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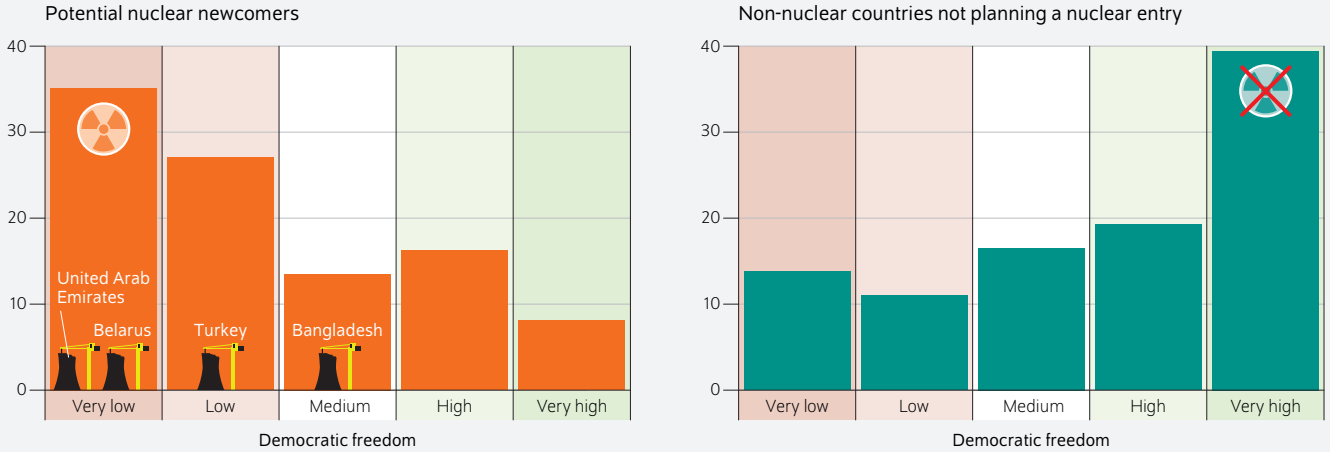
AT A GLANCE

Nuclear Power Worldwide: Development Plans in Newcomer Countries Negligible

By Lars Sorge, Claudia Kemfert, Christian von Hirschhausen, and Ben Wealer

- An analysis of current decommissioning and new construction projects reveals a downward trend in nuclear power worldwide
- Only four newcomer countries are currently constructing nuclear power plants and all are plagued by financial difficulties and delays
- An econometric analysis suggests that countries classified as potential newcomers tend to be less democratic
- On the supply side, the dominant driving force is the geopolitical interests of countries that export nuclear power
- Within the relevant international organizations, Germany should work to ensure that no support is given to the construction of nuclear power plants in newcomer countries

Potential nuclear newcomer countries tend to have a lower degree of democratic freedom
Frequency in percent



Source: authors' own calculations.

FROM THE AUTHORS

"Nuclear power accounts for a low share of total power generation worldwide and, due to aging nuclear power plants, is also on a sharp downward trend. As few as four countries are in the process of building their first power reactors, with generous subsidies. Other potential newcomer countries are often just pawns in geopolitical power games."
— Christian von Hirschhausen —

MEDIA

Audio Interview with Ben Wealer (in German)
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Nuclear Power Worldwide: Development Plans in Newcomer Countries Negligible

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ABSTRACT

At just 4.4 percent, the contribution made by nuclear power to meeting the world's primary energy requirements is marginal and on the decline. The current nuclear power fleet is outdated with around 200 plants due to be phased out over the next ten years compared to as few as 46 new nuclear power plants under construction worldwide. Yet the nuclear industry, particularly the World Nuclear Association (WNA), is propagating the narrative that there is a plethora of countries interested in constructing their first nuclear plants. The reality is quite different, however. As few as four countries are in the process of building their first nuclear power plants and even these projects are heavily subsidized and experiencing significantly delays. As for other potential newcomers, their plans are, at best, vague, frequently abandoned, or delayed. Given the absence of economic and financial incentive, DIW Berlin has conducted an empirical analysis of other characteristics in potential newcomer countries. Our findings show that these countries tend to have a lack of democratic freedom, something which generally goes hand-in-hand with centralized power structures and weak opposition. Moreover, our analysis suggests that countries exporting nuclear technology more often than not pursue geopolitical objectives, something that currently applies to Russia, in particular. Within international organizations, especially the International Atomic Energy Agency (IAEA) but also Euratom, Germany should be working toward ensuring that countries are not encouraged to construct their first nuclear power plants, that the necessary safety standards are met where nuclear power plants are already built or are in operation, and that as yet unresolved issues relating to decommissioning and the long-term storage of nuclear waste worldwide are addressed.

In the 1950s and '60s, there were high hopes that the development of nuclear energy would be the answer to providing cheap and clean power generation. Symbolic of this was the announcement made by Commissioner of the United States Atomic Energy Commission, Lewis L. Strauss, in 1954: "Our children will enjoy in their homes electrical energy too cheap to meter."[1] To this day, however, this expectation remains unfulfilled. In truth, nuclear power is still expensive and, even if we disregard the costs for decommissioning and the final storage of nuclear waste, uncompetitive.[2] Since 1975, the number of new nuclear power plants being built has been declining, in other words, even before the first of the well-known nuclear reactor accidents in Three Mile Island (U.S., 1979) or in Chernobyl (Ukraine, 1986) (Figure 1). The share of nuclear energy in power generation has declined from its peak of 17 percent in 1996 to around ten percent today. This means that nuclear power now meets as little as 4.4 percent of the world's primary energy requirements.[3]

As a result of the decline in new nuclear power plant construction, the global nuclear power fleet is becoming increasingly outdated. In July 2019, the average age of the world's reactor fleet was 30 years, in other words three-quarters of the approximately 40-year service life that plants are generally designed for (Figure 2).[4] Assuming a service life of 40 years, by 2030 another 207 reactors will have been taken off the grid (those that went online between 1979 and 1990) and a

1 See the manuscript of the speech by Lewis L. Strauss, "Remarks Prepared by Lewis L. Strauss, Chairman, United States Atomic Energy Commission, For Delivery At The Founders' Day Dinner, On Thursday, September 16, 1954, New York, New York," 1954 (available online, last accessed February 26, 2020; this applies to all other online sources in this report unless stated otherwise).

