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In a Nutshell!

What is the Significance of Nuclear Energy to the Future of Global Power Generation?

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In a Nutshell!

In 2018, nuclear power plants (NPPs) generated 10.2 per cent of the world's power. Future trends will be marked by the following aspects:

1. **Largely economically uncompetitive on deregulated markets:** In western countries, NPPs have in recent decades only still been planned if governments guarantee to purchase the power or assume the entrepreneurial risks in some other way.

2. **Costs cannot be reliably compared:** It is difficult to compare generation costs for nuclear energy with those for renewable energies because system costs also have to be taken into account: in the case of renewables, for instance, the costs of flexibility options to compensate for fluctuations in feed-in due to weather conditions or, in the case of nuclear power, costs for intermediate and final disposal. The challenges of final disposal and falling capital costs for renewables will, however, ensure that the ratio will probably shift in favour of renewable energy sources.

3. **Low-CO_2 but politically controversial in many countries:** Power from NPPs is very low in CO_2. Nevertheless, most governments are backing renewable energies and only a few nuclear energy in the „Intended Nationally Determined Contributions" (INDCs) under the Paris Climate Agreement.

4. **Still globally present for decades:** In particular outside Europe, nuclear energy will still continue to play a major role for decades. Recent years have seen more NPPs started up, especially in China and Japan, than have been shut down.

Economic Aspects: Ever Less Competitive

The level of future costs for nuclear power generation is disputed. Studies into cost trends vary widely: on the one hand, one concludes that the presence of NPPs in the generation mix will distinctly reduce the costs of low-CO_2 electricity [1]. Other authors come to the conclusion that in the USA both relatively recent and small reactors will cease to be economically competitive in the coming decades [2]. It is a fact, however, that the USA is already subsidizing eight NPPs with emission credits to prevent their premature closure. Up to 35 further power plants would appear not to be competitive while the closure of another six has already been announced [3].

In any event, renewable energies are now less costly than nuclear power in the USA [4][5]. Globally, however, **generation costs per kilowatt-hour of electricity** from renewable energy sources and from nuclear power plants vary from country to country [6][7]. In Germany, the costs for electricity from solar and wind power systems are of the same order of magnitude as for nuclear power [8][9][10], while in South Korea renewable energies are more expensive than nuclear power [6]. It is, however, highly probable that the ratio of costs will shift in favour of renewable energy sources over the coming decades:

- In recent years, the **capital costs** for renewable energies have fallen continuously, while those for NPPs have risen, *inter alia* due to more stringent safety requirements [3][11][12]. It is highly probable that costs for renewable energies will continue to fall [10]. In addition, the capital amounts required for relatively small generation units such as rooftop photovoltaic installations, wind turbines or small onshore wind farms is a multiple lower than those for nuclear power plants. Investing in renewable energies is therefore within the reach of a greater number of stakeholders, such as private individuals or small associations. Additional capital spending is required for flexibility options such as grids or storage systems in order to compensate for fluctuations in feed-in of wind and solar power due to weather conditions. Comprehensive comparisons of these system costs have not yet been made. Investigations for Great Britain would, however, indicate that the system costs for wind and solar power are modest.[1]

1 The authors of the study emphasize that the system costs for power generation systems with fluctuating feed-in are difficult to calculate and may vary over a wide tolerance range. They depend on factors such as not only the proportion of volatile sources in the overall system, the breakdown of renewables (onshore/offshore wind power, PV), the flexibility options in the system, grid expansion, but also market design. Overall, the authors conclude that the additional costs are modest, with higher total costs above all being due to an inflexible system [13].

- Radioactive waste storage in turn contributes to the system costs for nuclear energy. Germany has not yet concluded its search for a nuclear waste repository.[2] Such uncertainties, some of which are of political origin, increase costs because private investors include risk premiums in their calculations in such cases. In Germany, however, the **responsibility for intermediate and final disposal** was transferred to the federal government in 2017. Costs [15], which exceed the 24 billion euro of the fund established for this purpose, have thus been transferred to society [16][17]. Moreover, the costs of major nuclear incidents comparable with Chernobyl or Fukushima[3] are so high that NPPs are not comprehensively insured for such events.[4] In addition, some countries such as France have deliberately limited the liability of NPP operators.

These shifts in costs are likewise reflected in investment: in western countries companies or consortia are only still building nuclear power plants if governments guarantee purchase prices or provide some other form of financial backing. In the case of the planned Hinkley Point C NPP in Great Britain, the French group EDF, which is building the plant, negotiated a guaranteed feed-in tariff from the British government which is set to escalate continuously over the coming years [21].[5] This has led Greenpeace Energy and the governments of Luxembourg and Austria to bring an action before the European Court of Justice for inadmissible subsidies in an amount of up to 108 billion euro [23][24].

