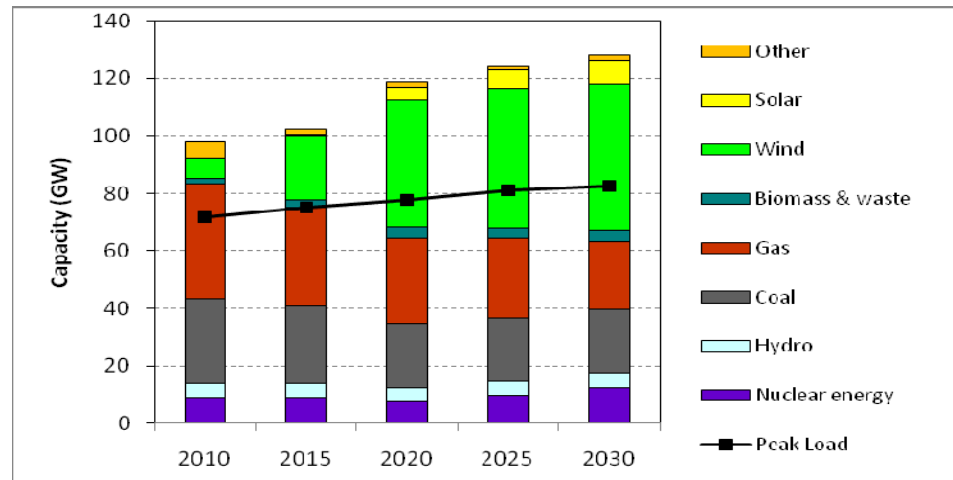
Figure 21 Nordel-Baltics Block generation mix forecast (TWh)



UK-Ireland Block: United Kingdom and Ireland

Figure 22 displays the dominance of gas and coal in the UK-Ireland Block in the near-term, holding 41% and 30% shares of the market, respectively, and the switch to renewable capacity in the long-term. Over the study horizon, unconventional renewable capacity increases from 14% of total in 2010 to 69% by 2030. Approximately 54 GW of renewables are added in the region, 44 GW of which is assumed to be wind capacity. Renewable and nuclear capacity build lead to the economic retirement of approximately 30 GW of inefficient coal and oil/gas peaking plants by 2030.

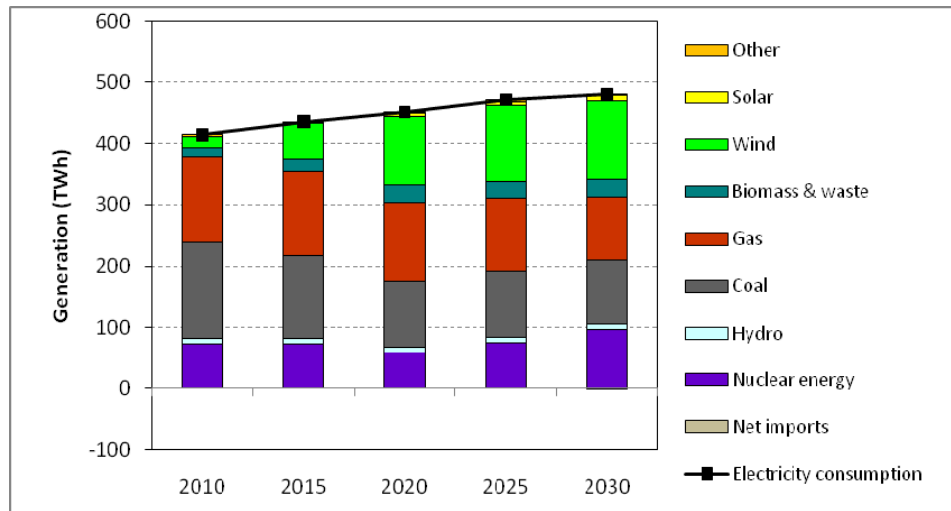
Figure 22 UK-Ireland Block capacity mix forecast (GW)



In the generation mix (Figure 23), gas and coal dominate in 2010 with a combined 71% share of the market. Their dominance falls to 43% by 2030. Much of the displacement is coming from increasing renewable and to a much lesser extent nuclear dispatch. The share of renewable generation rises from 10 to 36% during the period.



Figure 23 UK-Ireland Block generation mix forecast (TWh)



3.5 Market price and cost forecast

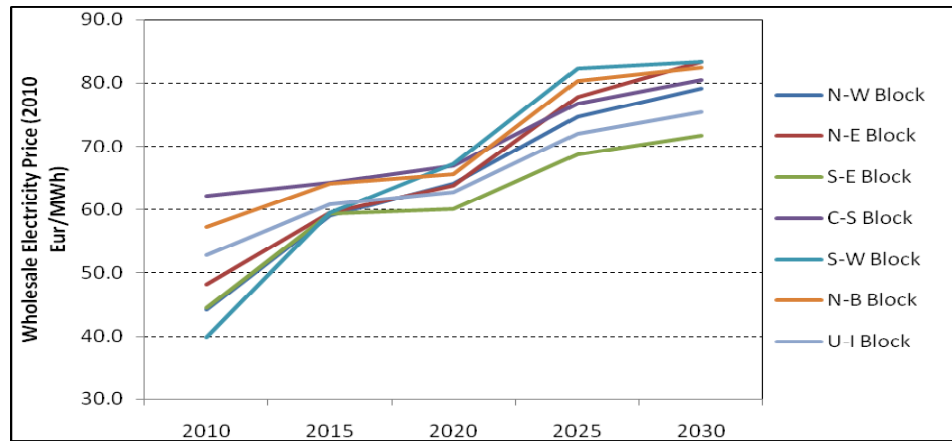
Wholesale price

The constant rise in average annual wholesale electricity prices shown in Figure 24 comes as a result of rising fuel and CO₂ prices in real terms, (following the assumptions of the Reference Scenario in the report 'EU Energy Trends' as previously mentioned) and the tightening of the supply/demand balance as demand rises and sections of the nuclear and coal fleet retire (again under the assumptions reproduced from the report). Over time and in 2010 real terms, EU energy-weighted average prices increase from 44 €/MWh in 2010 to 59 €/MWh in 2020 and 73 €/MWh in 2030.

The more pronounced rise in prices over 2010-2015 occurs as the supply/demand balance tightens coming out of the recent economic crisis (during which time demand and electricity prices dropped). Over 2020-2025, the price increases appear as growing shares of renewables engender a lower system reserve margin in peak times due to their less reliable dispatch. In both cases, the continued rise in demand encourages further new entrant investments for both thermal and renewable capacity types.

Most regional blocks have some convergence in their electricity prices as a result of better use of cross-border transmission capabilities (e.g., market coupling), leaving only the UK-Ireland and South-East Block largely apart. The South-East Block has low prices as the modelling assumptions for the region include a substantial build of nuclear capacity, depressing baseload generation costs.

Figure 24 Wholesale electricity price forecast for regional blocks



Peak and off-peak electricity price spread

As Figure 25 illustrates, forecasted baseload and off-peak power price trajectories climb smoothly with time, in real terms, reflecting the assumptions taken on fuel and CO₂ price rises over time, also in real terms. Baseload and off-peak demand however is increasingly met by low CO₂ emitting technologies with small marginal costs of generation (i.e., nuclear, most renewables and to a lesser extent combined cycle gas turbines), and as a result, the increase is lesser than for combined input fuel and CO₂ prices. EU baseload electricity prices rise an average 2.6% per year over 2010-2030, and off-peak prices rise an average 2.5% per year.

Fluctuations in peak prices are more pronounced as they reflect market tightness along with the rising marginal costs of generation in the corresponding hours of dispatch. From 65 €/MWh in 2010 (real 2010 €) prices climb to 87 €/MWh in 2020 and 122 €/MWh in 2030. Peaks in the curve, in 2015 and 2025, indicate the times of low system reserve margins as previously mentioned. Unlike in low demand times, peak demand levels still rely heavily on the retained thermal generation capacity (including coal and peaking units, due to their reliable availability), leading to the growing spread in peak to off-peak prices as seen in Figure 25. Figure 26 illustrates this point conceptually with an example dispatch stack, showing how marginal costs of generation under CO₂ pricing affect pricing under varying demand requirements.

Figure 25 EU peak, off-peak and baseload electricity prices

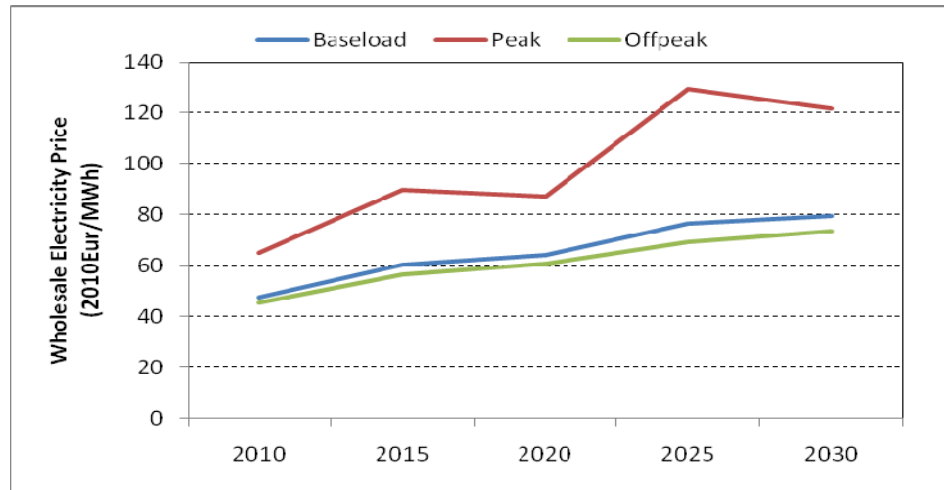
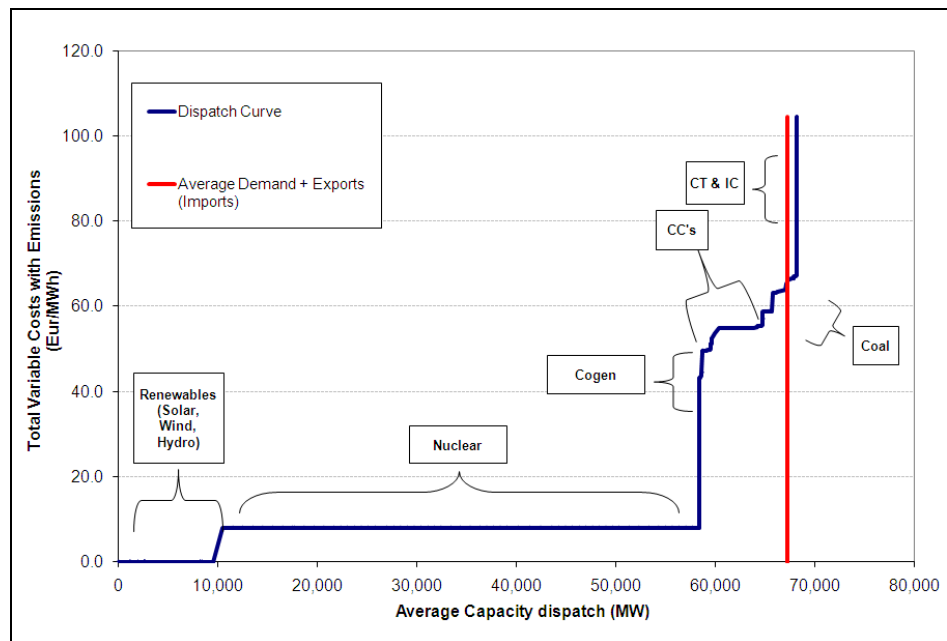


Figure 26 Illustrative dispatch stack

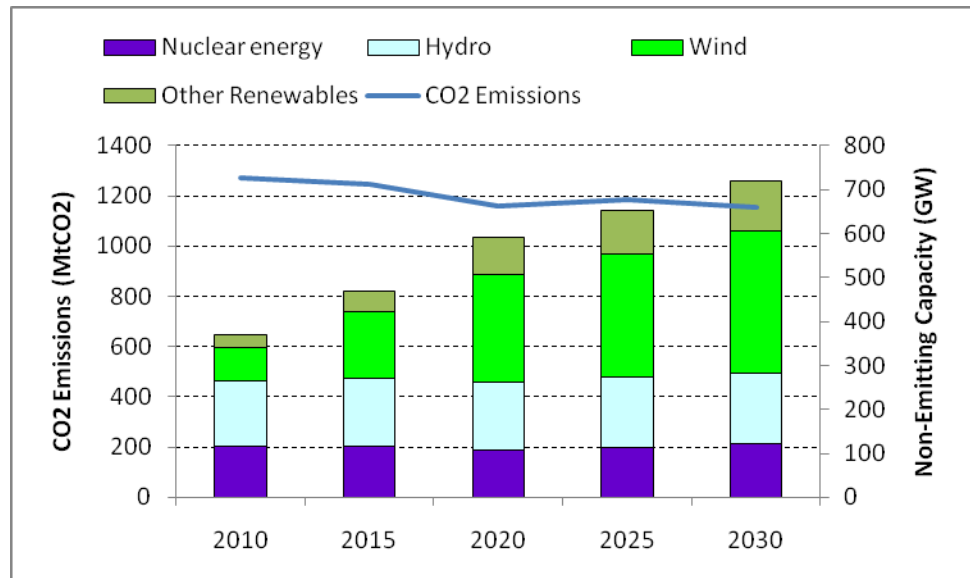


CO₂ emissions of the power sector

The increasing CO₂ prices and the large penetration of renewable energy in the forecasted European grid translate into substantial reductions in emissions in the power sector, principally in line with the 2020 targets discussed in the assumptions section above. Specifically, emissions drop from 1,274 MtCO₂ in 2010 to 1,159 MtCO₂ by 2020, representing a 9% decline. These values are for the EU power sector and do not equate to EU ETS covered combustion installations. Over the study period as a whole, 10% of emissions are abated. Figure 27 below shows these patterns along with the growth in non-emitting technologies (renewables and nuclear).



Figure 27 EU emissions and low carbon emitting capacity



4 Potential impacts of EVs on electricity and renewable energy generation

This chapter explores the interaction of electricity systems and Electric Vehicles in Europe and discusses potential impacts of EVs especially with regard to renewable energies. We examine both challenges and opportunities for the electricity system that arise from an introduction of Electric Vehicles.

As seen in the review of European and national energy policies (Section 2.1) and the description of the future energy system (Chapter 3), the share of renewable energies is expected to rise significantly over the next 20 years (up to 2030). A number of challenges, but also opportunities arise from this ongoing development. As part of this transition of the energy sector, Electric Vehicles are both part of the solution and a problem (Chapter 4). This chapter will present some of the key issues related to EV grid integration that all aim at matching power demand with supply.