2 Lucas W. Davis, "Prospects for Nuclear Power," *Journal of Economic Perspectives* 26, no. 1 (2012): 49–66 (available online); Ben Wealer et al., "High-priced and dangerous: nuclear power is not an option for the climate-friendly energy mix," *DIW Weekly Report*, no. 30 (2019): 512–520 (available online); for detailed model calculations also see Ben Wealer et al., "Economics of Nuclear Power Plant Investment – Monte Carlo Simulations of Generation III/III+ Investment Projects," *DIW Discussion Papers*, no. 1833 (2019) (available online).

3 Mycle Schneider et al., *The World Nuclear Industry Status Report 2019* (Paris, Budapest: 2019) (available online). Within the process of energy conversion and application, a distinction is drawn between primary energy, final energy, and useful energy. Primary energy is an energy form found in nature that has not undergone any conversion process. Konstantin Panos, *Praxisbuch Energiewirtschaft* (Berlin: 2013).

4 Mark Z. Jacobson, *Evaluation of Nuclear Power as a Proposed Solution to Global Warming, Air Pollution, and Energy Security* (Cambridge: 2019) (available online).

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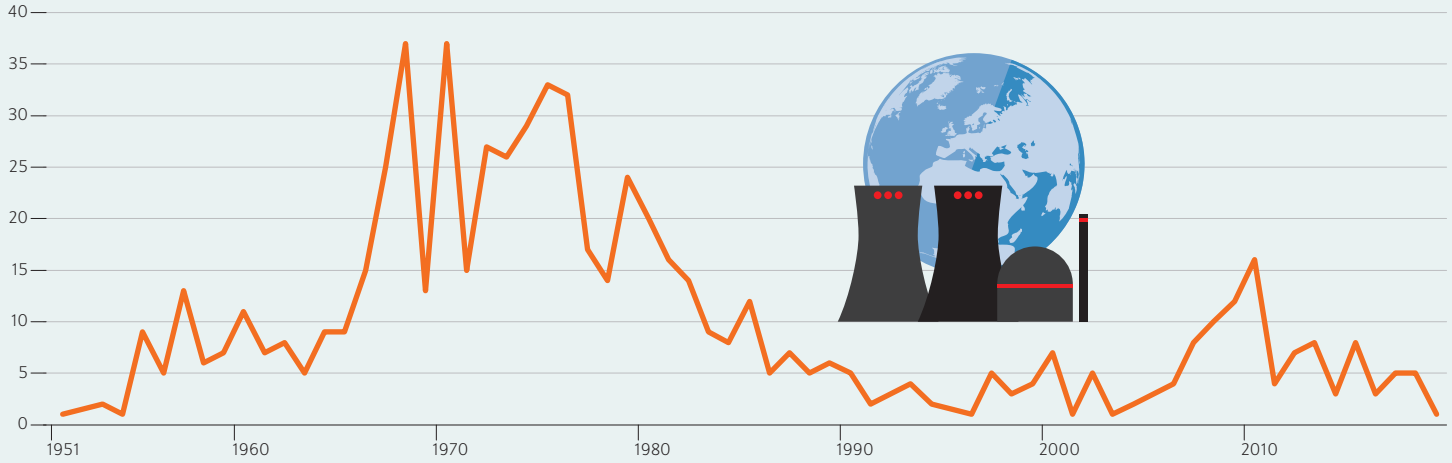
Figure 1

Number of new construction starts worldwide (1951 to 2019)



Source: authors' own illustration based on Mycle Schneider et al., *The World Nuclear Industry Status Report 2019* (Paris, Budapest: 2019) (available online).

New construction starts peaked in the 1960s and 1970s; in the 2000s new constructions were mainly in China.

further 125 plants by 2059.[5] This also includes 85 reactors commissioned before 1979 as well as an additional 28 reactors in what is known as 'long-term outage', where the plants have not produced electricity for over a year.

In contrast to this large number of closed plants, as few as 46 new reactors are currently under construction.[6] Western market economies have now more or less stopped building new nuclear power plants, with just a few exceptions including the three members of the United Nations Security Council France, the UK, and the U.S. (Figure 1). The construction of new nuclear power plants is concentrated primarily in China (ten projects), India (seven), and Russia (five). That said, even in these countries the share of nuclear power in total power production is falling.[7]

In short, nuclear energy is most certainly not experiencing a renaissance. Nevertheless, this narrative is still widespread in public discourse. In this Weekly Report, we will analyze the situation in a number of countries where the introduction of nuclear energy is purportedly under discussion. The article will include an econometric analysis of the demand side as well as a look at the supply situation in potential export countries, Russia in particular.[8]

Prevailing narrative of the nuclear industry: over 30 potential newcomers

In the public debate, there is frequently talk of a plethora of countries which are said to be in the process of introducing nuclear power or have even already concluded agreements to this end. These discussions are based on statistics provided by the World Nuclear Association (WNA), the main organization representing the interests of the global nuclear industry. The WNA's list of "Emerging Nuclear Energy Countries" thus includes a large number of countries (currently over 30) purportedly about to enter the nuclear sector.[9] Among other things, this classification is based on what are known as "cooperation agreements" concluded by these countries and potential suppliers of nuclear technology. Currently, the WNA divides newcomer countries into seven different categories (Table 1).[10]

A more detailed analysis, however, shows that in actual fact very few projects are being implemented and, moreover, these are plagued by technical and financial difficulties. In light of this, we will now provide an analysis of the current situation in the aforementioned countries.[11]

5 The 181 power plants taken off the grid to date had an average lifetime of around 26 years. Due to lifetime extensions, a total of 80 of the 417 reactors online are already over 40 years old.

