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Electric Power and Natural Gas Practice

Transformation of Europe's power system until 2050

Preface

This report summarizes the main results of a study of potential developments of the European power sector for the years 2020 to 2050. It was prepared by McKinsey & Company, Inc., and supported by various academic institutes.

The purpose of this report is to provide a fact base for discussions of European and national energy master plans. It builds on different scenarios in order to understand implications of reaching emission reduction targets as recently proposed by the European Union (e.g., 80 percent reduction of greenhouse gas emissions below 1990 levels in Europe by 2050) as well as achieving an 80 percent renewable share in European power generation in 2050. Key messages have been derived for Europe, and Germany in particular.

The report does not address specific policies, political platforms, or governmental interventions. Instead, it offers an objective, fact-based analysis that uses scenarios as a starting point for discussion and agreement among stakeholders on the best way to manage Europe's transition to a low-carbon power system.

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Transformation of Europe's power system until 2050 – Executive Summary

The transformation of the European power system has started and is going to continue for many years to come. Fundamental changes are happening in European power demand and supply. Both Europe's and Germany's current transformation paths are leading to unnecessarily high cost. A cost-optimal transformation requires coordinated European action, and Germany in particular needs to rethink its options for transforming its power sector in a European context.

Three cost-optimal European pathways until 2050 compared with current power sector development

The evolution of the European[1] power sector until 2020 is largely predefined by the commitment of the European Union to reach a set of sustainability targets. These targets are known as the "20-20-20 targets." They consist of a reduction in EU greenhouse gas emissions of at least 20 percent below 1990 levels, a share of 20 percent of EU energy consumption to come from renewable sources, and a 20 percent reduction in primary energy use compared with projected levels by improving energy efficiency. Given the progress individual EU member states are making toward these targets, we assume for the purpose of this study that the targets will be met.

For 2050, leaders of the European Union and the G8 announced the objective to reduce greenhouse gas emissions to at least 80 percent below 1990 levels, if other parts of the world initiate similar efforts.[2] The European power sector would need to contribute even more than other sectors to these targets and reduce its greenhouse gas emissions to more than 95 percent below 1990 levels.[3] From a purely technical point of view, these targets for 2050 can be met. However, the transformation into a low-carbon system will require the European power landscape to undergo fundamental changes. For competitive power prices, it is of the utmost importance that the transformation follows an optimal economic path.

In order to understand the key challenges and implications of this transformation for the European power sector from 2020 to 2050, we based our assessment on three scenarios that assume a Europe-wide cost-optimal investment rationale[4] across power generation and trans-regional high-voltage transmission.[5] In the first scenario, Europe achieves a 95 percent reduction in greenhouse gas emissions in the power sector in 2050 over 1990 levels ("clean" scenario[6]). In the second scenario, Europe achieves two targets by 2050: a 95 percent reduction in greenhouse gas emissions in the power sector and an additional target of 80 percent renewables-fueled power generation ("green" scenario[7]). For comparison, we defined a third scenario, for which neither greenhouse gas emission targets nor predefined renewables targets are set beyond 2020 ("lean" scenario[8]).

All three scenarios assume a Europe-wide cost-optimal investment rationale. The current development of the electric power industry in Europe, however, does not follow this optimization rationale. Therefore, we examined the deviations between our cost-optimized scenarios and the extension of the pathway currently pursued based on national renewable energy action plans. The following insights summarize key results of our analysis.

Fundamental changes occurring to European power demand and supply

Achieving both emissions and renewables targets will significantly impact the development of the European power sector. Four key developments seem most important:

Power demand grows by 40 percent until 2050. In order to achieve aggressive emission reduction targets, all CO_2e-emitting sectors have to make significant improvements (e.g., increase efficiency) and many will have to shift from primary, carbon-containing fuels to electric power (e.g., electric vehicles in transportation), as shown in the report "Roadmap 2050: A Practical Guide to a Prosperous, Low-carbon Europe" by the European Climate Foundation. As a result, European power demand will increase by 40 percent until 2050, from 3,500 TWh in 2020 to 4,900 TWh. Increasing power demand from fuel shifts and penetration of new technologies (e.g., heat pumps) outweighs decreasing demand from higher energy efficiency, even though energy efficiency measures of roughly 2 percent per year are assumed.[9] The net effect is an average growth in electricity demand of 1.1 percent per year from 2020 to 2050. Even though this rate is below the 1.5 percent demand growth per year between 1990 and 2007, it is important to realize that the dependence of Europe on electric power will increase not decrease.

