WORLD NUCLEAR ASSOCIATION

World Nuclear Performance Report 2022

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Country Pages data correct as of 1 July 2022.

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Nuclear generation bounced back from the pandemic-related decline seen in 2020, increasing by 100 TWh to reach 2653 TWh in 2021.

However, this positive development must be put into the context of the upheaval there has been in global energy supply over the last 12 months. While governments redoubled their commitments to reducing greenhouse gas emissions at COP26 in Glasgow, the recovery of economies following the harsh impacts of COVID-19 led to a surge in energy demand that outstripped the growth in production from clean sources such as nuclear, resulting in more reliance on fossil fuels.

The war in Ukraine has made vividly clear the fragility of the fossil fuel supply chain, underscoring concerns that were already exposed as a consequence of the pandemic. In many regions energy prices are rising, fueling inflation and worsening energy poverty. Fearful of losing access to gas imports and facing blackouts and energy shortages, governments are calling on coal-fired power plants to restart.

While such short-term actions may be necessary in the midst of a crisis, they are unsustainable. It is therefore welcome that many governments are now realizing that nuclear energy can propel the drive to net-zero emissions and be the foundation of a more secure energy system.

The challenge now is to take the concrete actions needed to turn those policy aspirations into operating nuclear power plants. The increase in nuclear generation in 2021 flatters the fact that there has been a decline in global nuclear capacity over the last two years. In other words: more reactors are being closed down than are starting up.

To reverse this trend, two things need to happen. First, reactors that are operating successfully today need to operate for longer. Too many of the reactor closures of the last few years have been motivated by political reasons or by dysfunctional markets. Long-term operation of nuclear reactors is the lowest cost form of additional low-carbon generation and helps reduce reliance on fossil fuels.

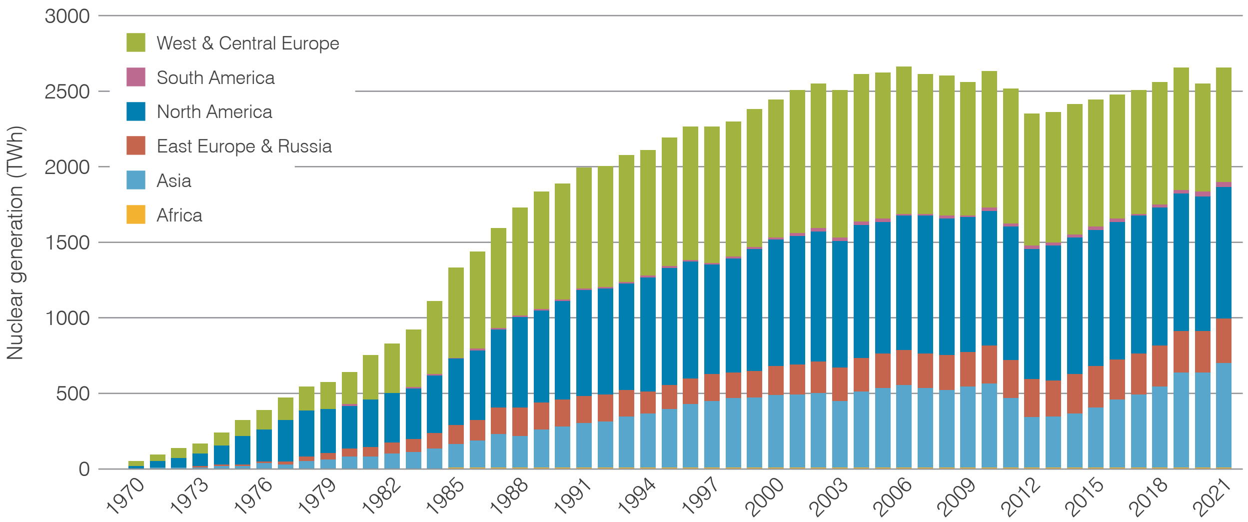
Second, the pace of new nuclear construction must increase. In 2021 first concrete was poured for ten new reactors. Although that is better than in recent years, we still need to see twenty, thirty or more new reactor construction starts per year soon, to ensure that nuclear energy plays the role it should in delivering a secure and sustainable net-zero future.

1 Nuclear Industry Performance

1.1 Global highlights

Nuclear reactors generated a total of 2653 TWh in 2021, up 100 TWh from 2553 TWh in 2020. This is the third highest ever total for global generation from nuclear, just short of the 2657 TWh output of 2019 and 2660 TWh in 2006, and reestablishes the upward trend in nuclear generation seen since 2012, following a decline in 2020.

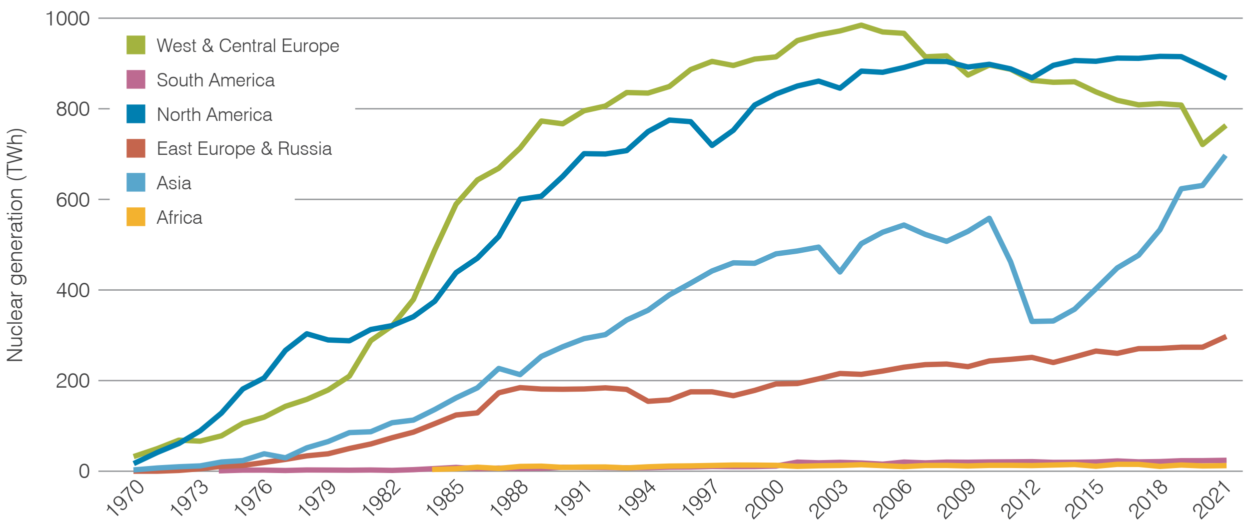
Figure 1. Nuclear electricity production



Source: World Nuclear Association and IAEA Power Reactor Information Service (PRIS)

In 2021 nuclear generation increased in Africa, Asia, East Europe & Russia, and in South America. These increases continued upward trends seen in recent years in those regions. Generation also increased in West and Central Europe, but in this region the overall trend remains downward. Generation declined for the second year running in North America as more reactors in the USA were closed.

Figure 2. Regional generation



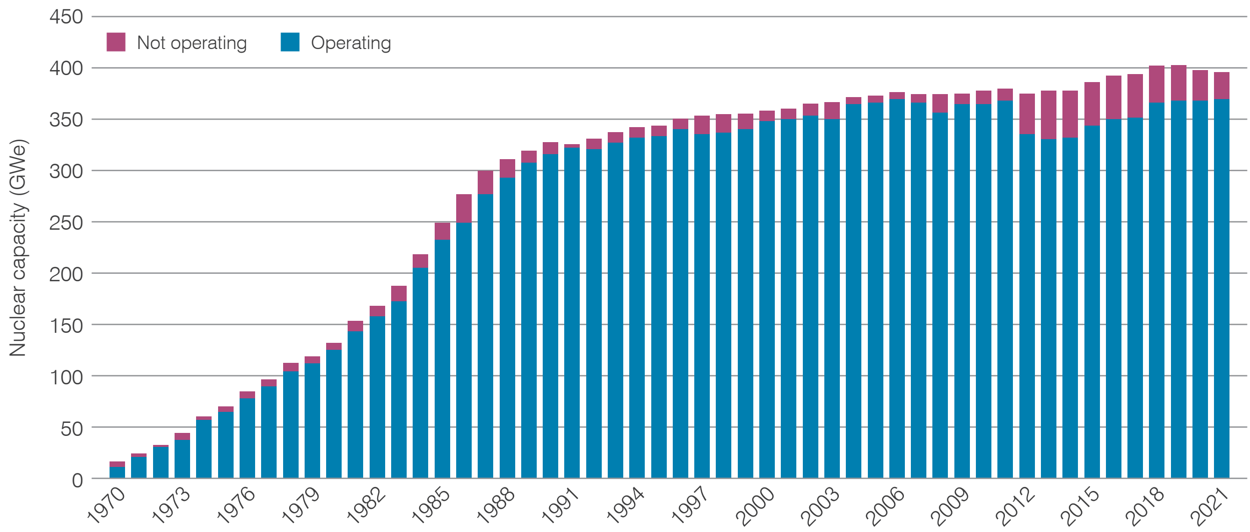
Source: World Nuclear Association and IAEA Power Reactor Information Service (PRIS)

In 2021 the end of year capacity of operable nuclear power plants was 396 GWe, down 1 GWe on 2020.

The total capacity of reactors producing electricity in 2021 was 370 GWe, up 1 GWe from 2020. This is the highest ever total capacity of reactors generating electricity in one year. In most years, a small number of operable reactors do not generate electricity. In recent years the figure has been higher, as reactors in Japan await approval to restart following the Fukushima Daiichi accident in 2011. As some Japanese reactors have now restarted, and others have been permanently shut down, the total number of reactors operable, but not generating, has gradually reduced.

370 GWe of nuclear capacity produced electricity in 2021, the highest ever

Figure 3. Nuclear generation capacity operable (net)



Source: World Nuclear Association, IAEA PRIS

Although the end of year capacity of operable reactors was up in 2021, the total number of reactors was 436, down five on 2020. Nearly 70% of all operable reactors are pressurized water reactors (PWRs), with all except one of the 34 reactors that have started up between 2017 and 2021 being PWRs.

Table 1. Operable nuclear power reactors at year-end 2021

	Africa	Asia	East Europe & Russia	North America	South America	West & Central Europe	Total
BWR		20		33		8	61
FNR			2				2
GCR						11	11
HTGR		1					1
LWGR			11				11
PHWR		24		19	3	2	48
PWR	2	99	40	61	2	98	302
Total	2	144	53	113	5	119	436

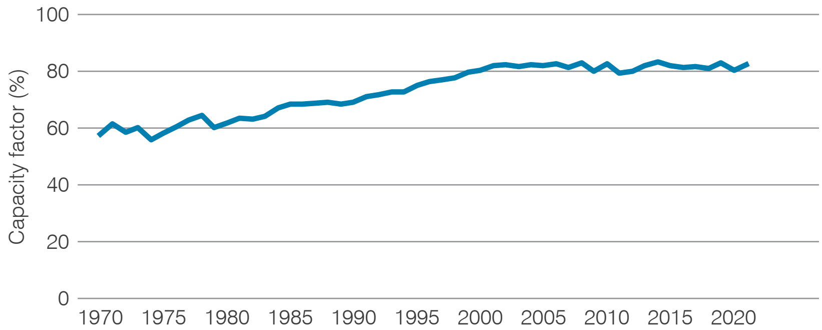
Source: World Nuclear Association, IAEA PRIS

1.2 Operational performance

Capacity factors in this section are based on the performance of those reactors reporting electricity generation during each calendar year.

In 2021 the global average capacity factor was 82.4%, up from 80.3% in 2020. This continues the trend of high global capacity factors seen since 2000.

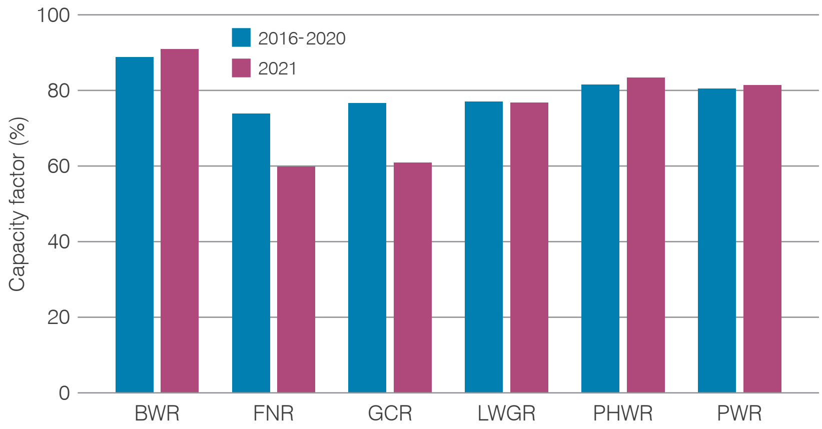
Figure 4. Global average capacity factor



Source: World Nuclear Association, IAEA PRIS

Capacity factors for different reactor types in 2021 were broadly consistent with those achieved in the previous five years. The UK's AGRs currently represent the entirety of the gas-cooled reactor category, and all are expected to have shut down by the end of the 2020s.

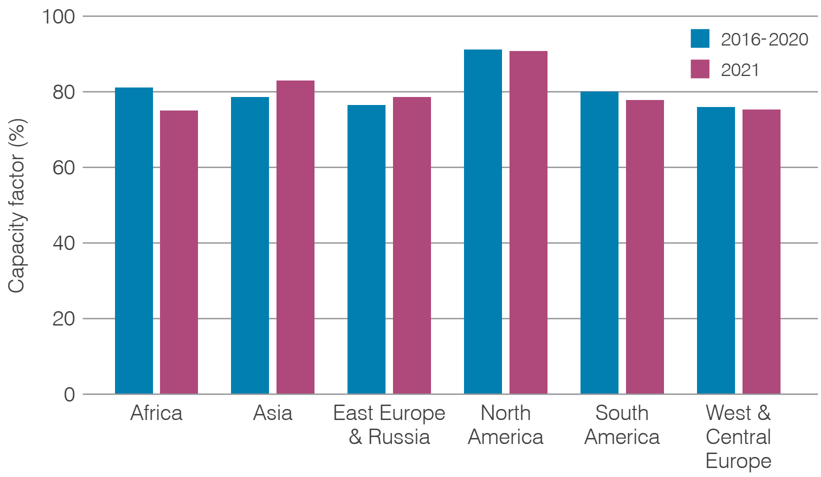
Figure 5. Capacity factor by reactor type



Source: World Nuclear Association, IAEA PRIS

Capacity factors in 2021 for reactors in different geographical regions were also broadly consistent with the average achieved in the previous five years, with North America maintaining the highest average capacity factors.

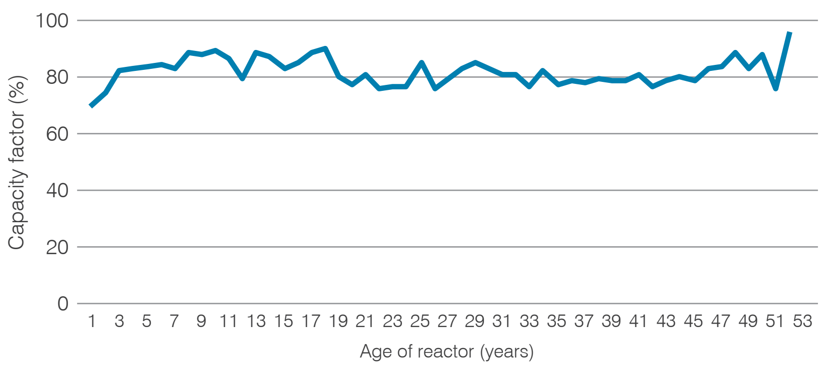
Figure 6. Capacity factor by region



Source: World Nuclear Association, IAEA PRIS

There is no age-related decline in nuclear reactor performance. The mean capacity factor for reactors over the last five years shows no significant overall variation with age. Improvements in average global capacity factors have been achieved in reactors of all ages, not just new reactors of more advanced designs.

Figure 7. Mean capacity factor 2017-2021 by age of reactor

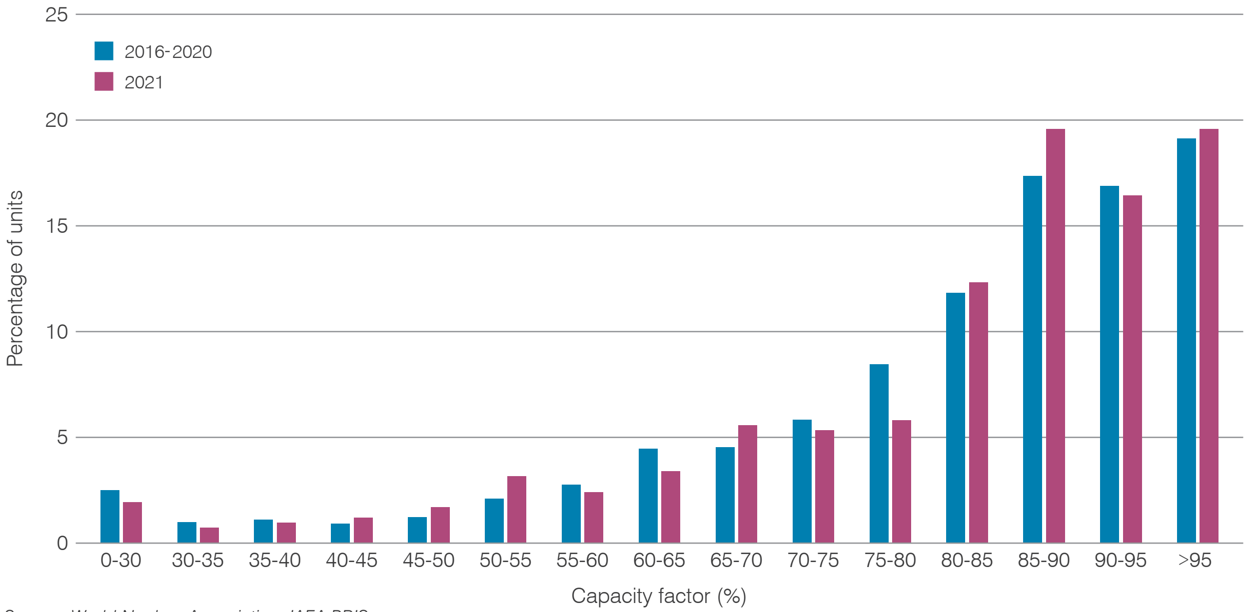


Source: World Nuclear Association, IAEA PRIS

Demonstrating high capacity factors for reactors of all ages strengthens the case for extending the operation of the current nuclear fleet.

The spread of capacity factors in 2021 is broadly similar to the average of the previous five years. Just over two-thirds of reactors have a capacity factor greater than 75%.

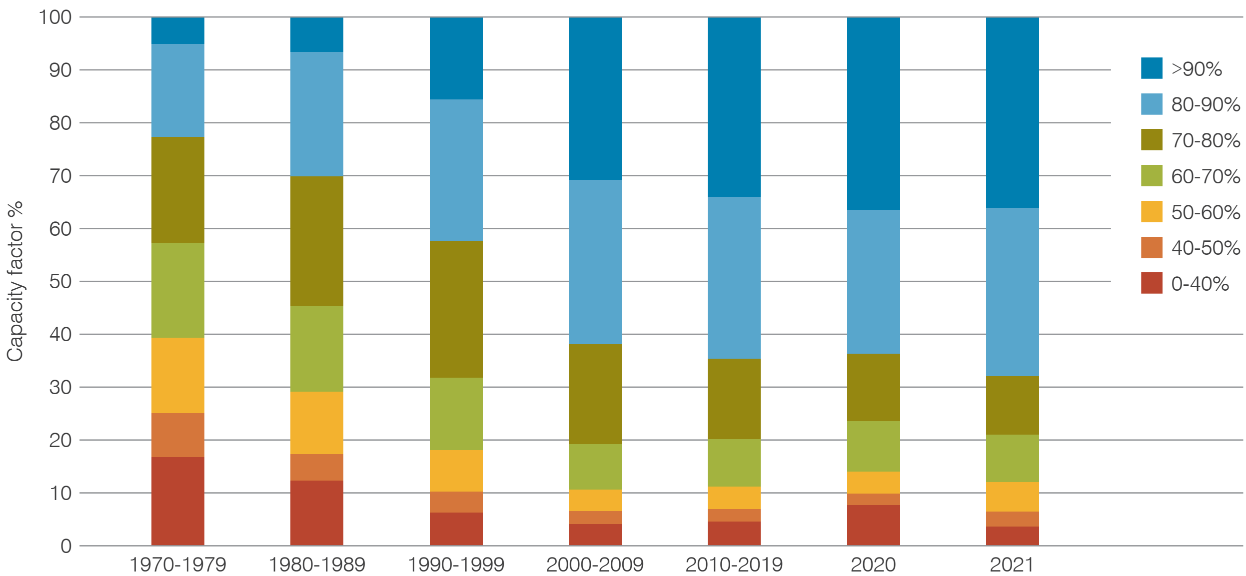
Figure 8. Percentage of units by capacity factor



Source: World Nuclear Association, IAEA PRIS

A steady improvement in reactor performance can be seen in the following chart, which presents the average capacity factors in each decade since the 1970s, as well as for 2020 and 2021.

