Sectoral Energy Report

The Machine Building Industry for Wind Power

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ESA^2 – Sectoral Energy Reports

The EU's ambitious energy and climate objectives require a coordinated approach by all involved stakeholders. While policy sets the legal framework, the decision for investments in the energy sector and the implementation of climate protection measures rests with a variety of actors (e.g. energy supplier, network operators, municipalities, industries, business and households) who have different economic preferences. Often individual decision makers lack sufficiently reliable information in advance to assess the ratio of costs and benefits of their own options and the effects of their decisions for the collective energy system and the environment. To enable sustainable decision support for all relevant decision makers in energy systems, instruments are needed which allow a dynamic system analysis, taking into account the interactions between political, technical and economic conditions and the behaviour of individual actors.

The Sectoral Energy Reports focus on the energy profiles of specific industry sectors and seek to identify action areas for ensuring competitiveness in a context of stringent climate change mitigation requirements and increased global market competition. The reports provide a knowledge base that goes beyond the specific sector in focus as new goals will have to be defined at the strategic level, requiring a broader system approach and involvement of multiple stakeholders. The Sectoral Energy Reports provide the broad contextualized background of the challenges being faced by industry sectors in Europe.

The Energy Systems Analysis Agency (ESA^2) builds on knowledge and experience of 14 European research groups/companies in the field of energy systems analysis. ESA^2 has its starting point in an innovation project developed within the Knowledge and Innovation Centre (KIC) InnoEnergy. KIC InnoEnergy is an initiative created under the leadership of the European Institute of Innovation and Technology (EIT) and aims to be the leading engine for innovation and entrepreneurship in sustainable energy.

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List of abbreviations

BFEC	Brut final electricity consumption
CCV	Carbon capture and storage
CAGR	Compound annual growth rate
CHP	Combined heat and power plant
GW	Giga watt
FEC	Final electricity consumption
GPS	Comprehensive production systems/Ganzheitliche Produktionssysteme
LPG	Liquefied petroleum gas
MW	Mega watt
NdFeB	Neodymium Iron Boron (magnets)
PEC	Primary energy consumption
PJ	Peta Joule
PV	Photovoltaic
REN	Renewable energy
OEM	Original equipment manufacturer
EIPC	Engineering, installation, procurement and commissioning
SME	Small and medium sized enterprises
WTG	Wind turbine generator

1 Description of sector

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The wind energy sector is a relatively young but rapidly expanding industry. The main drivers of market growth are the intended security of energy supply, economic interests and the increasing importance of environmental issues in the energy sector (EWEA 2009). Energy demand is rising together with a growing economy, population, and urbanization as countries look for sustainable ways to secure their energy supply in the face of limited fossil fuel reserves. The continuous increase in wind turbine size and efficiency coupled with economies of scale from fast growing production volumes have greatly reduced the cost of wind power to the point where some high yield onshore wind farms are approaching price competitiveness – especially at coastal areas, wind power is already competitive with conventional technologies (WWEA 2011).

When taking into account the price of carbon, wind power is even more attractive. Furthermore, economic benefits such as long-term job creation and the development of an indigenous industry are intended by governments supporting wind energy development. More recently, wind energy development has been identified, under climate change considerations, as an attractive way to reduce greenhouse gas emissions from the energy sector. These drivers pushed governments to create favourable regulatory frameworks that were pre-conditions for the diffusion of wind turbines.

1.1 Technology

1.1.1 Description

The type of wind turbine considered by this report is the horizontal-axis upwind turbine. This turbine generally features three rotor blades rotating around a horizontal hub and connected to a drive train consisting of a gearbox and generator which are housed by a nacelle on the top of the tower. The nacelle also contains the electrical components, including the control system. Wind blows through the blades, which face into the direction of the wind, and turns the rotor, which in turn drives the generator and produces electricity. A horizontal upwind turbine also includes a yaw system for turning the windmill into the wind where it will receive the most direct force and produce the most power. All types of wind turbines include a brake for manually stopping the motion of the blades in the event of an emergency (VDMA 2010; Hau 2008).

Using wind turbines as a source of electrical energy generation commercially started in the 1980s. In the last two decades, turbine power has increased by a factor of 100, while wind power generation costs have declined by about 80 %. Given adequate wind conditions, wind turbines are among the most reliable electricity generation technologies, with operating availabilities of about 98 %. This means they can almost be run the whole year. No other electricity generating technology has a higher availability.

There are currently two main design types of horizontal-axis upwind turbines:

1. Geared wind turbines,
2. Direct-drive (gearless) turbines.

The non-geared direct drive technology involves a generator operating at low speed (between 10 to 20 rounds per minute) while the geared technology has typical rotational speed values of 1000 to 1500 rpm (Kurronen 2011). In a conventional geared wind turbine, the blades are attached to a shaft that is connected through a gearbox with the generator. The gearbox is required to speed up the wind driven rotor to produce compatible alternating current. In the direct-drive technology, the blades are directly connected to the generator without the intervention of a gearbox. Magnets spin around a coil and generate an electric field. This electric field (i.e. voltage) is proportional to the magnet rotational speed (Patel 2009). As the rotational speed of the generator (without the intervention of a gearbox) is in this case significantly lower, the size of the generator needs to be increased to obtain higher rotational magnet velocities. Increasing the radius of rotation therefore linearly increases this rotational magnet velocity and the produced voltage. For the newly designed Siemens 3 MW turbine, this increase is already about four meters in diameter (Wulfers 2011). This increase in generator size does not result in a weight increase of the entire nacelle as the need for a gearbox is eliminated. The respective characteristics of both turbine designs are illustrated in detail by Figure 1-1.

Geared wind turbines currently represent the “standard” turbine design by holding a share of about 85 % on all turbines installed worldwide (VDMA 2010; Frost & Sullivan 2011). In this turbine design, the multiple wheels and bearings in a gearbox are exposed to high stress caused by wind turbulence. This problem is more pronounced in offshore wind turbines, which generally experience higher wind speeds than onshore turbines and are therefore more vulnerable to an eventual breakdown of the gearbox (Patel 2009; Constantinides 2011b). To solve this problem and to increase the reliability of the wind turbines, industry has increased its efforts to rectify fundamental issues in gearbox design, underestimation of operating loads, misalignment of gearbox and bearing, and bearing slip.

Elimination of a gearbox in direct-drive wind turbines improves reliability because fewer (up to ½) rotating parts are required (Dvorak 2009; Keane 2010). On the other hand, the most advanced direct drive wind turbine technologies require permanent magnets instead of the traditional electromagnetic-copper coils. Neodymium-Iron-Boron (NdFeB) permanent magnets are used in direct-drive wind turbines as they generate less friction inside the generator (increased efficiency), reduce breakage (less maintenance) and energy losses (increased efficiency) and reduce the overall weight of the nacelle (reduced structural demand on the tower) in comparison with other technologies (Avalon Inc 2010a). Though not at first sight evident, weight reduction is a top priority in the development of new wind turbines (McDonald 2011). This is achieved in direct-drive wind turbines by the absence of the gearbox and the need for less magnetic material to generate the same magnetic field (compared to electromagnetic copper coils). An overview of the respective advantages and disadvantages of both wind turbine designs is given in Figure 1-2 and Figure 1-3 (VDMA 2010; Hau 2008).

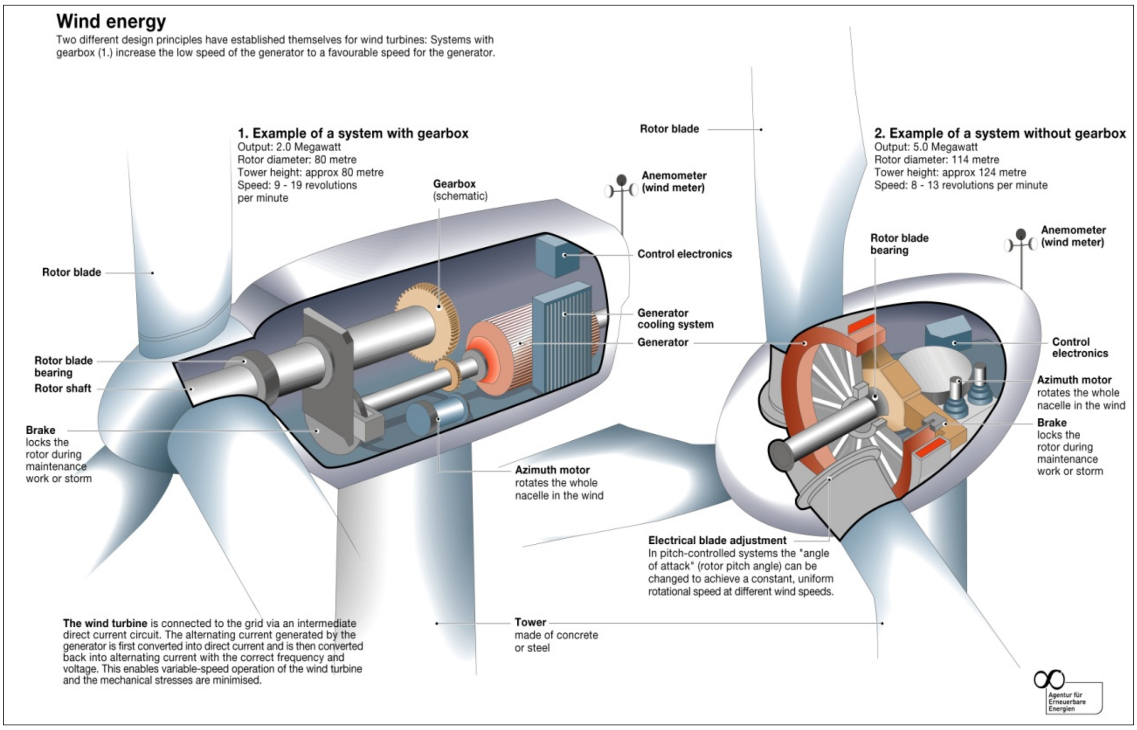


Figure 1-1: The two major different design principles for wind turbines (Agentur für Erneuerbare Energien 2011)

Pro	Con
• Gearboxes allow for a efficient and robust construction of the wind turbines drive train • Lighter and more compact design of generator due to higher rotation speed and gear transmission ratio • Short mechanical transmission • Good controllability of dynamic processes • Design of drive train allows for better balance of masses in the nacelle on the top of the tower • Standardised components that can be developed and provided by supplying industries • Independency of rare earth elements • Components can be repaired without decomposition of nacelle	• Higher frictional losses (2 %/gear), lower efficiency • Higher noise development • Shorter maintenance intervals due to abrasion of mechanical components leads to higher costs of maintenance and repair • Lesser accessibility of aggregate for maintenance and repair • Higher weight of steel-made gearboxes which has to be carried by tower • Higher stiffness of tower required

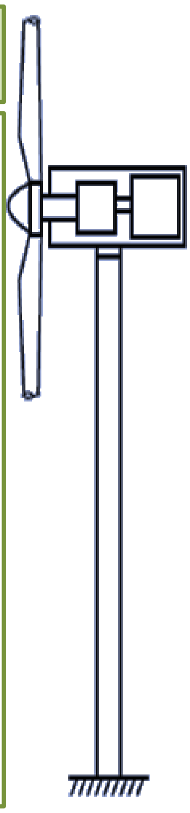
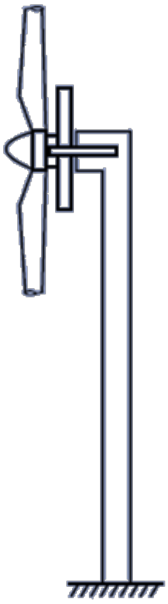


Figure 1-2: Advantages and disadvantages of geared wind turbines (own illustration)

Pro

- Absence of mechanical gearbox results in lower mechanical abrasion
- "Critical" component of gearbox is no longer required
- Higher efficiency at different wind speed
- Longer maintenance intervals due to higher robustness
- Lower weight and smaller dimensions of nacelles with permanent magnets than nacelles with gearboxes
- Simplification of gear ratio and lower speed of generator



Con

- Higher costs and complexity of generator construction
- Dependency on Chinese rare earth exports in the case of permanents magnets containing Neodymium and Dysprosium
- Repair of components often requires decomposition of nacelle

Figure 1-3: Advantages and disadvantages of gearless wind turbines (own illustration)

A third category of wind turbines consist of hybrids between the two main turbine types. However, these are in prototype stage (e.g. Winergy/Fuhrländer) or just entering the market (e.g. Multibrid/Areva). These are more compact than direct drive designs and more robust than regular geared wind turbines because they require fewer rotating parts. Moreover, the hybrid drive is prized as being maintenance-friendly (VDI Nachrichten, 2011; Energie & Technik 2011). To what extent these promises can be delivered in practice will be become apparent in the future.

1.1.2 Trends

Because wind energy output is proportional on a square basis with the rotor area, the rotor size (and the whole turbine size) has been increasing continuously. During the past 15 years, there has been strong growth of wind turbine size which has been promoted by all manufacturers, as seen in Figure 1-4 below.

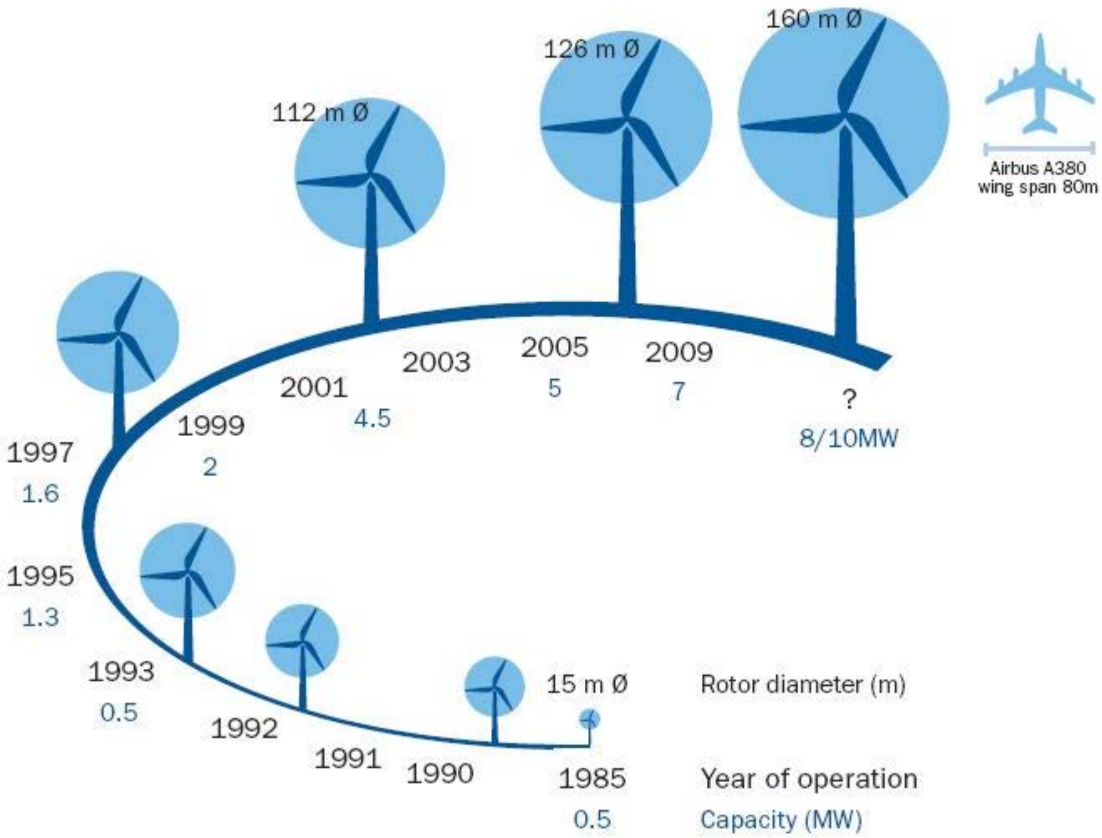


Figure 1-4: Growth in size of wind turbines (data and illustration: EWEA 2009)

This trend towards larger turbines is reflected by the average size of newly installed wind turbines worldwide. These are shown for the top nine markets in Figure 1-5. In 2008, the average turbine size was slightly over 1,5 MW. However, this is just a simplistic indicator, as regional markets have also regional preferences and show different dynamics. Lately, there has been a leveling of turbine size on the land based market and manufacturers now tend to increase volume supply in the 1.5 to 3 MW range (WWEA 2011).

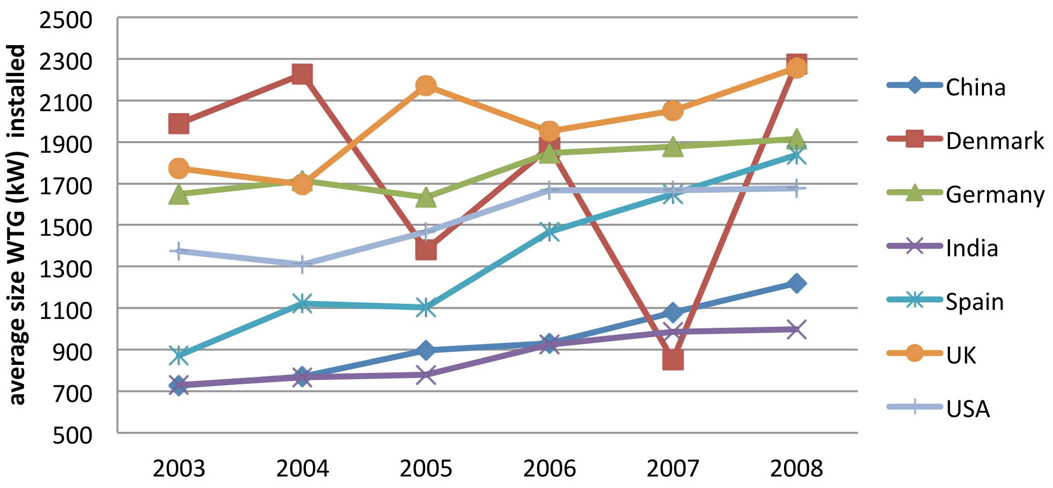


Figure 1-5: Average size of newly installed wind turbines in various countries (BTM Consult ApS 2009)

The key factor in continuing design into the multi-megawatt range has been the development of offshore wind turbine technology. Offshore wind farms are already operating off the coasts of Denmark, Sweden, Ireland, the Netherlands, Germany and the United Kingdom. For offshore applications, optimum overall economics, even at higher cost per kW in the units themselves, requires larger turbine units to limit the proportionally higher costs of infrastructure (foundations, electricity collection and subsea transmission) and lower the number of units to access and maintain per kW of installed capacity. Although there are still many challenges, including costs for both grid connection and foundations, there are major advantages in the higher mean wind speeds, low turbulence (i.e. longer turbine lifetime) and reduced constraints to be found offshore.

Although offshore wind capacity is still approximately twice as expensive as onshore wind, the opportunities associated with offshore capacity, such as higher wind speed, lower visual and acoustic impact and 30 % to 50 % higher productivity levels, are expected to increase its market share during the next years. This is also in line with the general trend of increasing average turbine sizes from about 500 kW in 2000 to 2 MW in 2010 (Frost & Sullivan 2011). The largest turbine currently available is the Enercon E126 with a rotor diameter of 126 meters and a power capacity of 6 MW, but capable of 7.5 MW. Offshore turbines are not faced with size limitations because transportation and installation take place direct at sea in contrast to onshore turbines with their limitations of transportation by road. Due to the higher efficiency of gearless turbines, less frequent maintenance and higher robustness, the percentage of installed turbines is expected to increase in time with offshore capacities.

The future challenges in extending the conventional three-bladed concept to size ranges above 7 MW are considerable, and will improve the offshore cost efficiency, even though the challenges in engineering remain high compared to the onshore technology.

In addition to the large growth in rotor and turbine size, innovations have emerged in other fields as well. In general, they aim to optimize the wind turbine for onshore applications (e.g. more efficiency, less weight and noise) or to adapt the wind turbine to fill market niches (e.g. extreme weather conditions). Mechanical noise has been practically eliminated and aerodynamic noise vastly reduced. For instance, in the development pipeline are to be found: improved power control and gearboxes or gearless mechanisms, new generator designs, composite materials (cheaper and lighter), also allowing larger wingspan (especially for offshore), sensors related to extreme environments (e.g. icing, stalling), advanced blade coatings for offshore applications, pitch-rotation/optimization of lift, short-term energy storage, and software systems for optimizing wind energy operations. The fast growth of offshore-related wind turbine patents also reflects increased attention given to offshore deployment (Susman 2009).

The coupling of strong expected increases in offshore installed capacities and the technological advantages of direct drive wind turbines for this purpose has drawn attention to the issue of supply of special raw materials for the production of gearless wind turbines. Concern centers on the availability of neodymium and especially dysprosium for the production of the permanent magnets (DoE 2010). The amount of Neodymium which is necessary to run a wind turbine is considerable: 200kg of Neodym per MW. This means 1 ton for a 5 MW wind turbine (Murphy & Spitz 2011). Because current primary production of rare earths is concentrated in China (over 95 %) and there are neither viable substitutes nor secondary (recycling) sources for these metals, the rare earths (including neodymium, dysprosium and 15 other elements) were recently classified as critical to the EU (Ad-hoc Working Group on Defining Critical Raw Materials 2010).

It is worth noting that gearless turbines can be run either by electromagnets or permanent magnets. The use of electromagnets, however, decreases the efficiency and in-creases the weight of the wind turbines such that permanent magnet generators are generally considered technically superior. However, only one sixth of all newly installed gearless wind turbines contain Neodymium magnets (Schoßig 2011). It remains to be seen how this percentage develops in the future and whether large manufacturers such as Siemens or Vestas continue to largely rely on Neodymium magnet offshore turbines to achieve the best performance. In contrast, Enercon as another manufacturer of gearless wind turbines has decided to avoid the deployment of Neodymium magnets and to prefer electromagnets instead (Murphy & Spitz 2011).

This short overview on recent technological trends has shown that the dominant technological design of wind turbines has proven itself in the last decade and thus is not likely to change fundamentally in the future. Instead, and this is also underlined by the development of the new hybrid drive, main technological developments can be assumed to aim at the improvement and maturing of existing components in terms of an increase of efficiency (especially for low wind speeds), reliability, performance and robustness (particularly in the offshore area) and grid compatibility, shown graphically in Figure 1-6 (Frost & Sullivan 2011; Roland Berger 2010).

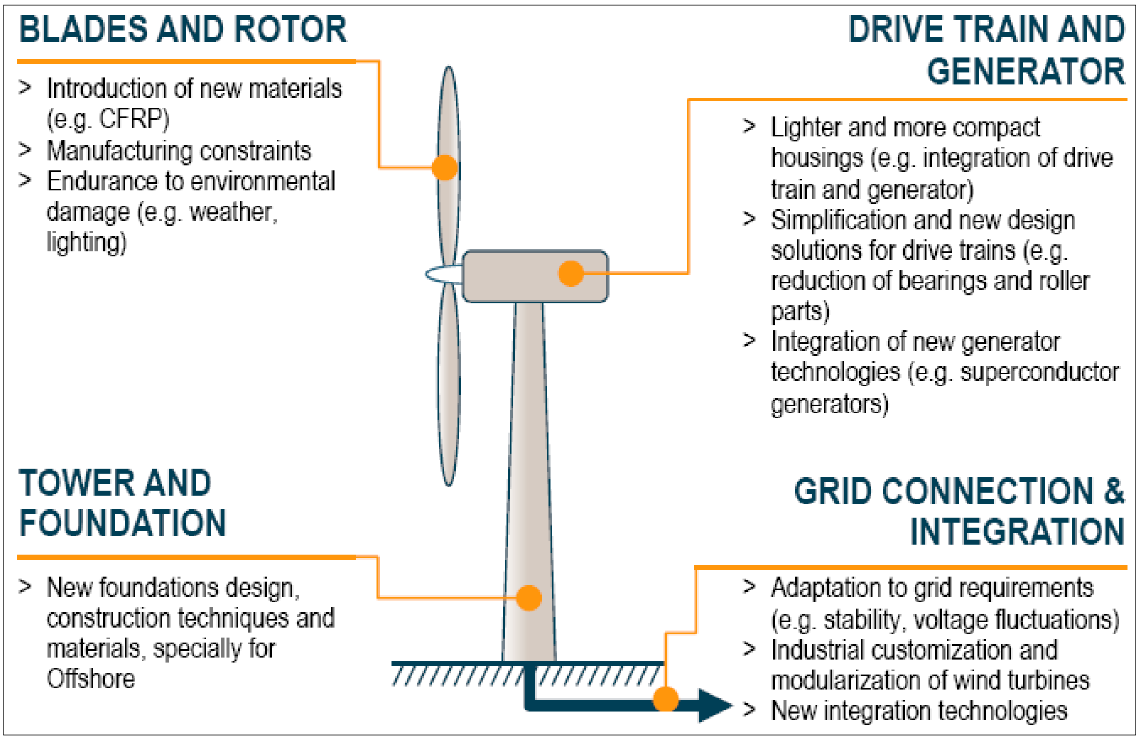


Figure 1-6: Main future technical challenges of wind turbines (Roland Berger 2010)

1.2 Installed capacities and global wind turbine market

Annual global demand for wind power has increased at a rate of 25 % from 2003 to 2008 (BTM Consult ApS 2010). In 2009, 38.312 MW were installed summing up global installations to 157,899 MW. However, in 2010 the market for new wind turbines declined for the first time in two decades and reached an overall size of 37.642 MW. This resulted in a worldwide installed capacity of 196 630 MW at the beginning of 2011 (WWEA 2011). With a new installed capacity of 18.928 MW in 2010 China accounted for more than half of the global wind energy market and surpassed the USA as the leading country in installed wind energy capacity. Figure 1-7 displays cumulative in-stalled capacities of the top nine markets.

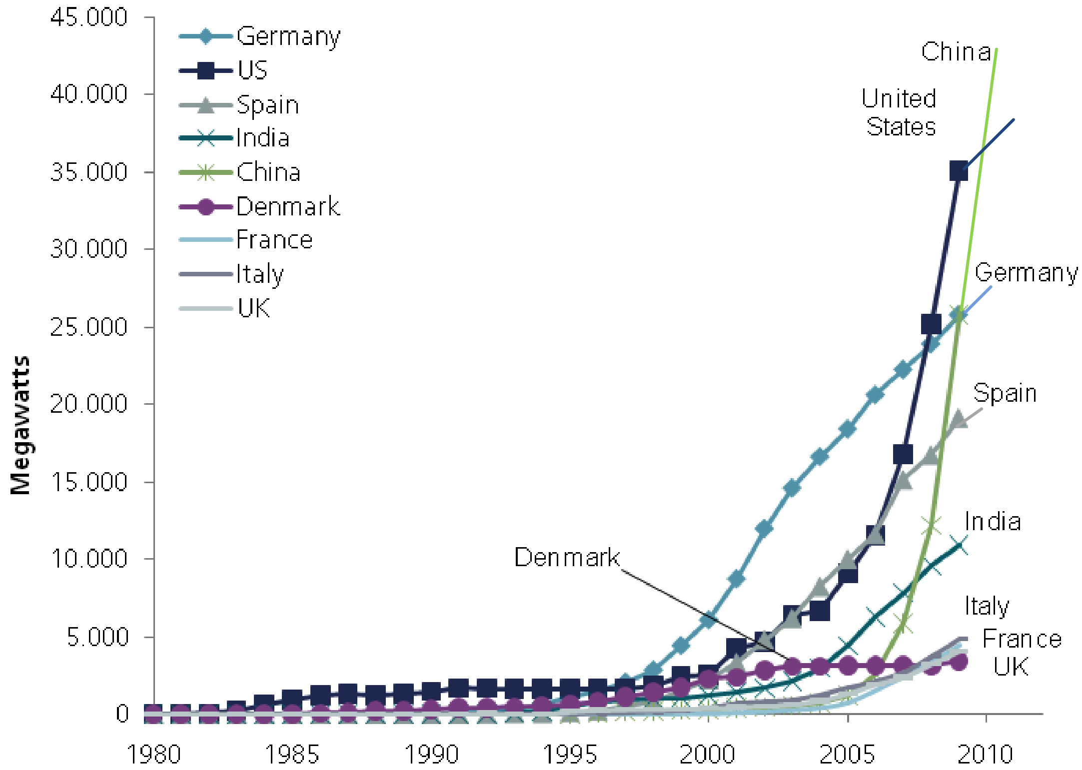


Figure 1-7: Accumulated installed wind power capacities from 1980 to 2009 in the top nine countries (Delgado 2010; WWEA 2011)

Today, China is installing wind turbines at an unseen speed and is expected to continue this development in the near and long term future (Delgado 2010). At the end of 2010, China's cumulative installed wind capacity ranked on the first position worldwide, even in front of the USA. With a share of about 23 % of globally installed capacities China has become a driver of wind energy development. During the last years, Chinese wind generation installations have grown up to 100 % annually, the highest growth rate ever achieved globally.

