European climate targets achievable without nuclear power

By Claudia Kemfert, Christian von Hirschhausen, Felix Reitz, Clemens Gerbaulet, Casimir Lorenz

The upcoming Climate Change Conference in Paris will once again highlight the need for action to reduce global greenhouse gas emissions in order to mitigate climate change. The relevant global energy scenarios are often still based on the assumption that the expansion of nuclear power can contribute to climate change mitigation. The spiraling investment and operating costs of nuclear plants, the unresolved issues concerning the dismantling of these plants and permanent storage of nuclear waste, and the continuing lack of insurability against nuclear accidents make nuclear power extremely unattractive from an economic perspective. As a result, many nuclear power companies are facing financial difficulties. The nuclear renaissance was simply a fairy tale: the majority of the around 400 nuclear power stations currently in operation around the world are outdated and will still need to be dismantled after they have been decommissioned. The construction of new nuclear power plants is restricted to a small number of countries, predominantly China.

DIW Berlin has modeled a number of scenarios to forecast European power supply up to 2050 and these show that, with a marked expansion of renewable energy sources, Europe can meet its climate targets without nuclear power. The proliferation of more cost-effective renewable energy technologies, particularly wind and solar power, can compensate for the anticipated decline in nuclear power. In a scenario that includes no new nuclear power plant construction at all, renewables account for 88 percent of power-generation capacity. Nuclear power was not, is not, and never will be a sustainable energy source and is, therefore, unsuitable for an efficient climate policy. A transition to greater use of renewables is the more cost-effective option overall.

The Climate Change Conference due to take place in Paris in December brings with it the hope of significant advances in international climate change. Global heads of government are tasked with formulating binding climate targets to reduce global greenhouse gas emissions. If we are to have a good chance of meeting the two-degree target, there must be a dramatic reduction in global greenhouse gas emissions. At their recent meeting, the Group of Seven (G7) industrial nations agreed that climate mitigation measures were imperative and that the global economy should be decarbonized over the course of this century.[1] Fossil fuels still meet around 84 percent of the world's primary energy requirements.[2] In order to mitigate climate change, fossil fuels must be replaced by low-carbon energy sources. Renewables, in particular, are becoming increasingly competitive and energy efficiency improvements can also make a major contribution.

Current energy scenarios: no consensus on role of nuclear power

To date, many relevant global energy and climate change scenarios have been based on a more intensive use of nuclear power in the future. However, since nuclear power is associated with increasing financial uncertainty and renewable energy sources are proving to be ever more cost-effective, these scenarios should be re-evaluated.

The most recent *World Energy Outlook (WEO)*, dated 2014, published by the International Energy Agency (IEA), outlines various possible development paths.[3] The authors of the New Policies Scenario (NPS), which is the central scenario presented in the publication, expect global nuclear power capacity to increase to 624 giga-

1 Leaders' Declaration G7 Summit, June 7-8, 2015.

2 British Petroleum, Energy Outlook 2035, Excel tables (2015), http://www.bp.com/content/dam/bp/excel/energy-economics/energy-outlook-2015/BP-Energy-Outlook-2035-Summary-Tables-2015.xls

3 IEA, World Energy Outlook (Paris: 2014), 345 ff.

watts (GW) in 2040. In this scenario, the highest net increases are in China (+132 GW), India (+33 GW), South Korea (+27 GW), and Russia (+19 GW). According to the NPS, nuclear power capacity in the OECD countries will remain constant. Although the US will slightly expand its nuclear power plant fleet (+14 GW), capacity in Europe will decline (−18 GW). The downturn will be slowed by new construction and life extension of some power plants: as a result of decommissioning outdated plants, the current European nuclear fleet would otherwise drop to just six GW in 2040. Despite the massive 60-percent expansion in global capacity, the IEA scenario still assumes that nuclear power will maintain a constant 12-percent share of global power generation.

The *WEO-2014* also contains other scenarios, including one forecasting minimal expansion of nuclear power accompanied by a slight decline in global capacity to 366 GW in 2040 and another scenario with major expansion (to 767 GW). Even these forecasts anticipate an increase in the share of total installed capacity accounted for by non-OECD countries such as China and India. A further scenario with a high probability of the two-degree target being met (the 450 Scenario) has the highest installed nuclear power capacity (862 GW in 2040).

