# SCENARIOS FOR THE DEVELOPMENT OF THE ELECTRICITY ECONOMY IN CONTINENTAL EUROPE

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## 1 MOTIVATION

Due to changes in significant influencing factors the European electricity economies undergo a process of transition. Climate change issues are getting more important but the realisation of a legal framework for emission certificates is still uncertain in the long run. In the last two years, the prices for fossil fuels reached historic peak levels and the forecast of the future trend is getting more and more difficult, which emphasises that the actual situation concerning the high import dependency on fossil fuels is no longer acceptable for the European Union (EU).

As a result of declining overcapacities and ageing power plants there is a need of building new generation capacity in the European Union. Moreover, the realisation of a functioning internal electricity market with higher volumes of energy trades and the increase of indigenous electricity production from European renewable energies require higher electricity transmission capacities in the domestic grids as well as between the member states. Finally, the ongoing financial crisis hinders investment into the power sector.

This paper shows a possible business-as-usual development path for the electricity economies in continental Europe and discusses the possibilities to reach the EU's emission targets in the power sector. After the description of the model itself the basic assumptions for the simulation will be outlined. The results show the development of necessary power plant investments and resulting greenhouse gas emissions from power production.

## 2 METHODICAL APPROACH

The scenario model ATLANTIS is a techno-economic model of the electricity industry of the European states which form the ENTSO-E[1] subgroup continental Europe (formerly called UCTE). This is the largest synchronous area in Europe with an installed capacity of about 660 GW and an annual power consumption of approx. 2,600 TWh in 2008. The main part of the scenario model is a database which consists of the most important facilities and companies in the investigated area. The database of ATLANTIS contains:

- 29 European States, most of them members of the European Union;
- more than 8,100 power plants (including projects, see Figure 1);
- 30 types of power plants with efficiency functions, specific costs, carbon intensities etc.;
- up to 15 types of fuels for each country, with the possibility to define an individual price development for each fuel;
- about 2,500 grid nodes in the highest voltages levels of 400 kV and 220 kV (and 110 kV if necessary);

[1] European Network of Transmission System Operators for Electricity

- more than 4,800 power lines and autotransformers of the 400/220-kV-transmission grid including DC-Links, phase shift transformers and some 110-150 kV lines which are important for load flow calculations (incl. projects, see Figure 2);
- about 100 generation and supply companies with simplified opening balance sheets for the year 2006.

Based on this comprehensive database, the intention of ATLANTIS is to provide a simulation model which is close to reality in technical matters and is also able to give an approximate explanation of the economic behaviour of markets and companies.