6 As of July 1, 2019.

7 Schneider et al., *World Nuclear Industry Status Report*.

8 This Weekly Report is based on current research findings, specifically Schneider et al., *Nuclear Industry Status Report*, a study that two of the authors of the current Bulletin contributed to, as well as Anne Neumann, Lars Sorge, Christian von Hirschhausen, and Ben Wealer, "Democratic quality and nuclear power: Reviewing the global determinants for the introduction of nuclear energy in 166 countries," *Energy Research & Social Science* 63, no. 101389 (2020) (available online).

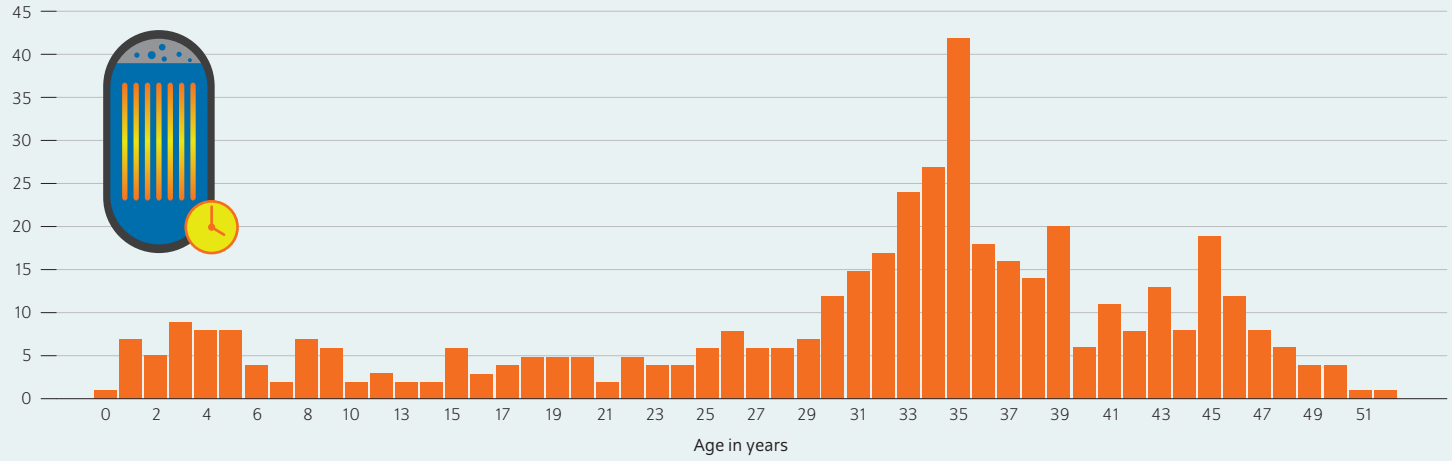
9 The WNA states: "About 30 countries are considering, planning or starting nuclear power programmes, and a further 20 or so countries have at some point expressed an interest." See World Nuclear Association, *Emerging Nuclear Countries* (2020) (available online).

10 The categorization published on the WNA's homepage is unclear. For instance, Qatar, Syria, Albania, and Rwanda feature in two different categories at the same time.

11 Unless otherwise stated, this overview is based on Schneider et al., *Nuclear Industry Status Report*, pp. 175ff.

Figure 2

Number of reactors worldwide by age (as of September 1, 2019)



Source: authors' own illustration based on Mycle Schneider et al., *The World Nuclear Industry Status Report 2019* (Paris, Budapest: 2019) (available online).

Most nucelar reactors are close to the end of their designed technical lifetime.

New construction in four countries plagued by technical and financial troubles

In four countries that previously had no nuclear power plants, construction work on one nuclear plant in each is currently underway. Apart from the United Arab Emirates (UAE), where a South Korean corporation is building its first reactor outside of South Korea, the construction projects in the newcomer countries are all firmly in Russian hands (Table 2).

In 2009, the UAE government commissioned Korean Electric Power Corporation (KEPCO) from South Korea to build four reactors with an output of 5.4 gigawatts (GW) at a cost of 28.2 billon U.S. dollars.[12] This equates to a dedicated investment of 5,300 U.S. dollars per kilowatt. No less than 18.7 billion U.S. dollars of the total sum was financed with public money. In early 2020 there was still no reactor on the grid but all four reactors are scheduled to be online by 2023.[13] The UAE's long-term plan is for six percent of energy generation to come from nuclear power by 2050, implying that the construction of a further nuclear reactor is not to be expected.[14]

In 2012, the Russian state nuclear energy corporation Rosatom concluded a supply contract with the Belarusian government for two reactors with an output of 2.2 GW to be constructed on the Ostrovets site. The project is financed almost entirely by the Russians. To date, neither of the reactors have gone online yet, but they hope to be in the early 2020s.[15]

Rosatom is currently also organizing construction of a nuclear power plant with four reactors at the Akkuyu site in Turkey. For this project, Rosatom holds 51 percent of the joint venture JSC Akkuyu Nuclear, which is struggling to find Turkish investors for the remaining 49 percent.[16] Half of all electricity produced by this plant is to be paid on the basis of a Power Purchase Agreement (PPA), which grants the power plant operator, a subsidiary of Rosatom, a guaranteed purchase price of 123.5 U.S. dollars per megawatt hour of electricity generated.[17] This is some two to three times higher than the average European wholesale price in 2019 (38 euros per megawatt hour).