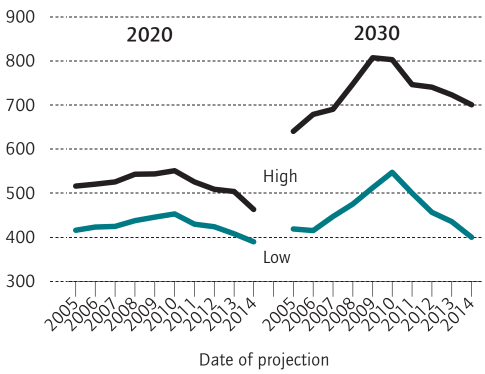
The Assessment Reports prepared by the Intergovernmental Panel on Climate Change (IPCC) have always described nuclear power as an important tool for combating climate change. However, the Fifth Assessment Report, which is the most recent, also outlines the considerable risks of nuclear plant construction. These include operating risks, risks of uranium mining, financial and regulatory risks, unresolved issues concerning the management of radioactive waste, and also the controlled proliferation of nuclear weapons.[4] A further consideration is that a technology mix that excludes further expansion of nuclear power and yet still meets the two-degree target is, according to a meta-analysis, only around seven percent more expensive than a fuel mix including nuclear power.[5]

The 2020 and 2030 annual forecasts conducted by the International Atomic Energy Agency (IAEA), however, do not show a clear picture of increased global nuclear power capacity.[6] In its forecasts, the IAEA distinguishes between a scenario with large-scale expansion and one with minimal expansion. In the latter scenario, installed capacity remains static despite expansion because of plant closures. Even in the scenario with the larger-scale expansion of nuclear power, the forecasts now indicate lower installed capacity. In recent years, the IAEA therefore adjusted its forecast for 2030 downward by between 100 and 150 GW (see Figure 1).

Figure 1

IAEA projections of installed nuclear generation capacities worldwide

In gigawatts



Source: IAEA (2014): International Status and Prospects for Nuclear Power, 4 August 2014.

The International Atomic Energy Agency recently lowered its projections for installed nuclear generation capacities.

Nuclear renaissance fails to materialize

In the Western world, the expansion of nuclear power has more or less come to a standstill. Nowadays, more capacity is removed from the grid than added to it. New construction projects are primarily concentrated in China (23 of 67 projects) and a small number of other non-OECD countries such as Russia (nine), India (six), and the United Arab Emirates (four).[7] The average age of the 435 nuclear power plants in operation around the world is currently 29 years and 58 of those power plants have been in running for over 40 years (see Figure 2).

In the past two decades, the significance of nuclear power generation worldwide has declined. While the level of installed capacity (currently 392 GW) has only experienced minimal growth in the past 20 years, the share of nuclear energy in global power generation declined from

4 IPCC, "Summary for Policymakers," in Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, eds. O. R. Edenhofer et al. (Cambridge University Press, Cambridge, UK: 2014), 21.

5 IPCC, Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (Cambridge University Press, Cambridge, UK and New York: 2014).

6 IAEA, International Status and Prospects for Nuclear Power (August 4, 2014), 16.

7 IAEA, Power Reactor Information System (2015), https://www.IAEA.org/PRIS/WorldStatistics/UnderConstructionReactorsByCountry.aspx.

17 percent to around 11 percent (see Figure 3). Even in the more ambitious expansion scenarios, nuclear power does not manage to achieve its previous shares of power generation and in the minimal expansion scenarios, nuclear power only plays a niche role worldwide. Only three new construction projects were initiated in 2014; by way of comparison: 15 new projects were implemented in 2010 and ten in 2013.[8] Further, three-quarters of all new construction projects lag behind their original schedules.[9]

The increasing average age of nuclear power plants in operation around the world is accompanied by escalating technical and financial risks. Extending the service life of power plants is a controversial issue, particularly in OECD countries, where distrust of nuclear power is on the rise. The *WEO-2014* assumes nuclear power capacity of 60 GW in the EU in 2040, which is only achieved by extending the service life of existing plants; this equates to approximately half of current capacity.[10] This scenario seems highly improbable, not least because of increasing competition from renewable energy sources.