- Integrating electric vehicle charging with renewable energy supply (Sections 4.1, 4.2, 4.3 and 4.4).
- Integrating Electric Vehicles as grid stabilisers (Section 4.5).

In this context, we will explore necessary changes to the existing electricity grid and prerequisites for Electric Vehicle technology.

4.1 Electricity generation in Europe: power plants and Electric Vehicles

Given the diversity of Europe's electricity system, no single type of plant dominates in terms of electricity generation. In 2008, 54% (1,814 TWh) of Europe's total electricity generation of 3,374 TWh was produced by fossil fuel fired plant. A further 28% (937 TWh) was produced by nuclear, and 11% (359 TWh) came from hydro. In total, around 17% was produced by renewable sources and only 4% of the total generation (119 TWh) was produced by wind.⁴

A range of different economic, technical and policy-related factors influence future electricity generation requirements. A similar set of factors also influences the mix of generating plants that will operate. Economic factors such as the rate of economic growth, prices of different fuels as well as the price of CO₂ are important. In addition, policy developments such as the Renewable Energy Directive, the EU ETS Directive and international climate change negotiations, as well as technical developments in renewable energy technologies, carbon capture and storage (CCS) and smart grid technologies will influence the way electricity is generated in the future.

⁴ EuroStat, Statistical Yearbook - Energy 2008. European Commission, 2010
http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-PC-10-001/EN/KS-PC-10-001-EN.PDF.



Moreover, as the share of renewable electricity generation in total electricity consumption increases, the need for additional back-up generating capacity or electricity storage options will increase as well.

In the Renewable Energy Directive, national targets are set to increase the level of renewable energy use to 20% of total European energy demand by 2020. This means that around 30-40% of total electricity generation will need to come from renewable sources within ten years.⁵ This brings significant challenges in terms of system operation, and ensuring that supply matches demand whilst optimising the use of often intermittent renewable capacity.

Different types of plants play different roles within the generation mix depending on factors such as their ability to adjust output and marginal cost of generation. Wind generation, and other intermittent renewables, are often the first sources used to meet part of the electricity demand as they have zero marginal costs (no fuel) and priority access to the grid, i.e., they are of a 'must run' nature. Other technology types provide base load capacity to meet minimum levels of demand which will always occur. These are typically relatively inflexible plants with higher capital costs and lower operating costs such as nuclear. At times of peak demand additional generating capacity is brought onto the system. Generally, these are plants such as single cycle gas turbines that are able to respond rapidly to demand fluctuations, can be turned on and off fairly easily and often have low capital costs but higher operating costs. Such peak capacity plants are generally generating electricity at higher costs per kWh, i.e., are less cost-efficient than other plants using the same fuel type (e.g., comparison of single cycle to combined cycle gas turbines). In addition, they are usually not emissions free, i.e., not renewable or nuclear, with the exception of pump storage generation. As such, their use tends to increase the GHG intensity of the electricity produced. However, the GHG intensity of load balancing power plants varies according to the technology used.

It is in this context that the implications on the electricity generation system of an increasing number of Electric Vehicles needs to be viewed. The issues associated with an increase in EV use on the electricity generation system are outlined below.

As electricity demand rises, 1) existing plants will be called upon to increase levels of generation and, 2) if overall long-term demand rises further, it is foreseeable that additional generating capacity could also be required. In terms of the first point, the nature of the marginal plant will influence the environmental impact (GHG intensity) of any marginal generation needed. The generation system will respond to additional demand from EVs by increasing the generation from the plant that has lowest marginal cost at that specific point in time. However, the specific impact of additional demand from EVs depends when the vehicles are being charged. For example, should smart charging infrastructure be implemented effectively, it may be possible to reduce the GHG intensity of the electricity generated by shifting charging demand to non-peak times. Vehicle-to-Grid (V2G) systems could even allow the grid to draw on stored electricity in batteries to help meet peaks in the demand. This would reduce the need for less efficient peaking plant to operate and assist with the integration of renewable generation.

Based on recent analysis by CE Delft, in the short term (up to 2020), additional electricity demand from EV charging is very likely to be met by the existing

⁵ Based on ICF analysis. In March 2009 Eurelectric estimated the range at 30-35%.



power plants, as capacity is enough and additional EV demand will not impact investments in the sector.⁶

4.2 EU ETS, renewable energy and Electric Vehicles

Electricity used for Electric Vehicles is subject to the EU ETS as total electricity production and resulting GHG emissions are covered under the trading scheme. The total amount of certificates in the EU ETS is set until 2020, while fossil fuels in road transport are not (yet) subject to the EU ETS. Thus, charging an electric vehicle with electricity from the grid will result in a demand for emission allowances to cover the GHG emissions from the consumed electricity, whereas the corresponding fossil fuel for fuelling ICE vehicles does not have to be matched with equivalent emission allowances.

Without further measures regarding Electric Vehicle charging - such as making renewable electricity mandatory for charging - , the electricity used in EVs will not necessarily come exclusively from renewable energies (CE, 2010). However, IFEU (2007) shows that even conventional fossil power generation is at least equal to the environmental performance of an ICE vehicle, i.e., even if the electricity is generated with lignite and coal - resulting in high GHG emissions per kWh - the GHG emissions of an EV are comparable to a similar ICE-powered car. However, CE (2010) shows that an EV with an energy consumption of 20 kWh/100 km will not necessarily yield lower emissions than today's average ICE car (coal fuelled EV: >200 g CO₂/km ; average ICE car in EU 186 g CO₂/km).

Since the amount of electricity used for EVs is additional and has to be covered by emission allowances which are capped, the introduction of EVs will de facto lead to overall emission reductions - taking into consideration both sectors within the EU ETS and those exempt from it - either in the electricity sector or in any other sector within the EU ETS (WF, 2009) This, of course, does only hold under three conditions: restricted use of CDM or JI credits, no increase in the overall cap due to electrification of the vehicle fleet, and - above all - Electric Vehicles have to replace existing ICE vehicles and not be additional traffic. Ensuring the latter point will be a cornerstone of EV policies (see WP 7).

Thus, introducing EVs basically comes down to an expansion of the EU ETS to road transport without increasing the cap. Assuming 1 million EVs with a specific yearly energy consumption of 20 kWh⁷ per 100 km and yearly mileage of 10,000 km, net energy demand would be 2 TWh. At the current EU average for power generation of 443 g CO₂/kWh, this results in emissions of 886,000 tCO₂. Actual allocations under EU ETS amount to approx. 2 billion tonnes of CO₂ (for 2008-2012). Thus, 1 million EVs would affect only 0.04% of European Union Allowance Units (EUA) and would therefore not cause significant disturbances in the EU ETS.⁸

⁶ CE, 2010, Kampman et al., Green Power for Electric Cars - Development of policy recommendations to harvest the potential of Electric Vehicles, Delft, CE Delft, January 2010.

⁷ Actual electricity consumption of Electric Vehicles depends both on driving and charging patterns. Fast charging results in higher charging losses that can increase up to 25% of electricity consumed (FAZ, 2010).

⁸ On the other hand, the electricity sector will become less carbon intensive over time - due to renewable electricity generation and carbon capture - and thus will most likely be able to compensate this pressure.



In summary, EVs do not have a negative environmental impact on the effectiveness of the EU ETS. The introduction of EVs leads to de facto EU-27 emission reductions.

However, it has to be borne in mind that the increased scarcity of emission allowances will lead to a stronger price signal that might affect sectors subject to EU ETS such as cement, electricity or oil in the longer term, if EV shares become significant and the cap is not increased.

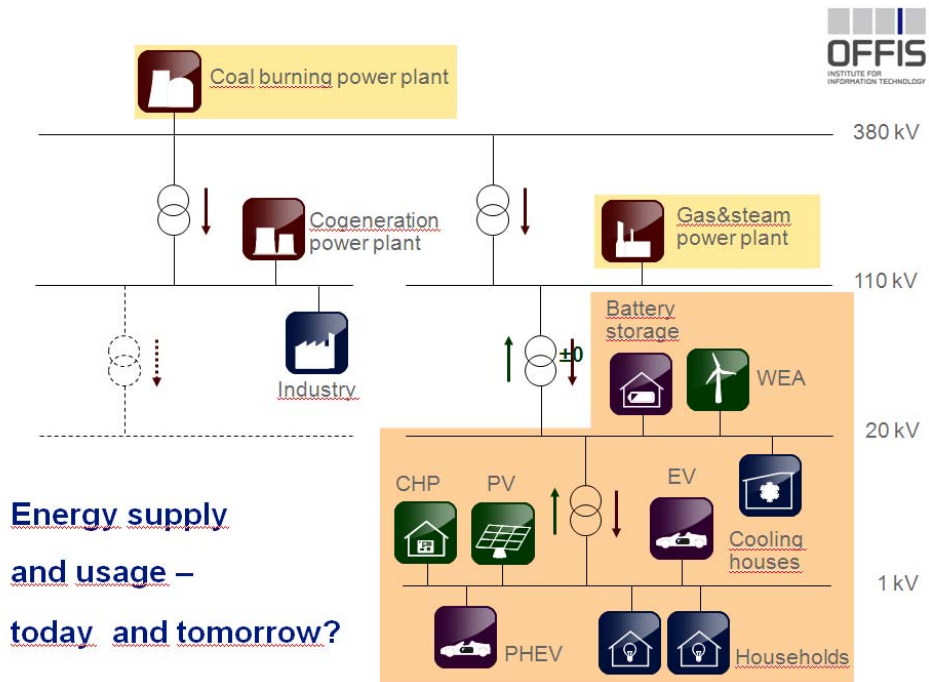
4.3 Renewable energies in the electricity grid

The electricity grid is divided into several layers of voltage, see Figure 28, starting at the ultra-high voltage or transmission level where most conventional power plants are situated, to the high voltage level where some industrial users can be connected to the low voltage or distribution level (below 1kV) linking to most end-users but also increasingly to small scale renewable energy generation (distributed generation).

Grid operators need to balance power supply and demand at all times, as a mismatching of the two sides leads to frequency changes in the grid which in turn negatively affect the performance of electric appliances connected to the grid. Usual variations in frequency that can be tolerated are +/- 0.2 Hz. Larger deviations require immediate load balancing by the transmission service operator (TSO). In a first step, an immediate frequency response reserve is triggered automatically. Longer lasting disturbances trigger the operating reserve which can be activated within less than 10 minutes. Even more severe disruptions can activate the replacement reserve in about 30 to 60 minutes. Germany alone has load balancing capacity of + 7 GW and - 5.5 GW. The larger the geographic scope of the grid, the less load balancing is usually necessary as unforeseen changes in supply and demand then cancel each other out. However, renewable energy sources, especially wind, are a major factor entailing a need for higher balancing capacity.



Figure 28 Grid structure overview



Source: OFFIS.

The distribution systems utilised for electricity grids were originally optimised without the prospect of large-scale contributions from intermittent sources of renewable electricity - i.e., wind and solar. Increasing electricity production will have implications for both supply and demand, and electricity grid operators are developing software and procedures for incorporating large-scale renewables. In this way, transmission service operators (TSOs) are developing methods of matching supply and demand, which can both improve system efficiency and thus profitability.

Efficiency in the context of electric grids or systems refers to cost efficiency of the entire system, i.e., the total costs for delivering one kWh to the final customer, including all generating and transmission costs as well as load balancing costs. These cost savings result primarily from:

- Reduced peak loads leading to lower peak production costs.
- Reduced excess generation capacities preventing negative prices.

According to the European Commission's Strategic Energy Technology Information System (SETIS)⁹, distributed generation is expected to represent 20-25% of EU power generation capacity by 2020 and 30-35% by 2030, with peaks of 40% in some countries. Especially Germany and Denmark showcase already today very high shares of distributed generation.

SETIS identified investment needs of 400 to 450 bn. Euros over the next 30 years: approximately 25% in transmission and 75% in distribution systems.

⁹ <http://setis.ec.europa.eu/mapping-overview/technology-map/technologies/smart-grids>.

Investments in the transmission system include:

- High Voltage Direct Current (HVDC) long distance and undersea cables.
- Flexible AC Transmission Systems (FACTS).
- Gas Insulated Lines (GIL).
- High Temperature Superconducting (HTS) cables.

The distribution system upgrades include:

- Wide Area Monitoring Systems (WAMS).
- Two way distribution grids (upgrade of transformers, etc.).
- Two-way high speed communications.

We will now examine the interactions between renewable energy sources and the electricity grid both from the supply and the demand point of view.

Supply side

Electricity generation involves the combination of electricity produced from different fuel types using different technologies as can be seen in Section 2.2. Many power generation technologies produce electricity most efficiently if they run at a constant output rate: nuclear, lignite, coal. Some power plants take a long time to start or stop (especially nuclear). These technologies are in many cases used to cover the base load, i.e., the load that prevails throughout the day.

Other power sources are very flexible such as gas turbines or renewable energy such as wind sources that can be shut down within minutes or seconds. Some power sources fluctuate by nature. This includes wind and solar power, see Figure 29 and Figure 30.

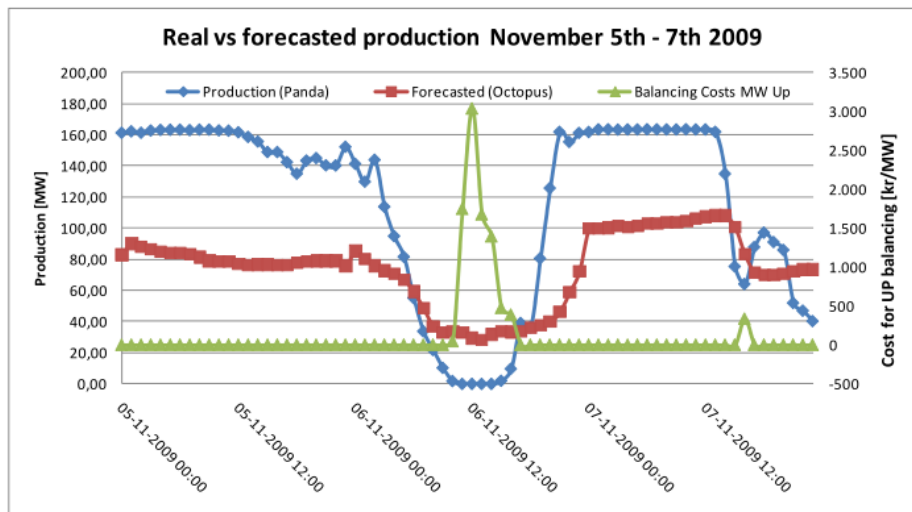
Before the large-scale introduction of renewable sources of electricity, natural gas facilities were utilised on a day-to-day and hour-to-hour basis to augment base load power generation and address fluctuations in electricity demand. Natural gas facilities can be turned on and off very quickly and have provided marginal supply.

Increased production from renewable sources combined with the requirement in EU Member States that renewable electricity have priority grid access (i.e., the grid operators must take all available renewable energy before electricity from any other source) have led to challenges for grid operators due in part to the intermittency of renewable sources (see Figure 29).