A closer look at the conditions under which the Chinese market has developed shows a very strong role of regulation. This is most clearly illustrated by a timeline of installed capacities vs. changes in the regulatory environment, as shown in Figure 1-8, below.

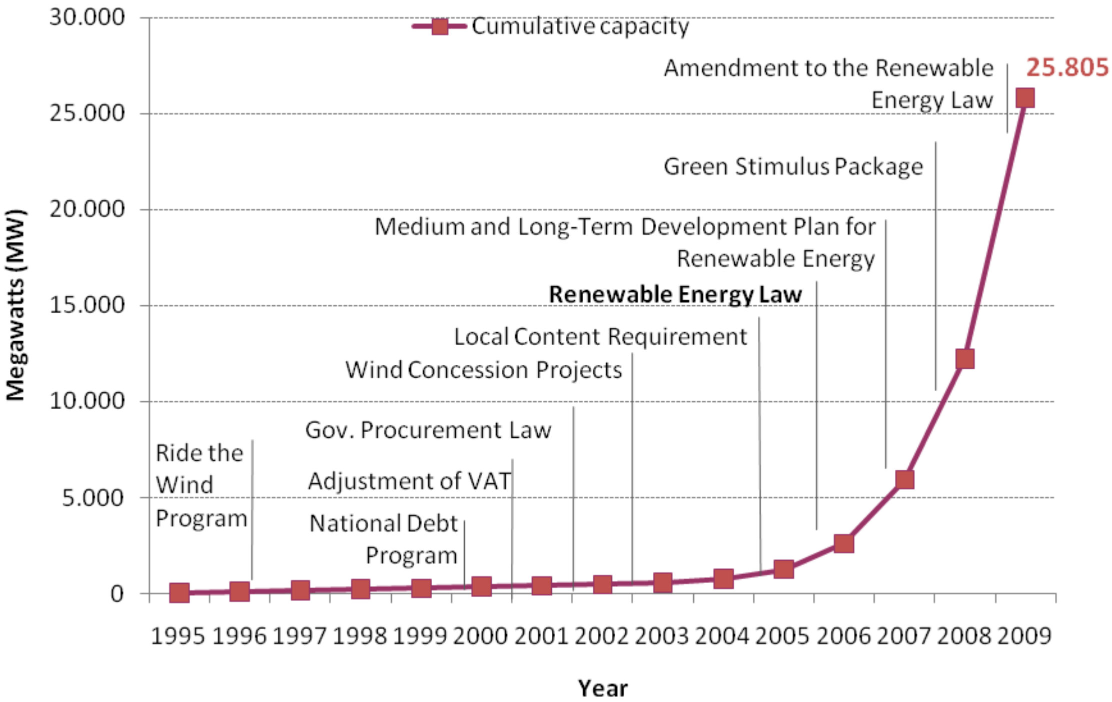


Figure 1-8:Overview of regulatory measures and total capacity in China (1995-2009) (Delgado 2010)

1.2.1 Characterizing the global knowledge base: Patent indicators

Patent activity in general is an indicator of technological capability and potential future product developments. Interestingly, global annual installations of wind and PV technologies increased steeply during the last decade – along with the annual number of filed patents (Walz et al. 2008). Wind technologies have the second highest patenting level among the renewable energy technologies (after PV). However, analyzing only patent assignee locations is limited because both filing location is at least equally important and technology licensing is widely available in this sector. Wind energy's absolute patenting levels have increased during the last decade. This is also attributable to the learning effects, which develop over time. Furthermore, while patent filing locations become more widespread, intellectual property ownership becomes more concentrated: the top 20 patent assignees control an increasing percentage of all patents in this field. Nevertheless, the number of patent applications by producers from developing countries (especially India and China) remains low compared to their global market share. This suggests that especially in the technical more sophisticated offshore technology western producers will keep the market leadership.

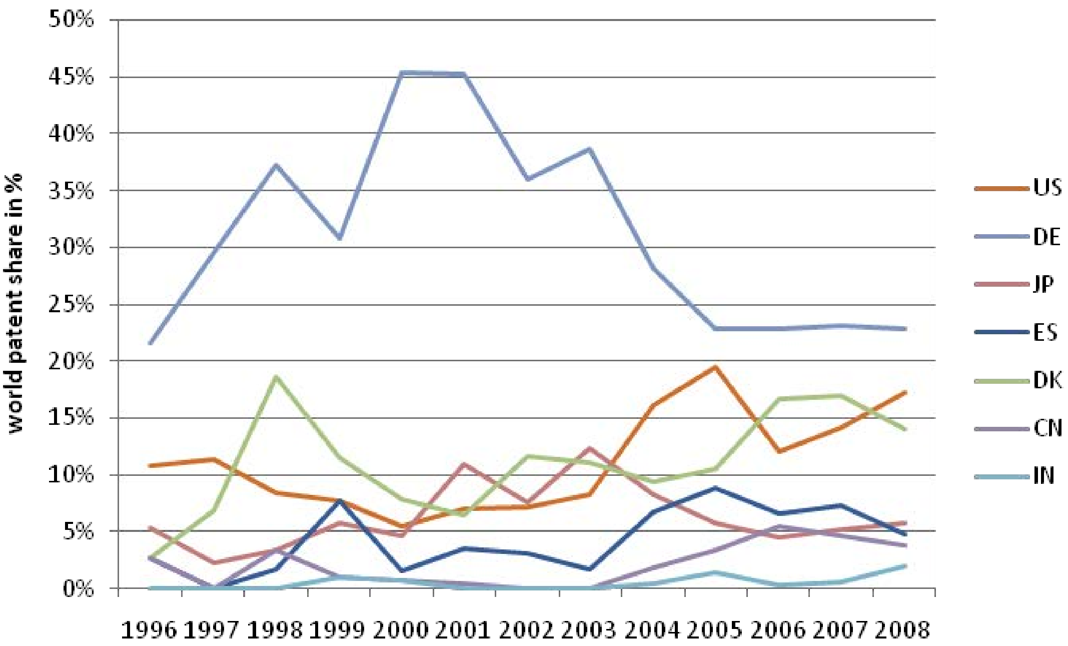


Figure 1-9: Annual world patent shares in wind turbine technology between 1996 and 2008 (Walz & Delgado 2010)

The patent share in wind technology related areas by producer country is demonstrated in Figure 1-9. However, technology transfer through acquisitions and joint ventures as well as licensing patented technologies from other companies are relatively common within the global wind turbine sector (see also section 1.3.2.2). Therefore, patent analysis can only be seen as one indicator among others when trying to predict future development in this sector.

1.2.2 Market volume and outlook

Looking at the global market volume it becomes apparent that the power market revenues declined in 2010 as a consequence of lower demand and the reduction in wind turbine prices due to the global economic crisis (Figure 1-10). In 2010, the total market revenues of wind power industry amount for approximately 57 billion U.S. dollar. This is about 10 billion dollars less than in 2009 and corresponds to a negative growth rate of 15.6 %.

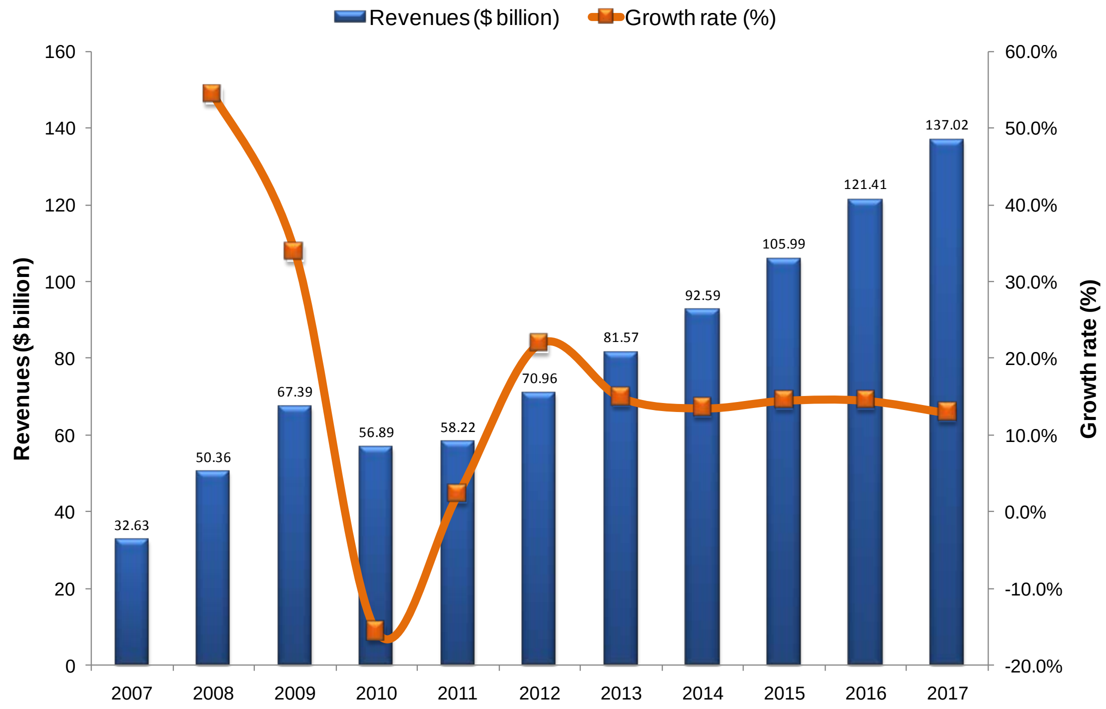


Figure 1-10: Revenue forecasts and growth rate (Frost & Sullivan 2011; own illustration)

Nevertheless, because the demand for wind power is expected to recover in the short to medium term, market revenues are expected to increase as well in 2011 and 2012. After the recovery period, the annual growth rate of wind power industry is expected to level out at a compound annual growth rate of about 13 % during the forecast period (Frost & Sullivan 2011). This indicates continuous and, compared to the previous years, maturing of the market.

Despite the restrained development of revenues, the installed capacity of wind power turbines has continuously increased in 2010 to 191,025 megawatts of onshore, and 3,449 megawatts of offshore capacity (

Figure 1-11). Although the forecast predicts the highest growth rates for offshore facilities, they will only still account for a minor proportion of installed wind turbine capacity in the future. In 2010, offshore installations represent only 1.8 % of the total wind power market.

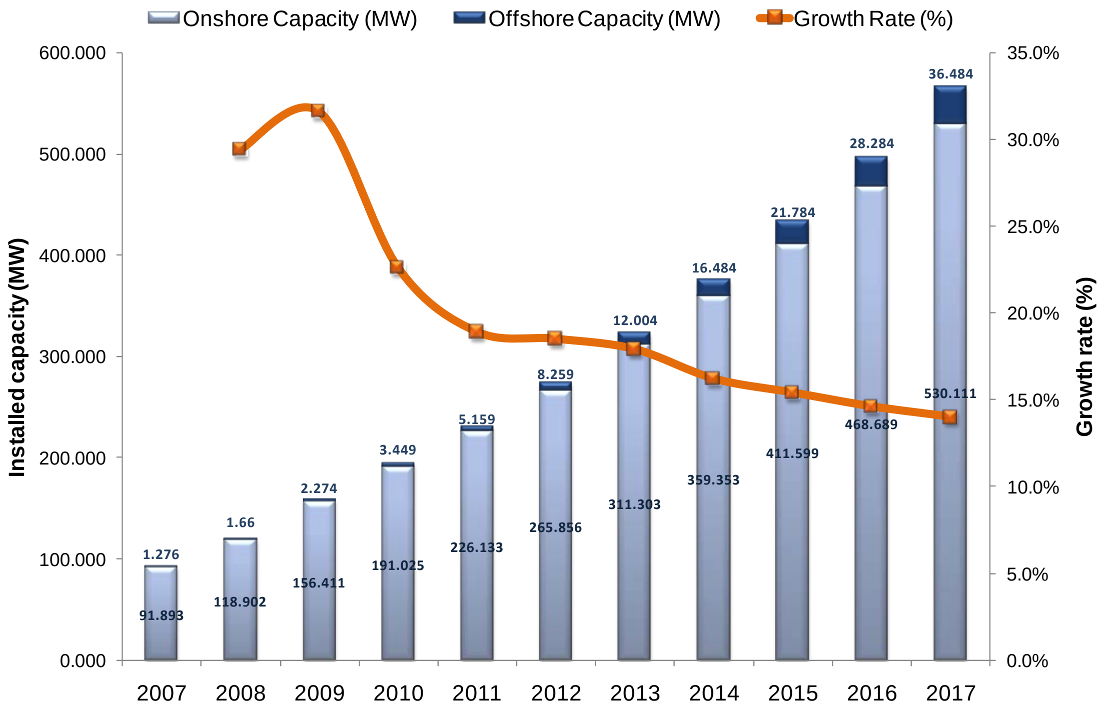


Figure 1-11: Installed capacity forecasts and growth rate (Frost & Sullivan 2011; own illustration

According to the market forecasts of Frost & Sullivan (2011), the global wind power market is expected to continue growing at a compound annual growth rate of 16.5 %, reaching 566,595 megawatts in 2017. Again, having experienced exorbitant growth rates in the previous years of more than 30 % p.a. between 1996 and 2009 (Hirschl et al. 2010), this average growth rate of installed capacity indicates a steady-state but decelerated development of installed capacity.

1.3 Market actors

A comprehensive overview of the wind energy sector requires highlighting the central elements and players along the wind energy industries' value chains. Figure 1-12 presents a systemic overview on the wind turbine industry's value chains.

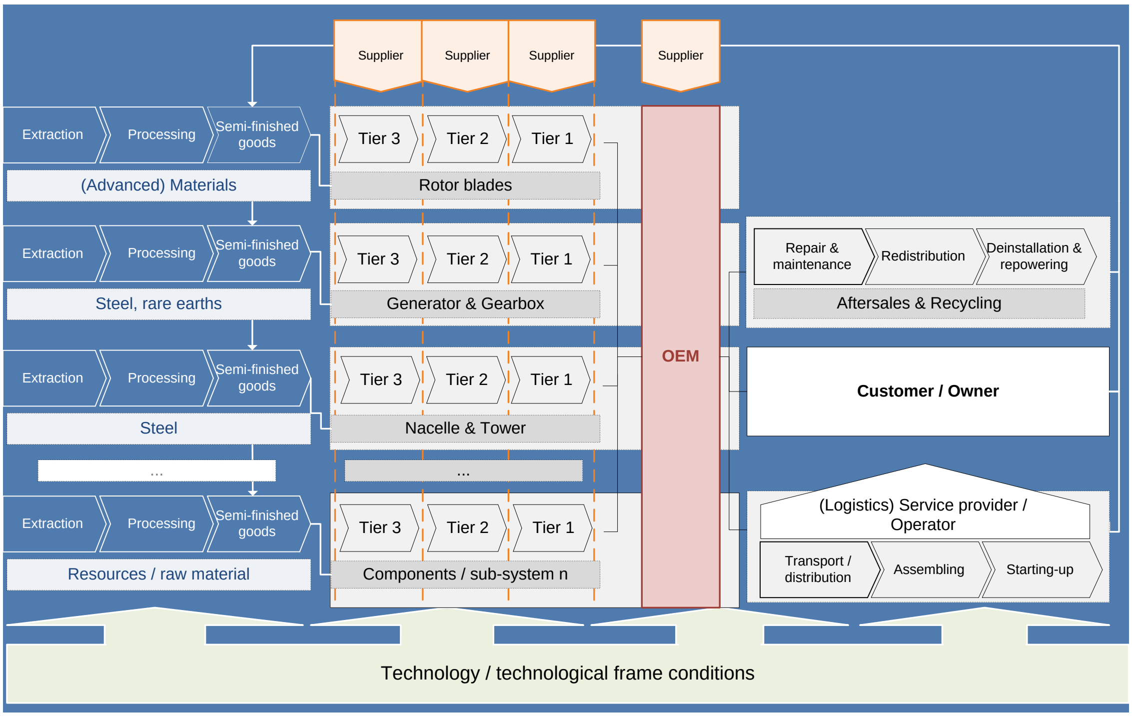


Figure 1-12: System of value chains in wind turbine industry (Fraunhofer ISI)

Of course, the most central actor in these value chains is represented by the entity of original equipment manufacturers (OEM). While some OEM mainly act as suppliers of wind turbine technology to be integrated into a wind farm by operators or owners, some manufacturers also offer an engineering, procurement, installation and commissioning (EIPC) option for all aspects of a wind farm.

The OEMs are provided by a multilevel system of component suppliers, for instance with the essential elements of rotor blades, gearboxes, generators, nacelles, and towers. Hereby, first tier suppliers are defined as companies that provide or supply components, consumables, and parts to the original equipment suppliers and developers, while second and third tier suppliers are those companies that provide component parts to the first (second) tier suppliers, such as electronics and electrical components, machined parts, flanges, fixings, etc. However, as it will be shown below, the density of the supplying network obviously varies with each OEM's vertical range of manufacture. While some OEMs get most of the components from suppliers, others produce most of the components such as blades, gearboxes or towers on their own.

Direct customers of wind turbines are diverse including project developers, independent power producers and electric utilities. Figure 1-13 shows the largest 15 wind farm operators worldwide. These owners of wind farms or wind power facilities are supported by operators and service providers that provide warranties, service and maintenance contracts along with the sale, installation, and commissioning of the wind turbines. On a global scale there has been a major shift in the customer base of wind energy market which affects the relationship with and the requirements on the turbine manufacturers. Larger financially strong companies increasingly invest in wind energy generating assets and start expanding into this business. In most cases they are large utility companies, independent power producers or companies from oil and gas industry. The previously fragmented wind operating market is increasingly consolidating; the 23 % market share of the top 15 operators in 2003 has increased to 36 % in 2008 (BTM Consult ApS, 2009). The financial crisis of the late 2008 and 2009 even accelerated this change in the ownership structure in Europe and the US. The wind operating market has changed from a previously private equity investment model particularly driven by tax benefits towards a corporate investment model performed by large operators. This trend has been reinforced by two aspects: first, a global (EU, US and China) trend can be observed towards forcing utilities to include a certain percentage of renewable energy sources into their power generating assets (renewable portfolio standard). Secondly, the extensive capital requirements for the increasing size of wind farms combined with a more favorable access to cheap financing by large utility companies.

Today large and globally operating turbine suppliers are in advantage as they are able to better match the needs of their large and internationally active customers. Furthermore, even large and international suppliers of wind turbines need to achieve a higher operational quality and efficiency in order to meet professional standards of their new super clients (BTM Consult ApS 2009; Roland Berger Strategy Consultants 2010).

Last but not least, the extraction, processing and supply with raw materials, resources and semi-finished goods builds the starting point of the wind turbine value chains. They are significantly shaped by the availability of certain raw materials and natural resources such as, for example, steel and rare earths. The requirement for certain raw materials and resources is finally also influenced by technological developments and trends which build the most relevant frame conditions for industrial value chains of wind turbines.

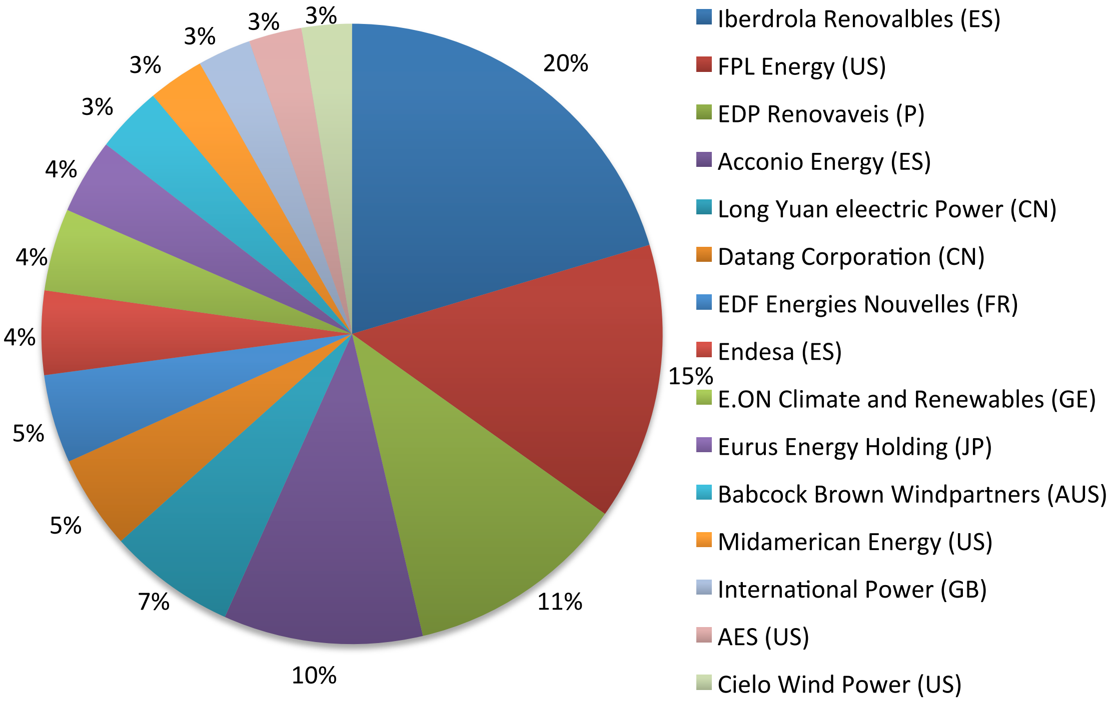


Figure 1-13: Market share of major utilities and IPPs (Delgado 2010)

In the coming sections, the following aspects will be addressed:

- Analysis of OEMs manufacturing structure and market characteristics
- Discussion of main technological developments and future trends
- Structure and challenges of suppliers in the wind turbines' value chain

The field of customers' demand and corresponding future scenarios is addressed by chapter 3. Due to the focus on industrial manufacturing of wind turbines, the aspects of aftersales, operating issues and grid connection will be not discussed here. Also not covered is the recycling of wind turbines. To a first approximation, the recycling of wind turbines should be considered equivalent to the recycling of any other large piece of industrial equipment. An exception to this are the rare earth magnets in direct drive turbines, for which there are currently no established recycling systems in the EU and technology development is still required and ongoing.

1.3.1 Original Equipment Manufacturers (OEM)

The aim of this first chapter is to cast a glance on the OEMs' structure within the wind turbine industry and their global footprint in terms of global market shares and globally distributed range of manufacture. This aspects are illustrated by the following figures which are mainly based either on the information contained on the corresponding OEMs' website or already existing studies.

This market volume is distributed among a number of important players (OEMs) of the global wind turbine industry (Figure 1-14). As this overview shows, the wind turbine manufacturers' market is still characterized by a heterogeneous nature. All in all the market is characterized by three major clusters of wind turbine OEMs:

- Pioneer wind turbine manufacturers (e.g. Vestas, Gamesa, Suzlon, RePower, Enercon)
- Regional focused players within growth markets (e.g. Goldwind, Sinovel, Dongfang (DEC), Unison)
- Large industrial corporations: (e.g. General Electric, Siemens, Alstom)

Figure 1-14: Wind turbine manufacturers (own illustration)

In general, the world market is currently operated by nine wind turbine OEMs that cover almost 80 % of the global market (Figure 1-15). The OEMs with the highest market shares are Vestas from Denmark and GE Energy from the United States with about 12.5 % market share. They are followed by a midfield of several OEMs with between 8 to 9 % and a large group of wind turbine manufacturers with market shares of almost 6 % to about 7 %.

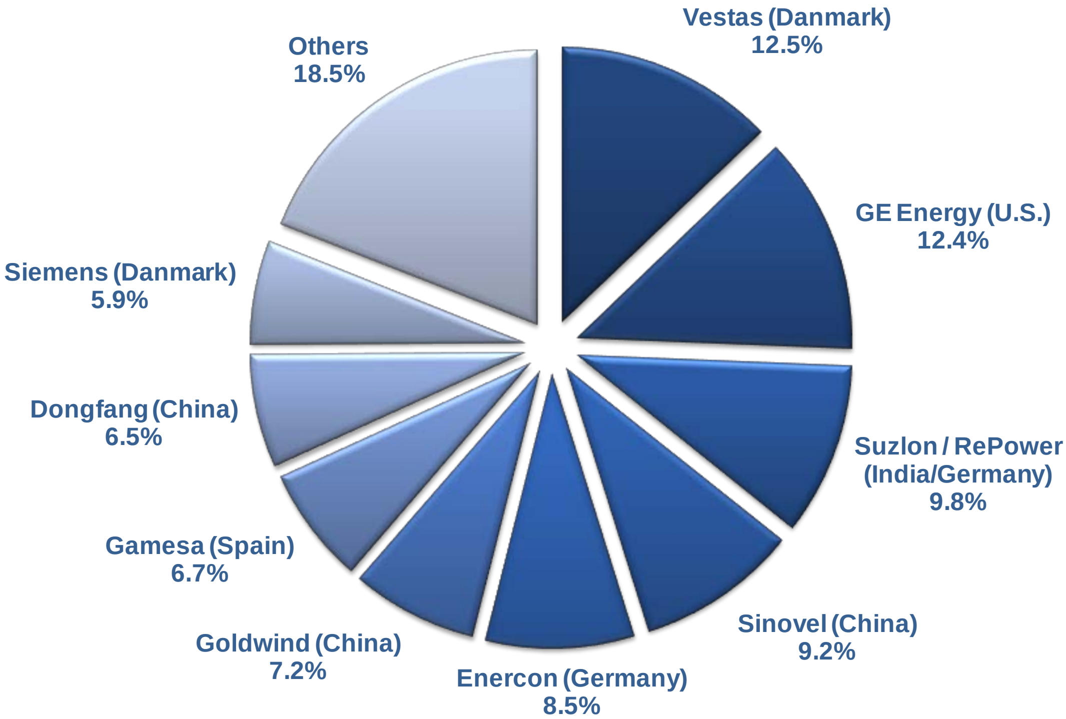


Figure 1-15: Global market shares of wind turbine manufacturers in 2010 (Hirschl et al. 2010; own illustration)

Looking at their market shares in more detail, the following figures (Figure 1-16 and Figure 1-17)) show that most of the wind turbine manufacturers are currently active in the field of onshore installations. The highest market shares are hold by Vestas and General Electric, followed by Gamesa, Enercon, and Suzlon. This point to the fact, that the field of onshore wind turbines also offers large potentials for small or regional OEMs to achieve considerable market share in regional, fast-growing markets like Asia or India. It becomes apparent that the onshore market is driven by a considerable number of OEMs which implies strong market competition. Nevertheless, most of the OEMs were able to increase their market share from 2009 to 2010, particularly Vestas, General Electrics, Enercon, and Suzlon (Frost & Sullivan 2011).

