GENI Global Energy Network Institute

Is 100% Renewable Energy possible for Germany by 2020?

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Introduction

This report focuses on how and whether it is possible for Germany to have all of its electricity generated by renewable energy resources within the next ten years. It is fairly obvious that if possible, the chances of fruition are extremely low. Nevertheless is it extremely important to show decision makers and leaders the high potential, technology and possibility of green energy in Germany.

Germany is like many other OECD countries which are highly dependent on fossil fuels, especially fossil fuels. Germany's fossil fuel deposits are very minor. Only 20.9 million tons[1] of petroleum oil are available for production. The lack of resources has created a high dependency on oil producing countries in the Middle East and Russia. Prices are rising every year and political conflicts have caused shortcuts several times in the past. Incidents and rising prices will continue.

For many decades, nuclear power plants were considered a safe and eco-friendly alternative to burning fossil fuels. The Fukushima nuclear disaster in 2011 has proven the advocates of nuclear power wrong. The dangers of this technology are simply too high and the waste problem has never been resolved. This catastrophe has led German politicians to pass a law that all remaining nuclear power plants have to be shut down by 2022. Consequently, nuclear power will not be taken into consideration in this report.

Detractors of renewables often state that by shutting down coal and nuclear power plants, etc. many will lose their jobs and create high economic losses. Many studies have proven them wrong. In 2011 Germany is already one of the world leaders in wind, solar and bioenergy and by the year 2020 there will be estimated investments of over €200 billion into the renewable sector and 500,000 jobs could be created by 2020 (More about the job market in the following).

So Germany has the potential and the need of becoming a leading market for resource-efficiency and green energies. The first step has been taken by phasing out its nuclear power plants. The clean energy technologies are ready and the urgency can be felt in everybody's consciousness.

[1] http://www.erdoel-erdgas.de/Reserven-175-1-69b.html

1. Germany's current situation – energy supply and consumption

Germany is amongst world leaders when it comes to renewable energies. But what is the current share of renewables in the energy generation mix? The following graphic shows that renewables already produce 16.3% of all electricity generated in 2009 where wind power has the biggest share with 6.6%. (38.6 bn. kWh)
Lignite, coal and nuclear power still produce about two-thirds (64.8%) of all electricity.

Based on official guidelines through the European Union the current German government has to increase the renewable percentage up to minimum 18% by 2020.[2] Due to the high rate of the actual development this goal will be reached and exceeded easily.

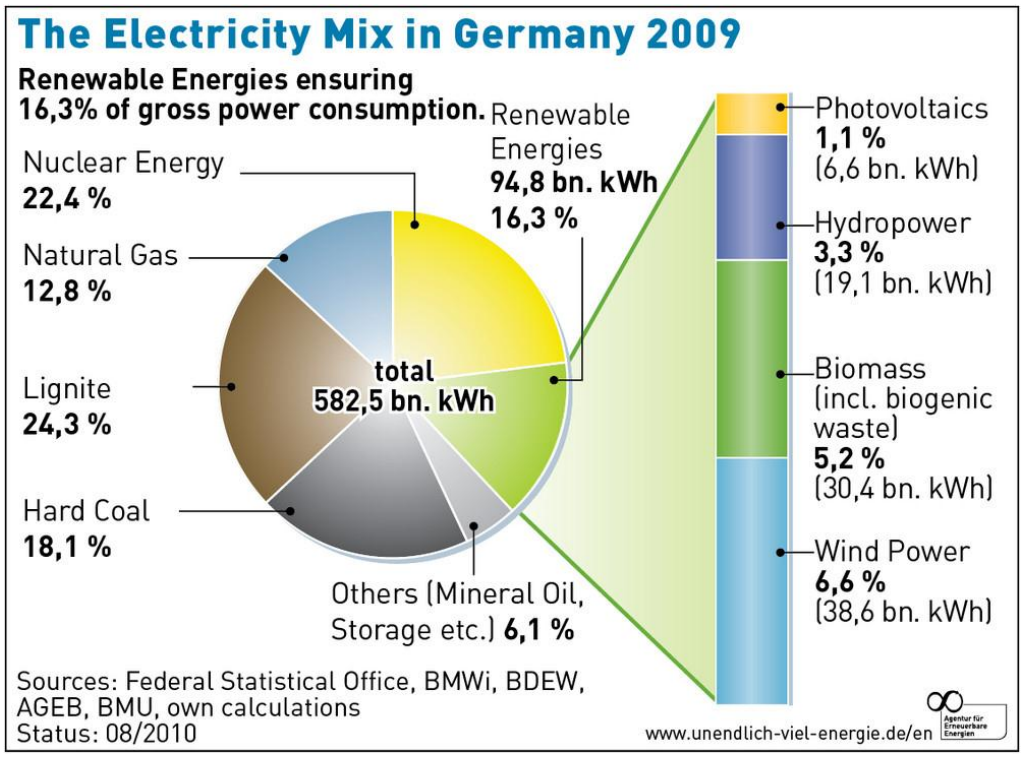

Figure 1 The electricity mix in Germany

The government has also committed to have all public buildings to become role models in energy efficiency. This will cost approximately €176 million (US $250 million) per annum. On the other hand €12 million will be saved per year.[3] This shows a serious commitment to decrease greenhouse gases to maintain Germany´s leading position in the renewables sector.

[2] http://www.bundestag.de/presse/hib/2010_11/2010_375/03.html
[3] http://dip21.bundestag.de/dip21/btd/17/036/1703629.pdf

1.1 Current CO_2 emissions and consumption

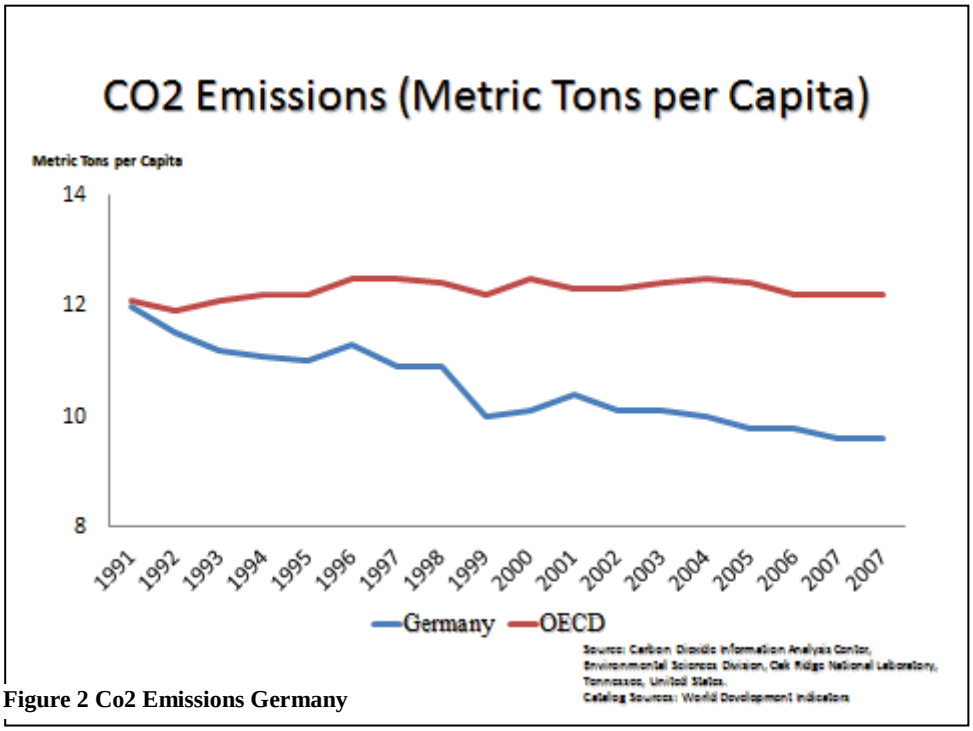

Figure 2 Co2 Emissions Germany

In the past seventeen years Germany has reduced its CO_2 emissions by approximately 22.2%. Bringing its total emissions today around 9.5 metric tons per capita. Since 1990, the production of greenhouse gases has been reduced by 220 million tons. With those numbers Germany has actually achieved its climate goals set 1997 in Kyoto (The goal was 21% by 2012) -- four years earlier than expected.[4]
Its enormous efforts in supporting the renewable energies will continue the downward reduction of carbon dioxide emissions.

Different Power Plants and their CO_2 Balance

Figure 3 shows a table with different power plants and their CO_2 emissions per kWh. Even renewable technologies have a CO_2 output. When they are produced or the raw materials are mined, carbon dioxide is released into the atmosphere. Lignite power plants have the worst CO_2 balance with 1153g per kWh. Biogas-block heat and power plants can actually reduce carbon emissions. Technically, biogas-block heat and power plants can actually reduce carbon emissions, because plants, used in biogas production, absorb more CO_2 than released during burning of biogas. A positive carbon dioxide balance is the result.

[4] http://www.spiegel.de/wissenschaft/natur/0,1518,675314,00.html

Plant type CO2-emissions	CO2-Emission
Biogas-block heat and power plant	- 409 g per kWh
Renewables	
Wind energy off-shore	23 g per kWh
Wind energy on-shore	24 g per kWh
Solarpower imported from Spanien	27 g per kWh
Nuclear power plant	32 g per kWh
Hydro-electric power plant	40 g per kWh
Multicrystalline solar cell	101 g per kWh
Natural gas	
Natural gas-combined-cycle plant-heating plant	148 g per kWh
Natural gas-combined-cycle plant-power plant	428 g per kWh
Coals	
Hard Coal-heating power plant	622 g per kWh
Lignite-heating plant	729 g per kWh
Bituminous coal-power plant	949 g per kWh
Lignite-powerplant	1153 g per kWh

Figure 3 Different power plant types and their Co2 emissions
Source: http://www.co2-emissionen-vergleichen.de/Stromerzeugung/CO2-Vergleich-Stromerzeugung.html

Since 1990 energy consumption grew rather continuously. In 2009 electricity usage dropped by 6% (618.1 to 578.9 TWh). The reason for this was the financial crisis that led to short time work, factory shut-downs and extended vacation closedowns.

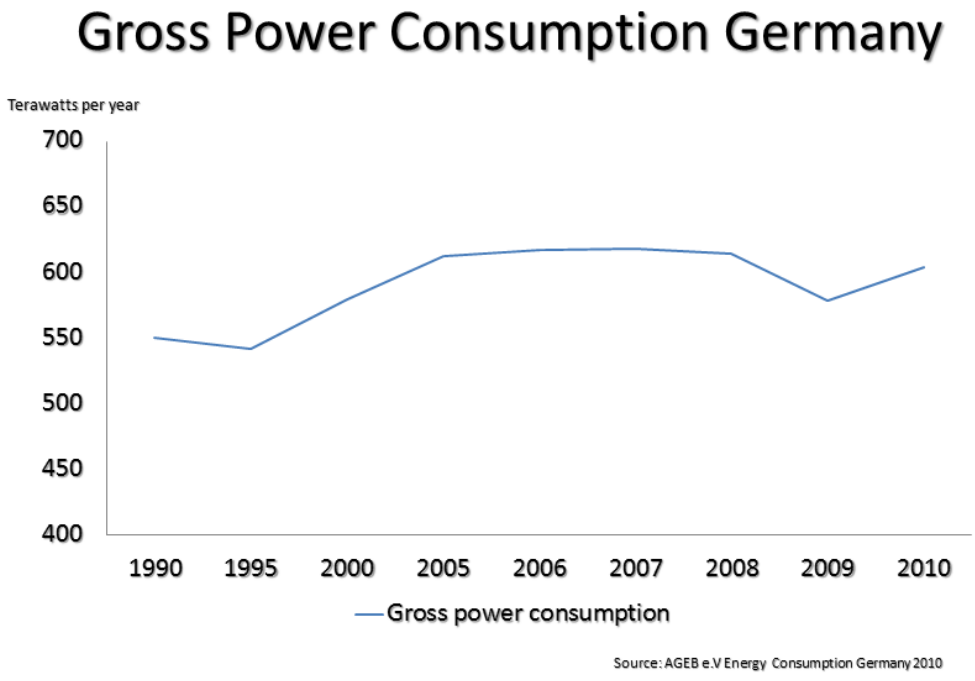

Figure 4 Gross Power consumption Germany

2. Job creation

A key question is "how many jobs will be created through renewable energies in the future?" According to a study by the German "Agency for Renewable Energies" currently 367,400 people are working in the renewable sector. This number is supposed to expand to about 500,000 in 2020[5]. This number is calculated by taking the current growth rate into consideration. This is happening at a time where most industry sectors would rather decrease their number of employees as opposed to creating new jobs.