Figure 9. Long-term trends in capacity factors



Source: World Nuclear Association, IAEA PRIS

1.3 New construction

Alongside eight large PWRs, in 2021 construction began on a lead-cooled fast reactor at Seversk, near Tomsk in Russia, and a small modular reactor at Changjiang, in the province of Haiyang in China.

Table 2. Reactor construction starts in 2021

	Location	Model	Design net capacity (MWe)	Construction start date
Akkuyu 3	Turkey	VVER V-509	1114	10 March 2021
Changjiang 3	China	HPR1000	1100	31 March 2021
Tianwan 7	China	VVER V-491	1100	19 May 2021
Seversk	Russia	BREST-OD-300	300	8 June 2021
Kudankulam 5	India	VVER V-412	917	29 June 2021
Changjiang SMR	China	ACP100	100	13 July 2021
Xudabao 3	China	VVER V-491	1100	28 July 2021
Kudankulam 6	India	VVER V-412	917	20 December 2021
Changjiang 4	China	HPR1000	1100	28 December 2021
San'ao 2	China	HPR1000	1117	31 December 2021

Source: World Nuclear Association, IAEA PRIS

With ten construction starts and six reactors connected to the grid, the total number of units under construction at the end of 2021 was 53, four more than at the end of 2020.

Table 3. Units under construction by region year-end 2021

	BWR	FNR	HTGR	PHWR	PWR	Total
Asia	2	2	0	3	29	36
East Europe & Russia		1			6	7
North America					2	2
South America					2	2
West & Central Europe					6	6
Total	2	3		3	45	53

Source: World Nuclear Association, IAEA PRIS

Six reactors were connected to the grid for the first time in 2021. Shandong Shidaowan is a notable new start as it consists of two 250 MWt high-temperature reactor pebble-bed modules (HTR-PM) connected to a single 200 MWe steam turbine. Future larger plants would be based on larger numbers of HTR-PM modules.

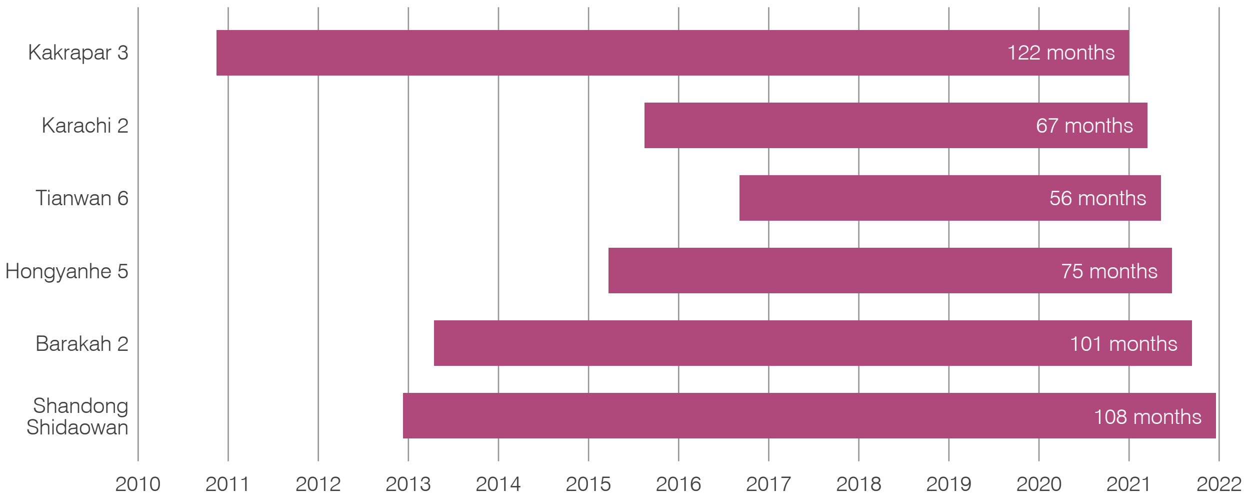
Table 4. Reactor grid connections in 2021

	Location	Capacity (MWe net)	Construction start	First grid connection
Kakrapar 3	India	630	22 November 2010	10 January 2021
Karachi 2	Pakistan	1014	20 August 2015	18 March 2021
Tianwan 6	China	1060	7 September 2016	11 May 2021
Hongyanhe 5	China	1061	29 March 2015	25 June 2021
Barakah 2	United Arab Emirates	1345	15 April 2013	14 September 2021
Shandong Shidaowan	China	200	9 December 2012	20 December 2021

Source: World Nuclear Association, IAEA PRIS

The shortest construction times were achieved with the construction of PWRs in China and the Chinese-designed HPR1000 reactor at Karachi, Pakistan. This continues recent trends, where series build and the retention of skills through ongoing new build programmes have helped contribute to more rapid construction times.

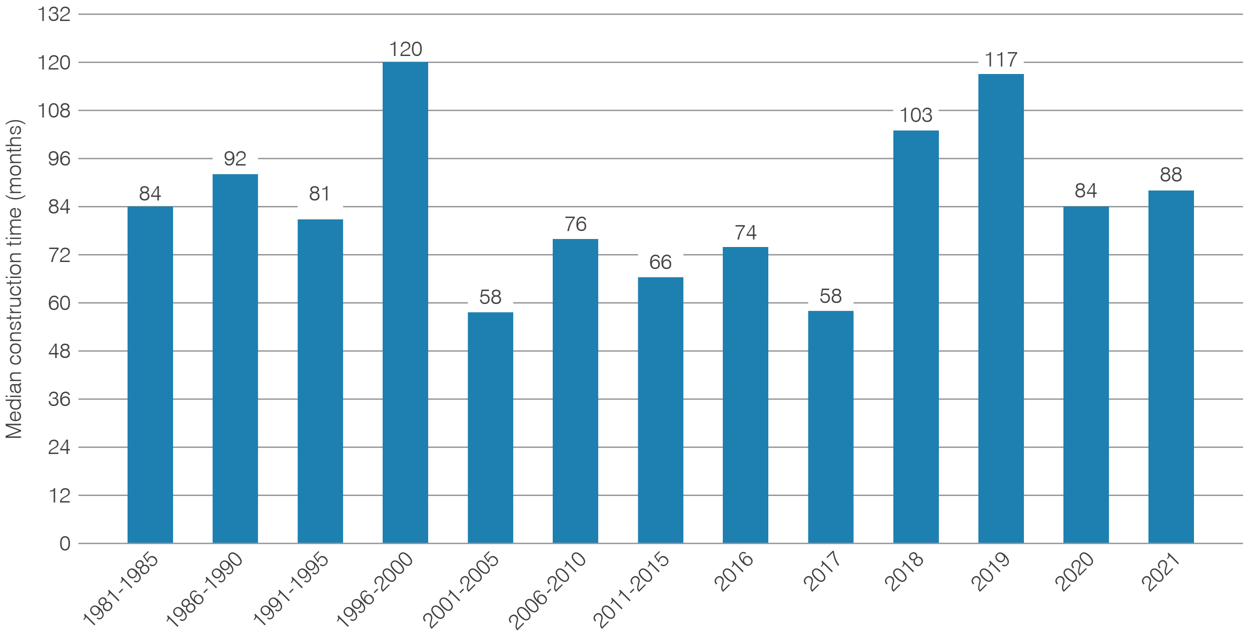
Figure 10. Construction times of new units grid-connected in 2021



Source: World Nuclear Association, IAEA PRIS

The median construction time for reactors grid-connected in 2021 was 88 months, up slightly from the 84 months recorded in 2020.

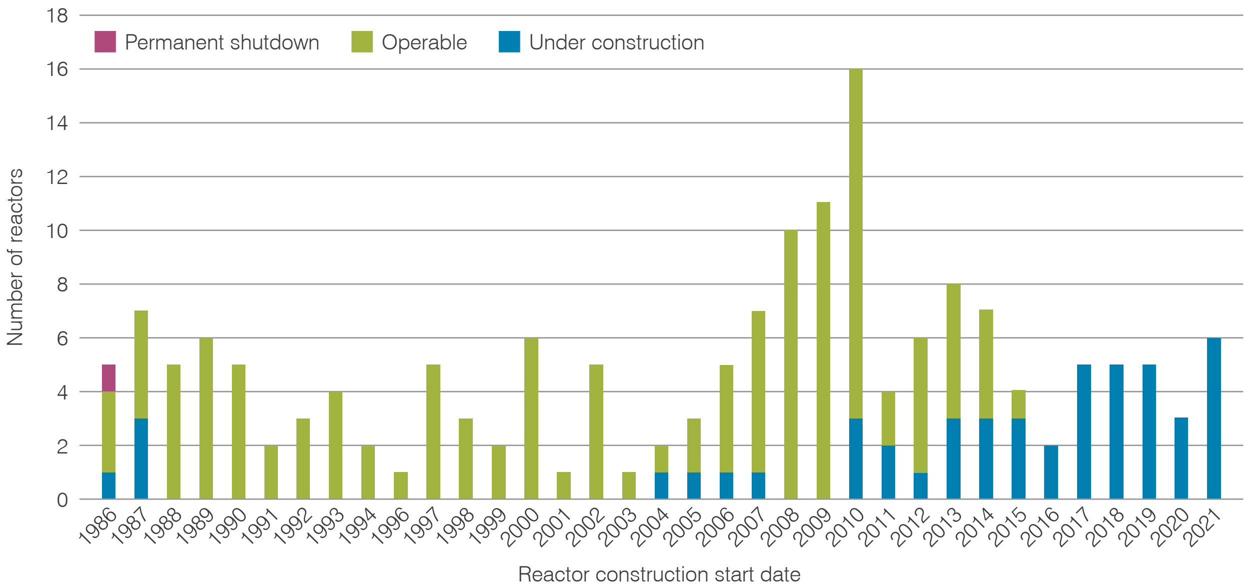
Figure 11. Median construction times for reactors since 1981



Source: World Nuclear Association, IAEA PRIS

Figure 12 shows the operational status of reactors constructed since 1986. Most reactors under construction today started construction in the last ten years. The small number that have taken longer are either pilot plants, first-of-a-kind (FOAK) reactors, or projects where construction was suspended before being restarted. In the case of Khmelnitski 3&4, Ukraine, two reactors that started construction in 1986 and 1987, there have been attempts to restart construction, but no active progress since 1990.

Figure 12. Operational status of reactors with construction starts since 1985 as of 1 January 2022

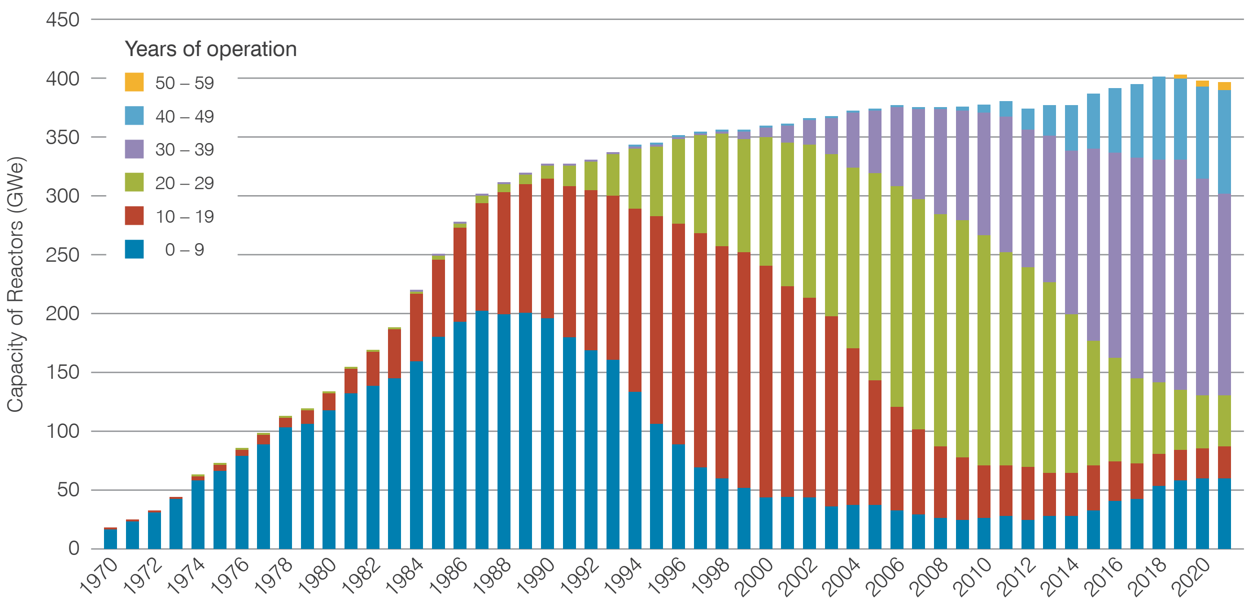


Source: World Nuclear Association, IAEA PRIS

Figure 13 shows the total capacity of reactors of different ages operating in any one year since 1970. As time passes those reactors that remain in operation move into the next category every ten years.

The total capacity of reactors that have been in operation for less than 10 years declined from around 1990, as the pace of new reactor start-ups slowed. With increased construction and subsequent commissioning of reactors in recent years the total capacity of reactors that have been in operation for less than 10 years has started to increase again.

Figure 13. Evolution of reactor ages



Source: World Nuclear Association and IAEA Power Reactor Information Service (PRIS)

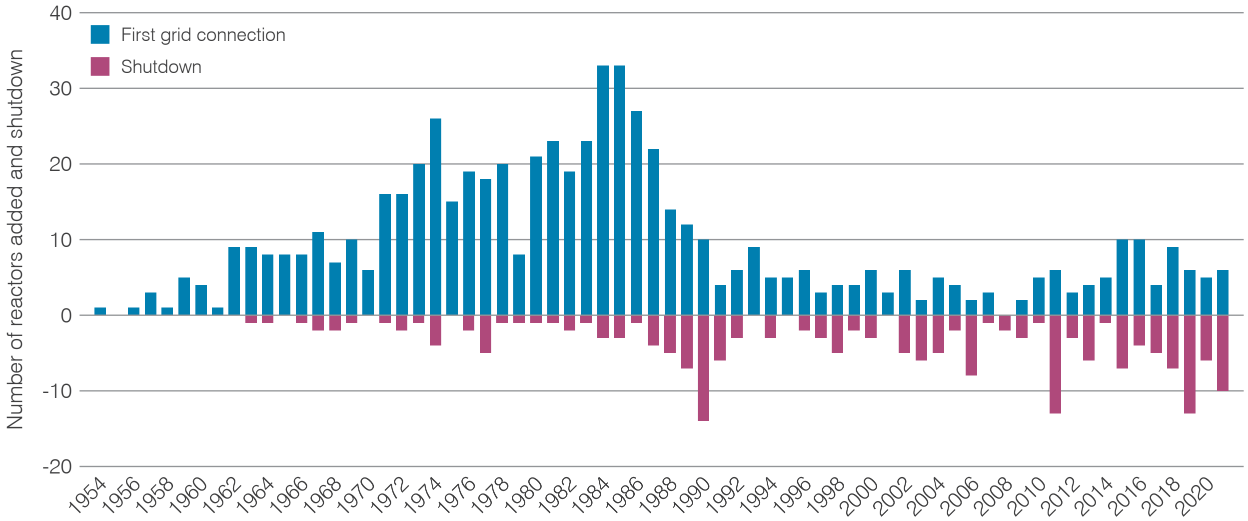
Ten reactors were permanently shut down in 2021. The three German reactors and the one Taiwanese reactor were closed as a result of a political decision to phase out nuclear generation. The last three reactors in Germany are due to close in 2022.

Table 5. Shutdown reactors in 2021

	Location	Capacity (MWe net)	First grid connection	Permanent shutdown date
Indian Point 3	USA	1030	27 April 1976	1 May 2021
Dungeness B1	UK	545	3 April 1983	7 June 2021
Dungeness B2	UK	545	29 December 1985	7 June 2021
Kuosheng 1	Taiwan	985	21 May 1981	1 July 2021
Karachi 1	Pakistan	90	18 October 1971	1 August 2021
Hunterston B1	UK	490	8 February 1976	26 November 2021
Kursk 1	Russia	925	19 December 1976	19 December 2021
Brokdorf	Germany	1410	14 October 1986	31 December 2021
Grohnde	Germany	1360	5 September 1984	31 December 2021
Gundremmingen C	Germany	1288	2 November 1984	31 December 2021

In 2021 six reactors were grid connected and 10 were permanently shut down. In terms of capacity, 5310 MWe was grid-connected and 8668 MWe was shut down.

Figure 14. Reactor first grid connection and shutdown 1954-2021



Source: World Nuclear Association, IAEA PRIS

2 | Case Studies

Constructing a high-temperature gas-cooled reactor

Image: NRI Huang Co.

China's High Temperature Gas Cooled Reactor - Pebble-bed Module (HTR-PM) demonstration plant at the Shidaowan plant in China's Shandong province commenced operation at the end of 2021.

The "large-scale advanced pressurized water reactor and high-temperature gas-cooled reactor nuclear power plant" project to build the demonstration HTR-PM as well as the demonstration CAP1400 also at Shidaowan, was announced in January 2006 as one of 16 National Science and Technology Major Projects under the National Medium- and Long-Term Science and Technology Development Plan (2006-2020).

Construction of the HTR-PM began in December 2012. After almost 10 years construction and commissioning, the first of the unit's twin reactors achieved criticality in September 2021 and the second reactor two months later, in November. The unit was connected to the grid on 20 December 2021.

The HTR-PM features two small reactors (each of 250 MWt) that drive a single 210 MWe steam turbine. It uses helium as coolant and graphite moderator. Each reactor is loaded with over 245,000 spherical fuel elements ('pebbles'), each 60 mm in diameter and containing 7 g of fuel enriched to 8.5%. Helium at 250˚C enters from the bottom of the reactor and flows upwards in the side reflector channels to the top reflector level where it reverses direction and flows downwards through the pebble bed. Bypass flows are introduced into the fuel discharge tubes to cool the fuel elements there, and into the control rod channels. Helium is heated up in the active reactor core and then is mixed to the average outlet temperature of 750˚C and then flows to the steam generator.

Shandong Shidaowan HTR-PM

Type	High-temperature gas-cooled reactor
Reactor thermal capacity	2 x 250 MWt
Electrical capacity (net)	200 MWe
First grid connection	December 2021

Due to the presence of U-238, there is a very strong negative temperature coefficient of reactivity, which guarantees an inherently safe stabilization of the core temperature in case of power excursions.

The inherent safety features of the HTR-PM guarantees that under all conceivable accident scenarios the maximum fuel element temperature could never surpass the design limit temperature, even without the dedicated emergency systems. In the hypothetical case of an accident characterized by a total loss of coolant and active cooling, the core of the HTR-PM would not melt due to its low power density and geometry. The fuel temperature can never exceed 1600˚C in the HTR-PM. This ensures that accidents, such as core melting, or the release of radioactive fission products into the environment, cannot occur.

Interview

Lü Hua Quan, Chairman of the Nuclear Research Institute, Huaneng Company

What particular lessons and challenges were learned during construction and commissioning of the HTR-PM?

The HTR-PM is a project with a research attribute. There have been some challenges with the nuclear island systems and equipment, resulting in a long construction cycle and high construction cost. Resolving these will be necessary for the successful industrialization of high-temperature gas-cooled reactors.

Take the fuel handling system for example: the HTR-PM adopts a non-stop stacking and changing operation mode, and the fuel handling system must operate reliably. During commissioning there were many problems with the fuel handling system, resulting in delays. Design changes and optimizations will be made to the HTR-600 design to improve the reliability of the system.

Additionally, the experience gained will be applied to future construction to optimize equipment design and reduce project costs. The auxiliary system will be shared by multiple reactors to reduce the cost and complexity of the system. We will adopt modular design and construction methods to shorten the construction period. We will optimize the system and equipment safety classification according to the inherent safety of high-temperature reactors and we will provide technical support for the adjustment of emergency planning zone and planning restricted zone to improve the adaptability of the plant site.

What is the future development of high-temperature gas-cooled reactor (HTR) technology beyond power generation? Could we expect reactors dedicated solely to supplying process heat?

HTRs have the highest operating temperatures of all existing reactor types, and are also the only reactors that can provide very high-temperature process heat. In the near future, HTRs could be used as a new generation of advanced reactors and a supplement to China's nuclear power, for small and medium-sized modular nuclear power generating units.

With further research and development, HTRs could in the future provide a source of high-quality high-temperature process heat for various industries, in particular those that are required to limit their carbon emissions. This would increase the number of advantages of HTRs, which can be used not only for urban heating and the chemical industry, but also in coal gasification and liquefaction, seawater desalination, metallurgy, and in the production of energy resources including synthetic fuels, petrochemicals and hydrogen.

Under what conditions is there the potential for exporting HTRs?

HTRs have great potential to help the world to decarbonize hard-to-abate sectors, but some areas still need to be fully addressed if they are to be broadly deployed. These areas include advanced high-temperature materials, the regulatory framework, safeguards and waste management for new fuels, and economics.

Once addressed, HTRs can be widely used in the applications I mentioned above. The outstanding advantage of HTGR "going global" is that it is highly consistent with the market demands of countries and regions along the "the Belt and Road". HTGRs are particularly suitable for countries and regions where freshwater resources are scarce, such as Saudi Arabia, and can replace conventional energy in a wide range of industrial fields. Secondly, HTRs have outstanding advantages in adapting to the needs of different power grids. Most of the power grids of countries and regions along the "the Belt and Road" are not suited to nuclear power plants of more than 1000 MWe. Through multi-module combination, nuclear power units with installed capacities ranging from around 100 MWe to 1000 MWe can be built. These small modular reactors are particularly suitable for countries and regions with small and medium-sized power grids, or in locations where the supply is required close to the load centre.