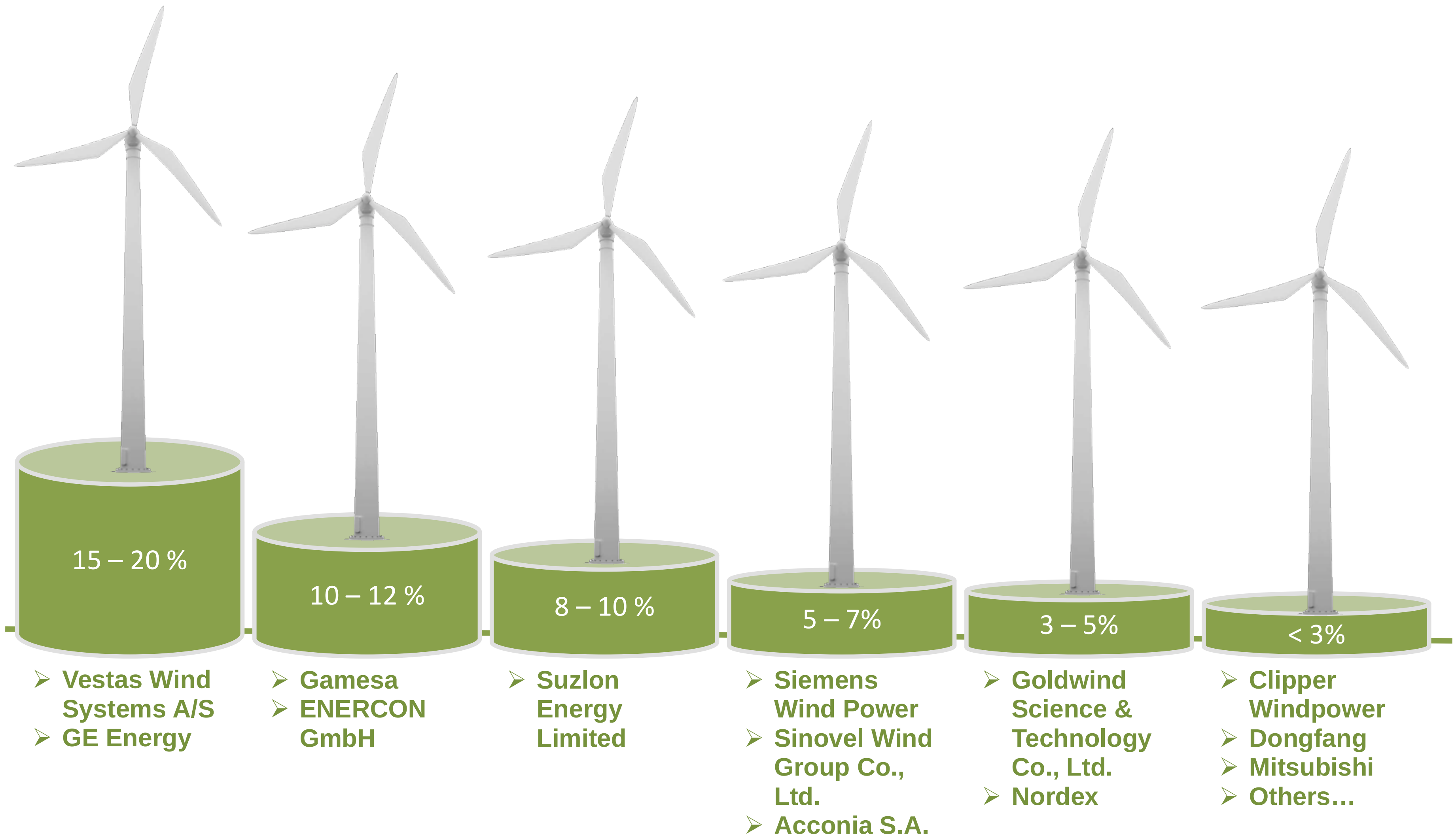


Figure 1-16: Market share of major wind turbine manufacturers based on global onshore installations 2010 (Frost & Sullivan 2011; own illustration)

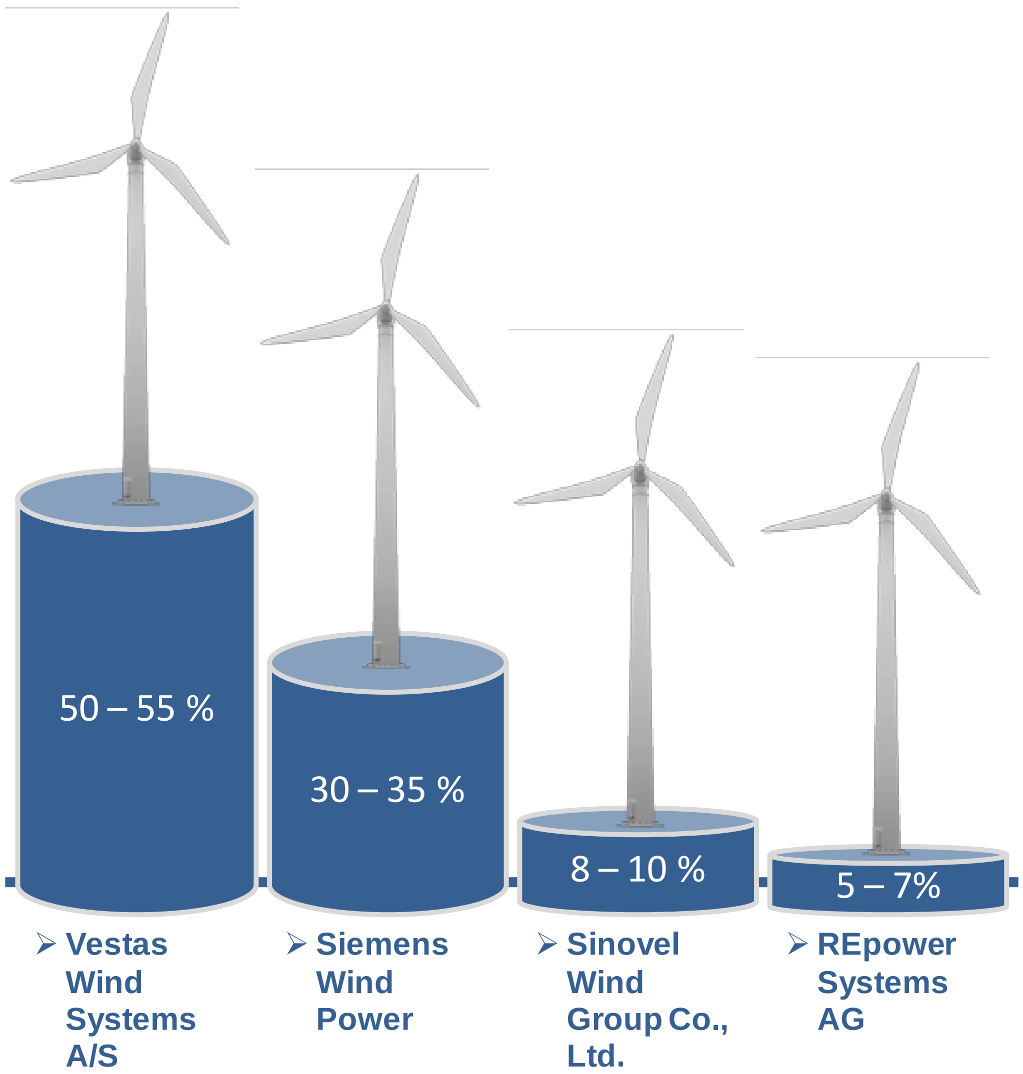


Figure 1-17: Market share of major wind turbine manufacturers based on global offshore installations 2010 (Frost & Sullivan 2011; own illustration)

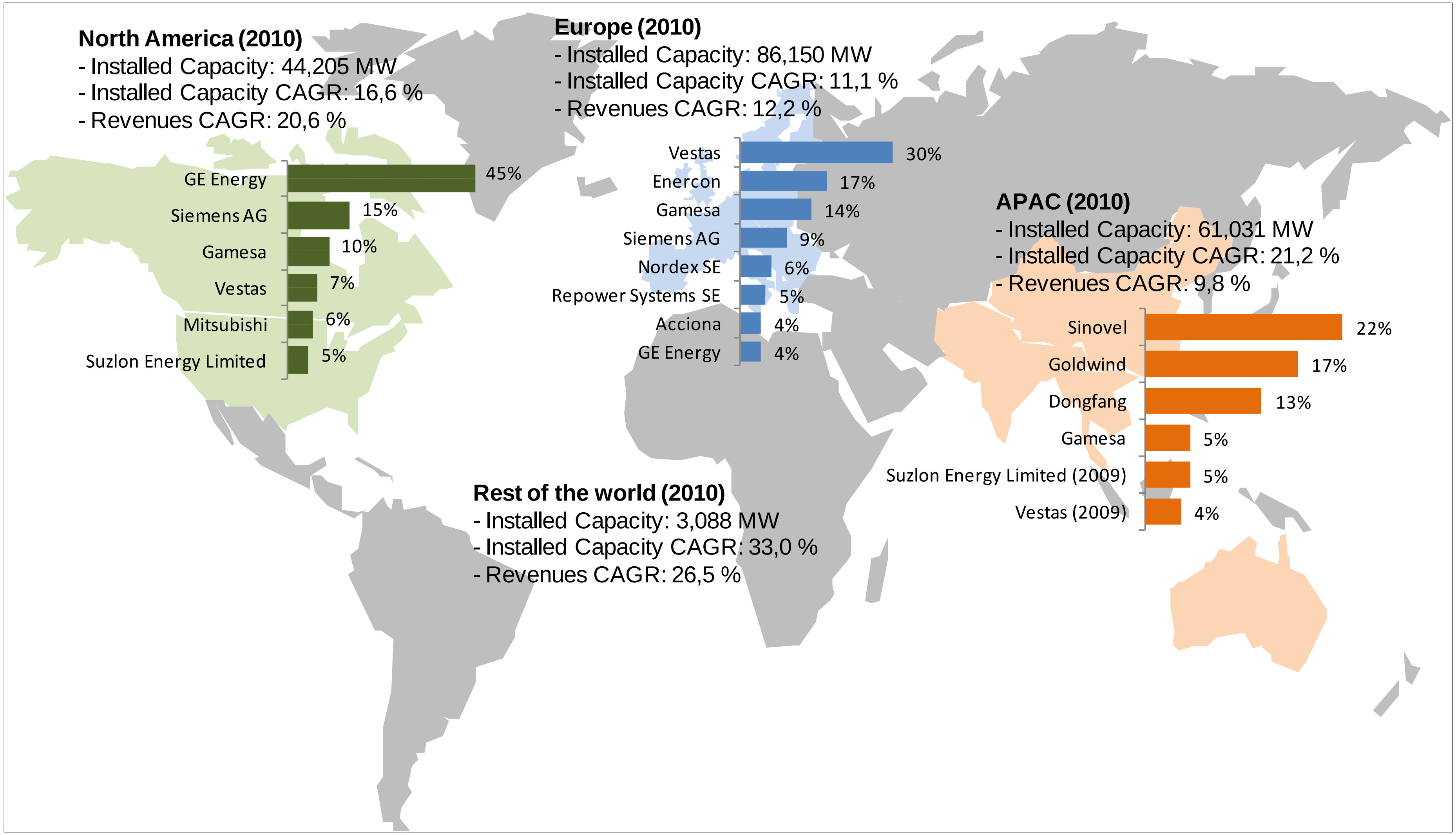


Figure 1-18: Market share range of major wind power facility manufacturers 2010 (Frost & Sullivan 2011, own illustration)

In contrast, the offshore market is so far dominated by only a few OEMs, particularly Vestas and Siemens. They are specialized in large wind turbines with up to 7 MW which are preferably deployed in offshore wind farms. There are no size limits to offshore turbines because transportation and installation are carried out at sea.

Last but not least, the OEMs' market share also varies with their regional affiliation (Figure 1-18). It can be seen that most of the large wind turbine OEMs are active on the global market. Nonetheless, regional OEM report by far for the highest market shares in their corresponding regional market (e.g. GE Energy in North America, Vestas in Europe, and Sinovel in the Asia Pacific region). Hence, despite the existence of global active, large OEMs, regional markets are still shaped by regional wind turbine manufacturers.

This might be caused by the fact that wind turbines due to their size and technological complexity cannot as easily be transported around the world like machinery or consuming goods. Being the wind turbine manufacturer with the highest global market share, Vestas for example maintains manufacturing facilities almost all around the world. Likewise, all of the major OEMs with global activity listed in the table have various manufacturing locations in their relevant markets (Table 1-1). The international pres-ence of wind turbine manufacturers can also be seen in Figure 1-19. Europe, home of most “pioneers”, still leading globally while other manufacturing bases such as USA, India and China are getting stronger by mainly supplying the domestic markets (Walz & Delgado , 2010).

Manufacturer of wind turbine	Countries with manufacturing location
Vestas	Denmark, China, USA, Germany, India, Italy, Norway, Spain
Suzlon Energy Limited	USA, India, China
Enercon	Germany, Sweden, Portugal, Brazil, Canada, Turkey
Gamesa	Brazil, USA, Spain, China, India,
Siemens AG	Denmark, China, USA
Dongfang	USA, Denmark
Repower Systems SE	China, Portugal, Germany
Nordex SE	China, USA
Sinovel	China, Inner Mongolia

Table 1–1: Manufacturing locations of selected wind turbine manufacturers

Hence, if a wind turbine OEM decides to engage in foreign markets, the mere establishment of a local sales and service network is not sufficient. Instead, global active wind turbine manufacturers are forced to set-up a complete production facility in the corresponding country in order to manufacture critical components locally. This aspect is exemplified by looking at the global distribution of manufacturing facilities of the three large OEMs Vestas, Suzlon and RePower Systems SE (Figure 1-20). In contrast to cost-driven relocations of production of other industries, the establishment of global manufacturing facilities in case of wind turbine manufacturing industry is driven by market activity. It is not the OEMs intention to replace home base production by relocating manufacturing facilities abroad to reduce labor costs. Instead, some of the components are produced simultaneously at different locations around the world to make them available in the local market without taking the risks, costs and enormous logistic challenges of transportation.

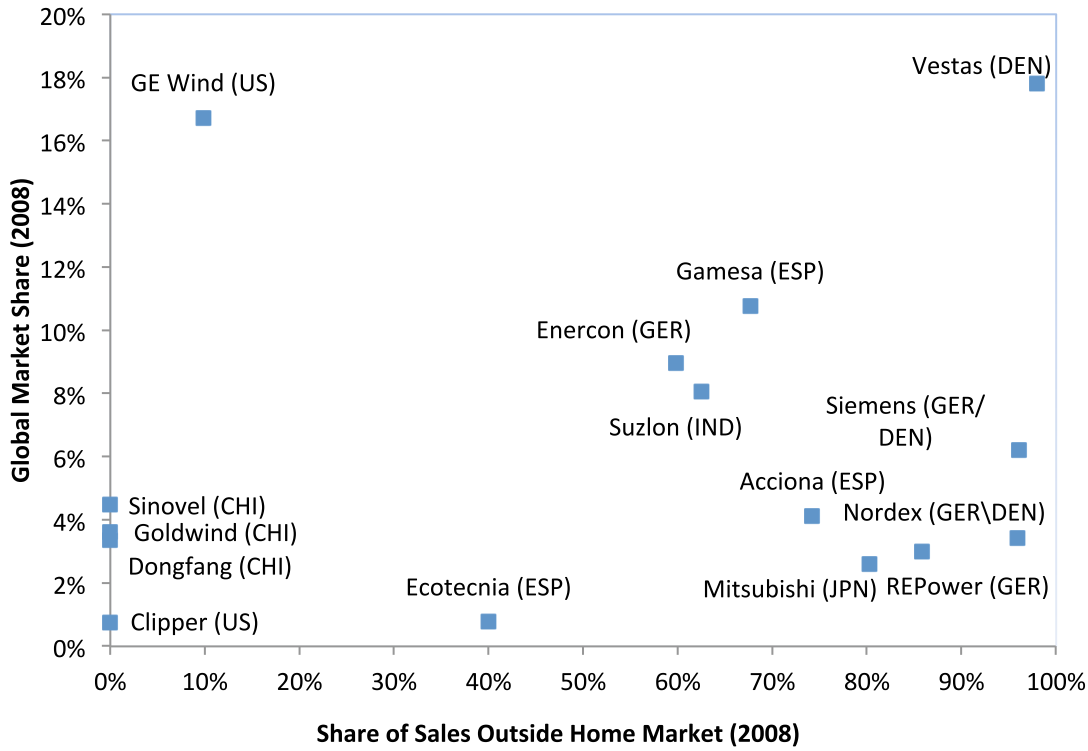


Figure 1-19: Share of outside home markets of major wind turbine producers (Delgado, 2010)

Regarding the globalization strategies and global set-up of production facilities, different strategies can be observed (May & Weinhold 2007; Roland Berger 2010):

- Late set-up of production facilities: the wind turbine Pioneer Vestas entered the U.S. market at the beginning of 2000. However, Vestas started to establish its first production facility for rotor blades in the U.S. only in 2008. The advantage of this strategy is to avoid the risk of loss the capital investments in the foreign location in case the demand side does not evolve as expected. Additionally, this strategy allows for thoughtful design and planning of foreign production facilities and processes accord-ing to the specific needs of the regional market. However, this strategy also takes the risk to miss out significant market potentials because the firm is not able to provide short and flexible delivery times due to the long and expensive transport of components.
- Early set-up of production facilities: Gamesa became an independent wind turbine manufacturer after redemption from Vestas and followed the approach of early set-up of foreign manufacturing facilities (rotor blades, nacelles, tower) in Spain and the U.S. between 2005 and 2007, followed by further facilities in China, Brazil and India. Today, Gamesa maintains 29 production facilities around the world. Similarly, in 1996 and 2002 the German company Enercon erected two production facilities for rotor blades in Brazil. On the one hand, this strategy runs the risk of losing capital investment in case market success does not appear as calculated in the models. On the other hand, this early-bird strategy enables the firms to position themselves on the regional market and to attract regional customers at an early stage.
- Regional concentration of production facilities: this strategy is mainly pursued by smaller wind turbine manufacturers who do not have the financial and human re-

sources to maintain a dedicated production facility for each regional market in the world in which they are active in. For example, Repower Systems maintain production facilities in the U.S., Europe, China, and Australia to serve the big regional mar-kets and to come to a compromise between being relatively close to the market by providing acceptable delivery times through manageable transportation and minimizing investment costs for setting-up production facilities in each country. Nonetheless, the ability to penetrate regional markets is less intensive than in case of a manufacturer who is located directly on-site.

- Market entrance through a mix of own manufacturing and acquisition of components from local suppliers: this strategy was pursued for example by Vestas when entering the Indian market. Vestas decided to manufacture the nacelles for their wind turbines in their local production facility while rotor blades are provided by a local supplier in India.
- Erection of manufacturing facilities on the basis of already existing corporate facilities: obviously, this strategy is reserved to large international energy corporations like Siemens and General Electric who can fall back on a large network of already existing production facilities around the globe. In the case of Siemens, the underlying rationale behind their global expansion is to establish industrially well-functioning (lean) processes in the home base and then transfer or even duplicate this industrial set-up to manufacturing facilities abroad.

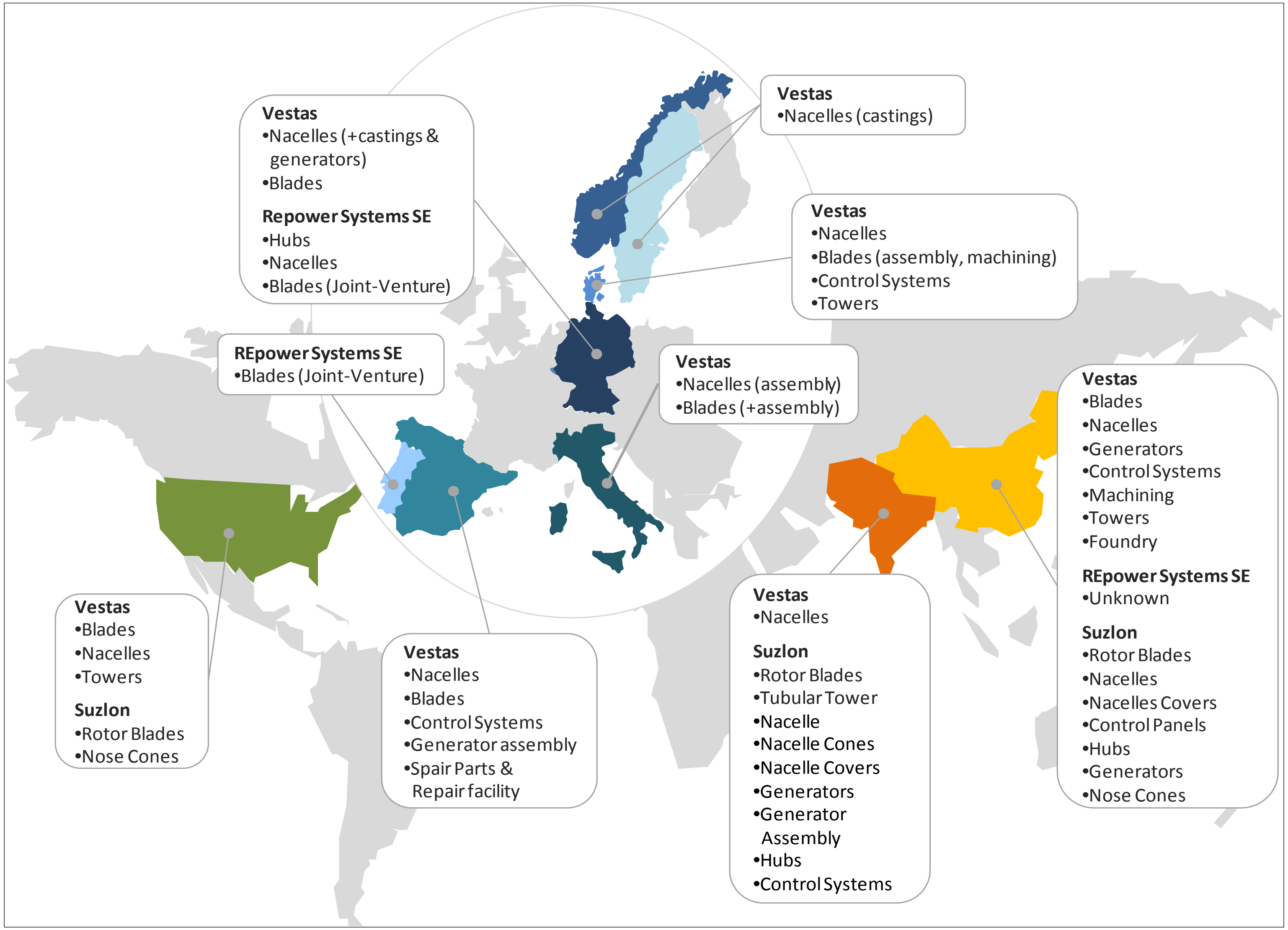


Figure 1-20: Worldwide distribution of production facilities of four large wind power facility manufacturers (OEM websites from Vestas 2011, Suzlon 2011, Repower Systems SE 2011; own illustration)

A very interesting question about these different strategies of wind turbine OEMs' globalization is to which degree they are based either on established suppliers in their home market or the acquisition of new suppliers on the regional and local markets. For instance in emerging regional markets OEMs are constrained by local content requirements to build up local facilities or to buy a certain quota of the pre-products from local suppliers. Especially for the established suppliers at the home base, these globalization strategies might be accompanied by severe implications regarding their ability to pro-vide their wind turbine OEMs with same high-quality components around the world. This point will be revisited again later.

To manage these global activities and maintain such a number of globally distributed multiple manufacturing facilities; most of the relevant wind turbine OEMs belong to the group of large enterprises and industry corporations (Figure 1-21).

Even the small firms like Fuhrländer, Sinovel, Nordex or Repower Systems count between 700 to 2,500 employees. This underlines the high labor intensity and complexity of wind turbine manufacturing which requires for a certain critical mass of employees. Small and medium sized enterprises (SME) are hardly to be found among the group of wind turbine OEMs. Moreover, Siemens and General Electric represent two of the world's largest energy corporations which cover all relevant energy sectors from nuclear power facilities and coal power stations to hydroelectric plants.

To summarize this consideration of wind turbine OEMs, the findings appear quite ambiguous. On the one side, there are still observable consequences of previous boom years. The wind turbine market is still characterized by a heterogeneous and fragmented set of different OEMs that ranges from large international corporations to smaller and regionally rooted manufacturers. This fragmented structure is also reflected by the different regional market shares of the actors. To date, a globally prevailing wind turbine OEM with a dominant market position on all regional markets is not visible. But, based on the empirical findings, it can be on the other side assumed that the wind turbine market will undergo some consolidation and maturing within the next years. This is for instance underlined by the forecast growth rates which tend to level off at a more moderate level.

Hence, the wind turbine market and its OEMs seems to be on the move and it will be interesting to see how its structure changes and how this will (re-)shape existing and emerging supply chains.

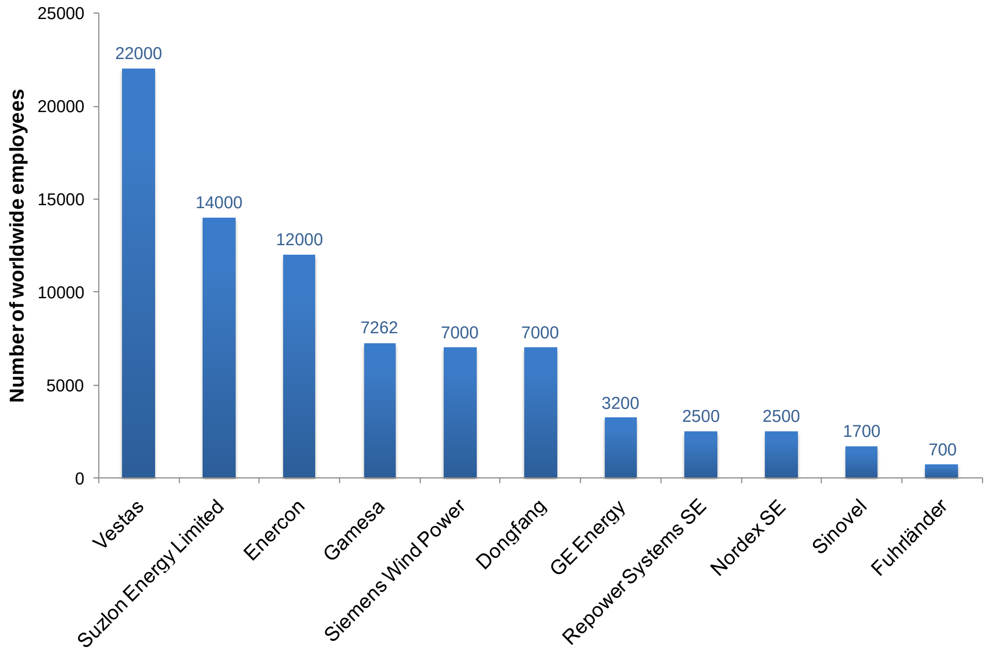


Figure 1-21: Number of wind turbine manufacturers' worldwide employees (OEM websites, Frost & Sullivan 2011)

1.3.2 Emerging markets

The prominent role of emerging markets, especially of China, warrants a closer look at their maturity and structure regarding wind power.

Figure 1-22 shows yearly capacity addition for four emerging markets, namely China, India, Brazil and South Africa. While India and especially China have certainly reached a phase of rapid growth, the Brazilian and South African markets are not as developed and may be characterized as being in experimentation and demonstration phases, respectively. Therefore, only China and India will be treated here. Both have profited from the establishment of local production facilities by foreign companies in order to supply local markets. However, the focus of the native wind power industry is different in India and China: while Indian companies are active internationally, Chinese have obtained operational experience in its domestic market only. First attempts of supplying turbines to abroad customers amounted to 17 turbines in 2009 (Walz & Delgado, 2010).

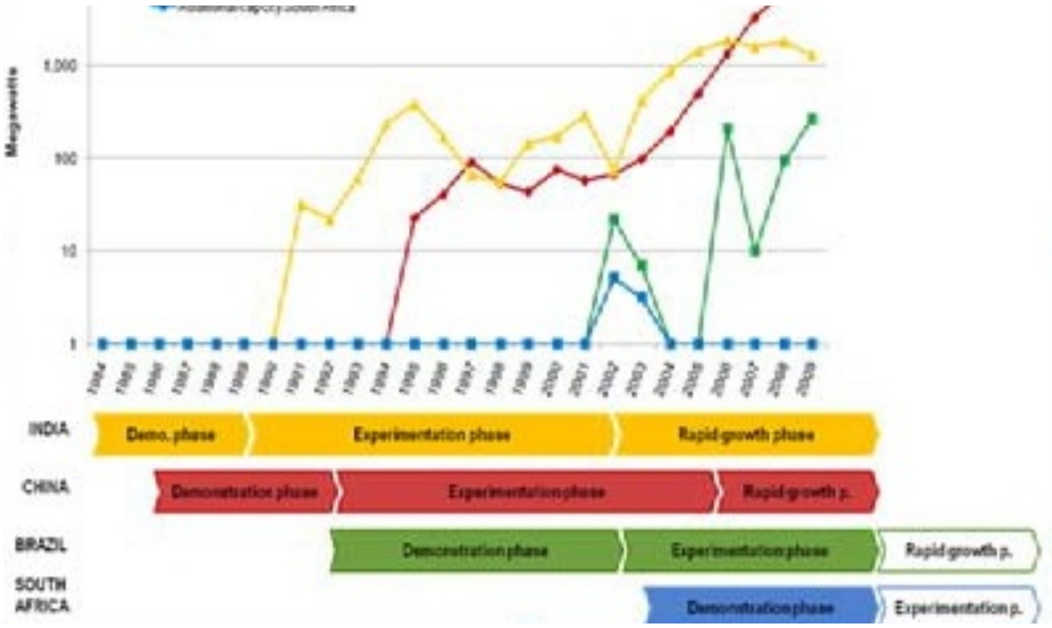


Figure 1-22: Yearly capacity additions within the BICS countries and their respective development phases (Kirkegaard, Hanemann & Weischer 2009)

1.3.2.1 Focus on China

China has successfully manipulated market development in order to build up a domestic wind turbine industry (Delgado 2010). A very strict local content requirement mandated manufacturers to source or produce at least 70 % of the value added in China (Walz & Delgado 2010).Therefore, foreign manufacturers were only able to tap into the Chinese market by partnering with a local player through technology transfer schemes (e.g. joint development / venture or production licensing). Furthermore foreign companies claim to be disadvantaged in assigning public orders in China (Delgado 2010). Table 1-2 shows the installed capacities by local and foreign companies on Chinese wind turbine market. This shows the state as of mid 2009 and reveals a dominance of local companies (cf. Figure 1-

18). While most Chinese manufacturers are state-owned, subsidiaries of foreign manufacturers are privately owned and mostly established through as joint ventures or as a 100 % owned sister company (e.g. Gamesa). Notice that Suzlon, an Indian company, is present with a market share of around 3 %.