According to the German Federal Labor Market Authority (Bundesagentur für Arbeit) as the main authority for labor statistics and data, there is no data available on how many people are working in fossil fuel power plants. It is rather crucial to collect those numbers in order to compare the labor intensity of both sectors. (for another researcher to compare).

As the graphic below shows, in 2009, 300,500 jobs were created in the renewable sector. Industry projections assume that up to 500,000 jobs could be created by 2020.[6] This number is calculated by taking the current growth rate into consideration.

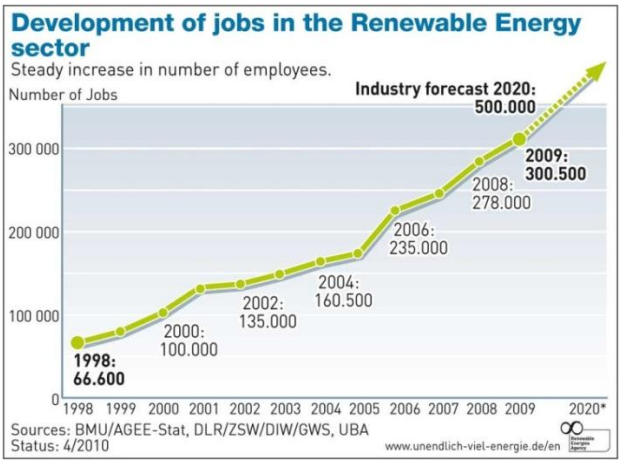

Figure 5 Development of jobs in the renewable energy sector

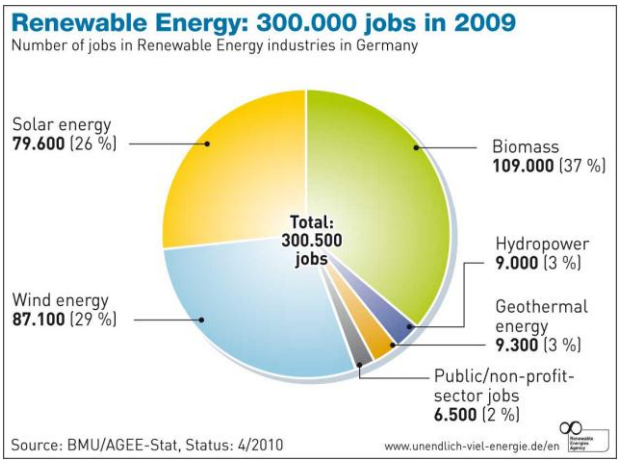

Figure 6 Renewable Energy: 300.000 jobs in 2009

An analysis of thirteen independent reports and studies of the clean energy industry commissioned by University of California Berkley found out that renewable technologies create a higher number of jobs per average megawatt of power generated, per dollar invested in manufacturing, construction and installation when compared to coal or natural gas.[7] Over the course of a 10-year period the solar industry creates 5.65 jobs per million dollars in investment,

[5] http://www.unendlich-viel-energie.de/de/wirtschaft/detailansicht/article/198/steigende-arbeitsplaetze-bei-den-erneuerbaren-energien.html
[6] http://www.unendlich-viel-energie.de/en/economy/details/article/16/renewable-energy-300000-jobs-in-2009.html
[7] http://rael.berkeley.edu/sites/default/files/very-old-site/renewables.jobs.2006.pdf

the wind energy industry 5.7 jobs, and the coal industry only 3.96.[8] In the case of coal mining, wind and solar energy generate 40 percent more jobs per dollar invested.[9]

It has to be said that those numbers were calculated in and for the United States and might not be completely accurate for Germany but an obvious trend arises. A more detailed analysis of the job situation and development in certain renewable sectors follows in the Chapter 3.

[8] http://blog.greenpointpartners.com/real-estate/solar%E2%80%99s-push-to-reach-the-mainstream/

[9] Virinder Singh, BBC Research and Consulting, and Jeffrey Fehrs, "The Work That Goes into Renewable Energy," Renewable Energy Policy Project, November 2001, 8.

3. The Electrical Grid in Germany

The German electrical grid is about 1.74 Million kilometers[10] long which is about 4 ½ times the distance of the earth to the moon. There are four voltage levels: Extra High, High, Distribution and Low. It is operated and divided by four transmission network operators.

Below is a basic and simplified outline on how the grid system works in Germany. Nuclear and coal power plants are still the main producers of electricity. There are four major grid systems outlined which are connected.

Figure 7 The electric grid system in Germany

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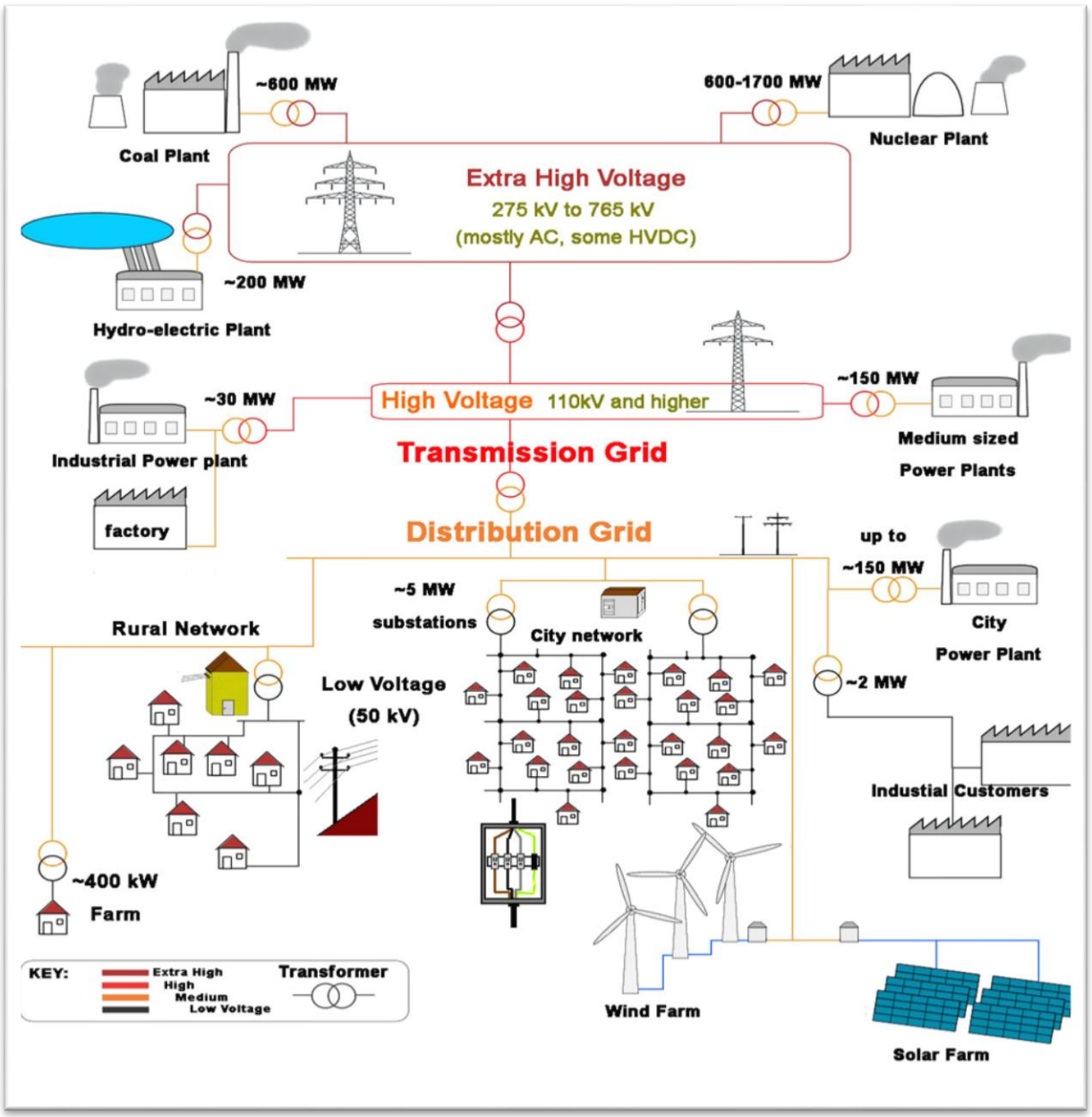


[10] http://www.verivox.de/ratgeber/die-stromnetze-in-deutschland-25551.aspx

- Extra High Voltage – The main transmission grid is a long-distance line that passes electricity from power plants and wind parks into the grid. The electricity is transmitted state- and nationwide and also within Europe. Most of the electricity exchange is done with France.

- High Voltage Grid – Is a transmission network. Regional transmission is its main task. Lines carry electricity into different regions, congested areas or big industrial centers.

- Distribution Grid – Distributes the electricity to the local transformer stations of the low voltage network to institutional users like schools, public authorities or factories. Municipal Utilities, which quite often run power plants or operate cogeneration feed power into this system.

- Low Voltage Grid – Low Voltage Grids are responsible for local delivery. Electricity from the distribution grid in Europe is usually transformed into the usual 400V or 230V and then delivered to private households, smaller industrial establishments, businesses and municipal administrations. This grid is often referred as the "last mile"

On the right side of the page is a map of Germany with the four transmission network operators. Those are service companies and they are responsible for maintaining grid reliability, prevent instabilities and to provide voltage control.

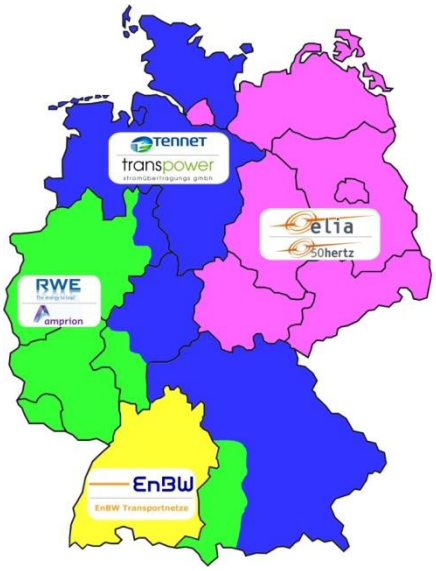


Figure 8 Transmission network operators
Source:http://de.wikipedia.org/w/index.php?title=DateiRegelzonen_deutscher_%C3%9Cbertragungsnetz betreiber _neu.png&filetimestamp=20110904132018

COSTS AND MATERIALS

The Deutsche Energie-Agentur GmbH (Dena) - the German Energy Agency – "is developing energy efficiency and renewable energy markets in cooperation with stakeholders from the worlds of politics and business and from society at large."[11] They developed a scenario with 40% electricity generated by renewables, mainly wind usage. Dena experts stated that about 3600km of additional high voltage lines

[11] http://www.dena.de/en/services/about-dena/

would be necessary. Also about 3100km of existing lines are supposed to be modified. The costs for expanding and modifying the grid are about 9.7 billion euros.[12] Since those numbers are only calculated for a 40% scenario the amount of commitment and the costs would be much higher in the 100% scenario due to increased material input, faster installation time frames and complicated application processes.

Cross Country Exchange

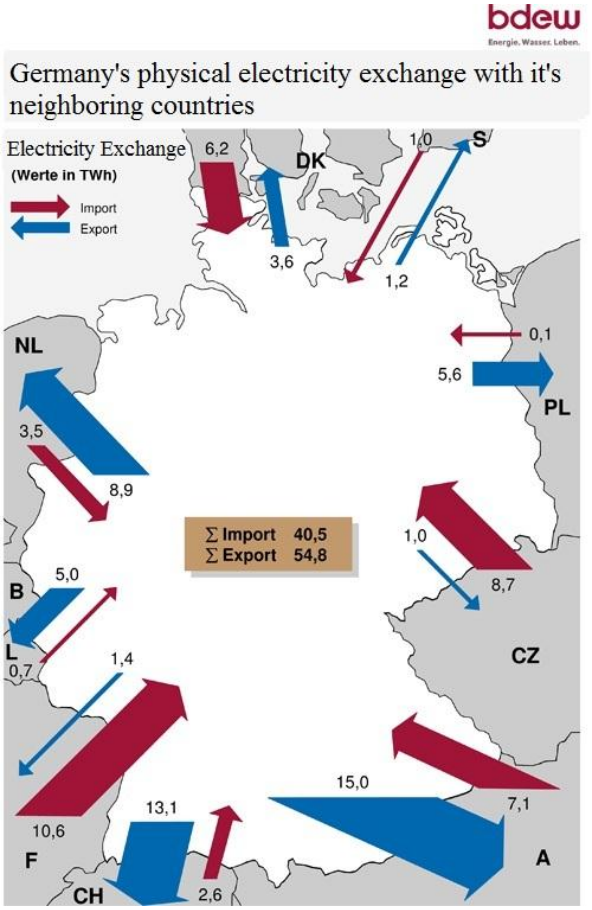


Figure 9 Germany electricity exchange
Source: http://www.kernfragen.de/kernfragen/img/Gesellschaft/ges0104a_stromaustausch09.gif

There already is a robust exchange of electricity with Germany's neighbor countries. It is a fact that for a 100% renewable solution Germany can't be an island in the middle of Europe. Especially renewable technologies require a higher amount of flexibility of supply to cover fluctuations in e.g. wind or sun availability. This has to be achieved by closely working together with the adjacent countries and system operators.