In addition, Rosatom took over the construction of the first nuclear power plant in Bangladesh, which will have two reactors and a total output of 2.4 GW. Russia has also committed to financing 90 percent of the project to the tune of 12.65 billion U.S. dollars, a sum equivalent to almost half of Bangladesh's total foreign debt. After initial delays, the two reactors are now on course to be connected to the grid in 2024.[18]

12 With a 51.1-percent share, the South Korean government is the controlling shareholder of KEPCO. This means that the South Korean government directly owns 18.2 percent of the shares in the company and, through the Korea Development Bank, indirectly owns 32.9 percent of the shares. See Kepco, *Kepco at a glance* (2019) (available online).

13 On February 17, 2020 the Barkah-1 reactor received its operating license, Mahmoud Habboush, "Arab World's First Nuclear Reactor Cleared for Startup," *Bloomberg*, February 17, 2020 (available online).

14 UAE government, *UAE Energy Strategy 2050* (2020) (available online).

15 Schneider et al., *World Nuclear Industry Status Report*.

16 Schneider et al., *World Nuclear Industry Status Report*.

17 Schneider et al., *World Nuclear Industry Status Report*.

18 Schneider et al., *World Nuclear Industry Status Report*.

Table 1

Classification of countries how far their nuclear power programs or plans have progressed according to the World Nuclear Association (WNA)

Category	WNA classification	Countries
1	*Power reactors under construction*	Bangladesh, Belarus, Turkey, United Arab Emirates (UAE)
2	*Contracts signed, legal and regulatory infrastructure well-developed or developing*	Egypt, Poland
3	*Committed plans, legal and regulatory infrastructure developing*	Jordan, Uzbekistan
4	*Well-developed plans but commitment pending/deferred*	Indonesia, Kazakhstan, Lithuania (deferred), Saudi Arabia, Thailand, Vietnam (deferred)
5	*Developing plans*	Algeria, Ethiopia, Ghana, Kenya, Laos, Marocco, Nigeria, Philippines, Rwanda
6	*Discussion as policy option*	Albania, Azerbaijan, Bolivia, Chile, Croatia, Cuba, Estonia, Israel, Latvia, Libya, Mongolia, Namibia, Paraguay, Peru, Qatar, Serbia, Singapore, Sri Lanka, Sudan, Syria, Tunesia, Venezuela
7	*Officially not a policy option at prsesent*	Albania, Australia, Cambodia, Ireland, Kuwait, Malaysia, Myanmar, New Zealand, Norway, Portugal, Qatar, Rwanda, Syria, Tanzania, Zambia

Note: Albania, Qatar, Rwanda, and Syria are listed in both the seventh and fifth or sixth category, respectively.

Source: World Nuclear Association, Emerging Nuclear Countries (2020) (available online).

Countries alleged to have firm supply contracts or firm plans for the construction of new nuclear power plants

Besides the four countries with new nuclear plants under construction, the WNA has developed other categories including countries which have allegedly already signed supply contracts (*contracts signed*) or which have concrete plans for the construction of nuclear power plants (*committed plans*) (Table 1). At the moment, Poland and Egypt fall into the first category and Jordan and Uzbekistan into the second. In each of these cases, with the exception of Poland, the commercial relationship is also with Rosatom.

In Poland, the construction of the Zarnowiec reactor using Soviet technology was abandoned in 1989. Since then, although nuclear power features in some of the scenarios developed by the energy industry, there are no firm construction plans or binding contracts.[19]

Egypt has purportedly been pursuing plans to develop its nuclear industry since the 1990s. That said, it took Rosatom's offer to almost entirely finance the construction of four reactors with a total output of 4.8 GW at the Dabaa site, 100 kilometers north of Cairo, for serious negotiations to begin. According to Rosatom, the documents required for construction to be approved have been duly submitted in full and the green light is expected in the course of 2020. As in Bangladesh, Russia has committed to bankrolling a significant proportion of the funds in Egypt, too, providing 25 of the total 30 billion U.S. dollars in construction costs. Russia will also be responsible for the supply of fuel as well as plant operation and maintenance. Exactly how this process will continue remains to be seen, however. At the moment, external observers have their doubts that the Egyptian nuclear regulator has the requisite human resources and technical capacity to carry out the construction project.[20]

In Jordan, a cooperation agreement signed between the Jordan Atomic Energy Commission (JAEC) and Rosatom in 2014 has since been terminated due to lack of prospects.[21] In this case, the Russian side did not offer any substantial funds for the construction and operation of the power plant. There has been some initial consideration as to whether the JAEC might purchase a small modular reactor or SMR but discussions are only in the very early stages.

Uzbekistan would be similarly reliant on reactor technology and financing from Rosatom. Following the establishment of the Uzbek Agency for Nuclear Energy, further specific steps were supposed to follow. As of yet, however, the timetable and details of these next steps remain unclear.[22]

Other countries with putative plans to introduce nuclear energy

Apart from the aforementioned designations, the WNA also has a category of countries with purportedly *well-developed plans* (Table 1). This group currently includes Indonesia, Kazakhstan, Lithuania, Saudi Arabia, Thailand, and Vietnam. In the majority of cases, however, these plans appear to be little more than rough declarations of intent. Even progress on the nuclear energy program in Saudi Arabia is uncertain. Although Russia and four other bidders (from South Korea, China, the U.S., and France) have submitted bids, there is still no binding timetable.[23]

19 Schneider et al., *World Nuclear Industry Status Report.*

20 Schneider et al., *World Nuclear Industry Status Report.*

21 M.V. Ramana and Ali Ahmad, "Wishful thinking and real problems: Small modular reactors, planning constraints, and nuclear power in Jordan," *Energy Policy* 93 (2016): 236–245 (available online).

