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# Technical Report on Grid Access

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# Table of Contents

## List of Figures

## List of Tables

# 1 Executive Summary

The EU's climate and energy package, adopted in 2008 by the European Parliament and Council, set out the following EU 2020 targets:

20% minimum share of renewable energy sources in energy consumption by 2020

20% minimum reduction of final energy consumption by 2020

20 % minimum reduction of greenhouse gas emissions by 2020.

In addition, the European Union is committed to decarbonising its economy whilst at the same time ensuring security of supply and preserving industrial competitiveness[1]. This objective implies the reduction of greenhouse gas (GHG) emissions by 80-95% in 2050 compared to 1990 levels. With regards to the energy sector, this means a minimum of 85% energy-related $CO_2$ emission reductions by mid-century.

The change in the energy policy through the recent targets of the European council has an impact on the power production market and the power exchange structure in Europe: in the future the highest volumes of cross-border exchanges will be in the heart of Europe. The cross-border exchange has already quadrupled over the last 20 years.

**Geothermal electricity could play a key role in this context, by providing locally a renewable base load power production. In that sense, geothermal could be used for stabilizing the grid when decommissioning nuclear and coal power plants.**

Related to the promotion of renewable energy sources, the European electricity grid has to adapt to its new requirements. Due to the upcoming shift in the European power generation mix a clear relocation of those systems is expected. Furthermore, with relatively large wind and solar capacities, more energy from volatile resources is fed into the grid. In this framework the expansion of base-load energy sources such as geothermal energy will become more and more important to ensure the security of supply.

Grid development is also needed because of the decommissioning of nuclear power plants from 2010 to 2022. In particular, this affects Germany and the United Kingdom. In Germany, eight nuclear power plants were shut down in March 2011. This is consistent with a missing electrical capacity of circa 8,500 MW. Assuming that it will take time to substitute this capacity with power production from non-nuclear resources, different experts expect imbalances in South and Northern Germany: The demand exceeds the power production in the South, whilst the situation is reversed in the North due to increasing wind power.

[1] "[…] in the context of necessary reductions according to the IPCC by developed countries as a group". European Council, Presidency Conclusions, October 2009, p.3.

Geothermal energy can be seen as an offset to the North-South divide, but also as a tool for balancing the electricity grid system. Due to the base load and controllable character, geothermal generation can make an important contribution in stabilizing the future transmission system.

According to the national renewable energy action plans[2], geothermal energy is needed to achieve the 20% renewable energy target by 2020

However, the development of geothermal projects does not only depend on political and technical aspects, but also on economic feasibility.

Like all other power generation technologies, the basic principles of balancing, backing up, and aggregating apply to geothermal power as well. However, geothermal energy as a low Greenhouse gases (GHG) emitter and a domestic energy resource have a prominent position in the future energy mix due to its high availability of around 90% and above.

The present document analyses the technical conditions for grid access in order to put forward recommendations as well as technical justifications for the inclusion of geothermal power plants in an existing or new power network. Under present grid architecture, the transport and distribution of electricity is handled by the top-down approach from transmission to distribution level. From the technical point of view, there is no difference for grid connection of a renewable generation system such as geothermal or a conventional one. **We can state that there is no technical barrier to the integration of geothermal power to the European electricity grid.**

In low enthalpy areas, where relatively small geothermal power plants are in operation or under development, geothermal energy is fed into the middle-voltage system. Here, only minor and local effects are expected, but this might be different with increasingly decentralised power production in future.

According to the European Commission's Baseline business-as-usual scenario (EU energy trends to 2030, 2009), electricity demand will increase by 52% between 2000 and 2030. Total installed power generation capacity will increase by about 400 GWe, from 656 GWe in 2000 to 1,118 GWe in 2030, at the same time about 365 GWe of current power stations are to be retired or decommissioned. The total required capacity in Europe until 2030 is 761 GWe, more than the entire existing European power plant capacity.

The vision document (TP Geoelec SRA, 2012) for geothermal electricity published by the Technology platform TP Geoelec in 2012, mentions that geothermal electricity capacity could reach about 100 GWe in Europe by 2050 and thus, provide 780 TWh per year.

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[2] Article 4 of the Renewable Energy Directive (2009/28/EC) required Member States to submit national renewable energy action plans by 30 June 2010. These plans were intended to provide detailed roadmaps of how each Member State expects to reach its legally binding 2020 target for renewable energy, including sectorial targets and the technology mix they expect to use.

**In conclusion, we can assume that the development of geothermal electricity could decrease the new electricity grid infrastructure to be built in the future and so save some money, as presented in the case study of Germany.**

# 2 Geothermal electricity production

Electricity production from geothermal power was first developed by Francesco Laderel from high enthalpy resources in Italy in 1904 (Stober & Bucher, 2012). Today around Europe 1 $GW_{el}$ of geothermal capacity is installed (Bertani, 2011). The following chapter shall give the reader a short introduction into geothermal power production.

## 2.1 Geothermal power plants

Geothermal energy is, together with solar and tidal power, one of the three renewable, primary energy sources available on the earth. Geothermal energy is in the form of heat stored under the surface of the solid earth (EU Directive on RES, 2009). (Verein deutscher Ingenieure, 2001)

The geothermal heat flow to the surface of the world is caused by energy, which results from mass collapse during the initial stage of the earth forming processes. Additionally the natural decay of radioactive isotopes contributes a significant amount of energy (Kaltschmitt, Huenges, & Wolff, 1999). As the heat conductivity of the different earth layers is relatively poor and the natural decay of radioactive isotopes is an on-going process, geothermal power is, in human time horizons, renewable.

Geothermal energy is not only a renewable energy source but also a closed loop energy production system. The hot water which is pumped onto the surface is kept in a closed pipe system. After its use in a heat exchanger it is either re-injected into a reservoir, or if it is not hazardous it is sometimes injected into surface waters. The operation of geothermal power plants only produces emissions through the self-consumption of electricity. In low enthalpy areas (like most of Europe excluding Iceland and Italy) you have to calculate 15% self-consumption (excl. thermal water pumps) (Weimann, 2011) which has to be accounted for with the emissions of the power plant mix in the energy system.

The main advantage of geothermal power is its base load capability. In contrast to other volatile, renewable energy sources like wind and solar power, geothermal power plants are dispatchable and can produce around 8000 h per year. This means a capacity factor[3] of 89,4 % (Tidball, Bluestein, Rodriguez, & Knoke, 2010). Figure 1 sets the capacity factor of geothermal power plants in the context to other generation technologies. It can be observed,

[3] The capacity factor is the ratio of the actual output of a power plant over a period of time and its potential output if it had operated at full nameplate capacity the entire time.

that geothermal power plants have one of the highest capacity factors and that they are superior to other renewable energy sources.

In comparison to other base-load power plants geothermal power systems are very flexible. A geothermal power plant needs only 5-6 hours to ramp up from a cold status to full power output (internal source EnBW). For the same operation a lignite power plant needs 9 h and a nuclear power plant even 50h (Grimm, 2007). Additionally geothermal power plants can vary their power output within a certain bandwidth and can be used in partial load operation. This flexibility makes geothermal power plants even usable for short-term grid support in the case of an unforeseen event in the electricity grid.

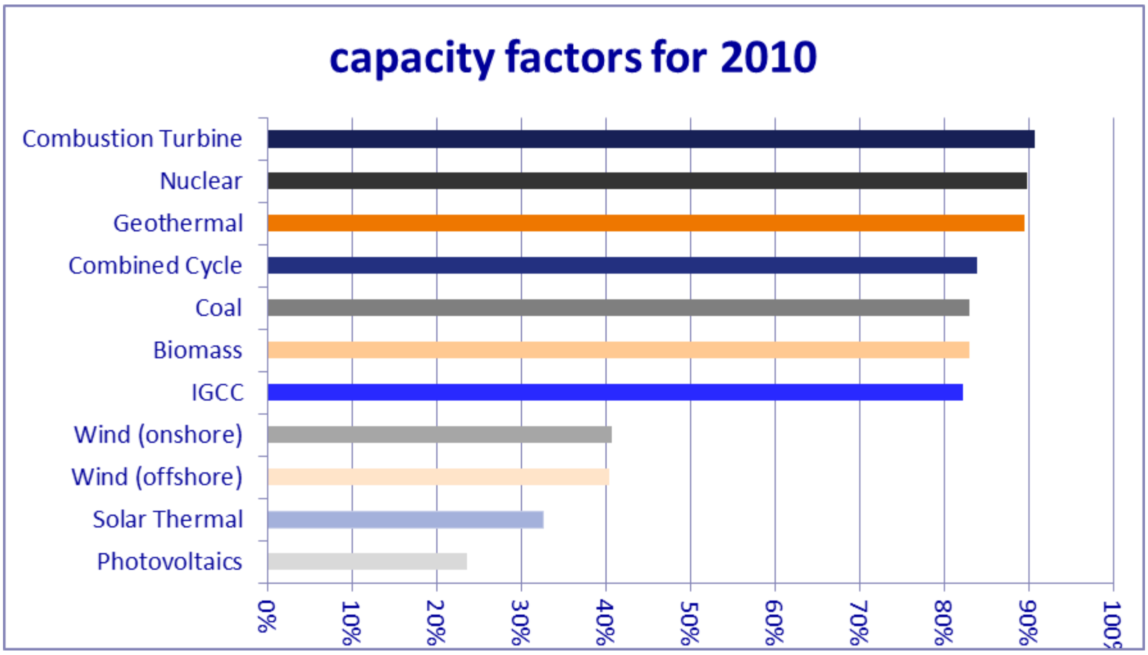


**Figure 1 capacity factors for energy production systems in the USA (Tidball, Bluestein, Rodriguez, & Knoke, 2010)**

Besides Italy and Iceland most of Europe can be characterized as low enthalpy area with reservoir temperatures below 150°C. In recent times the average size of a geothermal power plant has been around 5 $MW_{el}$ in those regions. These power plants are normally connected to the sub transmission level of the electricity grid. This level of the electricity grid connects different regions.

In a case study in chapter 4.4 this report shows how geothermal power plants can be used to support the grid in a general way. Geothermal power plants can be built close to centres of high electricity consumption. This means that geothermal power can be a counterpart to other volatile, renewable energy sources like wind turbines, which are often far away from the customer. An electricity production close to the customer unburdens the electricity grid and can possibly help to reduce necessary adaptions of the electricity grid.

## 2.2 Methodology for site selection of geothermal power plants

To produce heat respectively power with a minimum impact on environment and maximum economic benefits, geothermal power plants have to fulfil some requirements. Therefore, site selection for a geothermal power plant depends on several parameters. Differentiation is made between geological, technical and socio-economic criteria.

The installation of a geothermal power plant is usually dependent upon to several approvals from local or federal government agencies before construction can begin. Although the permitting process may differ in the individual states, there are some similarities such as application process, time for public comment, and time for agency staff to gather information and make a decision about the project.

*Geological criteria*: Geoscience related studies during exploration phase play an important role in all stages of geothermal power plant siting. This category includes all available geological, geophysical and geothermal data sets. The geologic data compilation contains, for instance, information about the geology, hydrogeology and tectonics, but also topographical data about slopes and rivers. For the sustainable operation of a geothermal power plant, information about geothermal activities and temperature distribution in certain depths are necessary. Here, data from existing wells and hot springs within the study area provides useful information. The latter can be used as evidence of a subsurface heat source. In addition, the temperature of springs is in correlation with amount of heat flows.

*Technical criteria:* When geothermal power plant developers construct a power plant, they build it near the best geothermal resources they can find in areas close to the consumer. The geothermal resource has to be utilised on or nearby site because heat cannot be transported over longer distances economically. If geothermal resources are located in a less density populated area, developers are more dependent on the transmission system to get their product to market.