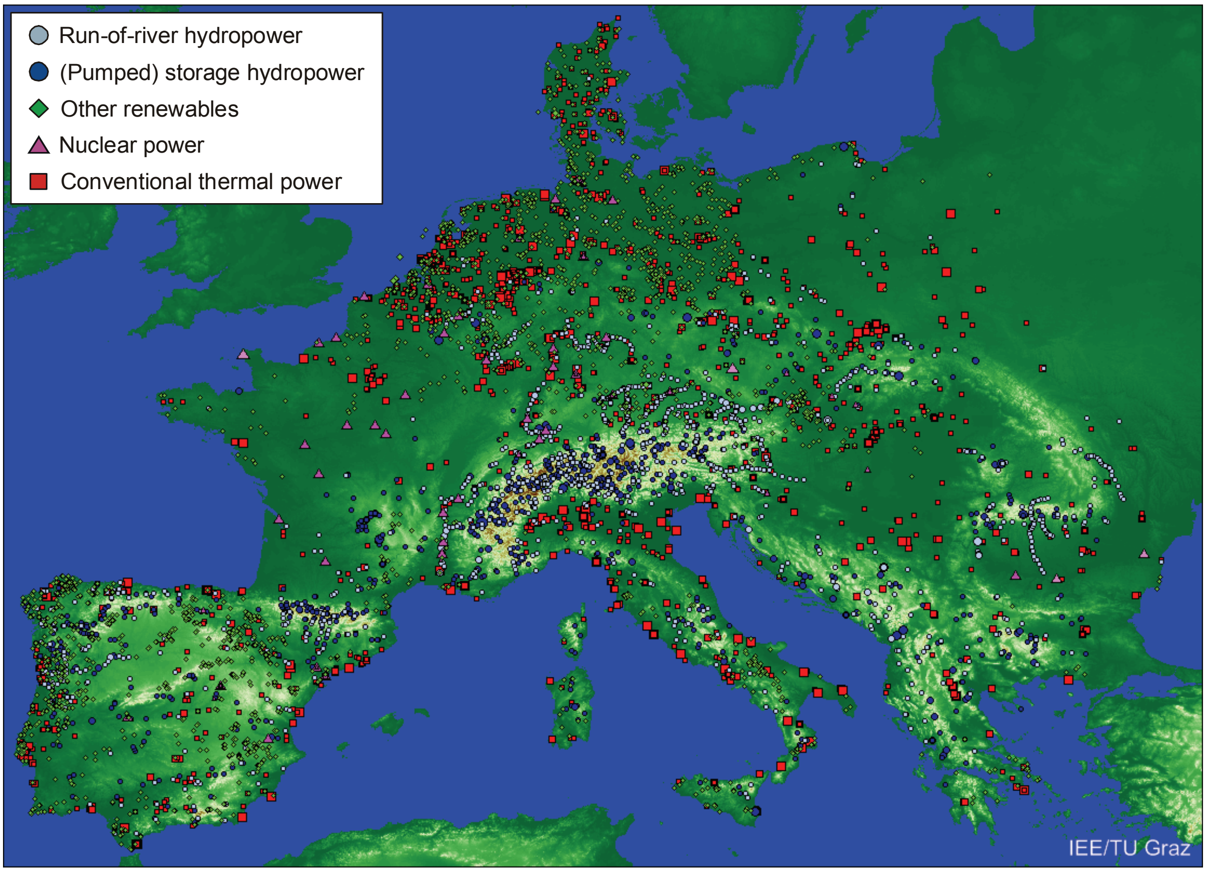


**Figure 1: The generation infrastructure of continental Europe in the ATLANTIS database**

The technical part of the model includes all necessary elements of the physical electricity system. These include the transmission network and power plants as well as the consumers' electricity demand. The economic part of the model covers the electricity trade, market coupling between states and major European power producers, which are described by simplified balance sheets and income statements.

Figure 3 shows the flow chart of a typical scenario calculation. According to the predefined scenario assumptions the calculations are performed on an annual respective monthly base. The calculation starts with a check whether the yearly peak load can be covered with the existing generation capacities considering the restrictions from the transmission grid. In the ATLANTIS model the load flow in the transmission grid is calculated by means of a DC load flow algorithm. Bottlenecks will be identified and new power plants will be built at appropriate locations based on an algorithm, which identifies the grid nodes were a minimum of additional feed-in power can cover the demand and thereby solve the grid congestions. The annual peak load check is performed for the winter peak load which is significant for most countries, and the summer peak load, which is important in the southern countries

Spain, Italy and Greece. The annual peak load test determines the power and location of new required generation capacities.