Figure 29 Real versus forecasted production of wind energy

Unexpected production imbalance >1h from Horns Rev 2, 209MW offshore windfarm

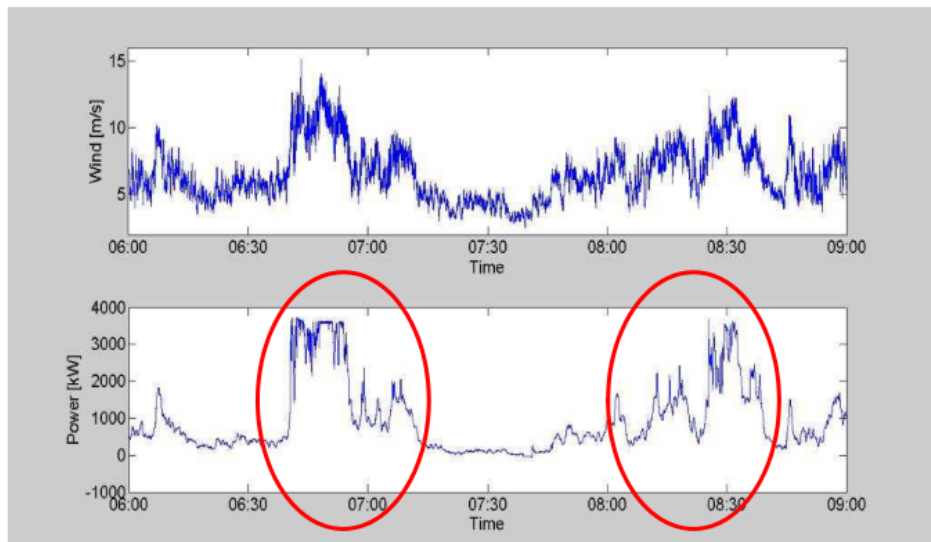


Source: Dong energy.

The accuracy of weather forecasts continues to improve, but significant gaps between forecasted wind and sun and actual electricity production from wind and sun continue. Grid operators must add these uncertainties to their system operations and also have back-up generation capacity to make up for unforeseen shortfalls from renewable sources. This need for back-up redundancy has resulted in some places in the construction of additional natural gas generating facilities as renewable production expands.

Figure 30 Wind turbine output fluctuation

A single wind turbine shows large variations <1h in power outputs



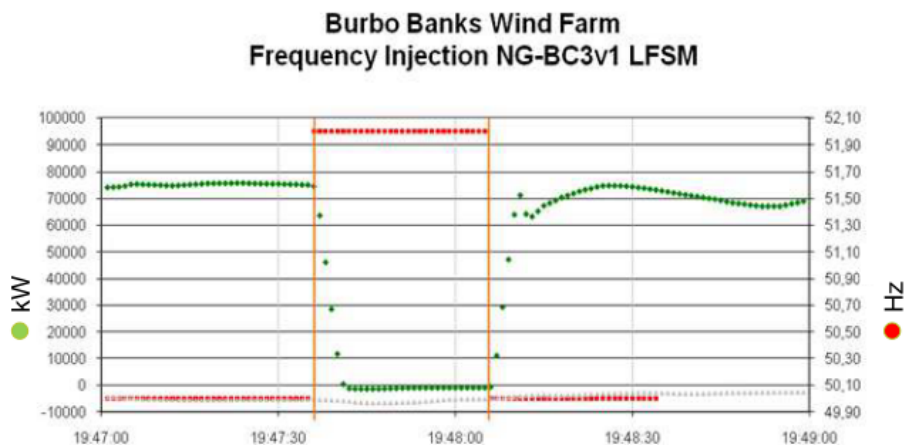
Source: Dong energy.

Transmission service operators (TSOs) aim at stabilising energy supply (and matching supply with demand). Therefore it can become necessary to disconnect certain power sources at short notice.

While certain energy sources are technically unfit for short term shut down, such as nuclear or large coal fired power plants, other sources are much more flexible, in particular gas turbines, but also wind power. As producers of renewable energy often have incentives to produce as much electricity as possible (e.g., through feed-in tariffs), the priority access of renewable electricity and the intermittency of production calls for combination of renewables with other flexible sources. Natural gas turbines, augmenting renewable electricity, offer a more promising solution to marginal supply requirements than nuclear or coal. With ever higher shares of renewables, the need for back-up generation capacities is bound to explode. Out of economic considerations, it is therefore necessary to make renewable power generation more flexible either by increasing the interconnection capacity (e.g., using pump storage hydro in Norway as a flexible source for electricity systems in other countries), or by managing renewable energy sources more directly (see Figure 30, showing the feasibility of short-term shut down of wind parks). In this context, priority access requirements should be debated to allow more flexibility to the transmission service operators (PWC, 2010).

Figure 31 Shut down and re-connecting of wind parks in Denmark

Windfarms have extreme regulating capabilities and rapid response proven at Burbo Banks



Source: Dong energy.

Some countries have additional legal restrictions on the operation of specific power sources. In Denmark, where a high percentage of CHP has been implemented, minimum operation standards for CHP ensure that district heating obligations are met. These requirements, however, limit the flexibility of the transmission service operator. This observed lack of flexibility, combined with a high abundance of wind power in Denmark (see Section 2.2), lead to periods of zero-prices in the Danish electricity market (see Figure 31). In December 2009, negative market prices were introduced for the first time, hitting as low as -120 €/MWh.

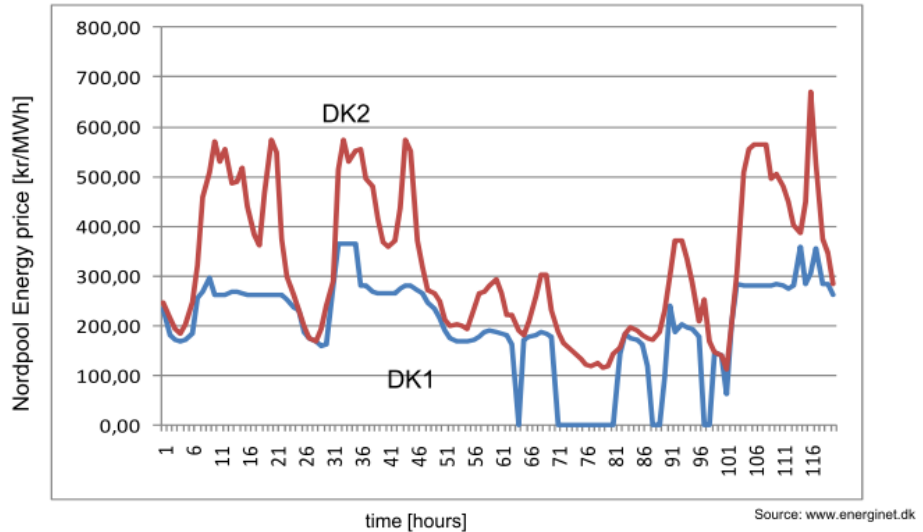


This development exemplifies the fact that a high share of renewable energy sources with no parallel measures to ease the grid integration can come to severe market limitations. We will discuss the potential for Electric Vehicles to integrate renewable energy sources in Section 4.2 on charging and Section 4.3 on grid stabilisation.

Figure 32 Fluctuating electricity market prices in Denmark

Example: Nordpool energy prices – market effects from wind

October 1—5 2009



In addition to the physical and regulatory necessities that guide grid access, Transmission service operators have to take into consideration the marginal costs of energy production when prioritising their energy sources for grid access: the sources with the lowest marginal costs have the highest grid access priority: nuclear and wind. These have almost no marginal costs and can therefore crowd out other energy sources. This effect is referred to as the Merit Order Effect (MOE) (EWEA, 2010). This study shows that an increased share of wind power lowers on average electricity wholesale spot prices. Wind energy can thus replace more GHG-intensive production technologies and can even become part of the base load, provided that sufficient transmission capacities exist.

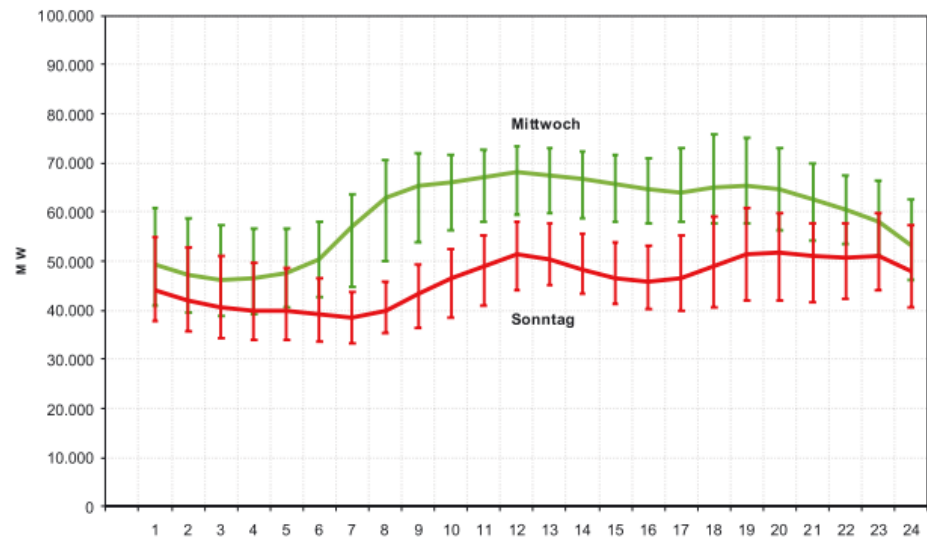
Demand side

Not only supply can be highly volatile, electricity demand varies widely over the course of the day - and weekday and weekend electricity demand also differs significantly. These fluctuations in demand can be seen in Figure 32.

For grid operators and electricity producers, the main obstacle stems from the fact that demand fluctuations do not necessarily coincide with daily (as well as hourly and season) fluctuations in the supply of certain renewable energies. For example, most land-based wind energy is produced during off-peak hours at night; while peak energy demand in most European countries occurs during daytime hours - with substantially higher demand during the week than in the weekend, see Figure 32 (WWF, 2009).



Figure 33 Load curve for a weekday (Mittwoch) and Sunday (Sonntag)



Source: WWF, 2009.

Photovoltaics and other solar systems present a different problem; while these sources produce electricity during times of higher demand, weather (specifically clouds) necessitates back-up energy sources.

Encouraging scaled-up production of electricity from renewables and balancing their intermittency with the fluctuations in energy demand calls for the use of buffers and energy storage technologies. Additionally, there are some demand-side management strategies that can help smooth the differences between supply fluctuations and the energy demand schedule; these are discussed further in Chapter 5.

Balancing supply and demand

In the first place, load balancing attempts to adapt power plant output to existing load profiles and will also attempt to switch on or off additional flexible load such as cooling houses or heat pump systems. Flexible loads are currently still the exemption to the rule and only few TSOs can rely on such options for extended load balancing.

There are several other options for storing or buffering electricity. Storage refers to long-term energy transfers, i.e., from high wind energy at night time to peak demand during daytime, while buffering refers to short term balancing that can consist of changes on the order minutes or seconds (see Section 4.3). Short term balancing smoothes consumption and production patterns and can reduce energy supply costs significantly. For example, ECN found that 6.5 million PHEVs and 1.5 million heat pumps in 2040 have the ability to flatten almost completely the electricity demand curve in the Netherlands allowing 10 GW of wind (ECN, 2010).

4.4 Integrating Electric Vehicle charging with renewable energy supply

Electric Vehicles create additional electricity demand. This demand affects the electricity grid, especially under a high renewable scenario, where energy supply often is highly volatile. This high volatility incurs high-back-up capacities and, thus, higher marginal costs for increases in peak-load.

Electric vehicle charging can have a significant impact both on the distribution and the transmission grid, depending on the amount of Electric Vehicles and their charging characteristics, especially whether EVs are fast-charged or whether large segments of the entire fleet charge simultaneously. This section addresses different approaches for integrating EV charging and renewable energies, taking into account consumer acceptance and consumer behaviour.

Electric Vehicles are likely to enter the market in clusters: consumers that are likely to buy an EV live in close proximity to other potential users. Recent estimates see a homogeneous user type: most users are expected to be male, have a high income, sharing similar work hours and live in an urban-suburban environment (Deloitte, 2010; ETC/ACC, 2009). Many drivers will therefore share behavioural patterns and arrive home near the same time when they might want to charge.

The distribution grid will be under considerable stress, if a high number of EVs attempts to charge simultaneously. Some Member States' distribution networks will be able to handle the added stress from EVs, while it may be difficult for others. Research in Milan, Italy, shows that already 5% market penetration lead to significant increase in peak load (JRC, 2009). It will therefore be essential to implement smart charging infrastructures and protocols that prevent transformer blow-outs due to overload. This implies phased charging over off-peak hours (see Chapter 6).

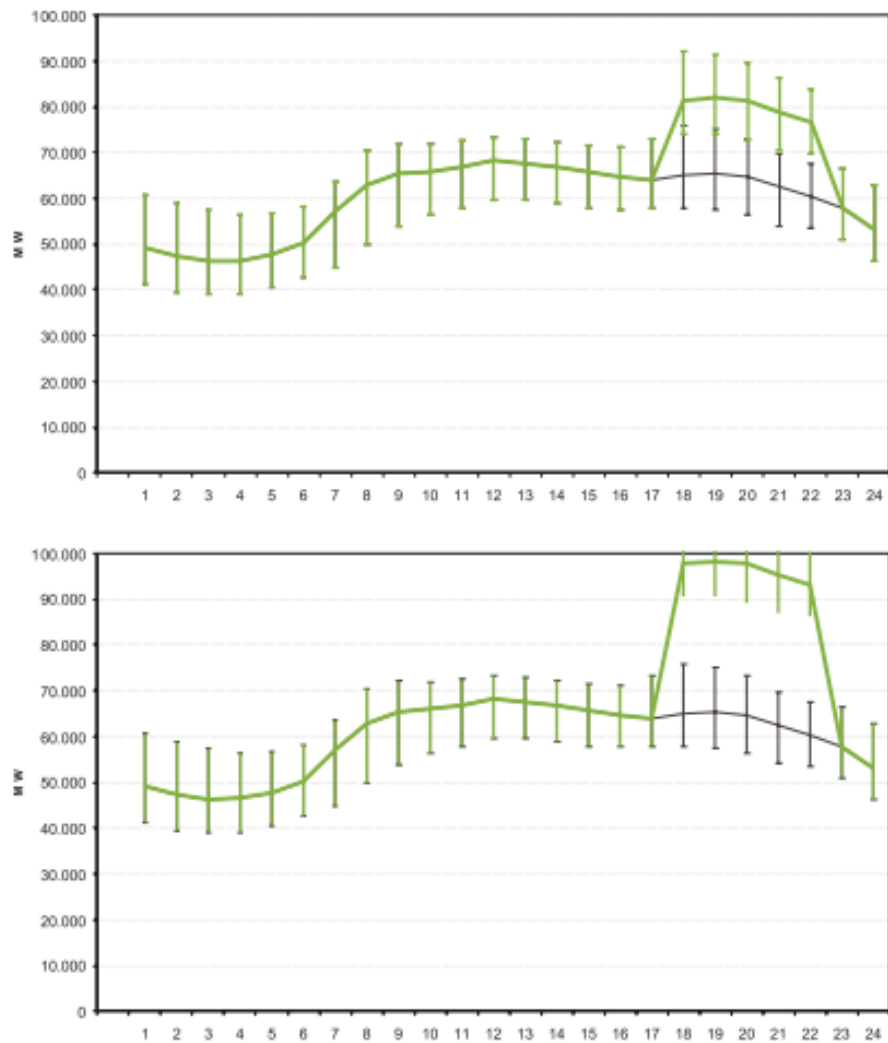
Currently, charging is limited by the design of single phase household connections, i.e., 3 kW in Germany (HAUPT, 2009). The study found that in Germany even an uncoordinated charging will not affect the transformers or power lines even at high EV penetration rates, assuming slow, e.g., overnight, charging. The picture changes drastically, though, if fast charging with more than 10 kW is applied. Countries with a weaker distribution infrastructure than Germany might suffer from transformer bottlenecks even under slow charging (see Chapter 5).