Barakah: a powerhouse for the UAE's sustainable development

Barakah 1-4

Type	PWR
Model	AP1400
Electrical capacity (net)	4*1345 MWe
Status as of 1 July 2022	Units 1&2 operable Units 3&4 under construction

Image: ENEC

The UAE's long-held vision of sustainably powering a growing economy with clean electricity has been reinforced with the successful power production at the Barakah Nuclear Energy Plant in the Emirate of Abu Dhabi. It is leading the rapid decarbonization of the UAE's power sector, securing the nation's energy supply against a backdrop of escalating energy prices, and advancing the UAE's sustainability goals. When fully operational, the Barakah plant will prevent up to 22.4 million tonnes of carbon dioxide emissions every year and will make a major contribution to meeting the country's international commitments for emissions reductions.

Within the past two years there has been a significant shift in the development of the UAE programme, from a construction site into a commercially operating nuclear plant. In February 2020, the UAE's independent nuclear regulator, the Federal Authority for Nuclear Regulation (FANR), issued the operating license for Barakah 1. Shortly thereafter, 241 nuclear fuel assemblies were loaded into the reactor vessel. Following the relevant testing procedures, unit 1 started up in July 2020, making the UAE the first country in the Arab World to operate a commercial nuclear power plant. The unit achieved commercial operation on 1 April 2021 – the start of a new chapter in the UAE's clean energy transition.

Building on the success of the first unit, the operating license for unit 2 was issued in March 2021, followed immediately by fuel loading. Using the lessons learned from unit 1, successful reactor start-up occurred in August 2021 and the unit achieved commercial operation in late March 2022. The delivery of unit 2, less than 12 months after unit 1, demonstrates the UAE's rapid increase in institutional nuclear knowledge and experience, with lessons learned and operating experience systematically being recorded and applied to subsequent units.

The commercial operation of unit 2 brought the total net capacity of Barakah to 2,690 megawatts and took ENEC to the half-way mark of delivering on the commitment to supply up to a quarter of the country's electricity needs. The now multi-unit operating plant is leading the largest decarbonization of any industry in the Arab World, delivering thousands of megawatts of carbon-free electricity every single day.

Emirates Nuclear Energy Corporation (ENEC), and its joint venture operating and maintenance subsidiary Nawah Energy Company, are now focused on building on existing experience and bringing Barakah 3&4 into operation. FANR issued the operating license for unit 3 in June 2022 to Nawah and fuel loading was completed shortly thereafter. These achievements on unit 3 demonstrate the great benefit in building multiple units, closely phased, to enable rapid progress in generating clean, 24/7 electricity for the UAE.

Nawah recently completed the first scheduled maintenance outage on unit 1, and has also focused on training and qualifying its next group of reactor operators as part of its strategy to ensure a sustainable pipeline of certified operators.

With COP28 due to be held in the UAE in 2023, all eyes will be on the Barakah plant as it demonstrates how nuclear energy complements renewables as part of a clean energy transition. ENEC is now looking beyond the Barakah plant to areas in R&D, clean hydrogen and advanced nuclear reactors, such as SMRs, to drive decarbonization and tackle climate change.

Interview

Eng. Ali Al Hammadi, CEO, Nawah Energy Company

What are your reflections on the first period of operation of units 1 and 2. Has anything differed from your expectations?

Barakah 1 has demonstrated strong performance through its first 12 months of operation. From the start of commercial operation on 1 April 2021 through to shutting the unit down for its first maintenance outage 12 months later, it generated about 10.5 TWh of electricity with on-target capacity. This is very much in line with expectations for a first-of-a-kind unit in a newcomer country.

There has been an incredibly beneficial learning curve on unit 1, with our teams of qualified UAE nationals and experienced international experts operating the unit in line with national regulations and striving for the highest international standards, demonstrating our continuous journey to excellence. Nawah brought in hundreds of additional specialists to support the outage, which comprised thousands of activities. With the unit back online as of July 2022 after its scheduled refuelling outage, we are aiming to ensure a capacity factor above 90%.

We can already see enhanced performance with unit 2, which entered commercial operation on 23 March 2022, and has been operating at close to 98% capacity factor ever since. We are utilizing the institutional knowledge and experience that we have built from our experience with unit 1 to boost our performance as we work to deliver clean electricity to the UAE 24/7 safely and in a quality-led manner.

We always knew that this would be a challenging period, with a steep learning curve, but we have planned for this for years, ensuring our people, plant, policies, processes and procedures were in place, having been tested, and tested again. We have also built a strong safety culture that permeates everything that we do and guides all of our decisions, and that has stood us in good stead as we navigate the dynamics of having three units in various stages of the operational lifecycle.

How will the experience gained from the start-up and operation of the first units on site impact the commissioning of units 3 and 4?

One of the main benefits from having four units which started construction one year apart is that we can also bring them into operation with about one year difference, taking on the lessons learned from the first and applying them to the subsequent units.

When you have a first-of-a-kind nuclear project, the first unit is always going to be challenging because it sets the bar for all subsequent units. Everything you do is for the first time, so a steady approach is needed to meet the high standards of the regulator. For example, unit 1 took 35 weeks to go from first criticality to commercial operation, while unit 2 took only 30 weeks. We did not compromise on safety or quality – we completed all processes and procedures in accordance with national regulations and international standards, but we benefitted from the build-up of knowledge and expertise from unit 1 to make efficiency gains.

What changes has it meant for operations on site? Is there any impact on construction taking place alongside operating units?

From the beginning of the project, we knew that we would have operational units alongside others still under construction. Of course, we were not expecting to be operating multiple units during a global pandemic, but we utilized our same approach to risk management and safety to successfully continue operations while in parallel protecting our Barakah team to safely operate the plant, and of course the wider community. The fact that we safely started up Unit 1 on schedule following receipt of the operating license – during the height of the pandemic – made the milestone an exceptionally significant achievement for us all.

As we move into 2022, the level of complexity increases further. On 23 March 2022, unit 2 became commercially operational and just weeks later unit 1 entered its first scheduled refuelling and maintenance outage. At the same time, we were working on finalizing our operational readiness preparations in order to demonstrate to the national regulator, FANR, that we are ready to operate unit 3. The key to managing multifaceted situations like this is to have the right people, with the right qualifications, in the right positions and to plan well in advance – nothing is left to chance. Our priority is the safe operation of the Barakah plant to reliably deliver clean electricity to the UAE, and we have been achieving this successfully so far, as we work to now bring units 3&4 online in the coming years.

Hinkley Point C: Build and Repeat

Image: EDF Energy

The Hinkley Point C project in Somerset, southwest England, is the first new nuclear power station to be built in the UK for more than 20 years. It will be capable of providing 7% of the country's electricity supply with two 1.6GWe EPR reactors. Hinkley Point C will avoid around 600 million tonnes of carbon dioxide during its operational life of at least 60 years.

The power station has revitalized the British nuclear supply chain. Construction was fully launched in September 2016 with the completion of the base for the first unit in June 2019 and for the second in June 2020. There now are around 8000 workers on site with 22,000 more workers around Britain involved in supplying the project.

UK adaptation

In common with other reactor designs, the EPR design went through a lengthy UK licensing process before it was approved in December 2012. The process led to significant design adaptations to enable the design to meet specific UK regulatory requirements. In effect the power station is the first-of-a-kind UK EPR.

Hinkley Point C nuclear power plant

Reactor type	EPR-1750
Total installed capacity	3400 MWe
First concrete:	
Unit 1	11 December 2018
Unit 2	12 December 2019

Replication strategy

Evidence from nuclear construction across the world shows that replication is a significant factor in reducing cost and schedule risk. Experience from Hinkley Point C bears this out, with major productivity gains in work repeated on unit 2. This will benefit the follow-on near identical plant at Sizewell C in Suffolk. The power station is also benefiting from experience gained at Flamanville and Taishan as well as innovations like large-scale prefabrication and the use of digital design tools.

Interview

Nigel Cann, Delivery Director at Hinkley Point C

What was the cause of the start-up dates for the reactors being put back recently, with the first unit now scheduled to start in June 2027?

Like any major construction project, we have faced more than two years of restrictions caused by the COVID-19 pandemic. Although we were able to find ways to keep the site open, while keeping workers and the community safe, numbers on site were held back.

At the height of the pandemic, numbers on site fell to around 1,500 and many of our suppliers faced disruption or temporary closures. Other factors have impacted the project, but we estimate the effect of the pandemic alone to be clearly in excess of 12 months.

Several examples of faster progress on construction of unit 2, from learning from unit 1, have been given. Is unit 2 'catching up' and would this have any impacts on the gap between grid connection for the two units?

During the pandemic, faced with limited availability of people and materials, we deliberately transferred resources from unit 2 to unit 1. In spite of this, major milestones on unit 2 like 'J-Zero' (the completion of the reactor base) and the installation of the second liner ring were completed just 12 months after the same operation on unit 1. We believe that the optimal gap between the two units is around 12 months and we aim to maintain that separation.

There have now been three EPRs that have started-up. Have there been lessons learned from these projects that will benefit the construction remaining at Hinkley Point?

Yes, absolutely. We have a big advantage in learning from the EPRs that preceded us, and there is good knowledge sharing between EPR operators and direct construction experience from EDF and CGN. Now that EPR reactors have started up, we can gain experience in every aspect of the project from construction to commissioning and operation. Many of the techniques at Hinkley Point C have already been influenced by experience from other projects and we continue to learn.

How will the experience of Hinkley Point C construction benefit the proposed Sizewell C project?

Hinkley Point C will give Sizewell C a big head start, including giving the Sizewell team a completed detailed execution design. This will give Sizewell C certainty over quantities and materials. The philosophy of replication is key to maximizing the benefits of our experience. We like to think of Sizewell C as the third and fourth Hinkley Point C units – our joint aim is to change as little as possible.

Image: EDF Energy

Designing and building the first land-based SMR

The ACP100 is a third-generation SMR design that maximizes the use of mature technologies and equipment. The reactor has a thermal power capacity of 385 MWt and a net electric output of up to 126 MWe.

The first unit is being built at Changjiang in Hainan province, where two CNP-600 reactors are already in operation and two 1100 MWe Hualong One reactors are under construction. Once completed, the Changjiang ACP100 reactor will be capable of producing 1 billion kilowatt-hours of electricity annually, enough to meet the needs of 526,000 households.

The project at Changjiang involves a joint venture of three main companies: CNNC subsidiary China National Nuclear Power as owner and operator; the Nuclear Power Institute of China (NPIC) as the reactor designer; and China Nuclear Power Engineering Group being responsible for plant construction.

When first concrete was poured on 13 July 2021, the ACP100 demonstration model became the first land-based commercial SMR to start construction in the world.

The containment vessel bottom head - which will support the steel containment shell - was assembled on-site from50 pre-fabricated steel plates. The assembled component was hoisted into place by crane onto the plant's concrete foundation plate on 24 October 2021.

The lower section of the containment shell - some 15 metres in height and weighing about 450 tonnes - was lowered into place upon the vessel bottom head on 26 February this year, 46 days ahead of schedule. The total construction period is scheduled for 58 months, and it is currently on schedule.

China National Nuclear Corporation (CNNC) started R&D work on the ACP100 in 2010 and the design passed the IAEA Generic Reactor Safety Review on 22 April 2016.

In October 2017, the Chinese Nuclear Society recognized the ACP100 technology to be one of “China’s Top 10 Advances in Nuclear Technology in 2015-2017”.
As an innovative SMR design, the ACP100 design has passive safety features that are expected to handle extreme environmental conditions and multiple failures without any significant radioactive release.

Changjiang SMR

Type	PWR
Reactor thermal capacity	385 MWt
Electrical capacity (net)	126 MWe
First concrete	13 July 2021

The ACP100 also features integrated reactor design technology, modular design and fabrication, and integral steam generator with the reactor coolant pump mounted on the pressure vessel nozzle. All these technologies provide high inherent safety to prevent large-scale loss of coolant accidents (LOCAs).

These design innovations allow the reactor manufacturing, transport and site installation processes – and the economics of the ACP100 – to be optimized.


Image: CNNC

Interview

Qu Yong, Deputy Chief Engineer, CNNC Hainan Nuclear Power Company

What consideration led to choose ACP100 design and Changjiang site to implement it?

In recent years, Chinese authorities have promoted the construction of the Hainan Free Trade Port. They are committed to developing Hainan island into a national ecological civilization pilot zone and a key gateway to the Pacific and Indian Oceans.

The construction of ACP100 nuclear power units can form the basis for green development in this pilot zone and contribute to achieving Hainan's clean energy development goals.

Besides electricity generation, the ACP100 can serve many other purposes such as seawater desalination, district heating (or cooling) and process heat supply. It is also suited to various locations and application scenarios, including small and medium sized power grids, industrial parks, islands and as a dedicated power source for high energy-consuming enterprises.

The ACP100 demonstration project will help Hainan to become a base for the promotion of China's advanced commercial small modular reactor technology to the world.

With two CNP-600 units in operation and a further two under construction at the Hainan site, the companies working at the Changjiang nuclear power plant have accumulated a wealth of experience in constructing, managing and operating nuclear power projects. The ACP100 demonstration project at the Changjiang site can make full use of the available resources to improve the economics of the project as much as possible.

Will the traditional supply chains be able to easily adapt to the new requirements specific to SMR?

Compared with traditional equipment supply, modular equipment relies on detailed design, advance orders, factory prefabrication, as well as the transport, lifting and installation of large modules. In addition, parallel operations offsite and onsite have to be carried out, reducing the time for onsite construction.

Much of the fabrication work is carried out in the manufacturing plant, where it is easier to control the temperature, humidity and cleanliness of the working environment, while avoiding onsite typhoons, rainstorms and dust.

For example, after the steam generator is manufactured, it has to be transported to the pressure vessel manufacturing plant to be incorporated into the reactor. After the welding is completed, the integral reactor will be transported to the site; at the same time the prefabricated steel containment shell plate has to be transported to the site for assembly. After the module equipment arrives onsite, only simple lifting operations are required to realize the installation of the entire equipment or system, which greatly reduces the construction period of the project.

Modular equipment has precise manufacturing and project management requirements, and some large modules pose new challenges in terms of transport and hoisting.

In general, the ACP100 supply chain builds on existing international and domestic modular equipment supply, with improved quality of modules and reduction of module manufacturing costs.

3 | Country Pages

Argentina

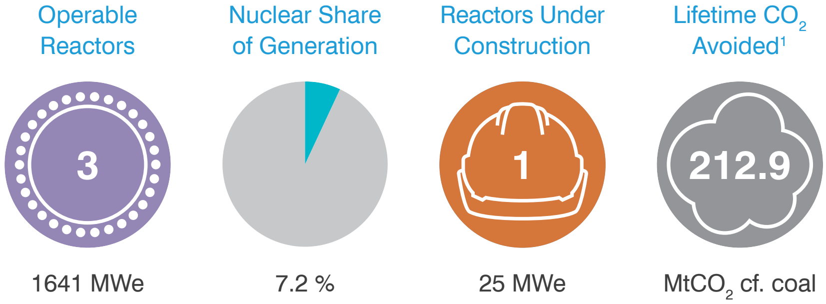
Argentina has two nuclear power plants: Atucha, about 100 km northwest of Buenos Aires; and Embalse, about 100 km south of Córdoba.

The two-unit Atucha plant has a total capacity of 1033 MWe. Unit 1 has a licence to operate until 2024, but Nucleoeléctrica Argentina will seek to extend this by 20 years.

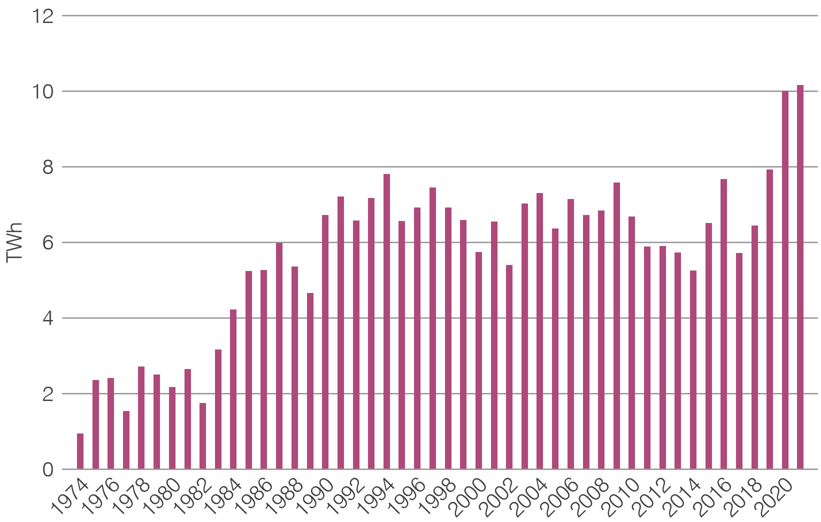
In February 2022 NA-SA and China National Nuclear Corporation (CNNC) signed an engineering, procurement and construction (EPC) contract for the development of a third unit, a Chinese-designed HPR1000, at the Atucha plant. Previously it had been planned that China would support Nucleoeléctrica Argentina to construct a new PHWR at Atucha.

Construction work on a prototype SMR, CAREM-25, began in early 2014 but has been suspended several times. It is the country's first domestically designed and developed nuclear power unit. In July 2021 Nucleoeléctrica Argentina signed a contract with the country's National Atomic Energy Commission (CNEA), which specified that construction would be completed within three years.

Embalse, a 608 MWe CANDU PHWR was returned to service in May 2020 following a three-year upgrade programme to prepare it for a further 30 years of operation. The Embalse reactor is used to produce cobalt-60, as well as electricity.

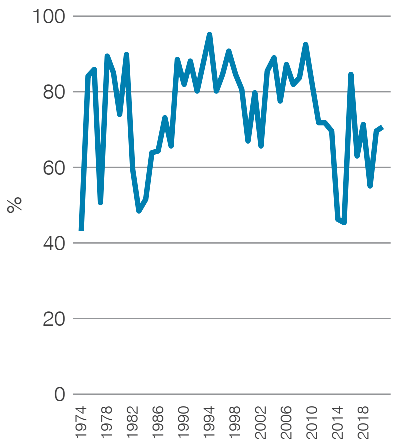


Nuclear electricity production



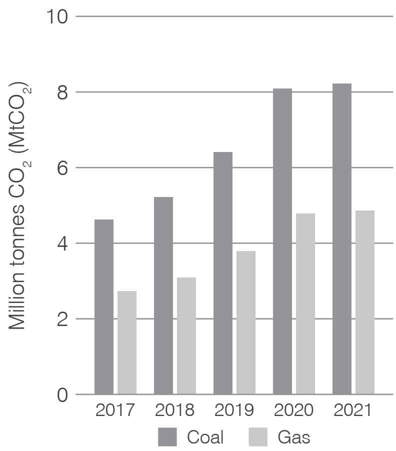
Source: World Nuclear Association, IAEA PRIS

Average nuclear capacity factor



Source: World Nuclear Association, IAEA PRIS

Emissions avoided cf. fossil fuels generation[2]



Source: World Nuclear Association, IAEA PRIS

Footnote:

[1] Total CO_2 emissions that would have been emitted if electricity had instead been generated from coal-fired plant.

[2] Annual CO_2 emissions that would have been emitted if electricity had instead been generated from coal-fired or gas-fired plant.

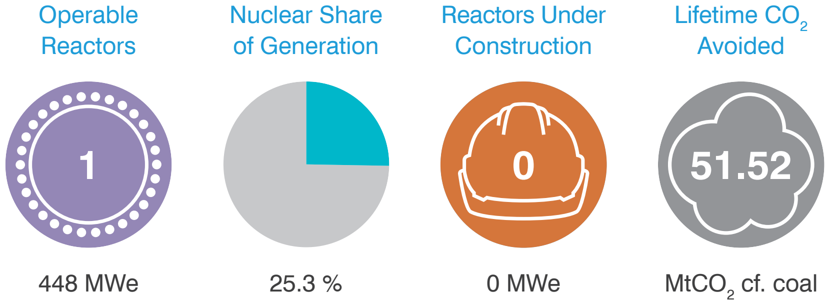
Armenia

Armenia has one nuclear power plant, Metsamor, located 30 km west of the Armenian capital of Yerevan. It is also known as the Armenian Nuclear Power Plant (ANPP).

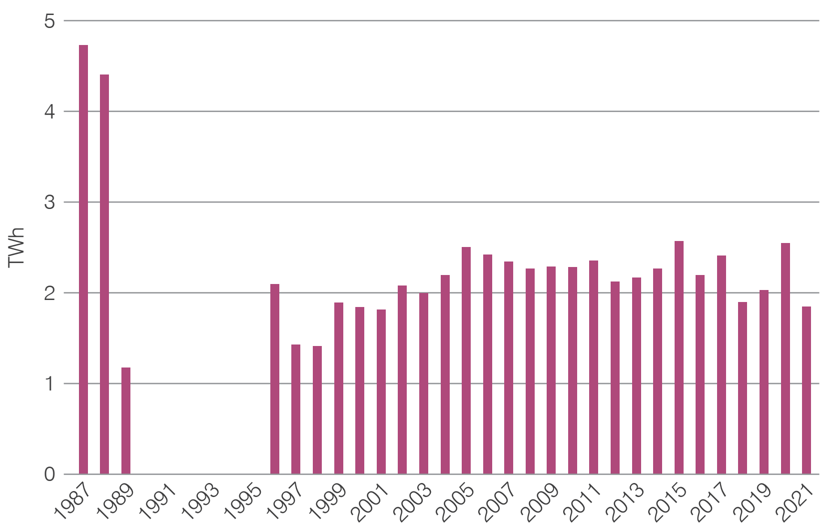
Two VVER-440 reactors were built at the Metsamor plant. Unit 1 was connected to the grid in 1976, followed by unit 2 in 1980. Both units were taken offline in 1988 due to safety concerns regarding seismic vulnerability, although they had not sustained any damage in a major earthquake in the region earlier that year and had continued to operate. Unit 1 was permanently shut down in 1989, but unit 2 was restarted in 1995 in the face of severe energy shortages. Both units originally had a reference unit capacity of 408 MWe, which was reduced to 376 MWe in 1988.

