Nuclear Power: Phase-Out Model Yet To Address Final Disposal Issue

by Christian von Hirschhausen and Felix Reitz

Three years after the nuclear disaster at Fukushima, Japan, countries around the world are beginning to look at extending the lifetime of existing power plants and building new reactors again. Advocates of nuclear power argue that it provides an affordable energy source, helps to secure energy supply, and makes a contribution to combating climate change. The European Commission's Reference scenario—which sets the agenda for the EU climate and energy strategy for 2030—assumes a massive expansion of nuclear power, including no less than seven new reactors in Poland alone. In Germany, too, there is a growing number of voices criticizing the imminent nuclear phase-out. In the view of DIW there is, however, no such thing as a "nuclear renaissance": current new-built projects concentrate on a small number of countries, primarily on China. Notably, the discussion ignores the fact that nuclear power has never been produced economically, when taking into account the risks to humans and the environment and the cost of dismantling nuclear power plants, final disposal of nuclear waste and of research and development(R&D). The question of where and how to store high-level radioactive waste is yet to be resolved.

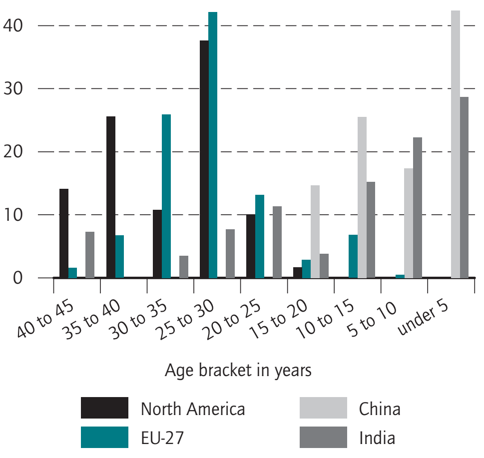
Consequently, phasing out nuclear energy appears to be the safest and most cost-efficient strategy. The European discussion should not be based on model calculations which neglect a large proportion of the costs. Germany can continue undeterred with its nuclear phase-out without endangering supply security; this also applies to the planned decommissioning of the Grafenrheinfeld nuclear power plant in 2015. Questions concerning the dismantling of nuclear power plants and final disposal of radioactive waste have been avoided for too long and urgently need to be addressed now in parallel to the phase-out.

Nuclear power is currently used for energy production primarily in Western industrialized countries, in post-Soviet states, in Japan and Korea, as well as in the emerging countries China and India. The oldest nuclear power park in the world is located in North America (see Figure 1). After two surges in growth following the oil crises in the 1970s, the American nuclear construction boom ended under the shadow of the Chernobyl disaster in 1986; the last reactor to be built was Watts Bar 1 in Tennessee which came online in 1996. Asian countries, however, have continued to regularly construct nuclear power plants. China and India in par-

Figure 1

Age Structure of Nuclear Power Stations in Selected Countries and Regions in 2013

Share of age bracket of total capacity, in percent

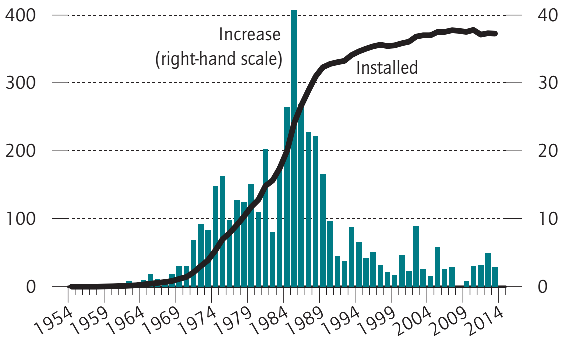


Source: calculations by DIW Berlin based on World Nuclear Association (2013).

The majority of nuclear power stations in North America and Europe are over 25 years old.

Figure 2

Global Development of Nuclear Power
In gigawatts

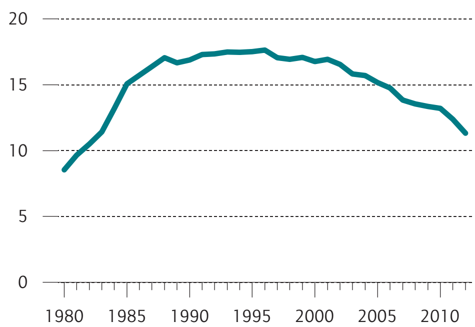


Source: calculations by DIW Berlin based on World Nuclear Association (2013).

Installed capacity has only risen slowly since 1990.