A further cost aspect applies to an energy supply with a high share of fluctuating renewable energy sources: if NPPs continue to be operated in base load, they do not readily adapt to fluctuating feed-in from the wind power and photovoltaic systems which will probably play a central role in the energy systems of the future. If they are operated more flexibly, the costs per kilowatt-hour for nuclear power increase. The reason for this is that NPPs are only economic at high levels of utilization because the largest proportion of their costs are fixed.[6]

2 In 2020, Finland will probably be the first country to bring a "repository" for high-level radioactive waste into operation, in which the waste can be safely stored for 100,000 years at depths of up to 450 metres [14].

3 The Japanese government puts the total cost of the reactor disaster at 170 billion euro. Other estimates are as high as 400-560 billion euro [18].

4 A study has shown that the 2.5 billion euro which the operators of German NPPs are required by the relevant legislation to have available as financial security are woefully inadequate to cover the costs of major accidents [19]. Pursuant to §31 of the Nuclear Energy Act, operator liability is unlimited in amount [20], but in reality is determined by the operator's net equity.

5 In 2012 prices, the "strike price" for electricity supplied from the Hinkley Point C power plant is 92.50 pounds sterling per megawatt-hour [21]. Converted into euro (exchange rate of 04.02.2019), that would amount to 10.55 eurocents per kilowatt-hour. In contrast, the feed-in tariff payable under EEG, Germany's Renewable Energy Sources Act, for onshore wind power systems constructed from February 2019 onwards is 4.63 eurocents and for photovoltaic systems with a capacity of 750 kilowatts measured under standard test conditions it is 8.24 eurocents [22]. The EEG feed-in tariff will moreover decrease over the years, whereas the feed-in tariff for electricity from Hinkley Point will rise.

6 Example calculations show that the costs per kilowatt-hour of nuclear electricity amount to 11.6 US cents at 80 per cent utilization of the power plant, rising to 21.3 US cents at 40 per cent utilization and to 40.6 US cents at 20 per cent utilization (based on figures for France from [1], p. 151 and 153).

National Positions: from Shutdown to Expansion

At present, a small number of countries dominate nuclear power generation. The USA and France together produce almost half of the world's nuclear electricity; France alone generates half of Europe's. The USA, France, China, Russia and South Korea accounted for some 70 per cent of the power generated worldwide by nuclear fission in 2017 [3][25].

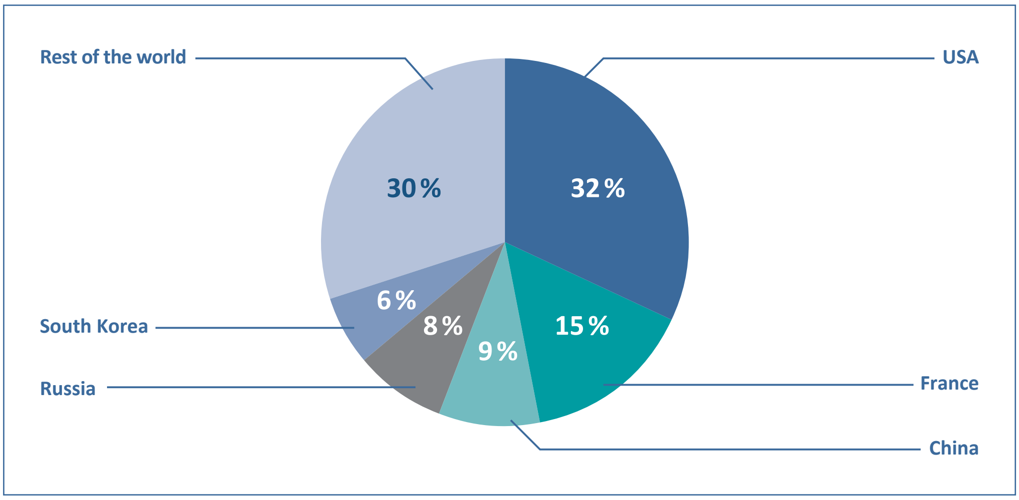

Figure 1: Shares of global nuclear power generation for selected countries, 2017 (own presentation using data from [25])

If the majority of the Japanese reactors shut down in 2011 were to come back on grid, Japan would also be included in this group [25]. These countries have different positions on the future of nuclear energy:

- The government of **US** President Donald Trump is favourable towards nuclear energy – unlike the US people, the majority of whom were for the first time found to be opposed to nuclear energy in 2016 [26].
- **France** intends to cut nuclear energy's share of overall power generation from around 75 per cent to 50 per cent by 2025 [27]. At present, just one reactor is under construction. Nuclear electricity is, however, set to remain a central pillar of France's energy supply.
- **China** is seeing the world's fastest growth in nuclear power generation, eleven reactors being under construction [25][28]. Chinese companies are also behind the construction of a number of NPPs in other countries. At the same time, however, China is expanding renewable energies more strongly and with higher levels of investment than nuclear energy [29][30].
- **Russia** is planning to expand nuclear energy, six reactors currently being under construction [28].
- The **South Korean government** newly elected in 2017 is critical of nuclear energy and is seeking to achieve a slow reduction in nuclear power generation. However, five reactors are currently still under construction [28].
- All **Japanese** NPPs were shut down following the Fukushima incidents. Nine reactors are now back in operation and up to a further 33 are set to come back online in the coming years. In 2030, NPPs are set to supply some 20 per cent of Japan's electricity [31].

Public opinion about nuclear energy became distinctly more critical in many countries after the Fukushima nuclear disaster [32][33]. However, complete phasing out of nuclear energy remains the exception worldwide.

Germany is currently the only nation which formerly had a double digit number of power plants and is comprehensively phasing out nuclear power. In its nuclear moratorium of 14 March 2011, the German government decided to shut down eight of the country's then 17 NPPs immediately and the remaining nine by 2022 [34].

Countries with very few nuclear power plants have already phased out electricity generation by nuclear fission: Italy shut down its last two NPPs in 1990, while Austria never put its only NPP into operation. Conversely, the United Arab Emirates and Belarus are just building their first NPPs [28].

Since 1970, around 12 per cent of NPP construction projects worldwide have been cancelled, most recently two reactors in the USA [3]. Many further **construction projects** in the USA **are delayed** or already mothballed [2] and the situation is similar in Bangladesh, Turkey, Argentina, Indonesia, Japan [3] or Great Britain [35].

Although electricity from NPPs is very low in CO_2 [7],[7] nuclear energy is of only secondary importance in climate protection plans and pledges. The Paris Climate Agreement of 12 December 2015 commits the signatory countries to make national climate protection contributions. A total of 162 plans for such contributions ("Intended Nationally Determined Contributions") were submitted, 111 of which propose to expand renewable energy sources in order to counteract climate change. Only Belarus, India, Japan, Turkey and the United Arab Emirates nevertheless plan to expand nuclear energy [36].

7 While NPPs do indeed cause no greenhouse gas emissions during operation, over their entire life cycle 3.7 to 110 g CO_2-equivalents are emitted per generated kilowatt-hour of electricity [7].

Global Trends: Rising Volume, Falling Share

Until around 2000, nuclear power generation was rising worldwide. Since then, it has remained relatively stable at approx. 2,500 terawatt-hours per year (see figure 2) [25].

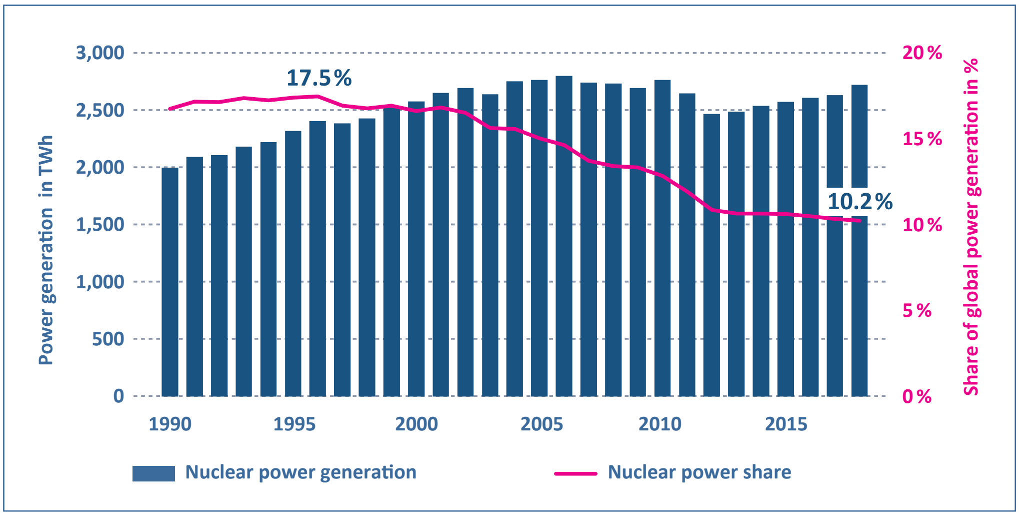

Figure 2: Share of nuclear power in global power generation, 1990-2018 (own presentation using data from [25][37])

Trends in the world's power plant fleet would suggest that the **volume of nuclear electricity produced** in the coming years will **rise slightly:** in recent years, **more new nuclear reactors** were brought on grid than shut down. All in all, the decline in capacity due to NPPs being shut down in Germany and other, above all western, countries is being more than offset.