22 World Nuclear Association, *Uzbekistan* (2020) (available online).

23 World Nuclear Association: *Saudi Arabia* (2020) (available online). Saudi Arabia's energy program envisages the construction of up to 16 reactors. In this context, the development of nuclear weapons is also likely to play a role, which is why the U.S. (along with other observers) are keeping a critical eye on developments. "U.S. Goals Unclear for Saudi Nuclear Deal," *Arms Control Today*, December 2019 (available online).

Table 2

Overview over the current construction projects in four newcomer countries

Country (Site)	Capacity in Gigawatt (number of reactors)	Supplier (country)	Conclusion of contract	Construction start	Expected completion	Cost, financing, and particularities
UAE (Barakah)	5.4 (4)	Kepco (South Korea)	2009	2012	2021–2023	28.2 billion US dollars 16.2 billion US dollars from Abu Dhabi's Department of Finance 4.7 billion US dollars equity of Emirates Nuclear Energy Corp (ENEC) 2.5 billion US dollars from other sources
Belarus (Ostrovets)	2.2 (2)	Rosatom (Russia)	2012	2013	2021–2022	1.8 billion US dollars (2001) 90 percent financed by a Russian loan with a term of 25 years
Turkey (Akkuyu)	4.4 (4)	Rosatom (Russia)	2010	2018	2023–2025	20 billion US dollars supported by a project company (shares: 51 percent Rosatom, 49 percent others) 50 percent of the generated electricity will be renumerated with a high guaranteed price (123.50 US dollars per Megawatt hour)
Bangladesh (Rooppur)	2.2 (2)	Rosatom (Russia)	2015	2017	Mid-2020s	12.65 billion US dollars 90 percent financed by Russian loan on concessional terms with a term of 28 years

Source: authors' own depiction based on Mycle Schneider et al., *The World Nuclear Industry Status Report 2019* (Paris, Budapest: 2019) (available online).

In addition, the WNA maintains a further list of countries that are allegedly *developing plans* for nuclear power. This group currently comprises Algeria, Ethiopia, Ghana, Kenya, Laos, Morocco, Nigeria, the Philippines, and Rwanda. In another category, the WNA lists 22 countries where nuclear power is under *discussion as a policy option*. In a further 15 countries, the introduction of nuclear power is no longer being discussed at present (Table 1).

Overall, the group of possible newcomers is rather sparse. Of the many countries listed, there are just four where a nuclear power plant is actually being built. Despite numerous cooperation agreements, none of the countries have committed to any firm construction plans. The total output of the power plants that are currently under construction in the newcomer countries amounts to 11 GW or approximately three percent of the total nuclear energy capacity worldwide. The aforementioned projects are not commercially viable in their own right and will thus, in one way or another, be subsidized by government funds. In light of this, the present article will now explore whether, if at all, the countries mentioned display certain characteristics, for instance when it comes to energy planning or foreign policy.

Econometric analysis: potential newcomers tend to be characterized by a lack of democratic freedom

Do the countries considering constructing new nuclear plants differ from other nations? For some time now, there have been a variety of approaches, including from the political economy field, that have attempted to explain the behavior of nuclear states. Such approaches have centered on the sociology of technology[24] or the political science perspective, for instance.[25] The decision to introduce nuclear power is always driven by centralist policy approaches with very limited citizen participation. However, a structural difference can be observed between the countries that introduced nuclear power in the 20th century and the current potential newcomers. Several of the countries that used (and indeed in many cases still use) nuclear power were *de jure* democracies, which *de facto* guaranteed their citizens a high degree of civil rights and liberties. These include France, Finland, and Germany.[26] Today, in contrast, freedom and democracy in many of the countries keen to introduce nuclear power tend to be rather underdeveloped. It is therefore reasonable to hypothesize that, due to the complex and often controversial political decisions required for nuclear energy planning, the less democratic countries are more likely to embark on this process. There is also the political economic argument that countries becoming involved in nuclear power, despite its lack of economic viability, are generally those where there is no critical public and parliamentary debate on the subject.

Bearing this in mind, we will now present an empirical analysis exploring the possible correlation between a country's plans to introduce nuclear power and its degree of democratic freedom. The analysis is based on a cross-sectional dataset comprising 177 countries. The countries were subdivided into three categories based on the nuclear strategy they opted to pursue in 2017. Provided that a country has at least one reactor generating nuclear power, this country

24 Langdon Winner, "Do Artifacts Have Politics?," *Daedalus* 109, no. 1 (1980): 121–136 (available online).

25 Benjamin K. Sovacool and Scott V. Valentine, "The socio-political economy of nuclear energy in China and India," *Energy* (2010): 3803–3813 (available online).

26 Sovacool and Valentine, "The socio-political economy of nuclear energy". The authors argue that, at least in the case of France, the introduction of nuclear power was made easier by the strong involvement of the government in controlling economic development as well as the centralization of national energy planning. In Sweden (1980), Italy (1987), and Switzerland (1990) referendums were held to decide whether to continue or discontinue nuclear power usage. Referendums of this type can, however, be a weak instrument as the participating members of the public are often insufficiently acquainted with or interested in the scientific, social, and economic information. Ji-Bum Chung, "Let democracy rule nuclear energy," *Nature*, 555 (2018): 415 (available online).

is classified as "nuclear". The second category comprises the group of "potential newcomer countries" that have concluded at least one nuclear cooperation agreement. Based on the information provided by the WNA, a total of 37 potential newcomer countries are identified, including Belarus, Bangladesh, Turkey, and the United Arab Emirates, where nuclear reactors are already under construction.[27] Countries with no nuclear power plants in operation or under construction are classified as "non-nuclear". In the further course of the analysis these three categories represent the dependent variable to be explained (Box).