On a larger scale, i.e., at the transmission level, no bottlenecks could be identified. However, EV charging impacts energy markets. Uncoordinated charging can lead to higher peak loads and thus increase electricity prices and reduces system efficiency, see Figure 33.

WWF (2009) found that uncontrolled slow-charging (5 hours) of 20 million EVs would lead to an increase of the peak load resulting in 33.000 MW additional capacity. Fast-charging (2 hours) would increase this value to 80.000 MW. The WWF study shows that simply shifting the charging time to 10 pm does not remedy the situation as the peak load would still be significant due to the fact that all the EVs are being charged simultaneously (see Figure 34). Only phased charging as part of a smart charging system would effectively reduce peak load values and reduce the stress on the power grid.



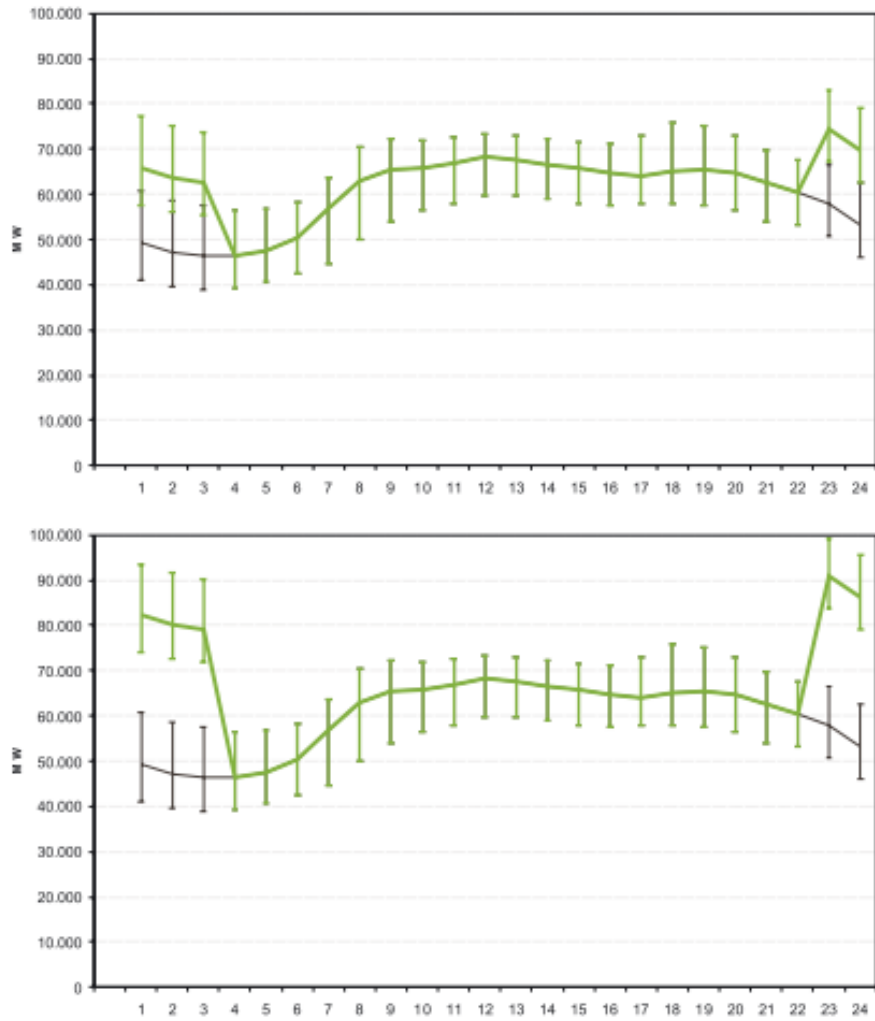
Figure 34 Effects of peak charging 10 and 20 million EVs in Germany



Source: WWF, 2009.



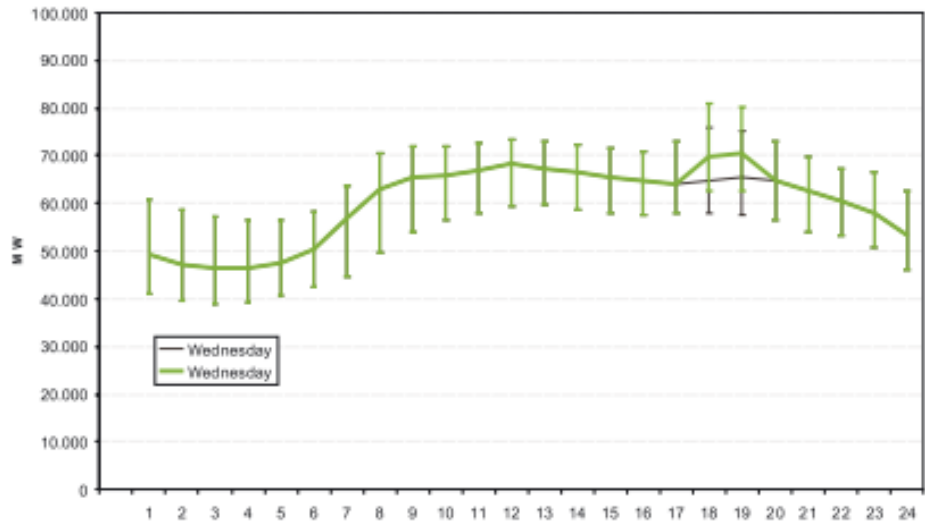
Figure 35 Effects of off-peak charging



Source: WWF, 2009.

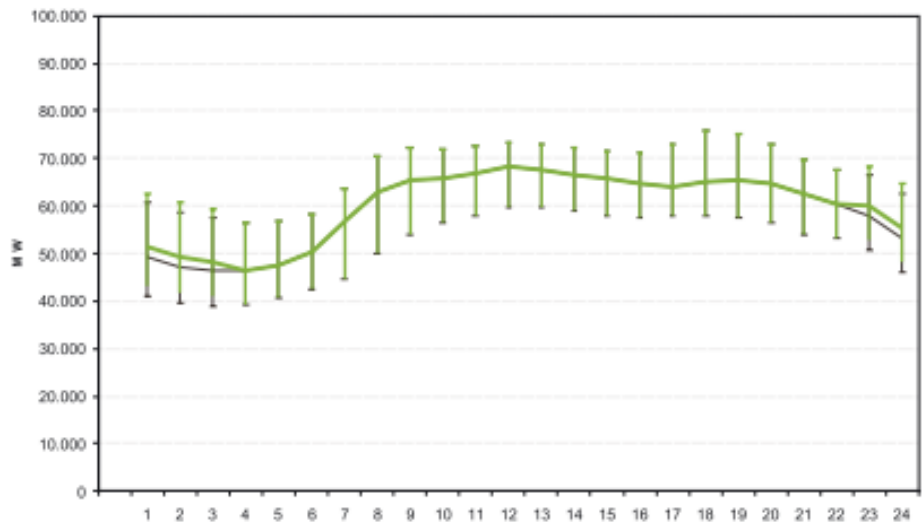
For smaller numbers of EVs, such as 1 million, the picture changes drastically. While evening charging results in an increase in the maximum load (see Figure 35), night-time charging avoids such effects (see Figure 36).

Figure 36 Effects of peak charging 1 million EVs in Germany



Source: WWF, 2009.

Figure 37 Effects of off-peak charging



Source: WWF, 2009.

This implies that controlled overnight charging of a limited number of EVs can result in no increase in peak load.

4.5 Integrating Electric Vehicles as grid stabilisers

In the short- to medium-term, Electric Vehicles could be integrated into the electricity grid through smart charging, i.e., 'Grid 2 Vehicle' (G2V). Specifically overnight, when large-scale wind systems would be producing large amounts of electricity that do not have ready-made demand, Electric Vehicles connected to the grid could serve as storage for this electricity. Vehicle owners would be able to take advantage of reliable and relatively inexpensive electricity prices (vs. day-time charging) to charge their vehicles, thus providing transportation fuelled through renewable energy. Grid



operators and electricity producers would then have demand for peak wind production.

The success of such an approach depends on clear price incentives. Dynamic tariffs and pricing of electricity consumption requires smart electricity meters and homogeneous standards and protocols for data exchange between meters and utilities (CE, 2010).

In the medium to longer-term, Electric Vehicles could thus (under proper technical and economical conditions), contribute to smoothing load patterns throughout the day, providing opportunities for a more efficient use of the system.

In addition, EVs could absorb electricity when it is abundant, i.e., during high wind energy supply and release it again into the grid in time of peak demand. This approach is commonly referred to as 'Vehicle 2 Grid' (V2G).

As batteries and other storage systems such as pump storage contribute already today to stabilising the grid, batteries in EVs constitute additional potential for supply and demand balancing, both short term and long term.

Electric Vehicles will be stationary most of the time, just like regular ICE vehicles. This opens up the opportunity to integrate their storage capacity in a virtual power plant with fluctuating renewable energies, as has been perceived in the Netherlands by ECN (see Section 4.3).

V2G was first introduced by Tomic and Kempton (2007), showing that the revenue stream from selling electricity back into the grid at high load times can create a significant momentum to foster the uptake of EVs.

However, the actual storage capacity of EVs will be extremely limited until their market penetration has increased significantly (IFEU, 2007): 1 million EVs represent approximately 10 GWh of stored electricity, which is only a little more than one large scale conventional pump storage plant (~8.5 GWh). The storage potential is even higher for compressed air storage facilities currently under development (~3 TWh). In addition, EVs will not be permanently available, as their owners will use them at certain times. Further, the negative impact of frequent charging and de-charging are a reduced battery life and limited control over the battery load status for the owner. These factors might significantly reduce the likelihood of EV owners participating in V2G.

Thus, V2G implementation is highly dependent on user acceptance and participation. Most models concede that this is not guaranteed due to the fact that car owners seek convenience.

It follows that EVs - at least in the near-term future - are not a solution for long term and large scale storage of surplus generation from renewable energy sources, i.e., the shifting of night-time over-capacities to day-time peak-demand. As of 2009, over 25 GW wind energy capacity was installed in Germany alone, far beyond the current balancing capacity or the near-term potential of an electric vehicle fleet.

On the other hand, EVs have a very high potential for local and regional short-term grid stabilisation: 1 million EVs can generate 3 GW regulating energy (IFEU, 2007), even with 3 kW household connections. Compared to the German balancing capacity of + 7 GW and -5.5 GW, this would be quite significant. 3 GW amounts to about half the installed pump-storage capacity in Germany (6.7GW_{el}). This means that even a small number of EVs can potentially stabilise the grid on a short term basis.

In order to achieve the full potential of grid stabilisation, however, necessary changes to the grid infrastructure have to be implemented (see Chapter 5). In addition, larger transmission cooperation regions, such as the current Central Western Europe/Nordic market coupling, or even larger load balancing co-operations, can help spread peak demand and ease the pressure on transmission grids, not however on the distribution side.

Other options for accommodating large quantities of renewable electricity exist such as the 'SolarFuel'-approach¹⁰ that converts CO₂, water and electricity to methane and oxygen. Even though this is still at the experimental stage, this methodology could provide a low cost alternative to other storage solutions as methane can be storage in the existing gas grid. The gas can then be used either as fuel for transportation or to generate electricity in gas power plants.

Extending this thought even further, the questions appears whether biofuel s represent a viable (or even superior) alternative to Electric Vehicles. This will be further examined in the following sub-section.

4.6 Electric Vehicles and biofuel s

Both biofuel s and Electric Vehicles are developed as ways to reduce the dependency on oil imports and to mitigate climate change.

While European governments (and much of the related industry) are committed to reducing GHG emissions from the transport sector, different options exist for different applications. Passenger cars can mitigate emissions either by switching to electricity or to biofuel s - as well as through increased efficiency and reduced vehicle miles travelled. Other modes of transportation have fewer options: shipping and aviation are about to adopt biofuel s certification, which could improve the emissions profile of these sectors. However, the use of electricity or alternative fuels such as hydrogen for aviation and shipping is currently not a viable option due to very high costs; the lack of these options does not preclude the usefulness of improved efficiency and the optimisation of routes to reduce kilometres travelled, contributing to reduced emissions.

Both biofuel s and renewable energy compete for physical space and infrastructure resources and, despite the moniker of 'renewable', they are still in a sense finite resources. DGS (2006) compared land use efficiency for different fuel types.

Table 3 Productivity and efficiency for different transport fuels

	First-generation biofuel s	Biogas	BtL	Solar (PV)
Resource productivity (kWh/ha p.a.)	10,000	40,000	30.000	250.000
Energy demand of a single car (kWh per 100 km)	46	62	46	15
Vehicles per ha (15,000 km p.a.)	1.45	4.3	4.35	111

Source: DGS, 2006.

¹⁰ <http://www.solar-fuel.net/loesung/>.



This comparison needs to be put into perspective: only a share of first-generation biofuel s plants and of biogas is used for transport fuels, the remainder being used in other areas (for food and feed, in case of biofuel s). Moreover, many Electric Vehicles will use more than 15 kWh per 100 km. However, the main message prevails: Fuel from biofuel s cannot deliver the same land use efficiency as the use of electricity in Electric Vehicles. Moreover, many applications compete for very limited biofuel supply. It seems therefore more efficient to limit the use of biofuel s in transport for aviation and shipping purposes. Furthermore, biofuel s seem a viable technology for heavy goods vehicles (AEA, 2010).