As described in chapter 5, the power plant operator bears all costs for grid access. For that reason, it is important to consider existing power distribution systems.

*Socio-economic criteria:* The investigation of socio-economic issues becomes an increasingly important issue which is strongly related to the needs of human beings. Due to the different characteristics, the attitude towards geothermics can change from one community to another and therefore, socio-economic studies always have to be site specific. In all cases, it is necessary to notify the public early about the project and to explain the need for the facility and its benefits. Apart from social acceptance, socio-economic criteria also include information about population centres, number of consumers, etc. In addition, information about the existing infrastructure is also needed.

*Methodology:* Due to the multi-layered information, a GIS based methodology for site selection seems to be expedient. Geographical Information Systems (GIS) are important tools for integral interpretation of geo-related data sets using a computerized approach, especially in exploration work (Prol-Ledesma, 2000). Furthermore, GIS models have already been used in regional exploration studies of mineral resources (Agterberg, 1989) (Bonham-Carter, 1994). With regards to geothermics, this tool can be used in early stages, but is even more successful in an advanced stage of exploration. That means that if enough data were collected and the project developers can make a decision about further detailed exploration measures or well drilling.

By means of GIS and its capacity to handle large amounts of data and different data types, suitable areas for site selection can be determined. GIS also help in creating thematic maps. The different datasets outlined above can be used for the analysis of and transfer to separate layers.

As presented in previous studies, there are different approaches of data integration in geothermal exploration on the basis of the input of thematic maps such as maps for main faults, surface manifestations or resistivity. First, the Boolean integration model involves logical combination of binary maps. Here, for each map, the area which assumed to be suitable will be assigned the value of 1, the others the value of 0. The inference model for data integration will be determined by the logic operations “AND” (Intersect) and “OR” (Union). The Boolean integration model is a restrictive one and can be seen as a “low-risk-model”. However, there is a risk that potential sites for geothermal power plants will be hastily excluded.

The Index Overlay model might be an alternative which could lessen the requirements. This model will use the same thematic maps as the Boolean model, but multiply them by weight factors with different scores. Thus, three instead of two classes for each map will be generated. Scores and weights will be chosen as integers in a scale from 0 to 10.

To give an example: the thematic map of main faults will be of a higher weight than the map concerning surface manifestations. Focusing on the faults in the study area, locations which are far from the identified fault system will be assigned a lower score than sites close to the faults. Hereby, in total three distance-dependant gradations have to be made by an expert.

In summary, Geographical Information System can be used as a decision-making tool to determine potential sites for geothermal power plants. The analyses are based on different datasets which includes geoscience, technical and socio-economic aspects. The data refers mainly to surface studies and publicly accessible data pools. Geological data is of special interest, due to identification of geothermal resources. Furthermore, the profitability of a project depends on cost-efficient realisation and a good consumer structure. There are different methods for data integration: the relatively restrictive Boolean model and the more flexible model of Index Layer. In both cases, thematic maps have to be created. That means in detail, that the complex data basis has firstly to be evaluated by experts.

# 3 Electricity Demand

This chapter informs the reader about the future development of electricity demand and production capacity in Europe. With respect to the growing electrification of the daily life and the change in power production from a fossil and nuclear dominated generation system to a renewable one, major challenges have to be managed.

## 3.1 Current status of electricity demand and production in Europe

According to the European Commission's Baseline business-as-usual scenario (EU energy trends to 2030, 2009), electricity demand will increase by 52% between 2000 and 2030. Total installed power generation capacity will increase by about 400 GWe, from 656 GWe in 2000 to 1,118 GWe in 2030, at the same time about 365 GWe of current power stations are to be retired or decommissioned. The total required capacity in Europe until 2030 is 761 GWe, which is more than the entire currently existing European power plant capacity (Figure 2).

Figure 2 gives an overview of the electricity generation and the electricity demand of the European countries. The data is from 2011 and was collected by Eurelectric. Nearly half of the EU states are characterised by an electricity demand that is higher than the current power generation. There is no clear subdivision in East or West Europe.

In Figure 3 and Figure 4 the energy mix 2011 of the West and East European states is presented. The use of renewable energy sources such as geothermics, wind, solar and biomass varies between countries. In Western Europe, Denmark is located at the top with a 35 % share of renewables. In combination with hydro power, Norway, Switzerland, Austria, Sweden and Portugal have already now reached an energy mix which consists over 50 % of non-conventional energy generation. In contrast, the United Kingdom, France and Belgium depend on nuclear power plants for 50% or more of their electricity generation. Germany has already reduced its nuclear power generation to 22 % of the total energy mix. Conventional thermal power plants are particularly well represented in Malta, the Netherlands, Greece, Italy and Turkey (Figure 3).

Concerning the Eastern European countries, the expansion of renewables is most developed in Hungary, Lithuania and Estonia. The use of hydro power is more common and thus, constitutes about 50% of the energy mix in Latvia, Croatia and Bosnia-Herzegovina (Figure 4). In contrast to Western Europe, there is only one country with 50% share of nuclear energy generation which is Slovakia. Nuclear energy additionally plays a role for Hungary, Slovenia, the Czech Republic and Bulgaria. As displayed in Figure 4, the share of nuclear energy varies from 31% to 44% of the individual countries' energy mix. The power generation of Poland, Cyprus, Estonia and Lithuania is dominated by conventional thermal power plants.

In summary, the promotion of renewable energy resources is of pan-European interest. Therefore, first steps have been taken in some countries. There are no significant differences between West and East Europe today. Due to Figure 3 and Figure 4, it becomes obvious that hydro power is currently the most important source of energy. However, the future development of hydro power seems to be limited because of the high population density of Europe and the small remaining potential for new plants in the majority of the European countries.

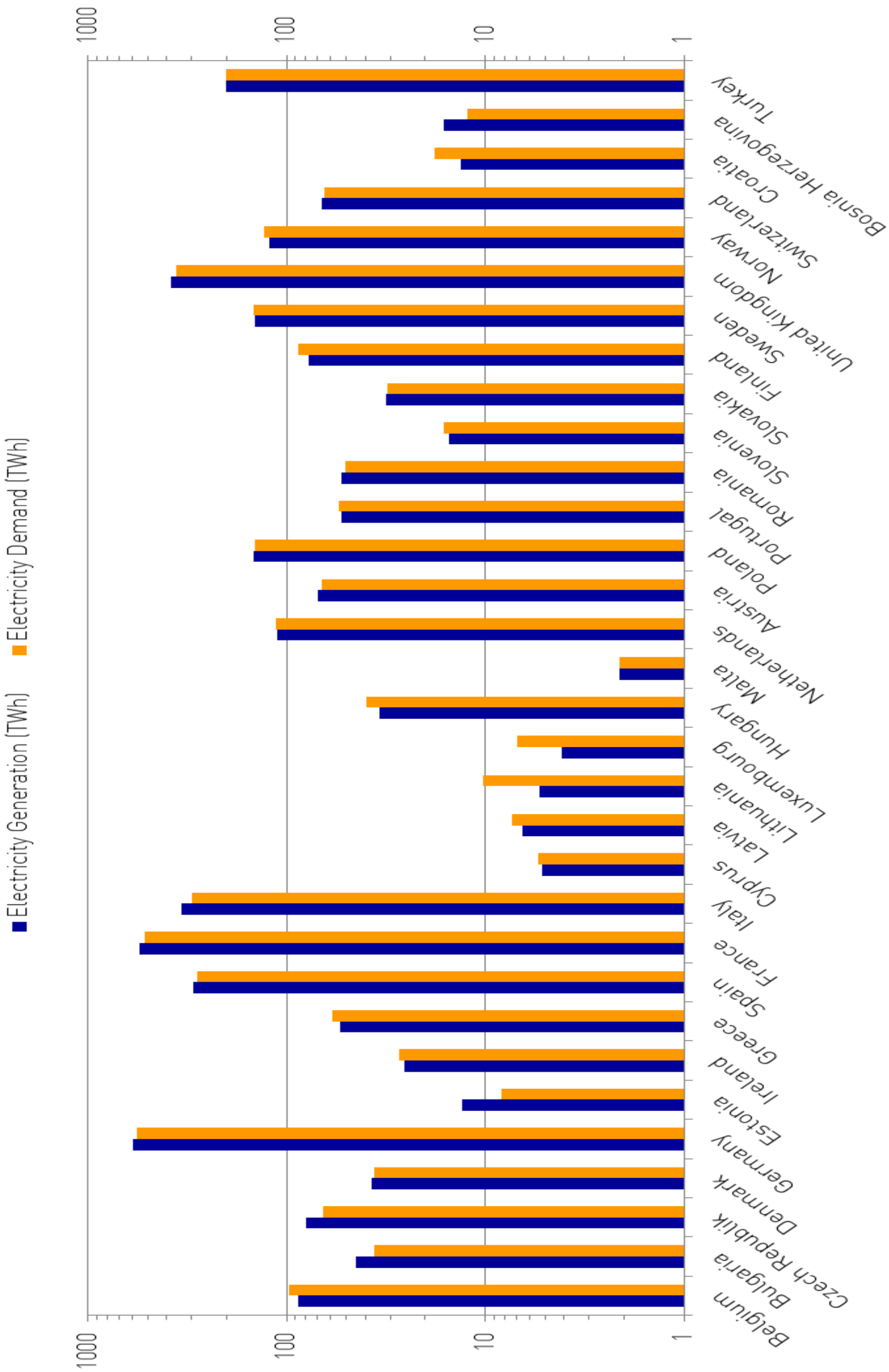


**Figure 2 Total electricity generation and electricity demand of the European Member States in 2011 (Eurelectric, 2012)**