In November 2021 upgrade work to allow unit 2 to operate until 2026 was concluded. Upgrade work included a ten-day operation, led by Rosatom, to anneal the reactor vessel; replacement of large number of emergency systems components; modernization of emergency systems and control and monitoring systems; and replacement of safety-related cable. Armenia will work to further extend the units' operating lifetimes by 10 years. Following the upgrade, the unit has been operating at 448 MWe.

Armenia has long been in discussions with Russia about renewing its nuclear capacity and in January 2022 both parties agreed to cooperate on the construction of new Russian-designed nuclear power units.

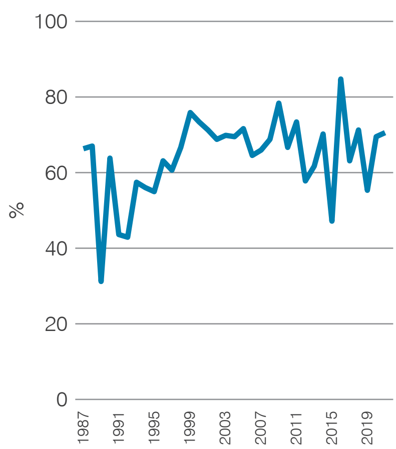


Nuclear electricity production



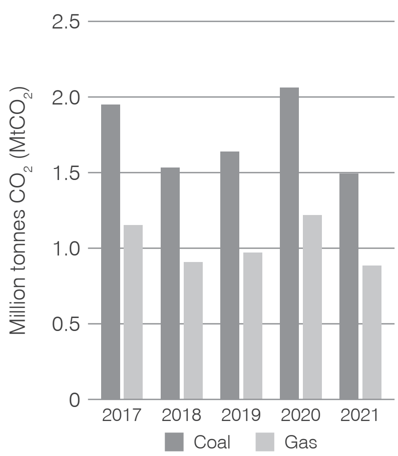
Source: World Nuclear Association, IAEA PRIS

Average nuclear capacity factor



Source: World Nuclear Association, IAEA PRIS

Emissions avoided cf. fossil fuels generation



Source: World Nuclear Association, IAEA PRIS

Bangladesh

Two Russian-designed VVER-1200 units are under construction in Bangladesh at Rooppur, on the east bank of the Padma river about 160 km northwest of Dhaka.

Construction of unit 1 began in November 2017, followed by unit 2 in July 2018. The reactors are based on the V-392M reactors at Novovornezh II. The two units are expected to be connected to the country's grid in 2023 and 2024.

Significant progress was made in 2021: in August the reactor pressure vessel for unit 2 and four steam generators were delivered after a 14,000 km journey by sea. The steam generators were lifted into position in November.

In December primary circuit welding began for unit 1, and the final containment ring for unit 2 was concreted into place.

Once complete, the two-unit plant will provide about 9% of the country's electricity. In October 2021 Sheikh Hasina, the country's prime minister, said that Bangladesh will build a second nuclear power plant once work at Rooppur is finished.

Operable Reactors	Nuclear Share of Generation	Reactors Under Construction	Lifetime CO_2 Avoided
0		2	0
0 MWe	0 %	2160 MWe	$MtCO_2$ cf. coal

Rooppur nuclear power plant (Image: Rosatom)

Belarus

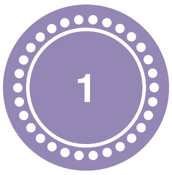
Belarus connected its first nuclear power reactor to the grid in November 2020. It is the first of two VVER-1200 reactors at Ostrovets, about 120 km northwest of Minsk. The two V-491 units are the first VVER-1200s to be built outside of Russia.

Fuel loading into the second reactor began in December 2021, and it is expected to begin generating electricity in 2022.

Lithuania – along with Estonia and Latvia – remains opposed to the Ostrovets plant, which is close to its border with Belarus and less than 50 km from its capital Vilnius.

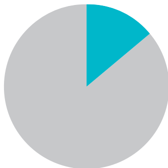
In September 2021 Lithuanian grid operator LitGrid capped the amount of electricity entering its grid from Belarus as part of measures to avoid importing power from the plant.

Operable Reactors



1110 MWe

Nuclear Share of Generation



14.1 %

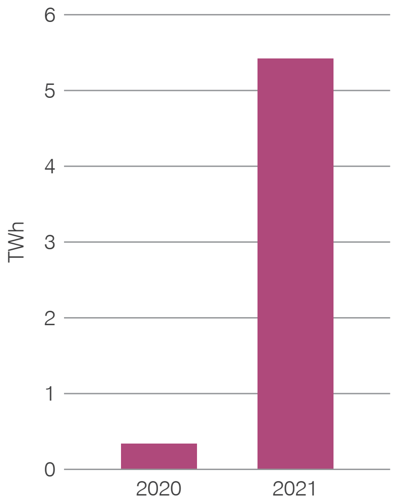
Reactors Under Construction

1110 MWe

Lifetime CO_2 Avoided

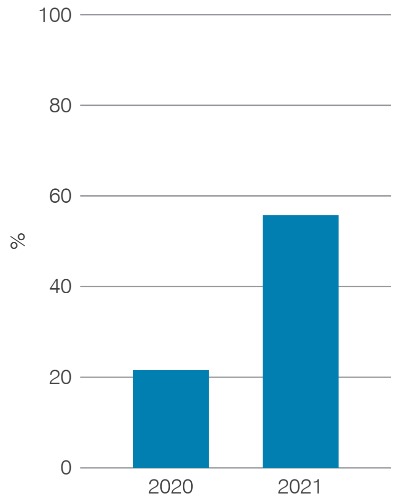
$MtCO_2$ cf. coal

Nuclear electricity production



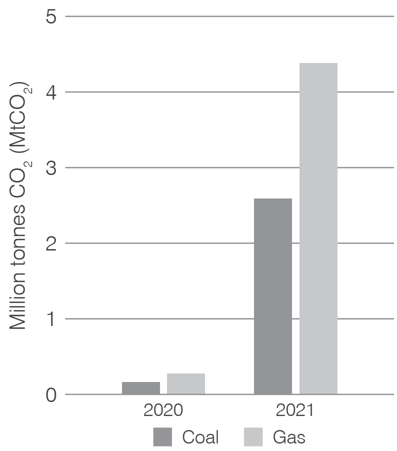
Source: World Nuclear Association, IAEA PRIS

Average nuclear capacity factor



Source: World Nuclear Association, IAEA PRIS

Emissions avoided cf. fossil fuels generation



Source: World Nuclear Association, IAEA PRIS

Belgium

Belgium has two operable nuclear power plants: Doel, a four-unit plant located 15 km northwest of Antwerp; and Tihange, a three-unit plant located about 25 km west-southwest of Liège.

Belgium's nuclear policy, which had been reaffirmed in 2020 following the election of a new coalition government, was that Doel 4 and Tihange 3 would close in 2025, following on from Doel 3 and Tihange 2, which were to be shut down in 2022 and 2023, respectively.

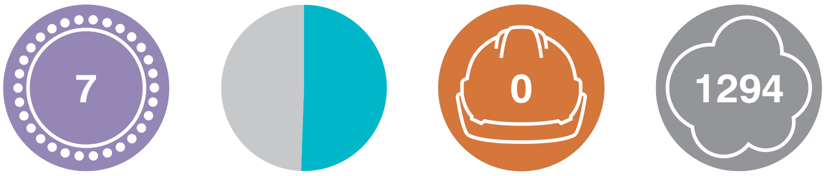
Events in Ukraine in early 2022 prompted a rapid reassessment of that policy. In March 2022 the government approved the extended operation of Doel 4 and Tihange 3 to 2035.

In January 2022 the country's regulator said that the units could continue to operate beyond 2025 with certain safety upgrades, but noted that the decision would be for the operator, Engie. Engie has said that the main hurdle preventing the units' extended operation will be the concurrent work to dismantle adjacent units at each site.

In May 2022 the Belgian government said that SCK-CEN, the country's nuclear research centre, will receive a budget of €100 million to research small modular reactors.

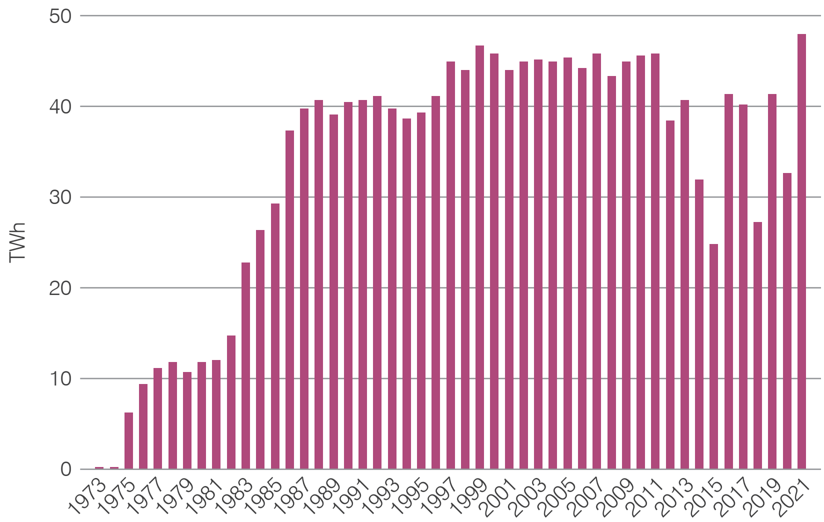
In July 2019 Belgium grid operator Elia concluded that the country would need more capacity than previously forecast to cope with its planned nuclear exit and is not yet ready for any scenario, including one where the phaseout of nuclear reactors is more gradual than envisaged at that time.

Operable Reactors	Nuclear Share of Generation	Reactors Under Construction	Lifetime CO_2 Avoided



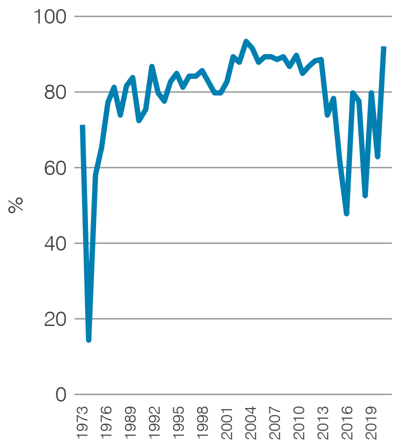
5942 MWe	50.8 %	0 MWe	$MtCO_2$ cf. coal

Nuclear electricity production



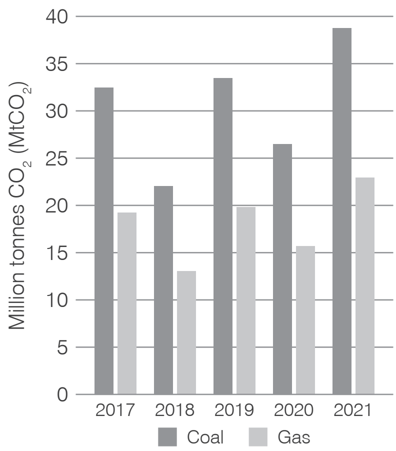
Source: World Nuclear Association, IAEA PRIS

Average nuclear capacity factor



Source: World Nuclear Association, IAEA PRIS

Emissions avoided cf. fossil fuels generation



Source: World Nuclear Association, IAEA PRIS

Brazil

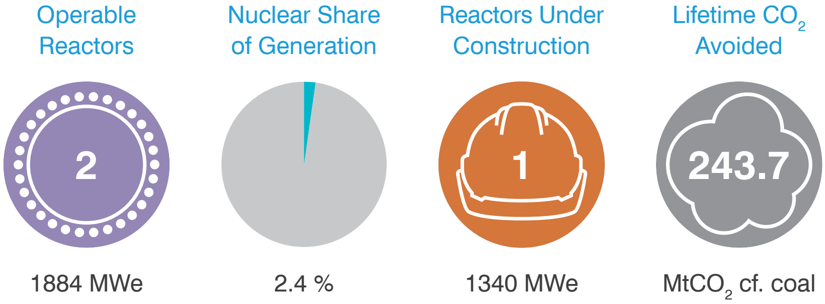
Brazil has one nuclear power plant at Angra, 200 km west of Rio de Janeiro. The plant has two operating reactors, with a combined capacity of 2006 MWe.

Construction of a third unit at Angra began in 2010, but was suspended for a second time in 2016, when just over 60% complete.

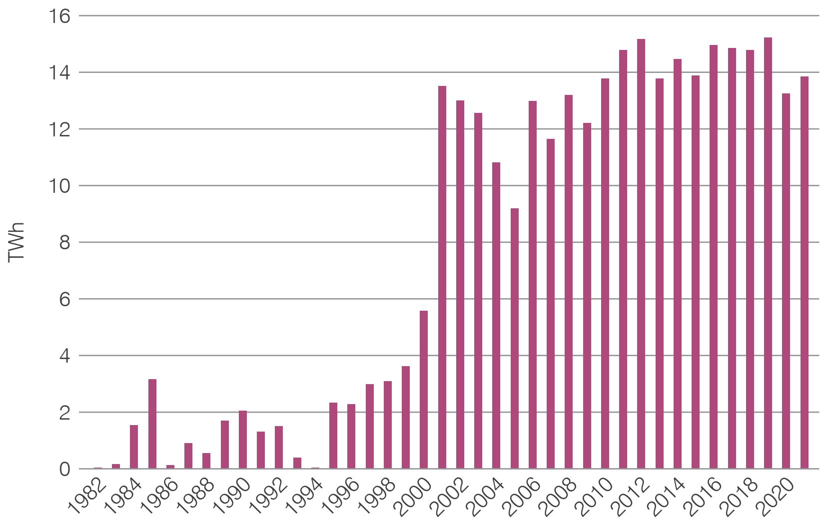
In July 2021 two key contracts for the completion of Angra 3 were announced. A Tractebel-led consortium was selected to structure the completion of the reactor, and a Brazilian consortium comprising Ferreira Guedes, Matricial and ADtranz was selected to do the construction work. The formal signing of the contract was completed in February 2022.

Brazil has historically relied on hydro to produce up to 80% of its electricity, but in drought years this figure is significantly reduced.

In January 2022 the country's Ministry of Mines and Energy, and the Center for Energy Research, a subsidiary of Eletrobras, began cooperation on a siting study for future nuclear power plants.

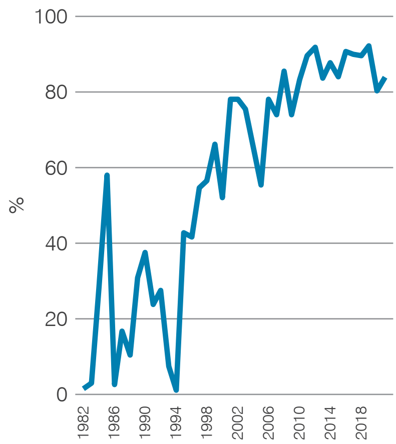


Nuclear electricity production



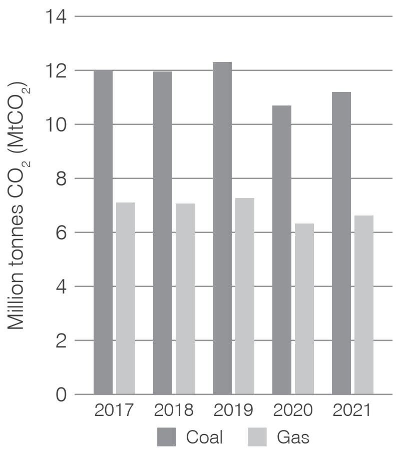
Source: World Nuclear Association, IAEA PRIS

Average nuclear capacity factor



Source: World Nuclear Association, IAEA PRIS

Emissions avoided cf. fossil fuels generation



Source: World Nuclear Association, IAEA PRIS

Bulgaria

Bulgaria has one operable nuclear power plant, Kozloduy, located on the Danube river about 110 km north of Sofia. It has two operating VVER-1000 reactors, with a combined capacity of 2006 MWe. Four VVER-440 units were shut down in the 2000s as a condition of the country joining the European Union.

In October 2021 it was announced that profits from the Kozloduy nuclear plant would be redirected to provide subsidies of €56 MWh to industrial customers. The measure was taken to protect industry from power prices driven by gas and coal.

Also in October 2021, Bulgarian Energy Holding signed an MoU with Fluor to look at the possibility of replacing the country's coal plants with NuScale SMRs.

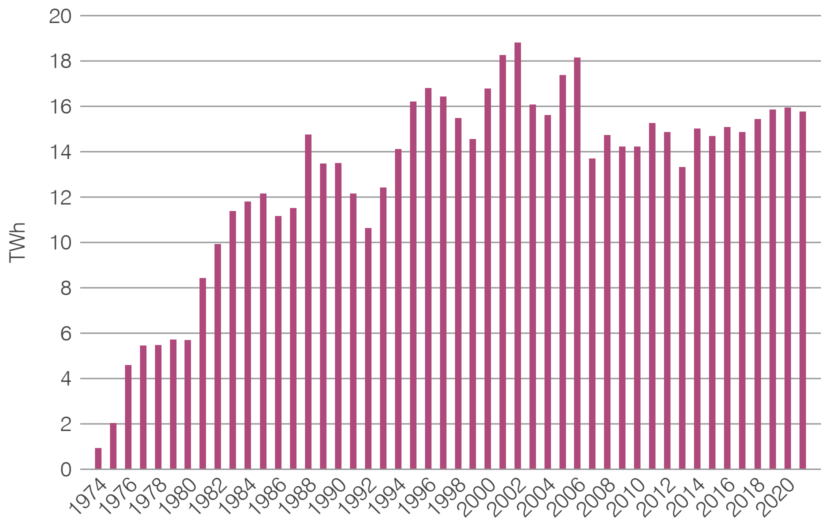
Faced with the need to phase out coal – which provides up to 40% of the country's electricity – whilst also maintaining energy security, Bulgaria's policymakers would like to expand nuclear capacity at either Kozloduy or Belene.

Whilst Bulgaria's commitment to the future of nuclear energy is strong, lack of finance and low electricity demand have slowed plans to build new plants. In March 2022 Kiril Petkov, the Bulgarian prime minister, announced his intention to propose a long-term electricity supply contract with Greece to support the construction of a new reactor in Bulgaria. Kyriakos Mitsotakis, the Greek prime minister, said in 2021 his country had no plans to build nuclear power plants due to the risk of seismic activity in his country.

Operable Reactors	Nuclear Share of Generation	Reactors Under Construction	Lifetime CO_2 Avoided

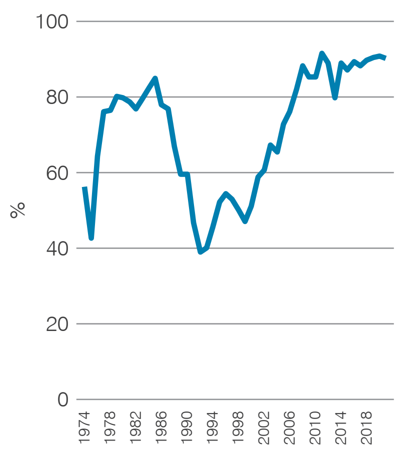
2006 MWe	34.6 %	0 MWe	$MtCO_2$ cf. coal

Nuclear electricity production



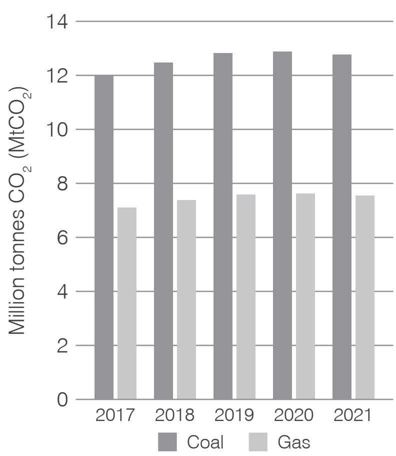
Source: World Nuclear Association, IAEA PRIS

Average nuclear capacity factor



Source: World Nuclear Association, IAEA PRIS

Emissions avoided cf. fossil fuels generation



Source: World Nuclear Association, IAEA PRIS

Canada

Nineteen reactors operate at four plants in southeast Canada, 18 of which are in Ontario and one in New Brunswick.

The Bruce nuclear power plant is the country's largest. It comprises eight PHWR units commissioned between 1976 and 1987 that have a combined capacity of 6358 MWe. In 2015 it was decided that six of the units (3-8) would be refurbished with major components being replaced to extend their operation to 2064. Work began on unit 6 in January 2020, and in July 2021 work to disassemble the reactor was completed. In December 2021 the last of eight replacement steam generators for unit 6 was lifted into place.