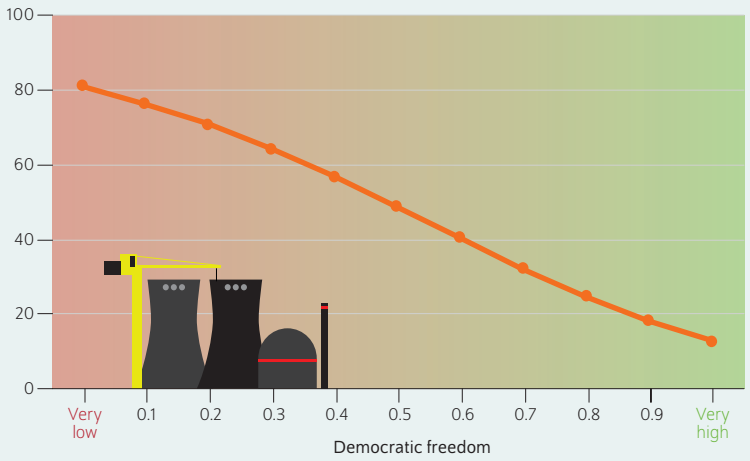
The indicator used to capture the degree of democratic freedom is based on a country assessment carried out by Freedom House. For the purposes of the present analysis, an aggregate indicator is used which is normalized from zero to one. Here, zero represents the lowest degree of democratic freedom (no political rights or civil liberties) and one denotes the highest degree of democratic freedom (full political rights and civil liberties) (Box). In addition to the degree of democratic freedom, the econometric analysis includes several other variables that explain a country's nuclear strategy, such as, for instance, CO_2 emissions, urbanization, or per capita GDP. The econometric model estimates how strongly correlated the individual determinants are with the probability of a country being classified as a potential newcomer when it comes to nuclear energy (Box).

The results of the econometric calculation indicate that the lower the degree of democratic freedom in a country, the more likely it is to be classified as a potential newcomer nation in terms of nuclear power. Countries with a high degree of democratic freedom, by contrast, are less likely to be classified as potential newcomer nations (Figure 3).[28]

The results of our analysis are also in line with existing findings from the relevant literature. A 2009 study lists 50 countries that have requested technical support from the International Atomic Energy Agency (IAEA) in order to explore the possibility of developing their own nuclear energy program. In this study too, the 50 countries identified have a lower score than the group of existing nuclear states when it comes to indicators for corruption, political stability, government effectiveness, and regulatory quality, as well as an aggregate indicator for the quality of democratic institutions.[29]

Figure 3

Predicted probabilities for membership in the group of potential nuclear newcomers
In percent



Reading example: a value of zero for a country indicates the lowest level of democratic freedom; a value of one indicates the highest level. If the level of democratic freedom in a country is 0.5, the predicted probability of being classified as a potential newcomer to nuclear power is about 50 percent.

Source: authors' own calculations based on sources described in the box.

The extent of democratic freedom tends to be low in countries classified as nuclear newcomers.

More in-depth analysis of global supply of nuclear power plants needed, especially when it comes to Russia and China

Not only has there been a shifting of structures among the potential users of nuclear power plants, we have also seen some movement when it comes to the key countries on the supply side. The U.S., which was the dominant export country of the 20th century, has now largely withdrawn from the international nuclear energy business, and the same applies to France.[30] Russia, in contrast, now occupies a dominant position when it comes to exports to newcomer nations. Three of the four current power plant projects (Bangladesh, Belarus, and Turkey) employ Russian technology and rely on funding from Russia (Table 2). Additionally, Russian firms have entered into more cooperation agreements for the supply of technology than the next four largest suppliers combined (France, U.S., China, and Korea).[31] Russia's focus here is on threshold and developing countries. On top of the

27 Specifically, this comprises the countries classified by the WNA as potential newcomers (see Table 1) that have concluded a nuclear cooperation agreement. Ecuador and Uganda are also in this group. According to the WNA, these countries have concluded a cooperation agreement but have not been assigned to a category.

28 The empirical findings are robust to alternatively classifying the countries as potential newcomers. Even if Vietnam and Lithuania as well as countries that have no WNA classification, where the "introduction of nuclear power is currently not a political option", are categorized as "non-nuclear", the results do not change substantially.

29 Steven E. Miller and Scott D. Sagan, "Nuclear Power without Nuclear Proliferation?," *Daedalus* 138, no. 4 (2009): 7–18 (available online).

30 Both the former U.S. market leader Westinghouse and the French Framatome (formerly Areva) are still struggling for economic survival. Westinghouse went bankrupt in 2017 and Framatome (at the time still under the name Areva) had to be rescued by the French government with a temporary four to five billion euro bail-out. See Martina Drupady, "Emerging nuclear vendors in the newcomer export market: strategic considerations," *Journal of World Energy Law and Business* 12 (2019): 4–20 (available online).

31 Jessica Jewell, Marta Vetier, and Daniel Garcia-Cabrera, "The International Technological Nuclear Cooperation Landscape: A New Dataset and Network Analysis," *Energy Policy* 128 (2019): 838–852 (available online); for a case study, see Ned Xoubi, "Economic Assessment of Nuclear Electricity from VVER-1000 Reactor Deployment in a Developing Country," *Energy* 175 (2019): 14–22 (available online).

Box

Econometric Analysis

A multinomial logistical regression model was used to implement an econometric analysis of the correlation between the degree of democratic freedom in a country and its use of nuclear power. The data basis is a cross-sectional dataset comprising 177 countries for the year 2017. The nuclear strategy chosen by a country in 2017 is described by a categorical variable that can take on three possible values and that is explained by a number of determinants.