Recent reports (CE, 2010a and JANNEUM, 2010) suggest that indirect land use changes which have not been taken into account previously distort the net impact of (first-generation) biofuel s in such a way that they do not reduce GHG emissions, but are at least as carbon intensive as conventional fuels.

Moreover, already in 2008, the JRC found that biomass is best used in other sectors than in transport and discouraged the use of biofuel s under cost-benefit considerations (JRC, 2008).

These evidences suggest that transport shall rely as little as possible on (first-generation) biofuel s and should instead aim for efficiency improvements and renewable-based electrification.





5 Grid capacity in relation to EVs

5.1 Introduction

This chapter draws conclusions building on the assessment of the future electricity sector (Chapter 3) and the potential for renewable energy integration (Chapter 4).

The transmission and distribution networks in most EU countries are already operating close to or beyond their rated capacity and some even frequently fail to meet supply due to demand which exceeds their design specifications (Dyke, 2009). Thus, the expected growth of electric vehicle sales will have a significant impact on electric power distribution networks in Member States. However, challenges facing the European distribution network go beyond dealing with peak demand and additional loads, also affecting grid frequency and voltage. These constraints factually limit the total number of vehicles that both the transmission and the distribution grids can absorb.

An essential prerequisite to a further integration of renewable energies and Electric Vehicles is an expansion of European transmission capacities. High shares of renewable can only be accommodated into the grids if major infrastructure measures are undertaken (ECF, 2010).

These transmission lines even-out the intermittency of wind and solar energies by connecting all Member States and ensuring a more balanced supply of renewable energies through diversification.

The necessary additional transmission capacity ranges from 50 to 170 GW, depending on the degree of decarbonisation and on the degree of decentralisation of future power systems. This equals a factor 3 increase. In addition 10-15% added back-up-generation capacity is required for a higher share of intermittent energy sources. ECF finds that added transmission capacities enable inter-regional supply and demand balancing, thus reducing the need for back-up and storage.

5.2 Grid resilience

There is, however, only relatively limited data available on the resilience of electricity Grids. The 4th benchmarking report (CEER, 2008) compares number and duration of power outages at different voltage levels over the time from 1999 to 2007.

So far, we analysed the number of minutes lost due to unplanned power outages (Section 2.2). Other aspects have to be taken into consideration as well, such as planned outages and frequency variations. In the result, some countries show significant issues with their power system, while others perform at higher quality standards.

Looking at both the planned and the unplanned interruptions of power supply as an indicator of supply quality, worst and best practice examples can be identified.



Table 4 Worst and best practice examples for supply security in the European power sector

Underperformers	Best-in-class
Estonia	Denmark
Hungary	Germany
Lithuania	Netherlands
Poland	
Latvia	

Source: CEER, 2008.

In almost all countries, performance values are superior in urban as compared to rural settings.

A number of countries also show severe issues with security of supply such as Spain and Portugal, but also Sweden. Other countries range in the centre span such as Italy. France and the UK are potential good performers. A number of countries have not submitted information at all, including Czech Republic, Romania, Slovak Republic and Slovenia. These countries have to be considered potential underperformers.

At the distribution level, as seen in Section 4.4, Haupt (2009) shows that highly developed distribution grids will not be affected by EV slow-charging. However, Member States with unstable distribution grids will be more prone to suffer under EV introduction. Moreover, fast-charging will drain power from the low-voltage grid. Connecting EV charging stations to the medium-voltage grid may relieve pressure somewhat (Retrans, 2010).

A study has voiced concerns in the UK (Putrus, 2009) over the impact of EVs on the grid quality, but also over local transformer capacity when EVs bundle geographically.

A recent case study by the JRC on the impact of EV introduction on Milan (JRC, 2009) shows that even a high market penetration of Electric Vehicles would not cause problems in terms of overall power requirements, but might indeed pose problems regarding daily load balancing. This effect of increased peak demand could be already observed at 5% total market penetration.

These findings imply that some Member States - such as in Eastern Europe - are not well suited for even a small scale introduction of Electric Vehicles at this point in time. At the same time, these countries are not the most likely candidates for a fast uptake of relatively expensive new vehicles¹¹. On the other hand, Member States such as Denmark, the Netherlands and Germany seem relatively well positioned for a wider introduction of EVs.

The more challenging question is, however, whether intermediate energy systems such as in the UK, Spain or Italy will be able to accommodate EVs in their distribution grids.

¹¹ In Poland, the secondary car market is still the main market.



5.3 Bottlenecks for EV charging

Our survey has shown that most bottlenecks for EV charging are expected at the distribution grid level, not necessarily at the transmission grid level.

In other words, constraints for EV deployment exist more in the domain of hourly load factors rather than in total energy consumption. That is, uncontrolled EV charging will affect peak load factors and thus increase overall generating costs.

At the transmission and generation level, current EU-27 electricity production is at ~3,300 TWh p.a. A typical EV can be estimated to consume approx. 20 kWh per 100 km. Assuming a yearly mileage of 10,000 km¹², this results in a yearly energy consumption of 2,000 kWh. The current EU passenger car fleet of ICEs is 223 million vehicles. If this entire fleet would go electric, this results in an additional electricity consumption of 446 TWh, i.e., increasing total electricity consumption by 13%. As this development is not likely to occur instantaneously, transmission grids and power generation will most likely be able to adapt in due time even if EV uptake is very fast. ETC/ACC (2009) states that Electric Vehicles pose no severe threat to the power system in France if they make up no more than 23% of the total.

At the distribution level, however, as shown in Section 5.2, severe bottlenecks will arise in most Member States beyond 5% EV market penetration.

From 2011 on, Directive 2009/72/EC stipulates common standards in the electricity sector for all Member States. Among others, this includes the access right for households and small businesses to be connected and delivered electricity from a power supplier.

Therefore, EV owners would under current legislation have the explicit right to charge their vehicles at any point in time (large commercial fleets excluded). In order to reduce the substantial investments that would be necessary to update the grid and power generation, either the legal framework has to be adapted (eliminating the access right) or other solutions have to be found. As the elimination of the access right would entail a large number of social and economic issues not related to Electric Vehicles and would go against the spirit of current legislation, this seems a non-viable option. However, using price signals might convince most EV owners to charge their vehicles at off-peak times.

5.4 Smart grid solutions

Even though electricity for EVs is additional electricity demand, total electricity production capacity does not have to grow at the same rate: Smart charging can allow phasing the charging processes in off-peak demand or peak supply hours and thus reduces stress on the grid (see Section 4.5). Thus, legal and/or financial incentives need to be put in place to encourage off-peak charging (Retrans, 2010).

¹² It is expected that future EVs will be used for a lower mileage than current average ICE vehicles. This is not to be taken as an indication as the mileage of ICE vehicles that are replaced by EVs.



Several technical measures are indispensable for enabling an integrated smart grid:

- Integrating renewable and conventional power sources into virtual power plants that stabilise supply.
- Increasing transmission capacities and implementing real-time transmission grid monitoring.
- For V2G, updating the distribution grid for two-way power transmission; this should not be a significant factor in the short term, where G2V smart charging will predominate.
- Smart metering and dynamic pricing for customers, giving incentives to off-peak consumption patterns.
- Demand management including intelligent household appliances.

In essence, all elements of the power system will be communicating on their current status. This, however, requires uniform standards and protocols for data exchange and transfer. Such standards for ICT and Electric Vehicles have been established by the International Electrotechnical Commission (IEC), Technical Committee (TC) 57, power systems management and associated information exchange. Work is currently under development for a draft standard on communication between the EV and the charging station (DKE, 2010), see also Section 6.2.

A number of current research projects develop solutions for EV grid integration such as the FP7 projects MERGE (Mobile Energy Resources in Grids of Electricity)¹³ and G4VTM (Grid for Vehicles)¹⁴.

These measures can considerably reduce the technical constraints for EV growth.

¹³ <http://www.ev-merge.eu/>.

¹⁴ <http://www.g4v.eu/index.html>.



6 Charging infrastructure

6.1 Introduction

The interaction between EVs and the electricity sector is largely dependent on the type of charging. Currently, three basic systems are competing for market dominance in EV charging:

- Charging with household connections (110 to 220 V AC at 30 kW or more).
- So-called fast-charging (300-600 V DC, more than 40 kW).
- Battery swap systems.

In addition, there are a number of developments proposing a contactless inductive charging process.

EV charging can be segmented in so-called levels, going from 1 for 110 V to 3 for higher than 400 V, see Table 5. Each level is associated with different technical characteristics.

Table 5 Description of charging levels for Electric Vehicles

Level	Application	Voltage	Amperage	Associated standards	Description
1	Residential	120	<30	SAE J1772	Same power source used for standard home appliances in the US. Provides AC energy to vehicles; often portable devices. Standard speed charging
2	Residential and Commercial	208-240	30-40	SAE J1772, IEC 62196, IEC 60309 16 A	Can use the same power source as larger home appliances in the US (i.e., dryer) to provide an AC energy supply. Moderate speed charging
3	Commercial	400+	>40	CHAdeMO	DC energy supply for networks and commercial use. High speed charging

Source: RAEL, 2010.

6.2 Standards and codes

Both charging with household connections and fast charging rely on a power connector or plug linking the EV to the charger. At the moment, a vast number of competing formats exists, see Table 6. Three major connector standards exist.



Table 6 Overview of electric vehicle plug standard and manufacturer support

Standard	Manufacturers	Country/region of manufacturer	Number of pins used in connector type
IEC 62196 ¹⁵ (presently VDA-AR-E 2623-2-2)	Mennekes	Germany	7
	EDF	France	
	CEEplus	Italy	
	Legrand	Switzerland	
	Gewiss	Germany	
	Marechal Electric	France	
	Scame	Italy	
	Schneider Electric	Germany	
	Radiall	N.a.	
	Vimar	Italy	
	Weidmüller France	France	
	Yazaki Europe	Europe	
SAE J1772	AeroVironment	North America	5
	Clipper Creek	North America	
	Coulomb Technologies	North America	
	ECotality Blink	North America	
	GE Wattstation	North America	
	GoSmart Technologies	North America	
	Leviton evr-green	North America	
	Yazaki	North America	
CHAdeMO	Aker Wade Power Technologies	USA	7
	Bosch	Europe	
	Epyon	Europe	
	Evtronic	Europe	
	Fuji Heavy Industries Ltd.	Japan	
	SGTE Power	Europe	
	Nissan Motor Company	Japan	
	Mitsubishi Motor Company	Japan	
	Tokyo Electric Power Company	Japan	
	Toyota Motor Corporation	Japan	
	Tyco Electronics	Japan	
	Vector Japan Co., Ltd.	Japan	

This severely fragmented development can lead to the situation that an EV driver needs to recharge, finds a charging station, but cannot access the electricity because his car is not compatible with the connector.

Presently the quick charging (level 2 and 3) stations often use the Japanese CHAdeMO standard. Quick charging standards are not as advanced as for slow charging because of the more recent development in technology but are becoming more necessary and discussed as quick charging becomes more common. A number of competing standards along with CHAdeMO also exist. A standard from the Society of Automotive Engineers (SAE International) was adopted in the US, and one from the International Electrotechnical Commission was adopted in Europe. The need for common standards for electric vehicle charging is becoming clear, not only for safety issues, but

¹⁵ The international standard has not yet been approved and is under preparation.



because the use of a common standard will make it cheaper to set up an electric vehicle charging station (EIU, 2010).

So far, no standard has won the majority support by car manufacturers. However, all stakeholders push hard for a uniform solution:

The European Automobile Manufacturers Association (ACEA) has defined European specifications for connecting Electric Vehicles to the grid. The ACEA aims to enable standardisation bodies to define common interfaces between Electric Vehicles and the electricity grid throughout Europe. The European specifications, which could eventually be used as a basis for a global standard, were developed with assistance from Japanese and South Korean manufactures. A common standard will be issued in 2017¹⁶.

Furthermore, the Union of the Electricity Industry-Eurelectric is engaged in promoting standards for electric vehicle charging infrastructures to ensure quick market penetration and avoid future compatibility issues. The association seeks to ensure standards for both hardware (connectors and cables) and communication software. Eurelectric engages in testing pilot projects, research and development and stakeholder dialogue as well as the preparation of pre-standards in preparation of officially approved standards (Eurelectric, 2009).

Moreover, the EV plug alliance, established in March of 2010, seeks to promote a plug and socket solution for electric vehicle charging in Europe and seeks to convey industry needs to the International Electrotechnical Commission (IEC). The Alliance consists of nine plug manufacturers¹⁷ who share an interest in producing products compatible with multiple suppliers¹⁸.

Figure 38 Example of electric vehicle plug (Mennekes)



¹⁶ http://www.acea.be/index.php/news/news_detail/auto_manufacturers_agree_on_specifications_to_connect_electrically_chargeab.

¹⁷ The EV Plug Alliance is: Schneider Electric, Lagrand, Scame, Gewiss, Marechal Electric, Radiall, Vimar, Weidmüller France and Yzaki Europe; the EV Plug Alliance also receives support from Gimélec, a French industry association made up of approximately 230 companies.

¹⁸ <http://www.edubourse.com/finance/actualites.php?actu=63700>.

6.3 Comparison of charging systems

The various systems have different social, economic and possibly environmental impacts which will be screened in this section.

Charging with household connections

Charging with household connections has the advantage of bearing relatively little implementation costs and the added benefit of relatively low health hazards for users. Moreover, batteries fare very well with slow charging and there is usually no cooling needed. However, drivers usually refrain from very long charging cycles that can easily take 8 hours and more (MINI E: 35 kWh battery). As this system requires only limited capital expenditures, it is possible for EV owners to finance the charging outlet themselves. Other options, especially for charging outlets away from home, can be considerably more expensive.

The need for external outlets in the EU especially may be large, as many car owners do not have their own garages or private parking spaces (ETC/ACC, 2009). Organising and financing the installation of charging outlets on a large-scale could present its own challenges. Therefore, it could be an option to focus on home owners with a garage or carport for primary market introduction of EVs (ETC/ACC, 2009). For EV owners with private spots or garages, DOE 2008 estimated costs for residential charging to be below € 2,000 per outlet. Costs per charging spot decrease for multi-unit charging stations. In theory, standard power outlets can be used as charging station. However, this is not encouraged due to safety concerns.

Fast-charging

Fast-charging can reduce charging times considerably by using higher voltage connections. Some systems can achieve a 50% charge in 10 to 15 minutes.

JFE Engineering has developed, available in June 2010 though not compatible with vehicles in the general market, a 'super-rapid' charging system that can charge vehicle batteries to 50% capacity in approximately three minutes, according to the company. The same amount of time required to fill up at a normal gas station. To charge to approximately 70% capacity, the system needs about five minutes. This fast-speed charging technology seeks to overcome the obstacle faced by Electric Vehicles of traditional slow charging. The Japanese firm uses technology which stores energy gathered at night in a battery within the system, which then enables the system to dispense energy rapidly into a vehicles battery system. Additionally, because the charging system transfers electricity at night, when electricity costs are lower, electricity costs can be reduced (JFE, 2010).