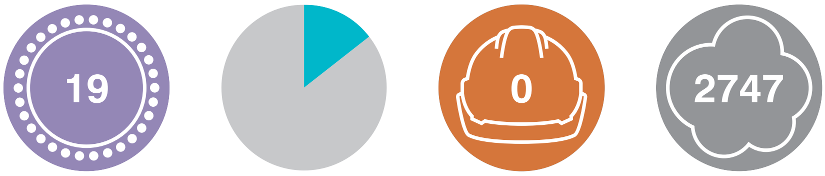
In 2015 Ontario Power Generation (OPG) decided on a full refurbishment programme for Canada's four-unit plant at Darlington to enable 30-year lifetime extensions for the reactors. Unit 2 was taken offline in October 2016 and returned to full operation in June 2020. In September 2020 unit 3 was taken offline for refurbishment, followed by unit 1 in February 2022.

In July 2021 Cameco, GE Hitachi Nuclear Energy and Global Nuclear Fuel Americas announced an MoU to explore collaboration to advance the deployment of the BWRX-300 in Canada and elsewhere.

In December 2021 OPG announced it had chosen the BWRX-300 SMR for the Darlington New Nuclear Project and signed a contract in March 2022 for the first phase of site preparation and support infrastructure.

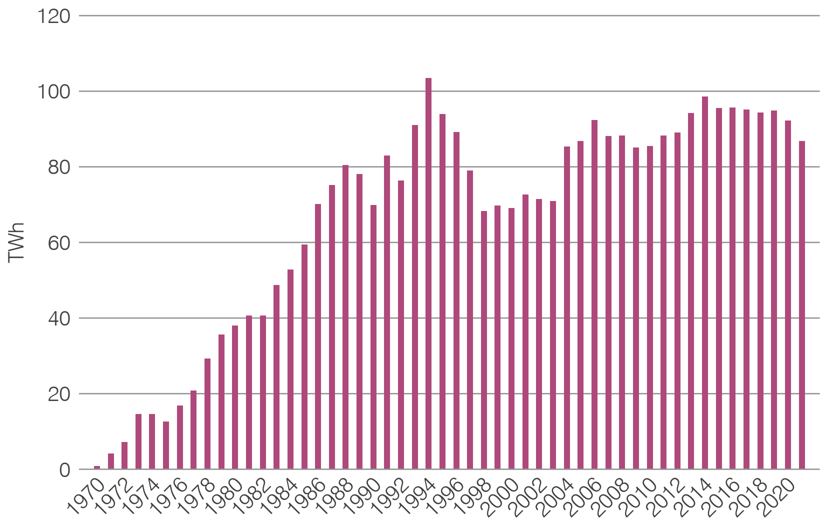
In April 2022 OPG and the Tennessee Valley Authority announced plans to work together to develop advanced nuclear technology including SMRs.

Operable Reactors	Nuclear Share of Generation	Reactors Under Construction	Lifetime CO_2 Avoided



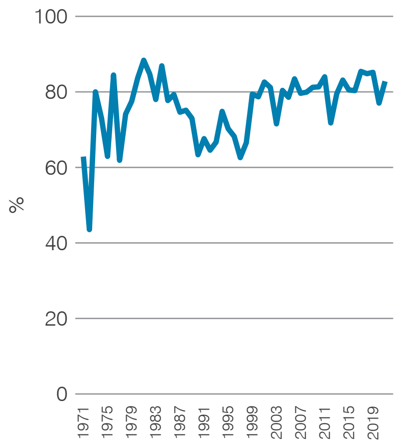
13,624 MWe	14.3 %	0 MWe	$MtCO_2$ cf. coal

Nuclear electricity production



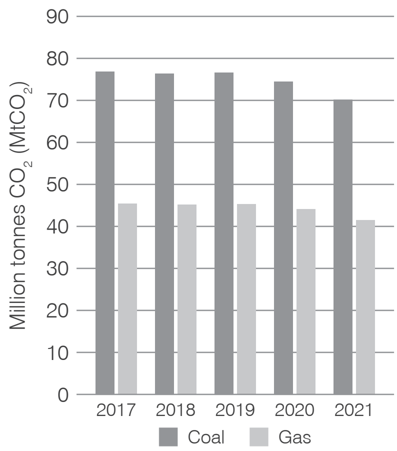
Source: World Nuclear Association, IAEA PRIS

Average nuclear capacity factor



Source: World Nuclear Association, IAEA PRIS

Emissions avoided cf. fossil fuels generation



Source: World Nuclear Association, IAEA PRIS

China, mainland

Mainland China has 54 operable reactors, primarily at sites along its southeast coastline.

In December 2021 the demonstration High Temperature Gas-Cooled Reactor – Pebble-bed Module (HTR-PM) at the Shidaowan site in Shandong province was connected to the grid.

In January 2022 Fuqing 6, a Hualong One reactor, began supplying electricity. This was followed in May 2022 by Hongyanhe 6, an ACPR-1000 reactor, in China's Liaoning province.

In July 2021 China commenced construction on an ACP100 SMR at the Changjiang nuclear plant on China's island province of Hainan; and Xudabao 3, a VVER-1200, in Huludao, Liaoning province. The ACP100 is designed for electricity production, heating and steam production or seawater desalination.

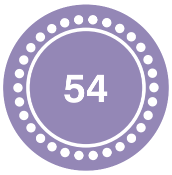
At the end of December 2021 China commenced construction of two Hualong One units: Changjiang 4 and San'ao 2.

First concrete was poured for Tianwan 8, a VVER-1200 unit in February 2022, and for Xudabao 4, another VVER-1200, in May.

In July 2021 CNNC launched a district heating demonstration project at Qinshan and in March 2022 a similar project was launched at Hongyanhe.

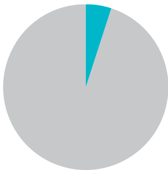
The use of nuclear heat for industrial processes is also being explored and in February 2022 a project commenced at the Tianwan nuclear plant to supply steam to a nearby petrochemical plant.

Operable Reactors



52,150 MWe

Nuclear Share of Generation



5.0 %

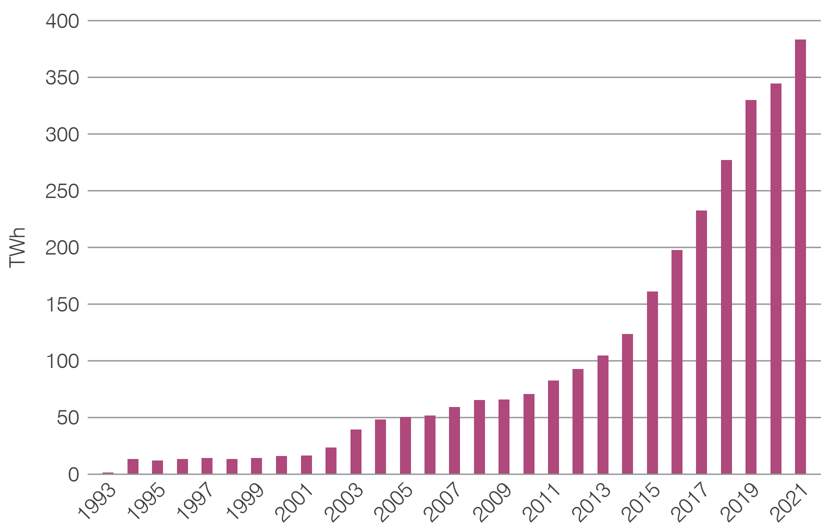
Reactors Under Construction

20,600 MWe

Lifetime CO_2 Avoided

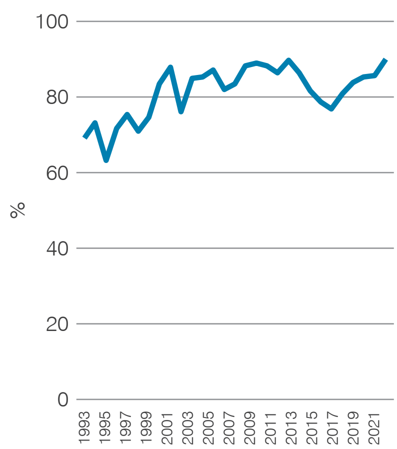
$MtCO_2$ cf. coal

Nuclear electricity production



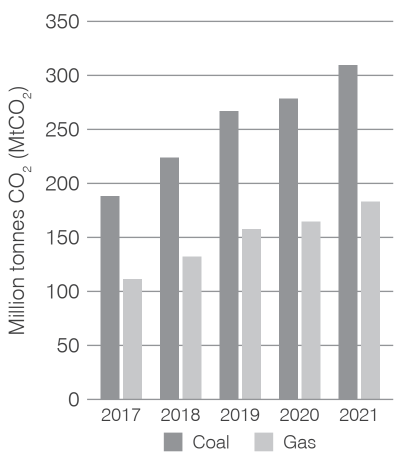
Source: World Nuclear Association, IAEA PRIS

Average nuclear capacity factor



Source: World Nuclear Association, IAEA PRIS

Emissions avoided cf. fossil fuels generation



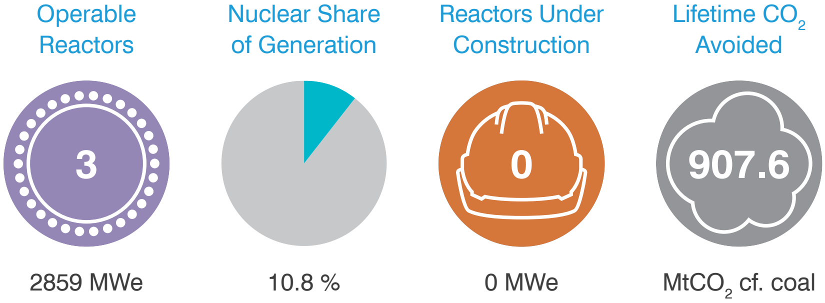
Source: World Nuclear Association, IAEA PRIS

Taiwan, China

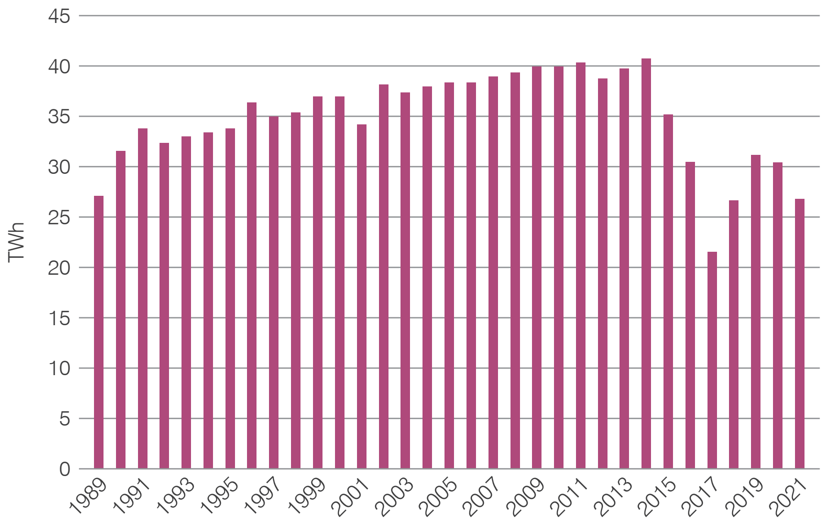
Taiwan has three operable nuclear power reactors with a combined capacity of 2859 MWe: two at Maanshan, on the southern coast of the island, and one at Kuosheng, on the northern coast, 25 km northeast of Taipei.

Since 2016 Taiwan has had a policy of phasing out nuclear energy by 2025. In July 2021 Taiwan Power Company (Taipower) announced the closure of unit 1 at the Kuosheng plant. The unit had been scheduled to operate until December, but a lack of used fuel storage capacity forced the earlier closure.

Construction of two large, advanced boiling water reactors at Lungmen had begun in 1999 but had been beset by delays before construction was halted in 2014. By this time it was reported that construction of unit 1 was complete and unit 2 over 90% complete. In December 2021 a majority of voters in a referendum rejected the possibility of restarting construction, and the project was officially cancelled.

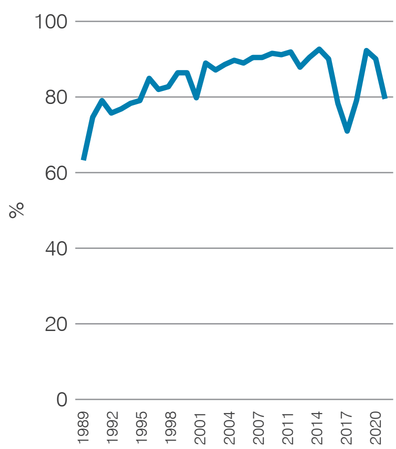


Nuclear electricity production



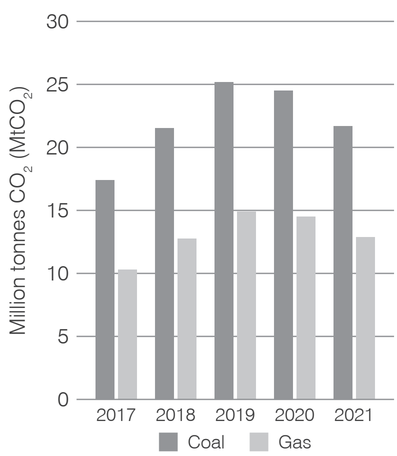
Source: World Nuclear Association, IAEA PRIS

Average nuclear capacity factor



Source: World Nuclear Association, IAEA PRIS

Emissions avoided cf. fossil fuels generation



Source: World Nuclear Association, IAEA PRIS

Czech Republic

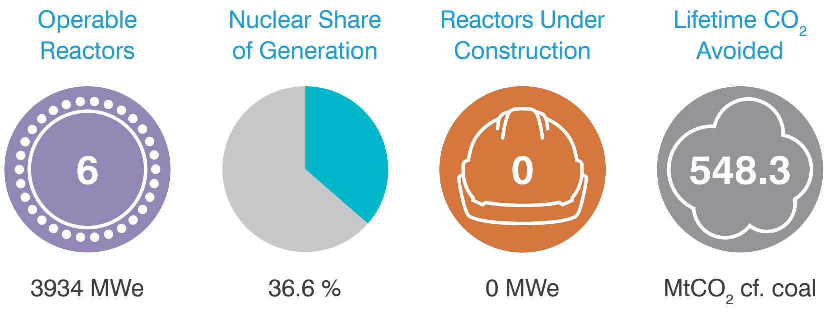
The Czech Republic has six operable reactors: two units are at Temelin, 100 km south of Prague; and four units at Dukovany, 34 km west of Brno.

The government's long-term energy strategy, adopted in 2015, forecasts the need to increase the share of nuclear power in the country's energy mix to 50-55% by 2050. Czech utility CEZ has said it expects to operate the four Dukovany units until 2045 and 2047, and the two Temelin units until 2060 and 2062.

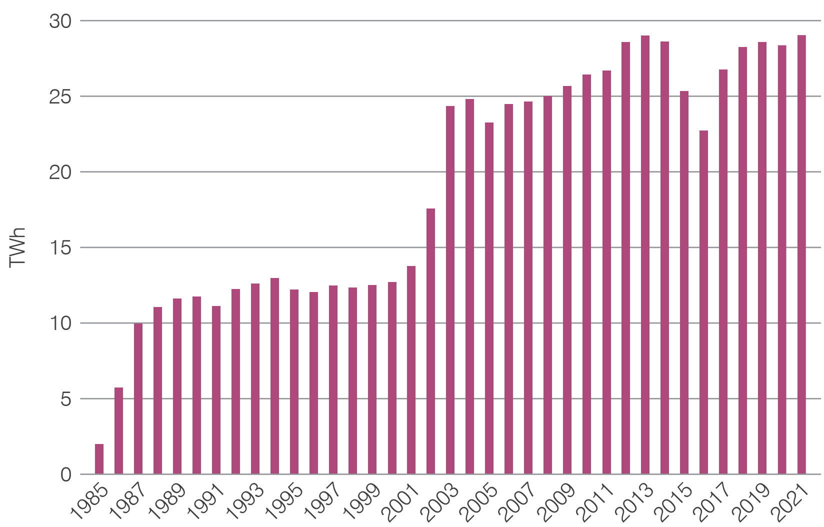
CEZ was awarded a site licence for two new 1200 MWe PWR reactors at its Dukovany plant in March 2021. The Czech Ministry of Industry and Trade selected EDF, Korea Hydro & Nuclear Power and Westinghouse for pre-qualification for the tender for the new units in the same month, notably excluding CGN and Rosatom. In June 2021 CEZ began its security assessment of the three vendors.

Under the current schedule, a reactor vendor is expected to be selected by the end of 2022, with a construction licence to be issued in 2029.

Earlier in May 2020 the Czech prime minister announced that the government would loan 70% of the cost of building a single 1200 MWe unit, with CEZ funding the remaining 30%. In October 2019 Deputy Prime Minister and Minister of Industry and Trade Karel Havlicek had said that the Czech Republic would need to build not only one new unit at Dukovany, but also more reactors at Temelin if it were to avoid becoming dependent on electricity imports from 2030.



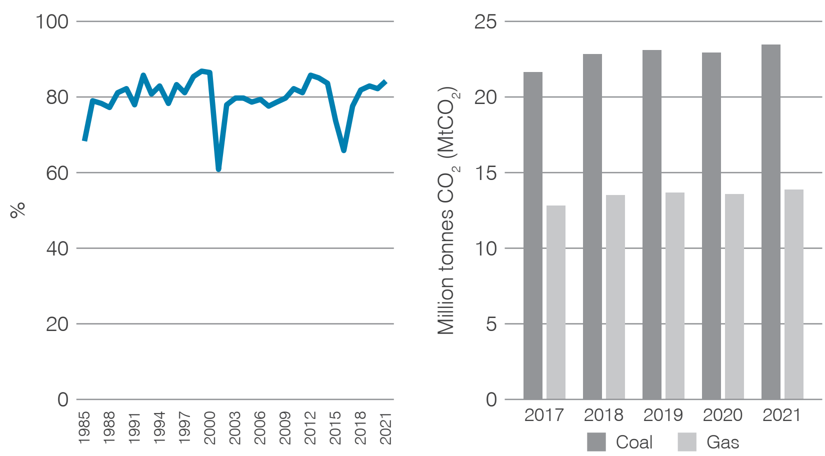
Nuclear electricity production



Source: World Nuclear Association, IAEA PRIS

Average nuclear capacity factor

Emissions avoided cf. fossil fuels generation



Source: World Nuclear Association, IAEA PRIS

Source: World Nuclear Association, IAEA PRIS

Finland

Finland has two nuclear power plants. Loviisa, a two-unit VVER plant, is located 80 km east of Helsinki, and Olkiluoto, about 220 km northwest of the capital, with BWR for units 1&2, and an EPR for unit 3.

Olkiluoto 3 was connected to the national grid in March 2022, and is due to achieve commercial operation in December. The unit will provide some 14% of the country's electricity.

During 2021 work continued towards obtaining a construction licence for a second large, modern unit – a VVER-1200 – to be built at a new site, Hanhikivi, on the coast of Bothnian Bay, near Pyhäjoki. However, in February 2022 the Finnish city of Vantaa announced it had instructed its municipal energy company to pull out of the project, and in May 2022 Fennovoima announced it was terminating the EPC contract with Rosatom's RAOS Project subsidiary and withdrawing its construction licence application.

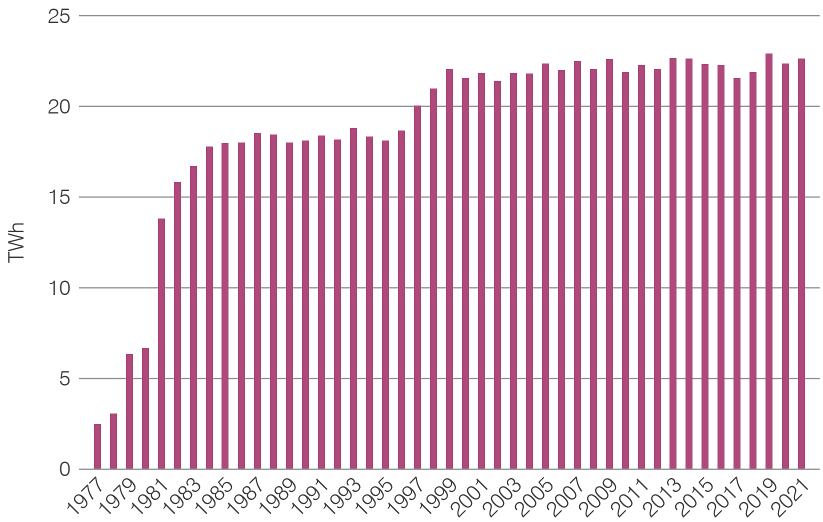
In March 2022 Fortum Power and Heat Oy submitted an application to operate units 1&2 of its Loviisa nuclear plant until the end of 2050. The current operating licences expire at the end of 2027 and 2030, respectively. Earlier in September 2021 Fortum had submitted an environmental impact assessment to the Ministry of Economic Affairs and Employment to examine the impacts of a potential extension of operation of the plant's two reactors.

In May 2022 it was announced that Finnish nuclear regulator, STUK, had started reviewing Posiva Oy's operating licence application for the country's used fuel repository at Olkiluoto. The repository will be the world's first used fuel disposal facility when it commences operation.