Certainly these nations would have to expand their amount of sustainable generated electricity. France for example gets about 80%[13] of its electricity from nuclear reactors. Also the country has one of the highest numbers in dangerous nuclear incidents every year.

In order to solve certain energy storage issues Germany would have to work closely with Denmark and Sweden. Off-shore electricity could be transferred over HVDC lines under the northern sea and stored in their multiple pumped hydro storage power plants. The geographical conditions are superb compared to Germany's flat land in the North. The same example can be made in the South. Switzerland has high hydro-power and storage potential, while Germany has more annual hours of sunshine. (About 1250kWh/m^2 per year)[14] So German solar PV generated electricity could be stored in Swiss hydropower dams for use the next day.

[12] http://www.dena.de/fileadmin/user_upload/Download/Dokumente/Studien___Umfragen/Summary_dena_Grid_Study_II_2.pdf
[13] http://de.statista.com/statistik/daten/studie/12914/umfrage/anteil-der-atomenergie-am-stromverbrauch-in-ausgewaehlten-laendern/
[14] http://photovoltaik.tumblr.com/post/670536241/sonnenstunden

FUTURE OUTLOOK

There have been a lot of discussions in politics and the media about the future of the German electrical grid. The problem was that the four major companies did not use their earnings to maintain and even more importantly to modernize and expand the grid. Some politicians advocate now to nationalize the grid to guarantee a grid that can cope with the needs of the future. A definite plan of the current government is to make the application process simpler and more consistent in every state.

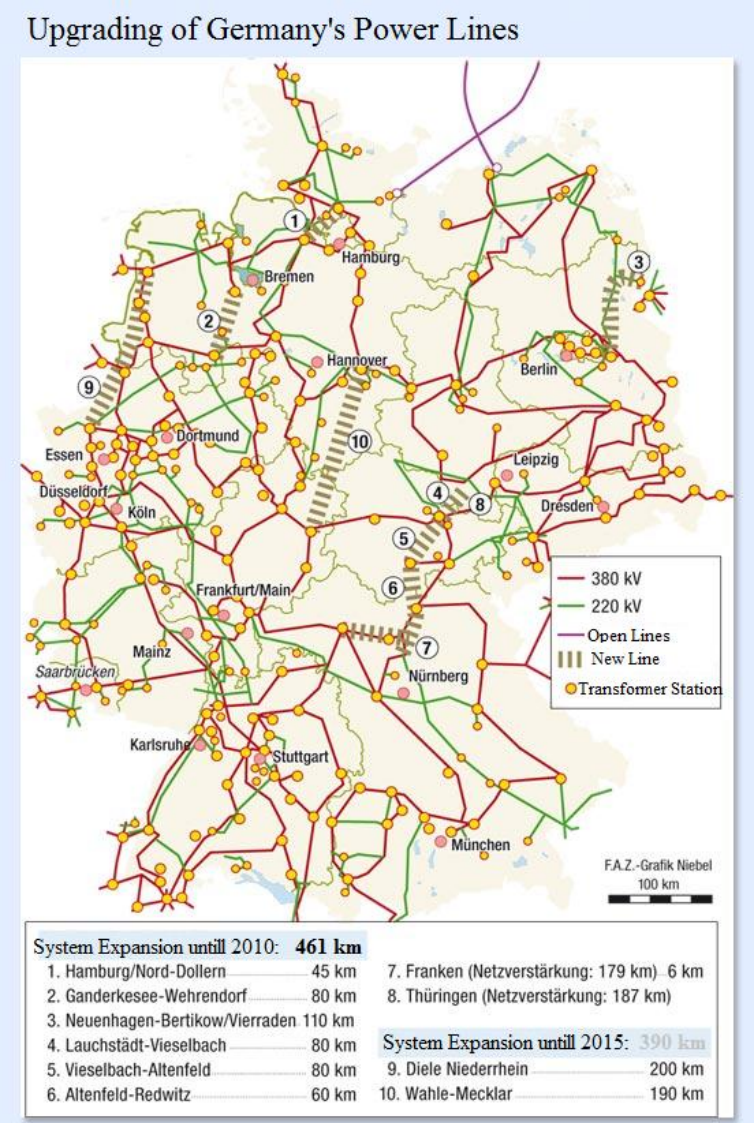


Figure 10 Planed expanison of the German electricity grid. 2007
Source: http://www.fazfinance.net/Aktuell/Wirtschaft-und-Konjunktur/Glos-will-Ausbau-des-Stromnetzes-beschleunigen-3780.html

The problem that the grid in Germany faces is the location of high capacity coal and nuclear power plants. They are in close distance to highly populated areas which are located in the middle and the south of the country, so electricity does not have to be transported over long distances.[15] Wind parks and biogas plants will replace high capacity coal and nuclear plants but that will mean a shift of electricity generation to the north. (More detailed descriptions about locations are to be found in the "potential section" of this report.)

High voltage direct current (HVDC) gridlines are needed, transporting electricity from low populated north Germany to the south. At present, the grid would work as a "bottleneck" in a 100% renewable scenario. This problem would be happening at a smaller scale in local areas, because the grid is not constructed for a steady mix between hydro, wind or solar power.

[15] http://www.verivox.de/nachrichten/regierung-legt-eckpunkte-fuer-stromnetzausbau-vor-71853.aspx?p=2

4. Five Different Plans for 100% Renewable Electricity Germany

One of the major issues in bringing Germany to 100% renewables is whether the renewable potential even exists. This question can be answered with great certainty – Yes, the potential is given. This report will take five 100% Renewable by 2050 plans into consideration and how those plans are feasible for a 2020 approach.

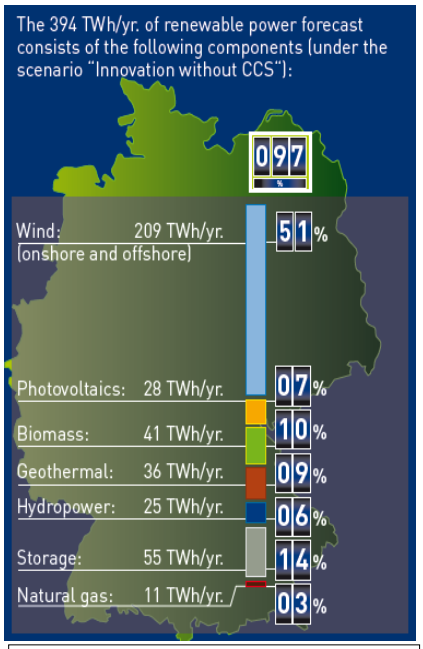


Figure 11 Energy Concept 2050: The FVEE feasibility study

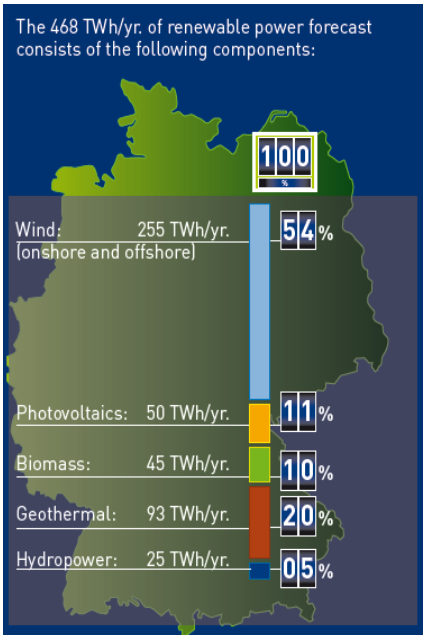


Figure 12 Climate-friendly, safe, affordable: The SRU's cost study

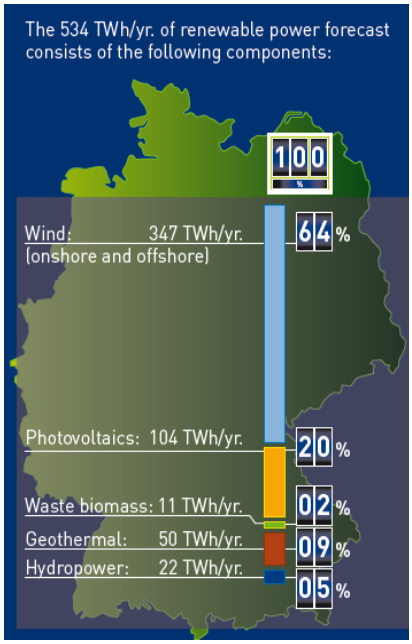


Figure 13 Energy Goal 2050: The power load study of the Federal Environment Agency

The five figures show, how experts estimate Germany's energy mix in the future. Even if those numbers are for 2050, the mix will be the same. As shown in all figures, wind power will provide over 50% of Germany's electricity. Another important number will be the total annual renewable electricity supply. This number varies a lot within all five reports from 394 TWh/yr to 766 TWh/yr.

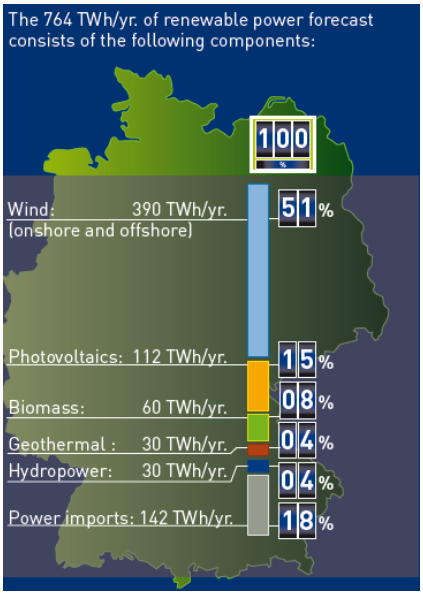


Figure 14 Energy Concept 2050:

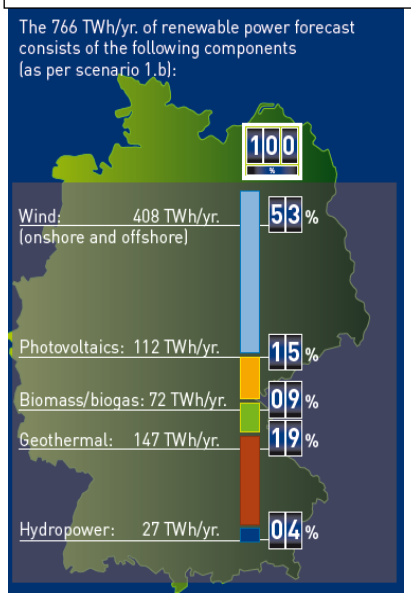


Figure 15 Climate-friendly, safe, affordable: The SRU's cost study

Source for all figures on this page: http://www.unendlich-viel-energie.de/uploads/media/AEE_Flyer_100_02.pdf

5. Renewable Technologies and their Potential

5.1 Wind Power

Wind power is the crucial renewable electricity sources today and in the future. Five different 100% renewable plans for Germany have made wind their most important technology. (A share of over 50%)

Figure16 Installed Capacity 2008
Source: http://www.unendlich-viel-energie.de/de/wirtschaft/detailansicht/article/432/sicher-sauber-schlauer-die-stromversorgung-der-zukunft.html

Wind turbines use the wind's kinetic energy. Air-Pressure differences near the earth's surface are the cause for this. In Germany the only purpose for wind turbines is the electricity generation. Modern wind plants only use the "Buoyancy Principle" instead of the principle of resistance. As the wind flows by, they do not set resistance towards the wind, but the wind creates buoyancy on the rotor blades and that makes them turn.[16]

In 1990, Germany produced 948 million tons of CO_2 emissions, whereas in 2009 only 774 million tons were produced. In 2009 wind-generated-electricity saved about 30 million tons of CO_2.[17] If wind power would be responsible for 50% of all electricity generated, about 40% of carbon dioxide emissions could be reduced. That shows the immense relevance of wind turbines when it comes to reaching climate goals and slow global warming.

