Nuclear power is not competitive—climate protection in UK and France also viable without it

By Casimir Lorenz, Hanna Brauers, Clemens Gerbaulet, Christian von Hirschhausen, Claudia Kemfert, Mario Kendziorski, and Pao-Yu Oei

The nuclear power industry is faced with profound challenges—not only in Germany, but throughout Europe as well. New nuclear power plants are very expensive to build and even at high carbon prices, nuclear power is not competitive. Nevertheless, the EU reference scenario assumes that within the next three decades, new nuclear power plants will be built with a total capacity of at least 50 gigawatts (GW), and licenses will be renewed for a further 86 GW. Model calculations show that nuclear power would disappear from Europe's power generation mix by 2050 were the decision based on economic factors and cost considerations alone. In Western Europe, the UK and France are still determined to implement their plans to build new nuclear power plants. But the model calculations for these two countries indicate that complete electricity sector decarbonization by 2050 would also be possible without nuclear power.

Nuclear power is represented as a building block for decarbonization[1] in many energy and climate scenarios, for example, in the European Union's reference scenario[2] and as part of integrated assessment modeling (IAM).[3] However, among 30 European countries—the 28 EU member states, Norway, and Switzerland—a majority of 17 do not consider nuclear power a future technology. These countries either have no nuclear power at all and no plans to commence with the technology (this applies to ten countries, including Greece, Portugal, and Norway), are not planning any more new construction (Spain), have resolved to phase it out (Germany, Belgium, and Switzerland) or have already phased out nuclear power (Italy, Austria). Most energy supply companies are turning away from nuclear power in view of the increasing costs of building new nuclear power plants and operating the existing ones, unsolved problems with insuring their risks, falling electricity prices, the increased awareness of the costs of dismantling these plants, and the final disposal of waste.[4]

Nuclear technology emerged as the "child of science and warfare" in the 1940s[5] and was primarily used during World War II and afterward for military purposes. Nuclear technology was not used for civil purposes such as generating electricity until the 1960s; it has never been

1 "Decarbonization" means converting the (energy) economy to value creation based on zero net CO_2 emissions.

2 See European Commission (2016): *EU Reference Scenario 2016: Energy, transport and GHG emissions—trends to 2050*.

3 See Kim, S.H., Wada, K., Kurosawa, A., and Roberts, M.: "Nuclear energy response in the EMF27 study," *Climatic Change* (2014), 123 (3) 123–443.

4 See also Kemfert, C., Gerbaulet, C., von Hirschhausen, C., Lorenz, C., and Reitz, F.: "Europäische Klimaschutzziele sind auch ohne Atomkraft erreichbar," *DIW Wochenbericht Nr. 45/2015* (2015): 1063–70.

5 See Lévêque, F.: *The Economics and Uncertainties of Nuclear Power* (Cambridge: Cambridge University Press, 2014), 212.

economically justified.[6] Even ignoring the external costs (such as the risk of power plant accidents and nuclear proliferation, defined as the spread of fissionable material), electricity generation in nuclear power plants has never been competitive and is still not today. Instead of becoming more affordable, since the 1960s nuclear power has become more expensive.[7]

Nuclear power is uncompetitive in Europe

Confirming earlier studies, Davis (2012) analyzed the levelized costs of electricity generation for different technologies and found that nuclear power is not competitive.[8]

Using a comparable methodology in the European context, the levelized costs of electricity generation were recalculated under the general conditions prevalent in 2016. The results show that nuclear power is not able to compete with either gas-fired or coal-fired power plants (Table 1). The analysis compared the levelized costs of electricity by source from nuclear, gas-fired and coal-fired power plants.[9] Regardless of the CO_2 price,[10] at 0.121 Euro per kilowatt hour (kWh), the production costs of nuclear power are much higher than the electricity generated with fossil fuels. The production costs of the electricity generated from coal vary between 0.051 Euro and 0.10 Euro per kWh depending on the CO_2 price, and the figure is between 0.05 Euro and 0.079 Euro per kWh for gas.[11] Even when assuming a CO_2 price of 100 Euro per ton, nuclear power is not competitive for electricity generation.