Figure 3

Share of Nuclear Power in Global Power Production
In percent



Source: graph by DIW Berlin based on EIA (2014).

Globally, the share of power generation contributed by nuclear power is on the decline.

ticular have a relatively new nuclear power park with an average age of around ten years.

The annual global expansion of nuclear power reached its peak back in the mid-1980s and has since virtually come to a halt (see Figure 2). In 1998, for the first time, more reactors were taken offline than new ones brought online. In four of the last six years, a net reduction in global capacity was observed (2008, 2009, 2011, and 2013). Given the age structure of the power plants currently operating, a further decrease is to be expected: over 80 percent of all reactors are already more than 20 years old, 50 percent are more than 28 years old, and 25 percent are more than 34 years old.

According to the International Atomic Energy Agency (IAEA) reactors with a total capacity of around 70 gigawatts are currently officially under construction, with China accounting for around 28 gigawatts. Although this increase appears to be substantial at first glance, the proportion of nuclear power plant projects actually implemented is traditionally low.[1] Moreover, nuclear power only accounts for a small share of power generated globally (see Figure 3). The 440 nuclear reactors which were in operation worldwide in 2012, with a total capacity of 370 gigawatts, generated just over 2,300 terawatt hours of power, corresponding to around 11 percent of global electricity production.[2] A further decrease in the nuclear share is to be expected: in China alone the capacity of renewable energy sources was increased by 57 gigawatts and coal power by 40 gigawatts in 2012.[3] In comparison, the planned increase in China of almost three gigawatts of nuclear power per year is negligible. The hypothesis of the "nuclear power renaissance,"[4] which might lead us to expect the technology to exhibit high growth rates again after a certain lull, is not confirmed by a global comparison, either.

Nuclear Power Beyond Economic Rationality

The discussion on nuclear power ignores the fact that, taking into account the operational risks and the immense costs of R&D, the dismantling of power plants, and the final disposal of radioactive waste, this form of energy has never been economical. Furthermore, to this day, over six decades since the first civilian use of nucle-

1 Investment in nuclear power plants which were never or hardly ever in operation amounts to at least 524 billion euros globally (as of 2012); if all nuclear installations are taken into account, such as failed repository projects or nuclear accidents, the total is over 1,000 billion euros. See J. Döschner, "Das Billionen-Dollar Desaster," www.tagesschau.de/inland/milliardengrab-atomkraft100.html, accessed on March 12, 2014.

2 See EIA, www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm?tid=2&pid=2&aid=12, accessed on March 20, 2014.

3 Source: bizzenergytoday.com/china_erneuerbare_%C3%BCberholen_kohle, accessed on March 12, 2014.

4 See, for example, P. Joskow and J.Parsons, "The Future of Nuclear Power After Fukushima," Economics of Energy & Environmental Policy, vol. 1, no. 2, (2012): 99–114; and Nuttall and Newbery, "European electricity supply security and nuclear power: an overview," in Leveque, Glachant, Barquin, Hirschhausen, Holz, and Nuttall, eds., Security of Energy Supply in Europe (2009).

ar power, the question of disposal of high-level radioactive waste remains unresolved.

When evaluating the economic viability of nuclear power, a distinction must be made between operational and social costs, with the latter also including environmental effects and technical risks. Construction of a nuclear power plant may be worthwhile from a microeconomic perspective, for instance from an investor's point of view, as long as the government or the energy customers bear a large share of the social costs. Operation of an existing nuclear power station can be profitable, provided that the government takes responsibility for the safety risks—the cost of which cannot be calculated—as well as for dismantling, final disposal of nuclear waste, and investment in R&D. However, a useful assessment of the cost-effectiveness of using nuclear power can only be made from a public policy perspective.

The actual motives for developing nuclear technology go beyond economic considerations. Due to the link between military and civilian use of nuclear power and also purely (national) political decision-making, the choice to expand nuclear power is not driven by economic rationality. Infrastructural, regulatory, and safety requirements are the result of political decisions. There are various different motives behind these decisions and they can generally be attributed to particularly well-organized interest groups, linked, for instance, to science or the military.[5]

Cost-Effective Nuclear Power? Just a Post-War Myth …

The common conception, even among experts, of cheap nuclear power is not based on empirical evidence but is driven by the political objectives of the USA and the prospective European nuclear powers of the 1950s which aimed at monitoring the civilian and military use of nuclear power worldwide. In his historical Atoms for Peace Speech to the United Nations General Assembly on December 8, 1953, the President of the United States of America at the time, Dwight D. Eisenhower, developed the concept of collective management of radioactive material under the supervision of an international authority. The International Atomic Energy Agency (IAEA) in Vienna was subsequently founded to prevent the misuse of fissionable material to build atomic bombs. The common notion of cost-effective nuclear power was thus emphasized by Eisenhower as a basis for fruitful cooperation.[6]