[16] http://www.neurohr-info.de/html/auftriebsprinzip.html
[17] http://www.erneuerbare-energien.de/inhalt/4642/

As you can see in figure 12 on the left side most installed capacity is in the north and fewer in the south. In order to reach a share of 50% wind energy in all areas, wind power has to be expanded. Over the past couple of years, continuous development has made wind electricity the most efficient and cost effective of all renewables. Currently Germany is number three worldwide in installed total capacity (40,180 MW) and is promising to maintain its position. Germany is also number two in capacity/land area ratio. This means that Germany is using its given space very efficiently. It also means that a lot of qualified and potential areas are already equipped or under development. That said, older German wind parks will have to be upgraded with new wind turbines which are utility scale and have a higher power output.

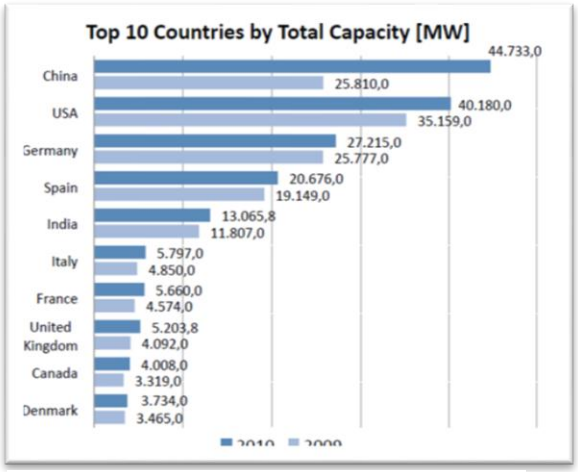


Figure 17 Top 10 Wind Countries
Source: http://www.wwindea.org/home/images/stories/pdfs/worldwindenergyreport2010_s.pdf

REPOWERING

Repowering has many advantages such as increased efficiency due to raised energy output with fewer wind turbines. Also the landscape is preserved, which reduces the negative environmental influences like noise and shadow impact. (Better locations and plant characteristics) In 1990, most turbines completed about 40-60 rotations per minute whereas now the number has gone down to 10-20 rounds per minute.[18] This leads to less noise pollution.

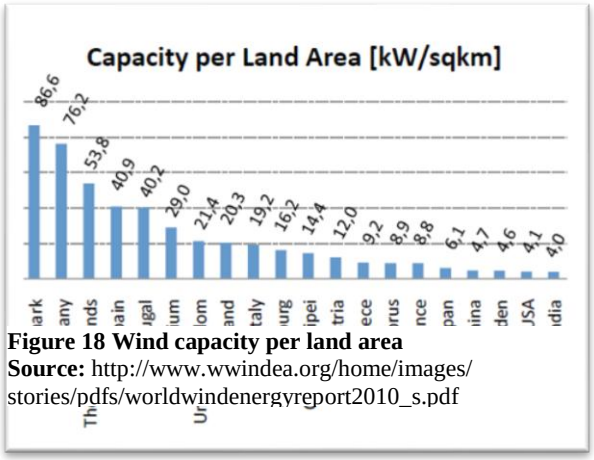


Figure 18 Wind capacity per land area
Source: http://www.wwindea.org/home/images/stories/pdfs/worldwindenergyreport2010_s.pdf

One of the biggest operators of wind parks are cities and local authorities. That is why the federal government established a project with guidelines to advance repowering. This outline gives information with the help of models and examples of how repowering is done in a fast and cost effective way. So far it has been a great success.

Certain laws in some states provide obstacles for repowering. It is mostly hub height limits that prevent some of the newly developed turbines from being installed. Thus, much good potential remains unused. In the state of North Rhine-Westphalia (NRW) for instance, hub height is limited to overall 100m. (2009)[19] 2700 plants (with overall 2700MW) produced 4.6 billion kWh in 2008. If only all 1MW turbines could be replaced with modern 2MW turbines with 150m hub

[18] http://www.wind-energie.de/politik/repowering
[19] http://www.unendlich-viel-energie.de/de/wirtschaft/detailansicht/article/432/sicher-sauber-schlauer-die-stromversorgung-der-zukunft.html

height, then it could produce about 10.2 billion kWh. The output would be more than doubled with fewer turbines. Without the hub height limit, NRW could be number two in wind power electricity output in Germany.

Figure 19 shows a great example for repowering. In the state of Schleswig Holstein a wind park with 13 turbines (43m hub height) and an output of 5.5MW was repowered to only 5 turbines. (120m hub height) The electricity output was tripled to about 15MW.

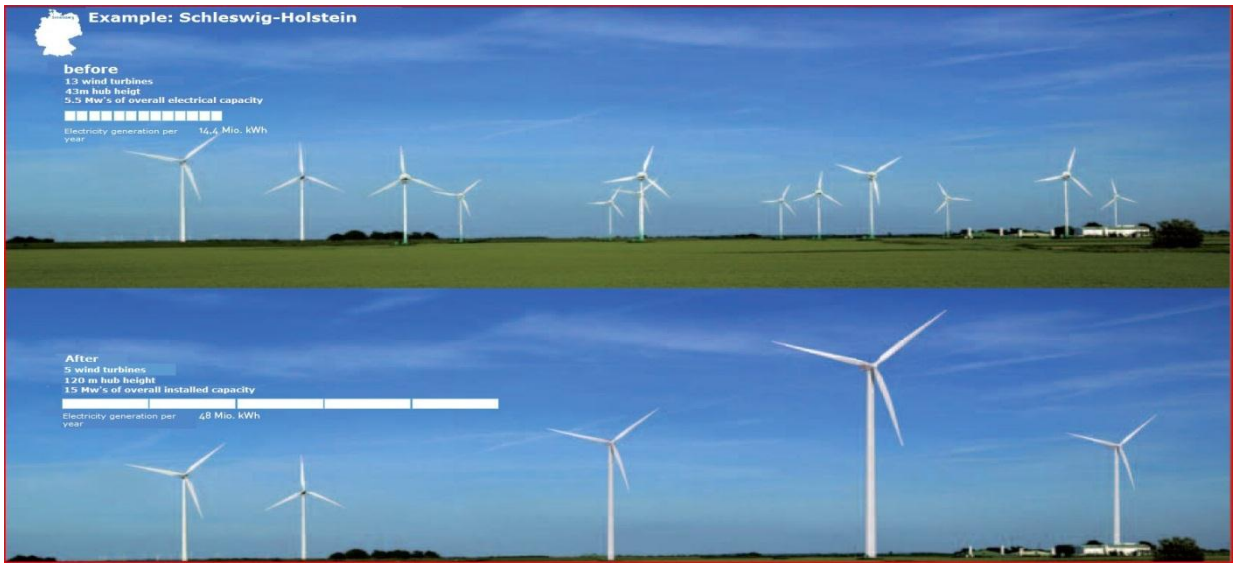
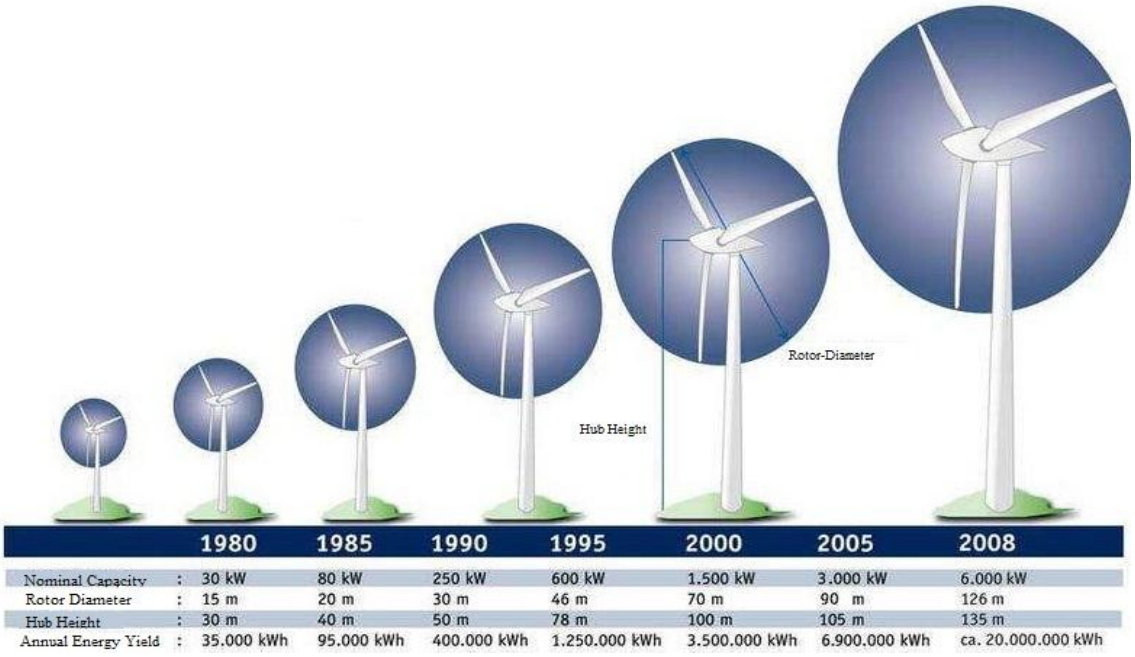


Figure 19 Repowering example Source: http://www.unendlich-viel-energie.de/de/wirtschaft/potenziale.html



	1980	1985	1990	1995	2000	2005	2008
Nominal Capacity :	30 kW	80 kW	250 kW	600 kW	1.500 kW	3.000 kW	6.000 kW
Rotor Diameter :	15 m	20 m	30 m	46 m	70 m	90 m	126 m
Hub Height :	30 m	40 m	50 m	78 m	100 m	105 m	135 m
Annual Energy Yield :	35.000 kWh	95.000 kWh	400.000 kWh	1.250.000 kWh	3.500.000 kWh	6.900.000 kWh	ca. 20.000.000 kWh

Figure 20 Expanding size of wind turbines
Source: http://www.wind-energie.de/infocenter/technik

Figure 20 shows how the size of wind turbines has increased over the past 28 years. Not only has the size increased but the nominal capacity also increased by the factor of 200! Nowadays the average rotor diameter is about 90m; nominal capacity is 2.5MW to 5MW and the hub height, depending on the location between 80 and 130 meters.

OFF-SHORE WIND POWER

Germany has just begun its off-shore development. There is a great potential at the Northwestern and Northeastern coasts of the country, which only needs to be harnessed.

The first off-shore wind park in Germany was finished and opened in August 2010.[20] It is called Alpha Ventus, has twelve 5MW wind turbines and can supply a city with 50,000 households'.[21]. The turbines need a minimum wind speed of 3m/s. The park was constituted as a test plant. The entire park has state of the art technology. For instance, the cables that transmit the electricity are all HVDC. Germany is a leader in modern 5MW off shore wind turbines which offers good future prospects for exports. Also about €100 billion investments and about 30,000 new jobs are predicted by the Federal Ministry for the Environment[22]

Currently there are 27 off-shore wind parks approved by the government with an overall electricity output of 8.7 GW[23]. Three of them are in the Northeastern Sea (Ostsee). Some are already under construction others still in the planning phase. All off shore wind parks have to be twelve nautical miles off the coast. Nevertheless most of them will be about 30 miles of the coast. Off shore wind parks are also a new growing industrial sector. About 14 harbors[24] are preparing for production, transport and maintenance.