Manufacturer	Cumulative until end 2007	added 2008	Cumulative until end 2008	added 2009 (first 6 months)	Cumulative until mid 2009
Sinovel	12.8 %	22.5 %	17.7 %	23.6 %	19.3 %
Goldwind	25.4 %	18.1 %	21.6 %	23.7 %	22.2 %
DEC	4.0 %	16.9 %	10.6 %	12.2 %	11.1 %
Windey	1.6 %	3.7 %	2.7 %	0.6 %	2.1 %
Sewind	0.4 %	2.9 %	1.7 %	3.5 %	2.2 %
Mingyang	0.0 %	2.8 %	1.4 %	4.9 %	2.4 %
XEMC	0.1 %	1.9 %	1.1 %	6.0 %	2.4 %
New Unite	0.2 %	1.2 %	0.7 %	0.6 %	0.7 %
Beizhong	0.0 %	1.0 %	0.5 %	1.9 %	0.9 %
SUM domestic	44.5 %	70.9 %	58.0 %	77.0 %	63.3 %
Vestas	14.5 %	9.6 %	12.0 %	6.4 %	10.4 %
Gamesa	17.7 %	8.1 %	12.8 %	1.3 %	9.6 %
GE	8.3 %	2.3 %	5.2 %	1.9 %	4.3 %
Nordex	3.1 %	2.3 %	2.7 %	1.2 %	2.3 %
Suzlon	3.7 %	2.1 %	2.9 %	3.9 %	3.1 %
CASC - Acconia	1.7 %	2.4 %	2.1 %	0.0 %	1.5 %
SUM foreign	49.0 %	26.8 %	37.6 %	14.6 %	31.3 %
Others	6.5 %	2.3 %	4.3 %	8.3 %	5.4 %
TOTAL	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %

Table 1–2: Market shares of added and cumulative capacity in China from 2007 until July 2009 according to turbine manufacturing company (Walz & Delgado 2010)

Comparison of Figure 1-9 with Table 1–2 reveals that the market share of Chinese companies cannot be based on locally developed technology. Instead, considerable technology transfer has taken place as shown in Table 1-3. For western manufacturers one of the main challenges will be to participate to the rapidly growing market in China on the one hand and to not completely lose technological leadership on the other hand. Companies focusing their research and development efforts in the field of offshore technology might have an advantage in achieving this.

Type of manufacturer	China-based turbine manufacturer	Turbine size	Technology partner, country	Technology transfer mechanism
Domestic first tier manufacturers	Sinovel	1,5 MW	Fuhrlaender, Germany	Joint development
	Sinovel	3,0 MW	Windtec, Austria	Joint development
	Goldwind	0,6 MW	Jacobs, Germany	Licensing
	Goldwind	0,75 MW	Repower, Germany	Licensing
	Goldwind	1,2 MW	Vensys, Germany	Joint development
	Goldwind	1,5 MW	Vensys, Germany	Joint development
	Goldwind	2,5 MW	Vensys, Germany	Acquisition of the foreign company
	Dongfang	1,5 MW	Repower, Germany	Licensing
	Dongfang	2,5 MW	Aerodyn, Germany	Joint development
Domestic second tier manufacturers	XMEC	2,0 MW	Harakosan, Japan	Licensing
	Windey	0,75 MW	Repower, Germany	Licensing
	Windey	0,8 MW	/	In-house development
	Windey	1,5 MW	/	In-house development
	Beizhong	2,0 MW	DeWind, UK	Licensing
Subsidiaries of foreign-owned manufacturers	RePower North	2,0 MW	Repower, Germany	Intra-company
	Vestas	2,0 MW	Vestas, Denmark	Intra-company
	Gamesa	0,85 MW	Gamesa, Spain	Intra-company
	GE Energy	1,5 MW	GE Energy, USA	Intra-company
	Suzlon	1,25 MW	Suzlon, India	Intra-company

Table 1–3: Technology transfer towards Chinese manufacturers (Delgado, 2010)

1.3.2.2 *Focus on India*

In a similar fashion, India has profited from technology transfer from pionier companies, as shown in Table 1-4. An important difference, however, is that India has already been exporting wind turbines for several years, supplying about 16 % of today's total global exports. India takes the third position of wind turbine exports after Germany (41.3 %) and Denmark (25.8 %). Like in China, the Indian market is dominated by local companies, prominently Suzlon with more than 40 % market share (see Table 1-5).

Technology transfer mechanism	India-based turbine manufacturer (start of operations)	Technology partner, Country	Turbines' capacity (production capacity per year)
Subsidiary of a foreign parent company	Enercon, India (1995)	Enercon, Germany	800 kW
	Gamesa, India (2010)	Gamesa, Spain	850 kW
	Kenersys, India (2003)	Kenersys, Germany	2000 kW
	Leitner (2009)	Leitwind, The Netherlands	1350 kW, 1500 kW (150 turbines)
	Vestas Wind, India	Vestas Wind, Denmark	750 kW, 1650 kW
	GE Energy, India	GE Energy, USA	1500 kW (300 turbines)
Joint development			
	RRB Energy	Vestas Wind, Denmark	500 kW, 600 kW
In-house development			
	Pioneer Wincon	-	250 kW
	Southern Wind Farms	-	225 kW
	Suzlon Energy, India	Suzlon Energy, Germany	1500 kW, 2100 kW
Licensing			
	Global Wind Power	NORWIN, Denmark	750 kW
	RegenPowertech	Vensys, Germany	1500 kW
	Siva Windturbine	Wind Technik Nord, Germany	250 kW
	Winwind Power Energy	Winwind, Finland	1000 kW

Table 1–4: India-based manufacturers of models in possession of a C-WET certification (Delgado, 2010)

Manufacturer	Cumulative capacity (MW)	Share
Suzlon Energy	4493	44 %
Enercon	2009	20 %
Vestas Wind	1274	13 %
RRB Energy	872	9 %
NEPC-Micon	325	3 %
NEPC-India	234	2 %
Pioneer Wincon	143	1 %
Shriram EPC (TTG)	108	1 %
Southern Wind Farms	99	1 %
Regen Powertech	24	0 %
GE Energy	5	0 %
Winwind Power Energy	2	0 %
Siva Windturbine	1	0 %
Others	594	6 %
TOTAL	10182	100 %

Table 1–5: Cumulative capacity in India by turbine manufacturing company as of 31 March 2009 (Data from Consolidated Energy Consultants Ltd., 2010)

1.3.3 Supply chain

Wind turbines are composed of very different parts and components which range from mechanical components (e.g. gearbox, clutches, hydraulics), electric and electronic/mechatronic parts (e.g. measuring, monitoring and steering systems and software, generator, power transmission) as well as large and heavy industry components (e.g. tower, rotor blades, nacelle). A section of these components is shown in Figure 1-23. This emphasizes not only the huge technological complexity of wind turbines but also the large degree of heterogeneity of the components included and the industries involved which range for instance from metal processing and metal forming via the manufacturing of compound materials and lightweight constructions to manufacturers of electronic and mechatronic parts as well as specialists of drive engineering.

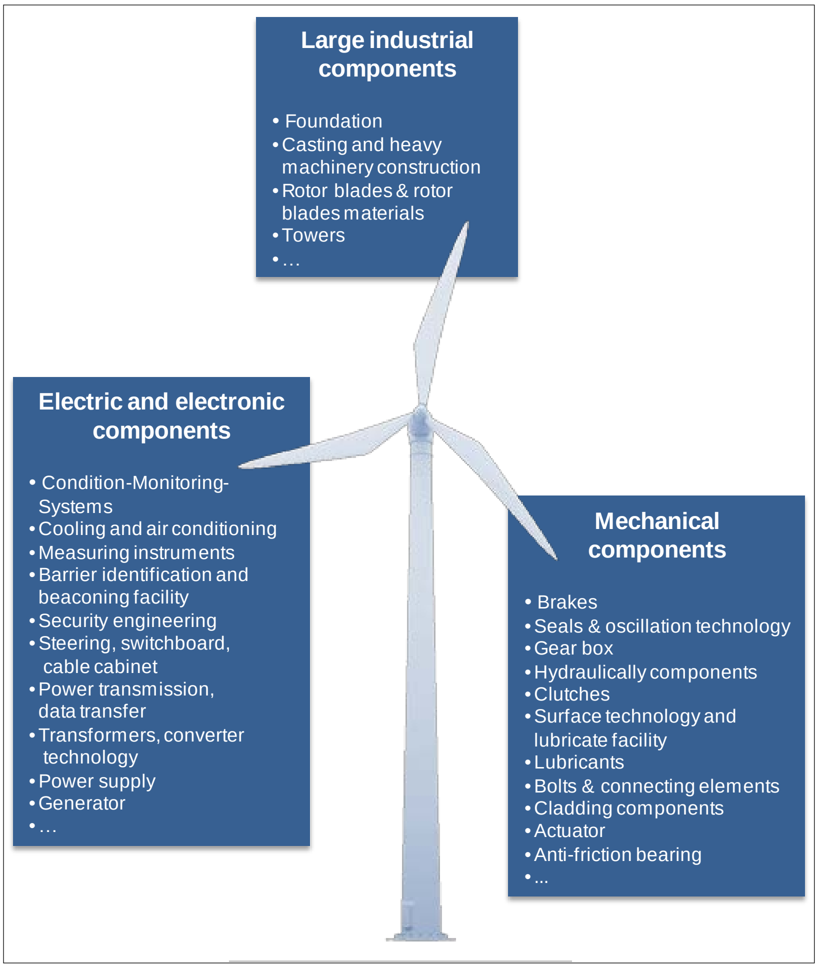


Figure 1-23: Supplying components of wind turbine industry (BWE 2011)

Considering the capital cost structure for a 2 MW wind turbine's main components, the turbine itself amounts for approximately 70 % of the total wind power system, followed by grid connection (~ 17 %) and foundation (< 10 %) (Frost & Sullivan 2011). To take a closer look on the biggest cost factor of turbine, Figure 1-24 below breaks down the turbines' cost structure by its several parts on the basis of an onshore system. As the figure depicts, tower, rotor blades and gearbox account for the biggest share of capital costs. Thus these components represent the highest opportunities for future cost optimization. In contrast, the field of electric and electronic/mechatronic components (e.g. sensoring, yaw system) represents just a minor cost factor. Regarding the production of these components, wind turbine OEMs thereby vary to great extent in their vertical manufacturing range.

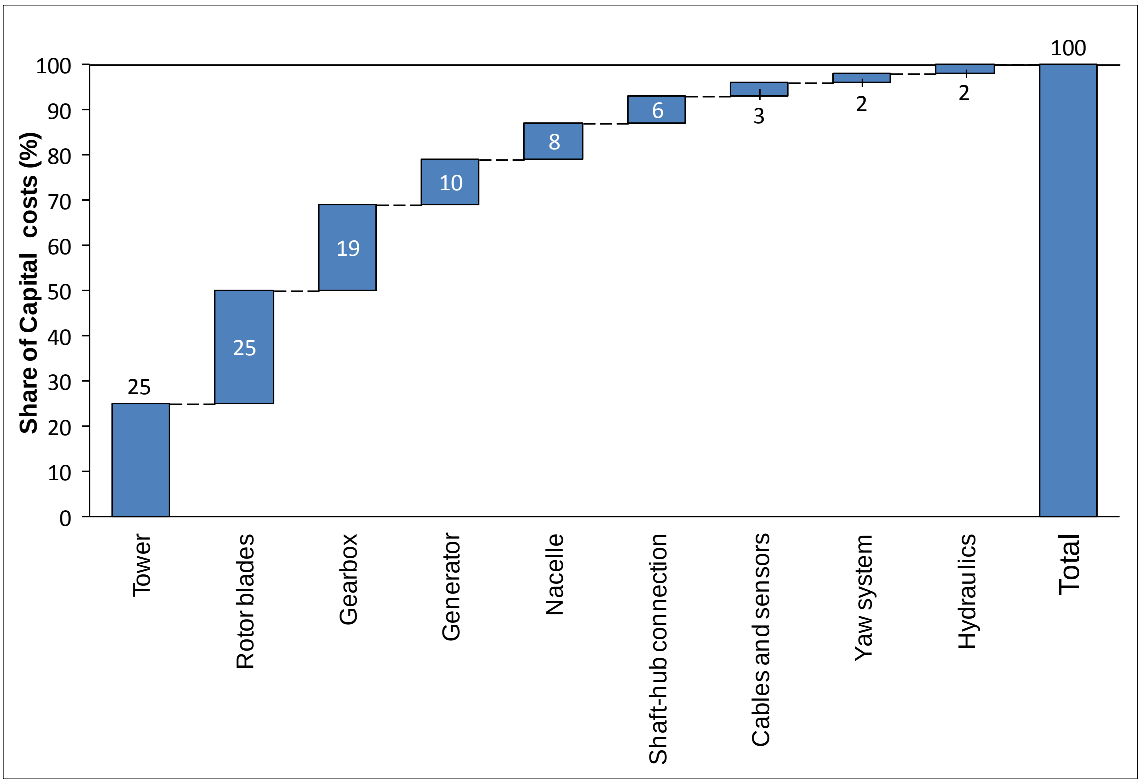


Figure 1-24: Capital cost structure for an onshore wind turbine in 2010 (Hirschl et al. 2010; own illustration)

As the worldwide distribution of production facilities (Figure 9) has already shown above, most of the large wind turbine manufacturers are characterized by a high degree of vertical integration of about 80 % (e.g. Vestas, Siemens). Main components like nacelles, rotor blades, generators, and sometimes even towers are developed and manufactured either in-house or by subsidiary companies (Erste Bank Research 2009).

On the contrary, the group of smaller wind turbine manufacturers (and General Electrics Wind as an exception) confine themselves to the mere assembly of components and global distribution of their wind turbines. They draw on the know-how of specialized suppliers which manufacture the components in large batch-sizes (Hau 2008). In consequence their degree of vertical integration is only about 20 % (Weinhold 2005).

According to the heterogeneous structure and technological complexity of wind turbines, the first and second tier suppliers' sectoral affiliation also ranges from steel and shipbuilding industry, mechanical engineering, aerospace to electrical and chemical industry (Hirschl et al. 2010), and thereby encompass all technology segments from so-called "Low- ‚Medium- and Hightech" Industries. To date, particularly in saturated, less dynamic markets, many of the suppliers have established the component supply for wind turbine OEMs as a distinct business segment that achieves significant shares of sales (Weinhold 2009). For instance, the wind turbine industry today already represents the one of the biggest purchaser of steel in Germany. Moreover, 35 % of worldwide foundries' capacity and up to 12 % of global generator production has been made available by wind turbine industry (Hirschl et al. 2010). Last but not least, the wind turbine industry also plays an important role as a customer of machinery and equipment, particularly in the field of machine tools and special engineering (VDMA 2010).

Due to its multiple interrelations and interdependencies with a broad set of upstream supplying industries inside and providers of machinery and equipment outside the value chain, the wind turbine industry is constantly developing itself to one of the most important industries in industrialized economies. Last but not least, the increasing economic importance of wind turbine industry is also reflected in increasing number of employees and value-added, for instance in case of Germany (VDMA 2010; BWE 2011).

The trends and developments on the OEM and the technology side as considered by the previous sub-chapters can be assumed to result in certain future challenges for the supply chain and the suppliers' innovation and competitive strategies.

There are several indications on the market and technology level that wind turbines will shift from the "pioneer phase" to a phase of consolidation and maturing (Roland Berger 2010). On the one hand, there is a tendency of OEMs to grow and increase their global presence. This is done particularly by means of setting-up production facilities all around the world. On the other hand, a dominant technological design of wind turbines with two major subdivisions of geared and gearless turbines has successfully manifested itself during the last decades. As Figure 1-25 shows, these findings imply that the suppliers along the value chain will be faced with changed requirements in the future:

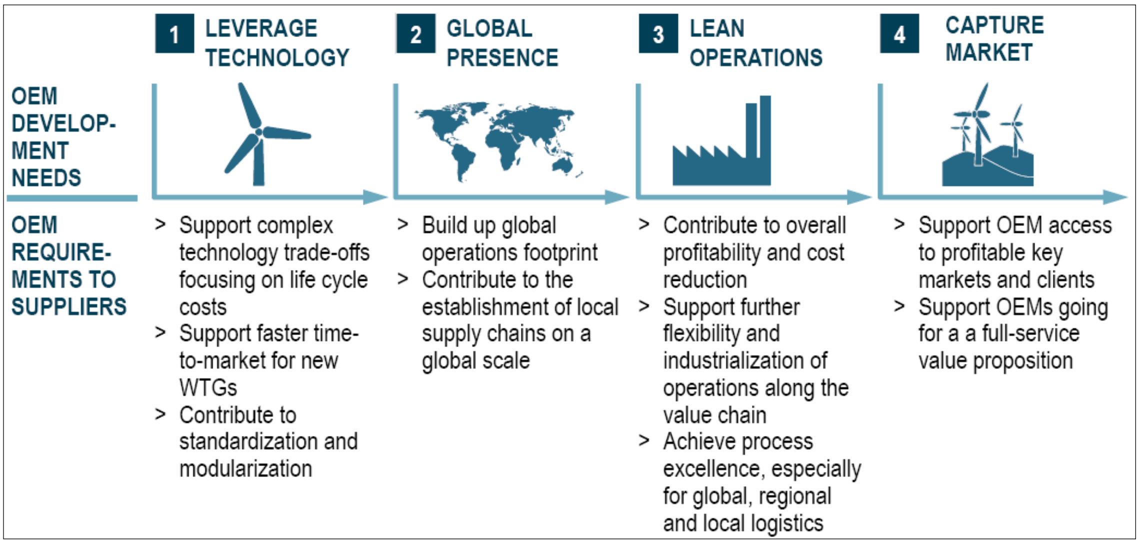


Figure 1-25: OEM developments needs and key requirements to suppliers along the value chain (Roland Berger 2010)

- As the basic technology and design of wind turbines has matured, future technological potentials for differentiation might shift attention to improvements in efficiency, quality and flexibility (e.g. through modularization, standardization, lean manufacturing processes).
- While large wind turbine OEMs with a high degree of vertical integration already have increased their global presence by setting-up regional production facilities, smaller wind turbine manufacturers face the need to increase their global footprint as well in order to exploit market potentials abroad. Because these smaller OEMs are characterized by a relatively low degree of vertical integration, their home base suppliers have either the

option to follow them into their worldwide regional markets and to establish supply chains on the global scale or to be replaced by local suppliers.

- When doing so, however, home base suppliers are forced to engage in competition with local suppliers that, besides their advantage of location, often also might have cost-advantages. Hence, if they want go global, home vase suppliers have to increase their profitability and their process excellence for global, regional, and local logistics.
- Last but not least, the establishment of global presence of OEMs might also cause severe challenges and problems to them. Hence, one opportunity for wind turbine suppliers might also exist in an increased offer of hybrid product-service solutions or support the OEM in accessing new markets and identifying new clients.

However, to meet these challenges, suppliers might be increasingly required to improve and adapt their operational and manufacturing processes to the needs of OEMs. These improvements on supplier side can principally take place by different kinds of innovation activity concerning both, products and processes as well material and immaterial aspects (Figure 1-26).

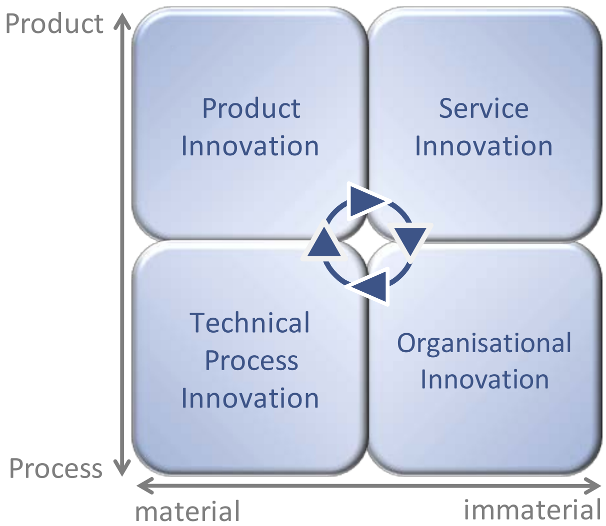


Figure 1-26: Dimensions of firms‘ innovation activity (Kinkel et al. 2004; Dreher et al. 2005)

Examples for concrete strategic options in each innovation field might be:

- *Product innovation:* increased participation in innovation partnerships for the development of new or improved products and components, proactive use of practical and engineering knowledge to trigger new product developments of OEMs, supporting OEMs to overcome technical complexity and challenges of critical components, increased focus on life-cycle costs in product development.
- *Process innovation:* implementation of intensification of use of advanced manufacturing techniques to increase process excellence (e.g. in the field of stock management, production flow, lead time reduction), reduction of manufacturing costs by feeding in industrialization requirements in early stages of technological development, standardization and modularization of manufacturing processes to make them globally available.

- *Organizational innovation:* establishment and improvement of well-functioning organizational and personal interfaces between suppliers and OEM, implementation of lean or comprehensive production systems (GPS), erection and expansion of collaboration networks at a global scale, implementation or intensification of organizational concepts (e.g. continuous improvement processes, teamwork, training and management of organizational and personal skills).
- *Product-related service innovation:* positioning of supplier as a problem solver by increasing the offer of product-related services and full-service propositions like the support and consulting OEMs in the field of new product developments, technical engineering and documentation, repair and maintenance for components, providing logistics solutions, monitoring and administration of supply chains, planning and scheduling of procurement.

1.4 Summary and issues for further research

This chapter has described the structure of the wind turbine industry and has analyzed current and upcoming challenges for the industry. In conclusion, general findings and further research requirements are outlined.

Market development and industry structure

- The global wind turbine industry has experienced exorbitant growth during the last years with average growth rates of more than 30 %. This enormous market growth was mainly driven by increasing government initiatives about energy security and independence as well as incentives on renewable energies. Despite the temporarily decline in 2009 and 2010 due to economic crisis, the global wind turbine industry will keep on growing in all regional markets. Market forecasts expect a compound annual growth rate of 13.4 % for industrial revenues respectively 16.5 % for worldwide installed capacity for years 2011 to 2017.
- As a result of previous periods of high market growth, the actual landscape of OEMs is characterized by a broad range and heterogeneity of actors ranging from wind technology pioneers and smaller regional players to large international energy corporations.
- Because of logistics and transport difficulties of large wind turbine components, almost all of the larger OEMs maintain production facilities in the regional markets distributed around the world. Thereby, different strategies of globalization can be observed, ranging from first-mover to late-comer strategies and from high to low vertical integration. Especially smaller, more regionally active OEMs frequently choose to rely on the know-how of specialized component suppliers while large, multinational OEMs prefer in-house manufacturing of all relevant components.
- There is a high probability that - despite the friendly market forecast - a consolidation within the wind turbine industry is occurring, comparable to the automotive industry in the 1980s and 1990s. The number of OEMs will be declining and merger and acquisition activities will increase with the result that that the future industry structure is characterized by two types of competitive OEMs: An handful of large and global present wind turbine OEMs serving the global market with mass products, and a certain number of small OEMs, which are focused on specialty product segments (technological or regional).

- The consolidation amongst existing players might lead to an aggravated competition within the market. In addition players in particular from China and India are currently expanding their global activities and going to enter the world market. They might establish as strong competitors for the traditional OEMs and enforce the *rivalry* in the wind turbine industry.
- Two mechanisms of market segmentation are expected: A segmentation based on regions (North America, Europe, Asia Pacific, RDW-market) and a segmentation based on application: onshore (important in countries with enough appropriate landscapes like U.S. and Spain) and offshore (important for countries with limited onshore potential, like Germany).

Technological developments

- Wind turbines are not only characterized by huge technological complexity of wind turbines but also by the large degree of heterogeneity of the components for instance strong metal housings, compound materials, high performance friction bearings and lightweight constructions, electronic and mechatronic parts.
- The basic technological development and design of wind turbines has been accomplished during the last decades. Today, the dominant design consists of a horizontal upwind turbine, either with mechanical gearbox or gearless driven by a permanent magnet. Furthermore a new type of turbine design is currently emerging: the so-called hybrid drive turbine.
- Gearless turbines – as the names imply – fundamentally differ from geared turbines in the non-existence of a mechanical gearbox which can be assumed to have great implications in the structure and challenges of the turbine types' value chain and implies a major change in the required raw material basis.
- Main technological developments can be assumed to aim at the improvement and maturing of existing components in terms of an increase of efficiency, reliability, performance and robustness and grid compatibility.

Current and upcoming challenges for the European wind turbine industry (OEMs and suppliers)

- As the basic technology and design of wind turbines has matured, future technological potentials for differentiation might shift attention to improvements in efficiency, quality and flexibility (e.g. through modularization, standardization, lean manufacturing processes).
- While large wind turbine OEMs already have increased their global presence by setting-up regional production facilities, smaller wind turbine manufacturers face an increasing need to increase their global footprint as well in order to exploit market potentials abroad. Smaller OEMs have either the option to follow them into their worldwide regional markets and to establish supply chains on the global scale or to be replaced by local suppliers. Local content requirements for OEMs in certain regional growth markets intensify this necessity.
- Regardless whether home based suppliers collaborate with large or small OEMs they are forced to engage in competition with worldwide suppliers that, besides their advantage of location, often also might have cost-advantages. Hence, if they want go global, home

based suppliers have to increase their profitability and their process excellence for global, regional, and local logistics.

- Last but not least, the establishment of global presence of OEMs might also cause severe challenges and problems to them. Hence, one opportunity for wind turbine suppliers might also exist in an increased offer of hybrid product-service solutions or support the OEM in accessing new markets and identifying new clients.

For mastering these challenges, different kinds of innovation efforts concerning both, products and processes as well material and immaterial aspects are advisable.

Issues for further research

The current situation of the wind turbine industry is characterized by two global trends. On one hand the economic importance of wind turbine industry has been steadily increasing within the last year. This trend is expected to be continued in the future. On the other hand the sector is faced with some severe economical and technological challenges and discontinuities. If the European wind turbine industry cannot master these challenges, the economic severely impacts both on the micro and macro level might be significant.

These sectoral trends are barely reflected in research. Most of the existing research studies focus on the market development of wind power industry in general and wind turbine manufacturers in particular. If at all, the implications for underlying supply chain structures are only addressed in terms of general trends and challenges. Based on the findings we deduced some important issues for further research:

Comprehensive analysis of the European innovation system of wind turbine industry:

- What are the specific roles and interrelationships between private, public and market actors? How can they be measured in terms of flows of goods and knowledge?
- What are the determinants for the innovation system’s innovative and competitive performance?

Comprehensive analysis of supply chains in wind turbine industry:

- How will supply chains develop in the context of different technological and market scenarios?
- To what degree will interrelations along the upstream supply chain be affected by these developments?
- What are the requirements and challenges for the actors along the supply chain that result from these scenarios?
- How do strategic raw material supply issues affect the development of the sector in general and the decision of individual actors in particular?
- What effect may current technological developments (e.g. use of superconductors) have on the structure of the supply chain and on the strategic dependencies for raw materials?