However, Atoms for Peace soon showed visible signs of failure, since neither the Soviet Union nor the emerging countries had any intention of complying with the proposed division of labor. Along with the UK and France, which forged ahead with military and civilian use parallel to the USA, the Soviet Union launched its own nuclear program and steadily advanced this during the Cold War. In other countries, too, the military and civilian use of nuclear power has been introduced, for instance in China, India, and Pakistan. Today countries such as Iran and North Korea are suspected of developing atomic bombs under the guise of civilian use.

In Europe, too, the concept of cost-effective nuclear power was associated with the objectives of political cooperation and economic development. Therefore, the Treaty establishing the European Atomic Energy Community (Euratom) signed in Rome in 1957 was intended to promote international cooperation concerning atomic energy as a basis for modernization and industrialization.[7]

No Prospects for Nuclear Power in Competitive Energy Markets

In view of still unresolved technical and institutional problems such as safety and final disposal, as well as the primacy of politics, it is not surprising that, to date, not a single nuclear power plant in the world has been fully financed and constructed by private investors under competitive market economy conditions. The high requirements regarding R&D, capital investment, insurance against the risks of nuclear accidents, and final disposal of radioactive waste make nuclear power unprofitable from a macroeconomic perspective.[8]

5 F. Lévêque, Nucléarie On/Off (Paris: 2013), 171: „L'énergie atomique est fille de science et de la guerre" („Nuclear power is born of science and war.").

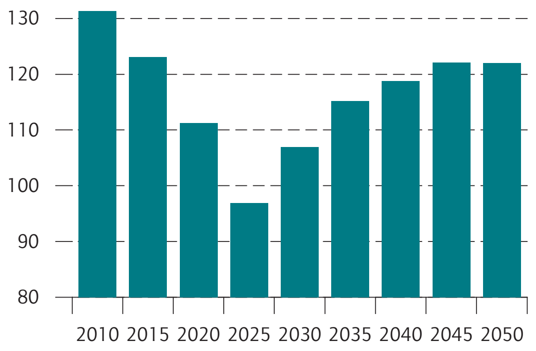
6 See Lévêque, Nucléarie On/Off, 172; the first reference to cost-efficient nuclear power is made in Eisenhower's speech: "Who can doubt, if the entire body of the world's scientists and engineers had adequate amounts of fissionable material with which to test and develop their ideas, that this capability would rapidly be transformed into universal, efficient, and economic usage," web.archive.org/web/20070524054513/http://www.eisenhower.archives.gov/atoms.htm, accessed on February 19, 2014.

7 The signatories even wrote in the preamble of the contract that this had been concluded "…recognising that nuclear energy represents an essential resource for the development and invigoration of industry and will permit the advancement of the cause of peace…" and „…desiring to associate other countries with their work and to cooperate with international organizations concerned with the peaceful development of atomic energy…", see. Euratom Treaty, http://europa.eu/eu-law/decision-making/treaties/pdf/consolidated_version_of_the_treaty_establishing_the_european_atomic_energy_community/consolidated_version_of_the_treaty_establishing_the_european_atomic_energy_community_en.pdf.

8 It is immaterial that estimates of the cost categories sometimes differ significantly, see Green Budget Germany, Was Strom wirklich kostet (Berlin: 2012); or W. D'haeseleer, Synthesis on the Economics of Nuclear Energy. Study for the European Commission, Final Report (2013), ec.europa.eu/energy/

Figure 4

EU-Wide Installed Nuclear Capacity Forecast in EU Reference Scenario
In gigawatts

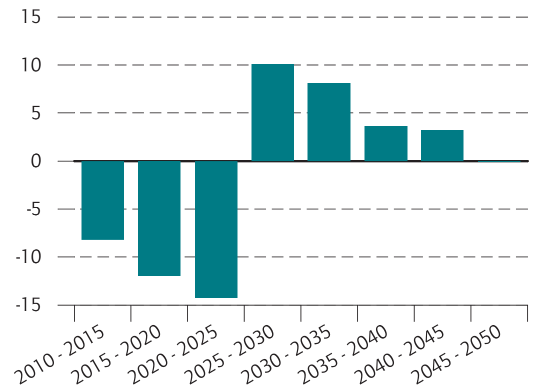


Source: graph by DIW Berlin based on European Commission (2013).