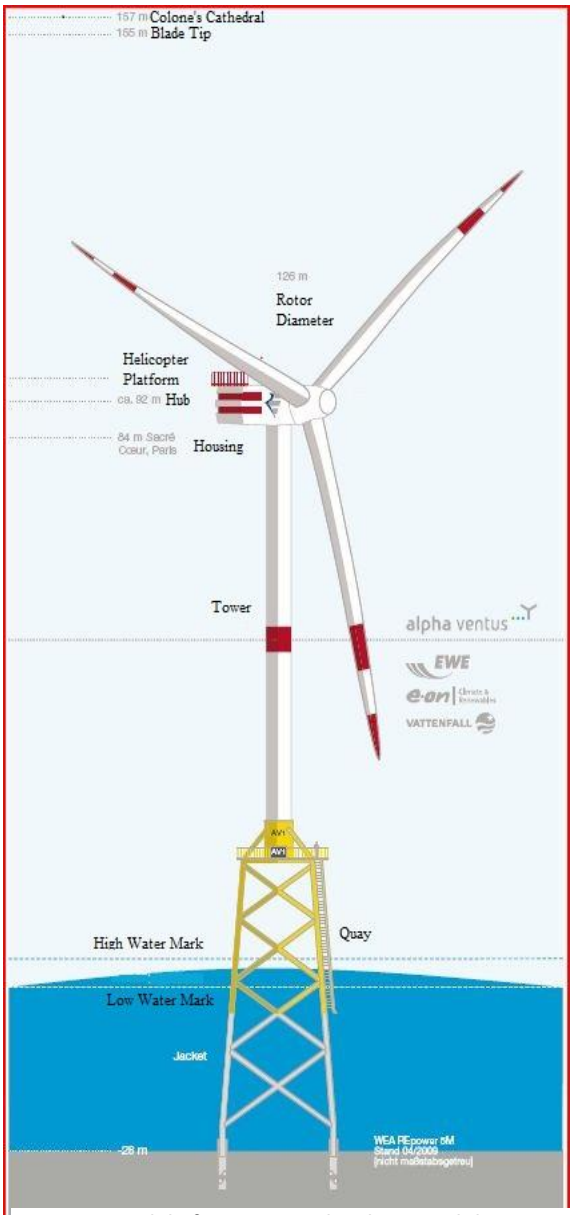


Figure 21 Model of a 5MW wind turbine at Alpha
Source: Ventushttp://www.alpha-ventus.de/fileadmin/user_upload/Broschuere/av_Broschuere_deutsch_web_bmu.pdf

[20] http://www.alpha-ventus.de/index.php?id=24
[21] http://www.erneuerbare-energien.de/inhalt/45213/20214/
[22] http://www.erneuerbare-energien.de/inhalt/45213/20214/
[23] http://www.iwr.de/wind/offshore/nat_plan.html
[24] http://www.wind-energie.de/politik/offshore

Also training facilities for service, assembling and maintenance personal are under development. Off shore wind parks are becoming a leading industry in northern parts of Germany. This can be shown in one example. The shipyard Emden had to close in 2010 due to its unprofitability. Many workers were about to be laid off when a new Company called Siag Off Shore took over the plant, kept all workers and actually hired extra labor.[25] Examples like this are found in many places that show the importance of wind energy for coastal regions.

The table below shows Germany's offshore capacity and how much the capacity grew. In 2008 the capacity was estimated to be about 12 MW. In 2009, 72MW and in 2010 it was 108 MW. Due to further development of viable areas the capacity grew to over 50%, showing the potential of offshore wind.

	Total Offshore Capacity 2010[MW]	Added Offshore Capacity 2010[MW]	Rate of Growth 2010[%]	Total Offshore Capacity 2009[MW]	Total Offshore Capacity 2008[MW]
Germany	108,3	36,3	50,4	72	12

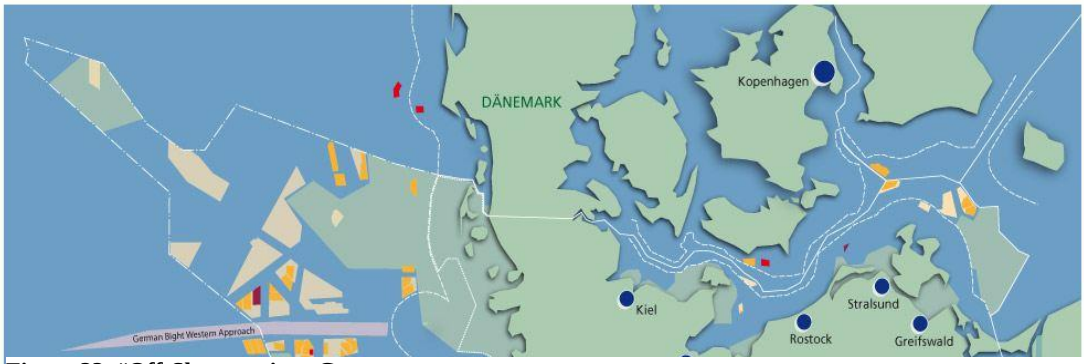


Figure 22 #Off-Shore regions Germany
Source(Table): http://www.offshore-stiftung.com/Offshore/aktuelles/-/51,51,60005,liste9.html
Source(Picture) http://www.southbaltic-offshore.eu/regions-germany.html

[25] http://www.faz.net/artikel/C31151/werften-ende-des-schiffbaus-in-emden-30074975.html

5.2 Solar Power in Germany

The sun is an energy source with the largest energy potential. Every year it generates over 219,000 trillion kWh for free. This is 3,000 times more than all mankind consumes.[26] Germany's average solar irradiation is somewhere between 975 and 1200 kWh/m², which is less than many southern European countries or North Africa (cf. 2200 kWh/m²[27]).

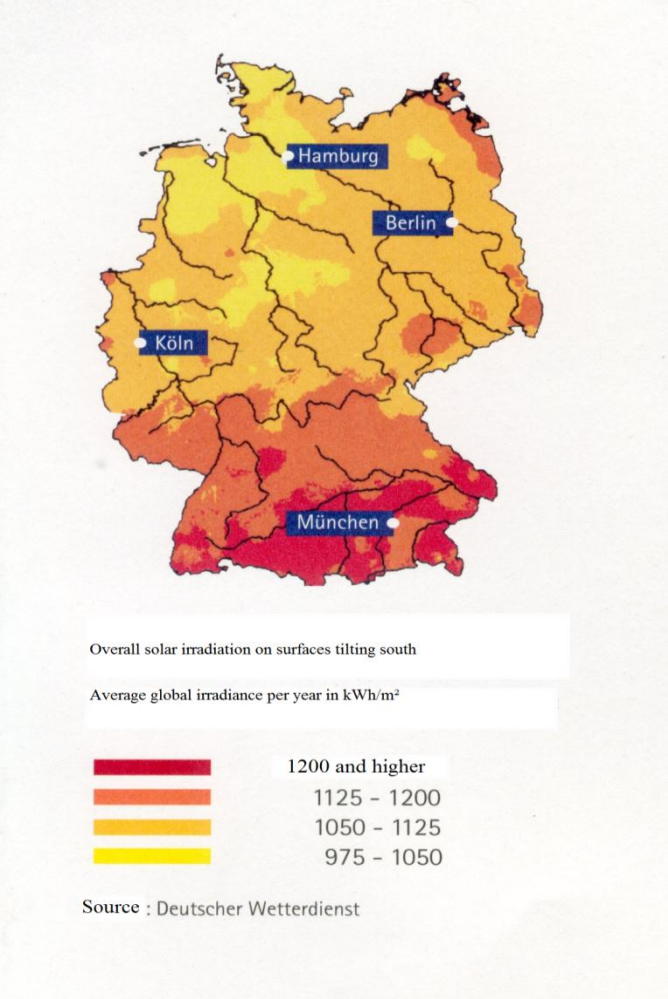


Figure 23 Solar irradiation Germany
Source: Deutscher Wetterdienst

This report will not take the technology of largely sized concentrated solar power (CSP) into consideration. The German solar irradiation is not strong enough. In comparison, Murcia (Spain) has a state of the art CSP plant which is operated at a solar irradiation between 1800-2000 kWh/m² [28]. This technology is better used in southern territories. Nevertheless, solar thermal solutions are already being used. For example, they are used to heat up public swimming pools or private households. This way electricity can be saved.

In order to supply Germany completely with electricity only by sun power an area of 5,000 square kilometers covered with photovoltaic cells would be enough. As a matter of fact there are more than 2,800 square kilometers of feasible roof areas available in Germany. Technically about a quarter of these could be instantly available.[29] In the past couple of years, open space solar plants (PV) have been developed all over the country on abandoned industrial spaces or old military test areas.

[26] http://www.solarbusiness.de/fakten/sonne-unendlich-viel-potenzial/100-saubere-energie/
[27] http://angebot-photovoltaik.eu/joomgallery/img_originals/strahlungskarten_und_sonneneinstrahlung_4/strahlungskarte-afrika_20091221_1397537949.jpg
[28] http://www.solarfeedintariff.net/images/spain+portugal.png
[29] http://www.solarbusiness.de/fakten/sonne-unendlich-viel-potenzial/100-saubere-energie/

Only 10m² of rooftop solar panels can generate enough electricity to supply one quarter of a household's electricity.[30]

Figure 18 shows the price development of solar and domestic electricity until 2020. The chart was developed by the Federal Environment Ministry (Bundesumweltministeriun) which is one of the most credible sources in Germany. In 2012 the price per kWh for both solar and domestic will be equal, and one year later solar electricity will even be cheaper. The price decline of solar

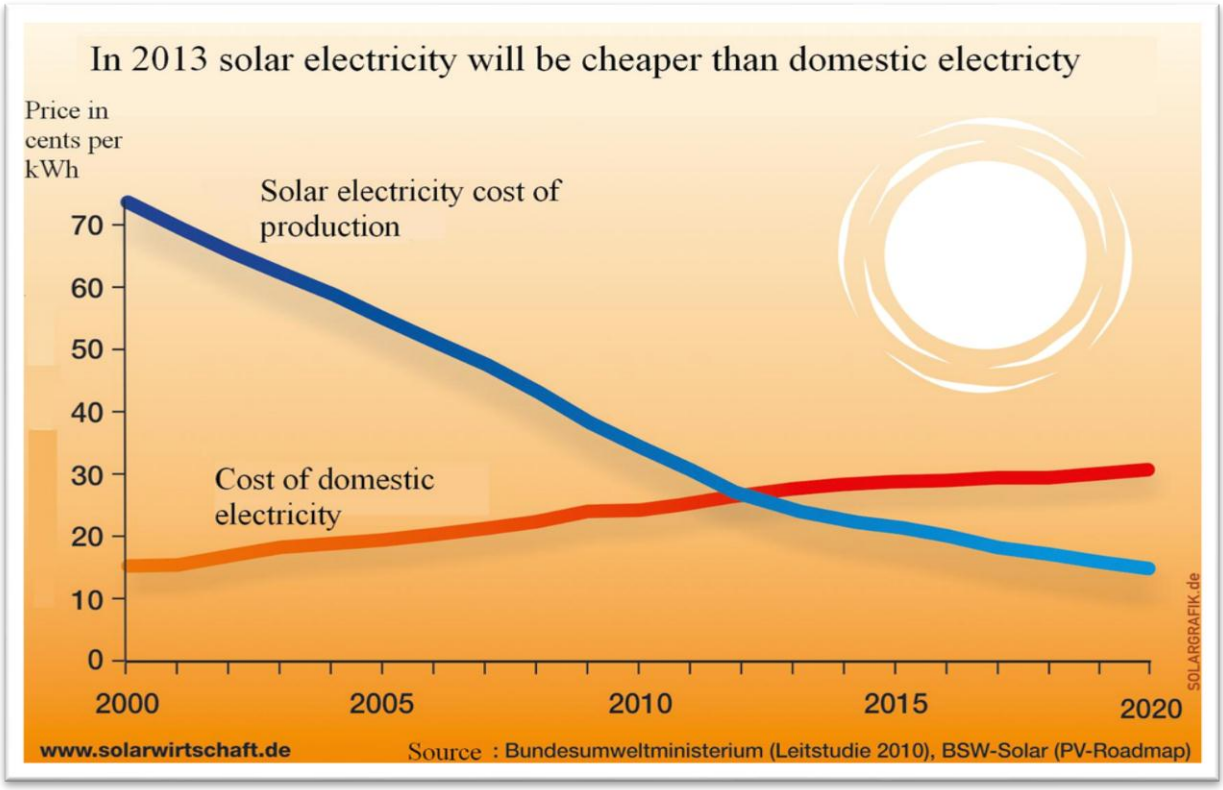


Figure 24 Future solar and domestic electricity development
Source: www.solarwirtschaft.de/fileadmin/content_files/BSW_Kostenkurve.jpg

can be explained with economies of scale whereas the price increase of domestic electricity is a consequence of rising prices for fossil fuels.

"Technological improvement and large scale production will make solar energy a "price dumper" and an indispensible element of the energy transition" said Karsten Körning, CEO of BSW-Solar and stated that "*The stronger the PV world market grows during the next years; the fast solar electricity will be competitive"*[31] Another strong indicator for economies of scale is the fact that since 2006, in only five years the installation price for PV systems has dropped 50% (as shown in figure 19). If this trend continues, the costs for PV would be the same as for wind turbines (cf. installation costs for middle and larger sized wind turbines 600-1000 € per kWh[32]).