Implication analysis of wind turbines market consolidation on the suppliers' innovation and competitive strategies:

- How can suppliers respond to changed market frame conditions in terms of their innovation and competitive strategies? What are strategic leverages, and how can they be implemented?
- How can existing technical manufacturing techniques and organizational concepts which have established in other industries be transferred and adopted by firms within the wind turbine industry?
- What are future requirements of wind turbine manufacturers on their machinery and equipment suppliers?
- How can firm maintain and extent their knowledge base by measures of organizational and personnel skill development?

2 Scenarios of future energy demand

European Institute for Energy Research – EIFER

Beside specific issues like rare earth and standards and best practices for wind power facility producers and wind power facility operators a presentation of possible long term future development paths in form of scenarios could be in addition beneficial. An overview of a selection of current studies in particular for Germany, but also to a minor extend for China, India and Denmark for the energy market is given.

The study starts with the description of scenarios of various research institutes (consortia) for the energy demand side, the prediction of the development of main economic sectors and the energy transformation sector. The section of the report closes with a comparison of the various reference scenarios of the research institutes.

2.1 Description of considered studies

Studies were considered which:

- Do not date before 2007, including data for 2005
- Refer to the scope of Germany
- Include scenarios, preferably to 2030 or to 2050
- Cover reference scenarios with a large spectrum of projecting institutions
- Each bases on an elaborated and transparent model

2.2 Germany

The scenarios are listed in the order of publication time, not as presented in the study.

Source	Scenarios
DG TREN (2007)	Reference scenario
EWI/Prognos (2007)	Coalition agreement (=Reference) | Nuclear Extension | Renewable energies
BSR-Sustainability/ECF/FhG ISI/Öko-Zentrum NRW/PIK (2008)	Energy need with and without measures of the Meseberg-Program, 2005-2030
Nitsch, J (2008b)	Reference | 3 "Efficiency" scenarios, meaning achievement of renewable objectives | 2 "Deficiency" scenarios, meaning failure to meet renewable objectives
FZJ-STE/VDI (2009)	Low price, nuclear extension | High price, nuclear extension | High price, nuclear phase out
DLR/Fhg-IWES/IfNE (2010)	"Leitstudie 2010" on behalf of BMU, Basic scenarios A und B | Basis scenario B + 100 % REN in 2050 + Hydrogen|
EWI/Prognos (2010)	Energy concept agreement (=Reference) | Nuclear Extension | Renewable energies
IER/RWI/ZEW (2010)	On behalf of BMWi, Reference prognosis | Version with prolongation of operating time of 40 years | Version with prolongation of operating time of 60 years
Öko-Institut/Prognos (2010)	On behalf of WWF, "Reference", |"Innovation" scenario, meaning implementation of far reaching objectives
SRU (2010)	100 % renewable self-sufficiency | 100 % renewable self-sufficiency with intra-period exchange with Denmark and Norway | 100 % renewable with max. 15 % imports from Denmark and Norway | 100 % renewable with max. 15 % from EU or North Africa; two variants of each scenario with 500 TWh/a in 2050 vs. 700 TWh/a
UBA (2010)	Reference scenario

Table 2–1: Characterisation of scenarios

Source	PEC	FEC	Gen.	Elec.	Time
DGTREN (2007)	X	X			1990-2030
BSR-Sustainability/ECF/FhG ISI/Öko-Zentrum NRW/PIK (2008)					2005-2030
Nitsch, J (2008a, 2008b)	X	X	X	X	2000-2050
FZJ-STE/VDI (2009)	X	X	X	X	2005-2050
DLR/Fhg-IWES/IfNE (2010)	X	X	X	X	2008-2050
EWI/Prognos (2010)	X	X	X	X	2008-2050
IER/RWI/ZEW (2010)	X	X		X	2007-2030
Öko-Institut/Prognos (2010)		X			2005-2050
SRU (2010)				X	2005-2050
UBA (2010)		X			2005-2050

Table 2–2: Scenario properties

The following table provides an insight of the socio-economic frame conditions regarding the parameter population, BIP, workforce and various fuel prices assumed in the reference scenarios. All studies indicate a decline of the German population between 2005 and 2050. The lowest could be find in the publication from FZJ-STE by 6 %, the largest in EWI/Prognose by 10 %.

Source	Assumption	Unit	2005	2030	2050
BSR-Sustainability/ECF/FhG ISI/Öko-Zentrum NRW/PIK (2008)	Population	1000	82438	79421	
Nitsch, J (2008a, 2008b)	Population 2006	1000	82400	79300	75100
FZJ-STE/VDI (2009)	Population 2005	1000	82400	81000	77300
EWI/Prognos (2010)	Population 2008	1000	82100	79100	73800
IER/RWI/ZEW (2010)	Population 2007	1000	82300	79700	
	Population 2005	1000	82516	78546	72178

Concerning economic growth, rates between 0,5 and 1,4 % p.a. are estimated for the period between 2005 and 2050. FZj-STE suggests the largest economic growth (1,4 % p.a.) and Öko-Institut the smallest (0,5 %p.a.)

Source	Assumption	Unit	2005	2030	2050
BSR-Sustainability/ECF/FhG ISI/Öko-Zentrum NRW/PIK (2008)	BIP	Mrd €2000	2129	3069	
Nitsch, J (2008a, 2008b)	BIP-Rate	%	1,8	1,12	0,51
FZJ-STE/VDI (2009)	BIP-Rate	%	1,4	1,4	1,4
EWI/Prognos (2010)	BIP	Mrd €2000	2270	2632	3158
IER/RWI/ZEW (2010)	BIP-Rate	Mrd €2000	2242	2784	
Öko-Institut/Prognos (2010)	BIP Rate p.a.	%	0,7	0,5	0,8
UBA (2010)	BIP Rate p.a.BIP	%Mrd €2000	0,7	0,7	0,72981

In 2050, nearly 50 % of the German population is estimated as workforce. In line with the shrinking population also the workforce is declining by 15 %in 2050 according to 2005.

Source	Assumption	Unit	2005	2030	2050
BSR-Sustainability/ECF/FhG ISI/Öko-Zentrum NRW/PIK (2008)	Employees	1000	38671	36843	
Nitsch, J (2008a, 2008b)	Employees	1000	39000	37500	35800
Öko-Institut/Prognos (2010)	Employees	1000	38851	36736	33135

Another varying assumption is crude oil. While all institutes prognoses an increase of oil prices until the year 2050, the increase deviate heavily. While FZJ-STE estimate only a rise of oil prices by 4 times until 2050, Nitsch forecasts a 6 times higher price level in 2050 according to 2005.

Source	Assumption	Unit	2005	2030	2050
BSR-Sustainability/ECF/FhG ISI/Öko-Zentrum	Crude oil	US-$/bbl	48,3	60	
Nitsch, J (2008a, 2008b)	Crude oil	US-$/bbl	52,5	177	314,2
FZJ-STE/VDI (2009)	Crude oil	€/GJ	5	14	21
EWI/Prognos (2010)	Crude oil	US-$/bbl	94	166	314
IER/RWI/ZEW (2010)	Crude oil (real)	US-$/bbl	69	75	
Öko-Institut/Prognos (2010)	Crude oil	US-$/bbl	51	182	429

Estimations for natural gas prices follow the same pattern. All Institutes foresee a ris of the prices until 2050, the lowest increase indicates EWI/Prognos with 144 % and the highest values are assumed by Nitsch (10 times higher)

Source	Assumption	Unit	2005	2030	2050
BSR-Sustainability/ECF/FhG ISI/Öko-Zentrum NRW/PIK (2008)	Natural gas	Ct/KWh	1,54	1,80	
Nitsch, J (2008a, 2008b)	Natural gas	Ct/KWh	1,68	8,14	16,22
FZJ-STE/VDI (2009)	Natural gas	€/GJ	3,5	12	18
DLR/Fhg-IWES/IfNE (2010)	Natural gas	€/GJ	5,5-9	5,5-14,5	8-20
EWI/Prognos (2010)	Natural gas	Ct/KWh	2,7	3,7	6,6
IER/RWI/ZEW (2010)	Natural gas (Ind)	€/MWh	32	34	
Öko-Institut/Prognos (2010)	Natural gas	Ct/KWh	1,6	5,5	12,5

Also hard coal prices will increase until 2050 in all scenarios, but the lowest rise of prices is assumed by EWI/Prognos with 100 % and 6 times higher prices by the Öko-Institut in 2050 related to 2005

Source	Assumption	Unit	2005	2030	2050
BSR-Sustainability/ECF/FhG ISI/Öko-Zentrum NRW/PIK (2008)	Hard coal	€/t SKE	61,9	56,0	
Nitsch, J (2008a, 2008b)	Hard coal	€/t SKE	61,7	202,1	288,7
FZJ-STE/VDI (2009)	Hard coal	€/GJ	1,5	5	8
DLR/Fhg-IWES/IfNE (2010)	Hard coal	€/GJ	2,5-3	3,5-6,5	4-9,5
EWI/Prognos (2010)	Hard coal	€/t SKE	112	117	227
IER/RWI/ZEW (2010)					
Öko-Institut/Prognos (2010)	Hard coal	€/t SKE	65	166	376

Lignite price increases are seen as relatively moderate. In the study from Nitsch prices increases by 60 % until 2050.

Source	Assumption	Unit	2005	2030	2050
BSR-Sustainability/ECF/FhG ISI/Öko-Zentrum NRW/PIK (2008)	Lignite	€/GJ	0,83	0,83	
Nitsch, J (2008a, 2008b)	Lignite	€/GJ	1,05	1,37	1,65

Also fuel oil for industry shows the same increasing trend until 2050. Only the consortia of IER/RWI/ZEW shows a stable trend. EWI/Prognos assumes an increase by nearly 4 times until 2050, while the study of Öko-Institut/Prognos displays a 6 times rise.

Source	Assumption	Unit	2005	2030	2050
BSR-Sustainability/ECF/FhG ISI/Öko-Zentrum NRW/PIK (2008)	Fuel oil EL (Ind)	€/t	485	695,3	
FZJ-STE/VDI (2009)	Fuel oil EL (Ind)	€/GJ	6	17,5	26,5
EWI/Prognos (2010)	Fuel oil EL (Ind)	€/t	699	1325	2640
IER/RWI/ZEW (2010)	Fuel oil EL (Ind)	€/t	560	554	
Öko-Institut/Prognos (2010)	Fuel oil EL (Ind)	€/t	499	1377	2994

The fuel oil for private households shows in all studies a rising trend towards 2050. The lowest rise of 3 times until the year 2050 could be find by EWI/Prognos. The highest growth is assumed by the consortia of DLR/Fhg-IWES/IfNE by 8 times.

Source	Assumption	Unit	2005	2030	2050
BSR-Sustainability/ECF/FhG ISI/Öko-Zentrum NRW/PIK (2008)	Fuel oil EL (HH)	ct/l	50,7	76,9	
FZJ-STE/VDI (2009)	Fuel oil EL (HH)	ct/l	6	17,5	26,5
DLR/Fhg-IWES/IfNE (2010)	Fuel oil EL (HH)	ct/l	2,5-3	3,5-6,5	8-20
EWI/Prognos (2010)	Fuel oil EL (HH)	ct/l	77,1	137,7	276,4
IER/RWI/ZEW (2010)	Fuel oil EL (HH)	ct/l	58	65	
Öko-Institut/Prognos (2010)	Fuel oil EL (HH)	ct/l	53,6	142,4	312,3

It can be concluded that in general from all studies with a time horizon until 2050 the study from EWI/Prognos 2010 has the most conservative socio-economic assumptions, while the study from DLR included for most parameters the most optimistic socio-economic developments.

Table 2–3: Assumptions of the reference scenarios

2.2.1 Scenarios of Total Energy consumption

2.2.1.1 Description of Scenarios

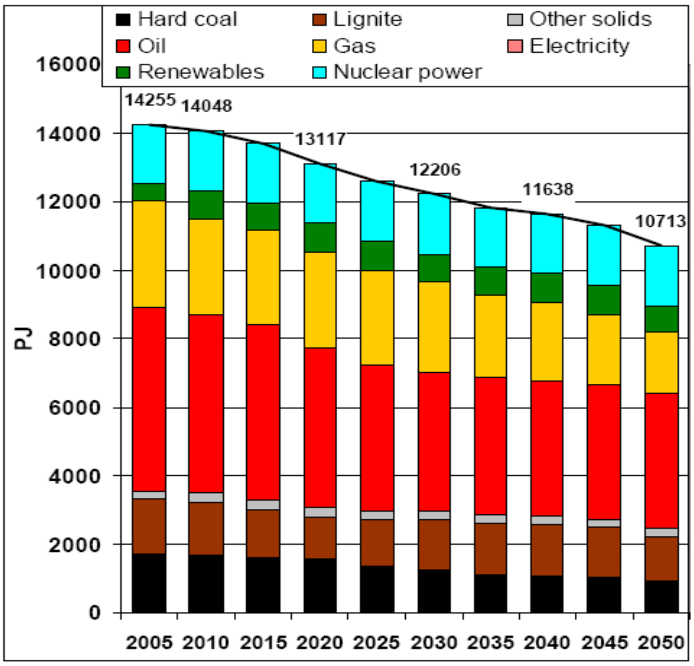
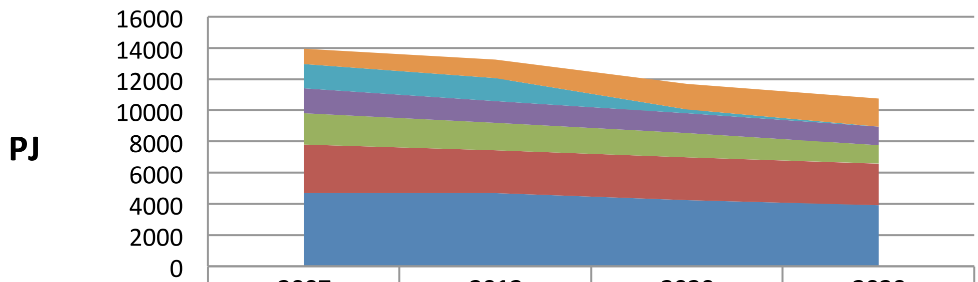


Figure 2–1: PEC by energy carrier according to FZJ-STE/VDI 2009

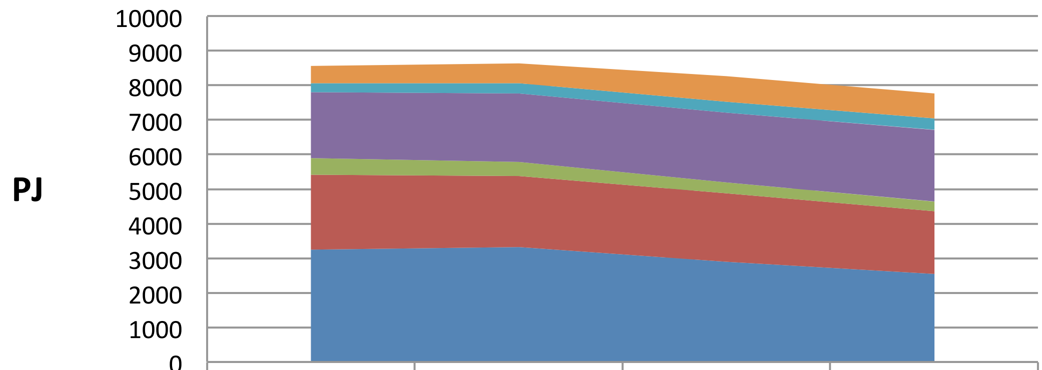
The reference scenario from STE of Research Centre Jülich shows a reduction of primary energy use between the years 2005 and 2050 for Germany by about 1/3. Mainly the use of classical fossil fuels like gas, hard coal and oil are responsible for the stronger decline.



	2007	2012	2020	2030
Renewable	**980**	**1206**	**1641**	**1818**
Nuclear	**1539**	**1448**	**252**	**0**
Lignite	**1609**	**1421**	**1270**	**1179**
Hard coal	**1987**	**1742**	**1557**	**1168**
Gas	**3120**	**2748**	**2743**	**2689**
Oil	**4702**	**4691**	**4241**	**3901**

Figure 2–2: PEC by energy carrier, own depiction according to IER/RWI/ZEW (2010) p. 6

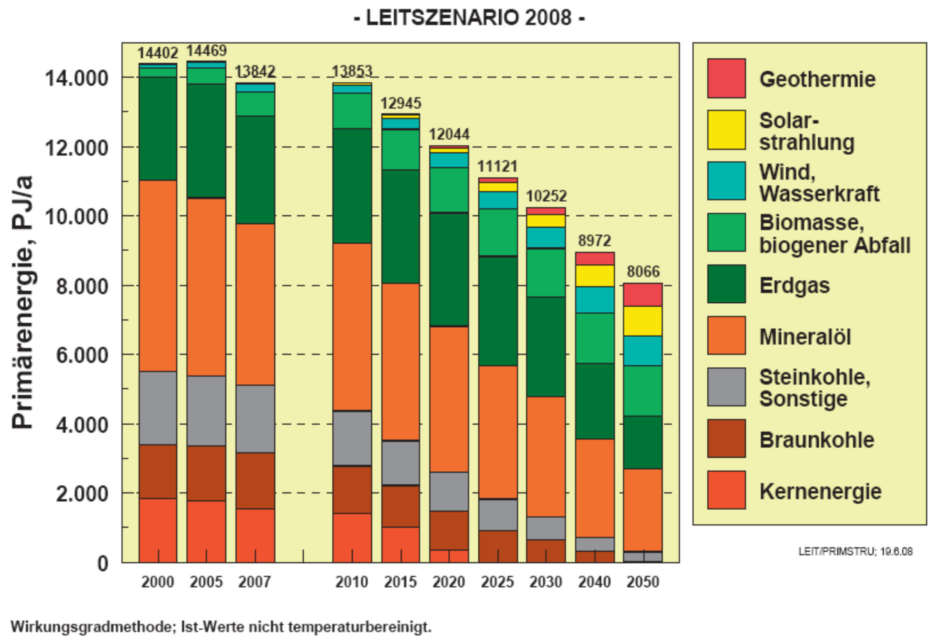
The second study from German research institutes, which are closer to the industry show a reduction from primary energy consumption between 2007 and 2030 by about 23 %. Here the main contributors to the decline are nuclear (100 %) and hard coal (41 %).



	2007	2012	2020	2030
Renewable	489	572	740	726
District heating	266	295	316	328
Electricity	1906	1993	2020	2076
Coal	481	399	324	289
Gas + LPG	2172	2062	1978	1810
Oil	3245	3318	2893	2544

Figure 2–3: FEC by energy carrier, own depiction according to IER/RWI/ZEW 2010

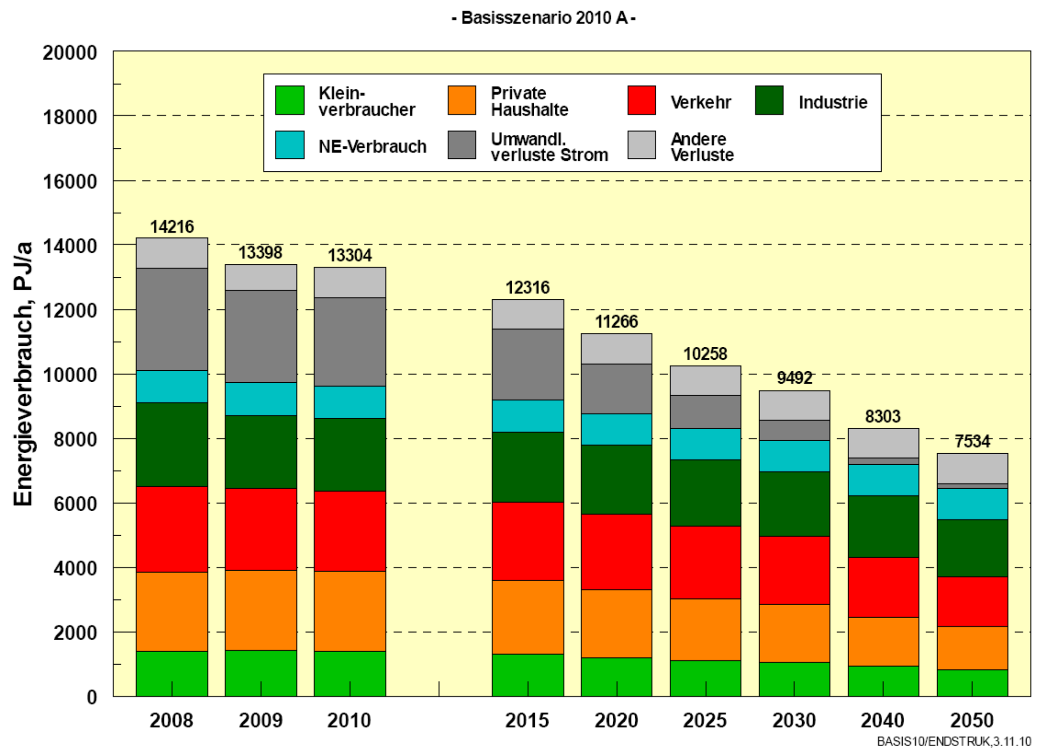
The same consortia of research institutes show for the final energy demand between 2007 and 2030 also a decline of 9 %. Large reductions in the use as an energy carrier could be found in oil (22 %) and gas (17 %).



- Geothermie = geothermal;
- Solarstrahlung = solar;
- Wind, Wasserkraft = wind, hydro;
- Biomasse, biogener Abfall = biomass, biological waste;
- Erdgas = natural gas;
- Mineralöl = oil;
- Steinkohle, Sonstige = hardcoal, others;
- Braunkohle = Lignite;
- Kernenergie = nuclear.

Figure 2–4: PEC by energy carrier according to Nitsch 2008b

The Federal Ministry of Environment predicts in its leading scenario 2008 between 2000 and 2050 a reduction of primary energy consumption by 43 %. Beside the assumption of a nuclear phase out lignite won't be used in 2050 anymore and hard coal only in minor quantities. Also oil consumption shrinks to 50 %. Natural gas is reduced by 1/3.

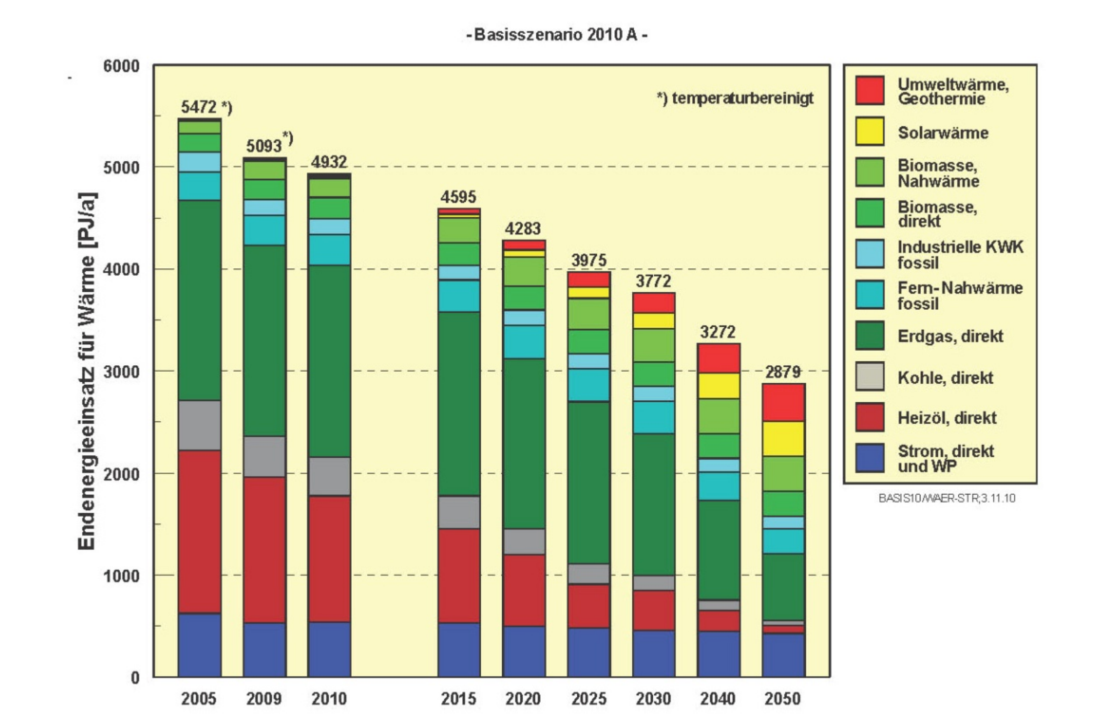


- Andere Verluste = other losses;
- Umwandlungs-verluste Strom = electricity transformation losses;
- NE-Verbrauch = non-energetic consumption;
- Verkehr = transport;
- Private Haushalte = private households (residential);
- Kleinverbraucher = small consumers;
- Industrie = industry.

Figure 2–5: PEC by energy carrier according to *DLR/Fhg-IWES/IfNE 2010*

The updated version of the DLR lead consortia for the Federal Ministry of Environment from 2010 estimates a decrease of the PEC between the years 2010 and 2050 by 43 %.

The estimated reduction in the study from 2010 is for the considered period between 2010 and 2050 1 % point larger compared to estimates from 2008.



- Umweltwärme, Geothermie = environment, geothermal heat;
- Solarwärme = solar heat;
- Biomasse, Nahwärme = biomass, locat heat;
- Biomasse direkt = biomass direct;
- Industrielle KWK, fossil = industrial CHP fossil;
- Fern-Nahwärme fossil = district local heat fossil;
- Erdgas, direkt = natural gas direct;
- Kohle, direkt = coal direct;
- Heizöl, direkt = oil direct;
- Strom, direkt und WP = electricity direct and cogeneration.

Figure 2–6: FEC for heat in „Basisszenario 2010 A“ (incl. electricity production for heat), REN, *DLR/Fhg-IWES/IfNE 2010*

For the FEC in the Basisszenario 2010A (Figure 3-6) calculated of a consortia lead by DLR for the Federal Ministry of Environment is also seen a decline between the years 2010 and 2050 by 42 %. In particular direct fuel oil and coal play in the year 2050 a tiny role. The direct use of natural gas is at that point in time reduced. Whereas solar heat and environmental heat receive more and more increasing shares.

	2008*)	2009*)	2010	2020	2030	2040	2050
Primary energy, PJ/a	14,216	13,398	13,304	11,266	9,492	8,303	7,534
Primary energy REN, PJ/a 1)	1147	1163	1270	2132	2957	3661	4128
Share REN on PEV, %	**8.1**	**8.7**	**9.5**	**18.9**	**31.2**	**44.1**	**54.8**
Final energy, PJ/a	9,098	8,714	8,630	7,783	6,958	,,228	5,485
Final energy REN, PJ/a	841	876	945	1710	2411	3021	3418
Share REN on FEC, %	**9.2**	**10.1**	**11**	**22**	**34.6**	**48.5**	**62.3**
Share REN on BFEC **), %	***8.9***	***9.7***	***10.6***	***21.2***	***33.3***	***46.7***	***60***
Electricity final energy, PJ/a	1,906	1,793	1,822	1,728	1,667	1,670	1,678
Electricity final energy REN, PJ/a	335	341	373	793	1,167	1,488	1,546
Share REN, %	**17.6**	**19**	**20.5**	**45.9**	**70**	**89.1**	**92.1**
Heat final energy, PJ/a 2)	4,606	4,435	4,391	3,787	3,316	2,822	2,450
Heat final energy REN, PJ/a	374	414	434	684	919	1,125	1,298
Share REN, %	**8.1**	**9.3**	**9.9**	**18.1**	**27.7**	**39.9**	**53**
Fuels final energy, PJ/a 3)	2,589	2,486	2,417	2,268	1,975	1,735	1,358
Fuels final energy REN, PJ/a	132	121	138	233	325	408	574
Share REN, %	**5.1**	**4.9**	**5.7**	**10.3**	**16.5**	**23.5**	**42.3**
Primary energy, PJ/a	14,216	13,398	13,304	11,266	9,492	8,303	7,534
Renewanle energies	**1,147**	**1,163**	**1,270**	**2,132**	**2,957**	**3,661**	**4,128**
Mineral oil	4,905	4,670	4,686	3,806	3,022	2,476	1,756
Coal 5)	3,483	3,156	3,028	2,230	1,130	373	187
Natural gas, Gasoil, Grubengas	3,058	2,937	2,902	2,803	2,383	1,793	1,463
Fossil energies, total	**11,446**	**10,763**	**10,616**	**8,839**	**6,535**	**4,643**	**3,407**
Nuclear energy	1,623	1472	1,418	295	0	0	0
CO2 emissions, Mio. t CO2/a	**797**	**739**	**729**	**585**	**394**	**243**	**152**
Reduction since 1990, % 6)	**20.3**	**26.1**	**27.1**	**41.5**	**60.6**	**75.7**	**84.8**
With REN avoided CO2 emissions, Mio. t CO2/a	109	110	119	217	291	379	411
GHG emissions, Mio t CO_{2eq}/a 7)	**988**	**905**	**893**	**710**	**498**	**336**	**233**
Reduction since 1990, %	18.4	25.3	26.3	41.4	58.9	72.3	80.7

1) Primary energy according to efficiency method; 2) Only fuels, d. h. without electricity use for heat production; 3) Fuel consumption for road transport, rail, naval and aviation, without electricity use; 4) Brut electricity consumption with electricity from pump storage; from 2030 including of consumption of H2; 5) Including other fossil fuels; including fossil electricity import saldo (without REN imports); 6) 1990 = 1000 Mio. t CO2/a (energy induced emissions and furnace processes); 7) Including change of land use (LULUCF; 1990 = 1211 Mio. t CO2eq/a); *) Data from: End August 2010. Von BMU/AGEE-Stat after that published figures from REN (http://www.erneuerbare-energien.de/inhalt/45919/) could deviated from current actualization; **) Brut final energy consumption (BFEC) = Final energy consumption + grid losses and own consumption of heat and electricity in power and cogeneration plants.