Renewables and possibly nuclear replace coal and gas over time. In the "green" and "clean" scenarios, conventional coal- and gas-fired power generation almost disappears over time and is replaced by renewable energies (including hydro) or nuclear.[10] Current nuclear new-build activities are limited, but they would be essential in a "clean" scenario to achieve the emission targets in a cost-optimal manner. Carbon capture and storage (CCS) does – at most – have some role to play as a bridging technology in selected markets in the power sector.[11] Hydro and CCGT[12] plants gain special importance as relevant storage and low-cost backup capacities.

Supply and demand regions decouple. With an increasing share of renewables, power generation centers will shift toward the most attractive regions in Southern and Northern Europe as well as the Middle East and North Africa (e.g., the Desertec[13] project), if a cost-optimal path is followed. Thus, current self-sufficient or export regions with energy-intensive industries such as Central Europe will become increasingly dependent on imports (e.g., Germany, see below).

Current power market pricing mechanism likely to fail. The increasing penetration of intermittent renewable power generation in the European power market is likely to have two effects. First, power price volatility will increase significantly.[14] Second, with increasing renewables penetration, average operating cost and therefore marginal generation cost[15] decrease. Our analyses show that average marginal generation cost will fall below full generation cost. This means power generators will not earn their full cost anymore and will stop investing given the current remuneration schemes. This would impose a threat to the reliability of the electric power system. As a consequence, we foresee the need for major changes to the current remuneration schemes in the power sector to ensure sufficient support for existing power plants and investments in new power plants for backup purposes.

Europe's current transformation path leads to unnecessarily high cost

Reducing emissions and increasing the share of renewable energies will increase overall system costs. If executed in a cost-optimal way and with a European focus, total system cost would increase by about 15 percent in the "green" scenario compared with the "lean" scenario. However, the pathway Europe is currently following clearly deviates from the cost-optimal way and leads to additional total system cost of 30 to 35 percent on top of the "green" scenario.

Minimum additional total system cost of 15 percent in the "green" scenario. Compared with the "lean" scenario with its total system cost of roughly EUR 5,700 billion until 2050, achieving the "green" scenario would increase the total system cost of the European power sector by about 15 percent to EUR 6,600 billion. The increase is driven by achieving the two targets in the "green" scenario: achieving low emissions would add EUR 500 billion to 600 billion ("clean" scenario) and meeting the renewables target in parallel would add a further EUR 300 billion to 400 billion. The additional cost for achieving the renewables target assumes a successful execution of the Desertec project at the cost and volumes published in the white book "Clean Power from Deserts" by the Desertec Foundation. If the Desertec project cannot be implemented, the additional system cost would be EUR 300 billion to 400 billion (an additional 5 percent) on top of the "green" scenario.

On a yearly basis, average system cost in 2050 would rise from EUR 200 billion in the "lean" scenario to EUR 250 billion to 300 billion in the "green" scenario, constituting a 30 percent increase in the yearly system cost in 2050.

Besides the increase in system cost, it is important to realize that the cost structure of the European electric power system will change even more. The decreasing share of coal- and gas-fired plants implies that fuel costs will be replaced by investment costs for new renewables and nuclear capacities, which are more capital intensive. Capital expenditure investments from 2020 to 2050 in the "green" scenario are EUR 2,200 billion to 2,400 billion, versus EUR 1,800 billion to 2,000 billion and EUR 1,100 billion to 1,300 billion in the "clean" and "lean" scenario, respectively. The projected investments in the "green" scenario exceed the realistic investment budgets of the European power industry of around EUR 1,800 billion for that period[16]. Hence, additional sources of financing as well as investment certainty are necessary.

Following the current non-cost-optimal pathway leads to an additional cost increase of 30 to 35 percent compared with the "green" scenario. Europe is currently deviating from a cost-optimal approach in two aspects. First, rather than applying a European focus, every European country has its own targets, which in total do not achieve cost optimization. Second, the national plans (as defined in the national renewable energy action plans[17]) do not always pursue cost optimization in terms of type of renewable energy. If these non-optimal plans remain unchanged, they put Europe on a path where total system cost increases by 30 to 35 percent[18] compared with the cost-optimized "green" scenario. This roughly amounts to an additional EUR 2,000 billion in Europe, equivalent to the total income of 2 million families over the 30 years.[19] Compared with the "lean" scenario, the current path leads to a cost increase of 50 to 60 percent.

Cost-optimal transformation requires coordinated European action

Achieving a cost-optimal transformation in the “green” scenario requires coordinated European action because only then can cost-optimal renewables be built and capacities be connected to demand centers via the European transmission grid. In addition, only a European approach can satisfy the demand for backup capacity with limited fossil capacities at manageable cost. For the “clean” scenario, reaching a cost-optimal low-carbon solution requires large investments in nuclear generation.