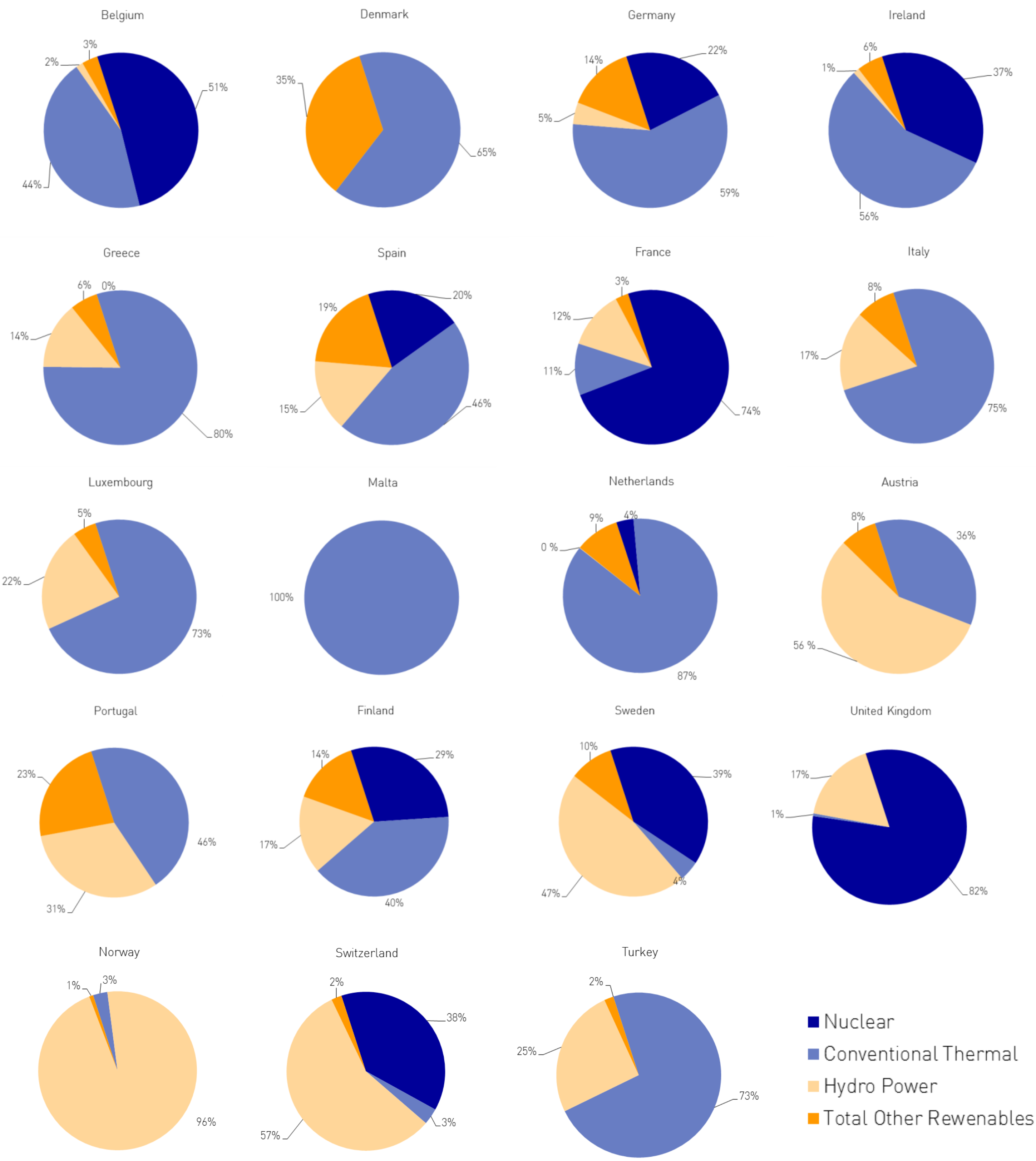


**Figure 3 Energy Mix of West European States, 2011 (Eurelectric, 2012)**

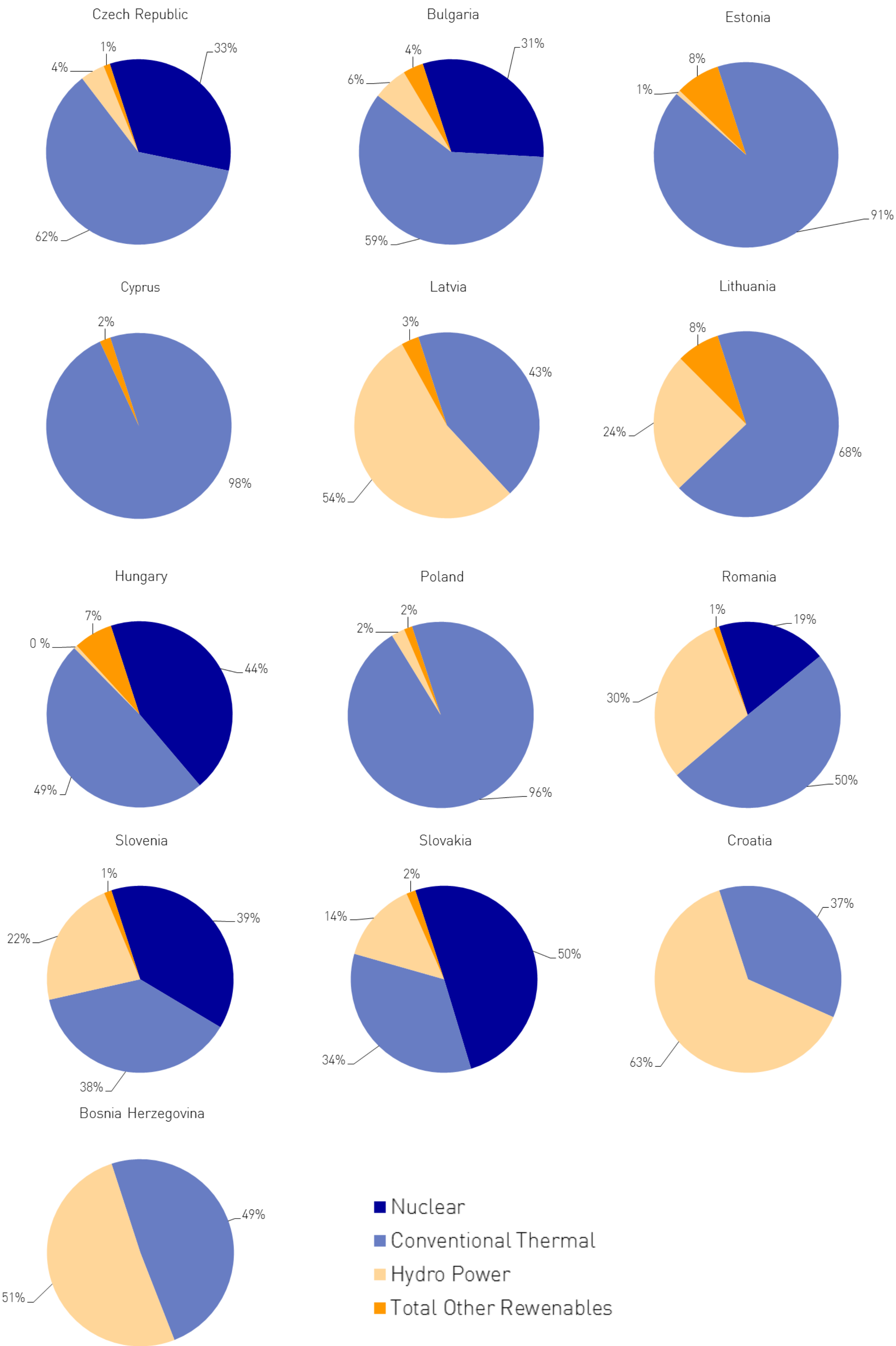


**Figure 4 Energy Mix of East European States, 2011 (Eurelectric, 2012)**

The vision document (TP Geoelec SRA, 2012) for geothermal electricity published by the Technology platform TP Geoelec in 2012, mentions that geothermal electricity capacity could reach about 100 GWe in Europe by 2050 and thus, providing 780 TWh per year.

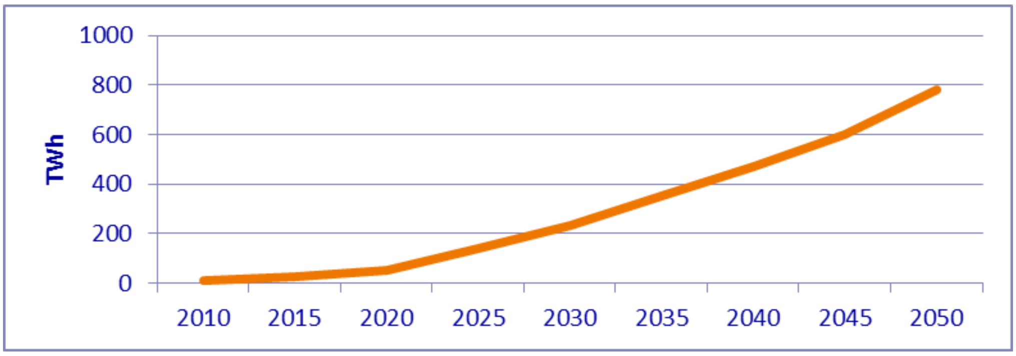


**Figure 5 Vision of the development of geothermal electricity production in Europe (TP Geoelec SRA, 2012)**

In the framework of GEOELEC, the project also deals with an assessment of the potential contribution of geothermal energy to the European electricity demand. In accordance with the prospective study of work package 2, a regional compilation of prospective areas will be done. Apart from the potential evaluation, the development of geothermal energy will also depend on further parameters such as technical issues (chapter 5) or siting.

## 3.2 Future development of the electricity system in Europe

To illustrate the future trend of the European electricity demand until 2050 we are using the "EU Energy Roadmap 2050".(European Commission, 2011).

Even though major influencing factors like energy prices or political decisions that can neither be influenced nor be predicted with a 100 % security, the roadmap presents six possible scenarios (we do not consider the outdated reference scenario) for the decarbonisation of the EU energy sector. A brief description of the different scenarios is provided below:

- **Current policy initiatives**
  This scenario takes into consideration several current political measure e.g. measures taken after the Fukushima-catastrophe, the energy efficiency plan or the energy taxation directive
- **High Energy efficiency**
  In this scenario several measures are implemented that reduce the energy demand by 41% compared to the peak demands in 2005/06
- **Diversified supply technologies**
  Every production technology has the same market base. There is no special remuneration system for any technologies. $CO_2$-reduction is achieved through a set $CO_2$-price. All energy technologies are socially accepted.
- **High renewable energy sources**
  Strong support for renewable technologies, which leads to a share of renewables in electricity consumption of 97%.

- **Delayed CCS**
  This scenario is similar to the “diversified supply technologies”-scenario besides the fact that CCS is delayed. This increases the importance of the $CO_2$-price and of nuclear power.
- **Low nuclear**
  This scenario is also similar to “diversified supply technologies”-scenario. Here the acceptance for nuclear power is low, so that no new plants are built and CCS reaches a 32% share in electricity production.

The predicted electricity demand in Europe for the different scenarios can be seen in Figure 6.

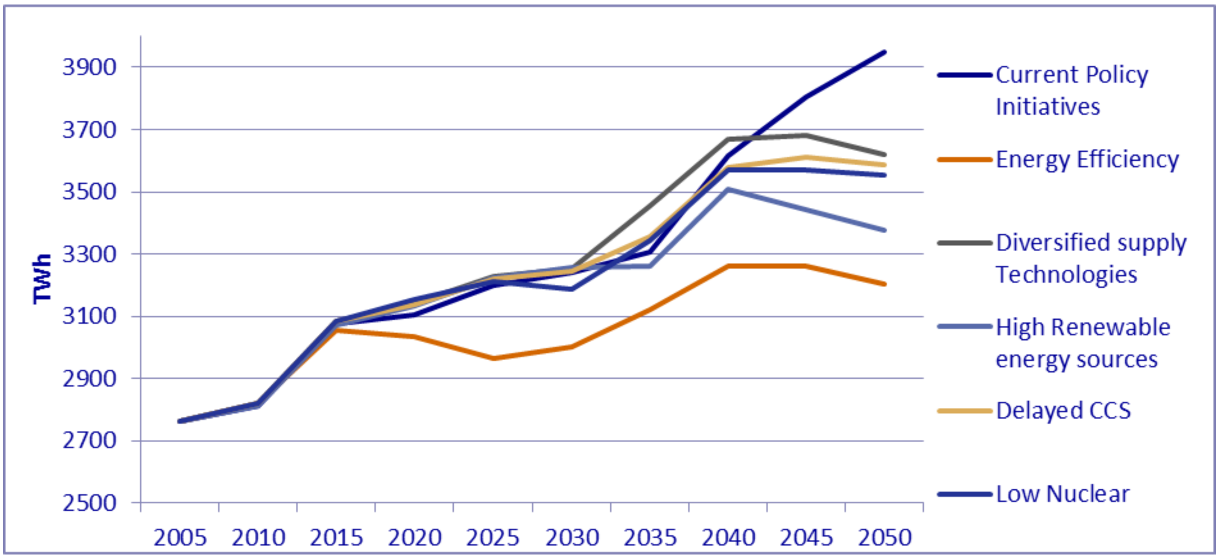


**Figure 6: Final electricity demand 2050 in the EU-27 (European Comission, 2011)**

Some interesting findings of the EU Energy Roadmap 2050 are briefly summarised below.