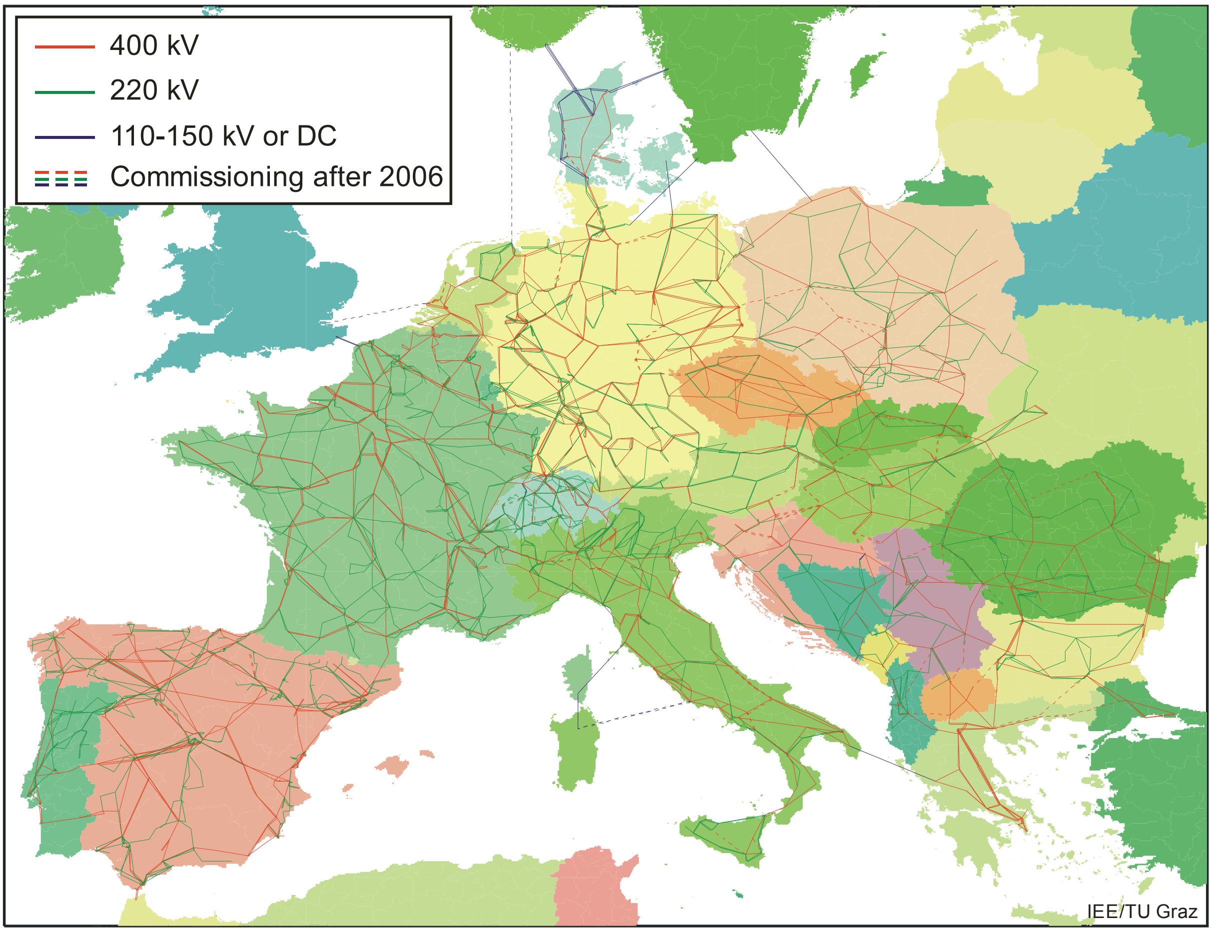


**Figure 2: The transmission grid of continental Europe in the ATLANTIS database**

In the next step the dispatch of power plants in order to cover the demand in the peak and off-peak period is calculated on a monthly basis. This power plant dispatch is performed according to market principles and orientated on minimum variable costs of generation. The fluctuating generation characteristic of run-of-river hydropower or wind power is considered by the long-term average generation in the particular month. Furthermore a power exchange, where the modelled companies trade generation surpluses, is calculated parallel to the dispatch. The resulting dispatch will be evaluated in terms of a load flow calculation. If there are congestions on transmission lines, a redispatch of generation units is carried out automatically. After this step the utilization of the power plant park is determined and the carbon dioxide ($CO_2$) emissions of each period can be calculated. Finally the individual profit and loss calculation of the modelled electricity companies is performed for each year.

The dynamic simulation of the chosen scenario over several years shows the effects of a simulated legal framework or business strategies on power production and grid utilization. The results like power plant dispatch, load flows, $CO_2$ emissions, fuel costs or development of profits and balances will be stored in an SQL database and visualized after the finalization of the simulation process.

A detailed description of the ATLANTIS simulation model is given in (Gutschi, Bachhiesl et al. [1]).