Renewed expansion of nuclear power is to be expected from 2025.

Figure 5

Forecast Change in Nuclear Power Capacity in EU Reference Scenario
In gigawatts



Source: graph by DIW Berlin based on European Commission (2013).

The further expansion of nuclear power in Europe is unlikely to come to an end until after 2045.

Various organizational models have developed around the world, none of which are based on the market-driven construction of nuclear power stations.[9] In socialist states such as the Soviet Union and later also its satellites (such as the GDR), China, and other emerging economies, all major developments in the energy industry were always subject to political decisions. But also in market economies the state entrusted either its own companies with the task (the UK and France) or awarded private companies state subsidies or guarantees in order to create incentives for developing nuclear power (Germany and the US).[10] All of the nuclear power plants planned in the US will be located in federal states that provide for a state-guaranteed profit margin. As far as long-term disposal of radioactive waste is concerned, all organizational models in the past 60 years have failed: to this day, there is no successful solution for the final disposal of high-level radioactive waste.

EU Climate and Energy Strategy for 2030: Can Nuclear Power Save the Climate?

Across Europe, opinion is divided on the future of nuclear energy. In addition to Germany, Belgium and Switzerland have also opted for a nuclear phase-out and Italy voted against plans to revive its nuclear program in a referendum in 2011. Lithuanians rejected a proposal to build a nuclear power plant in cooperation with the other Baltic States and Poland; the project is now on the brink of being abandoned. In 2012, the Bulgarian government halted construction of the Belene nuclear power plant with its two planned reactor units since implementation of the project had only been sporadic since the 1980s. Similarly, in 2013, a Slovakian court rescinded the building permits for two nuclear reactors.[11] Parallel to this, however, two nuclear new build projects are in progress, one in Finland and one in France.[12] European

nuclear/forum/doc/final_report_dhaeseleer/synthesis_economics_nuclear_20131127-0.pdf.

9 See. Lévêque, Nucléarie On/Off, in particular, part 4; Joskow and Parsons, "The Future of Nuclear Power"; and S. Thomas, The Realities of Nuclear Power, International economic and regulatory experience (Cambridge: 1998).

10 See Thomas, Realities of Nuclear Power, in particular, Chapters 4 (the US) and 6 (Germany) and for Germany also J. Radkau and L. Hahn, Aufstieg und Fall der deutschen Atomwirtschaft (Munich: 2013).

11 Paradoxically, however, a halt on construction was legally prohibited by the nuclear regulatory authority responsible (UJD) as a stop on power plant construction would have "...been seriously detrimental to the public interest...." Thus construction is continuing despite the court judgement. See orf.at// stories/2195771/, accessed on February 21, 2014.

12 Both of these are European Pressurized Reactors (EPR) developed by Areva and Siemens but both projects are running significantly behind time and over budget: the French operator, EDF does not anticipate commissioning the Flamanville plant (in France) until 2016 at the earliest and Olkiluoto (in Finland) will not be operational before 2017.

countries continuing to implement nuclear new builds include the UK, Poland (with new-build plans for up to three plants each with a capacity of 1.6 gigawatts by 2030[13]), and Hungary where the government is currently negotiating with the Russian Rosatom corporation regarding a new power station to replace the one in Paks.

Particularly in the wake of the nuclear disaster in Fukushima, the European Commission has been striving to improve safety standards and liability conditions, although, in accordance with the Euratom Treaty, the oversight of nuclear power plants remains the responsibility of the individual member states. In an initial step, in 2011, all nuclear reactors were subject to a "stress test" and safety provisions were reviewed. As a result, virtually all nuclear power stations would have to be upgraded at a cost of approximately 25 billion euros for the 132 reactor units investigated.[14] The directive subsequently proposed by the European Commission provides for the institutionalization of nuclear stress tests which, henceforth, should be implemented at least every six years according to predermined specifications.[15] Additionally, the Commission is currently preparing a proposal aiming to internalize the external risk costs.

EU Reference Scenario Envisages Widespread Nuclear New Builds...

A number of scenario analyses for the EU conclude that nuclear power is cost-effective and perceive it to be a key pillar for power supply in the run-up to 2030 and 2050. This applies to both the Energy Roadmap (Roadmap for moving to a low-carbon economy in 2050) and the December 2013 reference scenario for 2030/2050.[16] The Reference scenario which acts as the basis for the White Paper (A policy framework for climate and energy in the period from 2020 to 2030) forecasts that nuclear power capacity for 2030 will be similar to today's levels (see Figure 4): although, from a current level of 125 gigawatts, the capacity of existing nuclear power stations is forecasted to fall on a level of 97 gigawatts by 2025 and to rise again to 122 gigawatts by 2050. Following a period marked by power plant closures, on aggregate, capacity is seen to decline by around three gigawatts per annum until 2025. However, this phase will be followed by a radical trend reversal: according to the model, between 2025 and 2030 alone the scenario anticipates a net capacity growth of approximately ten gigawatts (see Figure 5).