Operable Reactors	Nuclear Share of Generation	Reactors Under Construction	Lifetime CO_2 Avoided

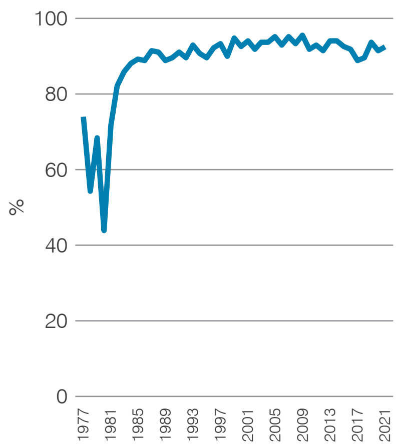
4394 MWe	32.8 %	0 MWe	$MtCO_2$ cf. coal

Nuclear electricity production



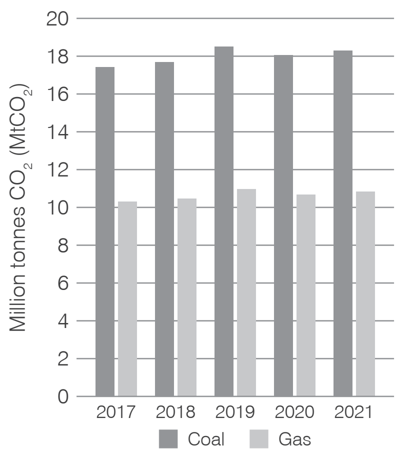
Source: World Nuclear Association, IAEA PRIS

Average nuclear capacity factor



Source: World Nuclear Association, IAEA PRIS

Emissions avoided cf. fossil fuels generation



Source: World Nuclear Association, IAEA PRIS

France

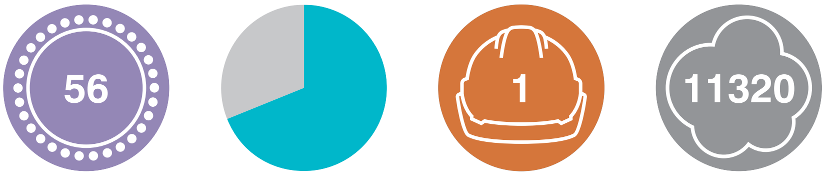
France has 56 operable reactors at a variety of coastal and inland sites throughout the country.

In October 2021 President Macron set out his 'France 2030' plan, which includes a programme to demonstrate SMR technology and mass production of hydrogen using nuclear electricity by 2030. In February 2022 he announced that the country would construct six new reactors, and consider building a further eight, with construction to begin by 2028, and the first reactor to be commissioned by 2035.

Macron's decision to support a major new build programme in the country was informed in part by a landmark report from the country's grid operator, RTE. In response to a referral from government, in 2019 RTE launched an extensive study of the evolution of the country's electricity system. The resulting report, titled 'Energy Futures 2050' was published in October 2021. Of the scenarios considered in the report, the cheapest implies constructing 14 large new nuclear power reactors, plus a fleet of SMRs, as well as investing significantly in renewables.

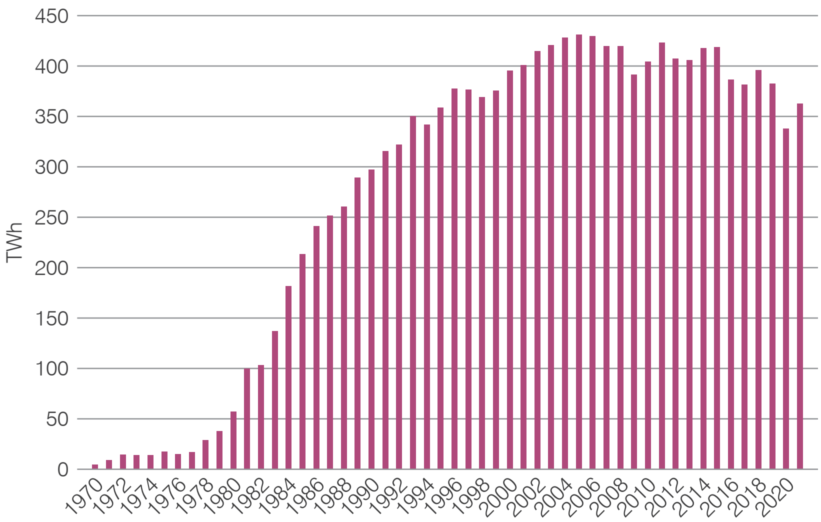
The positive decisions taken by the French government in the past 12 months come at a challenging time for the existing French nuclear fleet. In June 2022, half of France's 56 operable reactors were offline – a record number. Twelve of those offline were shut down because of corrosion inspections or repairs, following the discovery in December 2021 of corrosion near the welds on pipes of the safety injection system of Civaux 1 and 2. In May 2022 the French regulator, ASN, said that the issue would require a "large-scale" plan and could take "several years."

Operable Reactors	Nuclear Share of Generation	Reactors Under Construction	Lifetime CO_2 Avoided



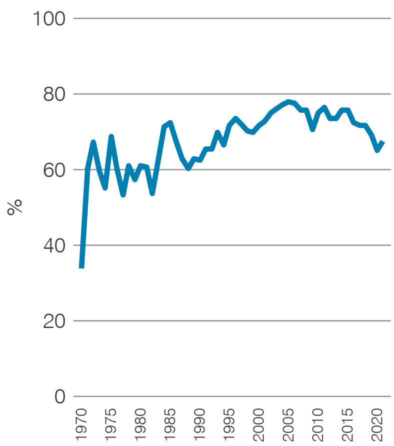
61,370 MWe	69.0 %	1630 MWe	$MtCO_2$ cf. coal

Nuclear electricity production



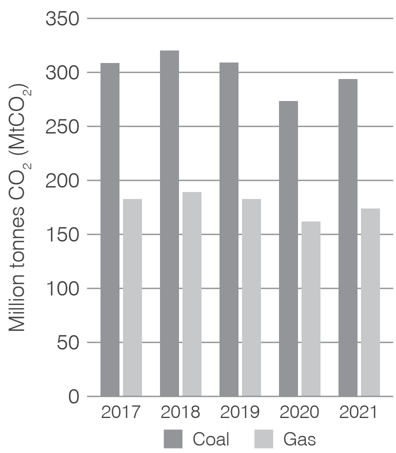
Source: World Nuclear Association, IAEA PRIS

Average nuclear capacity factor



Source: World Nuclear Association, IAEA PRIS

Emissions avoided cf. fossil fuels generation



Source: World Nuclear Association, IAEA PRIS

Germany

Nuclear capacity in Germany has fallen from 20.5 GWe in 2010 to 4.1 GWe as part of Germany's policy of closing all nuclear reactors by the end of 2022. Brokdorf, Grohnde and Gudremmingen C were shut down on Friday 31 December 2021, leaving the country with three operating reactors.

In October 2021 an open letter to the German public by 25 leading foreign and German environmentalists, journalists and academics warned that the country's phase-out of nuclear energy would lead to the country missing its 2030 carbon emissions target. Published in die Welt, the letter called on German politicians to be "brave enough" to change legislation to at least postpone the shutdown of the country's reactors.

In light of the war in Ukraine, the International Energy Agency (IEA) set out a ten-point plan that could enable the European Union to reduce its imports of natural gas from Russia. One of the ten measures identified by the IEA was to "maximize power generation from bioenergy and nuclear." Germany is particularly dependent on Russian natural gas.

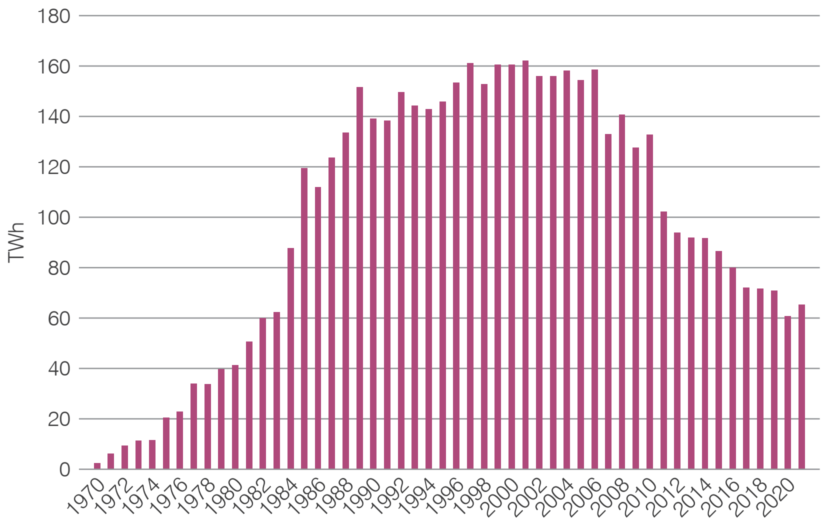
Despite the seriousness of concerns about security of supply, Germany's economy minister, Robert Habeck, said in May 2022 that prolonging the lifespan of the country's three remaining reactors would "help too little at too high a cost all-round."

In June Germany said it would reopen mothballed coal plants after Russia cut gas flows through the Nord Stream pipeline by 60%.

Operable Reactors	Nuclear Share of Generation	Reactors Under Construction	Lifetime CO_2 Avoided

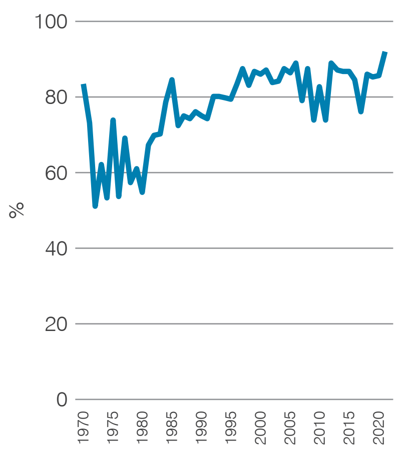
4055 MWe	11.9 %	0 MWe	$MtCO_2$ cf. coal

Nuclear electricity production



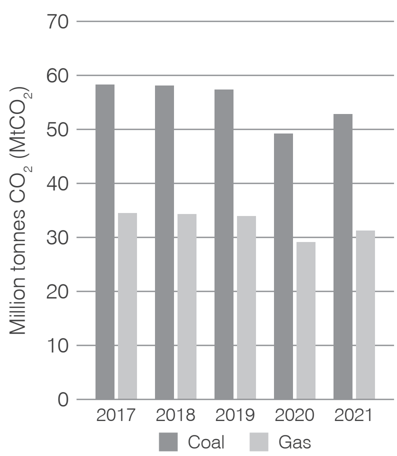
Source: World Nuclear Association, IAEA PRIS

Average nuclear capacity factor



Source: World Nuclear Association, IAEA PRIS

Emissions avoided cf. fossil fuels generation



Source: World Nuclear Association, IAEA PRIS

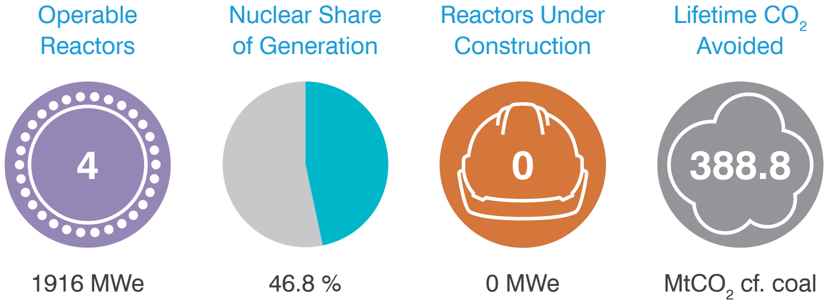
Hungary

Four VVER-440 reactors operate at the Paks nuclear power plant, 100 km south of Budapest, with a combined capacity of 1902 MWe. The plant generates around half of the electricity produced in Hungary, but supplies around one third of electricity demand, as Hungary relies on imports for around a third of its electricity requirements.

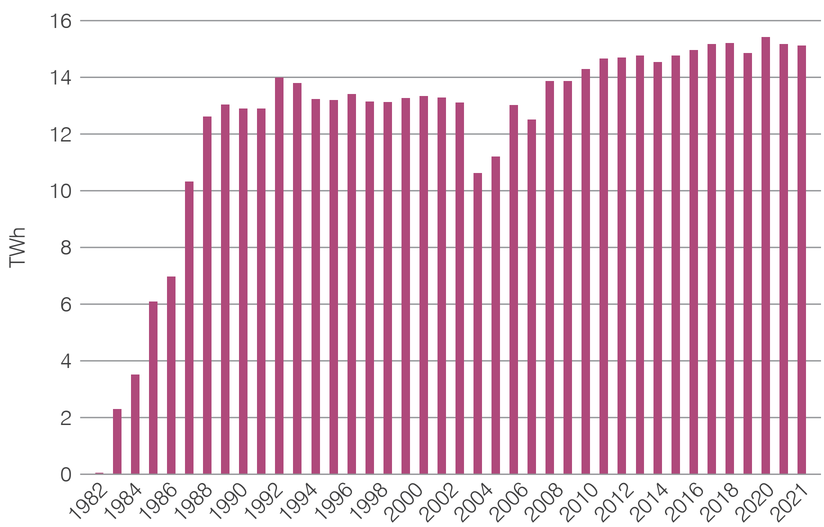
An application to construct two new VVER-1200 reactors at Paks was submitted in July 2020. The Hungarian Atomic Energy Authority had 12 months to make its decision, but in October announced that it needed more time "to fully verify all requirements."

In January 2022 project company Atomeromu Zrt submitted an application to build the containment building of the first new unit at Paks II, the first such regulatory submission for a nuclear building at the site.

In May 2022 Hungary said it had received reassurances from Russia's Rosatom that it remained able to complete the project, despite the war in Ukraine.

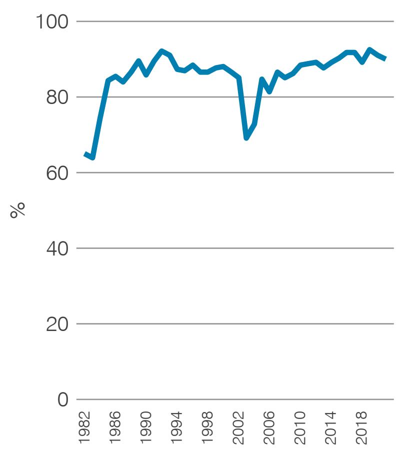


Nuclear electricity production



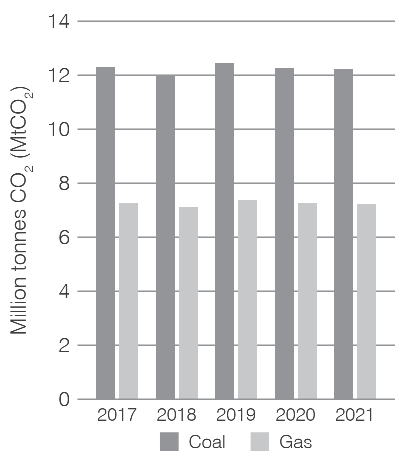
Source: World Nuclear Association, IAEA PRIS

Average nuclear capacity factor



Source: World Nuclear Association, IAEA PRIS

Emissions avoided cf. fossil fuels generation



Source: World Nuclear Association, IAEA PRIS

India

India has 23 operable reactors at seven nuclear power plants. The majority of reactors are indigenously-designed pressurized heavy water reactors (PHWRs).

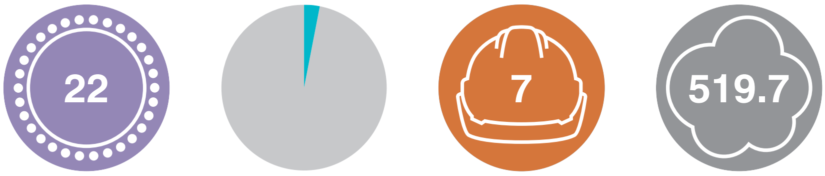
Two VVER-1000 units commenced operation at Kudankulam in 2013 and 2016 and a further four VVER-1000 units are under construction there, two of which (units 5&6) commenced construction in June and December 2021.

The Kudankulam site is a long-term project between India and Russia that began with an intergovernmental agreement in 1988. A further pair of reactors, likely VVER-1200 units, are planned for the development at India's southern tip.

In March 2022 the country's fast breeder test reactor, which has a key role in the country's preparations for a thorium-based closed fuel cycle, reached its full 40 MWt design power level for the first time, more than 35 years after it first started operating. Work continues on a 500 MWe prototype fast breeder reactor and in December 2021 the government said it expected construction to be completed by October 2022.

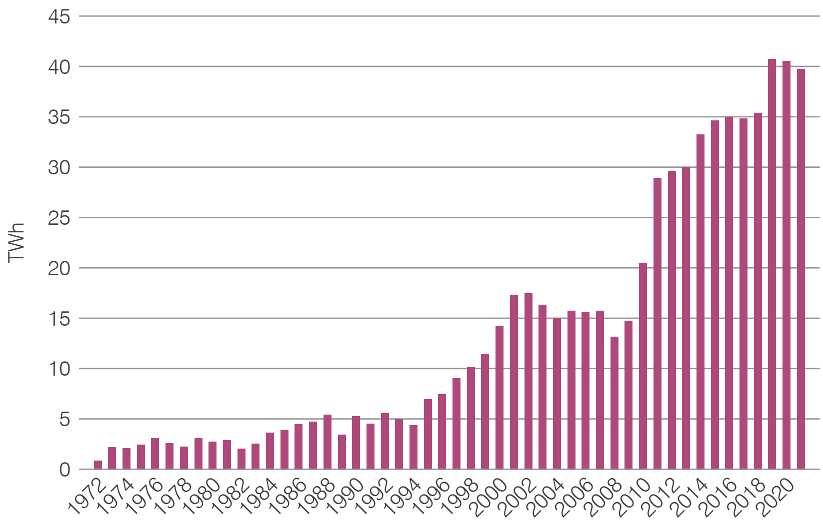
In April 2021 EDF submitted a binding techno-commercial offer to NPCIL to build six EPR reactors at Jaitapur in Maharashtra. In May 2022, following a visit of President Narendra Modi to France, French president Macron's office issued a statement saying that both sides had "reaffirmed the commitment to the success of the strategic Jaitapur EPR project for access to reliable, affordable, low-carbon energy, and welcome the progress achieved over the last months." Once built, the six units would be capable of supplying some 70 million Indian households.

Operable Reactors | Nuclear Share of Generation | Reactors Under Construction | Lifetime CO_2 Avoided



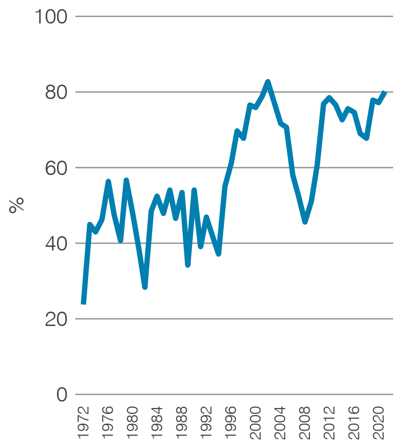
6795 MWe | 3.2 % | 5194 MWe | $MtCO_2$ cf. coal

Nuclear electricity production



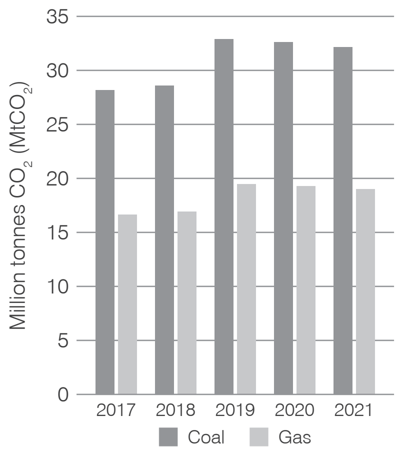
Source: World Nuclear Association, IAEA PRIS

Average nuclear capacity factor



Source: World Nuclear Association, IAEA PRIS

Emissions avoided cf. fossil fuels generation



Source: World Nuclear Association, IAEA PRIS

Iran

A single VVER-1000 unit is in operation in Iran at the Bushehr site, about 180 km west of the city of Shiraz.

Construction commenced on a second VVER-1000 at the same site in 2019, with a third unit planned.

Since 2015, nuclear activities in Iran have been carried out under the Joint Comprehensive Plan of Action (JCPOA) agreed by Iran, China, France, Germany, Russia, the UK and the USA. Under the terms of the JCPOA, Iran agreed to limit its uranium enrichment activities, eliminate its stockpile of medium-enriched uranium and limit its stockpile of low-enriched uranium over the subsequent 15 years.

In 2018 the USA withdrew from the agreement and imposed sanctions on Iran, and in January 2021 the IAEA reported that Iran had resumed enriching uranium to 20% purity at its underground Fordow plant.

In July 2021 the IAEA stated that Iran had informed the agency that it intends to use indigenously-produced uranium enriched up to 20% U-235 in the manufacture of fuel for the Tehran Research Reactor (TRR). The foreign ministers of France, Germany and the UK said in a statement that this action represented ‘a serious violation’ of Iran’s commitments under the JCPOA.

Throughout 2021 and 2022 to date the IAEA has facilitated negotiations among the parties to the JCPOA but these efforts have proved inconclusive.