[30] http://www.unendlich-viel-energie.de/de/wirtschaft/stromversorgung-2020.html
[31] http://www.solarwirtschaft.de/medienvertreter/pressemeldungen/meldung.html?tx_ttnews[tt_news]=14005&tx_ttnews[backPid]=547&cHash=14dfde38a0
[32] http://www.solar-und-windenergie.de/windenergie/kosten-und-bau-windkraftanlagen.html

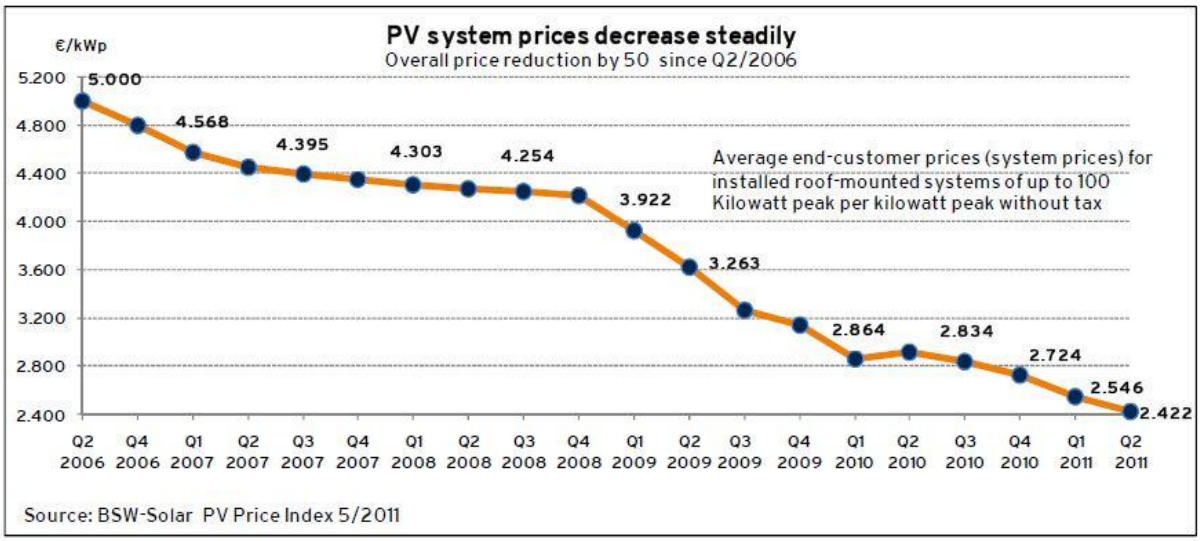


Figure 25 PV system prices decrease steadily
Source: http://en.solarwirtschaft.de/fileadmin/content_files/factsheet_pv_engl.pdf

HOW DOES A SOLAR CELL WORK?

Solar cells are made out of different semiconducting materials. Semiconductors are compounds which become electronically conductible under the influence of light or heat. Low temperatures will do the opposite and make them nonconducting. Over 95%[33] of all solar cells produced all over the world are made out of silicon(Si). Silicon has the advantage to be the second most common element in the earth's crust. This means that it is available in adequate amounts and processing is not dangerous for the environment.[34]

During the production of a solar cell, silicon is treated with certain chemicals to create a positive and a negative semiconductor layer. Between those two layers is a so called "p-n junction" in which an electric field is generated during solar irradiation. After that, metal contacts can abstract the electricity from the p-n junction.

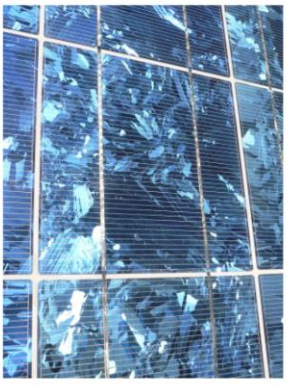


Figure 26 Silicon-Solar-cell in a solar module
Source:http://upload.wikimedia.org/wikipedia/commons/1/15/Polycristalline-silicon-wafer_20060626_568.jpg

JOBS AND THE SOLAR INDUSTRY

BSW-Solar states in its 2010 fact sheet[35] that there are approximately 133,000 full-time jobs created by photovoltaic technology. About 10,000 companies are related with PV (including installers and suppliers).More than 200 companies are involved in production of cells, modules and other components.

[33] http://www.solar-is-future.de/faq-glossar/faq/technik-und-funktionsweise/woraus-besteht-eine-solarzelle/
[34] http://www.sfv.de/sob99334.htm
[35] http://en.solarwirtschaft.de/fileadmin/content_files/factsheet_pv_engl.pdf

5.3 Geothermal Energy Production in Germany

The percentage of how geothermal energy will contribute to Germany's energy mix in the future is still debated between experts. The forecast ranges from 9% to 20% through the five studies mentioned before. The question is: Why is it so different to determine the future role of geothermal energy in Germany? – The answer to this leads us to another question: Should geothermal heat be used to produce electricity or to provide heat for the industry and private households?

Currently there are only three combined heat and power plans installed in Germany. Another ten heat plants only produce heat for industrial and private use. The Federal Environment Ministry assumes about 50 new combined heat 7 power plants by 2020. These plants are supposed to have an output of 280MW which is about 40 times more than existing plants.[36] One major advantage of geothermal energy is weather independence. It is available 24 hours 7 days a week, and even more significant when there is a lack of sun or wind production.

PREFERRED AREAS

From a human point of view geothermal energy is an inexhaustible source of energy. There is more than enough geothermal heat to supply all of Germany with electricity and heat. It is theoretically available at every place in Germany but not yet profitable to use elsewhere. Generally, when drilled into the ground the first 100 meters of temperature are about 10°C. After that the temperature increases by an average of 3°C per every 100m depth.[37] At a temperature of about 90°C electricity production gets interesting.

There is a distinction between three different depth levels where geothermal heat is "harvested."

1. Near – Surface Geothermal Systems down to max 400m deep. Mostly extracted with heat pumps for heat supply in private and industrial use. For the private house market there was quite a boom and technical development of heat pumps in the last two to three years.

2. Warm–Underground–Water systems that harvest warm underground water. Drilling depths can be down to 4500m.

3. Shifted layers Energy – These systems extract heat from deep rock layers up to the surface for power generation (Enhanced geothermal systems EGS) down to 5000m. Tariffs for the next 20 years are fixed by the government. Also certain funding help is provided by the government

[36] http://www.erneuerbare-energien.de/inhalt/44002/4594/
[37] http://www.erneuerbare-energien.de/inhalt/42723/

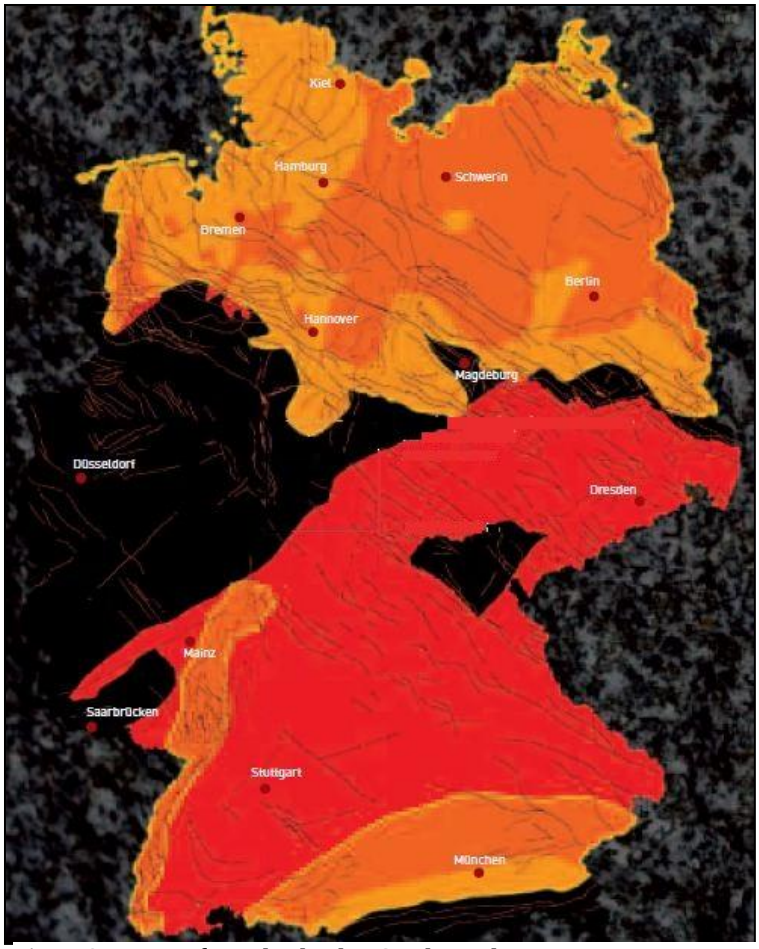


Figure 27 Energy from the depth – Geothermal Energy
Source: http://www.unendlich-viel-energie.de/de/wirtschaft/potenziale.html

Layers with hot water (Hydrothermal geothermal) are economically interesting for electricity production. These areas are for example around the city of Mainz, the Northeastern part of Germany and the very South.

Petrothermal geothermal energy is a process, where cold water is pushed under high pressure into warm rock layers. This creates tiny cracks in the rocks where the water can run through. Hot water is being pumped oil back up.

Shifted layers have natural "cracks" where water can be pumped through. They are naturally more pervious. Currently shifted layers are not yet used for heat or electricity generation.

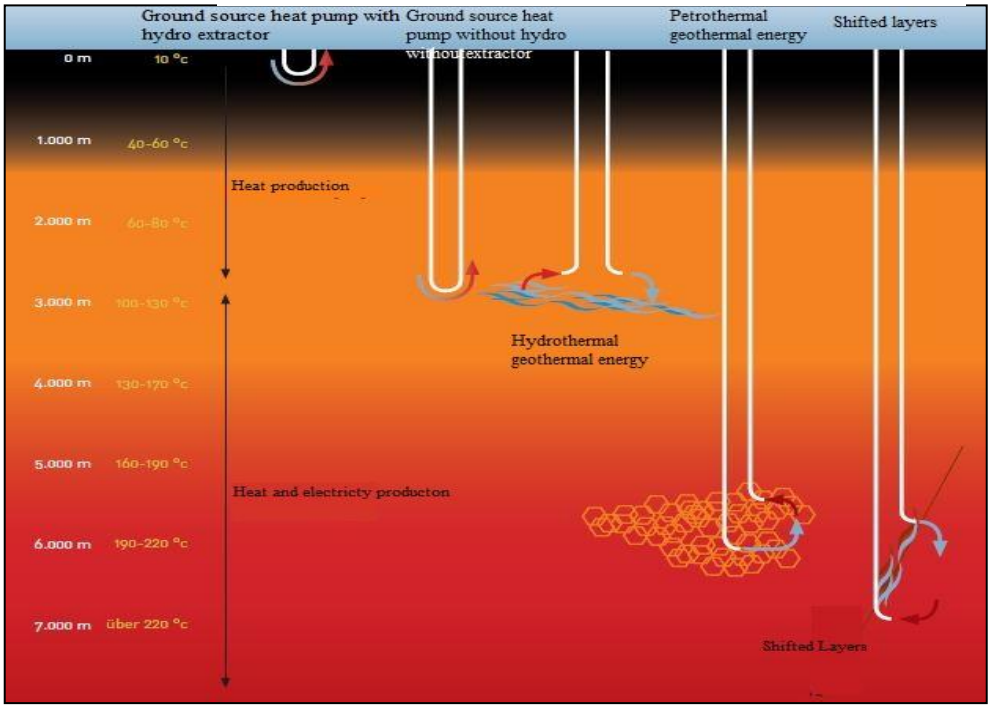


Figure 28 Technologies and operating depths
Source: http://www.unendlich-viel-energie.de/de/wirtschaft/potenziale.html

5.4 Hydropower in Germany

Electricity generation through the power of water is probably the most developed renewable energy sector in Germany. The current potential was already reached in 1995 (cf. Figure 22). There will be no new hydroelectric power plants in Germany. The focus in this sector will be