Changed framework conditions a challenge for nuclear industry

It has become evident, both in Germany and other Western industrialized nations, that nuclear power no longer represents a source of sustainable investment for private investors.[11] Since its development in the 1960s, nuclear power has become systematically more expensive, primarily because safety requirements and, therefore, power plant design have become increasingly sophisticated and complex.[12] In addition to the resulting rises in construction costs, the price of dismantling power plants and storing radioactive waste continue to rise and put a strain on the balance sheets of the companies concerned. Given the aging nuclear power plant fleet and massive problems with new construction projects, the nuclear industries in Europe, the US, and Japan face existential challenges.[13]

The French nuclear group, Areva, manufacturer of the European Pressurized Reactor (EPR), has huge sales problems. Four new reactors are currently under construction (one in France, one in Finland, and two in Chi-

8 Schneider et al., World Nuclear Industry Status Report (Paris/London: July 2015), 14.

9 Schneider et al., World Nuclear Industry Status Report (Paris/London: July 2015), 12.

10 IAEA, International Status (August 4, 2014), 397.

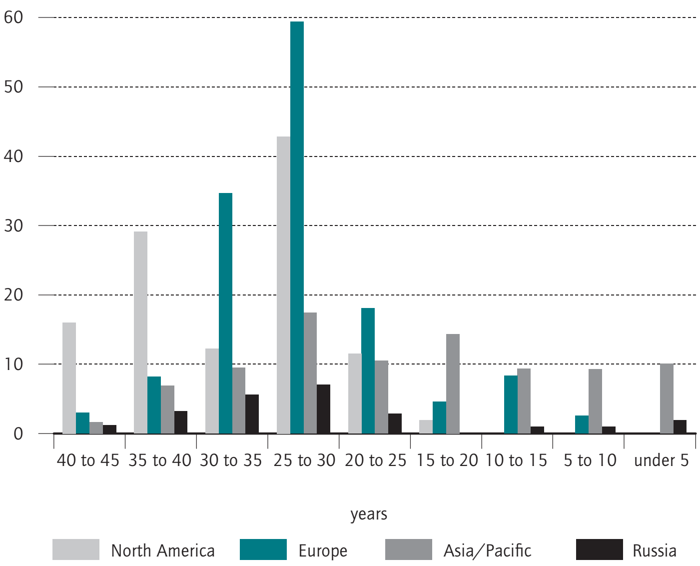
11 For a detailed discussion, see Hirschhausen and Reitz, "Atomkraft ohne Zukunftsaussichten," DIW Wochenbericht, no. 13 (2014).

12 Francois Leveque, The Economics and Uncertainties of Nuclear Power (Cambridge, UK, Cambridge University Press: 2014).

13 This section is largely based on Schneider et al., World Nuclear Industry.

Figure 2

Age distribution of nuclear power plants in selected regions in 2013
In gigawatts

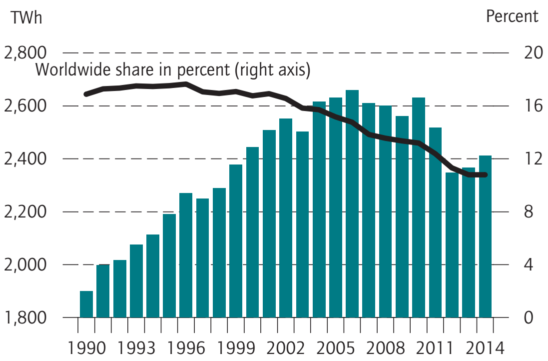


Source: World Nuclear Association.

Most of the nuclear power plants in Europe have been active for more than 25 years.

Figure 3

Worldwide net generation from nuclear power and share of total worldwide electricity demand



Source: Schneider, M. et al.

Nuclear power's importance decreased in the last decade.

na). None of these construction projects will be completed on schedule. The original cost estimate for the reference plant in Flamanville, France, was 3.2 billion euros. This sum has subsequently almost tripled — primarily as a result of considerable technical difficulties.[14] Even without this specific problem, the projected cost for the plant in Olkiluoto, Finland has also almost tripled to reach today's figure of 8.5 billion euros. The EPR, which was originally conceived as a showcase project for the French nuclear industry, failed to meet expectations. This was one of the reasons Areva's power plant division could only be saved from bankruptcy by a takeover from the state-owned EDF group. However, in light of its high debt, increasing price competition (also in the domestic French market), and the French energy transition (*transition énérgétique*), EDF itself faces major challenges.