Table 2–3: Basisszenarios 2010 A, specific contributions and shares of REN, *DLR/Fhg-IWES/IfNE 2010*

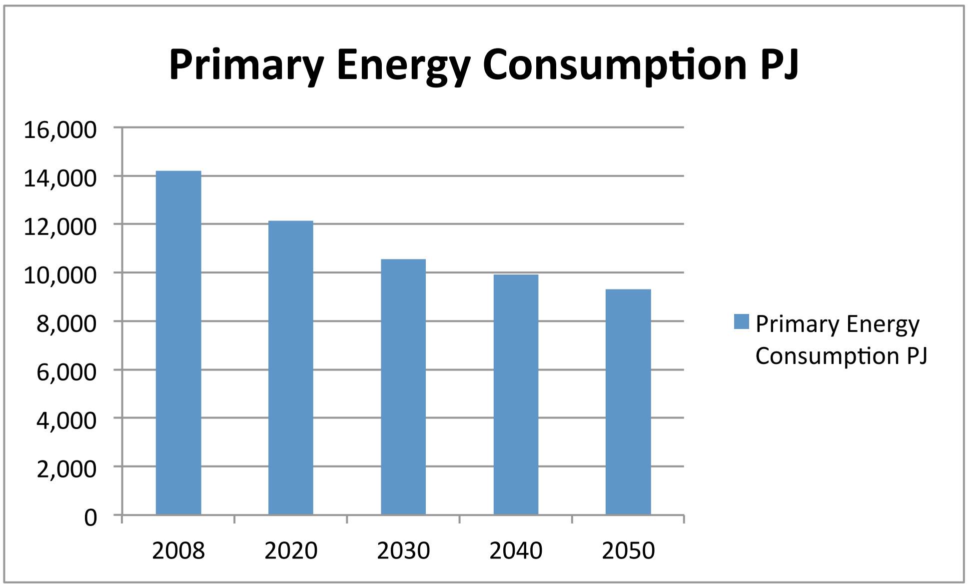


Figure 2–7: Primary energy consumption (EWI/Prognos 2010)

Figure 2-7 and table 2-3 shows that PEC will decrease in the reference scenario of EWI/Prognos (2010) in the years between 2008 and 2050 by 34 % from 14,194 PJ to 9,331 PJ.

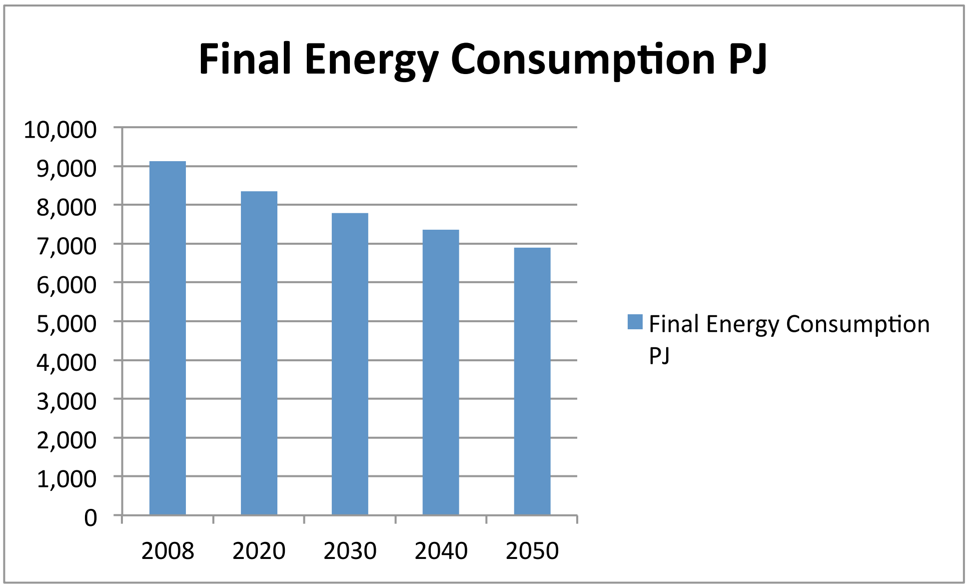


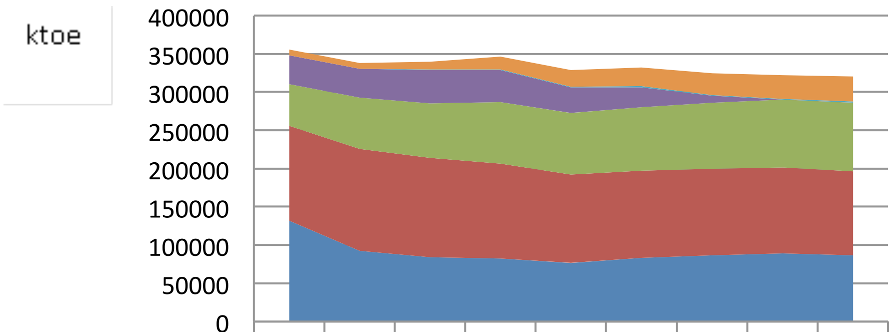
Figure 2–8: Final energy consumption (EWI/Prognos 2010)

The FEC as shown in figure 2-8 declines from 9,127 PJ (2008) to 6,897 PJ in 2050. This is a reduction from 24 %. So the decrease of PEC is seen until the year 2050 by 33 % less than the reduction of the FEC.

	Unit	Reference Scenario				
International Prices		**2008**	**2020**	**2030**	**2040**	**2050**
Primary Energy Consumption	**PJ**	**14,192**	**12,154**	**10,570**	**9,934**	**9,331**
Nuclear	%	11.4	4.4	-	-	-
Hard Coal	%	12.7	11.7	9.7	10.8	8.9
Lignite	%	11.0	12.0	7.0	4.6	6.0
crude Oil	%	34.4	34.8	34.6	31.5	29.1
Gazes	%	21.6	20.0	23.1	22.8	20.3
Renewable Energies	%	8.1	16.4	22.9	27.6	31.8
Importsaldo Electricity	%	-0.6	-0.3	1.5	1.4	2.6
		2008	2020	2030	2040	2050
Final Energy Consumption	**PJ**	**9,127**	**8,352**	**7,796**	**7,357**	**6,897**
Private household	%	27.4	27.3	27.4	27.6	27.3
Tertiary	%	15.4	14.9	14.4	14.0	13.2
Industry	%	29.0	27.9	28.2	29.2	31.3
Transport	%	28.2	29.9	30.0	29.3	28.1
Coal	%	5.0	3.8	3.3	3.2	3.2
Mineral oil products	%	39.4	36.9	33.8	29.8	26.7
Gazes	%	23.8	22.7	21.3	20.1	18.6
Electricity	%	20.7	21.3	22.6	24.3	25.9
District Heat	%	5.1	5.1	5.4	5.3	5.2
Renewable Energy carriers	%	5.6	5.6	12.9	16.6	19.6
Share of renewable energies of brut	%	9.5	18.7	24.8	30.2	34.5

Table 2–4: Quantitative assumptions and results of the reference scenario (EWI/Prognos 2010)

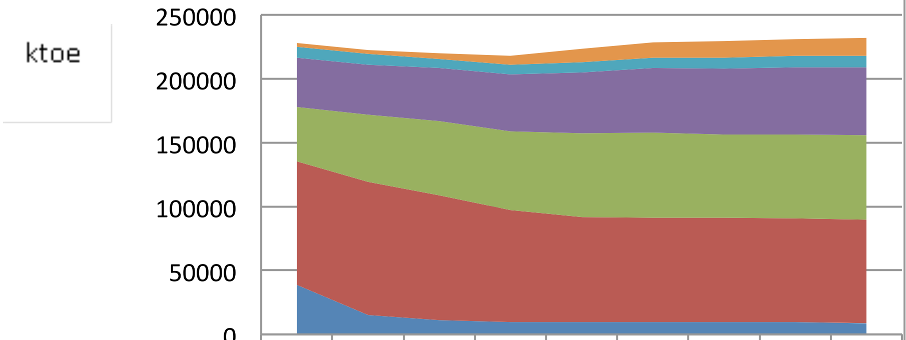
As it could be seen in table 2-4, renewable energies become the most PEC source, its share become until 2050 4 times higher according to 2008, while crude oil with the largest share in 2008 diminishes by 15 % until 2050. The share of gas remains constant and the consumption of the other fossil fuels decreases by nearly to the half.



	1990	1995	2000	2005	2010	2015	2020	2025	2030
Renewable energy forms	6820	7420	10656	16718	21759	24443	28021	30769	32684
Electricity	68	415	263	393	535	937	1364	1434	1451
Nuclear	37674	37322	43750	42061	33721	26138	8796	0	0
Natural gas	54976	67298	71853	80856	80653	83412	86578	88468	89999
Oil	124248	133627	129918	123409	115381	114122	113655	112127	109825
Solids	131510	92177	83727	82805	76822	82967	86224	89459	86518

Figure 2–9: Gross inland consumption in ktoe by energy carrier (own depiction according to DGTREN 2007)

Whereas in Figure 2-10 it could be seen, gross inland consumption decrease between 1990 and 2030 in Germany in the scenario from DG TREN by about 10 %. Particular is a 100 % nuclear phase out, while solids like hard coal and lignite decline by 34 % and oil by 12 %.



	1990	1995	2000	2005	2010	2015	2020	2025	2030
Other	2991	2734	4804	7222	10575	11784	12760	13400	14086
Heat (from CHP and District Heating)	8760	8747	6831	7426	7965	8231	8633	8684	8762
Electricity	38391	38912	41496	44497	47627	50269	51625	52783	53320
Gas	42724	52595	58030	61814	65839	66481	65173	65370	66132
Oil	96422	104474	98052	87411	81797	81695	81530	81374	80768
Solids	38693	14917	10951	9639	9778	9760	9740	9515	8798

Figure 2–10: Final energy demand by energy carrier (own depiction according to DGTREN 2007)

The final energy demand declines by 5 % between 1990 and 2005 and increases again by 2 % until 2030 in the DGTREN reference scenario. Particular is the use of solid fuels like hard coal, which decreases in the 1990s by 72 % and remain afterward constant. Also the use of oil declines by about 16 %.

2.2.2 Economic Sectors Overview Scenarios

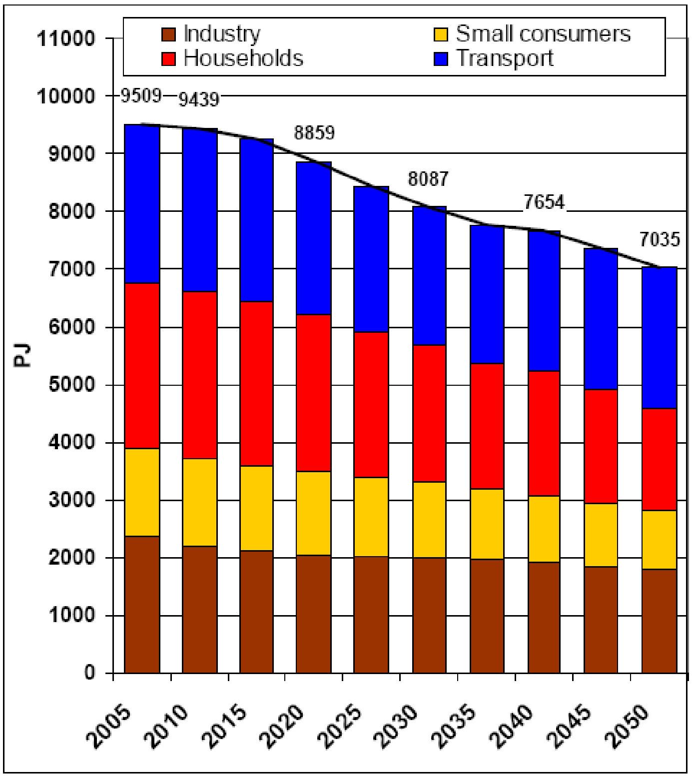
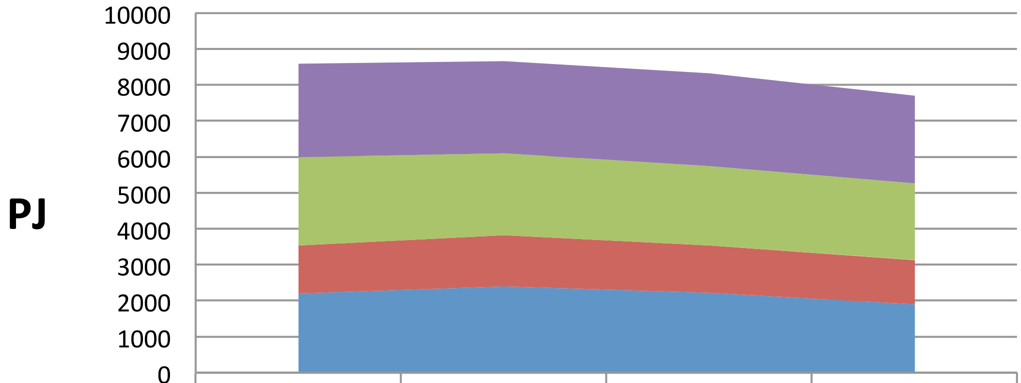


Figure 2–11: Final energy consumption (FEC) according to FZJ-STE/VDI 2009

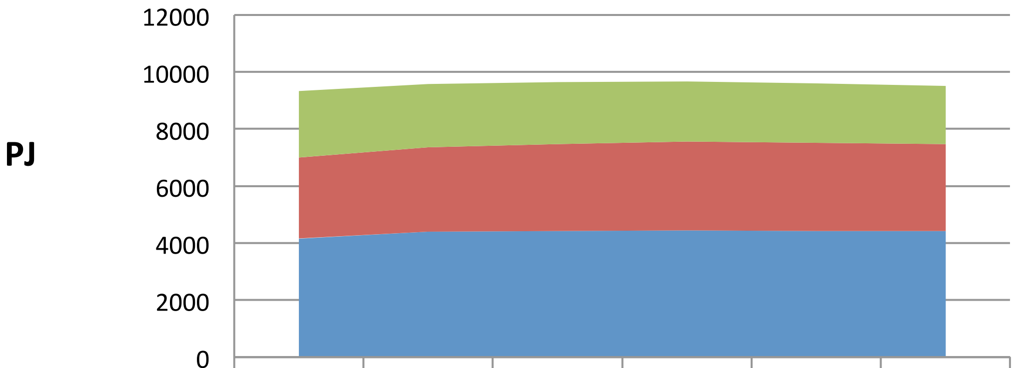
As Figure 2-11 shows, the final energy demand declines in Germany between 2005 and 2050 by about 26 % according to the reference scenario calculation of STE from the Research Centre of Jülich. The largest reduction of final energy consumption is seen in the residential sector by about 40 %. The second largest decrease faces small consumers with about 20 % between 2005 and 2050.



	2007	2012	2020	2030
Transport	2601	2573	2568	2442
Industry	2447	2270	2219	2130
Tertiary	1339	1421	1305	1241
Households	2206	2400	2228	1892

Figure 2–12: FEC, own depiction according to IER/RWI/ZEW 2010

The final energy demand of the transport sector in Germany is in 2007 as well as in 2030 the largest according to a research consortia, lead by IER (Figure 2-11). The smallest economic sector is the tertiary. It is 50 % of the transport sector. The largest decrease could be find during this period by the industrial sector (13 %) and the second largest reduction are the household sector with 10 %.

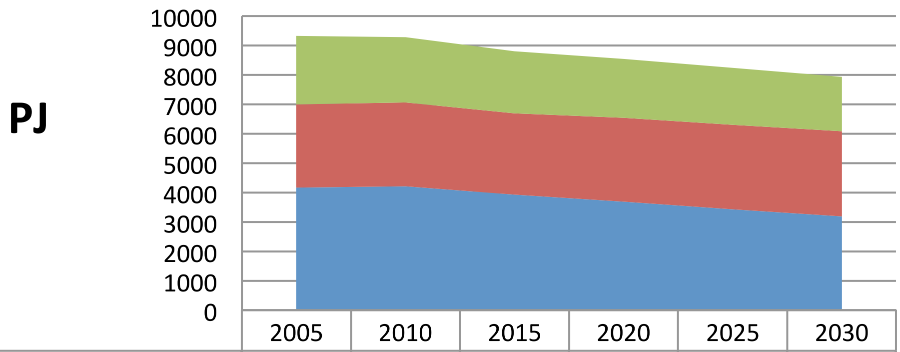


	2005	2010	2015	2020	2025	2030
Industry	2323	2239	2178	2113	2078.5	2044
Transport	2839	2939	3046	3117	3081	3045
Household and Tertiary	4164	4412	4431	4448	4432.5	4417

Figure 2–13: Energy demand of sectors without IEKP measures (own depiction according to BSR-Sustainability/ECF/FhG ISI/Öko-Zentrum NRW/PIK 2002)

Whereas in Figure 2-13 the consortia lead by BSR for the Federal Ministry of Environment provides their estimations for Germany for the time period between 2005 and 2030 without taking into account the “Integrated Climate and Energy Programme” (IEKP) measures.

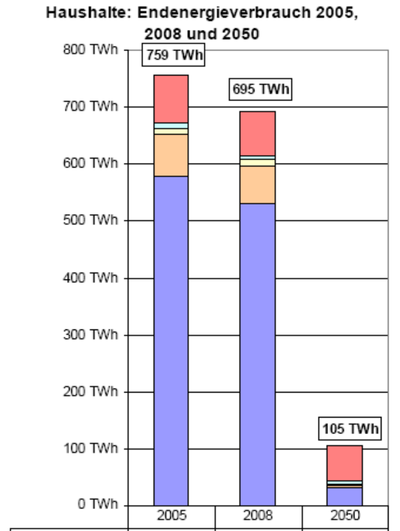
Hereafter the household and tertiary sector as well as the transport sector receives an increase by 6 %, while the industrial energy demand will decrease by 12 %.



	2005	2010	2015	2020	2025	2030
Industry	2323	2231	2113	2010	1932.5	1855
Transport	2839	2853	2757	2856	2876	2896
Household and Tertiary	4164	4206	3931	3683	3431.5	3180

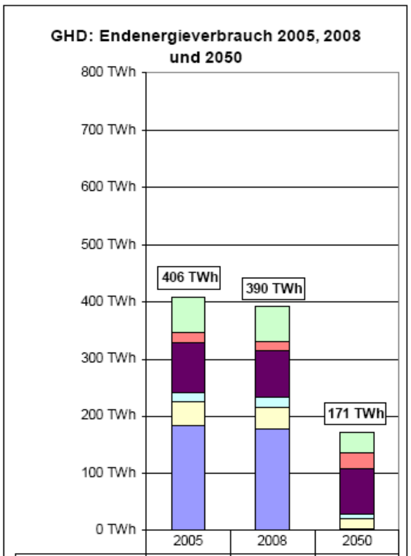
Figure 2–14: Energy demand of sectors with IEKP measures (own depiction according to BSR-Sustainability/ECF/FhG ISI/Öko-Zentrum NRW/PIK 2008)

Figure 2-14 shows the predictions of energy demand in the economic sectors in Germany from the BSP lead consortia for the Federal Ministry of Environment for the period between 2005 and 2030 while considering supporting measures from IEKP in 2007. The measures induce a reduction of energy demand in nearly all sectors. The largest reduction of final energy consumption is estimated in the household and tertiary sector by about 24 %. It follows the industry with 20 %, while transport still increases slightly by 2 %.



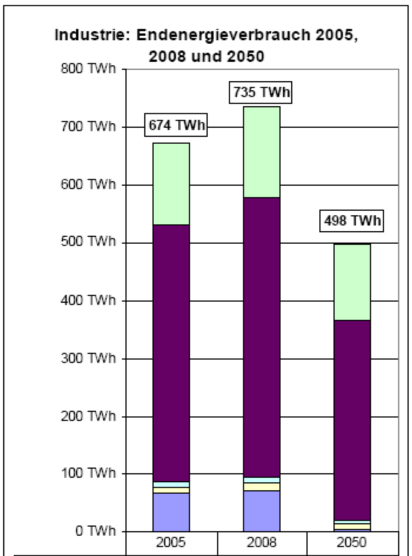
	2005	2008	2050
Sonstige Anwendungen	83,1 TWh	76,0 TWh	63,5 TWh
Umwälzpumpen	8,5 TWh	7,8 TWh	3,6 TWh
Beleuchtung	11,8 TWh	10,8 TWh	1,8 TWh
Warmwasser	71,9 TWh	65,8 TWh	5,6 TWh
Raumwärme	579,8 TWh	530,4 TWh	30,9 TWh

2005 nach WWF (2009), Umwälzpumpen nach eigenen Berechnungen.
2008 AGEB (2009), gewichtet nach WWF (2009).
2050 eigene Berechnungen.



	2005	2008	2050
mech. Energie	61,1 TWh	58,7 TWh	34,4 TWh
Kühlen und Lüften	18,1 TWh	17,3 TWh	28,1 TWh
Prozesswärme	86,1 TWh	82,7 TWh	80,8 TWh
IKT	15,6 TWh	14,9 TWh	7,8 TWh
Beleuchtung	41,1 TWh	39,5 TWh	18,3 TWh
Raumwärme	184,4 TWh	177,1 TWh	1,9 TWh

2005 nach WWF (2009).
2008 AGEB (2009), gewichtet nach WWF (2009).
2050 nach WWF (2009) Referenzszenario; "Kühlen und Lüften" nach eigenen Berechnungen.



	2005	2008	2050
mech. Energie	143,3 TWh	156,4 TWh	130,3 TWh
Prozesswärme	443,6 TWh	483,9 TWh	346,7 TWh
IKT	9,2 TWh	10,0 TWh	6,4 TWh
Beleuchtung	10,8 TWh	11,8 TWh	8,3 TWh
Raumwärme	66,7 TWh	72,7 TWh	5,8 TWh

2005 nach WWF (2009).
2008 AGEB (2009), gewichtet nach WWF (2009).
2050 nach WWF (2009) Referenzszenario; "Raumwärme" nach eigenen Berechnungen.

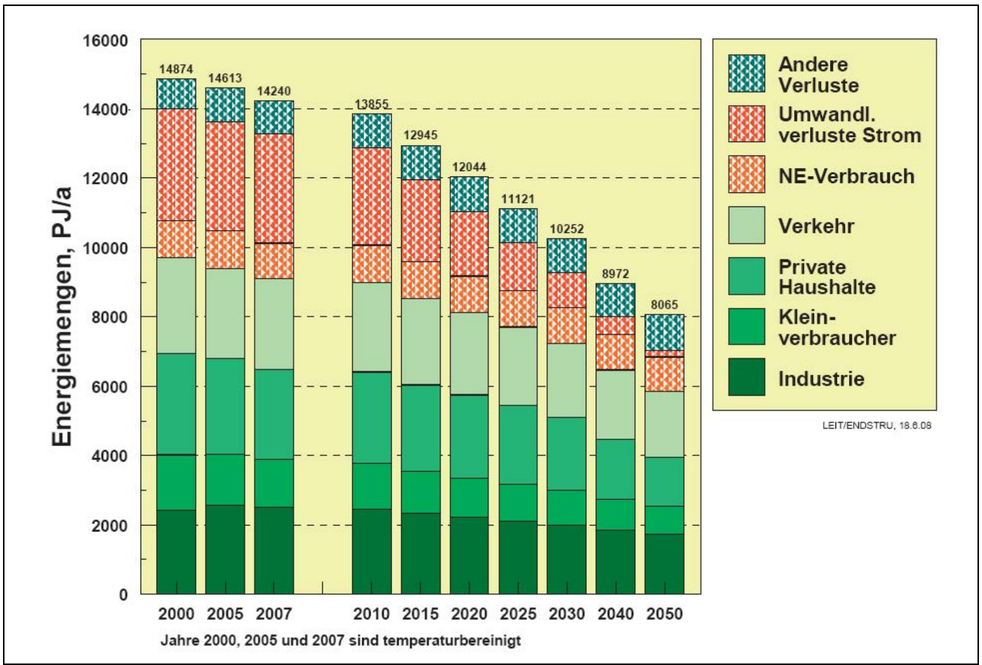
FEC of residential sector;	FEC of tertiary sector	FEC of industry
• Sonstige Anwendungen = other end uses; • Umwälzpumpen = circulation pumps; • Beleuchtung = Lighting; • Warmwasser = drinkable warm water; • Raumwärme = space heating;	• mech. Energie = mechanical energy; • Kühlen und Lüften = cooling and ventilation; • Prozesswärme = process heat; • IKT = information and communication technology; • Beleuchtung = lighting; • Raumwärme = space heating;	• mech. Energie = mechanical energy; • Prozesswärme = process heat; • IKT = information and communication technology; • Beleuchtung = lighting; • Raumwärme = space heating.

Figure 2–15: FEC of sectors according to UBA 2010

In particular Figure 2-16 shows the main reduction of the final energy demand in the household sector between 2005 and 2050 in Germany according to the Federal Environmental Agency (UBA) by the use of space heat with a reduction of over 95 % and warm water by 92 %.

In the tertiary sector the highest decrease between 2005 and 2050 will also face the use of space heat by 99 %. To a minor extend the reduction will be the use of lighting (55 %) and mechanical energy (44 %). In contradiction an increase is seen in the use of cooling and ventilation by 55 %.

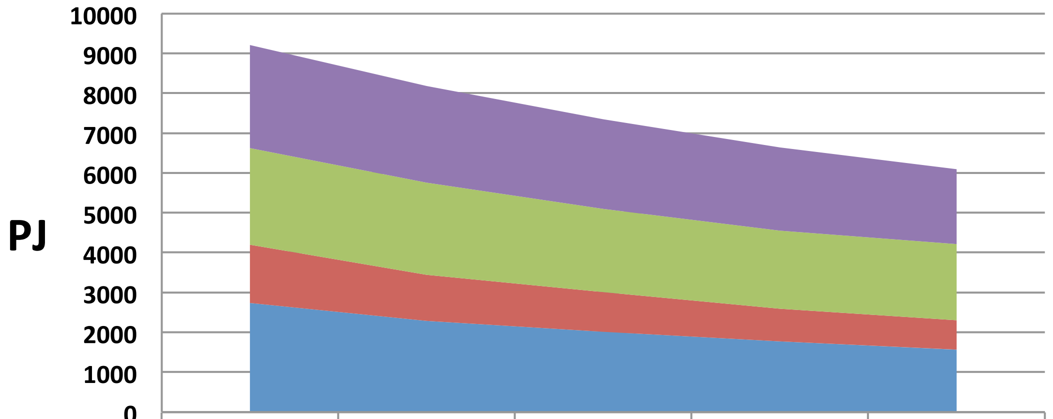
Process heat has the largest share of final energy consumption and is seen in the industrial sector as the dominant saving source for final energy between 2005 and 2050 by 21 %. Space heat is nearly 7 times smaller than process heat and will decrease by about 91 %.



- Andere Verluste = other losses;
- Umwandlungs-verluste Strom = electricity transformation losses;
- NE-Verbrauch = non-energetic consumption;
- Verkehr = transport;
- Private Haushalte = private households (residential);
- Kleinverbraucher = small consumers;
- Industrie = industry.

