Grid integration of geothermal electricity

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ABSTRACT

A growing share of renewable electricity requires an investment of 104 Billion € to construct and refurbish almost 52,300 km of electricity lines in the European transmission grid. A case study on the German geothermal resources shows that it could offset problems in the transmission grid by replacing decommissioned nuclear power plants and consequently reduce adaption needs. Geothermal power supplies necessary renewable and controllable power. The procedure of grid integration is the same for all renewables. The main point of interest is the grid connection point where the plant is connected to the existing electricity grid. Its geographical location and the connected voltage level mainly define the costs of grid integration. The best situation for gird integration in Europe can be found in Denmark and Germany. Unfavourable is the situation in Eastern- and South-Eastern-Europe. The remaining European countries show rather mixed preconditions for grid integration of renewable electricity.

1. INTRODUCTION

Geothermal electricity production in the low enthalpy regions of Europe is currently still in its infancy. Besides the high enthalpy regions in Italy, Turkey and Iceland only Austria, France and Germany have already geothermal power plants with a total of 14.82 MW_{el} installed capacity. For the future one can assume a strong increase of geothermal capacity in these regions. In 2012, 26 power plant projects (125.5 – 130 MW) were under development and 94 projects under investigation (EGEC, 2012).

This development of the geothermal branch in the European low enthalpy regions is met by a fundamental modification of the energy system. Several European countries introduced legislation with the aim to transform their energy system from a conventional dominated one to renewable power production. This fundamental modification leads to major changes in the electricity business with a certain impact on the grid infrastructure: Decentralised power generation systems fed by renewable resources require an adaption of the grid architecture on all voltage levels. The scale of this challenge can be estimated from the length of the network. The pan-European transmission network (380/220 kV) has a total length of 300,000 km (ENTSO-E, 2012a). Supplementary each country operates a distribution network. In Germany e.g. this network has a length of 1,679,000 km. Within the European transmission network 52,300 km extra-high-voltage-lines have to be refurbished or new built. Over a period of 10 years an investment of € 104 billion will become necessary (ENTSO-E, 2012b). Additionally the necessary adaptions of the distribution network have to be considered, too. For the German distribution network a study calculated the need for new construction or refurbishment of lines between 160,000 – 214,000 km until 2030. This would mean an investment of 27.5 – 42.5 billion € (dena, 2012). In Europe the grid integration of renewable power is mandatory, despite the high adaption needs through their grid integration. Directive 2009/28/EC introduces for all European countries a guaranteed or prioritized network access for renewable power (EC, 2009).

Under these circumstances, the European research project GEOELEC has evaluated the legal and technical conditions for grid access. The results of this study concerning the impact of geothermal electricity on the electricity grid will be discussed in the next chapters. Main topics are the costs and process steps for grids access and the barriers for grid integration in Europe.

2. REDUCTION OF ADAPTION NEEDS

The European electricity grid needs to be restructured. Three major reasons have been identified (ENTSO-E, 2012b):

- Decommissioning of existing generation capacity
- Decentralisation of generation capacity
- Volatile and difficult to predict feed-in of renewables

Caused by the German nuclear phase out and the end-of-life of fossil and nuclear power plants, mainly in Germany and Great Britain, the European generation system is facing the decommissioning of a serious amount of capacity. These power plants are often situated close to consumption centres. As replacement for decommissioned power plants and to satisfy the growing energy demand in Europe, 250 GW generation capacities have to be constructed until 2030. 220 GW of this capacity will be renewable energies (ENTSO-E, 2012b).