While being more convenient for EV users, this technology exerts more stress on the battery and shortens the battery life-time. Moreover, higher voltages also incur a higher health hazard during the charging process. Significant safety concerns arise when using technology to provide vehicles with a fast electric charge, which often involve roughly 250 kW of power. The high energy density incurs high temperatures and a need for cooling of the battery and charging structure. Moreover, future development of fast charge technologies suggests that professionals as well as lay people will be operating charging equipment. This technology necessitates additional infrastructure and is therefore more costly than low-voltage charging. Costs per charging station are estimated to be between € 20,000 and € 40,000 per public outlet (ELCOA, 2009), at approximately the cost of a gas station pump. Fast-charging



station can be connected either to the low- or to the medium-voltage distribution grid (Retrans, 2010).

Battery swap systems

Battery swap systems - currently proposed by Project Better Place - would allow drivers to exchange depleted batteries against fully loaded modules in an automated swap station, similar to the current gas stations and probably at a similar price. This system requires heavy investments in infrastructure and additional batteries but offers the fastest 'charging' process while at the same time being safe. The actual costs of a battery swap system are yet unknown. Project Better Place suggests a combined approach of using home-site charging, public charging and battery swap systems only for long distance travel. This concept seems very difficult to finance as the rare use of the swap stations will delay their cost recovery even further.

The Chinese company Kandi Technologies has also developed a battery swap system for a new two-passenger Electric Vehicle targeted towards city dwellers. The KD5010 is a small and light electric vehicle with a 150 km range and max speed of 83 km/h. The vehicle does not get plugged in to charge. Instead it uses six flat-profile lead acid batteries which slides in under the passenger doors and can be quickly and easily swapped. Batteries will be changed at a manual swapping station for about \$ 6, and the process should only take a few minutes, comparable with a fill-up at a traditional gas station. Batteries are then taken to a central smart charging facility which adjusts according to demand, maximising grid efficiency. Because batteries can be easily swapped manually, the company also offers an emergency roadside swapping service available for a small premium (Kandi, 2010).

The vehicle is considerably cheaper than other Electric Vehicles on the market because it uses the lead-acid batteries, which are however environmentally harmful. It costs about € 4,500 without batteries and before subsidies in China. Batteries cost around € 1,100, although customers will most likely lease them or pay a deposit because they will eventually be swapped. The use of a central charging station helps to eliminate expensive infrastructure investments and stability issues as well as maximise battery life and performance. Additionally, the lead-acid batteries can be recycled to reduce pressures on raw material (Kandi, 2010).

Induction charging

Induction charging represents yet another charging method which uses an electromagnetic field thus requiring no cable is also available to charge Electric Vehicles. Instead vehicles would use a form of docking station, in which they would park over or near the charging device while the energy transfers. The technology, called Magne Charge, was already used for vehicles in the US in 1990s, but was replaced by the SAE J1772 standard of wired or conduction charging method.

More recently, a US based company Evatran has developed a version of inductive charging for Electric Vehicles called Plugless Power. Plugless Power offers a system where drivers would align their cars over the system, which needs to be just a few centimetres away to work, and the vehicle would automatically begin charging. The advantage is a cable free convenient method to charge Electric Vehicles. The system is set to be available in late 2010. A major challenge for the system's widespread use is the various heights of different vehicles, though Plugless Power addressing this issue. A larger barrier is the challenge of competing with plug-equipped systems (Evatran, 2010).



Inductive charging is currently investigated further in at least three pilot projects, one by Daimler, one by Audi and one by Fraunhofer IWSE¹⁹.

In terms of safety and efficiency, inductive systems may offer some safety advantages because there are no exposed conductors while at the same time being slightly less efficient than conductive methods. However, differences in both safety and efficiency between the two methods is said to be minimal.

The Korea Institute of Science and Technology (KAIST) developed a form of inductive charging where vehicles wirelessly receive energy from cables buried underneath the surface of the road. The Online Electric Vehicle (OLEV) developed by KAIST can pick up a charge from the cables under the road while moving or parked. The technology, although in its early stages, offers a number of potential advantages. Namely, vehicles would be able to travel long distances without the use of batteries and needing to recharge. Additionally, because the vehicles would not require batteries they would be lighter and therefore potentially more efficient as well as requiring less high tech material such as lithium. A further advantage to the technology is potential safety features especially by using the technology to enable the vehicle to operate itself (KAIST, 2009).

Discussion on the various charging systems

For almost all discussed charging systems, significant capital expenditures have to be born in order to provide sufficient density of charging points. The main limiting factor for the financing of EV chargers is the slow payback time that can even exceed the expected lifetime of the outlet. ELCOA (2009). Estimated that a public charger would barely reach amortisation in its ten year lifetime, given average usage. This is mostly due to one of the main arguments in favour of adopting EVs: low electricity prices.

The only exemption is the system proposed by Kandi which is however only applicable to the Chinese market and is not transferable to European or US markets, mostly due to the use of environmentally harmful lead-acid battery technology.

Table 7 Comparison of charging systems

	Slow-charging	Fast-charging	Battery swap	Induction-charging
Voltage	230 V AC	300-600 DC	Flexible	Flexible
Charge speed	--	- +		Flexible
Health hazard	+	- ++		++
CAPEX	++	- ---		-
OPEX	+	+ -		+

Source: Authors.

¹⁹ <http://www.pt-elektromobilitaet.de/>.



6.4 Charging station businesses

A number of businesses have developed to support the expanding use of Electric Vehicles and to deliver them with the power they need to operate. Business models range from those which strictly manufacturer charging stations (i.e., AeroVironment) to businesses which manufacturer as well as operate the charging stations (i.e., RWE). Furthermore, while some companies (i.e., Coloumb Technologies) are well established in the charging business others are in the early stages of development.

Table 8 provides an overview of multiple companies currently producing electric vehicle charging systems and suggests some industry characteristics. Due to the large number of companies manufacturing charging technologies, the list is not exhaustive, but instead provides a small sample.

Table 8 Selected charging station businesses

Company	Application	Charging level	Smart (Yes/No)	Connector standards	Capacity (Voltage & Amps)	Regions of use
AeroVironment	Residential, Commercial	2, 3	Yes	SAE J1772, CHAdeMO	120 V, 208-240 V	N.a.
Aker Wade Power Technologies	Commercial	3	N.a.	CHAdeMO	90-125 A, 400 V	North America, Europe, Australia
Coulomb Technologies	Residential, Commercial	1, 2	Yes	SAE J1772, Shuko, BS AUZ	16-30 A, 120-240 V	North America, Europe
Ecotality - Blink	Residential, Commercial	1, 2	Yes	n.a	N.a.	North America
Epyon	Commercial	N.a.	Yes	CHAdeMO	N.a.	North America, Europe
GE Wattstation	Residential, Commercial	2	Yes	SAE J1772	208-240 V	Will be released in North America in 2011
Go Smart Technologies	Residential, Commercial	2	Yes	SAE J1772	15-30 A, 208-240 V	N.a.
JFE Engineering	Commercial	3	N.a.	none	None	n.a
Leviton evr-green	Residential	1, 2	Yes	SAE J1772	7-32 A, 120-240 V	N.a.
OpConnect EVCS	Commercial	1, 2	Yes	SAE J1772	120-240 V	N.a.
RVE	Residential, Commercial	2, 3	Yes	VDE-AR-E 2623-22	32-63 A, 400 V	Europe

Charging stations are built specifically for residential or commercial use and offer a different range in power supply.



Most charging infrastructure companies (AeroVironment, Coloumb Technologies, etc.) offer smart technology with their public charging systems which provide communication options. The charging systems, which communicate through either a wireless or wired connection, enable the collection of usage data over time. These options enable charger owners, fleet managers, utilities and also governments to remotely monitor energy usage²⁰. For owners and managers, communication options also mean the ability to remotely control charging systems to interact with customers, make software upgrades, control access to minimise theft and enhance safety, or take advantage of demand side management options such as preferred pricing. For governments, this information enables them to monitor electricity consumption in the transport sector, useful when seeking to determine electricity use by Electric Vehicles and thereby meeting CO₂ reduction targets.

EVs can rely on a set of charging options, including at-home and public charging. This means that the necessary number of public charging stations might be less than one charging spot per car, as some car owners will opt to charge at their homes. Additionally, because some charging stations offer the capability to charge multiple cars, usually up to four, commercial charging stations will not require one charger per vehicle. Most customers are likely to use a mix of residential and commercial charging, depending on individual convenience and driving patterns. Large fleet operators using Electric Vehicles are likely to purchase their own charging stations, receiving support from manufacturers, though still use public charging stations when necessary.

Figure 39 Commercial vehicle charging station



Seen in the table above (Table 8), most companies produce electric vehicle charging stations for both residential and commercial stations, while some manufacturers do focus on producing specifically residential or specifically commercial stations. Notably, those companies that build level 3, fast charging stations, appear to sometimes focus on producing commercial charging systems. For example, Aker Wade and JFE Engineering specialise in fast-speed charging systems.

Power utilities will be able to provide a small number of public chargers for pilot projects, however, will refrain from equipping the entire territory with outlets at their own costs.

²⁰ See <http://evsolutions.avinc.com/products/list/>.

Other business models will eventually emerge to compete with the present charging station business and to provide consumers with alternative charging options. For example, some businesses may include charging by the hour or by the parking spot, i.e., offering paid parking services. Charging by the hour is presently used in the US to avoid being considered a utility. Charging by the hour, however, does put cars which charge slower at a disadvantage.

Through the use of smart systems which could recognise vehicles or the use of an identification card, businesses may also compete to sign contracts with customers to use their service as a mobility provider. In this concept, businesses could even offer custom packages to consumers, depending on driving patterns and needs, and consumers would receive a monthly bill from their commercial and residential charging. Options include per-use charging or different stages of flat-rate packages.

Moreover, to account for longer charging times, charging stations are likely to be built in business and shopping areas such as parking garages as opposed to petrol stations. Therefore businesses seeking to establish charging stations there will need to make agreements with real estate owners or managers who therefore may also share in the revenues²¹. It is therefore also a possibility that shopping centres or other businesses may offer free or discounted charging to encourage business.

The specific circumstances of EV charging, i.e., long duration, high capital costs, low returns, will entail a completely different business model as compared to today's gas stations. So far, no viable and economically proven business model exists and there are substantial doubts as to the profitability of operating and building charging infrastructure under low electricity prices. This issue will be explored in more depth in the separate report on Business Models.

Several remedies to this dilemma exist such as

- Governments can subsidise or finance public chargers.
- The finance sector can develop instruments to support public charger construction.
- Utilities or charging companies can charge higher use fees that actual retail electricity prices to EV users.

This is ultimately a political decision. It should also be noted that different charging options feature different energy efficiencies: Fast charging leads to higher heat losses and can increase energy consumption by up to 25% (FAZ, 2010). More information regarding the technical aspects of battery charging can be found in report D2 - Assessment of electric vehicle and battery technology.

²¹ <http://wheels.blogs.nytimes.com/2010/08/26/e-v-chargers-planned-for-manhattan-parking-lots/?scp=1&sq=electric%20vehicle%20charging&st=Search>.





7 Monitoring of EV charging and energy mix

This chapter discusses possible options for monitoring EV electricity consumption. This is relevant in particular regarding taxation and government policies such as minimum renewable use in transportation (see Section 2.1). As such, monitoring serves two purposes: energy accounting and taxation.

7.1 Options for monitoring EV electricity consumption

Electric Vehicles can be charged through household connections or special fast-charging connections or in public charging stations. Not all vehicles will be charged from commercial sites because many Electric Vehicles will be charged at an electric vehicle owner's home.

In the case of household connections, having a special standard power plug for Electric Vehicles would ensure that EVs are not charged through the regular meter, but would have to use a separate meter instead. This special plug, one of the standards under discussion, would have to recognise the car through a RFID process and initiate charging. The car and the charger should both refuse charging in case of incomplete identification. Tempering with the power plug could result in fraud. However, the required identification stage will significantly reduce the risk. In addition, most customers will not want to incur the risk of electrocution. The additional costs can be shared between the utility provider and the EV owner.

The future use of smart meters, which has already begun, will play a substantial role in determining electric vehicle's electricity consumption. Smart meters enable the monitoring of energy use by time and purpose to provide a detailed breakdown of energy use. Installing a smart meter in every home may be expensive; however, they provide benefits to consumers, electric utilities and governments. Thus, they may perhaps be more willing to share the bill. The use of smart meters allows consumers to take advantage of off-peak prices when charging Electric Vehicles or other electric devices. The use of smart meters enables utilities to operate more efficiently by promoting off-peak consumption. Governments benefit through enhanced monitoring capabilities by being able to track electricity use by purpose, e.g., transport. The exchange of consumption data via smart meters entails a number of privacy issues, especially if the government will be accessing this information for its own purposes. A potential solution might be to limit individualised data transfer from homes to utilities. The latter could then aggregate information and provide this aggregated data to authorities, hence avoiding privacy infringements.

The risk of manipulation is greatly reduced, once smart meters are involved in monitoring the electricity use. However, a residual risk persists that is linked to information technology manipulations such as hacking. This risk will have to be properly addressed in any smart metering standard.



In the case of fast-charging at medium voltage (e.g., 380 V AC) at home, a separate meter is automatically installed, making separate metering straightforward and evasion impossible. In the case of public charging, separate metering is automatically given. Thus, even without smart charging and smart metering, separate metering for the Electric Vehicle would be technically possible.

At a later point in time, Vehicle 2 Grid (V2G) might lead to monitoring problems due to bidirectional energy flows and unaccounted energy losses due to storage.

The information on EV metering can be the basis for calculating total EV electricity consumption, assuming and recommending that legal requirements force utilities to report such data. Such data would be relating to the charging point and not to the individual vehicle.

A different approach would be to monitor EV electricity consumption through separate on-board metering devices that could relate the information to national authorities using satellite communication. This approach would incur substantial additional costs both for the vehicle owner and the surveying authority. In the case of EV charging through household connections using standard electricity outlets, this might be the only viable option, however. This data would relate to the individual vehicle.

Digital tachographs may be a potential tool for monitoring Electric Vehicles through onboard equipment. They provide digital monitoring of a vehicle's use such as distance, speed, driving times and rest periods. The use of tachographs is already mandatory for goods and passenger transport vehicles (more than nine passengers) in the EU. Additionally, legislation (Regulation EU No 1266/2009) already exists which requires Member States to use a common electronic data exchange system (TACHOnet) to collectively gather driving information about professional drivers²². However, requiring the use of tachographs for Electric Vehicles would be costly as well as burdensome and still leave issues such as consumer privacy open. Tachographs would allow, though, the specific tracking of individual electricity consumption across borders.