In their efforts to decarbonize electricity most European countries have decided not to rely on nuclear power.[12]

Table 1

Long-term costs of electricity by source with conventional electricity generation technology
Euro per kilowatt hour

	Nuclear power	Coal	Gas
Baseline (no CO_2 price)	0.121	0.051	0.050
CO_2 price: 25 Euro per ton	0.121	0.063	0.057
CO_2 price: 100 Euro per ton	0.121	0.100	0.079

Note: Cost assumptions on basis of the year 2016.

Source: DIW Berlin.

Electricity from nuclear power plants is not competitive regardless of CO_2 price.

Italy and Austria have already completed their nuclear power phase-out. Belgium decided in favor of a phase-out even before the Fukushima disaster in 2011, and Spain has announced that it will not build any new nuclear power plants. Germany and Switzerland passed phase-out resolutions in 2011. In Finland, where a *European pressurized water reactor* (EPR) is currently under construction, plans for an additional reactor, Olkiluoto 4, were canceled in 2015.

Some Eastern European countries are planning to build new nuclear power plants but may not realize them. In Lithuania, the population voted against new nuclear power plants in a 2012 referendum. However, the government has not given up its plans for new construction, arguing that the national referendum was only consultative. The Czech Republic, Slovakia, and Hungary are thinking about modernizing their existing nuclear power plants, but the financing for these expensive projects appears to be uncertain.[13] Poland is considering whether or not to join the group of countries that operates nuclear power plants but still has not substantiated its plans for six GW of new construction.

EU scenario still relies on nuclear power

The European Commission updates its reference scenario every three years as part of an energy system modeling process. Despite uncertainty as to whether plans will be realized and the technology's lack of competitiveness,

6 See the overview by Davis, L.W.: "Prospects for Nuclear Power," *Journal of Economic Perspectives*, 26 (1) (2012): 49–66; and analyses from the last decade, including: Massachusetts Institute of Technology MIT: *The Future of Nuclear Power* (2003); University of Chicago: *The Economic Future of Nuclear Power* (2004); Joskow, P.L. and Parsons, J.E.: "The Future of Nuclear Power After Fukushima," *Economics of Energy & Environmental Policy* 1 (2) (2912); and D'haeseleer, W.D.: *Synthesis on the Economics of Nuclear Energy—Study for the European Commission* (DG Energy, 2013).

7 See Lévêque, F., ibid.

8 See Davis, L.W. (2012), ibid. When considered over the power plant's service life, the total costs of electricity production—including power plant construction, fuel costs, operation and maintenance—result in an average value for the costs by source.

9 The data are based on *DIW Data Documentation 68* from 2013, and some of the core parameters were adjusted to reflect the situation in 2016. The investment costs for nuclear power plants were calculated to be 7,000 Euro per kilowatt and the fuel prices reflect the current levels. For nuclear power plants, we assumed an 80 percent availability (equals 7,000 full load hours) and a service life of 45 years. A Monte Carlo analysis run with the same parameters showed that the findings are valid even under significant variation in the main input parameters.

10 Here, we assumed a CO_2 price of 0 Euro, 25 Euro and 100 Euro per ton.

11 For wind turbines, we determined a value of 0.063 Euro per kWh. The current tender awards in Germany indicate that solar plants have achieved a value of 0.755 Euro per kWh.

12 See Schneider, M., Froggatt, A., Hazemann, J., Fairlie, I., Katsuta, T., Maltini, F., and Ramana, M.V.: *World Nuclear Industry Status Report 2016* (2016); and Lévêque, F.: *The Economics and Uncertainties of Nuclear Power* (Cambridge: Cambridge University Press, 2014).