Figure 2–16: Energy demand, according to Nitsch 2008b

Figure 2-16 expresses the quantities of energy in Germany between 2000 and 2050 referring to Nitsch (DLR) for the Federal Ministry of Environment. The largest reduction of energy demand could contribute to the reduction of electricity transformation losses and non-energetic consumption by 75 %. The second largest group in energy use is the private household sector with a reduction by 53 %. Transport and small consumers have lower decreases by about 30 % and 50 %.



	2005	2020	2030	2040	2050
Transport	2587	2426	2251	2090	1891
Industry	2424	2301	2094	1961	1909
Tertiary	1462	1169	993	815	731
Residential	2735	2282	2013	1777	1569

Figure 2–17: FEC by sector (according to Öko-Institut/Prognos 2010, own depiction, note that periods are not equidistant)

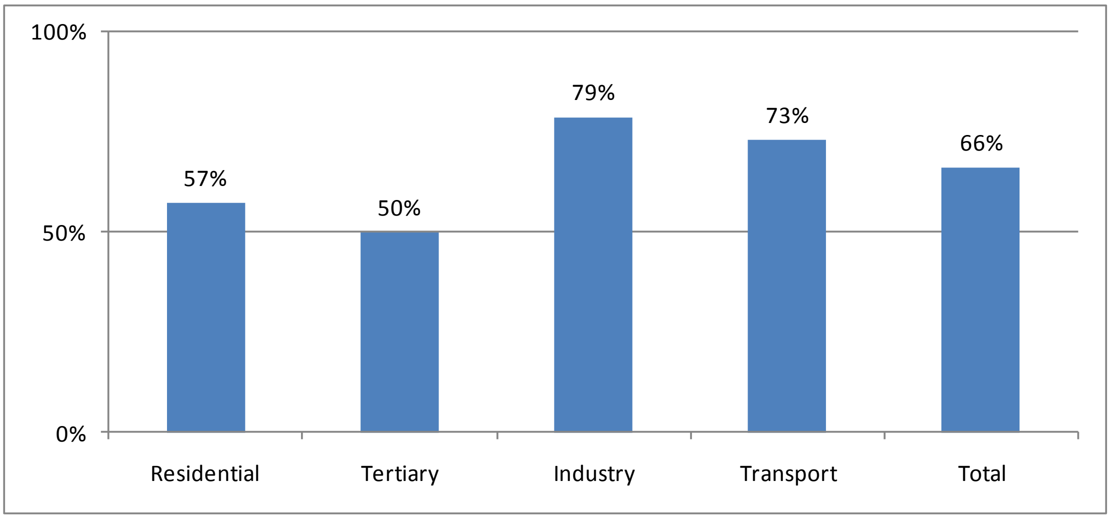
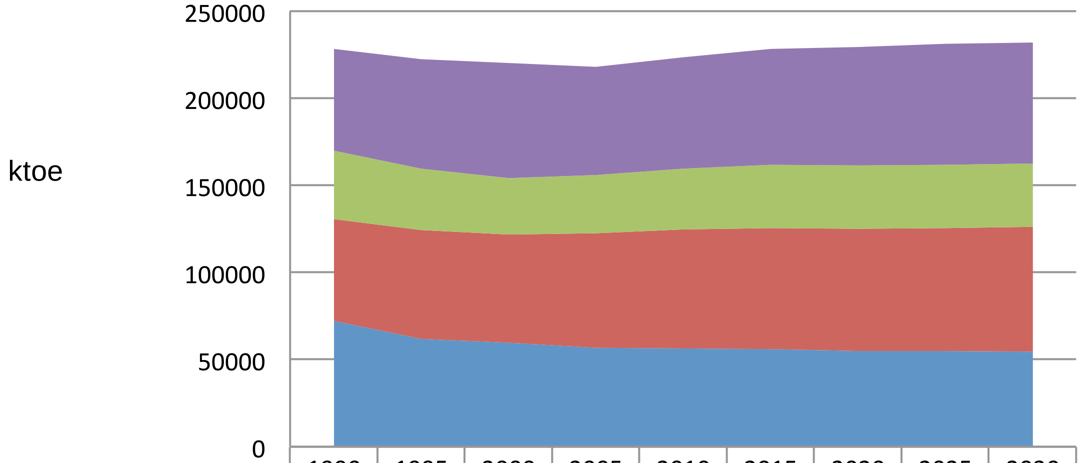


Figure 2–18: Relative changes 2050/2005 according to Öko-Institut/Prognos 2010

The study on behalf of WWF predicts a strong decrease of final energy consumption by 1/3 between 2005 and 2050 for Germany (Figure 2-17 and Figure 2-18). The final energy consumption of all economic sectors shrinks during this time. To this reduction in final energy consumption contributes most the residential sector by about 43 %. It was the largest energy consuming sector in 2005. Transport contributes with the second largest reduction by 27 % and is close to the largest final energy consumer in 2050, the industrial sector (21 %). The tertiary sector diminishes in relative terms most by 50 %, but is in absolute values the smallest. It is only 38 % of the largest sector (Industry) in 2050 (Figure 2-17).



	1990	1995	2000	2005	2010	2015	2020	2025	2030
Transport	58494	62910	65997	61958	63860	66433	68029	69173	69365
Services/Agriculture	39361	35275	32547	33416	35103	36482	36515	36482	36276
Residential	58400	62212	61905	65931	68107	69199	69910	70709	71617
Industry	72116	61981	59715	56706	56510	56106	55006	54763	54608

Figure 2–19: Final energy demand by sector, own depiction according to DGTREN 2007

The values of final energy demand by DGTREN predict a trend like the scenario of the study for the Federal Ministry of Environment without further measures from IKEP.

Most of the studies include additional measures against climate change and for energy savings. Although there is at first a decrease between 1990 and 2005, in the time focus, which is similar to the other studies, there is seen in contradiction to most studies an increase until 2030. The residential sector increases by 23 % between 1990 and 2030, whereas in most study it’s the source for the highest decrease. The industry looses in the scenario of DGTREN its position of the sector with the highest energy demand until 2030. The reduction of final energy consumption in accordance to lot of studies is 25 %. Residential is in 2030 the largest sector. The final energy demand of the tertiary and agricultural sector shrinks slightly by 8 % during this time period, while transport increases by 19 % like in most of the studies from the conservative research institutes or without additional measures like IKEP program or the Energy Concept.

2.2.3 Energy Transformation Sector

2.2.3.1 Description of Scenarios

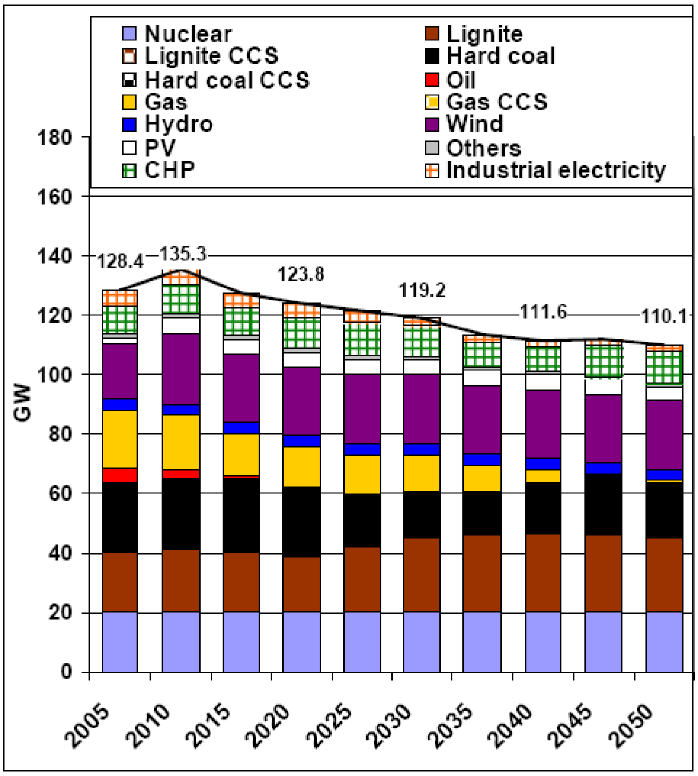


Figure 2–20: Net output capacity of electricity sector, according to FZJ-STE/VDI 2009

According to the reference scenario of STE/research centre Jülich Figure 2-20 shows that in the energy transformation sector the major source for the decline of the installed capacities result from the disappearance of gas installations until 2045. Hard coal diminishes less. But lignite power plants increase slightly until 2050. Nuclear remain constant above 20 MW between 2005 and 2050.

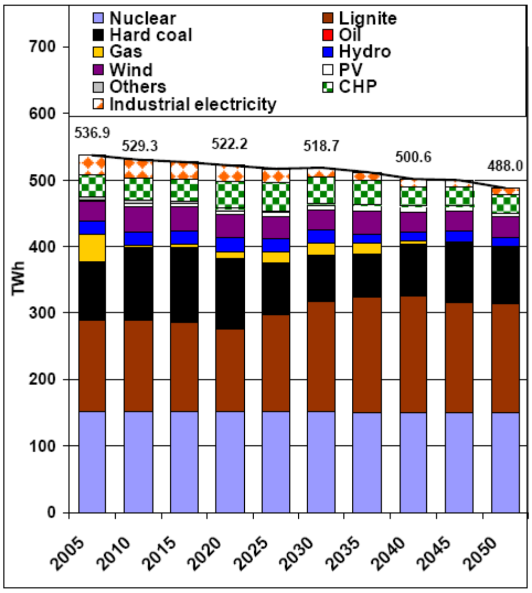
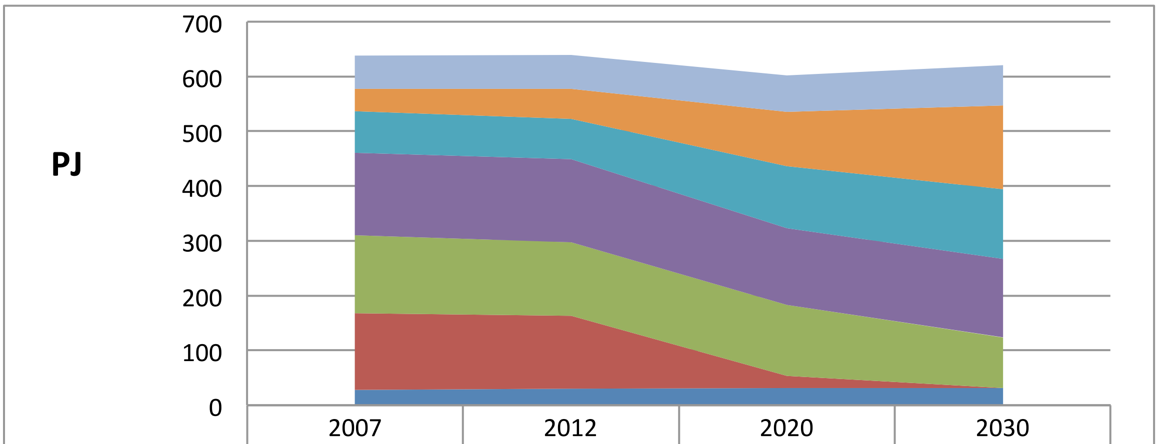


Figure 2–21: Net electricity production of electricity sector, according to FZJ-STE/VDI 2009

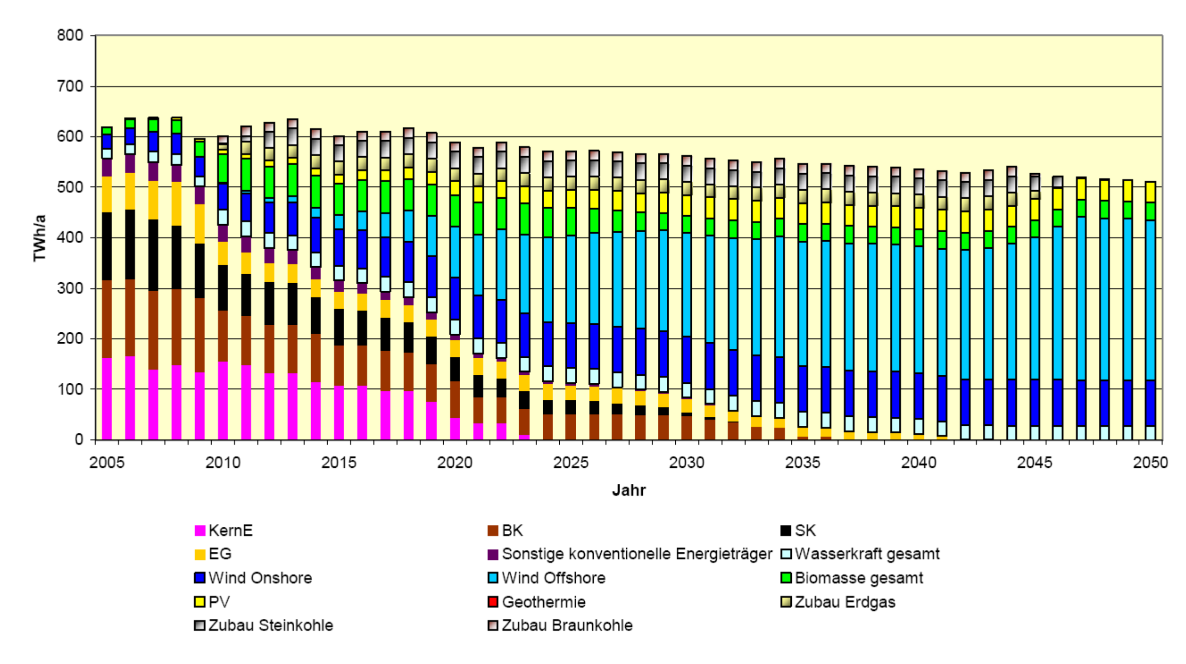
Regarding electricity production Figure 2-21 show in the reference scenario of STE/research centre Jülich between 2005 and 2050 a small decline of production by 9 %, induced by reduction of hard coal electricity and complete missing gas produced quantities from 2040 onwards. A rise of quantities could be found by lignite power and a constant power production from nuclear.



	2007	2012	2020	2030
Others	61	61	67	74
Wind	40	55	99	153
Natural Gas	76	74	113	127
Lignite	151	152	140	143
Hard coal	142	134	129	93
Nuclear	140	133	23	0
Hydro	28	30	31	31

Figure 2–22: Gross electricity production (own depiction according to IER/RWI/ZEW 2010, note that periods are not equidistant)

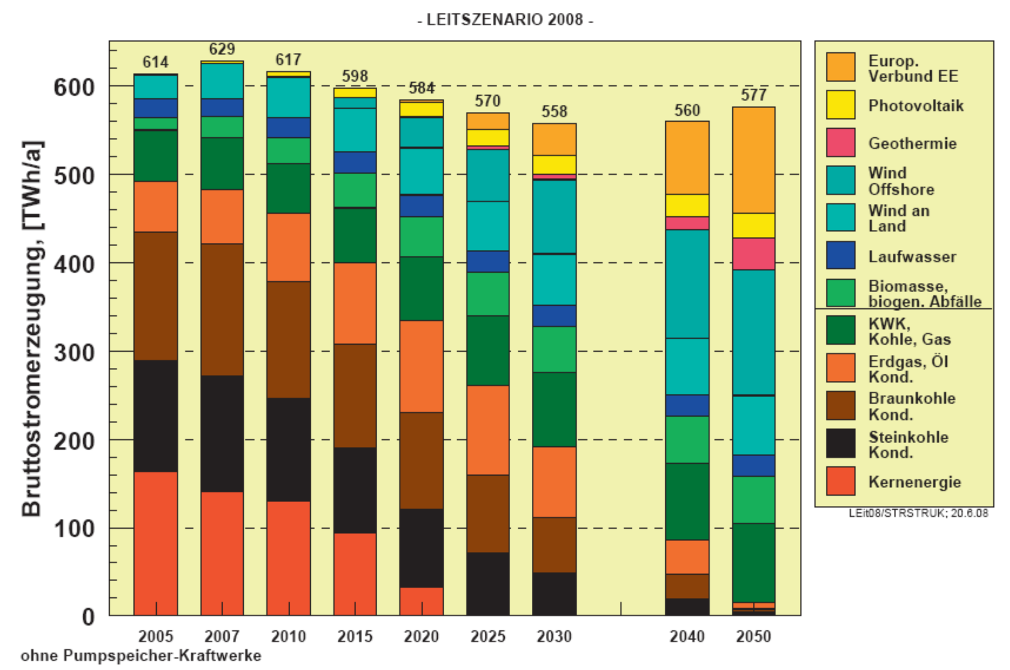
The reference scenario developed by an institutional consortia, lead by IER, assumes for the time period 2007 and 2030 a nuclear phase out and a diminishing of hard coal by 35 %, but an increase of gross electricity production in Germany by wind (about 283 %) to the largest share of electricity production. An increase is predicted for the use of natural gas by 67 %.



• KernE = nuclear; • EG = natural gas; • Wind Onshore = wind onshore; • PV = photovoltaics; • Zubau Steinkohle = new hard coal capacity;	• BK = Lignite; • Sonstige konventionelle Energieträger = other conventional energy carriers; • Wind Offshore = wind offshore; • Geothermie = geothermal; • Zubau Braunkohle = new lignite capacity;	• SK = hard coal; • Wasserkraft gesamt = total hydro; • Biomasse gesamt = total biomass; • Zubau Erdgas = new natural gas capacity.

Figure 2–23: Gross electricity production according to SRU 2010

Gross electricity production is seen from the perspective of the Council of Environmental Advisors between 2005 and 2050 (Figure 2-23) as a decrease by 15 % during this time period. To this increase dominantly contribute the nuclear phase out until 2023 and the phase out of lignite until 2035 and electricity production from natural gas until 2042. New installations of lignite, hard coal and natural gas come to an end in 2046. In contradiction wind offshore dominates electricity production since 2020 with a share of 65 % in 2050. Also wind onshore and PV increases its share of electricity production to about 16 % and 8 % in 2050.



- Europ. Verbund EE = european networked renewables;
- Photovoltaik = photovoltaics;
- Wind Offshore = wind offshore;
- Wind an Land = wind onshore;
- Laufwasser = hydro power;
- Biomasse, biogene Abfälle = biomass, biogenic wastes;
- KWK, Kohle, Gas = CHP, coal, gas;
- Erdgas, Öl Kond. = natural gas, fuel oil condensing;
- Braunkohle Kond. = lignite condensing;
- Steinkohle Kond. = hard coal condensing;
- Kernenergie = nuclear;
- Ohne Pumpspeicher-Kraftwerke = excl. pump storage.

Figure 2–24: Gross electricity production by energy carriers and technologies, according to Nitsch 2008a

The study from the Federal Ministry of Environment shows a decrease of electricity production between 2005 and 2030 by 9 % and an increase until 2050 by 3 %. Responsible for the first decline is the nuclear phase out and the reduction of production from hard coal by 50 % and of lignite by 75 %. Both production technologies play nearly no role anymore in 2050. While production from natural gas increase between 2005 and 2025, it decline to a minimum in 2050. In particular wind offshore increases to a share of 28 % and European imports of electricity rise to 20 % in 2050. Small increases are faced also by PV to about 5 % and geothermal sources to 7 %. A small increase over the total period could be found also by cogeneration plants of hard coal and natural gas.

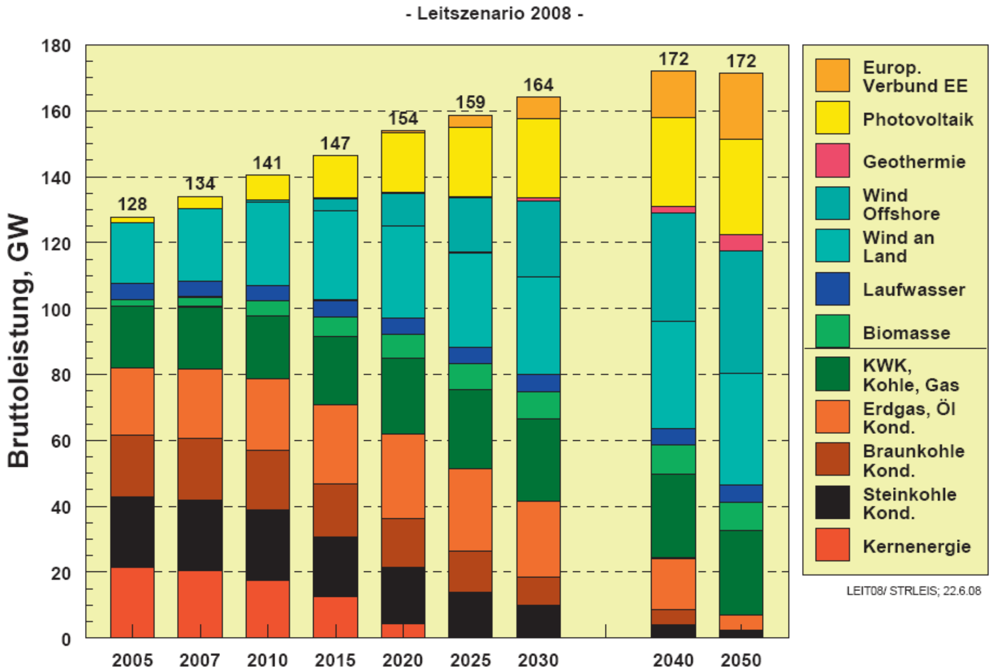


Figure 2–25: Gross capacities by energy carriers and technologies (according to Nitsch for translations see Figure 3-24)

Referring to the electricity production of the lead study of the Federal Ministry of Environment gross capacities are predicted in this reference scenario (Figure 2-25) between 2005 and 2050 as an increase of total capacity by 34 %. Nuclear face out until 2020 is assumed and lignite will be replaced by other facilities until 2040 completely. To a really minor extend hard coal installations will be used and gas capacities increase until 2030 by 20 % and decrease by 60 % until 2050. Cogeneration capacities of hard coal and gas increase until 2050 by 50 %. The largest share of installations will have wind onshore of 20 % and wind offshore by 25 %. PV increase from 1 % to share of 15 %. Also installation in other European countries contributes to the installations by a share of 10 % in 2050.

	2008*)	2009*)	2010	2020	2030	2040	2050
REN-Electricity generation, TWh/a	93.3	94.8	108	227	361	485	556
Part REN, %	**15.2**	**16.3**	**18.2**	**40**	**64.7**	**82.6**	**86.2**

*) Version: August 2010.

Table 2–5: Basisscenario 2010 A, specific contributions and shares of REN, *DLR/Fhg-IWES/IfNE 2010*

In table 2-5 for the Basisscenario 2010A it is estimated an increase of electricity generation by renewables between 2008 and 2050 more than 5 times with a share over 80 % in 2050.

GW	2008	2009	2010	2020	2030	2040	2050
Coal	52.8	52.8	51.1	42.9	27.6	14.2	9.6
Condensing power	40.6	40.2	39.4	30.8	16.3	5.3	3.8
CHP	12.2	12.6	11.7	12.1	11.3	8.9	5.8
Natural gas/ oil	28	27	26.8	29.3	26.8	28.3	29.9
Condensing power	20.9	19.9	18.6	17.3	12.4	12.4	12.4
CHP	7.1	7.1	8.2	12	14.4	15.9	17.5
Fossil total	**80.8**	**79.8**	**77.9**	**72.2**	**54.4**	**42.5**	**39.5**
Condensing power	61.5	60.1	58	48.1	28.7	17.7	16.2
CHP	**19.3**	**19.7**	**19.9**	**24.1**	**25.7**	**24.8**	**23.3**
CHP total; (incl. biomass	23.5	24.3	25	32.3	35.7	36	35.5
Nuclear power	21.4	21.4	19.6	4	0	0	0
Renewable energy *)	**38.4**	**44.5**	**55.5**	**111.2**	**147.9**	**174.2**	**185**
Total	**140.6**	**145.7**	**153**	**187.4**	**202.3**	**216.7**	**224.5**

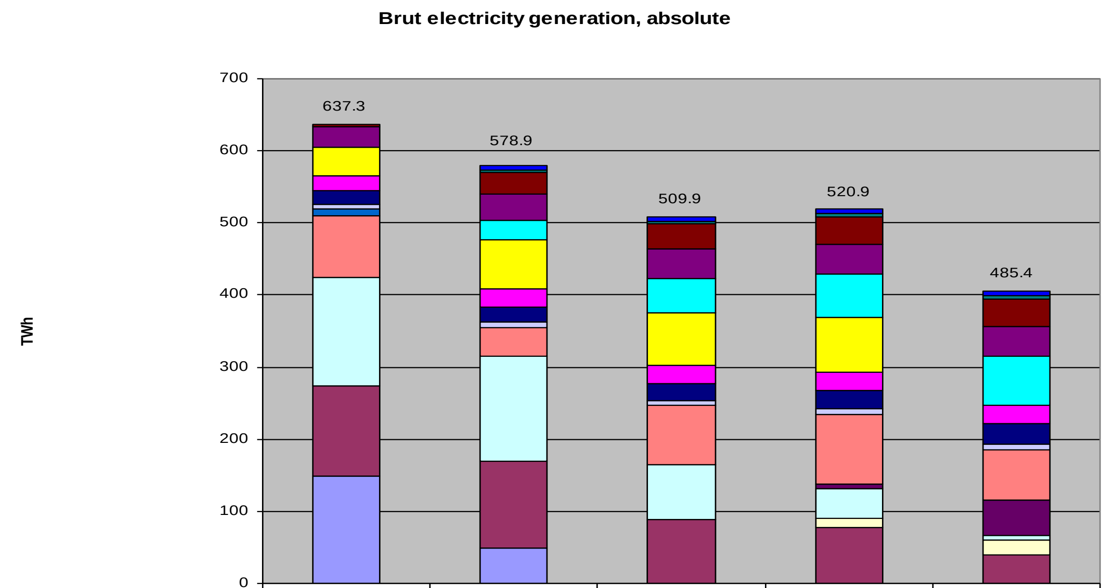
*) without capacities of waste-to-energy plants using biogenic wastes

Table 2–6: Power capacities condensing power plants and CHP, REN, *DLR/Fhg-IWES/IfNE 2010*

A similar development as in table 2-5 could be shown also in table 26 with regard to power capacities. Total capacities increase from 2008 to 2050 by 60 %. This development dominates again renewable energies. They became more than four times higher in 2050 according to 2008. CHP technologies also increases, but slightly by 21 %, whereas conventional fossil fuelled electricity production capacities diminishes by more than a half.

	Unit	Reference Scenario				
		2008	2020	2030	2040	2050
Brut electricity generation	**TWh**	**636.5**	**579.6**	**511.7**	**524.2**	**488.3**
Nuclear	%	23.4	8.5	-	-	-
Hard Coal	%	19.5	20.7	17.3	17.2	12.4
Lignite	%	23.6	25.1	14.9	9.1	11.4
Gazes	%	13.6	7.1	15.4	19.1	14.7
Renewable Energies	%	14.5	33.7	45.2	48	54

Table 2–7: Quantitative assumptions and results of the reference scenario, EWI/prognos 2010



	2008	2020	2030	2040	2050
other renewables	0	6.2	6.2	6.3	6.4
Geothermal	0	2	3	4	5
Solar	4.4	31	36	38	39
Biomass	27.2	37	40	41	41
Wind offshore	0	26	48	60	68
Wind onshore	40.4	68	73	77	0
Hydro & pump strorage	20.3	25.1	25.1	25.1	25.1
other fuels	18.7	21.1	23.4	25.7	27.9
Pump storage	6.2	7.7	7.7	7.7	8.5
Oil	9.3	0	0	0	0
Natural gas	86.7	40.4	81.5	96.5	69.1
Lignite CCS	0	0	0	6.4	49.9
Lignite coal	150.6	145.2	76.4	41.3	5.8
Hard coal CCS	0	0	0	13	20.3
Hard coal	124.6	120.2	88.4	77	40

a

Figure 2–26: Brut electricity generation, 2008 until 2050, in TWh, EWI/Prognos 2010

In the reference scenario of RWI/Prognos 2010, see table 2-6 and figure 2-26, the brut electricity generation decreases between the years 2008 and 2050 by 23 %. While the nuclear phase out until 2020 is assumed, decreases of fossil fuelled generation of hard coal and lignite between 36 % and 52 % is also seen, while gas rises slightly by 8 % and renewable go up more than 3 times until 2050 according to 2008.