Despite these problems, the British government is pressing ahead with its plans for the construction of a twin-unit EPR at Hinkley Point. This project would be the first EPR sale for Areva since 2007. The 35-year government-guaranteed "strike price" which is adjusted for inflation would currently be just under 13 cents per kilowatt hour (kWh) and thus higher than the feed-in tariff for renewable power from wind energy.

Model-based scenarios analyzed for the European energy market

A clear move toward renewable sources of energy can be observed throughout the European energy economy. In fact, renewables are on the brink of surpassing nuclear power in the field of power generation (see Figure 4). Wind and solar power generation have seen particularly rapid growth in recent years.

To examine various possible developments in the European energy economy, a model-based analysis comprising four different scenarios was performed. This analysis utilizes DIW Berlin's energy market model dynELMOD (see box) to determine the most economical development path for power generating capacities, as well as the optimum hourly utilization of those capacities for every country in Europe for the period 2015 to 2050 under fixed framework conditions. The dynELMOD model minimizes the overall costs including generation costs, capacity standby costs, network investment costs, and plant capacity investment.

14 It was established in April that the reactor core, the reactor pressure vessel, which is particularly important for the safety of the nuclear plant, contained faulty steel components. As a result, it is now uncertain whether the project will actually be completed since replacing the components at this stage would not be economically viable. The reactor pressure vessels in both Chinese EPR projects have the same fault.

Box

dynELMOD energy market model

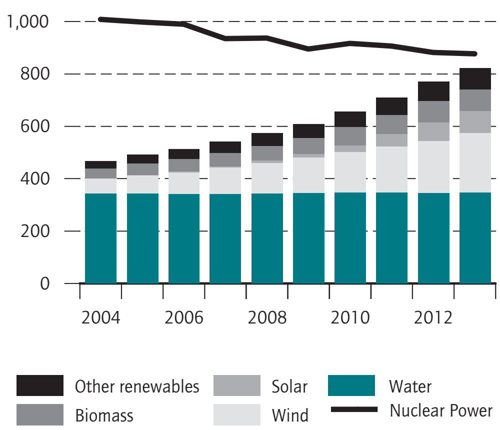
The dynELMOD[1] energy market model developed by DIW Berlin is a deterministic model used to determine the most cost-effective adjustment of energy generation capacities and power plant utilization for every European country in the period 2015 to 2050. This is done given fixed framework conditions such as the power plant fleet, demand development, CO_2 mitigation targets, and development potential of renewable energies with specified investment costs for new capacities and fuel prices for conventional power generation. Similar to the EU's Roadmap 2050, ambitious CO_2 mitigation targets are assumed. CO_2 emissions in the energy sector experienced a largely quasi-linear decline from 1,273 million tons in 2015 to as little as 19 million tons in 2050. The addition of new power generation capacities is based mainly on the given energy demand and the number of existing power plants which are assumed will close down after 50 years in operation once the plants have reached the end of their service life.

1 See Gerbaulet et al., "Cost-Minimal Investments into Conventional Generation Capacities under a Europe-Wide Renewables Policy," in *11th International Conference on the European Energy Market*, IEEE, 2014, doi:10.1109/EEM.2014.6861297.

Figure 4

Renewable electricity generation and nuclear electricity generation in the European Union

In terawatthours



Source: Eurostat.

In 2013, the generation from nuclear power was almost matched by renewable generation.

New power plant additions are broken down into ten-year periods, while plant utilization is modeled using hourly time series. Cross-border market coupling is limited according to assumed net transfer capacities.[2]

Power plant investment in capacity expansions can apply to conventional technologies such as coal- and gas-fired plants, renewable energies such as wind power (onshore and offshore), solar power and concentrated solar power (CSP), as well as energy storage. For energy storage, a generic technology with a ratio of power output to storage capacity of eight hours at 80 percent efficiency is used. This is roughly equivalent to parameters of pumped hydroelectric storage technology.