...but Based on Implausible Assumptions

However, the situation envisaged in the reference scenario is implausible, particularly with regard to investment costs and resulting economies of scale, the assumed considerations underlying investment decisions, and also in failure to take adequate account of insurance, dismantling and final disposal costs.

Despite slight revisions[17] between 2011 and 2013, the assumptions made in the reference scenario regarding investment costs remained overly optimistic. These figures were revised upwards slightly in the reference scenario compared with the 2050 Roadmap (4,350 euros per kilowatt versus 3,985 euros). However, the assumption is based on a ficitional second plant in a standardized serial production and that the construction of further plants of the same type would result in learning curve effects. However, this hypothesis contradicts past experience which indicates that investment costs for nuclear power plants tend to increase over time.[18]

The European Commission's calculations largely fail to factor in risks. If the risks stemming from the use of nuclear power were to be internalized, this would result in considerable cost increases. In Germany, there is a limitation on liability in the event of damage caused by natural disasters to the sum of 2.5 billion euros, in France, the cap is 91.5 million euros, and in Eastern European countries the limit is even lower.[19] Given that a nuclear disaster could lead to potential damages worth thou-

13 See Polish Nuclear Power Program, www.mg.gov.pl/files/upload/19990/PPEJ_2014_01_28_po_RM.pdf.

14 See European Commission, Communication from the Commission to the Council and the European Parliament on the comprehensive risk and safety assessments ("stress tests") of nuclear power plants in the European Union and related activities (2012), 8, eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2012:0571:FIN:EN:PDF.

15 europa.eu/rapid/press-release_IP-13-532_en.htm, accessed on February 21, 2014.

16 See European Commission, Trends to 2050 – Reference Scenario 2013 (Brussels: 2013).

17 In response to criticism, the European Commission commissioned an expert report to outline the basis for the estimates, see D'haeseleer, Synthesis on the Economics of Nuclear Energy.

18 See L. Rangel, F. Lévêque, and A. Grubler, "The cost of the French nuclear scale-up: A case of negative learning by doing," Energy Policy 38 (2010): 5174–5188; and also L. W. Davis, "Prospects for Nuclear Power," Journal of Economic Perspectives, vol. 26 (2012): 49–66. For the first EPR construction in Olkiluoto, the originally estimated costs of around 3.5 billion euros have since been revised upwards to 8.5 billion euros. The cost estimate for Flamanville has now also been upwardly adjusted to 8.5 billion euros.

19 J. Diekmann, "Verstärkte Haftung und Deckungsvorsorge für Schäden nuklearer Unfälle – Notwendige Schritte zur Internalisierung externer Effekte," Zeitschrift für Umweltpolitik und Umweltrecht (2011): 122. On the internalization of external costs, see also M. Fillipini, "Strom aus dem Reaktor, ist er tatsächlich so günstig?," Neue Luzerner Zeitung, March 3, 2007, 3.

sands of billions of euros, these liability sums seem, however, negligible.[20]

The calculations also neglect to take into account the prevailing uncertainty with regard to construction and operation, the cost of dismantling nuclear power plants and, particularly, of final disposal. Due to a lack of empirical data on the subject, it is impossible to estimate the real extent of these costs, but they are likely to be significant, particularly in view of the absence of repositories.

The algorithm for power plant expansion used in the Commission's model ignores the risk-induced investment costs of private investors and therefore significantly underestimates the actual financing costs; particularly with regard to capital-intensive technologies such as nuclear power, these costs are of prime importance. The model portrays the ideal nuclear power park (from an investor's perspective). However, it fails to factor in regulatory risks which in the private sector are of considerable significance and de facto reduce interest in capital-intensive and risky investment in nuclear power plants.