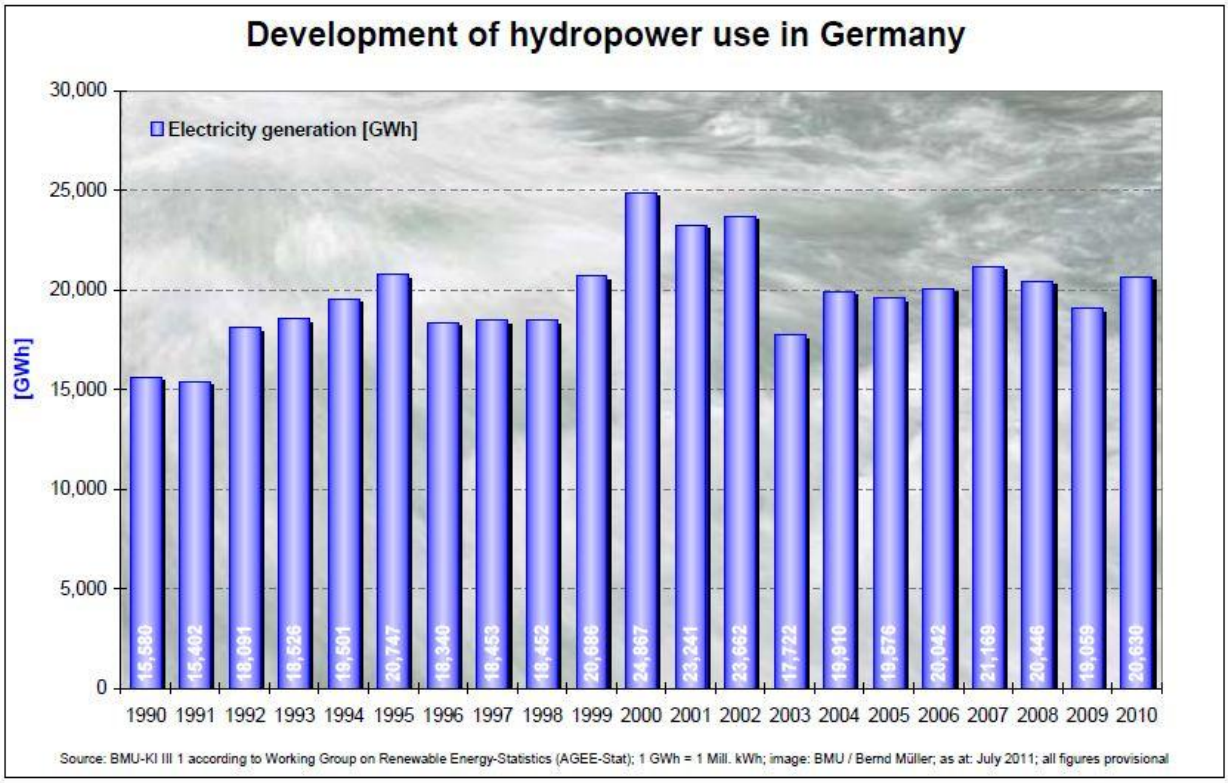


Figure 29 Development of hydropower use in Germany

making old plants more efficient and ecofriendly (installing fish passes). At the moment, Germany has 146 hydro power and hydro storage power plants.[38] The yearly output of hydropower will remain around 20 bn. kWh. About one quarter of them are small size plants with less than 5MW.[39] The biggest plant has an output of 1,060 MW[40] and is a storage facility.

Another interesting question would be to find out, how many of the current plants could be remodeled to also work as a pumped storage hydro power plant (PSHP). The storage problem will definitely be needed for wind and solar variability and at the moment this pumped-hydro storage technology is the most mature.

[38] http://www.wasserkraft-deutschland.de/
[39] Source: http://www.unendlich-viel-energie.de/de/wirtschaft/potenziale.html
[40] http://kraftwerke.vattenfall.de/powerplant/goldisthal

5.5 Biomass Energy in Germany

The Federal Environment Ministry believes biomass to be the "most important and multifunctional source of energy for Germany."[41] Referring to Figure 1, 5.2% of Germany's electricity was generated through biomass. That makes it for now the second largest renewable energy source in Germany. Regarding the land availability there are about 17 million hectare of agricultural spaces (approximately 12 million hectare of agricultural crop land and approximately 5 million hectare of grassland) . Primary Canola (1.1 mil. hectare, 2007[42]) was used as biofuel. There is also another 11 million hectare of woodland area.[43]

By far the most important natural resource is wood. One third of Germany's landscape is forest.[44] About one quarter of all wood lumbered is used for energy generation. The other three quarters are utilized to create building and commercial materials. Coming along are recycled materials which are also used for energy generation. The Federal Ministry for Forest Affairs (Johann Heinrich von Thünen Instiut) believes that there also is extra potential and reserves (13-35 million m³/ year) for sustainable forest harvesting.[45]

	Gross Energy Potential
Forestry	200-250 PJ
Agriculture – crop land	360-800 PJ
Agriculture – grassland	100 PJ
Waste material	550 PJ
Total	1,210 – 1,700 PJ

Figure 30 Roundup of Germany's future available biomass sources and their technical potential
Source: http://www.erneuerbare-energien.de/files/pdfs/allgemein/application/pdf/broschuere_biomasseaktionsplan_anhang.pdf

In 2007 there were 96,100[46] people working related directly and indirectly with the biomass energy production. The industry created a turnover of €10.23 billion. Most of the biomass energy potential will be used for heat production. The highest growth rates are in this area as the figures on the next page show.

[41] http://www.erneuerbare-energien.de/inhalt/4759/
[42] http://www.erneuerbare-energien.de/files/pdfs/allgemein/application/pdf/broschuere_biomasseaktionsplan_anhang.pdf
[43] http://www.erneuerbare-energien.de/inhalt/4759/4759/
[44] http://www.vti.bund.de/no_cache/de/startseite/startseite/die-bundeswaldinventur.html
[45] http://www.vti.bund.de/no_cache/de/startseite/vti-publikationen/detailseite/Bestellartikel/praxis-trifft-forschung-neues-aus-der-oekologischen-tierhaltung-2010.html
[46] http://www.erneuerbare-energien.de/inhalt/4759/4759/

Table 1

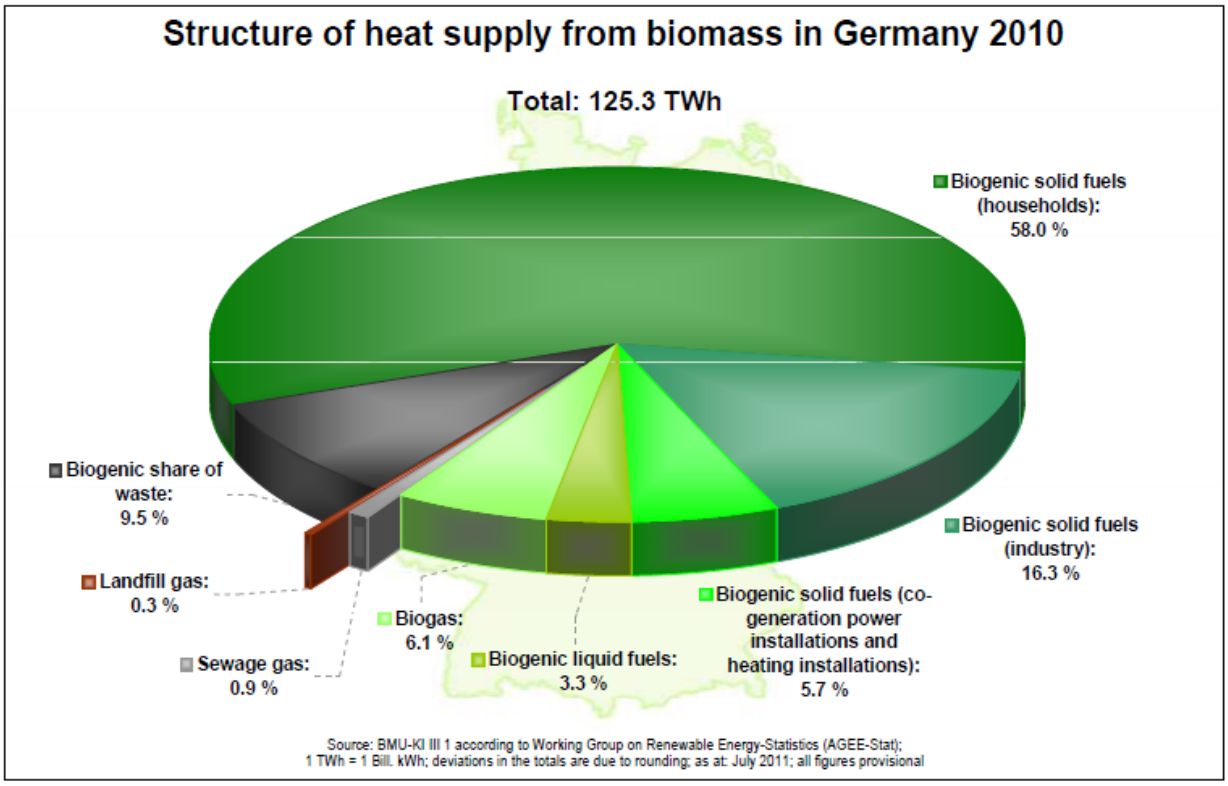


Figure 31 Structure of heat supply from biomass in Germany 2010

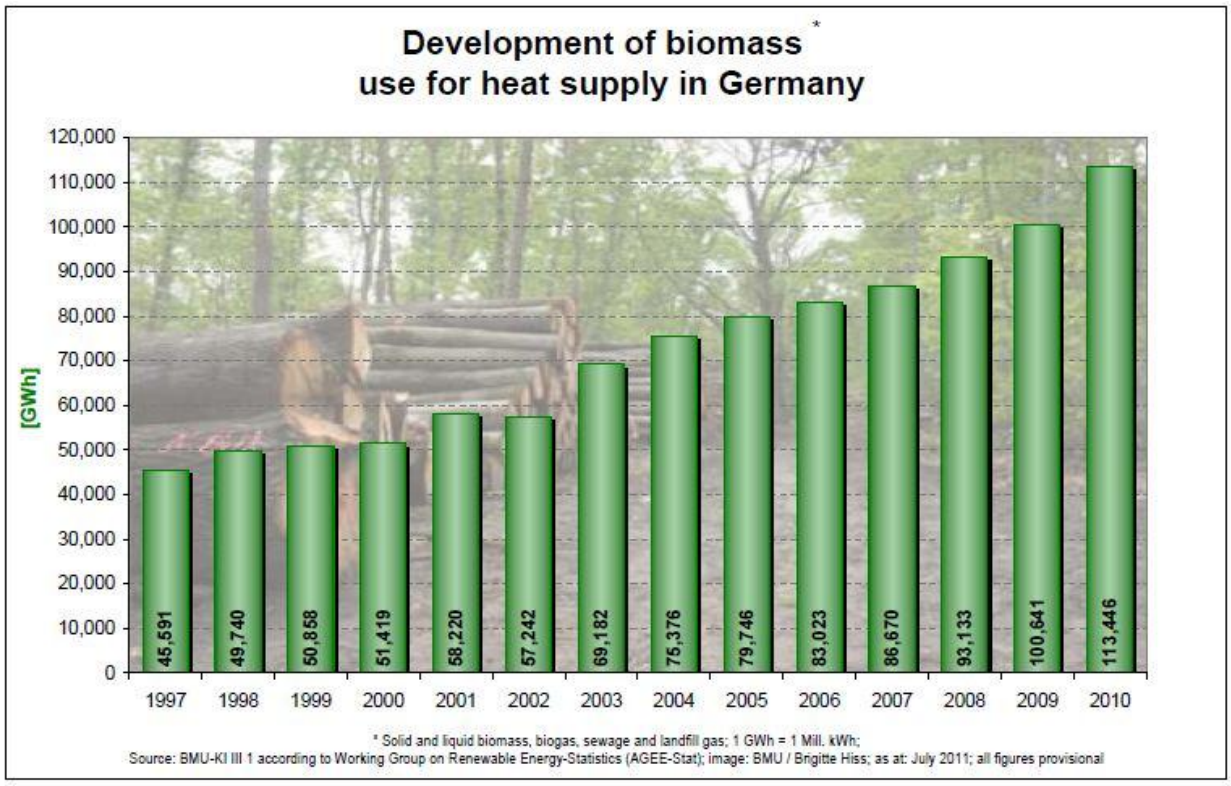


Figure 32 Development of biomass use for heat supply in Germany

6. Combined Cycle Power Plant

Figure 33 on the right shows what a future networked plant could look like. Three German companies, all leaders in renewable energy named Schmack Biogas, Solarworld and Enercon developed Germany's first "smart power plant". In theory the "virtual power plant" is already well known, but this is a first approach for what is possible. It is a pilot project designed for a city of about 12,000 households. Power plants will no longer be only in one place but rather spread all over the country with one central switching substation somewhere in the middle operating them. In the example above, three wind parks (12.6MW), 20 solar plants (5.5 MW), four biogas plants (4 MW) and one pump storage station (1.06 MW, Storage 80 hours[47]) are managed by one substation.