- The decarbonisation of the European energy system is possible and can, compared to the current policy scenarios, be less costly than current policies in the long run.
- All the decarbonisation scenario show a path towards higher investment cost but lower fuel costs for the future electricity system. This can partly be explained through the end-of-life of the current power plant park.
- Electricity is going to play a prominent role in the future energy system. Even in the “High Energy Efficiency”-scenario the demand for electricity is going to increase.
- Energy savings are crucial for the whole system. To achieve this economic growth and energy demand have to be further decoupled.
- All scenarios show a massive increase of renewable electricity production. The different decarbonisation scenarios show a share of renewables in the electricity consumption between 64% and 97%.

Final electricity demand increases over time. To achieve decarbonisation, the power generation system would have to undergo structural change and achieve a significant level of decarbonisation already in 2030 (57-65%) in 2030 and 96-99% in 2050). This highlights the importance of starting the transition now and providing the signals necessary to minimise investments in carbon intensive assets in the next two decades.

# 4 Electricity grid infrastructure system in Europe

The European electricity grid has been developed since the electrification from regional, unconnected island networks to a European transmission grid. The vital pillars of this system were and are today centralised, fossil, flexible, and adjustable power plants. In the course of the transformation of the electrical power production system towards a regenerative and decentralised power plant structure, it is necessary to adapt the grown structures of the electricity grid. The process of this transformation will be explained in the following chapter.

## 4.1 State of play of the European electricity transmission grid

Presently, the European transmission network consists of circa 305,000 km routes (ENTSO-E, 2012). Most of Europe's high voltage electricity transmission interconnectors are managed by the members of the international association of the European transmission system operators for electricity (ENTSO-E). The association includes 41 transmission system operators (TSO) from 34 countries, whereas EnBW is one of the members (Figure 7). The mission of ENTSO-E is to promote the development of the interconnected European grid as well as investments for a sustainable power system. Due to the EU 2020 targets the power grid has to support the secure integration and the expansion of renewable energy sources to achieve the European target of greenhouse gases reduction.

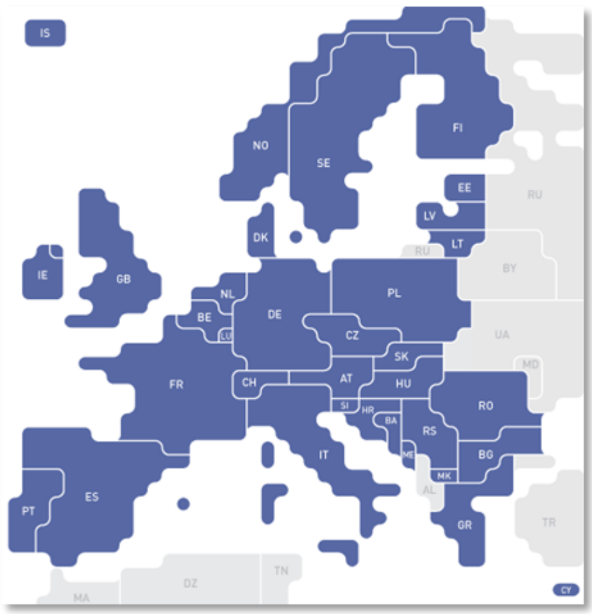


**Figure 7 Member states of the European Network of Transmission Network Operators (ENTSO-E, 2010)**

Although renewable power generation systems are mostly connected to lower voltage electricity grids, the reflection of the high voltage transmission system is obvious for the bulk transmission of electric power. Hereby, the operators of the transmission network provide grid access to the electricity market player such as utilities, traders, supplier, distributors or directly grid connected customers.

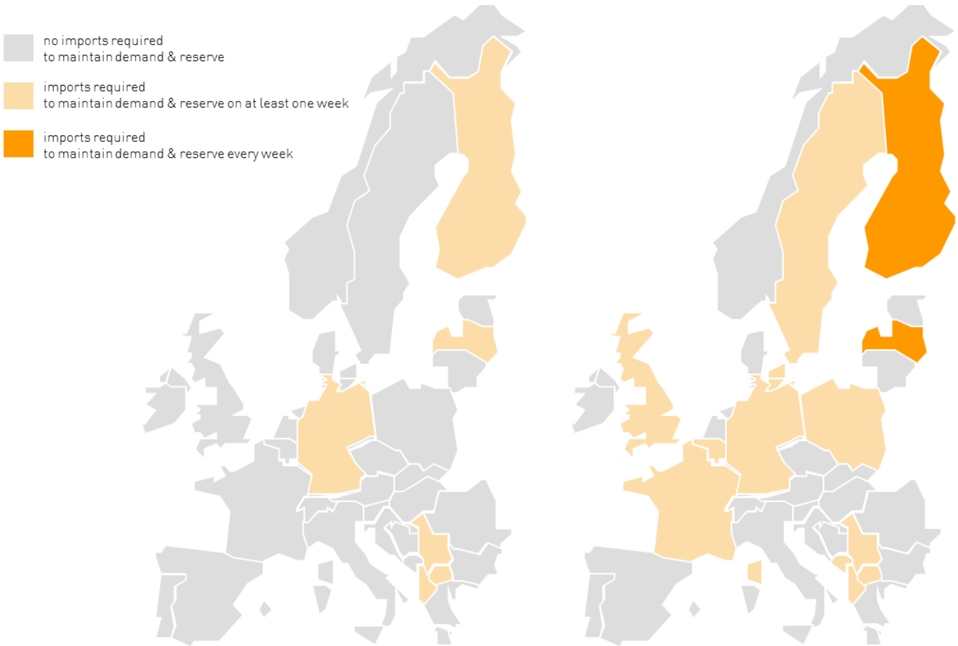


**Figure 8 Country analysis under normal conditions (left) and severe weather conditions (right) (ENTSO-E, 2011)**

To identify risks concerning security of supply and system adequacy, the requirements of the transmission network has to be checked every year for expected electricity flows. In this framework it is easy to make estimations about the European distribution of electricity demand and load. Figure 8 displays the demands of and reserve requirements for the European transmission system in 2011/2012. The map on the left side represents required imports under normal conditions for demand and load, while the right map shows imports required under severe weather conditions. Where a country is coloured grey, it always has excess capacity to meet demand and reserve. Countries which are coloured in a lighter orange have at least one period where imports are required to meet their electricity demand. Dark orange coloured countries have a need for imports throughout the year, and an especially high need especially under severe weather conditions.

The majority of European countries do not require imports to secure energy supply under normal conditions. Hence, the market will determine the economic energy transfer that is based on the respective price differences between the individual countries. For the regions where imports are required there is interconnector capacity from neighbouring regions (ENTSO-E, 2011).

The map on the right in Figure 8 clearly shows that the situation is different under severe weather conditions. The demand increases for each individual country. The increase is particularly significant, especially in countries which have predominantly electric heating, for instance France.

Figure 9 gives a regional overview about the contribution of import and export under severe weather conditions. Orange coloured regions are again identified as regions where imports are required. In fact, dark orange countries expected imports to account for more than 3 % of their demand.

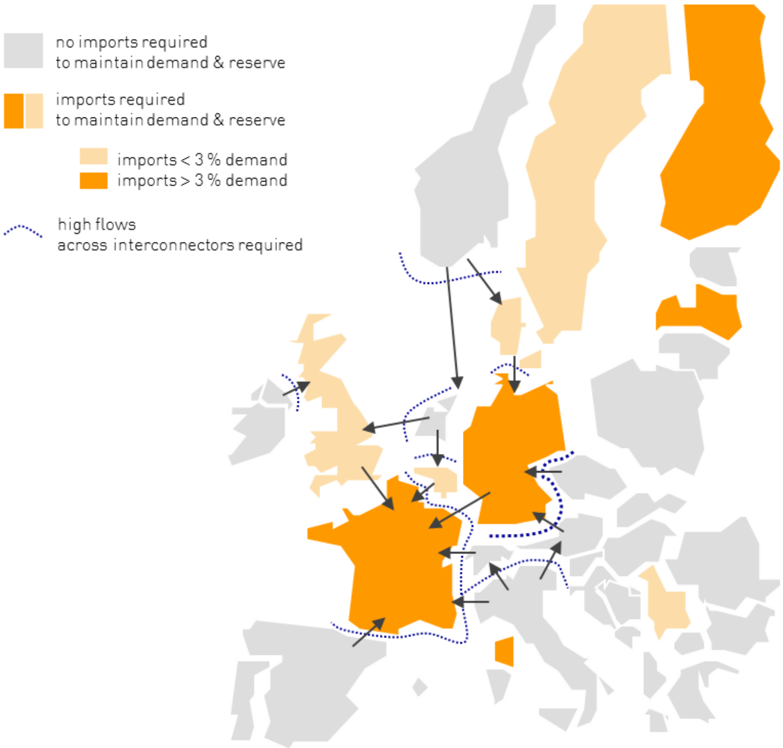


**Figure 9 Import requirements in the winter period 2011 (ENTSO-E, 2011)**

From the scenario presented in Figure 9 some basic messages can be developed. First, the required imports for Germany, France and Great Britain can be managed by a high power transfer through the interconnectors from the neighbouring regions. There are various countries that act as transit systems to ensure power gets to the undersupplied regions. In particular France would be supported by many countries: Germany which can export power via flows from Austria and Czech Republic. Additionally, Belgium and Great Britain can transit power by their interconnectors to France. In contrast, Italy and Spain are characterized by a significant excess of capacity.

In general, the level of the Net Transfer Capacity (NTC) differs clearly within Europe. A link between population density and NTC can be observed, whereas the highest transfer capacities are assigned to large urban centres ( (ENTSO-E, 2011). This analysis is not a market simulation. Thus, the flows shown on the map may not reflect exactly what would be delivered by the market. However, the high flows into France and Germany should be still be valid.

The described scenarios make clear that there are already possibilities to guarantee the security of supply. In fact, it can be realised by a cross-border exchange within the European Union. European electricity trading has quadruplicated over the last 20 years, which may underline the importance of a cross-border exchange (ENTSO-E, 2010). In this framework the expansion of base-load energy sources such as geothermal energy will become more and more important to increase planning certainty and the security of supply.

## 4.2 Future development of the European Electricity System

The integration of renewable energy will be the major challenge concerning grid development in the coming decade. Not only larger, but even more volatile power flows have to be transferred over greater distance across Europe. Today, about 100 bottlenecks are identified on the European transmission systems, 80% of these are related to the integration of RES. The requirements to build and to refurbish parts of the European network are shown by the Ten-Year Network Development Plan (TYNDP) (ENTSO-E, 2012).

For the TYNDP 2012 the European Network Association developed two scenarios.

1. The scenario EU 2020 has been built top-down, based on the European 20-20-20 objectives and the National Renewable Energy Action Plans.
2. The scenario SAF-B extrapolates information from market players' present investments perspectives in a bottom-up approach.

The scenarios differ clearly in their approaches. The EU 2020 is defined as reference the scenario and describes the necessary evolution to fulfil the EU 20-20-20 objectives that are at the same time the starting points. Thus, this scenario uses top-down principle.

In contrast, in the SAF-B scenario the present situation is taken as the starting point. Future developments are extrapolated until 2020 (bottom-up).

The main drivers for investment in new power lines according to the recent energy policy strategy are presented in Figure 10. Apart from issues of internal market integration and security of supply, the most important driver will be the expansion of renewables.