Operable Reactors

915 MWe

Nuclear Share of Generation

1.0 %

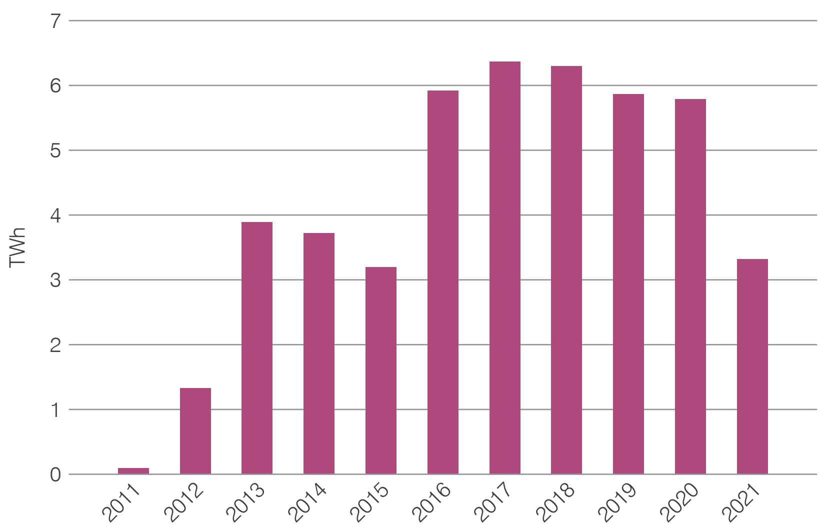
Reactors Under Construction

974 MWe

Lifetime CO_2 Avoided

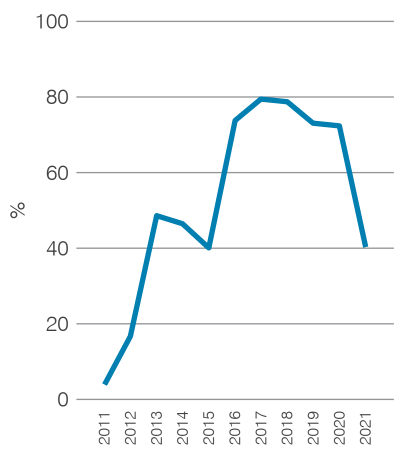
$MtCO_2$ cf. coal

Nuclear electricity production



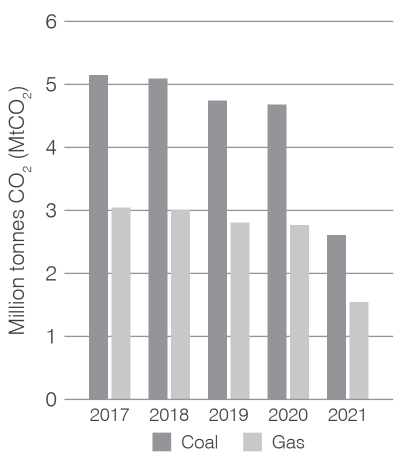
Source: World Nuclear Association, IAEA PRIS

Average nuclear capacity factor



Source: World Nuclear Association, IAEA PRIS

Emissions avoided cf. fossil fuels generation



Source: World Nuclear Association, IAEA PRIS

Japan

Following the March 2011 tsunami and subsequent accident at the Fukushima Daiichi plant, all reactors in Japan have had to get regulatory approval to restart. Ten reactors have restarted and currently, 16 reactors are in the process of restart approval.

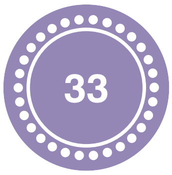
The Japanese prime minister has said his country will restart nuclear reactors to reduce its dependence on Russian energy in the wake of the military offensive against Ukraine.

In August 2021 the Japan Atomic Energy Agency (JAEA) resumed operation of the 30 MWt High-Temperature Test Reactor (HTTR) in Oarai, Ibaraki prefecture. In April 2022 it was announced that JAEA and Mitsubishi Heavy Industries (MHI) would establish a demonstration hydrogen production project at the HTTR. Japan's Basic Energy Plan, approved by the government in October 2021, states that high-temperature gas-cooled reactors would be used in the production of hydrogen.

In September 2021 the country's regulator approved the restart of Shimane 2, a 789 MWe boiling water reactor. In June 2022, the local governor gave his consent for the unit to restart.

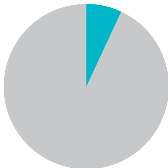
Japanese interest in SMRs is growing. In January 2022 JAEA, MHI and Mitsubishi FBR Systems agreed to cooperate with US SMR developer Terrapower on the development of sodium-cooled fast reactors. In April 2022 the Japan Bank for International Cooperation invested US$110 million in NuScale Power.

Operable Reactors



31,679 MWe

Nuclear Share of Generation



7.2 %

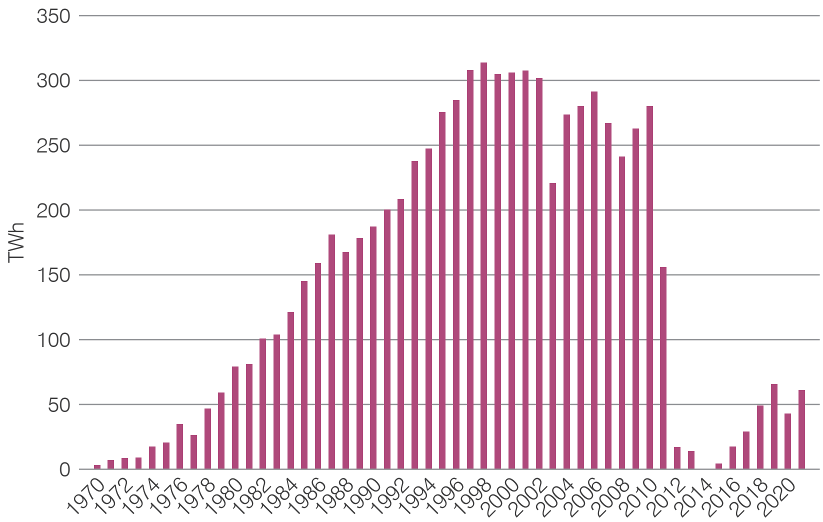
Reactors Under Construction

2653 MWe

Lifetime CO_2 Avoided

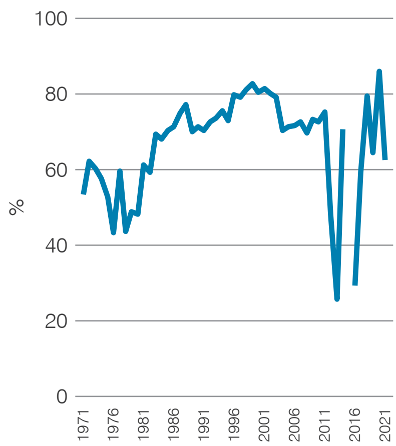
$MtCO_2$ cf. coal

Nuclear electricity production



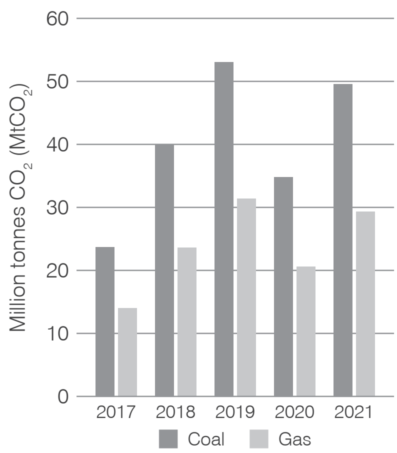
Source: World Nuclear Association, IAEA PRIS

Average nuclear capacity factor



Source: World Nuclear Association, IAEA PRIS

Emissions avoided cf. fossil fuels generation



Source: World Nuclear Association, IAEA PRIS

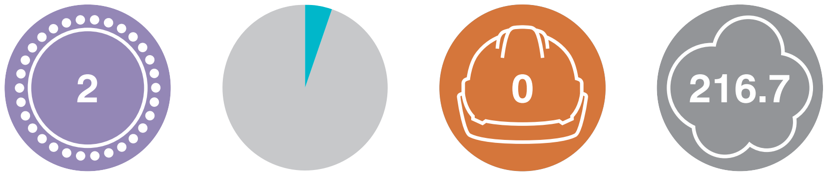
Mexico

Mexico has two operable nuclear reactors located on the east coast of the country, 285 km east of the capital, Mexico City. Laguna Verde 1 was grid-connected in 1989 and unit 2 in 1994.

In July 2020 the Mexico energy ministry gave final approval for a 30-year extension of the operating licence for the first unit at Laguna Verde. This would allow the reactor to operate until 2050. An application for a similar extension for unit 2 is under review.

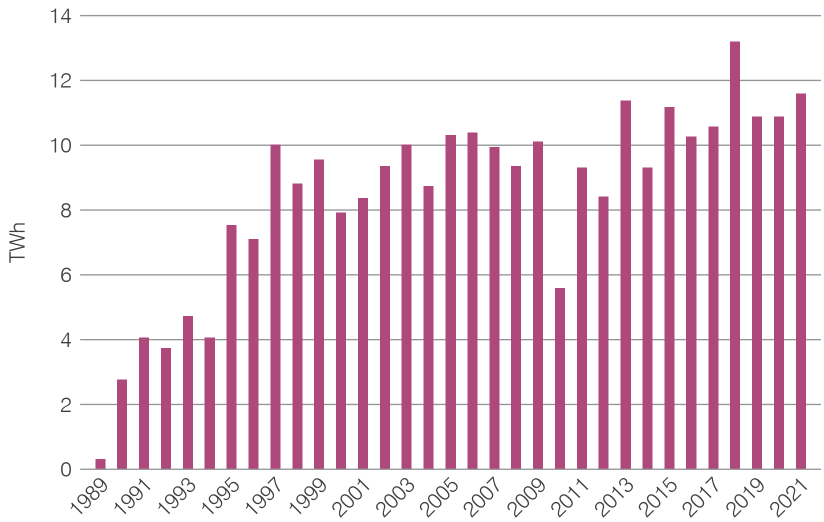
In October 2021 the country's president, Andrés Manuel López Obrador, proposed reforms that would see the Federal Electricity Commission (CFE) – the owner of the Laguna Verde nuclear plant – become a vertically integrated state agency. The proposal, if passed, would effectively reverse reforms made in 2014 to introduce more competition to the market.

Operable Reactors | Nuclear Share of Generation | Reactors Under Construction | Lifetime CO_2 Avoided



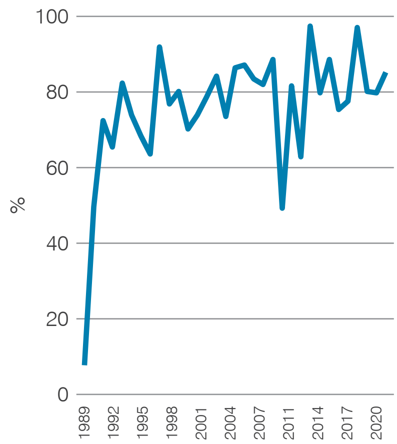
1552 MWe | 5.3 % | 0 MWe | $MtCO_2$ cf. coal

Nuclear electricity production



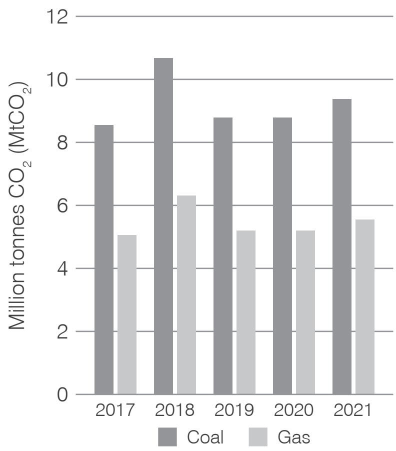
Source: World Nuclear Association, IAEA PRIS

Average nuclear capacity factor



Source: World Nuclear Association, IAEA PRIS

Emissions avoided cf. fossil fuels generation



Source: World Nuclear Association, IAEA PRIS

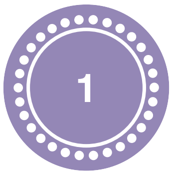
Netherlands

A single 485 MWe PWR is operating at Borssele, about 70 km southwest of Rotterdam.

Interest in nuclear has been rekindled following the government's announcement in May 2018 of a draft law for phasing out coal-fired generation by 2030. In April 2021 Dutch NGO e-Lise Foundation released a white paper with 13 recommendations for the Dutch government to help realize the construction of new nuclear power plants in the Netherlands. In July 2021 a KPMG study requested by the Ministry of Economic Affairs and Climate Policy concluded that market participants in the Netherlands – contractors, operators and suppliers –would invest in the construction of new nuclear generating capacity.

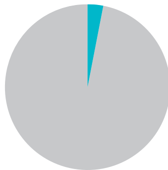
In December 2021 the Netherlands' coalition government placed nuclear power at the heart of its climate and energy policy, announcing that it plans to build two new nuclear power reactors. It said the Borssele plant would remain open longer, and earmarked some €5 billion to support nuclear new build to 2030. The document identified nuclear energy's role in reducing the country's dependency on gas imports and said that it "can complement solar, wind and geothermal energy in the energy mix and can be used to produce hydrogen."

Operable Reactors



482 MWe

Nuclear Share of Generation



3.1 %

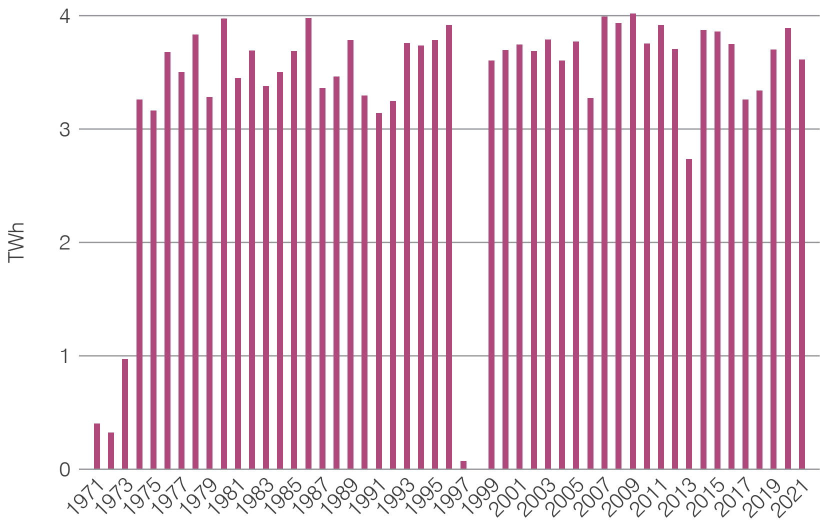
Reactors Under Construction

0 MWe

Lifetime CO_2 Avoided

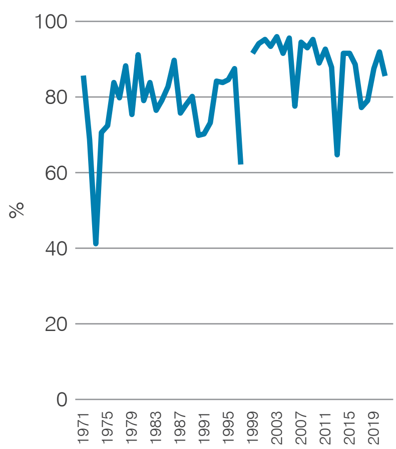
$MtCO_2$ cf. coal

Nuclear electricity production



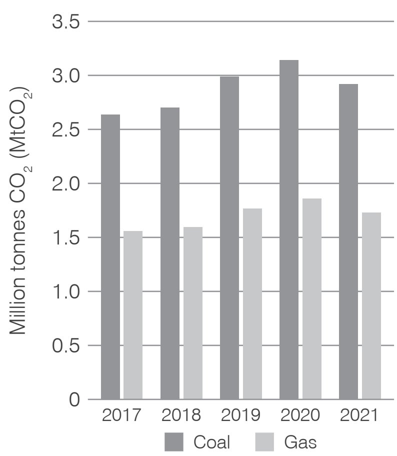
Source: World Nuclear Association, IAEA PRIS

Average nuclear capacity factor



Source: World Nuclear Association, IAEA PRIS

Emissions avoided cf. fossil fuels generation



Source: World Nuclear Association, IAEA PRIS

Pakistan

Pakistan has six operating nuclear power reactors supplied by China at two sites: Chashma, inland 200km southwest of Islamabad and Karachi, on the southeast coast.

The four units at Chashma are CNP300 models, based on the Qinshan 1 reactor in China. The first reactor came online in 2000 and the fourth unit was grid connected in 2017. With the start-up of these reactors the overall capacity factor for Pakistan's reactors has risen to be on a par with global levels.

Karachi hosts two Chinese-designed HPR1000 units (the export model of Hualong One). When the first unit was connected to the grid in March 2021, it almost doubled Pakistan's nuclear generating capacity. The second unit was connected to the grid a year later in March 2022.

The Karachi site, also sometimes referred to as KANUPP, was home to Pakistan's first nuclear power reactor, Karachi 1 – a 100 MWe (90 MWe net) pressurized heavy water reactor which shut down in 2021 after 50 years of operation.

Pakistan is not a signatory to the Nuclear Non-Proliferation Treaty and so it is unable to buy uranium on the open market. CNNC has agreed to provide Pakistan with lifetime fuel supply for the reactors, specified as 60 years.

Operable Reactors

3256 MWe

Nuclear Share of Generation

10.6 %

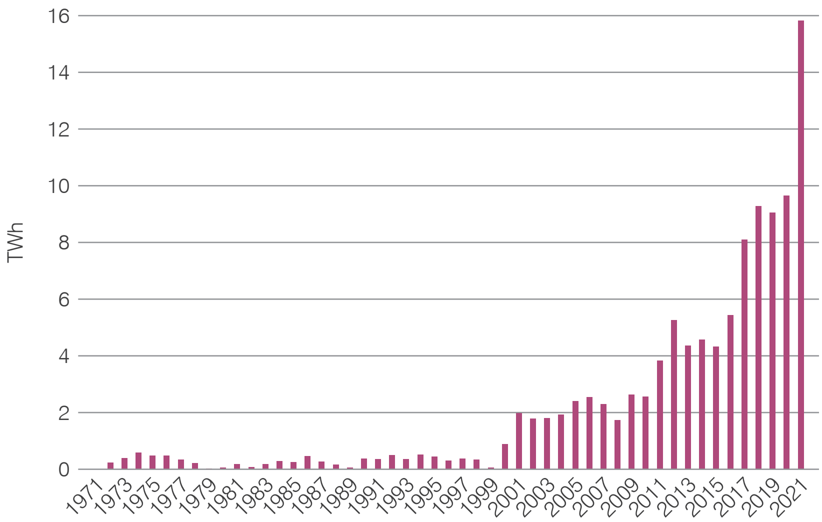
Reactors Under Construction

0 MWe

Lifetime CO_2 Avoided

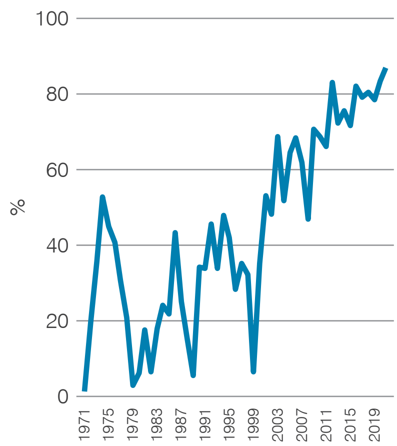
$MtCO_2$ cf. coal

Nuclear electricity production



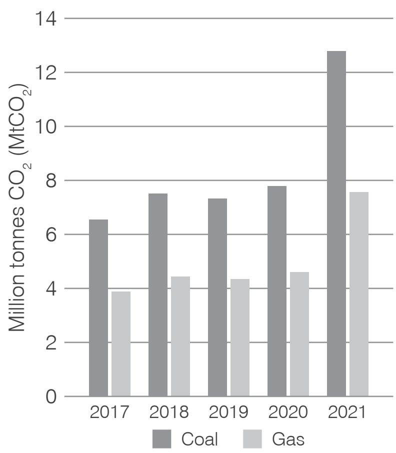
Source: World Nuclear Association, IAEA PRIS

Average nuclear capacity factor



Source: World Nuclear Association, IAEA PRIS

Emissions avoided cf. fossil fuels generation



Source: World Nuclear Association, IAEA PRIS

Romania

Two CANDU-6 PHWRs operate at the Cernavoda nuclear power plant, which is directly adjacent to the town of Cernavoda and 150 km east of Bucharest. In addition to electricity, the plant also provides district heating to Cernavoda town.

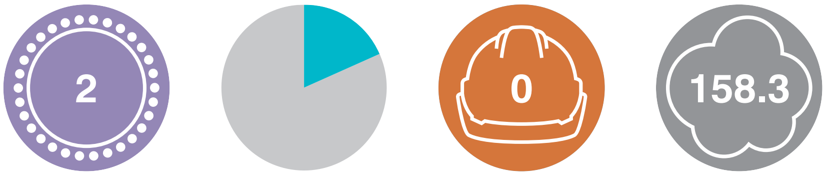
Cernavoda was originally planned to be a five-unit plant, but work on later units was suspended to focus on completing unit 1, and later unit 2.

Romania has been working since 2020 to assemble an international team to complete the third and fourth units, In October 2020 intergovernmental agreements were signed with both the USA and France. A similar agreement was signed with Canada in August 2021.

In October 2021 the Romanian government adopted the Integrated National Plan for Energy and Climate Change. . It confirmed plans for the construction of two new Candu units at Cernavoda by 2031 and for the refurbishment of the two existing units at the site. The refurbishment work would allow units 1&2 to operate for an additional 30 years beyond their original 30-year operating lifetimes. A contract to prepare the licensing basis for units 3&4 was awarded to Canada's Candu Energy in November 2021.