Nuclear New Build at Hinkley Point, UK: Dependent on Overt and Hidden Subsidies

The proposed nuclear new-build project at Hinkley Point in the UK illustrates the enormous volume of overt and hidden subsidies required to construct a new nuclear power station today. The Hinkley Point project will be implemented by a consortium consisting of the French energy companies EDF and Areva and two Chinese state-owned corporations.[21] The project entails the construction of a twin-unit power plant using a French-designed EPR nuclear reactor, the first twin unit of that kindto be built on European soil, with a total output of 3,200 megawatts.[22] EDF puts the cost of the project at 16 billion GB pounds;[23] which is the equivalent of approximately 5,000 GB pounds of specific investment per kilowatt (around 8,500 US dollars per kilowatt). The latest package negotiated between the British government and the consortium comprises various direct and hidden subsidies including:

- A "strike price" of 92.50 GB pounds for every megawatt hour of power that the reactors generate over a 35-year period, adjusted to inflation[24] (the equivalent of around 157 US dollars per megawatt hour). Should the power station's output have to be reduced for energy-system-related reasons, the operating company would receive financial compensation which de facto equates to a guaranteed minimum payment. In addition, the British government has offered the consortium a credit guarantee to underwrite up to ten billion GB pounds of debt on the project at preferential terms. Consequently, investors do not need to rely as heavily on expensive bank loans which are subject to the relevant risk premiums;[25]
- The British government will also protect the investor from changes in nuclear liability and insurance obligations at European level;[26]
- Further, discussions are underway as to whether the completion risk will also be borne by the British government;[27]
- Finally, the agreement between the British government and the investors also allows for possible increases of the strike price under certain, as yet unspecified, conditions.

When the agreement between the British government and operator consortium was announced, the European Commission launched a formal investigation into proposed state subsidies for the plant. Its initial statement on the project was highly critical.[28] According to the Commission, there is no proven need for the project from an energy economy perspective since the power stations are unlikely to be operational until the mid- to late 2020s at the earliest, by which time the imminent excess demand is likely to have diminished again.[29]

20 Thus the Leipzig Insurance Forum calculated the cost of one Maximum Credible Accident (MCA) in Germany at up to 6,000 billion euros. Versicherungsforen Leipzig GmbH, Berechnung einer risikoadäquaten Versicherungsprämie zur Deckung der Haftpflichtrisiken, die aus dem Betrieb von Kernkraftwerken resultieren (Leipzig: April 1, 2011).

21 The two state-owned companies are China General Nuclear Power Group (CGN) and China National Nuclear Corporation (CNNC).

22 The project is an attempt to update the UK's outdated nuclear power stations; in the medium-term, the UK's nuclear program envisages new builds with a total output of 16 gigawatts. See House of Commons/Energy and Climate Change Committee, "Building New Nuclear: the challenges ahead," Sixth Report of Session 2012–13, vol. 1-7.

23 See uk.reuters.com/article/2013/10/21/uk-britain-nuclear-hinkley-idUKBRE99J03X20131021, accessed on February 18, 2014.

24 UK Government, "Initial agreement reached on new nuclear power station at Hinkley," news release, October 21, 2013, https://www.gov.uk/government/news/initial-agreement-reached-on-new-nuclear-power-station-at-hinkley, accessed on February 14, 2014.

25 www.telegraph.co.uk/finance/newsbysector/energy/10611003/Nuclear-setback-as-EC-attacks-Hinkley-Point-subsidy-deal.html, accessed on February 19, 2014.

26 The European Commission is planning to make liability insurance mandatory, which is something that has been discussed publicly by EU Energy Commissioner Oettinger and could be enacted EU-wide.

27 House of Commons/Energy and Climate Change Committee, "Building New Nuclear," 17.

28 See ec.europa.eu/competition/state_aid/cases/251157/251157_1507977_35_2.pdf, accessed on February 4, 2014.

29 ec.europa.eu/competition/state_aid/cases/251157/251157_1507977_35_2.pdf, 18.

Nuclear Phase-Out Still Makes Sense for Germany

With the 13th Act amending the Atomic Energy Act, Germany made a decision that by the end of 2022 it would phase out nuclear power. The first older nuclear power plants were taken offline in response to the March 2011 moratorium and the remaining plants are to be decommissioned in the following order: Grafenrheinfeld by December 2015; Gundremmingen B (2017); Philippsburg 2 (2019); Gundremmingen C, Grohnde, and Brokdorf (2021) followed by Isar 2, Emsland, and Neckarwestheim (all by the end of 2022).

In its coalition agreement, the German government, made up of the CDU/CSU and SPD (Christian Democratic Union/Christian Social Union and Social Democratic Party), explicitly pledges to phase out nuclear energy.[30] However, as the decommissioning of the Grafenrheinfeld plant approaches, there is a growing number of voices which, for various reasons, are against the phase-out or have regrets over its high cost. Discussions have once again turned to nuclear power as a cheap source of energy.[31] However, given the cost structure of nuclear energy, a phase-out still makes sense for Germany. Alongside safety and cost arguments, there are also technical reasons for a phase-out: the way nuclear power stations operate makes them very inflexible and therefore prevents them from contributing to the flexibility of an energy system based on renewables.