Cost-optimal 80 percent renewables generation requires five times larger transmission grid capacities by 2050. Generating 80 percent of European power from renewables at optimal cost in 2050 (“green” scenario) requires a steep buildup of transmission capacities, reaching a larger than fivefold increase in trans-regional transmission capacities in 2050 compared with today. As optimal locations for wind and solar power are at the outer areas of Europe (coastal for wind and southern for solar) rather than at the center, renewable power needs to be transmitted to Central European demand centers via massively increased transmission grid capacities. Even in the “clean” scenario (40 to 45 percent renewables generation), transmission grid capacities will need to reach an almost fourfold increase in 2050 compared to today. Building these transmission grid capacities is significantly cheaper (but not easier with respect to regulation/permission and public acceptance) than placing renewables closer to demand centers but at inferior sites. Until 2020, a cost-optimal pathway would already require double the transmission grid capacities. Current European expansion plans for transmission grid capacities are only fulfilling half of this need,[20] proving that Europe is significantly deviating from a cost-optimal path. To enable optimal use of renewable energies, the total investment cost for trans-regional transmission infrastructure between 2020 and 2050 would be EUR 170 billion to 200 billion for a fivefold capacity increase. On the one hand, this contributes only 4 percent of total system cost and 8 percent of total investment cost. On the other hand, the investments will not happen without sufficient public acceptance, more efficient pan-European approval processes, and improved financial incentives.

National renewable energy action plans need to be aligned based on a European perspective. The cost-optimal approach for the “green” scenario is based on using the least expensive renewables at the best sites in Europe. However, current support for renewable energies is largely based on national targets (national renewable energy action plans), which lack pan-European coordination and often do not focus on cost-optimal solutions. A European renewable energy action plan with a pan-European coordinated approach to support the buildup of renewables is required to reach the targets in a cost-optimal way.

Old and new fossil power stations are needed to provide affordable backup capacity. The cost of keeping an old gas-fired power plant on line is only one-third the cost of building a new pumped storage facility. Further capacity extension of pumped storage is limited by availability of sites, and other potential solutions such as compressed air and hydrogen storage are estimated to be even more expensive. The impact on greenhouse gas emissions of using fossil plants for backup power would be limited as extreme weather events with high backup needs occur rarely.[21] However, in order to keep enough old power plants[22] available and build new ones over time, market mechanisms need to be adjusted. Otherwise, these valuable sources of backup power will be decommissioned and no new ones will be built.

Nuclear power provides the most cost-optimal supply option. In the "clean" scenario without a renewables target, nuclear turns out to be the most cost-optimal solution to reach low emission targets. Compared with the "green" scenario, system cost would be EUR 300 billion to 400 billion lower. In this scenario, nuclear would fuel up to 47 percent[23] of power generation in 2050 and would also be used to balance intermittent and volatile renewable capacities. In addition, 40 to 45 percent of generation in the "clean" scenario is supplied by renewables. The buildup of nuclear power will only happen if sufficient investment certainty is established. Lifetime extension of currently operating German nuclear power plants would further reduce the total system cost (but has not been assumed in our analysis for all scenarios).

Germany needs to rethink its options for transforming its power sector

We have identified three options for Germany to transform its power sector. It can try to shape a European coordinated approach ("full EU cooperation") or it can rely on an optimal national transformation ("optimized German self-sufficiency"). The first option would be cost-optimal but seems to have a low probability of success in the near to medium term given developments so far. The second option is currently being pursued, but costs are too high and need to be optimized. A third option could be a compromise between low system cost and ability to implement ("preferred partnerships").

Option 1 ("full EU cooperation") requires Germany to take a shaping European role and rely on its neighbors. In the "clean" and "green" scenarios, renewable capacities are installed in the most attractive locations across Europe in order to be cost-optimal. This means that most renewable capacities are built outside of Germany. In addition, we assume that there will be no nuclear power plants operating in Germany in 2050. In combination, these two factors will make Germany dependent on imports for up to almost 50 percent of its electric power in the "clean" and "green" scenarios. Hence, Germany is very exposed to European developments in this scenario and would have to ensure that sufficient renewable and nuclear capacities are built across Europe as well as sufficient transmission capacities across Europe and into Germany.