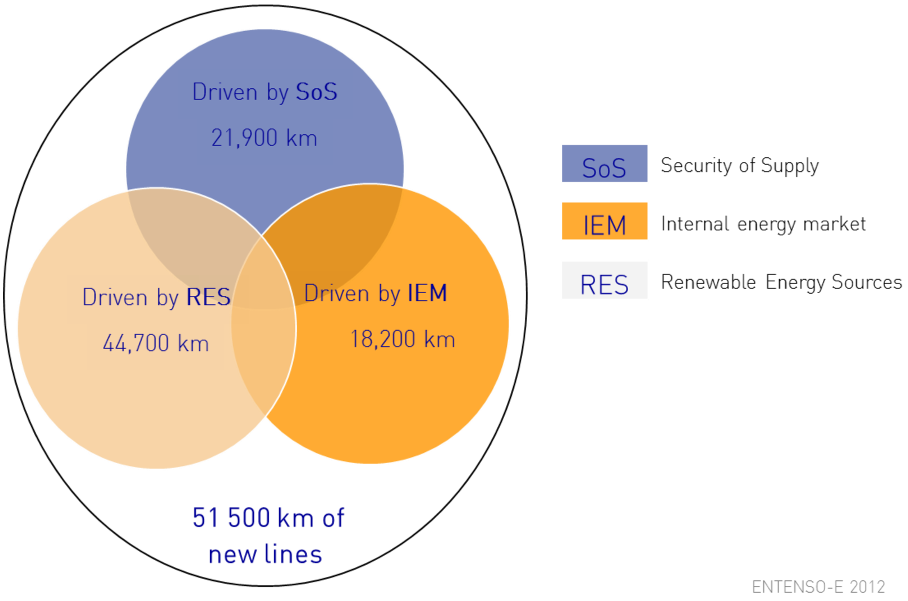


**Figure 10 Main drivers for investment in new or refurbished power lines (ENTSO-E, 2012)**

According to the TYNDP about 25% of the present net generating capacity will be built in the coming decade. This fits to a value of 250 GWe, whereof 220 GWe should be developed by RES generation.

Grid development is also needed because of the decommissioning of nuclear power plants from 2010 to 2022. In particular, Germany (16 GWe) and the United Kingdom (7 GWe) are affected (ENTSO-E, 2012) (See also Chapter 4.3). With regard to environmental standards, obsolete coal-fired power plants are also scheduled to be shut down. Related to the security of supply, it has to be mentioned that most of the decommissioned power plants were located within densely populated areas.

Due to the upcoming shift in the European generation mix a clear relocation of generation systems is expected. Furthermore, with relatively large wind and solar capacities, more volatile energy is fed into the grid. For that reason, the power network has to adapt to the changing conditions.

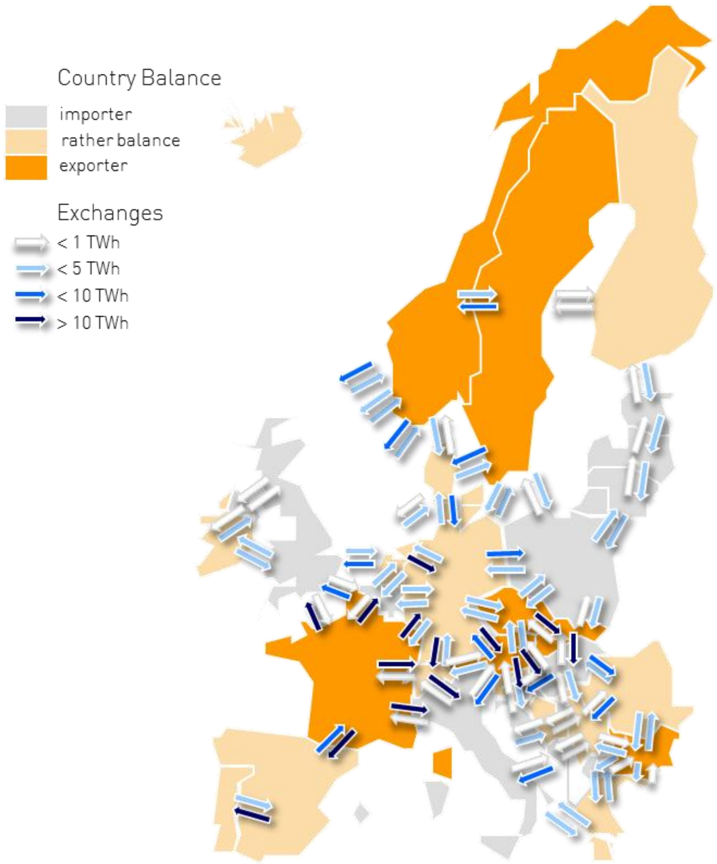


**Figure 11 Power exchange pattern in 2020 between the ENTSOE member states (ENTSO-E, 2012)**

The recent targets of the European energy policy will also have an impact on the power exchange patterns of Europe. As shown in Figure 11 the highest volumes of cross-border exchanges are in the centre of Europe. Germany, Spain and Portugal expect high imports and exports, which results in an overall balance.

The map above shows that, France and Scandinavia are the largest exporters, whereas Italy, the United Kingdom, Poland and the Baltic states have a clear import position.

Over 100 transmission projects of pan-European significance are dealing with the challenge of lager and more volatile power flows across large distances in Europe. The total investment of €100 billion includes the construction and refurbishment of over 50,000 km of network until 2020 (ENTSO-E, 2012). This number was also presented by the European Commission in their communication on Energy Infrastructure Package on November 17$^{th}$, 2011.

The investment per country correlates with its individual size and population density. Germany represents by far the highest investment with about €30 billion. First estimations suggest that the total length of the European network will increase by 14% within the next ten years. Due to the expansion and refurbishment of power lines, more than 100 GWe of renewable generation can be integrated in Europe's power network. This corresponds to a $CO_2$ reduction of 130 $MtCO_2$ (ENTSO-E, 2012).

Reliable statements are not yet available for the post 2020 structure of the electricity grid. However, the association of European transmission system operators (ENTSO-E) and its members are currently working within the e-Highways 2050 project on the structure of a pan-European electricity grid. The cornerstones of this structure are the further development of renewable energy sources, the legal frameworks, the economic incentives for grid development, the technical evolution of network components, and the integration of the public. (ENTSO-E, 2012)

## 4.3 The meaning of the German nuclear moratorium to the European electricity market

With this case study of the German nuclear moratorium an example for the impact of the phase out of a bigger amount of electricity production capacity on the electricity grid shall be given. This case study of the German nuclear moratorium examines the impact of the phasing out of large scale electricity production capacity on the electricity grid. The decommissioning of unprofitable or old fossil power plants in other European countries could have similar effects, although the time frame for adoption would probably be longer.

The public opinion in the aftermath of Fukushima nuclear incident and several countries' decisions to phase out nuclear energy was already felt by the European power market some months later in summer of 2011.

In Germany, eight nuclear power plants were shut down in March 2011. This is consistent with a missing electrical capacity of circa 8,500 MWe (Bundesnetzagentur, 2011). Five of the eight nuclear power plants belong to the Southern part of Germany and represented a total electrical capacity of 5,200 MWe. With the phase out of nuclear energy, a base-load capacity for the transmission network is lost. The shift in feed-in electricity from other power production systems caused a shift in electricity flows of the European transmission system. For this reason, the generation and load balancing is more stressed than in the past, especially in Germany. Geothermal electricity could serve here as a changeable and reliable energy source to support the grid. The moratorium of nuclear power plants caused a clear North-South disparity concerning electricity flows in Germany.

Due to the high North-South flows, the German transmission system operators are focused on the guarantee of the (n-1) security criterion. This criterion stipulates that there can be no overloading of the transmission system at any major grid components such as power lines, otherwise transformers break down. To control the compliance with the (n-1) security criterion, all potential network load scenarios are regularly simulated in order to check for grid failure (Bundesnetzagentur, 2011).

However, the discussion about the (n-1) security is not limited to Germany, but a general topic concerning security of supply. The network security is not only guaranteed by the use of grid and market related measures, but also renewable generation systems; geothermal energy, as a base-load resource, can help to stabilise the grid. However, the support of communities by small, decentralized power plants is often possible without using high-voltage transmission lines.

Apart from network stability, the supply of reactive power and voltage maintenance are very important for a well-balanced transmission system. The reactive power is part of the power fed into the grid. Simplified, the reactive power is that which is used by the grid itself, it is never delivered to consumers Thus, the reactive power swings endlessly within the transmission system and acts as a network's lubricant that enables the electricity conduction through the network. The need for reactive power results from the fact that power networks partly behave like small energy stores. Due to this storage capacity, grid components such as transmission lines act like condensers and coils - depending on the respective system loading. The capacitive behaviour (condenser) of the power network will dominate if power flow is quite low. In contrast, a strong loaded network is characterised by an inductive grid performance (coil) (Bundesnetzagentur, 2011).

As a result of the shutdown of German nuclear power plants, a shortage of available reactive power was observed in Germany. Due to the missing reactive power, the balancing of the transmission network was more difficult to manage. The strong North-South load flow led partly to under-voltage problems in the federal states of Baden-Wuerttemberg, Hessen and Rhineland-Palatine. In contrast, in Hamburg over-voltage problems occurred during low load conditions (Bundesnetzagentur, 2011).

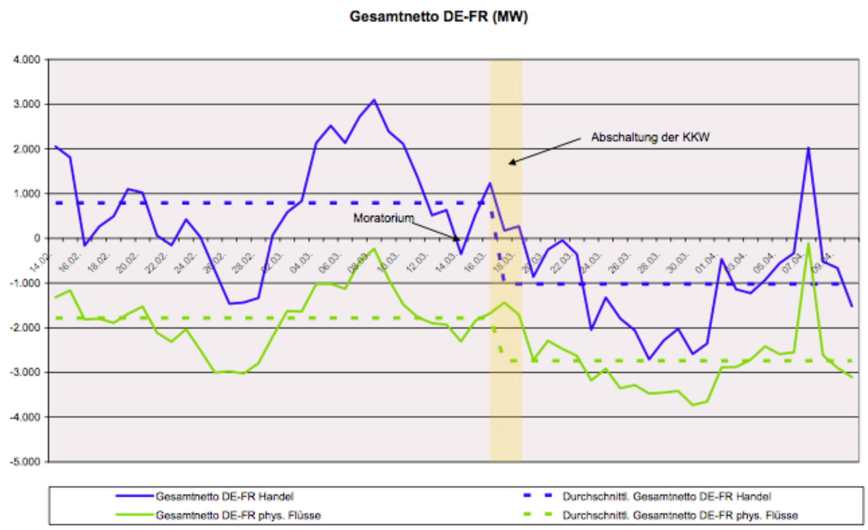


**Figure 12 German – French exchange of electricity in the time period of the German nuclear moratorium from 14th February till 10th February 2011 (Bundesnetzagentur, 2011)**

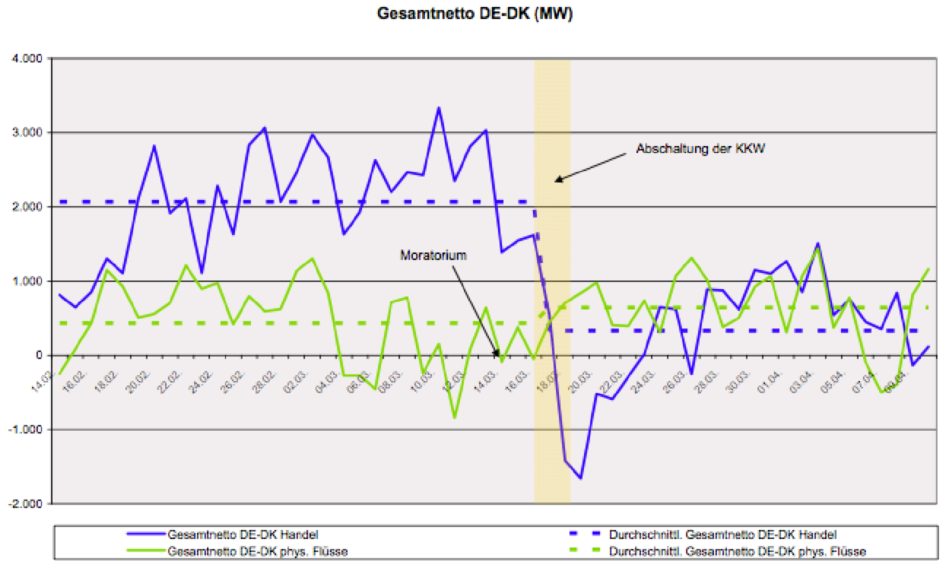


**Figure 13 German – Danish exchange of electricity in the time period of the German nuclear moratorium from 14th February till 10th February 2011 (Bundesnetzagentur, 2011)**