Nevertheless, Nissan's 'EV-IT' system already uses similar technology with an onboard transmitting device connected through mobile networks to a global data centre. The option is presently used to enable consumers to use remote functions such as to start battery charging or to monitor battery levels online or through mobile phone applications. Onboard communication devices, and their expanded use, would possibly enable further monitoring capability of electric vehicle power consumption.

Similarly, direct GPS transponders as used for electronic tolling services (in Germany: TollCollect) can be used to track EV use on streets covered by the tolling system. The Netherlands entertain a legislative proposal to charge for all road use by using satellite technology. This approach could in principle also be used to monitor EV use. The creation of such a system solely for EV monitoring would be prohibitively expensive. Sharing the infrastructure with a general road toll would however lower the costs for EV monitoring significantly.

²² http://ec.europa.eu/transport/road/social_provisions/tachograph_en.htm.



Table 9 EV monitoring options

Option	Application	Strength	Weakness
Residential smart meter	Residential charging	Detailed use of consumer energy use for Electric Vehicles	Privacy issues; Manipulation issues; Requires more widespread use of smart meters
Commercial data collection	Commercial charging	Relatively easy and cost effective to implement because most utilities are already collecting the information	No individual car data available
Tachographs/onboard communication devices installed in vehicles	Residential and commercial vehicles	Provides a detailed picture of vehicle activities; Activities could be analysed or taxed according to use (i.e., higher taxes for driving during peak periods); Some car manufacturers already install communication devices	Costly and burdensome to implement; Privacy issues; Manipulation issues

A uniform and unique power plug under one of the current standards seems to be the most cost-effective approach to EV monitoring.

7.2 Taxation

In principle, two approaches to taxation exist: direct and indirect. Most taxes are indirect, such as the fuel tax which is included in the final sales price and paid for by mineral oil suppliers. The income tax and property taxes are direct taxes and are paid for directly from the tax subject to the collecting authority.

In fossil fuels, different fuel taxation and regulation exists. Aviation and shipping fuels for example are currently exempt from taxation and some Member States apply reduced rates to a number of other uses based on Directive 2003/96/EC. These fuels are marked (colouring) and handled separately, reducing fraud risk.

Electricity, however, is a completely homogeneous good that cannot be marked accordingly. Still, already now, different users can have specific tariffs, either based on volumes and peak demand (mostly commercial users) or time and application. Households using electricity for heating purposes have often separate meters and can have access to lower fee night-time electricity. Separate metering for Electric Vehicles would enable different taxation for different electricity types. This way, the considerable losses in fuel taxes can be recovered without the introduction of road charges or raising revenues through other tax sources (e.g., VAT, income or fuel tax). This strategy should be followed from the early introduction of EVs on, enabling separate taxation once the market moves into maturity.



Tachographs would create the possibility to raise taxes as a direct tax or road fee. Similarly, a general road toll would allow for direct charging for EV usage. When assuming that the goal is to maintain a constant revenue flow from the road sector, the following approaches seem possible:

In summary, due to cost considerations, enforcing a uniform plug format that is incompatible with any other use form would ensure a least cost monitoring and taxation of EV use through smart metering technology.

Indirect taxation such as under the current fuel taxes and electricity taxes would incur lower transaction costs compared to direct taxation or fee based systems.

7.3 Electric Vehicle electricity consumption and government policies

A number of policies link to the use of electricity in Electric Vehicles. The most relevant are the Fuel Quality Directive (2009/30/EC) and the Renewable Energy Directive (2009/28/EC).

The Fuel Quality Directive of 2009 requires in article 7a that Member States reduce the lifecycle GHG emissions of fuels per unit of energy by 10% until the end of 2020. These reductions can be achieved through improvements in fuels themselves, by employing new technologies such as Carbon Capture and Storage or through other options, including Electric Vehicles. Lifecycle assessments follow strict rules. However, a number of issues are still open.

The Renewable Energy Directive of 2009 sets an explicit 10% target for renewable energies in the transport sector until 2020 (article 3). Electric Vehicles contribute to this target: Member States can either apply the share of electricity from renewable energy sources in the Community or the respective share in the Member State itself. Clear rules for measuring the electricity consumption of EVs are expected by the end of 2011.

Options laid out in Section 7.1, in particular separate metering at the charging station, will allow a precise accounting of electricity consumption of EVs. Depending on the electricity contract for the charging station, even the exact share of renewable electricity can be computed, if utility providers are required to report such data.

Thus, Electric Vehicles can contribute to reaching the targets laid out in the Fuel Quality and Renewable Energy Directives.

8 Conclusions

The EU seeks to meet shared energy and climate challenges of the Member States with a common strategy, manifested in the EU climate and energy package. Both the EU and a large number of Member States pursue very ambitious energy targets and specifically for higher shares of renewable energy in the electricity grid. By 2020, the set goal is to reach 20% renewable energy in final energy consumption in the EU and 35% of renewable energy in electricity consumption. The EU supports the use of market based and financial instruments as well as research and innovation to achieve its goals. It also funds infrastructure projects and seeks to foster international relations regarding energy.

Electricity sector forecasts

Electricity sector developments and energy supply quality in the Member States differ considerably, specifically regarding renewable energies. While some Member States make rapid progress towards goals, others lag behind due to a variety of issues.

In a scenario without EVs, long-term electricity demand in the EU is expected to increase, placing potential pressure on power distribution and causing concern about how to integrate EVs and PHEVs. The expected future electricity market of the EU was calculated based on the PRIMES model using the IPM® model. The analysis finds that energy demand in the European Union will increase by 21%, rising from around 3,300 TWh in 2010 to 4,000 TWh in 2030. Similarly, peak demand rises at an average of 1% annually, from approximately 540 GW in 2008 to 660 GW in 2050.

The Western and Nordel regions (UK, Germany, Sweden, and Italy) show lower growth compared to Eastern Countries (Poland, Slovakia, Czech Republic and Greece). Aside from Spain, Belgium and Ireland most of the growth in Energy Demand will occur in Eastern Europe.

Our analysis shows renewable units undergo rapid growth: 340 GW are added by 2030, with 70% of this capacity being wind, 6% being biomass and 18% solar. By the end of the study horizon, the majority of the capacity mix is composed of renewable (primarily wind) and nuclear capacity.

Renewable generation provides the largest market swing over time: from 19% of generation in 2010, it holds 32% in 2020 and grows to 36% by 2030. The largest share of renewable generation is in wind, which contributes to 5% of generation in 2010 and grows to 17% by 2030. Although solar generation and other non-conventional renewable technology (geothermal, fuel cell, etc.) show significant growth between 2010 and 2030, they only represent a small share of the mix in 2030. Nuclear generation grows roughly 4% from 2010 to 2030, but the share of nuclear generation falls from 28 to 24% over the course of the study horizon as energy demand grows more over the period.

Peak prices increase significantly over time, especially after 2015, while baseload and off-peak prices remain almost constant.



Given the increasing CO₂ prices and large renewable penetration into the system, our modelling results do show substantial reductions in emissions, which decrease by 9% from 1,274 Million tonnes CO₂ in 2010 to 1,159 Million tonnes CO₂ by 2020.

Large scale renewable energies cause severe balancing issues, both at the micro level and on a larger scale. Wind energy, for example, is mostly available at night time when demand is lowest. Without updates to the current electricity grid, zero prices and even negative prices will affect electricity markets.

Electric Vehicles and the electricity grid

Electric Vehicles can be a potential buffer for grid imbalances. However, our analysis shows that this refers mostly to micro-buffering, not to long-term storage. Only very high shares of electric vehicle market penetration will offer the potential to effectively store surplus energy from off-peak to peak demand (V2G). Moreover, serious concerns regarding battery cycling have to be addressed before vehicle owners might be willing to commit to grid stabilisation. In either case, high battery costs in Electric Vehicles prohibit the use of these as load balancing instruments.

Still, there is considerable potential for smart charging, cutting off-peak demand and smoothing electricity demand curves.

Even a complete electrification of the EU-27 passenger car fleet would increase electricity demand by only 13% (compared to current electricity use, using rough estimates of EV energy use). However, uncontrolled charging can significantly increase peak load and thus incur a high cost burden.

No significant risk for distribution or transmission grids could be identified for countries with a developed distribution grid, even for high shares of Electric Vehicles as long as charging uses household connections. Member States with insufficient distribution grids could face severe local stress on their power grids. Fast charging applications could change the picture and lead to bottlenecks in all Member States.

Electric Vehicles offer the potential to substitute biofuel s in passenger cars and allow aviation and shipping to benefit from less resource competition on scarce biofuel s.

Smart charging requires smart grid updates to the entire electricity sector, incurring substantial investments.

Electric Vehicles: charging, monitoring and policy

Charging can be segmented into three categories: household connections, fast charging and battery swap systems. A major obstacle in Europe is that most car owners do not own a garage but park their car at the curb. This requires a multitude of capital intensive public charging stations. Given the immense investment needs and low electricity prices, no viable business concept has emerged so far. Especially swap stations seem to have a particularly low return on investment. Current charging stations are either free or at least highly subsidised by either electricity providers or car manufacturers. Future business models might charge rather for the parking space than for the electricity.



At the time, three standards for connecting EVs to charging stations (power plug) compete for worldwide recognition: one from the American SAE, one from the European/international IEC and the Japanese CHAdeMO. Even though all players insist that they support a uniform standard, allowing any vehicle to charge at any station, also reducing the total number of charging stations needed. The outcome of this race for an international standard is still widely open. National governments are also involved - such as the German government who is supporting the IEC-based 'Mennekes' plug. A common standard is expected in 2017.

A look into the mid-term future reveals that induction charging might become a safe and user-friendly solution to charging EVs.

Electricity consumption by Electric Vehicles can be monitored by separate meters if outlets are not compatible with standard electric power outlets. Metering at the charging station is preferable to on-board monitoring. Electric Vehicles can thus contribute to reaching the targets laid out in the Fuel Quality and Renewable Energy Directives.

Fuel taxation is currently a major income source to finance road infrastructure. Hence, it will be paramount to replace lost income through other revenues. Separate and smart metering would allow for a differentiated taxation of different electricity uses, collected indirectly through the electricity bill. The standardised power plug for EV charging, incompatible with other outlets, would prevent tax evasion.

EVs are relevant to a number of EU policies, most notably the Fuel Quality Directive (FQD) and the Renewable Energy Directive (RED). EVs can contribute to the reduction of carbon intensity of transport fuels as required under the FQD and can help achieve the set target of 10% renewable energy sources in transport by 2020. Both cases require a more detailed accounting of EV electricity consumption.

Key Findings

The impact of EVs on the electricity sector depends on:

- Magnitude of the market penetration.
- Timing of charging (peak/off-peak).
- Charging duration (slow/fast).
- Load management and demand management.
- Structure of the power sector.
- Availability of renewable energy sources.

EVs can contribute to a higher potential for intermittent renewable energy source and can serve to buffer short term and potentially even long-term imbalances between electricity supply and demand. As such EVs would serve as flexible sinks ('Grid-to-Vehicle' G2V).

Charging and monitoring of Electric Vehicles will require common standards and protocols for data exchange, which should be a priority area for policy making.





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Annex A Electricity policy per Member State

In the following overview, we summarise energy policies and quality of the electric grid in various EU Member States with a special focus on renewable energies. Information on energy policy is based on EREC fact sheets, while information on grid quality is derived from CEER (2008). The Member States represent both the key economic players in the EU and a diverse geographical and cultural mix: Austria, Belgium, Denmark, France, Germany, Netherlands, Poland, Spain and the United Kingdom.

Austria

Austria promotes a long-term energy policy and uses a mix of renewable energy sources. In 2007 renewable energy sources accounted for 65% of gross electricity consumption (without pump storage consumption). The primary renewable energy source is hydropower (86.6%) followed by solid biomass and wind power. Austria has a target of 34% renewable of gross final energy consumption by 2020. The most significant renewable energy source is biomass (47% of Austrian territory is covered by forests), followed by hydropower. Austria depends on natural gas, oil and coal to cover its additional electricity needs. Austria has been working to liberalise its electricity market and completed this with the Electricity and Organisation Act in 2000.

Policies: Feed-in tariffs for small-scale electricity plants from renewable sources with obligation for purchase; investment subsidies for medium scale hydro power plants and newly erected combined heat and power plants; feed-in tariffs and support for heating and cooling plants; investment subsidies for geothermal and solar thermal for federal/regional/local schemes; tax exemptions for biofuels, biodiesel and bio ethanol.

National Commitments: Federal Renewable Action Plan (RAP) which follows the European Climate and Energy Package Goals by 2010. The Ökostromgesetz from 2002 and 2006 requires that 4 and 10% of all electricity delivered to end consumers in 2008 (2010) by the public distribution network comes from indigenous biomass combustion and digestion, liquid biomass, wind, solar and geothermal sources.

In 2006, the grid failed on average for 49 minutes per customer per year, significantly below the observed average in other EU Member States.

Belgium

Belgium receives 77% of primary energy consumption from fossil fuels and 21% from nuclear energy. Nuclear energy provides Belgium with about 55% of its electricity supply. Its main renewable energy sources are hydropower and biomass, although it has a relatively limited potential for hydropower. Belgium ambitiously decided to phase out nuclear power between 2015 and 2025. To meet the challenge, new supply sources such as imports, new generation capacity and improved energy savings are necessary. Accordingly, Belgium is quickly developing wind power, and an offshore wind park was developed which will produce 300 MW of electricity by 2010.



In Belgium targets are established based on regions: Walloon, Flanders and Brussels. Targets for renewable electricity for 2010 are 8% Walloon region, 6% (13% by 2020) Flanders and 2.5% (2006) Brussels. The Walloon region uses mainly heat from wood and vegetable by-products as well as wind, while the Flanders region primarily uses wind. Both regions are expected to meet their targets.

Policies: Quota obligations - all electricity suppliers are required to supply a specific portion of renewable energies; tradable green certificates; investment support schemes for renewable technologies; fiscal incentives - tax deductions for the use of renewable technologies; investment subsidies; quota obligations for biofuels.

Urban medium voltage connection failed on average for 23 minutes in 2006.

Denmark

Denmark has promoted district heating (including increased use of biomass) and energy efficiency along with increased use of renewable energy. This has led to relatively flat energy consumption since 1980 and decreased CO₂ emissions with economic growth. Coal is the dominant source of electricity in Denmark and accounted for 46% of generation in 2004. However, renewable energies and natural gas are replacing coal and oil in the energy mix.

Targets: 30% renewable energies of final energy consumption by 2020 (11.45% in 2007).

Policies: Feed-in tariff for renewable electricity production; investment incentives (subsidies based on fuel type) for de-centralised combined heat and power plants; support for the first two large offshore installations; fiscal incentives for small-scale solar cells. Dong Energy - the state-owned, Danish utility - has an agreement with the City of Copenhagen, Renault, and Better Place to promote the use of renewable energy (Dong is a major producer of wind energy and is moving away from coal energy to wind, biomass, and natural gas) during the push to introduce up to 100,000 electric cars per year on the streets of Copenhagen.