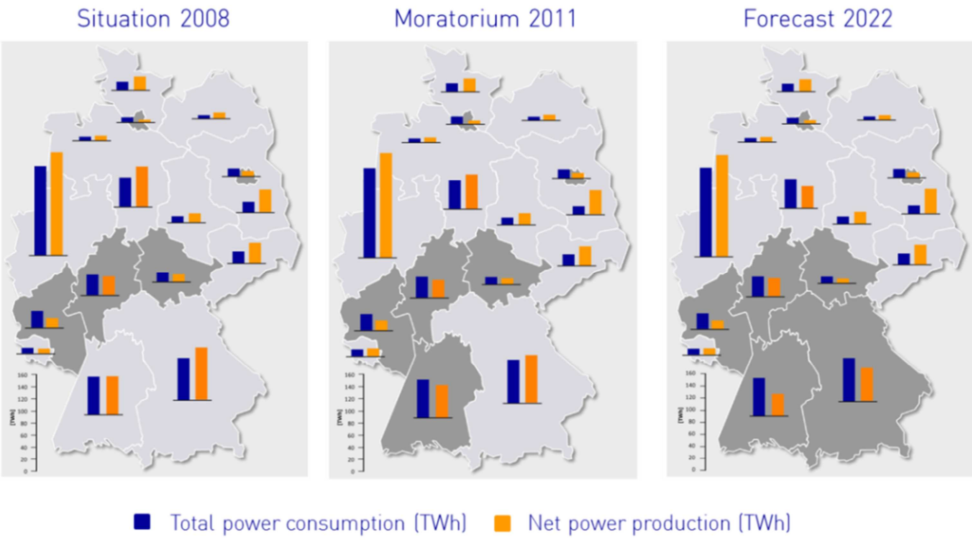

Figure 1: Evolution of the power consumption and the installed gross capacity in Germany in dependence on the nuclear phase-out. (Agentur für Erneuerbare Energien, 2012) (IWR, 2012)

The German nuclear-phase-out and the natural end-of-life of conventional power plants lead to a reduction of conventional capacity from 95 GW to 55 GW until 2030 (dena, 2010a). The recent capacity is mainly located close to densely populated areas in the South and West of Germany whereas their replacements (especially windfarms) are located in the North and East of Germany. This situation endangers the stability of the grid and cannot be managed by the existing infrastructure.

A considerable number of geothermal power plants in the South of Germany could reduce the grid adjustments significantly. This shall be shown with a case study. Figure 1 presents the ratio between electricity production and consumption in the single states of Germany. In 2008 only three states weren't able to satisfy their electricity demand by local power production. In 2011 the nuclear moratorium came into force. This lead to an immediate shut down of 7 nuclear power plants. Consequently the state of Baden-Wuerttemberg was no longer able to cover its consumption by local electricity production. Until 2022 all German nuclear power plants have to be decommissioned and a certain number of fossil power plants will reach their end-of-life. It is assumed that the fossil power plants will be substituted by renewable power production capacity. But the capacity gap caused by the nuclear phase out still exists. As a result, South Germany loses its ability to feed the demand by local power production and new North-South grid connections have to be established.

In 2003 a study on behalf of the German Bundestag analysed the potential for geothermal electricity production in Germany. The study of (Paschen et al., 2003) approved, that the technical potential for hydrothermal electricity production is about 2600 TWh. This is about four times the annual Germany electricity consumption. The potential differs considerably for the different geothermal provinces in Germany: Almost three quarters of the hydrothermal potential is located in the North German Basin. This leaves around 550 TWh for the Upper Rhine valley and around 150 TWh for the Bavarian Molasse. A part of this energy could support the security of supply and additionally contribute to grid stability in South Germany. Figure 2 shows the calculation results for the technical geothermal potential in the federal states of Bavaria, Hessen and Baden-Württemberg. These three states contain a technical potential of 500 TWh or 23 % of the total hydrothermal potential. This would mean around five sixth of the annual gross power consumption in Germany. (Paschen et. al, 2003; Eurelectric, 2012)