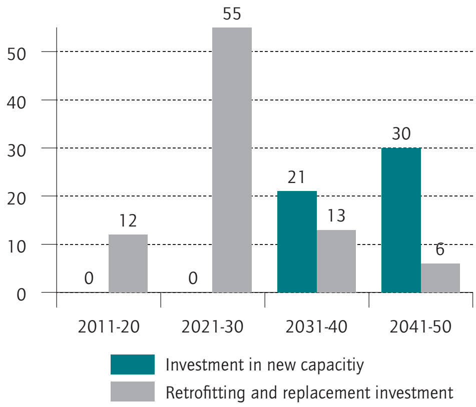
13 For Hungary's case, see "EU to Probe Hungary Nuclear Plant Financing," *The Wall Street Journal* (2016). http://www.wsj.com/articles/eu-to-probe-hungary-nuclear-plant-financing-1448296592 (Web October 19, 2016).

the scenario still exhibits a high share of nuclear energy in the European power generation mix. The current reference scenario—based on PRIMES model calculations and published this year—assumes that the total output from Europe's nuclear power plants will only trend downward slightly until 2050.[14] From 2030 until 2050, the scenario foresees many nuclear power plants being built, replaced or modernized to achieve a total cumulative capacity of over 130 GW of which at least 50 GW for new investments (Figure 1).

To check the plausibility of the EU reference scenario, we calculated the various energy carriers' share of European electricity generation until 2050 using dynELMOD, the dynamic European electricity sector model.[15] Assuming a specific CO_2 reduction pathway[16] for the electricity sector, the model determines the most economical trend for the European power plant complex and the optimum power plant deployment for each European country in five-year steps for the period from 2015 to 2050. Under the framework condition of extensive decarbonization of the electricity sector by 2050, we determined the investment in new generation capacity and storage technology (Figure 2). The result shows an overall shift in power generation complexes from fossil to (primarily) renewable electricity. As of 2040, coal-fired power plants will generate less than one percent of total electricity, and gas-fired power plants will still be responsible for a 20 percent share of power production until the end of 2040. In the subsequent ten years, gas-fired power plants will be mainly used as backup capacity. There will not be any investment in nuclear power plants; therefore their production will have dropped sharply by 2050. Starting in 2030, wind turbines will be generating the largest share of electricity, followed by photovoltaics. Due to capability constraints, hydroelectric power's share will remain constant and biomass' share will rise very slightly. Storage will begin to expand its role in the electricity system in 2030.[17] In 2050, nine percent of the electricity generated will end up in storages in order to balance out fluctuations in production.

Figure 1

New construction of nuclear power plants in Europe in the European Commission's reference scenarios for 2013 and 2016
In gigawatt

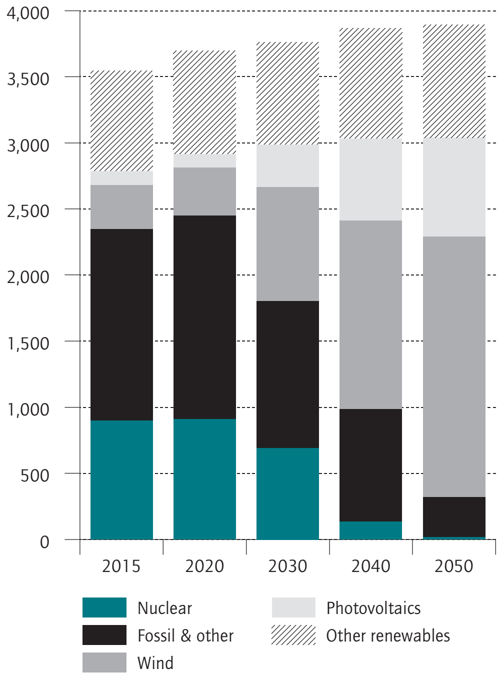


Source: European Commission.

The EU plans with more than 50 gigawatts in new capacities as well as 86 gigawatts in retrofits until 2050.

Figure 2

Electricity generation in Europe until 2050 in the dynELMOD calculations
In terawatt hours



Source: DIW Berlin.

The share of renewables will rise significantly by 2050.