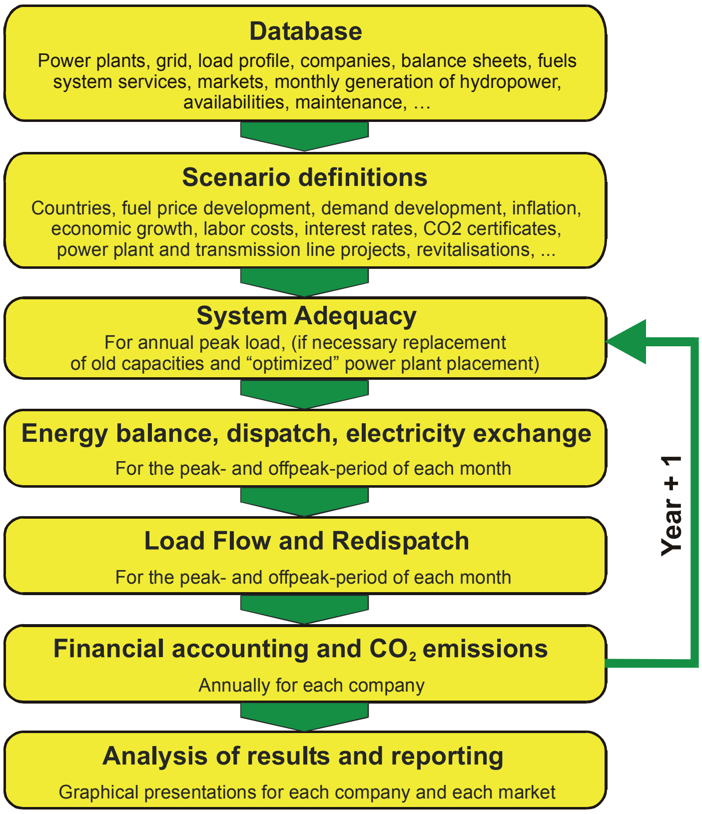


**Figure 3: Flow Chart of the ATLANTIS scenario model (cf. Gutschi, Huber et al. [2, 3])**

## 3 SCENARIO ANALYSIS

In the present work three scenarios for a possible future development of the generation infrastructure are simulated. The results are analysed in respect to the development of generation capacities and $CO_2$ emissions in the whole market area.

**Table 1: Assumed technical lifetime of generation facilities**

| Technology | Lifetime |
|---|---|
| Coal fired steam turbine | 45 |
| Oil/gas fired steam turbine | 45 |
| Combined cycle gas turbine | 30 |
| Gas turbine | 30 |
| Nuclear power plants | 50 |
| Hydropower plants | 60 |
| Wind power plants | 25 |
| Biomass, biogas | 25 |
| Photovoltaics | 30 |
| Solar thermal power plants | 45 |
| Other technologies (geothermal, waste, …) | 25 |

Before the scenarios are explained in detail, the basic assumptions valid for all scenarios are given. The expected technical lifetime of different generation technologies is shown in Table 1. The development of the power demand was predefined on the basis of forecasts from ENTSO-E [4] and EURELECTRIC [5]. As shown in Figure 4 the average demand growth in the simulated region is about 1.8 % from 2010 to 2020 and about 1.0 % after 2020. In 2009 there was a demand decrease of about 5 % as a consequence of the economic crisis.

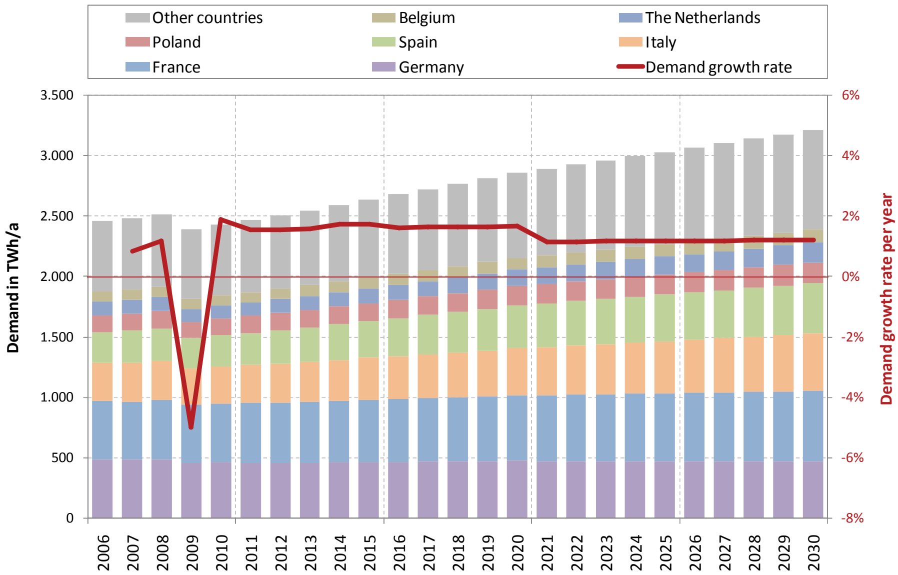


**Figure 4: Assumed demand growth rate based on prognoses from ENTSO-E [4] and EURELECTRIC [5]**

Further assumptions for all three scenarios concern the variable costs of power generation in coal fired power plants, which are assumed to be lower than that of gas turbines and combined cycle power plants during the considered period 2006 to 2030. It is estimated that the efficiency of power generation will increase up to 52 % for new coal fired power plants and to 65 % for new combined cycle power plants in 2030 (cf. European Commission [6]).