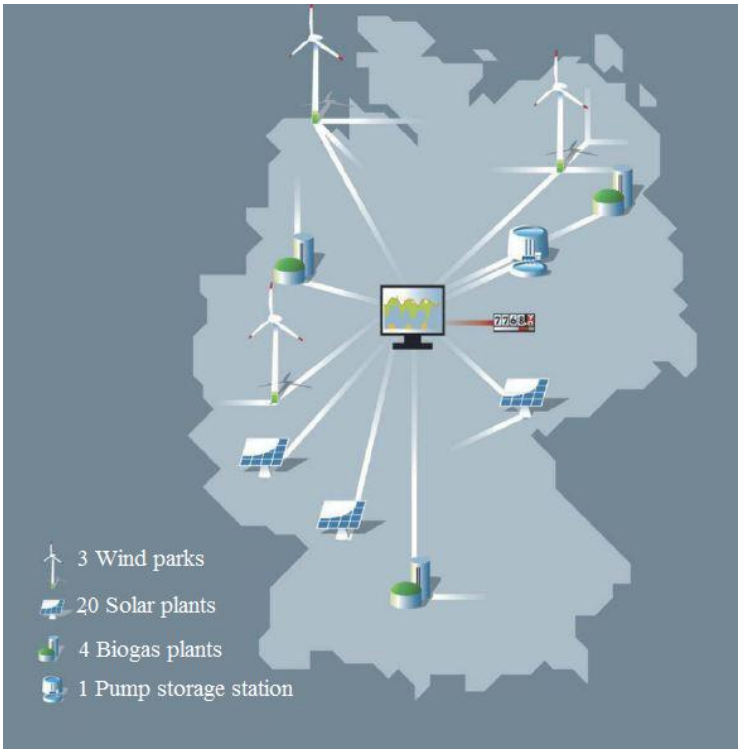


Figure 33 Combined Cycle Plant
Source: Frauenhofer IWES

Wind parks and solar plants are located all over the country. This way energy bottlenecks through bad weather conditions can be prevented. For example on cloudy days in south Germany when solar plants cannot produce enough electricity, wind parks in the north country will be able to level out the supply. Or quite simply during the night when demand is usually lower, wind might still be available and combined with the pump storage station can maintain the electricity supply. The plant adjusts to the actual demand every minute and uses forecasts to predict a future demand pattern. The central control unit is also linked directly to the German Weather Service (DWD) which provides current wind strengths and projected hours of sun.[48]

Combined cycle power plants do not necessarily need the named mix of renewable technologies. It could also contain geothermal, hydro-electric power plants or compressed air power stations subject to the condition that the necessary electrical grid infrastructure is available for use by all producers.

[47] http://www.solarserver.com/solarmagazin/anlagejanuar2008_e.html
[48] http://www.solarserver.com/solarmagazin/download/The_Combined_Power_Plant_anlage_0108_e.pdf

7. Steps in the Wrong Direction – Lignite (Brown Coal)

In 2010, 151.9 million tons of domestic mined lignite was used in electrical generating stations. That is about 90% of all extracted lignite. It shows that power plants are the primary customer for German brown coal. Lignite fired power plants have produced 147 billion kWh which means that almost one fourth of electricity used in German households was coming from lignite fired power plants.[49]

Extraction of Lignite in million tones(2009)

#	Country	1970	1980	1990	2000	2007	2008	2009	Percentage %	Cumulation in %
1	Germany	369,0	387,9	356,5	167,7	180,4	175,3	169,9	17,2	17,2
2	China	15,4	24,3	45,5	47,7	97,4	115,0	120,0	12,1	29,3
3	Turkey	4,0	14,5	44,4	60,9	70,0	81,5	70,5	7,1	36,5
4	Russia	116,2	141,5	138,5	87,8	71,3	82,0	68,2	6,9	43,4
5	Australia	24,2	32,9	46,0	67,3	72,3	72,4	68,0	6,9	50,2
6	USA	5,4	42,8	79,9	77,6	71,2	68,6	65,7	6,7	56,9
7	Greece	7,9	23,2	51,9	63,9	64,4	65,7	64,7	6,5	63,4
8	Poland	32,8	36,9	67,6	59,5	57,5	59,6	57,1	5,8	69,2
9	Czech	77,0	90,1	76,0	50,3	54,5	46,8	45,6	4,6	73,8
10	Indonesia	0,0	0,0	0,0	13,8	28,0	38,0	38,2	3,9	77,7

Figure 34 Lignite extraction by Country
Source: „Bundesanstalt für Geowissenschaften und Rohstoffe“

[49] http://www.braunkohle.de/pages/layout3sp.php?page=573

Since 42.4% of all electricity (Lignite 24.3/ Hard Coal 18.1%) is generated by burning coal, and is the main cause for Germany's carbon dioxide emissions. A study by the World Wildlife Fund shows that 10 out of Europe's 30 "dirtiest" power plants are located in Germany. And it gets worse by taking a closer look at the list, because 6 out of the top 10 are German.[50] And even with this fact and put into consideration of Germany has very ambitious climate goals, still new coal plants are planned.

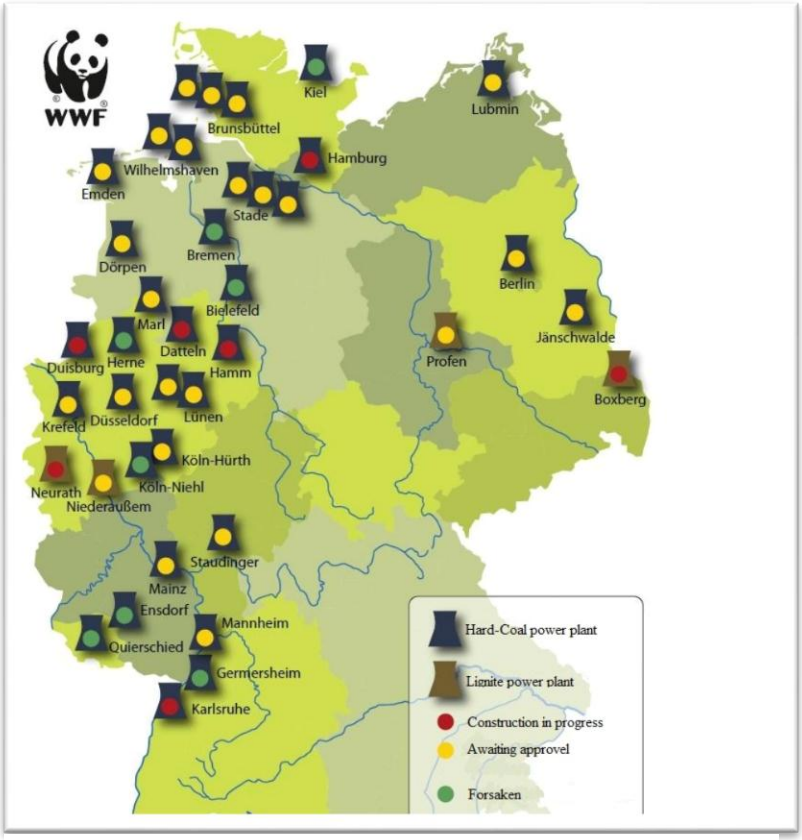


Figure 35 Actual and planed coal power plants in Germany
Source: http://www.wwf.de/fileadmin/fm-wwf/pdf_neu/Karte_-_Standorte_der_Kraftwerke.pdf

Certain research projects are attempting to develop a coal power plant with zero carbon emissions by separating the CO_2 gas and storing it in sequestration storage facilities. This technology might mature by 2015-2020. Nevertheless, this report will not put storing CO_2 into consideration because postponing emissions is not an adequate solution for global warming and Germany's climate goals.

[50] http://wwf.panda.org/about_our_earth/aboutcc/cause/coal/dirty_30/dirty30_ranking.cfm

Above is a satellite picture of the brown coal open cast mine Garzweiler II (NRW). The red marked area is the planned surface expansion of the mine until 2044 (4.800 hectare; electricity output per hectare 7.3 mil. kWh). The blue square is the space requirement of a wind park (22.5 mil. kWh/ hectare) with a similar power output as a coal power plant fired by the coal from this mine. Also 7,600 people and 13 towns have to be relocated in order for the mine to expand. The burning of brown coal releases a huge amount of carbon dioxide and is one of the major contributors of global warming.

Coal mine Garzweiler II	2008	2008		Wind park Bergheim(Rheidt)
Annual potential return per hectare	approx 7.3 million kWh	approx. 22.5 million kWh	only fundamental space	Annual potential return per hectare
		approx. 225.000 kWh	including setbacks	

Figure 36 Space requirements of coal mines
source: http://www.unendlich-viel-energie.de/de/wirtschaft/potenziale.html

8. Concluding Remarks

When the Berlin Wall collapsed in 1989, people around the world wondered how long it would take the country to integrate former GDR (German Democratic Republic) into the BRD (Federal Republic of Germany). A country under the protection of the Soviet Union had become extremely worn down. The industry was in a very sorry state, infrastructure was poor, political leaders were released by the people, environmental standards did not exist, currency had to be replaced and a cultural integration took place between two populations that had been separated for 40 years. It was a great challenge; probably the biggest challenge apart from rebuilding the country after WWI. However, in only two decades, Germany reunited and accomplished something that many countries aren't able to do.

Now there is a new mission. Germany has to end its dependence on fossil fuels and stop emitting greenhouse gases to prevent the consequences of global warming. When Germany decided to shut down all of its nuclear power plants within ten years it became a role model for the rest of the world. Germany's efforts are being watched around the world and if successful will guide other countries to follow the same path.

After working on this report and reviewing the question if 100% clean, green energy supply for Germany is possible, the answer is: Yes. The past 15 years have shown how fast Germany can develop renewable energies. Germany has the renewable potential, the technical know-how and the mentality to do it. But how can it be done?

There has to be a mix of many different renewable technologies – the more the better. However, two are most prominent. A major role in Germanys' future energy supply will have wind turbines and solar cells. Both will be responsible to secure the electrical base load where Germany is one of the world leaders in both. Extreme growth rates were accomplished in the past years but the rate is slowing down due to the financial crises. Germany has to help out flagging EU Countries financially which takes away money from being invested into the wind and solar sectors.

On-shore wind park development is very advanced especially in the northern and central parts of Germany. With the help of the world's largest wind turbine manufactured by the company Enercon, newer, better and higher wind turbine models made it profitable in weaker wind sites to install wind plants. Wind is the renewable technology with the fastest return on investment. Economies of scale and constant research and development have made wind electricity the cheapest and grid-compatible electricity source. Wind turbines are also very efficient. In 2009, 3% of all European electricity was generated through wind. This is equivalent to the power that 10 nuclear power plants would have produced.[51] Estimates from reputable institutions attach great importance and high growth projections to wind power.

[51] http://www.energieblog24.de/e126/

Experts say it will produce more than 50% of Germany's electricity in the future. Included in the 50% is off-shore wind power. Germany is massively expanding its off-shore efforts by building 27 wind parks along the coast while many more are pending.

Electricity generated by the sun, the world's largest energy source, will be Germany's second primary source of electricity. Photo-voltaic PVcells are already installed on many roof tops. Especially on large roof buildings and farm sheds. The acceptance of solar cells is immense. Farmers, which often show bias against any new technology, have suddenly invested in solar panels on farms. Some would think Germany does not have great potential for solar power but this is not true. Almost every roof top facing south has the potential to supply electricity at a profitable level, particularly with declining production costs. The decision of the German government to eliminate subsidies has hit the industry hard but many companies are still making profits. Daytime solar power, combined with wind power at night will be Germany's energy future.

In cases of low wind and solar input, alternate renewable electricity sources such as geothermal, hydro and biomass energy will assist to maintain base load generation. It will be very interesting to see how fast the development of geothermal energy will be and how much of the immense potential can be developed. The government has guaranteed to support investments for the next 20 years so planning security has already been given. The problem is that in the past, Germany failed to be consistent in policy. It also has to be said that even if geothermal energy might not play a major role in electricity production, it definitely will be very important for heat production. It will also indirectly help to reduce electricity demand. The same can be expected for certain solar technologies installed on rooftops that can help heat up water and therefore reduce energy consumption.

The importance and urgency of the expansion and improvement of the German electrical grid cannot be emphasized enough. Without a modern grid, Germany's transition into a green country will not be possible. The government needs to invest in the electrical grid order to achieve climate goals. It will pay off in the long run. Only with a state of the art grid can Combined Cycle Power Plants be able to compensate for the intermittency of wind and solar power mentioned earlier. That's why modern HVDC power lines are essential. They will connect off-shore wind to the inland. Off-shore wind is more reliable and readily available.

But are there any alternatives? With a limited supply of oil and the effects of global warming already taking place, action needs to be taken now. Do we really want our kids to live with the consequences of global warming? It is imperative that we change our mentality and fix what we have done before it becomes too late. With the findings presented here, and a positive new attitude, Germany can be a leader for a zero CO_2 emission future.

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