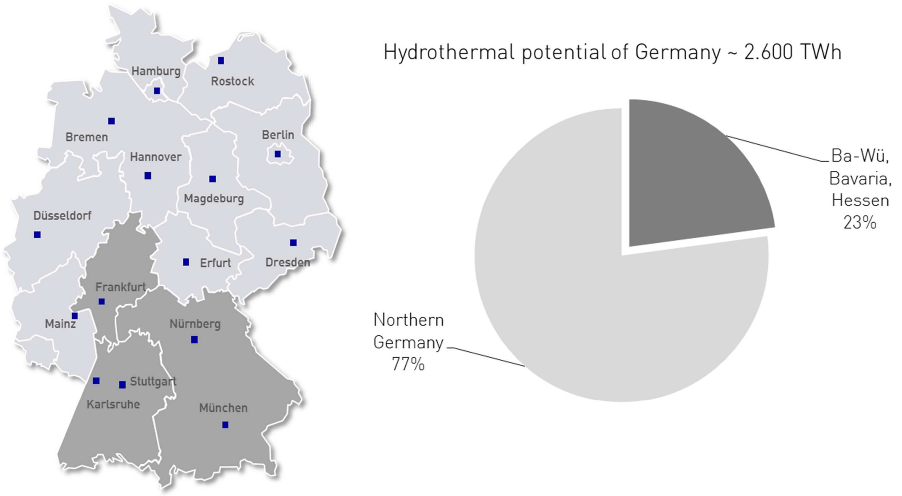

Figure 2: Geothermal exploitation in Germany: Distribution of the technical potential of hydrothermal systems between the Northern and Southern part.

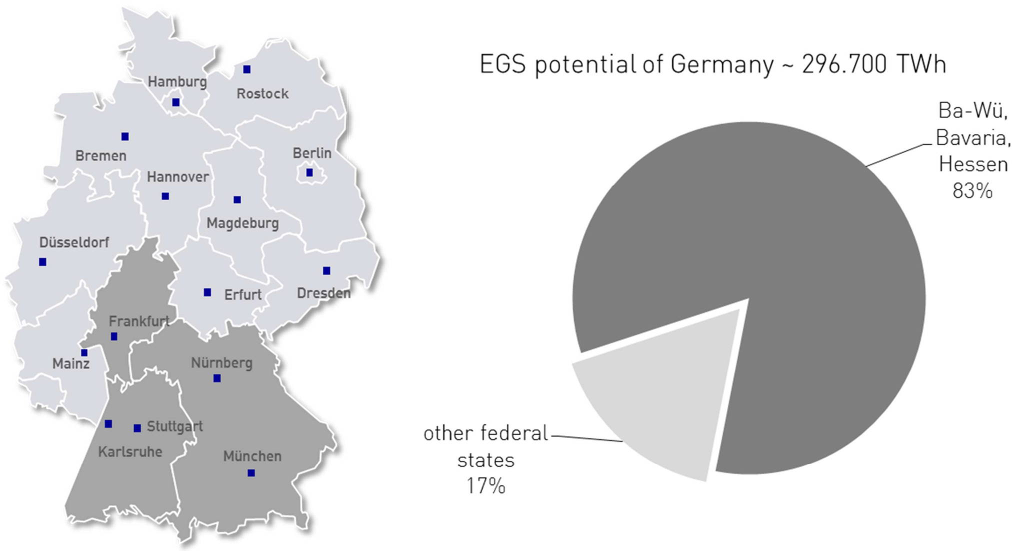

Figure 3: Geothermal exploitation in Germany - Distribution of the technical potential of Enhanced Geothermal Systems (EGS) between the Northern and Southern part.