14 See European Commission (2016), ibid.

15 See Gerbaulet, C., Kunz, F., Lorenz, C., von Hirschhausen, C., and Reinhard, B.: "Cost-minimal investments in conventional generation capacities under a Europe-wide renewables policy," 11th International Conference on the European Energy Market (EEM) (2014). A description is also available on: http://diw.de/elmod#dynELMOD.

16 This corresponds to the CO_2 path for the electricity sector in the Energy Roadmap 2050's "Diversified Supply Scenario." This scenario achieves an 83.9 percent decarbonization level in all sectors. See European Commission: *Impact Assessment SEC (2011) 1565* Attachment 1 (2011), 70.

17 Generation from storage is not represented in the figures since the electricity is buffered only (for example, charging and discharging in the case of batteries) and not generated. Higher production from other sources will compensate for feed-in and feed-out loss, which are mapped as part of total generation.

Comparison of the modeling results with country studies from the *Deep Decarbonization Pathways Project*

As part of the Deep Decarbonization Pathways Project (DDPP), international research institutes have developed national energy scenarios with the objective of limiting global temperature warming to a maximum of 2 degrees Celsius in harmony with the worldwide climate goal. The Institute for Sustainable Development and International Relations (IDDRI) and the Sustainable Development Solutions Network (SDSN) head the consortium. Local experts support their work on the country studies. We also re-calculated the pathways developed for the UK[18] and France[19] with the help of the electricity sector model dynELMOD. The calculations are based on the same electricity demand data as the DDPP scenarios, but use updated[20] cost assumptions for the various generation technologies.[21]

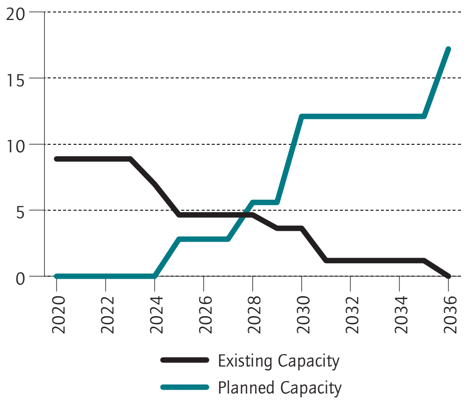
The UK: deep decarbonization is possible without nuclear power

Despite the adverse financial picture, the UK is following a new construction program aimed at replacing the second generation of advanced gas-cooled reactors (AGRs)—a legacy of the post-war era. The showcase project is the construction of two large units with 1,600 megawatts (MW) each at the Hinkley Point location. The project is politically controversial, since the consortium consists of two foreign companies: Electricité de France (67 percent) and China National Nuclear Corporation (33 percent). They plan to build an EPR reactor.[22] According to current drafts, the UK plans to realize up to 17 GW of new nuclear power plants until 2036 (Figure 3). At the same time currently existing capacities will be decommissioned successively.

Figure 3

Expected shutdowns and new construction of nuclear power plants in the UK energy strategy

In gigawatt



Source: National Audit Office (2016), PRIS Database, own assumptions.

Until 2035 over 16 gigawatts of newbuild nuclear capacity is planned.

Electricity generation in the UK until 2050 in a model comparison

In the framework of the DDPP, the UCL Energy Institute's UK TIMES model was applied to the UK.[23] The project identified two main scenarios.

- The *D-EXP scenario* (decarbonize and expand) provides for far-reaching sector interconnection—via the electrification of the heating and transport sectors, for example—which would lead to an increase in the annual demand for electricity from 230 terawatt hours (TWh) to around 600 TWh by 2050. CCTS (carbon capture, transport and storage) is the primary decarbonization method in this scenario. Wind power would only have a small share of the electricity consumption; nuclear power is the main generation source.

- The alternative *M-VEC scenario* (multi-vector transition) focuses less on electrification, consequently foreseeing a rise in demand to around 450 TWh until 2050. By 2050, nuclear power and CCTS together will have an almost 50 percent share of electricity generation, and wind power will make up the rest.