The installation of new power generation units would strictly be determined by the annual peak demand and reserves are only as high as required for system services and system stability. Finally it is assumed that the overall power of generation units for "green" electricity will not increase after 2012[2] and the use of fuel oil for electricity generation would be discontinued when the respective units are decommissioned. Additional demand is covered by the construction of new combined cycle power plants.

Based on these assumptions three scenarios are analysed in the following chapter:

In the **business-as-usual (BAU) scenario** decommissioned power plants are replaced by new power plants of same technology and same or slightly increased capacity which are connected to the same grid node. The demand growth is covered by additional combined cycle power plants with a unit capacity of 400 MW.

In the **combined cycle (CC) scenario** it is assumed that all decommissioned coal power plants are replaced by combined cycle units fired by natural gas.

The **combined cycle and nuclear (CC+EPR) scenario** is similar to the CC scenario but decommissioned nuclear power plants are replaced by EPR[3] units with a higher capacity. Thus the

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[2] Although this assumption is unrealistic it is taken into account for the investigation if the EU's emission targets could be reached without additional generation from renewable sources.

[3] European Pressurized Water Reactor

installed capacity of nuclear power is rising from about 118 GW in 2006 to 125 GW in 2020 and about 150 GW in 2030. (In the CC scenario the nuclear power capacity is about 129 GW in 2030.)

# 4 RESULTS AND INTERPRETATION

## 4.1 Development of generation infrastructure in continental Europe

The development of the minimum required generation capacity is similar in all three scenarios; therefore this chapter only deals with the BAU scenario.

Figure 5 shows the development of generation capacities by fuel. Due to the rising demand the overall generation capacity of about 700 GW in 2010 will reach more than 800 GW in 2030. According to the assumptions the highest growth of capacity appears at gas fired power plants with combined cycle technology.