Besides the hydrothermal potential Germany also has a considerable potential of petrothermal resources (Enhanced Geothermal Systems, EGS). (Paschen et al., 2003) limited this potential on crystalline rocks. Today the state of scientific knowledge says that the EGS technology has a wider range of application. Besides the enhancement of hydrothermal reservoirs, this technology can be applied on a variety of brittle rock formations like e.g. sandstone under a certain stress regime. Nevertheless in the following we want to rely on the calculations of (Paschen et al., 2003). The study calculates the petrothermal, potential of Germany to 297,000 TWh, which is 4.5 times the annual German electricity demand (Paschen et. al, 2003; Eurelectric, 2012). According to the (Paschen et al., 2003) study Germanys petrothermal potential is mainly located in South Germany. The federal states of Hessen, Bavaria and Baden-Württemberg together stand for around 80 % of the German EGS-potential. Figure 3 shows the above explained results. The case study showed that for the future an imbalance between North and South Germany can be expected. This imbalance has to be offset by a growing electricity transport. As different studies showed (ENTSO-E, 2012b; dena, 2010b) this leads to a considerable adaption need in the German electricity grid. The combined geothermal potential (hydrothermal and petrothermal) of South Germany tops the German annual electricity demand by far. This potential could contribute to grid stability and security of supply in two ways. Firstly geothermal energy production in the South could reduce the North-South imbalance and reduce the adaption needs for the electricity grid. Secondly, geothermal power is a controllable energy source and could therefore contribute to grid stability.

Grid stability is a growing challenge for the network operators. The transformation of the conventional based electricity system towards more renewable energy requires an adjustment of infrastructure and the control system of the electricity grid on all voltage levels. Whereas fossil power plants are controllable and easy to plan, volatile energy sources like wind and solar power require new ways of securing grid stability and supply. The main problem appears to be the difficult process of forecasting the amount and time of availability of renewable energy. Modern forecast methodologies become more and more precise but still there are considerable differences between forecast and reality.

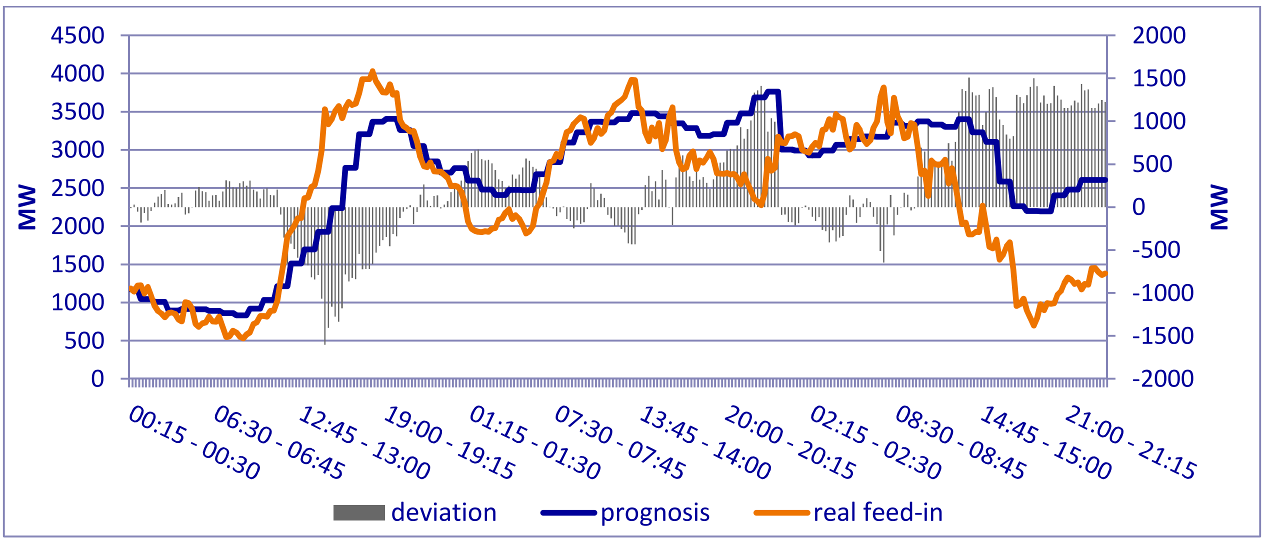

Figure 4: Wind feed-into the Amprion grid (Germany) 03 Feb. - 05. Feb. 2013

Figure 4 displays the situation of wind feed-in into the grid of the German transmission network operator (TNO) Amprion between February 2nd and the 5th 2013. The figure shows a considerable deviation between predictions and real feed in. Particular challenging are the fast load jumps which have to be regulated by other power plants.