18 See Pye, S., Anandarajah, G., Fais, B., McGlade, C., and Strachan, N.: *Pathways to Deep Decarbonization in the United Kingdom*, SDSN – IDDRI (2015), http://deepdecarbonization.org/wp-content/uploads/2015/09/DDPP_GBR.pdf. (Web October 21, 2016).

19 See Criqui, P. and Hourcade, J.-C.: *Pathways to Deep Decarbonization in France*, SDSN – IDDRI (2015), http://deepdecarbonization.org/wp-content/uploads/2015/09/DDPP_FRA.pdf. (Web October 21, 2016).

20 The investment costs, etc. were updated (for 2020 and 2050 respectively) (excerpt): Nuclear power (6,000 Euro per kW; 6,000 Euro per kW, plus 1,000 Euro per kW for dismantling and storage), CCGT with CCTS (1,400 Euro per kW; 1,300 Euro per kW), wind power onshore (1,028 Euro per kW; 851 Euro per kW), wind power offshore (2,636 Euro per kW; €1,592 per kW), photovoltaics (769 Euro per kW; 230 Euro per kW), Li-ion (130 Euro per kW; 35 Euro per kW and for the storage capacity 563 Euro per kWh; 188 Euro per kWh), NaS Ion (135 Euro per kW; 35 Euro per kW and for the storage capacity 467 per kWh; 90 Euro per kWh).

21 See Schröder et al.: *Current and Prospective Costs of Electricity Generation until 2050*, DIW Data Documentation 68 (2013).

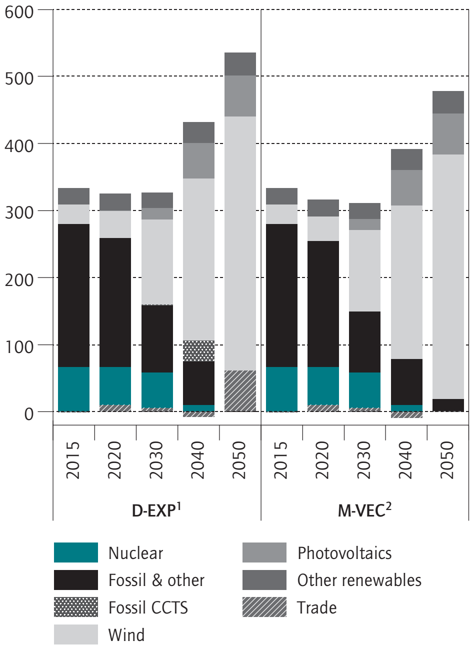
22 The additional projects include the construction of three nuclear power plants near Sellafield by a consortium consisting of parts supplier, Toshiba-Westinghouse, and Engie, the French-Belgian electric utility company. China General Nuclear Power Corporation would also like to build its proprietary development, the Hualong One reactor (HPR-1000), at a location that is yet to be determined. See Schneider, M. et al., (2016), ibid.

23 See Daly, H.E. and Fais, B.: *UK TIMES model overview*, UCL Energy Institute (2014), see https://www.ucl.ac.uk/energy-models/models/uktm-ucl/uktm-documentation-overview (Web October 19, 2016).

Figure 4

Electricity generation 2010–2050 in the UK in the dynELMOD calculations for the D-EXP and M-VEC scenarios

In terawatt hours



1 The scenario D-EXP (decarbonize and expand) is characterized by intensive sector coupling which leads to a strong demand increase in the electricity sector.
2 In the M-VEC scenario (multivector transition) the demand increase is lower than in the D-EXP scenario due to less intense sector coupling.