The model calculations are based on cost assumptions relating to specific investment costs, as well as fixed and variable O&M costs taken from *DIW Data Documentation* 68.[3] Additional framework conditions such as the total country demand throughout the observation period until 2050, fuel prices, CO_2 emissions limits, as well as limits for the expansion of renewable energies are taken from the Diversified Supply Technologies scenario outlined in the European Commission's Energy Roadmap 2050 Impact Assessment and Scenario Analysis.[4] Technological developments and improvements in newer plants are taken into account, resulting in a greater number of full-load hours for new wind power plants. The model is based on wind power feed-in time series generated from weather data and scaled to expected full-load according to technology and year of construction. The limited regional lignite resources are also taken into account. The model does not include power generation technologies based on carbon capture, transport, and storage (CCTS).

The model is solved simultaneously for all of the points in time in the model. Since power plant investment cannot be modeled across all 8,760 hours in one year, a reduced hourly set is used. This set covers seasonal and time of day-dependent variations in the input parameters. The results achieved are robust overall but do not take into consideration all of the extreme hours. For power plant utilization, the model is solved for the entire 8,760 annual hours.

2 See Entso-E, NTC Matrix (Brussels: 2013). ENTSO-E, *Ten-Year Network Development Plan 2014* (Brussels: 2014). Federal Network Agency (Bundesnetzagentur, BnetzA), *Genehmigung des Szenariorahmens 2025 für die Netzentwicklungsplanung und Offshore-Netzentwicklungsplanung* (Bonn: 2014).

3 See Schröder et al., "Current and Prospective Costs." DIW Data Documentation No. 68.

4 See EC, "Energy Roadmap 2050: Impact Assessment, Part 2/2." SEC(2011) 1565. COMMISSION STAFF WORKING PAPER (Brussels: 2011).

The installed capacity of nuclear power plants is not one of the decision variables in the model but is instead a given model parameter. The scenarios vary with regard to assumed nuclear power plant capacity (see Figure 5).

- In the base scenario, the values used are those assumed by the European Commission for nuclear power expansion in its reference scenario (2013 update). In this scenario, numerous power plants are given extended service lives and new power plants constructed across Europe, in particular after 2030. Relatively stable long-term capacity calls for new nuclear power plants with a capacity of around 120 GW by 2050, mainly in the period 2030 to 2040. Approximately half the new installed capacity is located in France.

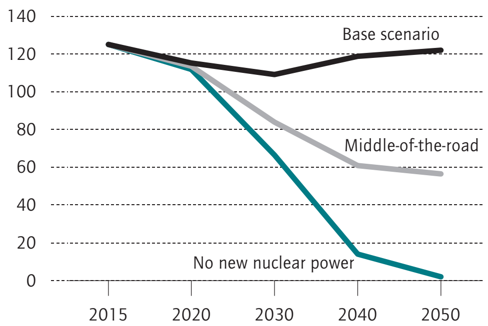
- The "middle-of-the-road" scenario assumes 50 percent of the expansion of nuclear power generating capacity predicted in the EU reference scenario.

- The "no new nuclear power" scenario works on the assumption that no new nuclear power plants are

Figure 5

Installed nuclear power capacities by scenario

Installed capacity in gigawatt



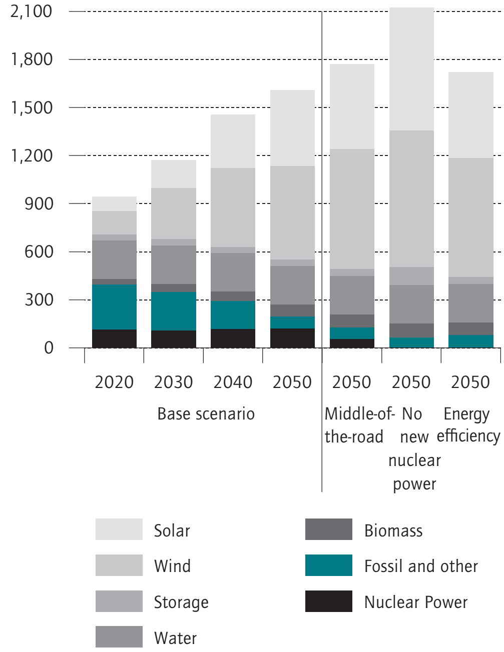
Source: DIW Berlin.