In contrast geothermal power is a controllable renewable power source with a high capacity factor. The capacity factor sets the produced power in contrast to the possible power output of a power plant operating at full load the year around. Therefore it is an indicator for the availability of a power plant. Figure 5 shows the capacity factor for geothermal power in Europe. It can be seen, that capacity factors above 70 % are common, also in low enthalpy areas like Germany. In contrast wind and solar power have comparable low capacity factors of 20 % and 8.5 % (EGEC, 2012; BMU 2012).

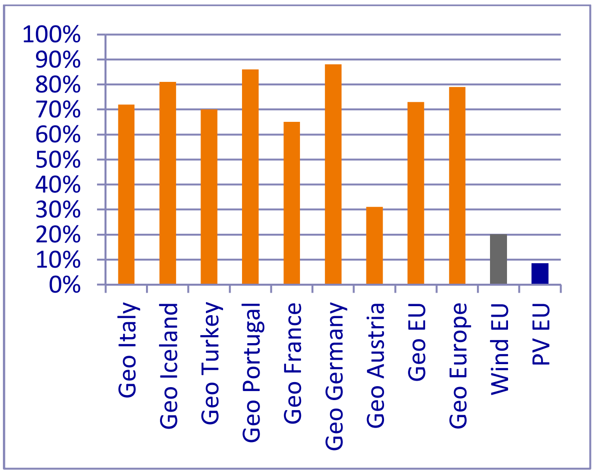

Figure 4: Capacity factor of geothermal, wind and solar power in Europe

Currently the geothermal impact on the electricity grid is very limited. In low enthalpy areas like Germany the largest power plants so far have an installed capacity of 5 MW_{el}. Capacities of this size are normally connected to the middle or low voltage grid, so that the impact on the European transmission grid is currently negligible. However in the framework of decentralization geothermal power plants already supply electricity to local communities and regions. The above case study on the German geothermal potential has shown that geothermal electricity is able to supply a considerable amount of electricity especially in South Germany. Together with a high capacity factor (see Figure 4) a growing geothermal capacity will be able to support the grid and reduce grid adaption needs.

3. PROCESS OF GRID INTEGRATION

The general construction of the electricity grid is more or less the same all over Europe. Especially on the transmission network unique standards for Europe regulate the long distance electricity transport. In the lower voltage levels differences can occur depending on the used cables, the type of cable laying or other local preconditions. In cities e.g. cables are often laid underground and especially in the city centers they are rather old. This implies a lower voltage level. Generally spoken one can separate between four different voltage levels as it is presented in Figure 5. The voltage level depends on the power that has to be transported and the distance that has to be bridged. A European connection only exists on the extra high voltage level. Here different countries are connected with a voltage level of 380 kV / 220 kV. Shorter distances are connected with lower voltage levels. On the high voltage level regions are connected. The middle voltage level connects cities and the low voltage level mainly connects single houses or villages. Geothermal power plants in low enthalpy areas are currently only built with a capacity between 1 MW_{el} and 10 MW_{el}. In this range power plants are usually connected to the middle voltage grid. In high enthalpy areas like Iceland or Italy, higher generation capacities per power plant are common. These power plants are usually connected to higher voltage levels as Figure 5 shows.