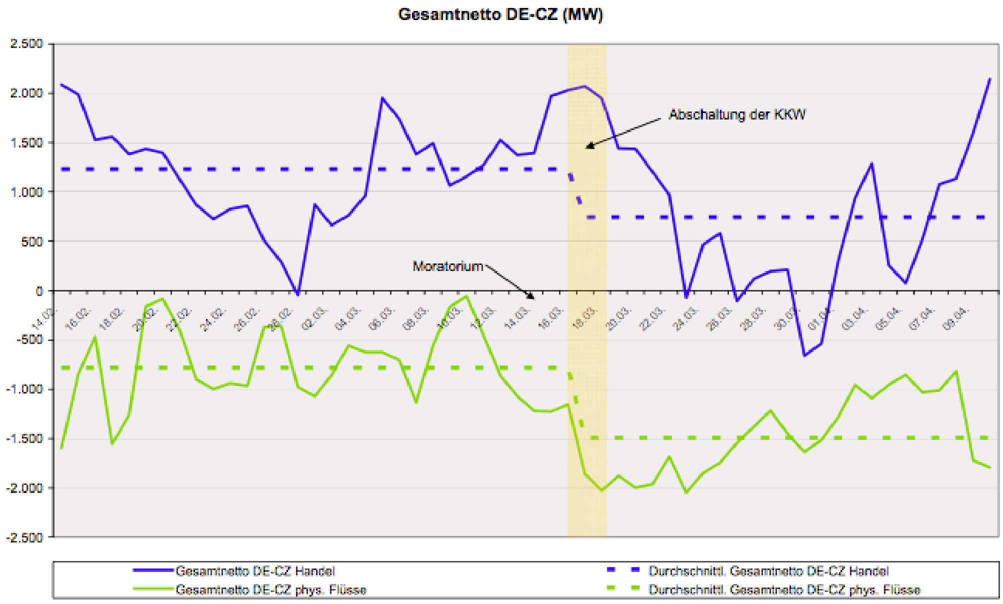


**Figure 14 German – Czech exchange of electricity in the time period of the German nuclear moratorium from 14th February till 10th February 2011 (Bundesnetzagentur, 2011)**

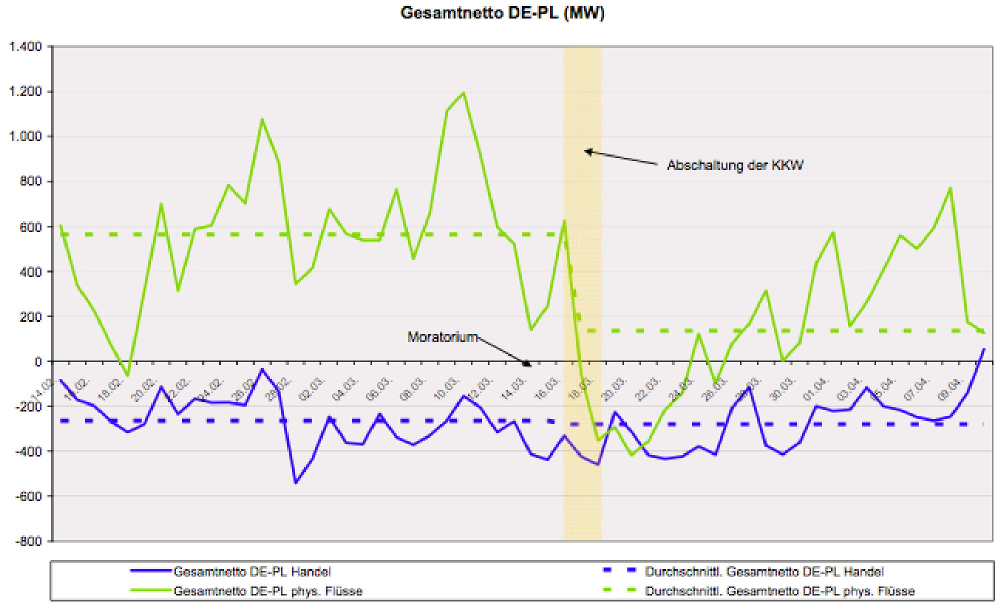


**Figure 15 German – Polish exchange of electricity in the time period of the German nuclear from 14th February till 10th February 2011 (Bundesnetzagentur, 2011)**

The German moratorium has caused changes in energy importing and exporting within Europe. As presented in Figure 12, France imported 790 MWnet till 14th of March 2011, while after the moratorium the country changed its role to a net exporter to Germany (provided capacity of 1,020 MW). That fits to a daily import volume to Germany about 24.5 GWh. The trading with Czech Republic changed significantly, too. The German export capacity surplus was reduced from 1,230 MW to 585 MW after the moratorium (Figure 14). The same phenomenon was observed for the German-Danish exchange of electricity. Here, the German excess of export capacity shrank from 1,740 MW to 330 MW (Figure 13). In contrast, the trade with Poland remained more or less the same. Due to the moratorium, the reserved capacity in Poland slightly increased from 265 MW to 280 MW (Figure 15).

This data only reflects snapshots and thus, it is not possible to extrapolate for future years. The direction and amount of current exchanges strongly depends on the different electricity prices the European member states. Nevertheless, electricity from renewable energy sources (RES-E) will increase continuously within the European electricity market and will play an increasingly important role in supplying the European electricity demand. In particular geothermal energy is an essential part of the mix of renewables due to its $CO_2$-free and base-load character. Although the installed capacity of geothermal power plants in low enthalpy areas is relatively low, even at present, a positive impact on regional respectively local level can be observed.

In high enthalpy areas such as Italy, the exploitation of geothermal energy is easier to implement because of the special geological conditions. In 2010, over 840 MWe electrical capacities were installed thanks to geothermal power plants in Italy. This makes the geothermal contribution (ca 5,3 TWh) to the country's total electricity consumption (ca. 340

TWh) about 1.5 %. The total amount of all renewables and non-conventional energy sources was about 12% (Unione Geotermica Italiana , 2011). A detailed consideration of the European countries' energy mix will be made in chapter 2.

## 4.4 Contribution of geothermal energy to grid stability on the example of Germany

Due to the change in energy policy, the German federal government declared the nuclear phase out will continue until 2022. Instead the new focus will be on renewable energy. At the moment, around 19% the total German electricity is provided by RES (Eurelectric, 2012). In 2030, the role of RES shall increase to 50% and to 80% in 2050. Today, future scenarios indicate that the majority of the renewable energy will be produced by huge off-shore wind farms on the North Sea coast and the Baltic coast of Germany. Until recently, nuclear power plants and fossil-fuel power stations were the main power producer for agglomeration areas, but also for the large industrial sites in the Southern and Western part of Germany. This case study presents the adaption needs of the electricity grid, which arise through the growing distance between electricity production facilities and consumers. It will be shown that in Germany, geothermal electricity production could help to reduce the adaption needs for the electricity grid.

Figure 16 displays the German evolution of the total power consumption and the installed gross capacity with respect to the moratorium of nuclear generation. The left map reflects the status quo in 2008. It is obvious that in the federal states of Rhineland-Palatinate, Hessen and Thuringia (coloured in a darker grey) the energy consumption tops the available production. However, the majority of Germany had an excess of power gross capacity in 2008.

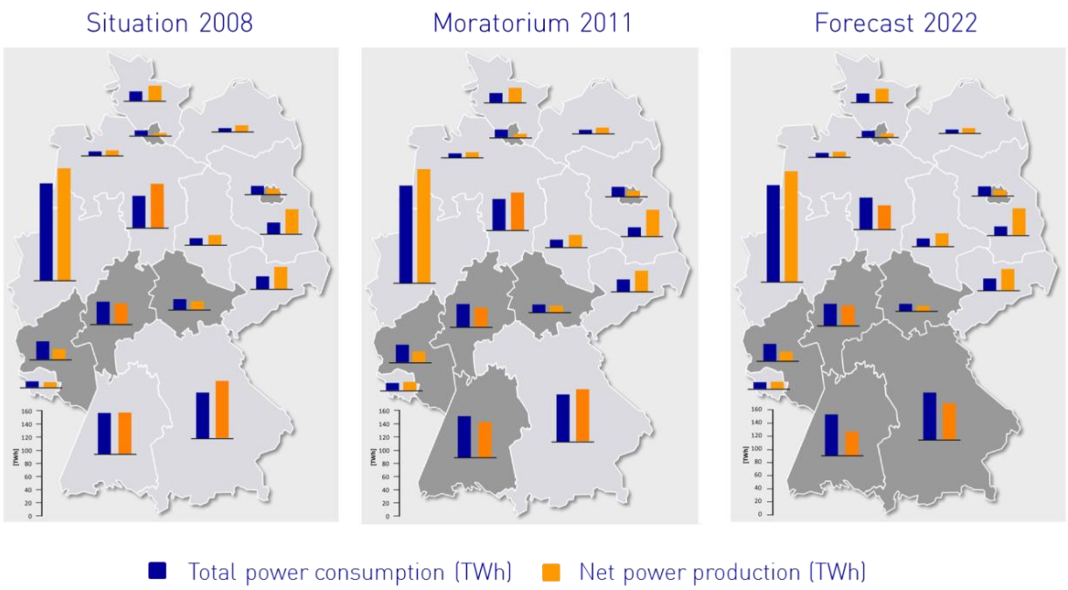


**Figure 16 Evolution of the power consumption and the installed gross capacity in Germany in dependence on the nuclear moratorium. (Agentur für Erneuerbare Energien, 2012) (IWR, 2012)**

Due to the moratorium on 14th March 2011, eight nuclear power plants were shut down and thus, an electrical output of circa 8,500 MW has recently been missing (Bundesnetzagentur, 2011).

Five of these nuclear power plants belong to the Southern part of Germany and represent a total electrical output of 5,200 MW. The consequence of the moratorium is shown in the middle illustration of Figure 16. Under present circumstances, power consumption and power production of Baden-Württemberg is not balanced.

Assuming that no new power plants are installed in the next few years, a forecast for 2022 is displayed on the right map in Figure 16. It is obvious that the entire southern part of Germany will be undersupplied due to the shutdown of the remaining nuclear power plants. Additionally there is a steadily growing wind capacity in the north, which increases the imbalance between the location of capacity and load. Of course, the federal government is working on alternative solutions such as the promotion of renewables.

Nevertheless, in the following a consideration of the impact of geothermal energy is made. In the TAB study, made on behalf of the German Bundestag in 2003, a detailed overview about the technical potential of geothermal energy in Germany is given (Paschen et al., 2003). In addition, one work package of GEOELEC deals with a prospective study for geothermal energy in Europe. Starting from an assessment of the resource and the potential of geothermal power, the consortium will distil forecasts, taking into account technical, legal and institutional, financial and communication aspects. Due to the fact that the prospective study will cover the first twenty months of the project, EnBW is for the moment working with the data from the TAB study. An update of the results by the GEOELEC findings is of course not excluded.