Option 2 ("optimized German self-sufficiency") requires a comprehensive and balanced long-term plan to keep transformation cost under control. The self-sufficient "green" scenario (80 percent renewables in Germany) requires Germany to build up large amounts of renewable energies at less attractive sites. Hence, the national energy action plan for renewables needs to be adjusted and extended to achieve lower cost. In addition, Germany will need to keep conventional fossil plants operating in order to back up high-cost and intermittent renewable energies. The combination of less attractive sites for renewable energies in Germany, the nuclear phase-out, and the limited connectivity to other regions results in a 15 to 20 percent higher system cost for Germany compared with the European "green" scenario. It is important to remember that this is after optimizing current plans in Germany. If the German national renewable energy action plan is pursued and extended until 2050, additional costs relative to the "green" scenario are 30 to 35 percent, or almost twice as high as they need to be. An alternative path for optimizing cost would be to move from the "green" to the "clean" scenario as additional cost can be reduced from 30 to 35 percent to about 5 percent relative to the "green" scenario, but only if Germany adopts a massive carbon capture and storage (CCS) approach for about 50 percent of its power generation. It is worth mentioning that extending the lifetime of nuclear power plants in Germany (no new builds) would reduce overall system cost, but this would not overcome the challenge in the long term, since all existing German nuclear power plants would still be decommissioned by 2050.[24]

Option 3 ("preferred partnerships") may be a good compromise for Germany between the cost-optimal and self-sufficiency paths. In this option, Germany pushes a combination of the most economical renewable energies within Germany and starts preferred partnerships with other regions for additional wind and the most economical solar capacities. Examples of countries that could be advantageous cooperation partners include: the United Kingdom to develop significant on- and offshore wind potential, France to develop wind parks along the Atlantic coast, Southern European countries for attractive solar capacities, and Norway to further develop and optimally use large hydro reservoirs for balancing and potentially for export purposes. All these examples require grid buildup but only directly with the partner regions. Although this solution is not cost-optimal, it enables cooperation on highly attractive projects, reducing the cost for Germany compared with a go-it-alone solution. Such partnerships may also have the potential to catalyze Europe-wide solutions by attracting other countries to join the effort on the way.

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None of these options is easy to implement. Nevertheless, it is worth the effort. If Germany were to continue along the current path of the 2020 national renewable energy action plan, the transformation could be 30 to 35 percent (EUR 300 billion to 350 billion) more expensive than in the cost-optimal "green" scenario. Hence, it is clear that Germany needs a comprehensive transformation plan that achieves targets for CO_2e emissions and renewables, while keeping total system cost under control. To manage the transition in the short term, four elements need to be part of a comprehensive energy concept: (1) significantly building up trans-regional transmission grid capacities, (2) optimizing and extending the national renewable energy action plan, (3) further developing mechanisms to push energy efficiency measures, and (4) extending the current power remuneration system to ensure sufficient investment incentives in new power plants and retention of existing power plants as sources of backup power.

We believe it necessary to incorporate the four elements into the German energy concept in the short term and to initiate a process in Germany with all relevant stakeholders to develop a viable and comprehensive solution for Germany, including European aspects.