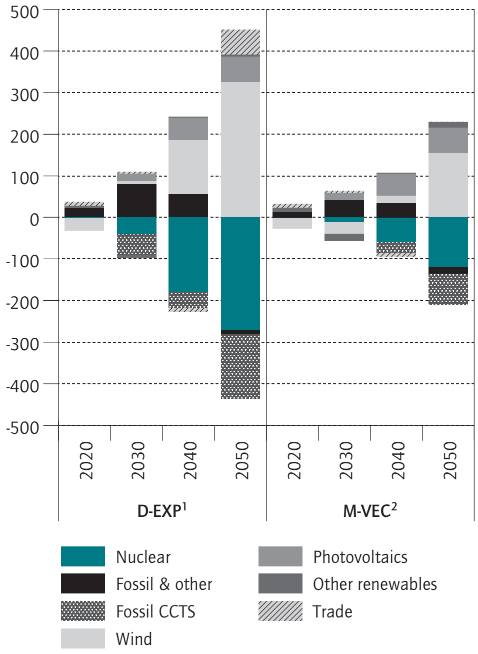
Source: DIW Berlin.

Wind is the main source of energy by 2050.

Figure 5

Differences between the dynELMOD and DDPP calculations for the D-EXP and M-VEC scenarios in the UK

In terawatt hours



1 See figure 4.
2 See figure 4.

Positive values correspond to a higher current production of the respective technology in the dynELMOD model compared to the DDPP calculations, and negative to a lower production.

Source: DIW Berlin.

The results differ widely.

The alternative comparative calculation adopted certain framework conditions from the DDPP project, such as electricity demand and an installed minimum CCTS capacity. For both the D-EXP and M-VEC scenarios, the results show a substantial transformation in the power generation mix (Figure 4). Renewable energy sources attain an 82 percent share in the D-EXP scenario in 2050. Wind power plays the leading role with almost 75 percent of total generation. Gas is the only remaining fossil energy carrier.[24] In M-VEC, the lower demand scenario, renewable energy in the form of wind power and photovoltaics satisfies almost all of the demand. It is supported by up to 45 GW of installed battery storage capacity.

Its electricity generation differentiated by energy carriers varies significantly from those of the DDPP results (Figure 5). The UK TIMES model assumes significantly higher nuclear power plant and fossil fuel power plant capacities; whereas dynELMOD shows a competitive advantage for wind power in conjunction with storage capacity. Furthermore the DDPP results still do not contain any information on imports. On the contrary, the model applied here includes imports and exports, primarily from France and the Netherlands, which play a role in the D-EXP scenario in particular. Both models achieve electricity sector decarbonization of more than 90 percent.

24 The D-EXP scenario is based on 5 GW of gas CCTS capacity as part of the exogenous scenario assumptions.

France can also do without nuclear power

In the aftermath of the successful international climate protection conference organized in Paris in 2015, the 21st Conference of the Parties (COP 21), the public opinion in Europe and the world are putting pressure on France to comply with the adopted climate protection goals: a 75 percent reduction in greenhouse gas emissions against the 1990 levels by 2050.[25]

In 2015, France's net production from nuclear power plants was 417 TWh, which equals a 76 percent share of its total electricity production. The country's nuclear electricity is generated in 58 pressurized water reactors on 19 sites that are all operated by Electricité de France (EDF), the national electric utility company. The majority of the plants were built at the end of the 1970s/beginning of the 1980s. In the near future, many units will therefore be more than 40 years old.

The players' political and entrepreneurial capacity for action is severely limited right now. Faced with record debt and persistently low electricity prices, EDF is struggling to remain profitable. The company's current plans target license renewals of ten to 20 years for several power plant blocks, which would require tens of billions in investment. However, the national nuclear security board has already demanded guarantees, which will drive the costs even higher. And the cost increases for the new EPR reactor in Flamanville (approximately 6,500 Euro per kW instead of the originally planned 3,000 Euro per kW[26]), plus increasing skepticism about EDF's participation in the new Hinkley Point C nuclear power plant in the UK are aggravating the problem.