In Denmark, renewable energy sources have access to the grid on a non-discriminatory basis. Further, renewable energies have priority over non-renewable energies in terms of use of the grid.

Danish high and medium voltage power grids failed on average for 23 minutes in 2006.

France

Nuclear power is the dominant means of electricity production in France accounting for 78.3% in 2004. In addition, coal and gas together contribute to about 12% of France's electricity production. However, France is developing policies to diversify its energy production and support renewable means such as wind, photovoltaic electricity, solar energy and biofuels.

Policies: Feed-in tariffs and fiscal measures are used to promote renewable energy at the national level, while regional bodies also use subsidies to support renewable energies. Renewable sources are granted non-discrimination in terms of grid access, but there is no special provision for renewable energies.

French low voltage grids failed on average for 86 minutes in 2006.



Germany

Electricity generation in Germany is dominated by coal and nuclear energy, although in 2002 a law was adopted to begin phasing out nuclear energy. Since the initial adoption of the law, the time-limit for the phase out of nuclear facilities has been re-negotiated and a final decision will be made in autumn 2010. Nuclear power constitutes roughly 12% of Germany's energy mix and 25% of its total electricity supply. Coal remains the most important electricity source in Germany and accounts for nearly 50%.

Germany has established a policy framework to support market penetration of renewable energy. The Renewable Energy Sources Act of 2009 looks to increase the proportion of renewable energy sources in the total energy supply to 30% by 2020 with proportional increases afterward; the law also stipulates priority grid access for renewable energy sources.

Policies: Feed-in tariff for renewable electricity; financial incentives to support electricity.

In 2006, unplanned power outages in Germany accounted for 23 minutes.

Netherlands

The Netherlands are a major producer and exporter of natural gas. It uses gas and hard coal imports to generate the majority of its electricity. In 2008 59% of electricity production²³ came from natural gas and smaller portions came from nuclear, oil and renewable sources. Nevertheless, the use of renewable energy sources for electricity production is increasing 2009, the Netherlands had the eighth largest capacity of installed MW in the EU. However, the new installations are slowing down and in 2009, were only at rank 17 of all EU Member States.²⁴

Policies: Subsidies for renewable electricity (feed-in-premium); tax incentives for biofuel s and renewable energy projects; subsidies for biofuel projects.

In 2006, Dutch power grids failed on average for 36 minutes in total.

Poland

Poland is the largest producer of hard coal in the EU and it is significant to Polish energy production accounting for approximately 92% in 2004. Poland also uses natural gas, and to a lesser degree oil and renewables to produce electricity. Hydropower is the largest renewable energy source and its installed capacity is steadily increasing. Second to hydropower, biomass has a large potential in Poland due to the high share of arable land per capita.

Policies: Purchase obligation of electricity sellers to purchase energy from renewable sources; sale of green certificates; minimum quotas on energy suppliers to provide a minimum share of renewable; excise tax exemption for renewable electricity; exemption of excise duty to support biofuel s; grants and loans for renewable energy developers.

In 2007, Polish power systems were unplanned offline for an average of 410 minutes.

²³ Eurostat ten0009 and ten00087.

²⁴ EWEA, 2010a.



Spain

The Spanish economy is relatively dependent on imported energy and has a high level of energy intensity compared to the rest of the EU, mostly due to its high dependency on energy imports and Spain's lack of own energy resources. In 2007 natural gas accounted for about 31% of electricity generation in Spain while coal accounted for 24% and nuclear 17% with oil contributing roughly 6%. However, the changing dynamics of the Spanish energy system has been a significant driver for growth in renewable energies. Spain has become one of the world's leading producers of wind energy. In 2007 renewable energy sources accounted for about 20% of electricity supplies in Spain.

In Spain renewable energies are promoted through price incentives. A renewable system chooses either a guaranteed feed-in tariff or a guaranteed bonus on top of the market price. Also, investments in required equipment and systems for renewable generation may be tax deductible. Renewable systems have priority grid access.

In 2006, the Spanish electricity grid failed for an average of 113 minutes.

UK

The UK was traditionally reliant on oil, gas and coal production and relied little on imports. However, the depletion of domestic resources has led to an increasing dependence on imports. A large step towards renewable energy production was made with the Renewable Energy Strategy of 2008, followed by the 2008 Energy Act.

Policies: Energy suppliers to increase their sales from renewable sources; renewable electricity is exempt from the climate change levy on electricity; grants and funding to support heating from renewable sources; obligation of fuel suppliers to ensure a percentage of sales comes from biofuel s; tradable certificates; level of buy-out prices (financial penalty for fuel suppliers who fail to meet sales quotas); rewards for biofuel s that meet sustainability standards; fuel duty incentives; enhanced capital allowance for biofuel plants that meet certain criteria; government grant programmes; direct support for industry through regional selective assistance grants; capital grants scheme for bio energy; feed-in tariffs for renewable energy production.

In 2006, the British power grid faced unplanned power outages for an average of 90 minutes.



Annex B Overview of EU Energy Policy

Annex B provides an extended overview of EU energy policy and expands on Section 2.1, EU energy policy

1. In the European Commission's **2006 Green Paper: A European strategy for sustainable, competitive and secure energy**, the Commission promotes a common European energy policy focused on six major areas to improve sustainability, competitiveness and security of energy. The six areas are:
 1. Completion of the internal energy market for growth and jobs.
 2. Solidarity between Member States to secure energy supply.
 3. A more sustainable, efficient and diverse energy mix.
 4. The EU as frontrunner for tackling climate change.
 5. Research and innovation; 6. A coherent external energy policy.
2. **The Energy Policy for Europe 2007** aims to create a shared EU voice on the international stage in the area of energy, secure a smooth functioning internal energy market and reduce greenhouse gas emissions. It focuses on:
 1. Establishing the internal energy market:
 - a Market competition.
 - b Market integration and interconnection.
 - c An energy public service.
 2. Ensuring a secure energy supply.
 3. Reducing greenhouse gas emissions.
 - a Energy efficiency.
 - b Renewable energy.
 4. Developing energy technologies.
 5. Considering the future of nuclear energy.
 6. Implementing a common international energy policy.
3. **The Energy Security and Solidarity Action Plan 2008** focuses on energy security and a common EU vision for the future. Its goal is to reduce EU energy consumption by 15% and energy imports by 26% by 2020. In the long term, it is hoped that renewable energies will meet all of the EU's energy needs. It focuses on five main points to reach its targets:
 1. Improved energy infrastructure and the diversification of energy needs.
 2. Viewing energy supply as a priority in international relations.
 3. Oil and gas stocks crisis response mechanisms.
 4. Improved energy efficiency.
 5. Making the best use of the EU's internal energy resources.
4. **European Energy Programme for Recovery** - the EU established a programme in July 2009 to support economic recovery through investment in 2009 and 2010 for three important areas of the energy sector: a. Gas and electricity infrastructures (€ 2.37 billion); b. Offshore wind energy (€ 565 million); and c. Carbon capture and storage (€ 1.05 billion).

Goals:

1. Establish the internal energy market.
2. Ensure a secure energy supply.
3. Reduce greenhouse gas emissions.
4. Develop energy technologies.
5. Consider the future of nuclear energy.
6. Implement a common international energy policy.



Instruments to implement the goals/objectives:

1. Create competitive internal gas and electricity markets where network owners and operators are distinct from producers and sellers.
 2. Establish an integrated and interconnected market that addresses differences in national technical standards and network capacity and increases cross-border trade in energy - this will include collaboration between energy regulators and an obligation to take the internal energy market objective into account.
 3. Increase the diversification of the sources of supply as well as transportation routes, also work to ensure solidarity between Member States.
 4. Reduce energy consumption in the EU by 20% by 2020 through increased energy efficiency.
 5. Increase the percentage of energy from renewable sources (with special emphasis on electricity, biofuels, and heating and cooling) to 20% by 2020, which will contribute both to limiting climate change and also to the diversification of energy supply.
 6. Support the development of new renewable and energy efficient technologies, as well as low-carbon fossil fuel technologies, covering the entire innovation process from initial research to market entry.
 7. Develop a common and coherent set of policies related to nuclear power including security, safety, waste, and non-proliferation, while leaving the decision to use nuclear power to the Member States.
 8. Assist in the development of international energy policies with the EU serving as a leading force for developing international energy agreements and a post-Kyoto climate change agreement.
5. An important element of the EU's energy programme is the **EU Climate and Energy Package** (herein after referred to as CARE). It was introduced in 2007 to combat climate change and increase EU energy security while also enhancing EU competitiveness and entered into force in June 2009. It uses an integrated approach intended to turn Europe into an energy-efficient and low-carbon economy. As part of the package EU leaders agreed to a set of climate and energy targets to be met by 2020. They are often referred to as the 20-20-20 targets. These targets include: reducing EU greenhouse gas emissions by at least 20% below 1990 levels, the use of renewable energy sources for 20% of EU energy consumption and reducing primary energy use by 20% compared to projected levels through an increase in energy efficiency.

Four pieces of integrated legislation provide the base of the CARE. The Emissions Trading System (EU ETS) is modified by the CARE to reduce emissions in a cost-effective manner. The concept of Effort Sharing reduces emissions from sectors which do not fall under the span of the EU ETS - each Member State sets 2020 emission goals relative to national wealth. Binding national targets for renewable energy collectively improve the overall EU average and enable it to reach the 20% target. Finally, a legal framework underpins the advancement and safe use of carbon capture and storage (CCS). So far, no specific actions within CARE were adopted on energy efficiency.



6. Regarding renewable energy generation, the European Commission has been supportive and proposed the first renewable energy targets for the EU in 1997. The original **Directive on renewable energy** set concrete targets and promoted the use of renewable energy by removing barriers and encouraging growth. Since its implementation the use of renewable energies has grown from 13% in 2001 to 16% in 2006, though this is expected to need to grow to over 30% by 2020 for the EU to reach its overall 20% target.

The **Renewable Energy Directive 2009/28/EC** establishes a legal framework to promote the use of energy from renewable sources. The Directive aims to ensure that the EU will meet its 2020 goals and reach a 20% share of energy from renewable sources and a 10% share of renewable energy specifically in the transport sector. The Directive defines individual Member State targets to meet the objective and should be implemented into national law by December 2010. By 2020 each Member State must increase their share of renewable energies by 5.5% from 2005 levels with additional requirements based on the Member State's GDP. The European Commission requires that Member States detail their strategy to reach targets in a national renewable energy action plan. Member States are to provide detailed reports every two years which distinguish between sectoral targets and highlight their activities.

More recently, after the Second Strategic Energy Review - Securing our Energy Future in 2009, the European Commission outlined new rules to improve the security of gas supplies.

Improvements in the area of energy supply and infrastructure are also underway in Eastern Europe and third countries with support from the EU. Due to the conflicts of the 1990s the unified energy system of the South East European Region was dispersed into a patchwork of energy systems. Although many countries and their energy infrastructures were separated, they remained dependent on each other to ensure stable and operational power supplies. The European Energy Community (EEC), comprised of the EU and a number of third countries, provides a **cooperative framework for the European region** to rebuild its energy network and ensure stability. The community seeks to encourage investment and create conditions to effectively rebuild economies through strong and stable energy networks.

Liberalisation of the electricity market in the South East Europe Region is to be completed by January 2015. A number of EU measures are used to provide a policy framework and guide the process. Directive 2009/72/EC, which replaced Directive 2003/54/EC, establishes **common rules for the generation, transmission and distribution of electricity** for the EU internal electricity market. The Directive focuses on creating competitive conditions while also protecting consumers and promoting economic and social cohesion between the Member States. In addition, Regulation 1228/2003, amended by Decision 2006/770/EC, provides guidelines for the management and allocation of available transfer capacity between national electricity systems. It proposes methods to manage cross-border electricity interconnection capacities and efficiently handle system congestion.

The Regulation recognises Member State differences in network systems and operators and seeks to create fair, transparent and directly applicable rules to ensure the effectiveness of cross-border transactions. Directive 2003/54/EC and Regulation 1228/2003 were to be transposed into Member State and third country legislation by July 2007.



The EU supports electricity and gas infrastructure projects and contributes about € 25 million annually to research. The Trans-European energy networks (TEN-E) underpins electricity projects of European interest including the Priority Interconnection Plan (PIP). PIP focuses on interconnecting Member State electricity networks traditionally organised at the national level. Through increased interconnectedness the EU aims to support completion and the creation of an internal energy market as well as increase energy security. Additionally improved energy infrastructures will enable the introduction of a network based on renewable technologies. Presently the programme faces numerous challenges and the Trans-European network remains underdeveloped due to lack of significant funding. The PIP has proposed a variety of priority actions to produce a stable environment and encourage investments in the internal market. Actions focus on: increased monitoring of projects to ensure the likelihood of success; appointing regional coordinators for key areas; planning networks according to consumer requirements at the regional level with increased cooperation from transmission system operators; simplifying and harmonising authorisation and planning procedures and requiring Member States establish national procedures; and consider increasing EU funding to support energy interconnections.

Recognising the importance of harmonised energy infrastructure, a number of third countries and Member States including Austria, Belgium, Denmark, France, Netherlands, Spain and the UK participate in an international forum for information exchange and collaborative research and analysis of electricity networks. The forum, Electricity Network Analysis, Research, and Development (ENARD), aims to facilitate new operating procedures, architectures, methodologies, and technologies in electricity transmission and distribution networks to improve performance and overcome common challenges to network renewal, integration of renewables and network resilience.

In May 2010, former Commission president Jacques Delors presented a proposal to revive and strengthen the EEC (Notre Europe, 2010), aiming at energy security, competitiveness and sustainable development.

The above-pictured legal framework underscores the fact that energy policy is major concern for European politics and affects Europe in many ways: energy security, economic competitiveness, climate change and other aspects of sustainable development.



Annex C IPM[®] model

ICF's IPM[®] model is designed to replicate the operations of the actual power system. The modelling framework includes an accurate engineering representation of all of the physical assets needed to create a power system, i.e., every power plant, every transmission link, every fuel supply option available to the power system. By including the economic and environmental constraints facing system operators in the real world, the IPM[®] replicates how actual decisions are made by power system operators when subject to any slate of operational constraints, regardless of whether these constraints are physical, economic or environmental.

The IPM is a dynamic linear programme that optimises the development and operation of a power system over a long term time horizon. Both the development and operation of the system are optimised on the basis of underlying costs. The analysis is therefore driven by a combination of assumptions on costs and physical/technical characteristics. The cost information includes projected fuel costs for the main fuels used in power generation, assumptions on the cost for power generators of the carbon emissions from generation and assumptions on the evolution of the capital costs of a variety of power generation technologies. The physical characteristics detailed include demand growth, the load shape, the performance of different generation technologies and the power flow capability over the transmission links connecting national markets.