In the scenario "no new nuclear power", all nuclear power plants will be decommissioned by 2050.

Figure 6

Generation capacities in Europe by scenario

Installed capacity in gigawatt



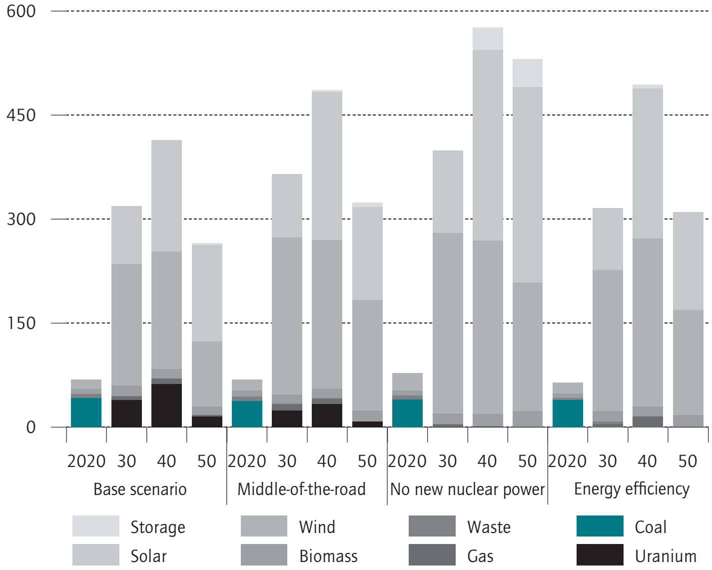
Source: DIW Berlin.

With decreasing nuclear power capacities, more renewable generation capacities are installed.

Figure 7

Additional installed capacities by scenario

In gigawatt per decade



Source: DIW Berlin.

The additional installations are lowest in the scenario „Energy Efficiency".

built in future. After 50 years in operation, existing nuclear power plants are decommissioned.

- The "energy efficiency" scenario is based on the "no new nuclear power" scenario. In 2050, the energy demand is ten percent lower than at the outset as a result of linear increases in energy efficiency over time.

The decline in nuclear power generation is due to renewable sources such as energy, wind, and solar power in particular, increasingly replacing nuclear power in the energy mix. In the "no new nuclear power" scenario, the renewable energy capacity is correspondingly higher due to the fewer full-load hours per year of renewables (see Figure 6). Investment is also being put into energy storage in order to offset feed-in fluctuations that are common with this form of energy. In 2040 and 2050, coal- and gas-fired power plants play a lesser role in these calculations, since the model increasingly curbs CO_2 emissions over time. In the "energy efficiency" scenario, the required power generation capacities are far lower than in the "no new nuclear power" scenario, especially in 2030 and 2050. In particular, the expansion of energy storage infrastructure is reduced.[15] Power generation capacities from wind and solar power are also lower (see Figure 7).

In the base scenario, annual average discounted costs in the European energy sector model come to around 200 billion euros.[16] Equivalent costs in the other scenarios differ slightly (see Figure 8). Investment into new power plant capacities makes up around half of overall system costs. Investment in nuclear power plants is approximately one-fifth of overall costs: in the "no new nuclear power" scenario, there is investment in renewable sources of energy and energy storage instead. The resulting decrease in variable generation costs is offset by slightly higher fixed costs. This results in marginally higher overall system costs for the "no new nuclear power" scenario than for the base scenario.

The assumed investment costs do not include the dismantling of nuclear power plants, the interim or final storage of radioactive waste, or insurance. If these costs were factored in, it can be assumed that the "no new nuclear power" scenario would have the lowest overall costs. As expected, the "energy efficiency" scenario is the most cost-effective scenario. This is because the