Based on the TAB study, the technical potential of hydrothermal systems in Germany is about 2,600 TWh. This is about four times of the German annual power consumption. Hydrothermal systems are limited according to their local resources. In the TAB study the use of hydrothermal systems corresponds to the geothermal exploitation by the use of aquifers in 2-4 km depth (Paschen et al., 2003). The potential differs for the geothermal areas of Germany: the Upper Rhine Valley and the Molasse Basin in the South, and the North German Basin. The geothermal potential for the latter is almost three quarters of the total technical potential of hydrothermal systems in Germany. The remaining potential refers to the Upper Rhine Valley with 550 TWh and 150 TWh for the Bavarian Molasse.

Returning to the question how geothermal energy can (a) support the security of supply and (b) contribute to grid stability in South Germany, EnBW calculated the hydrothermal potential of Bavaria, Baden-Wuerttemberg and Hessen based on the federal state’s territory and the potential geothermal resource areas (Figure 17). The results show that the three federal states contain a technical potential for hydrothermal systems of about 23%. This percentage fits to circa 500 TWh – five sixths of German’s annual cross power consumption (Eurelectric, 2012).

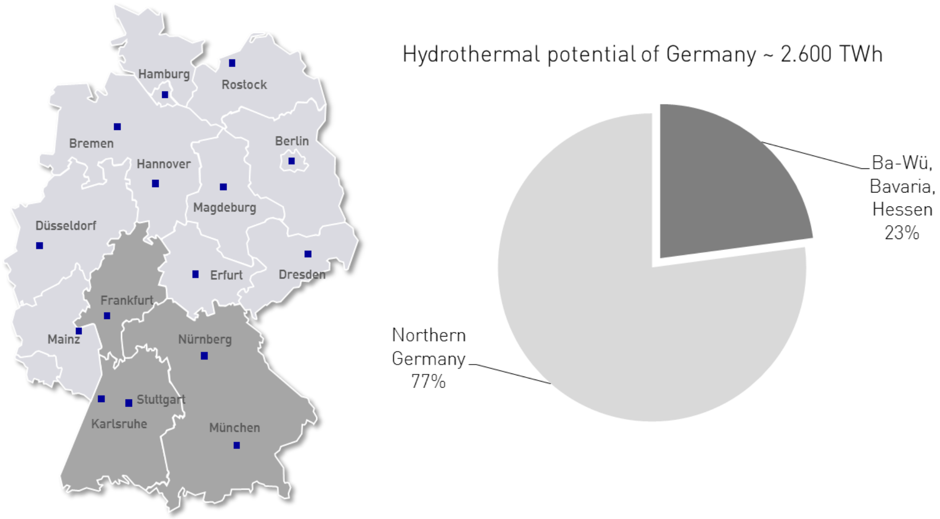


**Figure 17 Geothermal exploitation in Germany: Distribution of the technical potential of hydrothermal systems between the Northern and Southern part.**

Due to the fact that hydrothermal energy is limited and linked to special geological conditions, Enhanced Geothermal Systems (EGS) are seen as a key future technology. In the TAB study, EGS refers only to the geothermal exploitation of crystalline rocks. Today, it is quite common that the development and improvement of a geothermal reservoir by EGS is not limited to crystalline rocks, but also useful for other rock types such as sandstone. However, in the next part of this report be concentrated to the technical EGS assumption made in the TAB study. Here, for Germany an EGS potential of 297,000 TWh is defined (Paschen et al., 2003). Over 80% of these resources belong to the three southern federal states coloured in darker grey in Figure 18, whereas the remaining parts of Germany have a relatively low technical EGS potential based on the occurrence and distribution of crystalline rocks in certain depth.

It is obvious that the total technical EGS potential of Germany is a multiple of the German annual power consumption. Even the potential of Enhanced Geothermal Systems of South Germany alone tops the total power consumption by far. Together with the hydrothermal potential it could contribute to grid stability and security of supply in two ways. Firstly, geothermal energy can be seen as an offset to the North-South divide. An additional production capacity in the south could reduce the need of electricity transport from the north to the south and the need to adapt the grid. Secondly, the geothermal electricity production is an adjustable energy source and could be a useful tool for grid control. Due to the base load character, geothermal generation can provide an important contribution to stabilise the transmission system in future. This would reduce the need of adapting the grid to the change from adjustable, fossil to volatile, renewable energy sources.

Today, however, in low enthalpy areas such as Germany, geothermal power plants are mostly characterised by relatively low electrical output. At present, the maximum power plant unit installed in Germany is about 5 $MW_{el}$. Therefore, the impact of geothermal power plants to the German electricity network is currently very local and mainly limited to the lower voltage network. However, in the framework of decentralisation, geothermal power plants already supply energy to communities and smaller regions.

In addition, due to the objectives of the National Renewable Energy Action Plans (European Commission, 2010), geothermal energy is needed to fulfil the issues of environment protection and decarbonisation. Of course, the development of geothermal projects does not only depend on political and technical aspects, but also on the economic feasibility. Today the power production costs are already comparable to other RES and range between 17-22€Ct/kWh for the German market (Kölbel et al, 2011). There is still a huge potential of cost reduction by using ‘low hanging fruits’. The detailed description of the cost situation for geothermal power is content of work package 3.

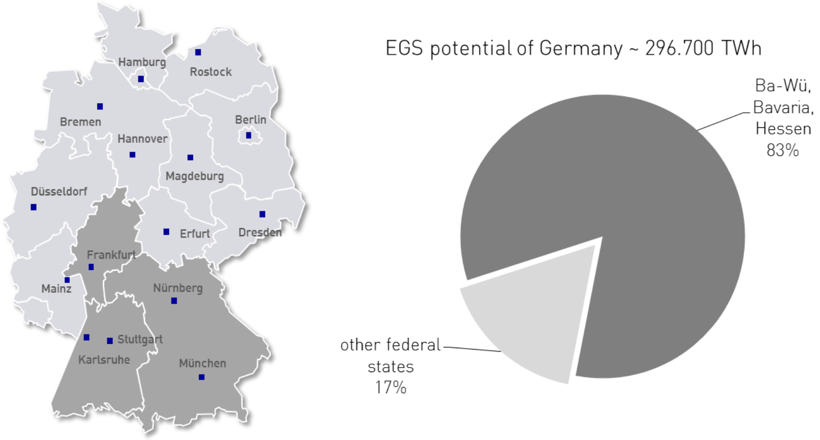


**Figure 18 Geothermal exploitation in Germany: Distribution of the technical potential of Enhanced Geothermal Systems (EGS) between the Northern and Southern part.**

# 5 Technical conditions for grid access of geothermal power plants

Like other generating technologies that are fed into the electricity grid, the basic principles of balancing, backing up, and aggregating apply to geothermal power as well. However, geothermal energy as a $CO_2$ free and domestic energy resource will have a prominent position in the future energy mix due to its high availability of around 90%. Thus, operators of geothermal power plants must be able to connect to the grid.

Technical conditions for grid access are studied in order to make recommendations as well as technical justifications for the inclusion of geothermal power plants in an existing, respectively new, power network. Due to the present grid architecture, the transport and distribution of electricity is handled by the top-down method from transmission to distribution level. The different voltage levels are interconnected by substations. Here, the voltage will be converted to a higher or lower level.

The top level is formed by the international transmission system. Here, electricity is transferred form large power stations to consumption centres. Due to the extremely high voltage of 380 kV or 220 kV, long distances can be covered and comparatively large volumes of power can be transported. In addition, the extra-high voltage network part of the European grid system enables a cross-border power transport through Europe (chapter 4).

The second level is covered by the individual distribution networks of the regional utilities. Due to these networks, electricity is transmitted to larger areas and industrial enterprises. The level of voltage is about 110 kV and represents the high-voltage grid. The next level of the electricity network is made of more local systems that supply the industry with power. This middle-voltage grid is characterised by a smaller voltage level of 110 kV. The lowest voltage level is responsible for the power supply of households and small industrial enterprises. For this low-voltage system, a voltage smaller 1 kV is quite typical.

In the European context, the voltage of the transmission system (extra-high voltage level) and the distribution network (high-voltage level) are compliant with international standards (IEC, 2002). Thus, in Europe's extra-high voltage system, a voltage of 220 kV or 380 kV is quite common, while the high-voltage level normally works with a voltage level of 110 kV. Exceptions might be large cities with older cable systems (60 kV).

Outside Europe, other levels of voltage are common. For instance, in the USA the transmission system is characterized by a voltage level of 765 kV. In Russia, there are extra-high voltage levels of 330 kV, 500 kV, 750 kV or even 1050 kV.

20 kV are typical for the middle-voltage system, but in urban centres 10 kV-grids also exist due to old underground cable. In contrast to the other voltage levels, the middle-voltage level has only a poor standardisation, whereas low-voltage systems are characterised by a voltage of 230 kV/ 400 kV (single-phase/three-phase) in mostly all European countries.

In low enthalpy areas, where relatively small geothermal power plants are usual, geothermal energy is fed into the middle-voltage system. Hereby, only minor respectively local effects are expected, but this might be different with increasing decentralised power production in future.

**Figure 19 Transfer station**

From the technical point of view, there is no difference for the grid connection of a renewable generation system like geothermal or a conventional one (BDEW, 2008). The technical preconditions are the same and they are regulated in the according directives. The technical equipment that is needed will now be described in detail. The so called ‘transfer station’ (Figure 19) includes all the required technical equipment such as transformer, medium-voltage switchgear and a low-voltage distributer (VDN, 2003).

The transformer is used to transform voltage to a lower or higher level. A high level voltage is necessary to ensure lossless transport over long distances. However, the final consumption system is characterised by relatively low values so that the voltage has to be reduced significantly after transport.

The medium-voltage switchgear is responsible for a safe energy distribution. The switchgear includes one or more busbars and a certain number of switching devices. Here, a distinction is made between isolation switch and power switch. Isolation switches are used to separate a grid component from live parts. With the help of power switchers, operating currents and residual currents (short-circuit) can be turned on and off easily.

Similar to the medium-voltage switchgear, the low-voltage switchgear is usually fed by the transformer and used as an energy distributing device in public grid substations or in the industrial sector. The rated voltage does not exceed 1,000V alternating voltage or 1,500 V direct voltage.

Apart from this, technical requirements have to be met. Thus, the operation of an electricity generation systems have to be suitable for the grid operator’s network. In addition, inadmissible reactions to the electricity grid and to other power plants have to be ruled out.

This includes, inter alia, the compliance with the agreed connected load (BDEW, 2008). The access to the power grid should be coordinated in time with the network provider, preferably starting in the planning phase of the project.

In the framework of the application procedure, it is obvious that the grid operator receives all technical information required for grid access. The network compatibility of the power generation system itself is proven by a special test. Not only for the network compatibility test, but also for the development of a grid connection offer, technical data about the power plant is needed. These include, beside the application of the transfer station following documents (BDEW, 2008):

- Site plan of the location in a detailed scale with information about place, road holding and boarders of the land plot
- A data-sheet of the technical data of the power plant and additional certificates
- Overview plan of the whole electricity generation system including information about applied utilities, medium-voltage connection parts, cable length and switchgears, as well as an overview about protective measures for the power plant
- Information about short-circuit strength of the equipment
- Data about the transformer, generator and other compounds of the power plant

Due to these data the network operator is able to determine the most suitable grid connection point. This connection point ensures on the one hand a safety power supply operation. On the other hand it guarantees the intake and transfer of the electrical power being claimed.

## 5.1 Site related costs of grid connection

The cost of grid connection consists of (a) costs for the technical equipment and (b) distance dependent costs for connecting the power plant with the allocated grid connection point.