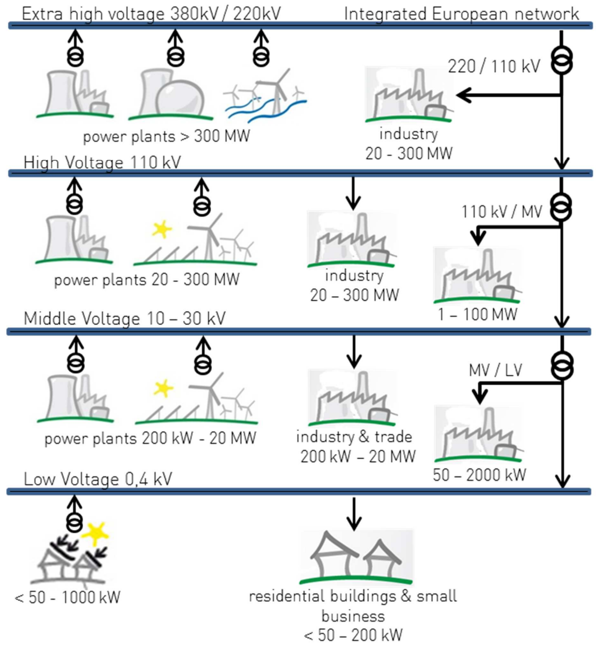

Figure 5: Basic layout of the electricity grid in Europe (own illustration based on Konstantin, 2007)

From a technical point of view, the grid connection of geothermal power has no differences to other conventional or renewable power stations. Like other generating technologies, which feed into the electricity grid, the basic principles of balancing, backing up and aggregating also apply to geothermal power as well (BDEW, 2008). The technical preconditions are the same and they are regulated in the according directives. These directives strongly depend on the regulations of each country. Therefore for each case the national directives have to be respected. For the grid connection of a power plant besides the cable a 'transfer station' is needed. These standardized buildings are similar to containers and include all the required technical equipment such as transformer, medium-voltage switchgear and a low-voltage distributer (VDN, 2003). Apart from this, technical requirements have to be met. Thus, the operation of an electricity generation system has 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. In the course of the grid connection it is obvious, that the network operator receives all technical details of the generation system. To prove the network compatibility of the generation system a so called network compatibility test is mandatory in Germany. This test investigates the compatibility between the grid and the generation unit

Figure 6: Main steps of the procedure for grid connection

For the network compatibility test and the final grid connection, the grid operator needs among other the following data:

- Site plan of the power plant (very detailed)
- Technical data of the power plant and different certificates of the single components
- Circuit diagram of the electrical equipment and detailed information about the used components
- Information about the short circuit strength of the equipment

On the basis of this data the grid operator will determine the grid connection point. This point marks the property line between grid operator and power plant owner. This means that the gird connection point significantly determines the costs of the grid connection. While the network compatibility test is only valid for 6 months the general process should already be started in the planning phase of the project. Depending on the duration of approval processes, negotiations with land owners and the construction phase itself, the grid connection process can take between 3 and 18 months.

In the framework of the GEOLEC research project a survey under 18 German power plant operators was conducted. Although the geothermal projects are in a different development stages, a common procedure for grid connection was observed (Figure 6). The German legal system relies on negotiations between grid operator and power plant owner. Through existing regulations legal disputes are rare.

4. COSTS OF GRID INTEGRATION

The costs of grid integration are mainly determined by two cost blocks. Firstly there are the costs for the technical equipment and secondly distance dependent costs for the cable routing. While the technical equipment can be seen as a fixed cost block, the routing costs are strongly depending on the local situation and the grid connection point.

All relevant technical equipment for electricity transmission is included in a transfer station. Table 1 lists the single components and the according costs.

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

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

The data is based on EnBW experience in provision of transfer stations. The equipment costs are valid for power plants with 1 MW_{el}. For capacities higher than 1 MW_{el} the transformer system has to be adapted to the higher capacity. While all other components stay the same only the additional costs for an adapted transformer system would have to be respected.

As already mentioned the routing costs can vary in a wide range. They depend on the one hand on the location of the grid connection point and on the other hand on the type of cable routing technique (e.g. over ground; underground). The grid connection point is determined by the network operator. The determination of the exact location has to be done under technical and economical frame conditions. The gird operator has to determine a point in the network respecting technical and security issues as well as the economical optimum. The grid connection causes costs for both, the power plant operator (cable costs, technical equipment …) and the network operator (grid reinforcement). The total costs for the network connection have to be optimized. This could mean that not necessarily the shortest distance between power plant and grid is chosen. Depending on the cable diameter for the power produced in a geothermal power plant routing costs of 100 – 150 €/m can be estimated. As already mentioned a survey under geothermal power plant operators was carried out. The results show that only in few cases the closest network connection point could be used. An optimal solution is normally found during the negotiations between grid operator and power plant owner.