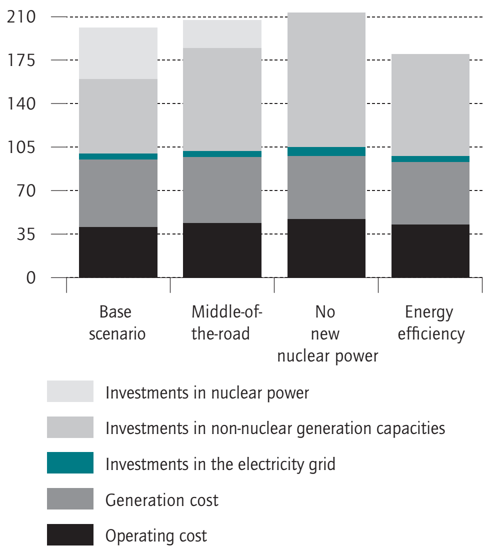
15 For a detailed analysis of the need for different types of energy storage in scenarios with a very high share of renewables, see W.-P. Schill, J. Diekmann, and A. Zerrahn, "Power Storage: An Important Option for the German Energy Transition," DIW Economic Bulletin, no. 10 (2015).

16 This is equivalent to average energy production costs of approximately 55-60 euros/MWh.

Figure 8

Average discounted generation and invest cost in the electricity sector 2015–2050

In billion Euro per year



Source: DIW Berlin.

The costs differ only slightly in the four scenarios.

lower energy demand is coupled with lower investment and generation costs.[17]

Conclusion

The upcoming Climate Conference in Paris will once again underline the need for urgent action to lower global greenhouse emissions in the fight against climate change. The international community aims to slow down the rate of global warming to two percent by the end of the century. For this to happen, the energy economy has to be largely decarbonized to cut CO_2 emissions to almost zero. Many relevant energy scenarios still assume this aim can only be achieved by increasing the use of nuclear power. However, the reasons for the future of nuclear power generation being so bleak are the stricter security requirements and risks involved in reactor construction, operation, dismantling and, in particular, nuclear waste storage. The huge technical, market-related, and regulatory risks are further reason for the financial difficulties encountered by nuclear power plant operators. In global terms, nuclear energy is not experiencing a renaissance. In fact, new nuclear power plants are being constructed in very few countries, primarily China.

Model calculations by DIW Berlin show that, if the use of renewable sources of energy is significantly expanded, Europe's climate targets can be achieved without nuclear energy. As wind and solar power become increasingly economically viable, the reduced use of nuclear power can be more than offset; in the "no new nuclear power" scenario, renewable energy sources account for 88 percent of power generation capacities in 2050. Nuclear power was not, is not, and never will be a sustainable energy source and is not compatible with current climate policy. Since renewable power generation and energy storage are becoming increasingly affordable and, consequently, more competitive, the move toward greater use of renewable sources of energy is the cheapest option in overall economic terms.[18] This is all the more relevant if the overall efficiency of renewable power generation is also increased.

17 The assumed increase in energy efficiency may, however, call for further investment, which is abstracted from in this case.

18 For more details, see our earlier studies: C. von Hirschhausen, C. Kemfert, F. Kunz, and R. Mendelevitch, "European Electricity Generation Post-2020: Renewable Energy Not To Be Underestimated," DIW Economic Bulletin, no. 9 (2013): 13-29; see also A. Schröder, F. Kunz, J. Meiss, R. Mendelevitch, and C. von Hirschhausen, "Current and Prospective Costs of Electricity Generation until 2050," DIW Data Documentation 68 (2013), as well as a more recent study: "Klimafreundliche Stromerzeugung: Welche Option ist am günstigsten?," commissioned by Agora Energiewende (Berlin: 2014).

Claudia Kemfert is head of the department energy, transportation, environment of DIW Berlin | ckemfert@diw.de

Clemens Gerbaulet is guest researcher of the department energy, transportation, environment of DIW Berlin | cgerbaulet@diw.de

Christian von Hirschhausen is Research Director for International Infrastructure Policy and Industrial Economics at DIW Berlin | chirschhausen@diw.de

Casimir Lorenz is guest researcher of the department energy, transportation, environment of DIW Berlin | clorenz@diw.de

Felix Reitz is guest researcher of the department energy, transportation, environment of DIW Berlin | freitz@diw.de

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DIW Berlin — Deutsches Institut für Wirtschaftsforschung e. V.
Mohrenstraße 58, 10117 Berlin
T +49 30 897 89 -0
F +49 30 897 89 -200

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Press office
Renate Bogdanovic
Tel. +49-30-89789-249
presse@diw.de

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