The nuclear strategy categories were created using data from the Power Reactor Information System database (PRIS) of the International Atomic Energy Agency (IAEA) as well as information from the World Nuclear Association (WNA). The first category identifies the strategy as "nuclear" if a country operates at least one fully functional nuclear reactor to generate power. There are a total of 31 countries in this category. The second category identifies the group known as "potential newcomers". A country will be assigned to this group if, according to information from the WNA, it has entered into at least one international agreement over nuclear energy cooperation. A total of 37 countries fall into this category, including Belarus, Bangladesh, Turkey, and the United Arabic Emirates, where the construction of nuclear reactors is already underway. The third and final category identifies a country as "non-nuclear" if it has either no nuclear power plant in operation or none under construction or in planning. There are 109 countries in this category.

The indicator used in this study to measure the degree of democratic freedom is based on an well-established assessment of the quality of democracy in 194 countries carried out by Freedom House, an NGO based in Washington D.C.[1] This indicator takes into consideration both political rights and civil liberties. These two sub-indicators are measured on a scale of one to seven, where low numbers indicate greater rights and/or liberties.

In countries that were rated "1" for political rights, the citizens enjoy a wide range of political rights, including free and fair elections. Elected candidates do in fact form the government, there is active competition between political parties, the opposition plays an important role, and the interests of minority groups are represented in policymaking and government.

In countries which were rated "1" for civil liberties, citizens enjoy a wide range of civil liberties, including freedom of opinion, right of assembly, freedom of association, freedom of education, and religious freedom. These countries have a well-established, fair legal system, which guarantees that the rule of law is upheld (including an independent judiciary), facilitates free economic activity, and seeks to achieve equal opportunities for everyone, women and minorities included.

For the purposes of the analysis, an aggregate indicator is used which is normalized from zero (no political rights or civil liberties) to one (full political rights or civil liberties). To do so, the sum of the values for the two sub-indicators as rated by Freedom House is subtracted from the value 14, in other words from the maximum possible sum of the values for the two sub-indicators. The result is then divided by 12.[2]

For the analysis, additional variables that influence a country's chosen nuclear strategy from the fields of development, energy, and climate are factored into the generalized estimating equation. The variables selected were identified as important in relevant literature. These are the per capita GDP, the share of the total population living in urban areas, primary energy consumption, revenue from the extraction of fossil fuels as a proportion of GDP, CO_2

1 Freedom House is a non-governmental organization (NGO) which is dedicated to the expansion of freedom and democracy. The organization is financed primarily through U.S. government subsidies (available online). The data used on the degree of democratic freedom were downloaded from the Freedom House homepage (available online). A more detailed description of the data can be found on the homepage (available online).

2 John F. Helliwell, "Empirical Linkages Between Democracy and Economic Growth," *British Journal of Political Science* 24, no. 2 (1994): 225–248 (available online).

aforementioned cooperation agreements, according to the WNA, Russia would also appear to be maintaining strategic relations with a further 20 countries.[32]

At the moment it is unclear whether China will follow Russia's lead when it comes to nuclear energy diplomacy and take a similarly aggressive approach to engaging with potential newcomer nations. Since the 1980s, China has invested heavily in its nuclear industry and has now become a nuclear power on a par with Russia and the U.S.[33] Particularly noteworthy here is China's development of its own nuclear power reactor under the name "Hualong One", a third generation reactor design which is intended to compete with established reactor designs in future.[34] Besides the four reactors under construction in China itself, two Hualong reactors are currently being built in Pakistan, too.[35] Moreover, an application submitted by China for the construction of a Hualong reactor

32 These are Tunisia, Morocco, Ghana, Ethiopia, Sudan, Zambia, Venezuela, Bolivia, Paraguay, Myanmar, Indonesia, Laos, Cambodia, Philippines, Kazakhstan, Uzbekistan, Rwanda, Azerbaijan, Congo, and Cuba. World Nuclear Association, *Emerging Nuclear Countries* (2020) (available online).

33 Ben Wealer et al., "Nuclear Power Reactors Worldwide – Technology Developments, Diffusion Patterns, and Country-by-Country Analysis of Implementation (1951–2017)," *DIW Berlin Data Documentation* 93 (2018) (available online).

34 Stephen Thomas, "Is It the End of the Line for Light Water Reactor Technology or can China and Russia Save the Day?," *Energy Policy* 125, (2019): 216–226 (available online).

35 Schneider et al., *World Nuclear Industry Status Report*.

emissions, the share of renewables in total energy consumption.[3] To factor in historical connections between Russia, which plays a major role in the global nuclear energy supply chain, and potential newcomers,[4] a dummy variable is added to the estimating regression equation. This takes on the value one for all the former Soviet Union countries as well as all the former members states of the Warsaw Pact.[5]

A multinomial logistic regression is used for the analysis. This econometric method measures how the degree of democratic freedom as well as all the other variables can affect the likelihood of a country falling into one of the three categories: non-nuclear, potential newcomer, or nuclear, with non-nuclear being used as the reference category. The model parameter values describe the log-likelihood ratio of classification in one given category as compared with the reference category. The parameter values are determined using what is known as maximum likelihood estimation, where the estimate is that value that makes the observed data most probable. Owing to the categorical target variables, the regression modeling was based on two estimating equations—one comparing the "nuclear" strategy with the "non-nuclear" strategy, the other comparing "potential newcomer" with "non-nuclear".