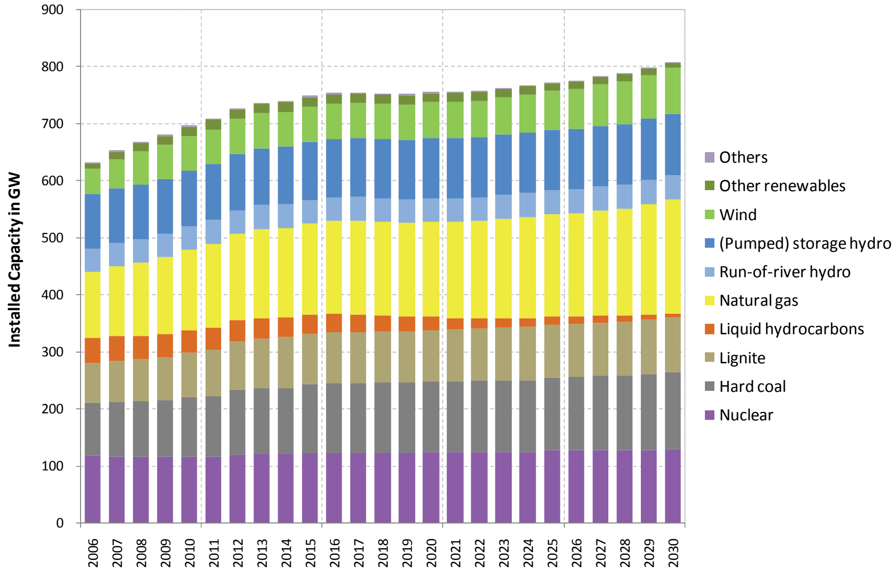


**Figure 5: Development of installed capacities in the BAU scenario**

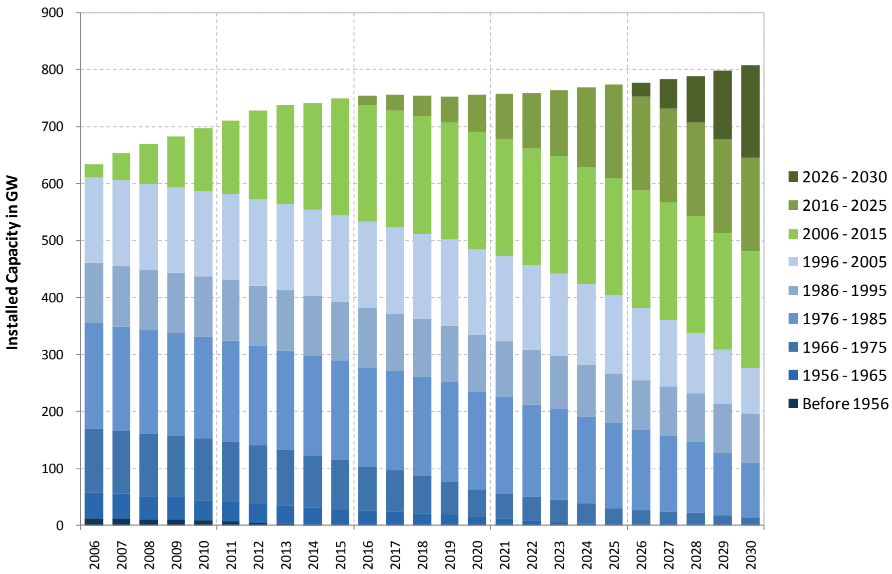


**Figure 6: Age distribution of power plants in the BAU scenario**

The development of the age distribution of generation is visualized in Figure 6. Only 45 % of the capacity installed before 2006 will still be available in 2030. From 2006 to 2030 at least 530 GW will have to be built or refurbished. More than 40 % of the power plant capacity in 2016 will have to be added or renewed until 2030. Figure 7 shows these facts in a dramatic manner. To a great extent, the replacement of wind turbines and nuclear power plants, which starts around 2020, leads to the constantly increasing need for new generation capacity until 2030. Especially in the wind power sector, the same effort which is used to build new wind turbines today will be necessary to keep the capacity constant in later years. Figure 8 shows the replacement needs in different European countries. The two largest power producers in continental Europe are also facing the largest investment needs in the 2020s, Germany has to replace its coal and wind power plants and France hast to replace the nuclear fleet.

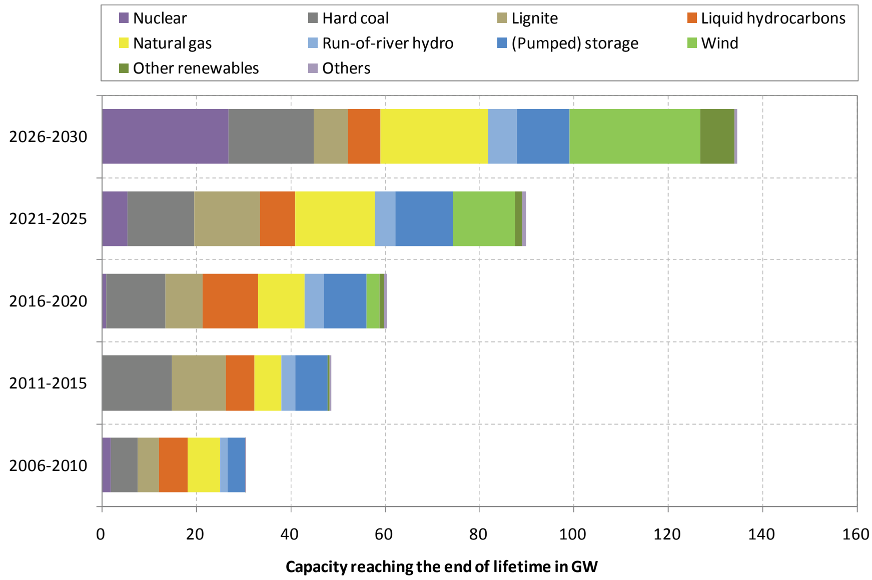


**Figure 7: Requirements for replacement or refurbishment of generation facilities (by primary fuel) according to the BAU scenario**