However, since electricity generation is constantly rising worldwide, **nuclear energy's share of global power generation is falling** and has dropped from 17.5 per cent in 1996 to 10.2 per cent in 2018 [25][37]. In contrast, in 2017 wind power systems generated approx. 1,200 terawatt-hours and solar systems approx. 570 terawatt-hours of electricity, these figures respectively corresponding to 4.6 and 2.1 per cent of global power generation [37]. Since the early noughties, greater investment has been made in wind power and photovoltaic systems and their capacity is growing faster than that of NPPs [38]. It is therefore to be expected that nuclear energy's share of global power generation will fall further in the coming years.

Worldwide, 55 new **NPPs are under construction**, primarily in China [39]. The centre of gravity of nuclear energy use is thus shifting, with western countries tending to use fewer NPPs while China in particular is building new ones. Many of the new plants belong to the "third generation" of reactors.[8] The existing **power plant fleet** is, however, comparatively **old.** The majority of the 449 NPPs are over 30 years old (see figure 3). Many NPPs undergo inspections after 40 years of operation and require new operating licences, for example in the USA [3]. NPPs may, however, also continue to operate for some further decades.

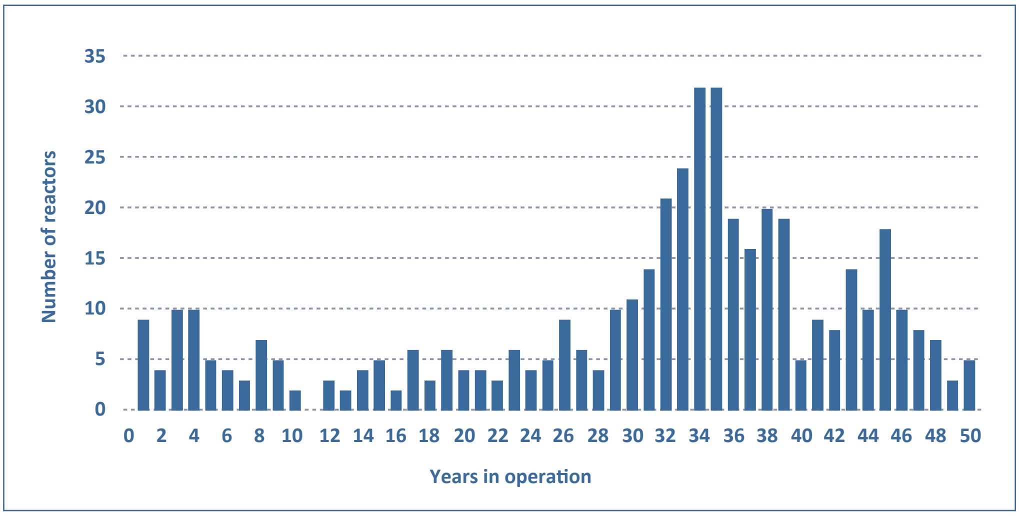

Figure 3: Age of the power plant fleet, as at March 2019 (own presentation using data from [39])

It is thus to be expected that, in view of recommissioning and new construction, an on average ageing power plant fleet will produce slightly increasing volumes of electricity over the coming decades. Nuclear energy's share of global power generation will, however, decline. There is as yet no solution which is capable of achieving consensus for handling nuclear waste. Expertise in dismantling and final disposal must be maintained and, in some cases, established from scratch.

8 Reactors of this generation have a safety design which has been upgraded to ensure that, in the event of nuclear incidents, the consequences should be limited to the plant or can even be ruled out.

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The „Energy Systems of the Future" (ESYS) initiative is the strategy chosen by acatech – National Academy of Science and Engineering, the German National Academy of Sciences Leopoldina and the Union of the German Academies of Sciences and Humanities to provide impetus for the debate about the challenges and opportunities presented by the energy transition in Germany. Over 100 experts from science and research are working together in the Academies' Project in interdisciplinary working groups to formulate options for implementing a secure, affordable and sustainable energy supply.

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The compact „In a Nutshell!" publication format communicates scientific findings from the project in order to explain live issues relating to the energy system which are often raised in public debate without any solid scientific foundation. Graphs and diagrams illustrate the textual content. „In a Nutshell!" is published under the authors' responsibility and was drawn up by a group of ESYS members.

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