5. CONDITIONS FOR GRID INTEGRATION IN EUROPE

Grid integration of renewable electricity can be divided in three phases (Binda et al., 2012):

- grid connection
  … means the physical connection of a power plant to the electricity grid and the process of implementation
- grid operation
  … means the operation of the electricity grid with a growing share of renewable electricity
- grid development
  … means the adaption of the grid to geographical distribution, distributed generation, volatility and intermittency of renewable power plants

For further information in this topic the authors want to reference to the “report on legal conditions for grid access”, which was prepared within the GEOELEC research project.

The grid connection and the grid integration of renewable energy sources in general is the same for all renewable energy sources (RES) (See chapter 3). The main challenge for the existing grid is the change from an electricity system based on conventional power to the integration of renewable energy. While in the grown structure of the energy system, conventional power plants, industry and settlements have developed dependent on each other, RES are geographical bound to their occurrence. As small scale generation capacities feed their electricity in the low voltage grid. The traditional vertical electricity distribution from extra high to low voltage levels changes. Additionally the variability and intermittency of renewable energy sources like wind and solar power require an inherently difficult prognosis for the feed-in and a complex regulation of the grid to guarantee grid stability and security of supply (Timpe et. al, 2010).

With directive 2009/28/EC and the third European energy package the European legislation has created the basis for the liberalization of the grid based energy markets and the further growth of renewable electricity in Europe. The most important point for the grid integration of renewable electricity was Article 16.2 of directive 2009/28/EC, where a prioritized or guaranteed access to the grid for renewable energy sources is anchored (Lehnert, Vollprecht, 2009).

The grid connection poses the strongest barriers for the grid integration of RES. Within the whole grid integration the grid connection is the first contact point between the different stakeholders. Additionally the grid connection is a cost intensive process, which leads to tension between the stakeholders (Binda et. al, 2012). The overall situation in Europe for grid connection of RES is rather difficult. Only two countries offer favorable conditions. Figure 7 gives an overview of the situation in Europe. A good overall situation doesn't exclude single barriers within the process of grid connection. While Denmark, and Germany offer favorable conditions, the remaining countries of Western Europe have neutral conditions, whereas in Eastern Europe strong barriers exist.

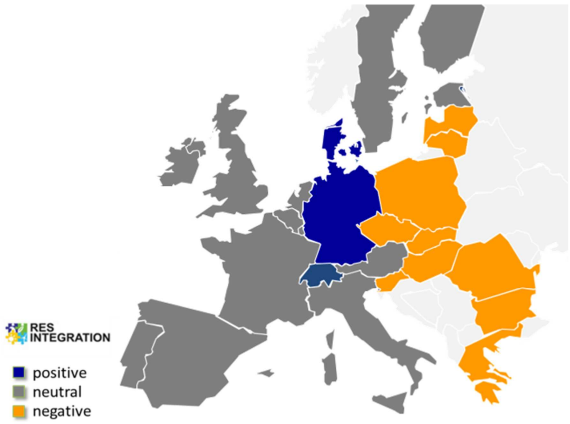

Figure 7: Assessment of connection Process in European member states (Binda, et al., 2012)

In each European country barriers for grid connection exist. Between the different countries similar barriers were identified. The most frequent barrier (17 countries) is the lack of grid capacity often linked with a different pace of grid and RES electricity development. In such a case the connection of RES capacity is not possible because of insufficient grid infrastructure. This situation requires a reinforcement of the existing grid. Another major barrier is a long lead time or an inefficient process (16 countries). The reasons for this barrier are complex. Inefficient, slow or non-uniform processes can delay the grid connection (Binda et. al, 2012).