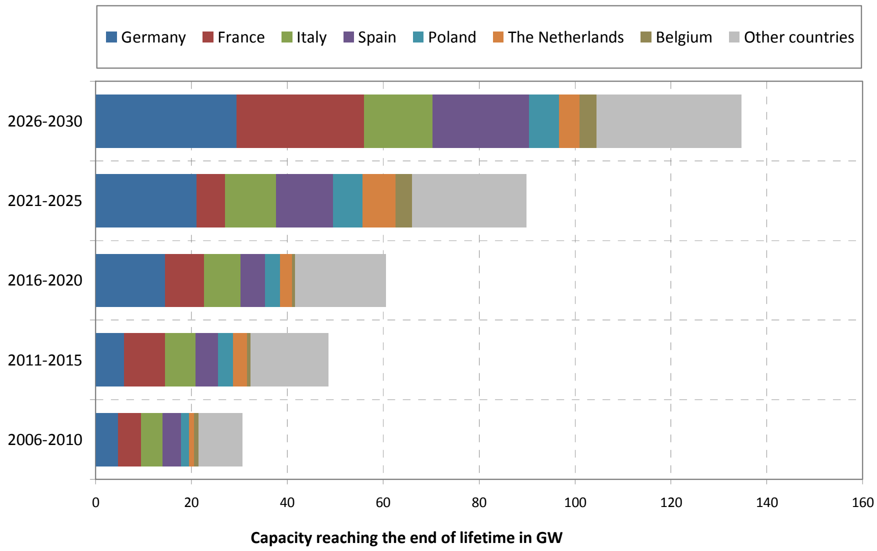


**Figure 8: Requirements for replacement or refurbishment of generation facilities (by country) according to the BAU scenario**

## 4.2 Development of carbon dioxide emissions

The European Union has defined ambitious targets for the reduction of greenhouse gas emission until 2020. In general $CO_2$ emissions should be reduced by 21 % from the level in 2005 [7]. In the case of power generation there are four main strategies to deal with this challenge. The first strategy is the replacement of coal with natural gas. Due to the lower carbon intensity of gas compared to coal and the high efficiency of combined cycle power plants, this strategy is able to reduce the specific carbon emissions by 50 % but the use of natural gas also increases the energy import dependency.

The second strategy is the installation of additional nuclear power plants, but the use of nuclear energy faces criticism from electricity consumers in many countries. The third strategy is the increased power generation from renewable sources like hydropower or wind power, which leads to high costs and some environmental issues. Finally the forth strategy is the development of "clean" fossil technologies with carbon capture and storage. The last strategy has to be considered as a future option since it results in a decrease in the overall efficiency of the processes, furthermore only a few prototypes exist at the moment. [8]

In this chapter the first two strategies will be investigated concerning their potential to reduce the greenhouse gas emissions and to reach the EU's emission targets. The development of the $CO_2$ emissions in the three simulated scenarios is shown in Figure 9. In the BAU scenario the emissions can be kept constant at about 105 % of the level of 2005. In the CC scenario the emission target of the EU can be reached in 2029 instead of 2020. Finally the CC+EPR scenario shows a faster emission reduction than the CC scenario. But taking into account the preliminary time for construction of new nuclear power plants there won't be much emission reduction by additional units before 2020.