The transfer station includes all the necessary technical equipment. The costs of the individual components of a 1 MW-transfer station are listed in Table 1. The data is based on EnBW experience in the provision of transfer stations of comparable capacities. For power plants with a higher electrical output, mainly the costs for the transformer will change, while the remaining equipment stays more or less the same. Given the cost estimation of a 1 MWel power plant, the transfer station will cost about 80,000€ to 85,000€. These are fixed costs and the figures can be used when planning the project.

In contrast to this, the costs for routing and cable installation are strongly related to the grid connection point assigned by the grid operator and therefore have site specific costs. Depending on the cable’s diameter, a price of 100-150 € per meter is quite common.

**Table 1: Cost overview of a transfer station including all technical components for grid access of an 1 MW generation system**

| Technical equipment | Cost |
|---|---|
| Envelope of the station | 35,000 € |
| Medium-voltage switchgear | 20,000 € |
| Transformer (1000 kVA) | 18,000 € |
| Low-voltage distribution | 6,000 € |
| Incidentals | 3,000 € |

For that reason, the selection of the grid connection point is essential and has an impact on the grid access costs for the power plant operator. Figure 20 shows the best-case-scenario for the connection of a geothermal power plant to the medium-voltage grid. The plant operator is able to use the next grid connection point without having any technical or economic disadvantages. In contrast, there will be a financial saving due to the short linear distance.

However, as shown in Figure 20 to Figure 22, in some cases there are technical difficulties so that the grid provider has to check alternative connection points. Not only technical issues, but also local infrastructure can complicate the procedure of grid access.

In exceptional cases, the construction measures for grid connection become very complex due to the existing of a broad road which has to pass through. Another cost factor is private land and buildings lying within the planned routing. In those cases the project is no longer profitable for the power plant operator and thus, the grid operator has to provide another point for connecting - like it is shown in Figure 21.

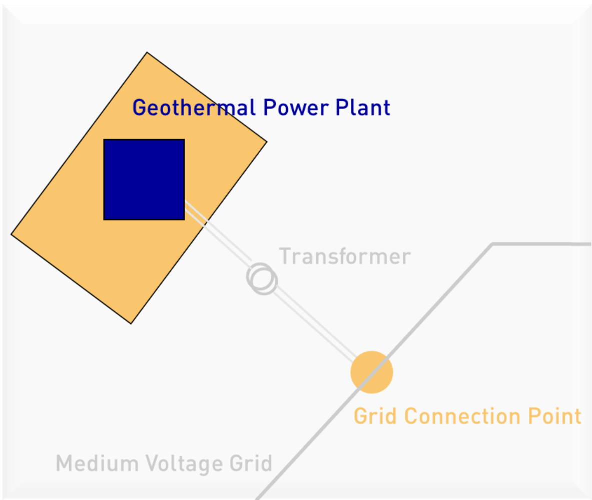


**Figure 20 Allocation of the grid connection point. Best-case-scenario: connection of the power plant to electricity grid by using the shortest distance (linear distance).**

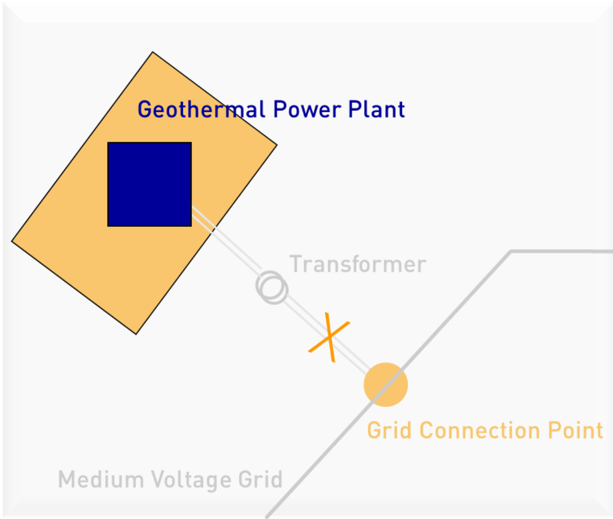


**Figure 21 Allocation of the grid connection point. The nearest (linear distance) grid connection point is unsuitable due to technical issues.**

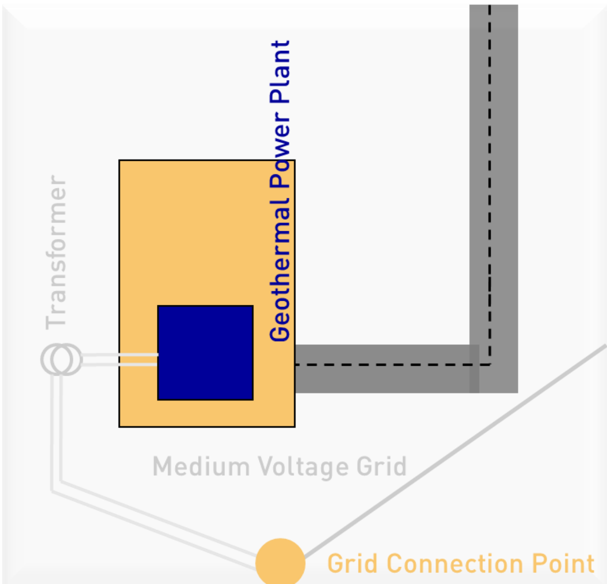


**Figure 22 Allocation of an alternative grid connection point. The nearest (linear distance) grid connection point is unsuitable due to economic issues.**

## 5.2 Case Study: Grid access of geothermal power plants in Germany

Due to the evolution of geothermal energy in Germany, EnBW designed a questionnaire and sent it to operators of geothermal power plants that are already operating, under construction or still in the planning stage. In total 18 facilities were contacted in the framework of this survey. The participants include planning offices, project companies, utilities, but also communities (Figure 23). The response of the questionnaire was about 40% and the questions were properly answered.

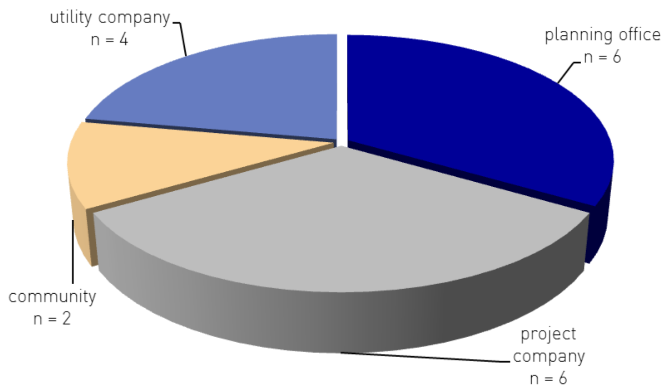

Figure 23 contacted facilities questionnaire

The power plant operators were asked for their experiences with the procedure of grid connection and the costs involved. Furthermore, it was important to get some information about the power plant, for instance about the installed electrical capacity, to identify a possible link between power plant size and grid access. Finally, the operators were asked for an individual assessment concerning the effect on the design of the German electricity grid of building new geothermal power plants.

The evaluation resulted in more or less common procedure for grid connection (Figure 24). First, the power plant operator has to contact and inform the local grid operator, who will work out a feed-in agreement and assign the grid connection point for the geothermal power plant. The geothermal power plants in questions are characterised by an electrical output from 0.5 MW to 6.6 MW. Due to these capacities, all power plants feed their electricity directly into the medium-voltage grid.

To localise the technically most efficient, but also the most economically advantageous grid connection point, the network compatibility has to be proven with special regard to the local grid structure. In Germany, the validity of the network compatibility test is limited to six months. If there is no grid connection within this time frame, a new application has to be made.

According to the German Renewable Energy Sources Act (EEG, 2011), there are costs for the network compatibility test and the commissioning of the power generation system, which depend on the installed capacity.

The charges shown in Table 2 will be refunded, if the power plant (a) fulfils the technical parameters respectively the declared feed-in power and (b) is getting into operation within the reserving period of six months.

Figure 24 Main steps of the procedure for grid connection

With regard to geothermal systems, the plant operator has to make firstly a contract for testing the network compatibility. In addition, he has to give detailed technical information about the power plant, including a site plan of the location of the electrical power unit.

Due to the results of the questionnaire, in the majority of cases, it was not possible to use the nearest grid connection point because of technical issues. For that, the operator of the geothermal power plant has to consider additional effort and costs. The costs for the routing clearly depend on the distance. Depending on the cable's diameter, a price of 100 – 150 € per meter can be given as a rough number.

Before starting the operation, the plant operator has to consider further formalities. Here, a registration for the connection to the medium-voltage grid is needed, as well as a general plan of the transfer station, including a short description of the medium-voltage installations.

The agreement for the supply and remuneration of the geothermal energy will be concluded separately. Hereby, the feed-in rates follow the legal basis which will be described in detail in work package 4 of GEOELEC.

For connecting to the medium-voltage system, the transfer station has to fulfil special requirements. The costs for commissioning of medium voltage power plants depend on the actual expenditure. Due to the results of the survey several types of costs could be identified as presented in Figure 25. Apart from planning costs, engineering work mainly for routing and cable installation as well as material costs such as costs for the cables have to be considered. These costs types are distance dependent costs. In contrast, the transfer station's costs depend on its component parts, which are already described in detail in chapter 5.

**Table 2: German net charges for grid access depending on plant capacity**

| Installed capacity | Net costs |
|---|---|
| ≤ 30 kW | - |
| > 30 kW ≤ 150 kW | 225 |
| > 150 kW ≤ 500 kW | 546 |
| > 500 kW | 2,248 |

The installation of those transfer stations are within the responsibility of the plant operator. Due to the findings of the survey for the transfer station total costs about 80,000 k€/MW to 90,000k€/MW are quite common in Germany. This price range fits very well to EnBW experiences.

The installation cost is not only valid for geothermal power plants, but also for other renewable energy systems with a relatively small installation size (<10 MW) such as biomass or solar parks. In this context, several discussions with respective departments inside EnBW took place.

On the question how important geothermal energy is for power supply and for the electricity grid, a general positive trend could be observed. In all, the interviewees were optimistic that geothermal energy as a base-load energy source will strongly support the stabilisation of grid in the future and that it is needed as a compensation for fluctuating energy sources. But due to the relatively small capacity of the Germany's geothermal power plants, some argue that effects are only seen at a local framework level.

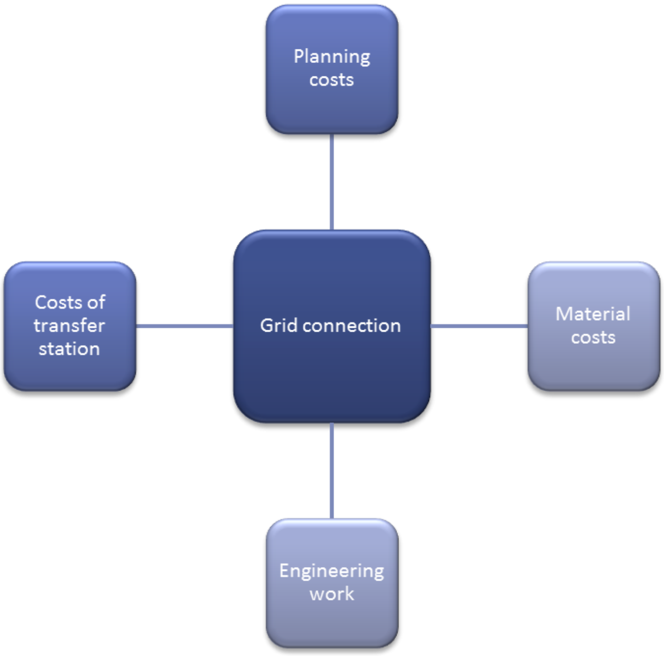


**Figure 25 Cost types for grid connection of geothermal power plants identified by the evaluation of the questionnaire**

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