6. CONCLUSION

The European energy system faces a fundamental transformation from conventional to renewable based electricity generation. In the course of this process the grid infrastructure has to be adapted to the changing situation. Alone on the European transmission level 52,300 km of lines have to be constructed or refurbished. This lead to € 104 billion cost during the next decade. Additionally the lower voltage levels also need to be adapted. A case study for the situation in Germany shows that geothermal power could have a positive impact on adaption needs of the electricity grid. The existing technical potential is sufficient to cause a serious impact. Furthermore geothermal power has through its controllable character and its high capacity factor the ability to improve the security of supply and grid stability. The process of grid connection is determined through cooperation between grid operator and power plant owner. In general the process itself is the same for all RES. Although European legislation has made a guaranteed or prioritized grid access of RES mandatory, the situation in Europe is still difficult. Only two countries offer favourable conditions for grid connection. The cost for grid connection strongly depends on the routing cost. While the cost for the technical equipment can be determined precisely, the costs for the cable routing depend on the one hand on the network connection point and on the other hand on local conditions of the routing.

REFERENCES

Agentur für Erneuerbare Energien, föderal erneuerbar: Bundesländer mit neuer Energie. Retrieved 03 10, 2012, from http://www.foederal-erneuerbar.de/landesinfo/kategorie/strom/bundeslannd//bundesland/D, (2012)

BDEW, Technische Richtlinie - Erzeugungsanlagen am Mittelspannungsnetz: Richtlinie zum Anschluss und Parallelbetrieb von Erzeugungsanlagen am Mittelspannungsnetz. Germany, BDEW, Berlin, (2008)

Binda, E., Brückmann, R., Bauknecht, D., Jirouš, F., Piria, R., Trennepohl, N., et al, Integration of electricity from renewables to the electricity grid and to the electricity market - RES integration, DG Energy, Berlin, (2012)

BMU, Erneuerbare Energien in Zahlen – Nationale und Internationale Entwicklungen, BMU, Berlin, (2012)

dena, Analyse der Notwendigkeit des Ausbaus von Pumpspeicherwerken und anderen Stromspeichern zur Integration Erneuerbarer Energien, dena, Berlin, (2010a)

dena, Netzstudie II, dena, Berlin, (2010b)

dena, Ausbau- und Innovationsbedarf der Stromverteilnetze in Deutschland bis 2030, dena, Berlin, (2012)

EC, Directive 2009/28/EC, European Parliament and the Council of the European Union, Brussels, (2009)

EGEC, EGEC – Geothermal market report 2012, EGEC, Brussels, (2012)

ENTSO-E, Statistical Yearbook 2011, ENTSO-E, Brussels, (2012a)

ENTSO-E, 10-Year network development plan 2012, ENTSO-E, Brussels, (2012b)

Eurelectric, Power Statistics & Trends 2011, Retrieved 03 12, 2012, from http://www.eurelectric.org/PowerStats2011/Map.asp, (2012) IWR, Entwicklung des Gesamt-Stromverbrauchs in den Ländern. Retrieved 03 10, 2012, from http://www.iwr.de/re/eu/energie/str_bl.html, (2012)^

Konstantin, Praxisbuch Energiewirtschaft, Springer Verlag, Burgstetten, (2007)

Lehnert, W., & Vollprecht, J, Neue Impulse von Europa: Die Erneuerbare-Energien-Richtlinie der EU, Zeitschrift für Umweltrecht, Baden-Baden, (2009), pp. 307 – 317f

Paschen, H., Oertel, D., & Grünwald, R., Möglichkeiten geothermischer Stromerzeugung in Deutschland – Arbeitsbericht Nr. 84, TAB Büro für Technikfolgen-Abschätzung beim Deutschen Bundestag, Berlin, (2003)

Timpe, C., Bauknecht, D., Koch, M., & Lynch, C., Integration of electricity from renewable energy sources into European electricity grids, Bithoven, The European Topic Centre on Air and Climate Change, (2010)

VDN, Technische Richtlinie - Transformatorstationen am Mittelspannungsnetz: Bau und Betrieb von Übergabestationen zur Versorgung von Kunden aus dem Mittelspannungsnetz, Berlin, VDN, (2003)