	2008[1)]	2020	2030	2040	2050
Brut capacities, absolute, GW					
Nuclear [2)]	20.4	6.7	0.0	0.0	0.0
Hard coal	30.7	28.5	18.0	17.9	10.9
CCS	0.0	0.0	0.0	2.5	4.9
Lignite	22.4	21.4	11.8	7.9	7.9
CCS	0.0	0.0	0.0	1.0	7.0
Natural gas	25.7	24.4	45.7	44.5	41.5
Oil	6.7	0.7	0.4	0.1	0.0
Pump storage [3)]	7.5	7.7	7.7	7.7	7.7
Other fuels[4)]	3.2	3.5	3.8	4.1	4.4
Renewable Energie	39.1	87.6	97.5	103.1	106.4
Pump storage hydro	5.2	5.6	5.6	5.6	5.6
Wind onshore	23.9	33.3	33.7	35.2	36.4
Wind offshore	0.0	7.6	12.6	15.2	17.0
Biomass	3.5	5.7	6.0	6.0	6.0
Solar	6.0	33.3	37.5	38.8	39.0
Geothermal	0.0	0.3	0.4	0.6	0.7
Other renewable fuels [5)]	1.2	1.6	1.6	1.6	1.7
Total	**156.3**	**180.5**	**185.0**	**185.4**	**178.8**
Brut capacities, structure, %					
Nuclear [2)]	13.0	3.7	0.0	0.0	0.0
Hard coal	19.7	15.8	9.7	9.6	6.1
CCS	0.0	0.0	0.0	1.3	2.7
Lignite	14.3	11.9	6.4	4.3	4.4
CCS	0.0	0.0	0.0	0.5	3.9
Natural gas	16.4	13.5	24.7	24.0	23.2
Oil	4.3	0.4	0.2	0.1	0.0
Pump storage hydro[3)]	4.8	4.3	4.2	4.2	4.3
Other fuels[4)]	2.0	2.0	2.1	2.2	2.5
Renewable energies	25.0	48.5	52.7	55.6	59.5
River and pump storage hydro	3.3	3.1	3.0	3.0	3.1
Wind onshore	15.3	18.5	18.2	19.0	20.3
Wind offshore	0.0	4.2	6.8	8.2	9.5
Biomass	2.2	3.2	3.3	3.2	3.4
Solar	3.8	18.5	20.3	20.9	21.8
Geothermal	0.0	0.2	0.2	0.3	0.4
Other renewable fuels [5)]	0.8	0.9	0.9	0.9	0.9

1) Without Müllheim-Kärlich (1302 MW); 2) With Vianden (Luxembourg); 3) Waste, mine gas and others not non-energy according to the definition of AGEB; 4) In 2008 biological waste is added to biomass; 5) Biological wast, sewage and dump gas; 6) In 2008 sewage and dump gas is not considered as renewable fuel.

Table 2–8: Brut electricity capacities production 2008-2050, in GW, EWI/Prognos 2010

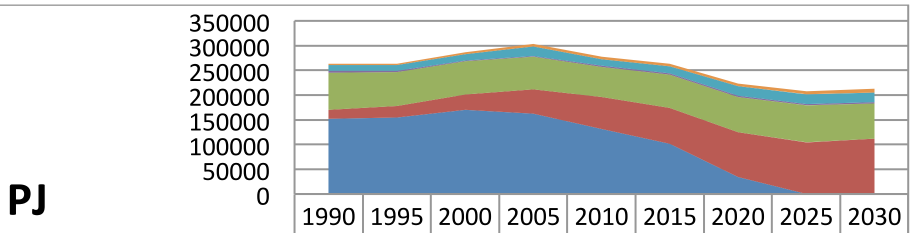
EWI/Prognos 2010 predicts a rise in its reference scenario of the brut capacities for electricity generation between 2008 and 2050 by 14 %. While capacities for hard coal and lignite are reduced to 1/3, natural gas capacities increase by about 50 % and renewable energy capacities rises by over 150 % until the year 2050 according to 2008. They receive a share of 59.5 % in 2050.

Real (price basis 2008), EUR/ MWh	**2008**	**2020**	**2030**	**2040**	**2050**
Whole sale base	65	44	54	68	63
End consumer price					
Household	217	217	222	225	218
Trade and commerce	127	147	151	152	147
Industries	96	104	107	107	105
Electricity intensive industries	71	50	62	62	71
Brut electricity demand [TWh]	537.7	507.8	500.3	506.6	506.6

Table 2–9: Electricity price and brut electricity demand, EUR/ MWh, EWI/Prognos 2010

While wholesale prices referring to the reference scenario of EWI/Prognos 2010 decrease heavily until 2020 according to 2008 by 35 %, but afterwards prices rises until the year 2050 again and arrive nearly the level of 2008.

Concerning end consumer prices this development could also be observed for households and tertiary, while prices for the industry increase steadily between 2008 and 2050 by 9 %. But industries are faced with the largest price jump until 2020 by 8 %. Electricity intensive industries are also faced with a decline of prices by 27 % until 2020 and then until the year 2050 with a rise by 42 %.



	1990	1995	2000	2005	2010	2015	2020	2025	2030
HydrogenMethanol	0	0	0	0	0	0	0	0	0
Geothermal heat	0	0	0	0	10	21	36	56	63
Biomass & Waste	1824	2665	3174	5102	4435	4953	5733	6503	7011
Gas	12676	11982	12906	19233	13322	14262	19325	20072	20375
Oil (including refinery gas)	2871	2083	1108	2038	2848	2131	2123	2170	1747
Solids	75843	69147	68066	66172	61111	67737	71364	74889	71766
Hydro & wind	17495	23495	31138	48083	64784	72729	90947	104593	111710
Nuclear	152441	154063	169575	163026	130723	101327	34100	0	0

Figure 2–27: Electricity generation including fuel inputs for thermal power generation (own depiction according to DGTREN 2007)

The reference scenario of DGTREN foresees a decline of total electricity generation for Germany between 2005 and 2025 and a slight increase until 2030. Responsible for this decline is the nuclear phase out until 2023, while the share of hydro and wind increase most until 2030 according to 2005 by 132 % and receive the largest share in 2030 of 48 %. Solids as the second largest source group in 2030 increase between 2005 and 2030 by 9 %.

2.2.4 Scenario comparisons

In the following the scenarios will be compared with regard to the parameter total energy consumption, sector overview and transformation sector.

2.2.4.1 *Comparison of total energy demand*

	Primary energy consumption in PJ				
Institution	**2008**	**2020**	**2030**	**2040**	**2050**
EWI/Prognos (2010)	14,192	12,154	10,570	9,934	9,331
Nitsch, J (2008b)	14,469**	12,044	10,252	8,972	8,066
FZJ-STE/VDI (2009)	14,255**	13,117	12,206	11,638	10,713
DLR/Fhg-IWES/IfNE (2010)	14,216	11,266	9,492	8,303	7,534
IER/RWI/ZEW (2010)	13,937*****	11,704	10,755	-	-
DGTREN (2007)	346,242*	324,638*	320,477*	-	-

*for year 2005 in ktoe; **for year 2005 in PJ; ***in TWh; ****in PJ; *****for year 2007 in PJ.

Table 2–10: Overview primary energy consumption

The smallest PEC of 7,534 PJ in the year 2050 is estimated in the study of the consortia lead by DLR from the year 2010, while the largest PEC is seen by FZJ-STE/VDI from 2009 with a value of 10,713 PJ. The difference between the two studies is 30 %.

A higher difference (37 %) can be finding in the year 2030. FZJ-STE predicts the highest primary energy consumption in a reference scenario and DGTREN the lowest.

2.2.4.2 *Comparison of sector demand*

	Final energy consumption in PJ				
Institution	**2008**	**2020**	**2030**	**2040**	**2050**
EWI/Prognos (2010)	9.127	8.352	7.796	7.357	6.897
Nitsch, J (2008b)	14.613**	12.044	10.252	8.972	8.065
FZJ-STE/VDI (2009)	9.509**	8.859	8.087	7.654	7.035
DLR/Fhg-IWES/IfNE (2010)	5.472**	4.932	4.283	3.272	2.879
IER/RWI/ZEW (2010)	8.559*****	8.271	7.773	-	-
Öko-Institut/Prognos (2010)	9.208**	8.178	7.351	6.643	6.100
UBA (2010)	1.820***				774***
DGTREN (2007)*	218,009*	229,461*	231,866*	-	-

*for year 2005 in ktoe; **for year 2005 in PJ; ***in TWh; ****in PJ; *****for year 2007 in PJ.

Table 2–11: Overview final energy consumption

The highest final energy consumption is estimated for the year 2050 by Nitsch from 2008, the lowest by UBA in the year 2010. Also the highest FEC reduction is calculated in the study from UBA with a decline of 57 % between 2008 and 2050. The lowest reduction is seen during this period by EWI/Prognos with a reduction of 24 %. The authors are of the opinion that the predicted reduction of FEC from UBA and Öko-Institut are too optimistic, because energy efficiency in the building sector (which has the highest potential) will not be realized during this time frame as desired. Moreover in other sectors economic growth will compensates all efforts for lowering energy consumption.

2.2.4.3 *Comparison of the transformation sector*

	Brut electricity generation in TWh				
Institution	**2008**	**2020**	**2030**	**2040**	**2050**
FZJ-STE/VDI (2009)	536.9**	522.2	518.7	500.6	488.0
Nitsch, J (2008a)	614**	584	558	560	577
IER/RWI/ZEW	638*	602	621	-	-
SRU (2010)	610**	590	570	540	510
EWI/prognos 2010	636.5	579.6	511.7	524.2	488.3
DGTREN (2007) in ktoe	303,654**	223,628	212,672	-	-

* 2005; ** 2007.

Table 2–12: Brut electricity generation

The largest electricity generation is seen by Nitsch 2008 in the year 2050 of 577 TWh. The smallest by FZJ-STE 2009 of 488 TWh. The largest reduction of electricity generation in the period between 2008 and 2050 with a decline of 23 % is predicted by EWI/Prognos 2010, the smallest reduction can be finding in the study from FZJ-STE with 9 % between 2005 and 2050.

	Brut electric power capacities in GW				
Institution	**2008**	**2020**	**2030**	**2040**	**2050**
FZJ-STE/VDI (2009)	128.4**	123.8	119.2	111.6	110.1
Nitsch. J (2008b)	134*	154	164	172	172
DLR/Fhg-IWES/IfNE (2010)	140.6	187.4	202.3	216.7	224.5
EWI/Prognos (2010)	156.3	180.5	185.0	185.4	178.8

* 2005; ** 2007.

Table 2–13: Brut electric power capacities

Concerning power capacities the reference scenario from FZJ-STE show in 2050 the smallest power plant park with an installed capacity of 110,1 GW, while DLR offer in its reference scenario the largest one with 224.5 GW.

The development of generation capacities is seen ambiguous. While FZJ-STE estimate a decline between 2005 and 2050 by 14 %, the consortia lead by DLR foresees a rise by 60 %, Nitsch prognoses an increase by 28 % and EWI/Prognos by 14 %.

The authors of the study are of the opinion that the estimation until 2050 from DLR are too high. They also assume a decline of capacities on a medium level like EWI/Prognos, because there will be a decrease of capacities of large power plants (nuclear phase out and vintage of fossil power plants), which will not be replaced. Instead to a minor extend renewable energy technologies will be used and smaller CHPs.

	Brut electric production in TWh				
Institution	**2008**	**2020**	**2030**	**2040**	**2050**
FZJ-STE/VDI (2009)	30**	40	30	30	30
IER/RWI/ZEW (2010)	40*	99	153	-	-
SRU (2010)	30**	170	280	320	380
Nitsch, J (2008a)	40*	90	170	190	210
EWI/Prognos (2010)	40.4	94	121	147	68

* 2005; ** 2007.

Table 2–14: Electricity generation from wind power

The estimations of the trajectories of the research institutes are ambiguous. While all research institutions predict an increase until the year 2030, assumes FZJ-STE/VDI and EWI/Prognos a decline afterwards until the year 2050 by 54 % and SRU (an increase by 12 times according to 2008) and Nitsch (5 times increase according to 2005) calculate also a further increase in electricity production from wind power.

	Brut electric power capacities in GW				
Institution	**2008**	**2020**	**2030**	**2040**	**2050**
FZJ-STE/VDI (2009)	20**	23	23	23	23
Nitsch, J (2008b)	33*	47	80	98	107
EWI/Prognos (2010)	23.9	40.9	46.3	50.4	63.4

* 2005; ** 2007.

Table 2–15: Capacities for wind power

Capacity development for wind power is also seen in the various reference scenarios very different by the research institutions. While FZJ-STE/VDI sees a relative constant development from 2020 onwards until the year 2050, prognoses Nitsch an increase by 3 times according to 2008 and EWI/Prognos foresees a nearly two times rise during the period from 2008 to 2050.

The authors believe that the estimations of Nitsch are too optimistic; they follow medium sized developments like EWI/prognos for Germany. Because with increasing density of onshore and offshore wind parks the social concerns of the population will rise and become a limited factor.

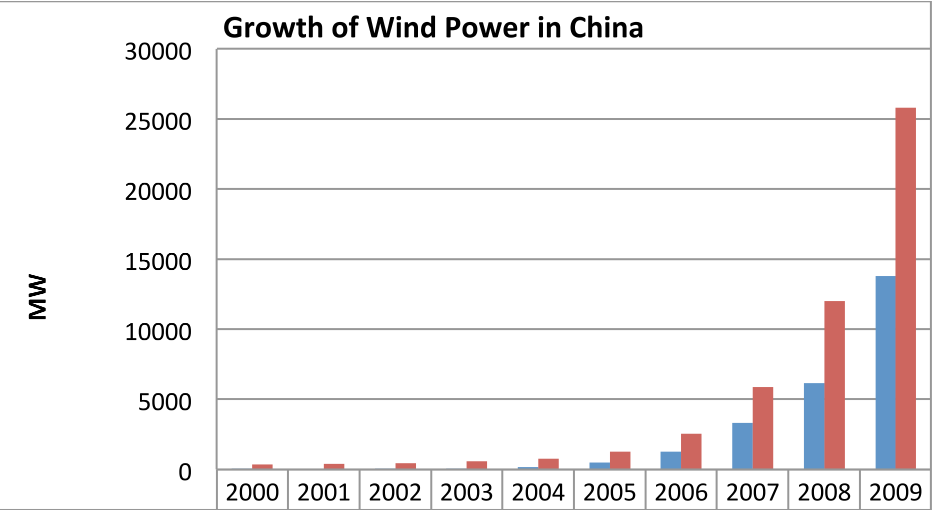
2.3 China

2.3.1 Goals and national energy policy frame conditions

Goal: The installed capacity of wind power should reach 200 GW by 2020 and the annual electricity supply will be 440 TWh; The installed capacity of wind power will reach 400 GW by 2030 and the annual electricity supply will be 850 TWh;

China committed end of 2009 that non-fossil fuels should satisfy 15 % of the country's energy demand by 2020. This goal became a binding target for short-term and medium-term national social and economic planning, together with a subsequently formulated target that CO2 emissions per GDP would be 40-45 % lower in 2020 than in 2005.

2.3.2 Scenarios of Wind power



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Newly Installed Capacity (MW)	73	53	66	98.3	196.8	506.9	1288	3311	6154	13803
Cumulative Installed Capacity (MW)	342	404	470	568.1	764.9	1271.8	2559	5871	12024	25828

Figure 2–28: Growth of wind power in China, GWEC China Wind Power Outlook 2010, p. 14

In the year 2008 China reached a total installed capacity for the first time over its target for the year 2010 of 10 GW. This means 12.024 MW.

In 2007 the Chinese Academy of Engineering asked experts to estimate China's expected wind power development in the short and medium-term. The most optimistic estimate was that the installed capacity of wind power would reach 120 GW in 2020, 270 GW in 2030 and 500 GW in 2050. Since it was expected that non-fossil energy should account for 15 % of demand, the renewables industry enhanced the expectation for wind power and projected that its installed capacity should reach at least 150 GW in 2020. It would be even better if it could reach 200 GW, at which point it would account for 3-5 % of the total renewable energy supply of 15 % (GWEC 2010, p. 22).

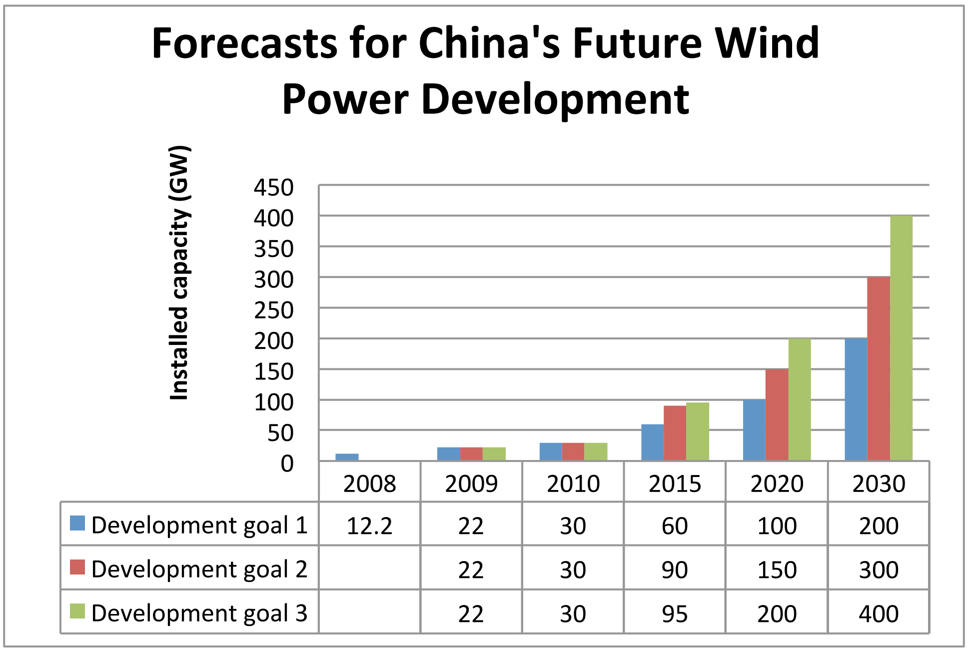
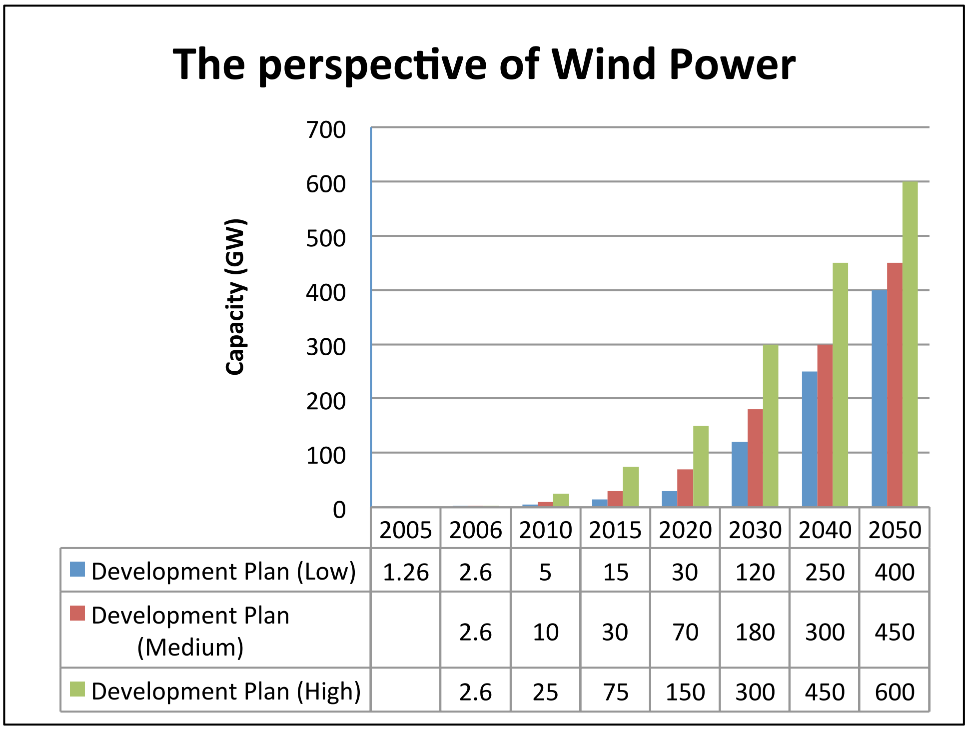


Figure 2–29: Forecasts for China's Future Wind Power Development, GWEC China Wind Power Outlook 2010, p. 86

The GWEC in its report about China from the year 2010 shows three scenarios. Scenario 1 formulates a rise between 2010 and 2030 by nearly seven times, scenario 2 offers a larger growth for installed power capacities by ten times and scenario 3 shows the highest rise more than 13 times until 2030.



	2005	2006	2010	2015	2020	2030	2040	2050
Development Plan (Low)	1.26	2.6	5	15	30	120	250	400
Development Plan (Medium)		2.6	10	30	70	180	300	450
Development Plan (High)		2.6	25	75	150	300	450	600

Figure 2–30: The perspective of wind power in China, Junfeng 2009

The newly installed wind capacity was 1,333 MW in 2006, 3400 MW for 2007 and 5500 for 2008. The 10 GW target for total installed wind power capacity for 2010 has been reached. For the future perspective Junfeng formulates three scenarios. These are “Low”, “Medium” and “high”.

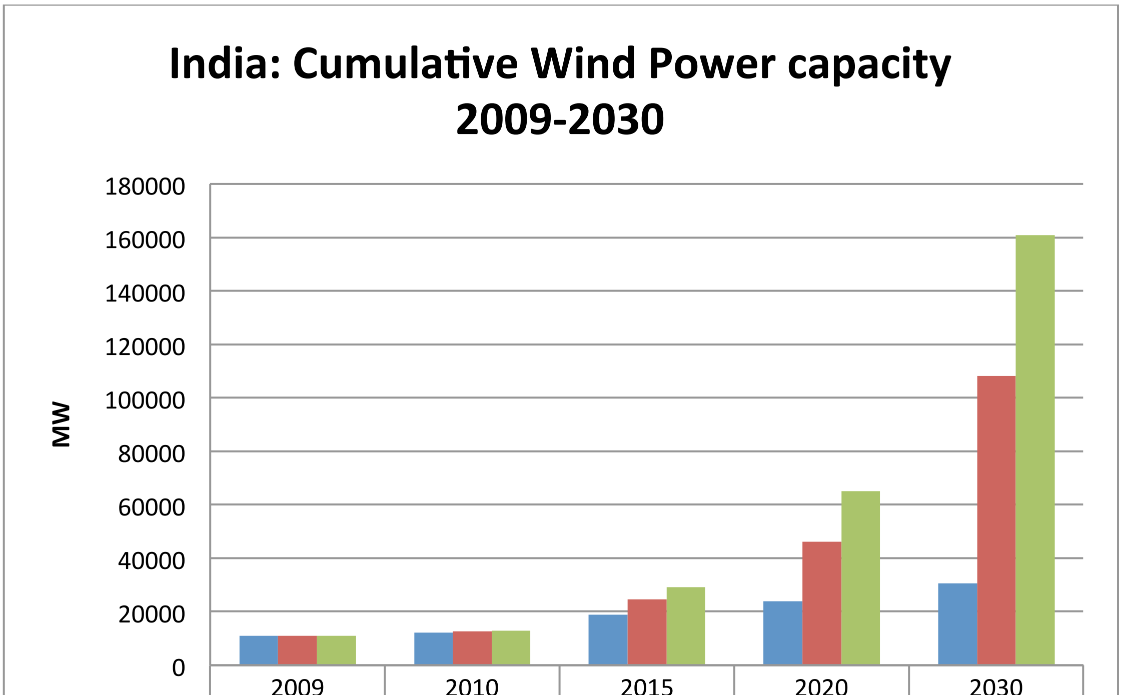
The scenario “Low” assumes a 40 times higher wind capacities in the year 2050, the “medium” scenario 45 times higher and the “high” scenario prognoses a rise 60 times until 2050 according to the year 2010 (Junfeng 2009).

2.4 India

2.4.1 National energy policy frame conditions

In 2009, the Government of India implemented a Generation Based Incentive (GBI) scheme for grid connected wind power projects. A GBI of Rs. 0.50 per kWh, with a cap of approximately $33,000 per MW per year, in total $138,000 per MW over 10 years of a project's life is being offered under this scheme. The GBI is over and above the tariff approved by respective SERC and will be disbursed on a half yearly basis through the Indian Renewable Energy Development Agency (IREDA). This scheme is applicable to wind power projects not using accelerated depreciation benefits and which are commissioned before 31st March 2012. However wind power projects selling power to third party/merchant power plant are excluded from the GBI incentives.

2.4.2 Scenarios of wind power



	2009	2010	2015	2020	2030
Reference	10926	12276	19026	24026	30526
Moderate	10926	12629	24747	46104	108079
Advanced	10926	12833	29151	65181	160741

Figure 2–31: Cumulative wind power capacity 2009-2030, GWEO Indian Wind Energy Outlook 2011

GWEO scenarios expect that during the period 2009 and 2030 in all their scenarios there will be a rise of wind power capacities. In the reference scenario the installed capacity from wind power is seen in the year 2030 three times higher. The "moderate" scenario shows an increase nearly eleven times higher, the advanced scenario predicts a growth 16 times higher in 2030 according to 2009.

2.5 Denmark

2.5.1 National energy policy frame conditions

Goal of Denmark is to cover 30 % of final energy consumption in the year 2020 from renewable energy sources. Currently it is 20 %. Moreover the country will produce 50 % of its electricity consumption with renewable energies in 2020. In particular wind power should contribute to that with a share of 30 % (EAD 2011).

2.5.2 Scenarios of Wind power

In 1890 Denmark started with the use of wind power for electricity generation and about 1908 hundreds of facilities in the power rage between 5 and 25 kW already existed. (see http://www.energyprofi.com/jo/Ausgewaehlte-Laender-IV-Windenergie.html)

The level in the year 2030 could be 10,000 MW of installed capacity, up from 3,200 MW today. It could be realized by replacing existing smaller windmills with new, large ones and expanding the off-shore development from close 500 MW today to 5,000 MW. In this way about 2/3 of the power production will come from wind. (see http://www.inforse.dk/europe/VisionDK.htm)

The Danish wind turbine industry has a 27 %share of the global market and employs approximately 27,000 people. Furthermore 20 % of domestic electricity production in Denmark comes from wind energy.

2.6 Summary

The report provides a selected choice of current long term future scenarios of the energy sector mainly for Germany The considered time period of the analysis are the years 2005 - 2050. The studies of the most relevant research institutions in Germany provide statements for the development of primary (PEC), final energy consumption (FEC) as well as electricity power capacities and generation. Further scenarios are provided for the countries China, India and Denmark as other examples with a large growth in renewable energies.

All institutes estimate for Germany in their reference/baseline/business as usual scenarios a decline for PEC and FEC in the period 2008 to 2050. But the reduction of PEC vary between 25 % and 47 %, while the FEC decline in a range between 24 % and 57 %. In most of the studies, power capacities rises in the considered period between 14 % and 60 %. In addition, power generation decreases between 9 % and 23 %.

In particular the consumption of oil and gas goes down over time in all studies until the year 2050. It varies between a share of 15 % and 20 % for gaz in the year 2050. And for coal, the share indicated varies between 9 % and 29 % in 2050.

Transport and the private households are the economic sectors, where the consumption diminishes most. The reduction varies from 43 % to 85 % in the year 2050 for private households. The transport sector scenarios show a decline between 8 % and 48 %.

The studies predict shares of renewable energies for Germany in their reference scenarios in the year 2050 between 64 % and 80 %. Other analysis show explicit the developments of wind power. Estimates for wind power capacities in Germany vary between 23 GW and 107 GW for the year 2050.

For China wind power capacities are seen until the year 2050 40 to 60 times higher compared to the year 2010, and for India studies estimate that capacities will rise between three and 16 times until the year 2050 according 2010. For Denmark the increase of wind power capacities are predicted three times higher until the year 2030 compared to the year 2010.

3 Outlook

A lot of studies provide only long-term energy sector related scenarios showing explicit the development of wind power capacity and generation in Germany. For further questions about the market potential in various regions or if a target for wind power will be met (if there is any for a country), the underlying assumptions of the reference scenarios with regard to economic, energy and environment related policy frame conditions need to be analysed in more detail. In addition further policy scenarios and also those related to further resources (like rare earth) have to be taken into account to broaden the scope of the various development paths. For China and India further scenarios need to be elaborated for making the market studies more complete.

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