For the variable "degree of democratic freedom," the estimated coefficient is statistically significant at the one percent level. Assuming the hypothesis that there is a correlation between the degree of democratic freedom in a country and its nuclear strategy, there is just a one percent probability that the estimated values can be explained by chance. The results of the analysis show that a country with a high degree of democratic freedom is more likely to fall into the group of countries with no plans to introduce nuclear power than in the group of potential newcomers. As anticipated with the method used, the estimated parameter values can be translated into probability forecasts for a country falling into the category of potential newcomers.[6]

Table

Results of the econometric estimation
Dependent variable: status of nuclear energy use

	Estimated coefficients (regression equation atomic states)		Estimated coefficients (regression equation potential nuclear newcomers)	
Variables	Coefficient	Standard error	Coefficient	Standard error
Democratic freedom	2.671	1.761	−2.512***	0.855
GDP per capita	−0.006	0.022	−0.014	0.022
Urbanization	0.006	0.023	0.002	0.014
Primary energy consumption	1.608**	0.742	0.347	0.685
Fossif fuel rents (percent of GDP)	−0.001	0.001	0.000	0.000
CO_2 emissions	−0.009	0.011	0.004	0.010
Share of renewables	−0.002	0.019	0.000	0.010
Soviet history	2.479***	0.783	0.198	0.710
Constant	−5.712***	1.951	−0.264	1.030
Observations	177			
Pseudo R^2	0.3927			

Notes: the results are based on a multivariate multinomial logistic regression. The parameter estimates are obtained using the maximum likelihood method. The reference category is "non-nuclear." The data basis is a cross-sectional data set comprising 177 countries. Statistical significance levels: ***p<0.01; **p<0.05; *p<0.1.

Source: authors' own calculations.

3 Fabienne Gralla et al., "Energy Transitions and National Development Indicators: A Global Review of Nuclear Energy Production," *Renewable and Sustainable Energy Reviews* 70 (2017): 1251–1265 (available online).

4 Gloria Duffy, "Soviet Nuclear Exports," *International Security* 3, no. 1 (1978): 83–111 (available online).

5 Albania, Bulgaria, Poland, Rumania, Czech Republic, Hungary, and Slovakia, all of which were formerly included in the Warsaw Pact. See Herbert Vent, "European Satellites of the USSR," *Journal of Geography* 56 (1) (1957): 26–33 (available online). Former Soviet Union countries besides Russia: Armenia, Azerbaijan, Belarus, Estonia, Georgia, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Moldova, Tajikistan, Turkmenistan, Ukraine, and Uzbekistan.

6 For a more in-depth description of the method see, for example, chapter 18 in William Greene, *Econometric Analysis*, 7th ed. (Essex: 2012).

at the Bradwell (Essex) site in the UK is currently under review by the UK licensing authorities.[36] China has further partnerships in the nuclear industry with Sudan, Kenya, Thailand, Uganda, and Cambodia.[37] These developments on the global nuclear power plant and equipment markets are becoming increasingly interesting for industrial economic and geopolitical analysis.[38]

Conclusion: newcomer countries' development plans negligible

Given the aging nuclear fleet and the limited number of new constructions, we can expect a gradual decline in the share of nuclear power in global energy generation over the next ten years. Due to the absence of a business model, the construction of new nuclear power plants in Western market economies has all but ground to a halt. Even the ongoing new construction projects in China (10), India (7), and Russia (5) will have no impact on this trend. Of the 46 current construction projects, more than half are delayed, in some cases significantly.

In response to the decline of the nuclear industry in the majority of Western market economies, the World Nuclear

36 Adam Vaughan and Lily Kuo, "China's long game to dominate nuclear power relies on the UK," *The Guardian online*, July 26, 2020 (available online).

37 World Nuclear Association, *Emerging Nuclear Countries*.

38 Paul Bracken, *The Second Nuclear Age – Strategy, Danger, and the New Power Politics* (New York, USA: 2012); François Lévêque, *The Economics and Uncertainties of Nuclear Power* (Cambridge, MA, USA: 2013); as well as Christian von Hirschhausen, "Nuclear Power in the 21st Century – An Assessment (Part I)," *DIW Discussion Papers* 1700 (2017) (available online).

Association is developing a narrative of a multitude of potential newcomer nations working diligently toward the introduction of nuclear power. At the moment, there are more than 30 countries on the WNA's list which have concluded cooperation agreements with supplier states. Yet, if we look more closely, we can only identify four countries that are, in fact, currently constructing their first nuclear power plants (Bangladesh, Belarus, Turkey, and the United Arab Emirates). What is more, all of these projects are plagued by serious financial problems and delays. In addition, the status of the other countries' plans to introduce nuclear power are more often than not unclear or imprecise. As such, a major, quantitatively relevant development is not to be expected in these countries. An econometric analysis shows that less democratic countries are far more likely to become newcomers to nuclear power. These are countries with a much lower level of political participation and fewer positive civil rights.

The shift in the supply side of nuclear power plants from the former dominance of the U.S. toward Russia, in particular, explains some countries' plans to introduce nuclear power. Since the retreat of Western suppliers, Russia has been pursuing an aggressive strategy of nuclear diplomacy and attempting to increase its geopolitical influence by selling nuclear power, a strategy that also includes offering extremely favorable financing conditions to potential purchasing countries. Three of the four nuclear power plants currently under construction in newcomer countries rely on Russian technology and financing. China, too, is increasingly engaging in nuclear diplomacy, particularly in Pakistan and recently even in the UK. The industrial economic and geopolitical consequences of this development require a more in-depth analysis in order to provide a more accurate picture of potential developments in this strategic field.

In light of the lack of economic prospects and the unresolved safety issues related to nuclear energy, international organizations such as IAEA and Euratom need a change in direction. Instead of encouraging new countries to introduce nuclear power, the focus should be on implementing safety standards and addressing the as yet unresolved issues associated with decommissioning and permanent storage of nuclear waste. Within these organizations, Germany should therefore be calling for the cessation of the practice of awarding institutional subsidies for the introduction of nuclear power (often in politically unstable countries). The Euratom Treaty established in 1957 has to be restructured such as to remove subsidies on the construction of nuclear power plants, in Europe as well.

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