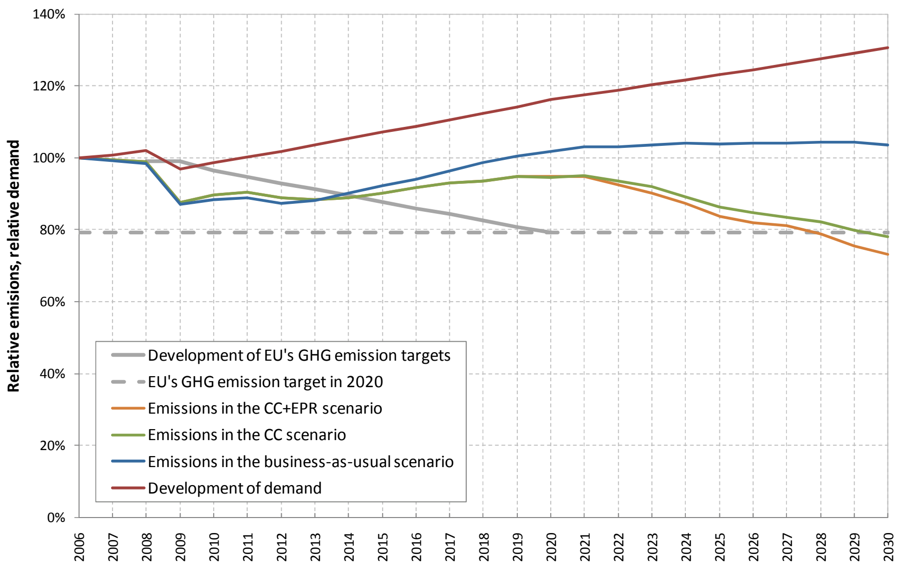


**Figure 9: simulation of the development of $CO_2$ emissions in comparison to the EU's emission targets**

The three scenarios show the possibilities of emission reduction by the first two strategies. It can be seen that the coal to gas shift as well as new nuclear generation is coming too late to reach the targets for 2020. There might be a higher speed of emission reduction if coal units would be taken out of the market before the end of lifetime and replaced by new gas fired combined cycle units. In fact this is a minor European trend in the last years although the problem of sunk costs may arise for some generating companies.

Finally, in the case of the predicted increase of demand it seems very difficult to reach the EU's reduction targets for green house gas emissions until 2020. All three available strategies will have to be applied in the short run and the use of additional renewable power sources supplementary to the other two strategies will be the only possibility for a sustainable reduction of greenhouse gases from power production.

# 5 SUMMARY

ATLANTIS is a multi purpose scenario model for the investigation of effects in the electricity system of continental Europe. The model consists of a physical part for the simulation of power generation and load flow as well as an economic part for the investigation of power markets and the business development of generation and supply companies.

The simulation of three scenarios for the development of power generation in continental Europe leads to the following results:

More than 500 GW of new or refurbished generation capacities are required in continental Europe until 2030. In the 2020s the first generation of wind turbines has to be replaced as well as many fossil and nuclear power plants.

By the replacement of decommissioned coal power plants with new gas fired power plants the EU's reduction targets of greenhouse gas emissions for 2020 can be reached until 2030. Additional nuclear power plants might increase the speed of emission reduction after 2020. Finally, the use of additional renewable power sources supplementary to the other two strategies will be the only possibility for a sustainable reduction of greenhouse gases from power production.

# 6 REFERENCES


[1] Gutschi, Bachhiesl et al., *ATLANTIS – Simulationsmodell der europäischen Elektrizitätswirtschaft bis 2030*, Elektrotechnik & Informationstechnik (2009) 126/12: 438–448. DOI 10.1007/s00502-009-0703-8.

[2] Christoph Gutschi, Christoph Huber et al., *Business-as-usual scenario for the development of the electricity economies in South Eastern Europe*, 18th International Expert Meeting Komunalna Energetika (Power Engineering) University of Maribor, 2009.

[3] Gutschi, Huber et al., *ATLANTIS – Szenariomodell für die Entwicklung der europäischen Elektrizitätswirtschaft bis 2030*, 6. Internationale Energiewirtschaftstagung, TU Wien, Vienna, 11.-13.2.2009.

[4] ENTSO-E, *System Adequacy Forecast 2009 – 2020*, http://www.entsoe.eu/fileadmin/user_upload/_library/news/UCTE_SAF-2009-2020_Report.pdf (8.2.2010).

[5] EURELECTRIC, *36th Edition, Statistics and prospects for the European electricity sector*, (EURPROG 2008), http://www2.eurelectric.org/docsharenoframe/Common/GetFile.asp?DocID=24646&Stype=SaveAS&mfd=off&pdoc=1 (8.2.2010).

[6] Commission of the European Communities, *Energy Sources, Production Costs and Performance of Technologies for Power Generation, Heating and Transport.* COM(2008) 744, Commission staff working document, Unofficial version. Brussels.

[7] *DIRECTIVE 2009/29/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 April 2009 amending Directive 2003/87/EC so as to improve and extend the greenhouse gas emission allowance trading scheme of the Community*.

[8] VGB PowerTech, *Zahlen und Fakten zur Stromerzeugung 2009/2010*, VGB PowerTech e. V., September 2009, http://www.vgb.org/daten_stromerzeugung.html?dfid=25742 (7.2.2010)

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