From an energy economy perspective, too, a nuclear phase-out is unproblematic. According to DIW Berlin's research findings, security of supply should be guaranteed by the mid-2020s in Germany, even without nuclear power. The findings show that, even after the nuclear phase-out, demand for power can be met across the country even during peak load times as long as available options such as load management or capacity contracts with other countries are used.[32] As part of the present analysis, a power sector model is used to simulate, inter alia, critical grid and supply situations for 2023 (i.e., after a complete nuclear phase-out). These calculations indicate that the continued implementation of Germany's Regulation on Reserve Power Plants (Reservekraftwerksverordnung) would ensure a balanced capacity in the German energy system by the mid-2020s; potential trade flows from abroad also help the situation. Even in extreme cases when there is a particularly high or particularly low level of wind, a secure power supply would still be guaranteed for the whole country during peak load times. This will still apply even if, ultimately, the two high-voltage direct-current transmission lines (HGÜ) which are planned to connect the coal-mining regions of the Rhineland and central Germany/Lusatia with southern Germany are not built.

Interim and Final Disposal Problem Yet To Be Addressed

Apart from issues relating to the energy economy, however, a number of technical and organizational questions still need to be resolved before the final nuclear phase-out and beyond. Issues include inadequate accident insurance and liability, suitable final repository locations for the spent fuel elements, and liability for long-term risks. Key issues around final disposal in particular remain unresolved. At its last sitting, the Bundestag adopted the Repository Site Selection Act (Standortauswahlgesetz, StandAG) which aims at finding a repository site for high-level radioactive waste by a federal-state commission to be completed by the beginning of the 2030s;[33] at the same time, the establishment of a new body, the Federal Agency for Radioactive Waste Management (Bundesamt für kerntechnische Entsorgung, BfE), is also in the pipeline. Consequently, the Minister for the Environment in Lower Saxony rescinded his authorization to survey the salt dome in Gorleben (based on German mining law) since it is now mandatory for the selection of repository sites to comply with the aforementioned Repository Site Selection Act.[34] This step might be interpreted as a relaunch of the search for a repository site and an admission that Gorleben in Lower Saxony is not the only option. Originally, the German government had planned for all high-level radioactive waste

30 See Coalition Agreement between CDU, CSU and SPD, Deutschlands Zukunft gestalten (2013), 59: "Wir halten am Ausstieg aus der Kernenergie fest. Spätestens 2022 wird das letzte Atomkraftwerk in Deutschland abgeschaltet." "We remain committed to a nuclear phase-out. The last nuclear power station in Germany will be decommissioned by 2022 at the latest."

31 This includes the study commissioned by the European Commission on the costs of nuclear power which assumes considerably lower energy prices in Germany for scenarios with nuclear power than without, see D'haeseleer, Synthesis on the Economics of Nuclear Energy, 8. The editor-in-chief of the Wirtschaftswoche criticized Germany for prohibiting "affordable sources of energy such as nuclear power," see R. Tichy, "Strom als Müll," Wirtschaftswoche, no. 6 (2014).

32 See F. Kunz, C. von Hirschhausen, and C. Gerbaulet, "Mittelfristige Strombedarfsdeckung durch Kraftwerke und Netze nicht gefährdet," DIW Wochenbericht, no. 48 (2013).

33 The "Law on the Search and Selection of a Repository Site for Heat-Generating Radioactive Waste and on Amendments to Other Laws (Repository Site Selection Act–StandAG)" entered into force on July 23, 2013. Section 1 defines the aim of the law: "The objective is to implement a transparent process with a robust scientific basis to identify a location for a repository site for the disposal of domestically-produced high-level radioactive waste in particular, in accordance with Section 9a, Para 3, Clause 1 of the German Atomic Energy Act, which ensures an optimal level of safety for a period of a million years."

34 www.endlagerung.de/language=de/taps=7012/17134, accessed on February 21, 2014.

produced in Germany to be disposed of in the Gorleben salt dome at a depth of around 800 meters.

The final disposal costs for nuclear waste are still not known, but they are estimated to be in the high double-digit billion euro range.[35] It is unclear whether the operators[36] will have sufficient provisions to cover these costs.[37] The possibility cannot be ruled out that this process will also require the investment of more public money.[38] Therefore, although the CDU/CSU-SPD coalition agreement states that "we expect the operators to bear the costs for nuclear waste and the dismantling of the nuclear power plants," at the same time "there must be a new system for the sharing of costs," including, inter alia, for the dismantling of power plants and safe storage and disposal of radioactive waste. The central and Länder governments are keen to hold talks on these issues.