1 Europe being defined here as the European Union, Norway, and Switzerland.
2 Europe agreed to a target of 80 percent emission reduction in 2050 (compared with 1990 levels) in the G8 meeting in l'Aquila in July 2009, if global action is taken. In October 2009, the European Council set the appropriate abatement objective for Europe and other developed economies at 80 to 95 percent below 1990 levels by 2050.
3 "Roadmap 2050: A Practical Guide to a Prosperous, Low-carbon Europe" by the European Climate Foundation. In order to achieve 80 percent greenhouse gas savings, the power sector has to reduce emissions by 95 percent compared with the baseline in 2050. This translates into "allowed" remaining emissions of 60 million metric tons (Mt) of CO_2e. The power sector has to contribute more than other sectors as it can reduce emissions more easily than other areas (e.g., industrial processes) and, due to a fuel shift toward electricity, the power sector directly affects emissions of other sectors (e.g., electric vehicles).
4 We applied a macroeconomic optimization rationale. This differs from the current market development, which is driven by non-optimal boundary conditions, which in turn drive business investment decisions.
5 Investments in the distribution grid are not assessed in the context of this study.
6 "Clean" scenario: a CO_2 reduction of 95 percent is achieved and there are no specific renewables targets.
7 "Green" scenario: a CO_2 reduction of 95 percent is achieved and 80 percent of the electricity is produced by renewables (including 14 percent imports from the Desertec project).
8 "Lean" scenario: cost-optimal scenario of providing electricity for Europe in a world without CO_2 targets and without renewables targets (no cost for CO_2 considered).
9 Our assumptions for future power demand growth are in line with the detailed economic analysis conducted by the European Climate Foundation in its "Roadmap 2050." Based on modeling by Oxford Economics, the study assumes that GDP in Europe will grow by an average of 1.8 percent per year and the industrial sector by 1.9 percent per year with a stronger focus on light industry and engineering until 2050. In the base case of 2050 electricity demand, 1 percent efficiency improvements per year are assumed, based on the World Energy Outlook 2009. Additional implementation of all the GHG abatement levers up to EUR 60 per metric ton of CO_2e add another 1 percent efficiency improvement per year, resulting in a total of roughly 2 percent efficiency improvements per year. The latter levers are based on an extension of McKinsey's report "Pathways to a Low-carbon Economy – Version 2 of the Global Greenhouse Gas Abatement Cost Curve." Without these strong efficiency improvements, power demand would be even higher. Excluded are behavioral changes that affect the quality of life. It is assumed that demand-side management measures could reduce peak demand by up to 10 percent. Demand-side management will not have an effect on the total power demand over a period longer than days.
10 It is worth noting that investment certainty for nuclear is not a decision criterion in a macroeconomic cost-optimization rationale.
11 In order to achieve the 80 percent GHG reduction target for the full economy in 2050, a rollout of CCS in the industry sector is required as efficiency opportunities reach their limits. In the "Roadmap 2050" study, it is assumed that CCS is applied to 50 percent of heavy industry in Europe (cement, chemicals, iron and steel, petroleum and gas) by 2050, in order to reach the 80 percent GHG reduction target.
12 CCGT: Combined Cycle Gas Turbine.
13 The Desertec project is assumed in the "green" scenario to supply Europe with electricity originating from concentrated solar power in the Middle East and North Africa, as stated in the white book "Clean Power from Deserts" by the Desertec Foundation.
14 As long as the power supply from renewables is defined as "must take" (i.e., when it is available it has to be used), the remaining power demand has to be supplied by classic, mostly fossil sources, which will become marginal plants as a consequence. These marginal plants will bid into the power wholesale markets based on an "avoided-cost rationale," i.e., they will be willing to accept negative prices to not shut down as shutting down is costly and, once they have been switched off, they will require very high prices before they switch on again. This effect has already driven the increased volatility in the European wholesale power markets.
15 "Marginal generation cost" is the short-term operating cost of the most expensive generating unit producing power at any given point in time. Traditionally, this cost largely determines the price of electricity.

16 Based on a rough extrapolation of current investments plans, taking into account power demand growth.

17 Article 4 of the renewable energy directive (2009/28/EC) of the EU requires member states to submit national renewable energy action plans. These plans provide detailed roadmaps of how each member state expects to reach its legally binding 2020 target for the share of renewable energy in their final energy consumption.

18 Assessment based on an extrapolation of the German renewable energy action plans for 2020 and the "European RES-E Policy Analysis" by EWI published in 2010. The assessment does not include distribution cost and therefore could be even higher.

19 Assuming an average yearly disposable income of EUR 35,000 per household.

20 Given that Europe is currently building renewables based on national targets rather than at the most optimal sites, the current transmission grid expansion might be sufficient to ensure reliable supply, but it would certainly be far from cost-optimal.

21 Our estimates show that it would amount to a maximum of 5 Mt per year (0.5 percent of current emissions).

22 This study assumed that as of 2020, those fossil plants that retire at the end of their defined lifetime (e.g., 30 years for gas-fired CCGT; 40 years for coal) would remain on line to provide backup capacity in the case of extreme weather events (e.g., extended periods without sun or wind generation).

23 For nuclear, we took the phase-out in Germany as a given. For Belgium, we assumed constant nuclear generation in response to the 2009 phase-out postponement. No nuclear buildup potential was assumed for Portugal, Ireland, Austria, Norway, Greece, Luxembourg, Malta, Cyprus, Estonia, and Latvia. For all other countries, we defined a maximum capacity. Buildup potential for these countries is based on figures from the "Nuclear Century Outlook" by the World Nuclear Association and follows an average between the WNA's high and low case.

24 Even if the lifetime of Germany's full nuclear capacity is extended to 60 years, imports would amount to almost 50 percent in 2050, as the newest German nuclear power plant (Neckarwestheim 2) would go off line in 2050. Intermediate years would see lower imports.

Contacts

Editorial staff:

Peter Feldhaus, Daniel Fürstenwerth, Matthias Gohl,
Bastian Schröter, Thomas Vahlenkamp

Key contacts:

Dr. Thomas Vahlenkamp
McKinsey & Company
Kennedydamm 24
40476 Düsseldorf
Germany
thomas_vahlenkamp@mckinsey.com

Dr. Peter Feldhaus
McKinsey & Company
Kennedydamm 24
40476 Düsseldorf
Germany
peter_feldhaus@mckinsey.com

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