If France turned away from nuclear energy as its main energy carrier, the country could only achieve the climate protection goals it set itself with a massive expansion of its renewable energy capacity.[27] The law on the *transition énergétique* (energy sector transformation) that France adopted in summer 2015 provides neither orientation for the future of nuclear energy nor an answer to the issue of nuclear phase-out. It contains targets to reach by 2025, but lacks a roadmap detailing when which nuclear power plants must be shut down in order to achieve the promised reduction in nuclear electricity production.[28]

Electricity generation in France: a comparison of models

In the framework of the DDPP calculations for France, the *IMACLIM-R-France-model* was applied. It is a dynamic equilibrium model and identified two development pathways.[29]

- The *Diversity* (DIV) *scenario* assumes a slight rise in the demand for electricity to 560 TWh by 2050. It also presupposes that up to 60 percent of the building inventory will have undergone energy refurbishments. At the same time, it assumes that by 2050 passenger transport will increase by 55 percent and goods transport by 25 percent.

- The *Efficiency* (EFF) *scenario* assumes a drop in the demand for electricity to 380 TWh by 2050. It posits that the entire building inventory will have undergone an energy refurbishment and the transport sector will remain stable.

In both scenarios, nuclear power retains its role as a key energy carrier with 44 and 29 percent of the electricity generation respectively in 2050.

We also carried out a comparative calculation with dynELMOD here. The results show that a renewable energy expansion will be able to compensate for a reduction in nuclear electricity production (Figure 6). Between now and 2050, the amount of electricity generated from nuclear power plants will decrease dramatically—especially in the decade beginning in 2030. In both scenarios, electricity production from renewable energy sources will have exceeded conventional production in 2040. To a greater extent than the EFF scenario, the DIV scenario is based on the extremely ambitious expansion of wind power and other renewable energy sources. Wind power and photovoltaics, which combine to generate 83 percent of the electricity in the DIV scenario and 75 percent in the EFF scenario, are supported by the widespread implementation of storage. In both scenarios, the production from hydroelectric and biomass power plants remains constant during the entire period. Electricity production from gas-fired power plants will drop to a very low level by 2050, primarily serving as a backup. At the same time, both scenarios see France as a net electricity exporter

25 *Loi de Programmation fixant les Orientations de la Politique Énergétique* (POPE), law adopted on 7/13/2005; the target was confirmed in 2015, ahead of COP21, see http://www.gouvernement.fr/cop21-les-engagements-nationaux-de-la-france-3403 (Web October 19, 2016).

26 See EDF: *2015 Management Report–Group Results* (2016): 18, https://www.edf.fr/sites/default/files/contrib/groupe-edf/espaces-dedies/espace-finance-en/financial-information/publications/financial-results/2015-annual-results/edf_annual_results_2015_management_report.pdf. (Web October 19, 2016).

27 For more detailed information on this section, see Kendziorski, M., Kruckelmann, J., Paschke, J. and Oei, P.-Y.: "Transition énergétique à la française – Dekarbonisierung mit oder ohne Atomumstieg?" *Energiewirtschaftliche Tagesfragen* No. 11 (2016).

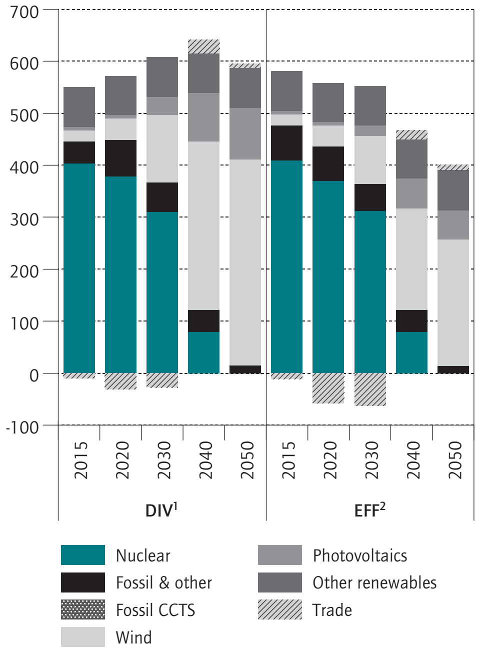
28 *Loi Relative à la Transition Energétique pour la Croissance Verte*, law adopted on 8/17/2015 and Bayer, E.: "Report on the French Power System," *The Regulatory Assistance Project (RAP)* (2015).