However, the situation regarding the disposal of low- and intermediate-level radioactive waste is also unclear. Thousands of barrels of low and intermediate-level radioactive waste were deposited in the former salt mines in Morsleben and Asse, for example. Both of these repositories are now in danger of collapsing. The plan is to backfill the Morsleben repository and the nuclear waste deposited there with salt concrete at an estimated cost of 2.2 billion euros[39] for radiation protection, according to the Federal Office for Radiation Protection (Bundesamt für Strahlenschutz). On the other hand, the 125,000 storage containers in Asse will be recovered in an even more expensive retrieval operation. Since this process will continue well into the 2030s, the salt mine will be injected with concrete to delay its collapse. Further, at least one new mine shaft will have to be drilled since the existing shafts are not suitable for salvaging the containers. The storage drums, the condition of which can, to a certain extent, only be speculated upon due to their inaccessibility, will then have to be conditioned, i.e., packaged for final disposal. Although the Konrad repository has a permit for the final disposal of low- and intermediate-level radioactive waste, it will, however, not become operational in this decade. Further, its capacity is also limited: the authorized 303,000 cubic meters are not enough to accommodate all the low- and intermediate-level radioactive waste from Asse as well as the other nuclear power stations that are still to be decommissioned. The Federal Office for Radiation Protection is therefore currently planning another interim repository site, including a conditioning plant, to be built as close as possible to Asse. The associated costs are likely to be borne by German tax-payers.

35 Forum ökologisch-soziale Marktwirtschaft, Rückstellungen für Rückbau und Entsorgung im Atombereich – Thesen und Empfehlungen zu Reformoptionen (2012), 10.

36 As of December 31, 2011: approximately 33.5 billion euros, see Forum ökologisch-soziale Marktwirtschaft, Rückstellungen für Rückbau und Entsorgung, 37.

37 See VDI-Nachrichten, January 27, 2012, 5.

38 See Deutschlands Zukunft gestalten, 60.

39 M. Von Deggerich and M. Fröhlingsdorf, "Merkels Altlast," Der Spiegel 43, October 20, 2008, 43–48, www.spiegel.de/spiegel/print/d-61366517.html.

Conclusion and Economic Policy Implications

Globally, nuclear power is being phased out: it does not constitute an economical energy source since a wide range of cost components—insurance, dismantling, and the final disposal of fuel rods, for example—have been overlooked. There is not a single nuclear power station in the world that was built under competitive market conditions. In recent years, the West has observed an overall reduction in the capacity of nuclear power stations, whereas Asia has seen an increase. This can, however, by no means be considered to be a "nuclear energy renaissance": ongoing expansion projects are concentrated in a small number of countries, primarily China. In Japan, the prospects for nuclear power are uncertain in the wake of the nuclear disaster in Fukushima in 2011. Global installed nuclear capacity is stagnating and its relative share of electricity production is on the decline.

The future significance of nuclear power in Europe is the subject of some controversy. Germany, Switzerland, and Belgium have opted for a nuclear phase-out and the Italian population rejected plans to restart its nuclear program following a referendum on the issue. Costs for the ongoing construction of new reactors in Finland and France have skyrocketed, making these reactors the most expensive power plants ever to be built.

The European Commission's scenario framework portrays a very optimistic image of nuclear power which, according to DIW Berlin, is based on implausible assumptions, however. The costs shown in the EU reference scenario do not cover the actual social costs, and the cost effectiveness of nuclear power stations derived from these figures does not reflect reality. In view of unresolved safety and final disposal issues, the EU and its member states should refrain from further promoting nuclear energy. The tightening of safety assessments ("stress tests") for existing nuclear power plants planned by the European Commission should be implemented as soon as possible.

Policy-makers should actively address the issue of final disposal of nuclear waste which has been neglected to date. During the process of dismantling existing power plants, fierce debates over cost-sharing have materialized: true to the "polluter pays" principle, nuclear power station operators should be required to comply with their obligations as far as possible. Member states are requested to develop robust strategies to address the final disposal issue.

With its nuclear phase-out, Germany is moving toward a sustainable energy policy. The German phase-out makes economic sense and does not jeopardize the country's security of supply. Currently, there is nothing to stop the Grafenrheinfeld nuclear power station being decommissioned by December 2015 at the latest.

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