29 See Criqui, P. and Hourcade, J.-C. (2015) ibid., 50–53.

Figure 6

Electricity generation 2010–2050 in France in the dynELMOD calculations for the DIV and EFF scenarios

In terawatt hours



1 The scenario DIV (diversity) assumes a slight demand increase due to only moderate energy efficiency measurements.
2 In the EFF (efficiency) scenario the demand decreases due to extensive energy efficiency measurements.

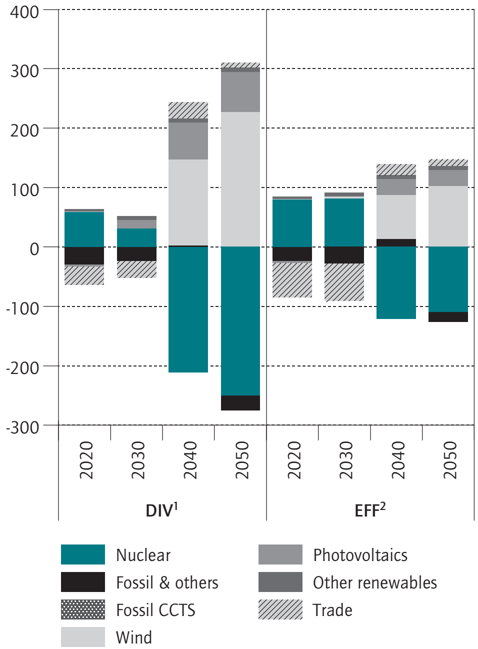
Source: DIW Berlin.

Nuclear power plays no role anymore by 2050.

Figure 7

Differences between the dynELMOD and DDPP calculations for the DIV and EFF scenarios in France

In terawatt hours



1 See figure 6.
2 See figure 6.

Positive values correspond to a higher current production of the respective technology in the dynELMOD model compared to the DDPP calculations, and negative to a lower production.

Source: DIW Berlin.

In dynELMOD wind power replaces nuclear.

until the end of 2030 and as an importer of small quantities of electricity thereafter.

The results of these calculations also differ significantly from the results of the DDPP (Figure 7). The alternative calculations show a complete lack of new investment in nuclear power plants. Consequently, they provide significantly less electricity as of 2030 than in the DDPP scenarios and foresee a complete phase-out of nuclear capacity by 2050. The DDPP assumes there will be 250 TWh of nuclear electricity production in 2050, which alternative calculations show can be replaced by renewable energy in conjunction with storage capacity. The radical decarbonization of the French electricity sector also appears to be viable without nuclear power.

Conclusion

During the post-war era, great effort was expended to establish nuclear power as an economical electricity generation technology—without success. The consensus in the literature is that based on economic standards, nuclear power is not attractive in a competitive environment. In addition, the negative environmental externalities of nuclear accidents and the storage of nuclear waste are strong arguments against the use of nuclear power.

Some European countries have detailed plans for closing their nuclear power plants. Nevertheless, the EU reference scenario continues to rely on nuclear power as a key pillar of the future supply of electricity. This perpetuates an image of the European energy mix that economic analysis does not support.

The decisions of the individual member states determine the composition of the European energy mix, but they do not base their decisions on economics alone. Political, strategic and even military considerations also play a role. This is the only possible explanation for why the UK and France continue to rely on nuclear power.

The model calculations show that even without nuclear power, both countries could count on a reliable, affordable electricity supply that satisfies their climate goals. The UK will be able to rely on excellent wind resources supplemented by storage and gas as a backup. In the context of its *transition énergétique*, France has developed a pathway built upon a combination of energy efficiency and renewable sources. Following this pathway consistently would render nuclear energy unnecessary without endangering the country's self-imposed climate goals. The calculations also show that an electricity mix that includes nuclear electricity represents a risky expensive option for Europe as a whole as well as individual member states.

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