Romania is also interested in the use of SMRs. In a November 2021 joint statement NuScale and Cernavoda owner-operator Nuclearelectrica said they had signed a "teaming agreement" that could see the first SMR deployed in the country in 2027/2028.

Operable Reactors	Nuclear Share of Generation	Reactors Under Construction	Lifetime CO_2 Avoided

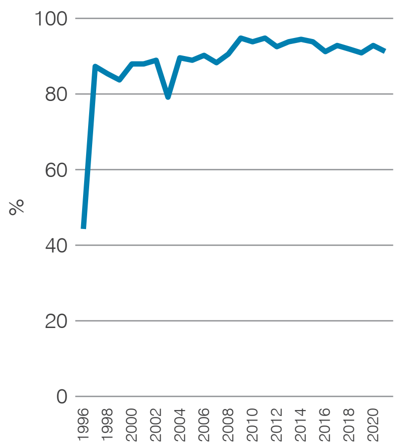


1300 MWe	18.5 %	0 MWe	$MtCO_2$ cf. coal

Nuclear electricity production

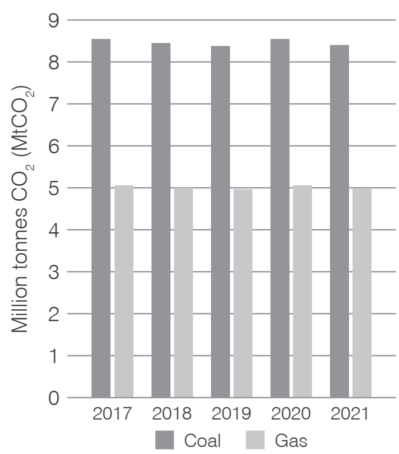
Source: World Nuclear Association, IAEA PRIS

Average nuclear capacity factor



Source: World Nuclear Association, IAEA PRIS

Emissions avoided cf. fossil fuels generation



Source: World Nuclear Association, IAEA PRIS

Russia

There are 37 operable reactors in Russia, with the majority in the west of the country. An additional three reactors are under construction: two large VVER-1200 units at the Kursk power plant, and a demonstration new-generation fast reactor, BREST-300-OD, in Seversk.

Russia is a major exporter of nuclear technology and fuel. As of June 2022, a total of 17 VVER reactors were under construction outside of Russia in Turkey (3), Iran (1), India (4), Slovakia (2), Belarus (1), Bangladesh (2) and China (4). In May 2022 Fennovoima in Finland announced its decision to terminate an EPC contract with RAOS Project, a Rosatom subsidiary, for the planned Hanhikivi project.

Rosatom has progressed its plans to use land-based and floating SMRs to provide power to remote communities and industrial sites. In July 2021 an agreement was signed with KAZ Minerals to supply three floating plants, each employing a pair of RITM-200M reactors, to power the new Baimskaya copper mining project in the Chukotka region of eastern Siberia.

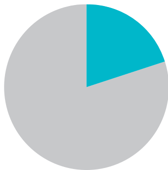
Russia's first land-based SMR will be based on the RITM-200 reactor and is scheduled to operate in the Russian Arctic town of Usk-Kuyga from 2028.

Russia announced in February 2022 that construction of the BREST-300-OD reactor was 8% ahead of schedule at the end of 2021. As a result, Rosatom said that it now expects the reactor to be completed in 2027, one year earlier than previously planned.

Operable Reactors

27,727 MWe

Nuclear Share of Generation



20.0 %

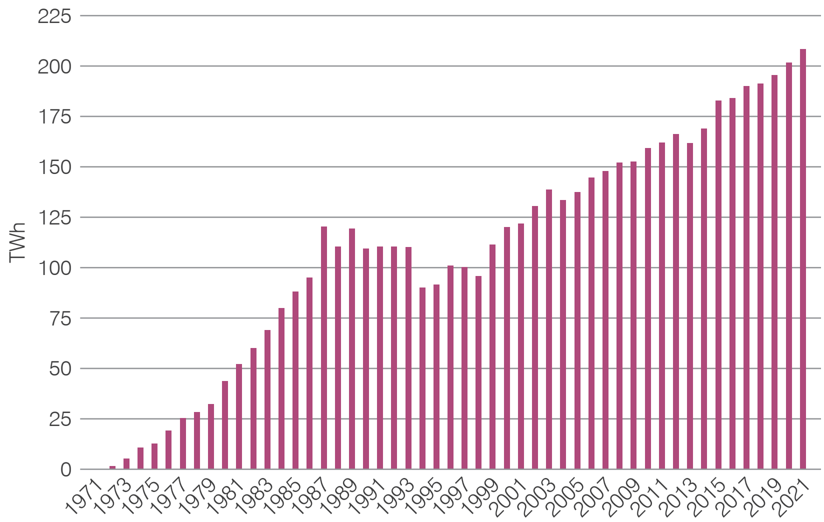
Reactors Under Construction

2650 MWe

Lifetime CO_2 Avoided

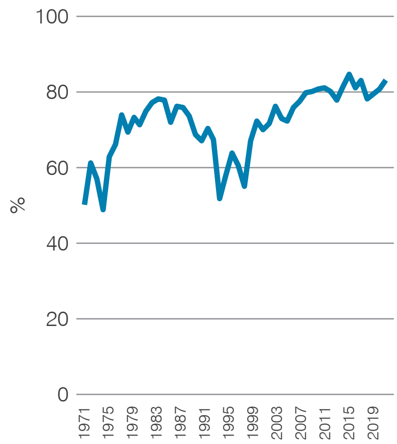
$MtCO_2$ cf. coal

Nuclear electricity production



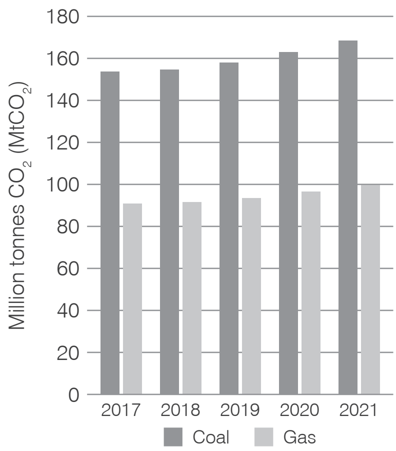
Source: World Nuclear Association, IAEA PRIS

Average nuclear capacity factor



Source: World Nuclear Association, IAEA PRIS

Emissions avoided cf. fossil fuels generation



Source: World Nuclear Association, IAEA PRIS

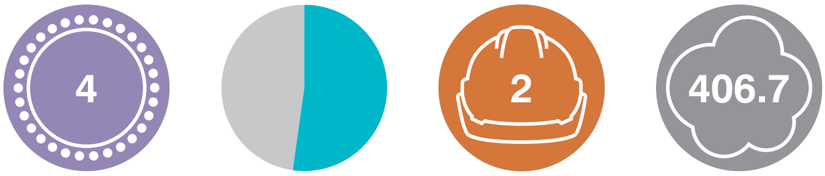
Slovakia

Slovakia has two nuclear power plants each with two VVER-440 reactors: Bohunice, 140 km northeast of Bratislava, and Mochovce, 100 km east of Bratislava.

Construction on two more reactors at Mochovce originally started in 1987, before being halted in 1992. Construction restarted in 2009, but startup has been delayed, partly due to repeated appeals by the Austrian anti-nuclear group Global 2000. Startup of unit 3 is now expected this year, with unit 4 a year later. Unit 3 received an operating licence in May 2021, and a commissioning licence in January 2022.

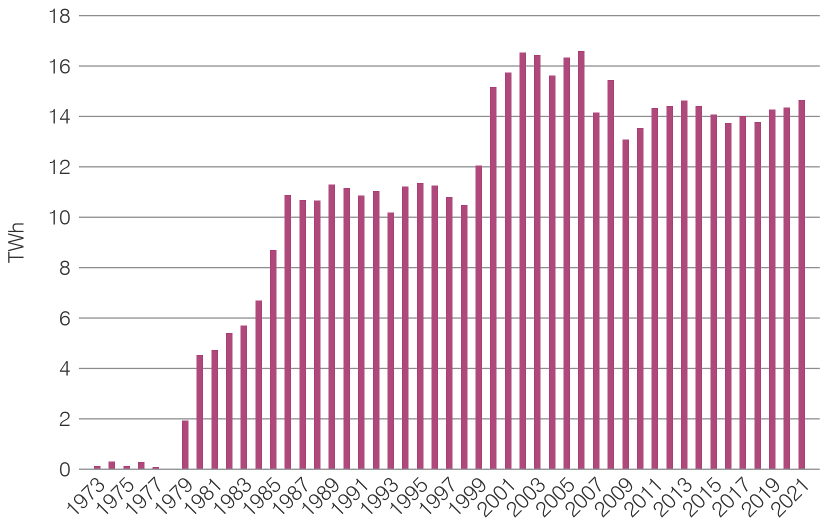
Operator Slovenské Elektrárne (SE) expects the two new VVER-440 reactors, with a combined capacity of 942 MWe, to produce about 7 TWh per year, which would cover about 10-15% of Slovakia's electricity demand. According to a report from the Ministry of Economy in August2021, once it is supplying electricity to the national grid, Mochovce 3 would make Slovakia a net power exporter.

Operable Reactors	Nuclear Share of Generation	Reactors Under Construction	Lifetime CO_2 Avoided



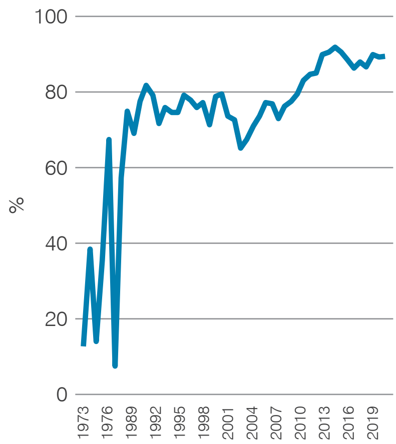
1868 MWe	52.3 %	880 MWe	$MtCO_2$ cf. coal

Nuclear electricity production



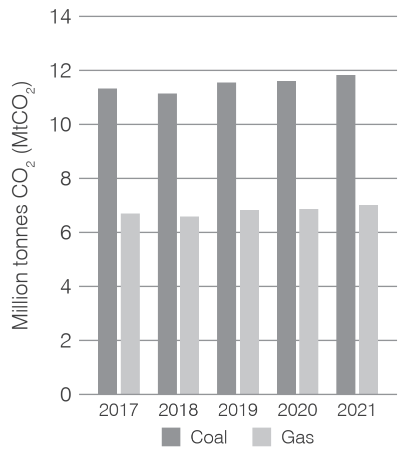
Source: World Nuclear Association, IAEA PRIS

Average nuclear capacity factor



Source: World Nuclear Association, IAEA PRIS

Emissions avoided cf. fossil fuels generation



Source: World Nuclear Association, IAEA PRIS

Slovenia

Slovenia has a single reactor operating at Krško, about 40 km northeast of Zagreb. It is a two-loop Westinghouse PWR with a net capacity of 688 MWe.

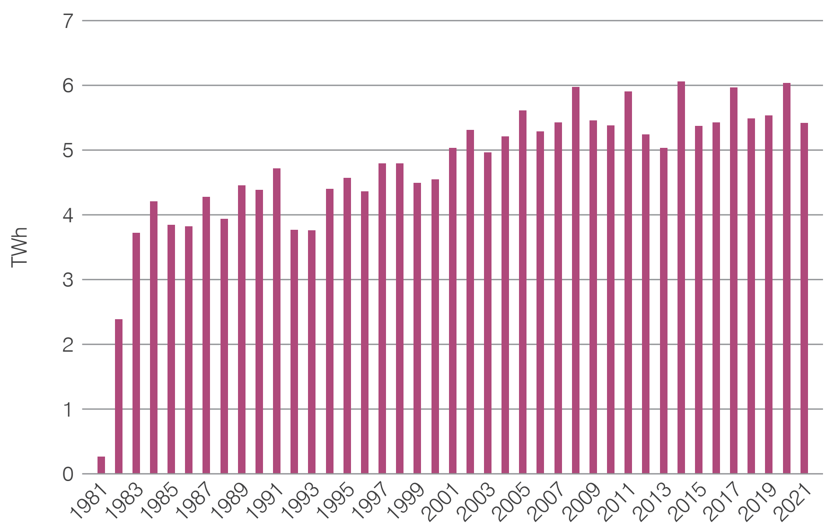
The plant's operating company Nuklearna Elektrarna Krško (NEK), is jointly owned by Slovenian state-owned company GEN-Energija and Croatian state-owned company Hrvatska elektroprivreda (HEP). The plant generates about 35-40% of the electricity produced in Slovenia and supplies more than one-quarter of Slovenia's and 15% of Croatia's electricity demand.

In May 2020 infrastructure minister Jernej Vrtovec said that the country would make a decision by 2026 at the latest on whether to build a second unit at the Krško site. In July 2021 the country's Ministry of Infrastructure issued an energy permit to GEN-Energija for the proposed second reactor, referred to as the JEK2 project, allowing licensing procedures to begin.

GEN Group has proposed to decarbonize all Slovenian electricity generation by 2035 through the construction of a new reactor with assumed capacity of 1100 MWe, the completion of the Mokrice hydro plant and the addition of 1000 MWe of solar panels.

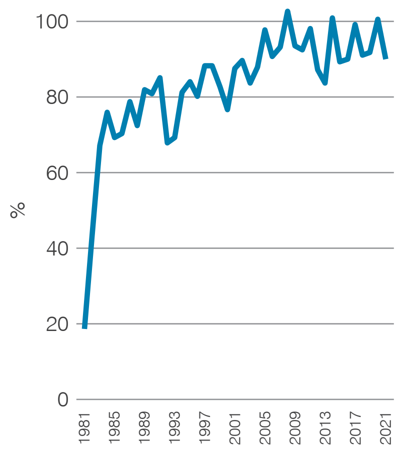
Operable Reactors	Nuclear Share of Generation	Reactors Under Construction	Lifetime CO_2 Avoided
688 MWe	36.9 %	0 MWe	$MtCO_2$ cf. coal

Nuclear electricity production



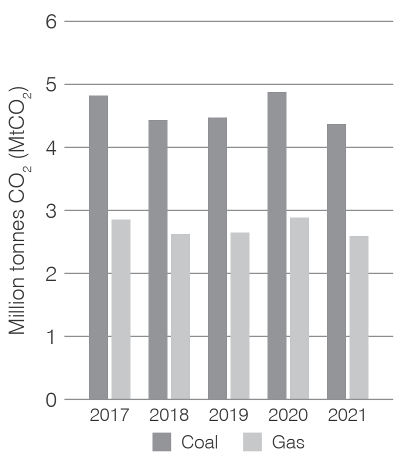
Source: World Nuclear Association, IAEA PRIS

Average nuclear capacity factor



Source: World Nuclear Association, IAEA PRIS

Emissions avoided cf. fossil fuels generation



Source: World Nuclear Association, IAEA PRIS

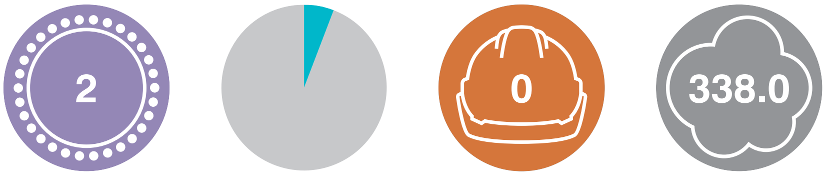
South Africa

South Africa has a single nuclear power plant, Koeberg, in the southwest of the country, 30 km north of Cape Town. The plant's two reactors, connected to the grid in 1984 and 1985, have a combined capacity of 1854 MWe, and are the only commercial nuclear power reactors operating in Africa.

Eskom, Koeberg's owner, is seeking to extend the two reactor's operations by 20 years to 2045, which would give a total operational lifetime of 60 years. In January 2022 Koeberg 2 was taken offline for refuelling and the replacement of its reactor pressure vessel head and three steam generators. The work was scheduled to take five months, but was postponed in March due to concerns that the reactor would not be returned to service in time for the high-demand winter period. The unit was returned to service in May and the replacement will now take place in August 2023 during the next planned outage. Later in March 2022 the IAEA completed a safety aspects of long term operation (SALTO) mission to review Eskom's lifetime extension plans.

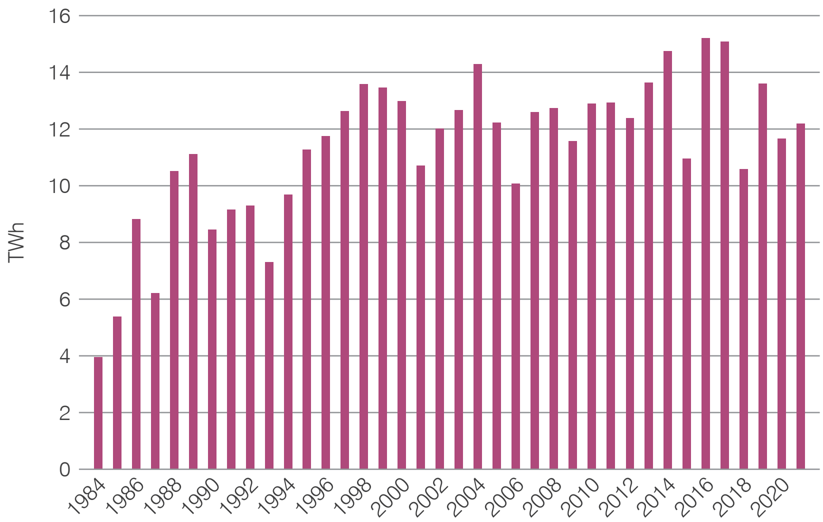
In February 2022 South Africa's Department of Mineral Resources and Energy issued a request for proposal for 2500 MWe of new nuclear capacity. The country aims to complete the procurement process for new capacity by 2024. In March 2022 the government published its National Infrastructure Plan 2050. The plan states "The transition away from fossil fuels will progress in a measurable, just and sustained manner. New installed capacity will consist primarily of wind, solar and nuclear, where South Africa has a competitive and comparative advantage."

Operable Reactors	Nuclear Share of Generation	Reactors Under Construction	Lifetime CO_2 Avoided



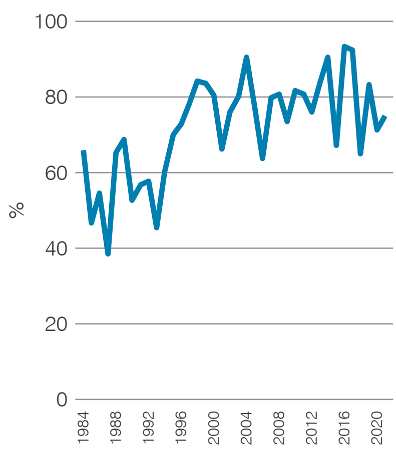
1854 MWe	6.0 %	0 MWe	$MtCO_2$ cf. coal

Nuclear electricity production



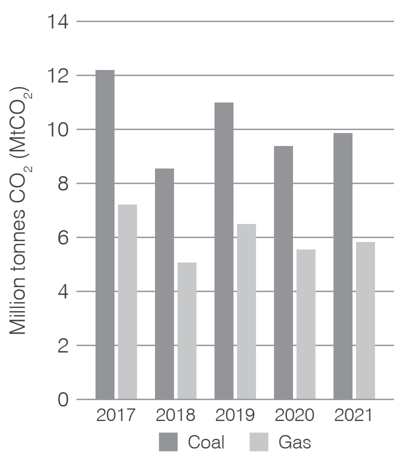
Source: World Nuclear Association, IAEA PRIS

Average nuclear capacity factor



Source: World Nuclear Association, IAEA PRIS

Emissions avoided cf. fossil fuels generation



Source: World Nuclear Association, IAEA PRIS

South Korea

There are 25 reactors operating in South Korea. Together they provide about one-third of the country's electricity.

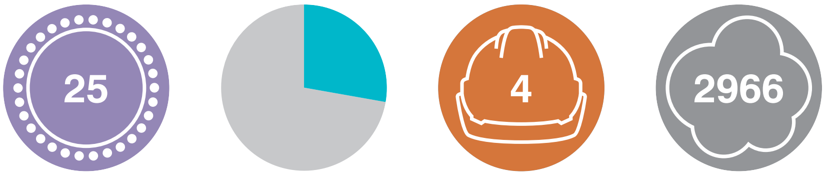
In March 2022 a new president, Yoon Suk-yeol, was elected. In his campaign he rejected the policy of phasing out nuclear energy that had been adopted by his predecessor, and pledged to boost investment in the country's domestic and export nuclear industry. In May 2022 lee Chang-Yang, the incoming Industry Minister of Trade, Industry, and Energy, said nuclear was "a major means of achieving energy security and carbon neutrality."

In June 2022 unit 1 of the Shin Hanul nuclear plant was grid-connected. A development licence for a further two units at the site was issued in February 2017, but in May 2017 Korea Hydro and Nuclear Power (KHNP) instructed Kepco Engineering & Construction to suspended the design work in light of the then government's phase-out policy. In May 2022 the Yoon administration announced that construction would begin in 2025.

The new administration has also said it plans to win 10 new nuclear power plant orders abroad by 2030. In January KHNP was named as the sole bidder for a contract for equipment and materials for the El Dabaa site in Egypt, where four VVER-1200 units are planned, and in April KHNP submitted an offer to Poland for the construction of six APR-1400 reactors.

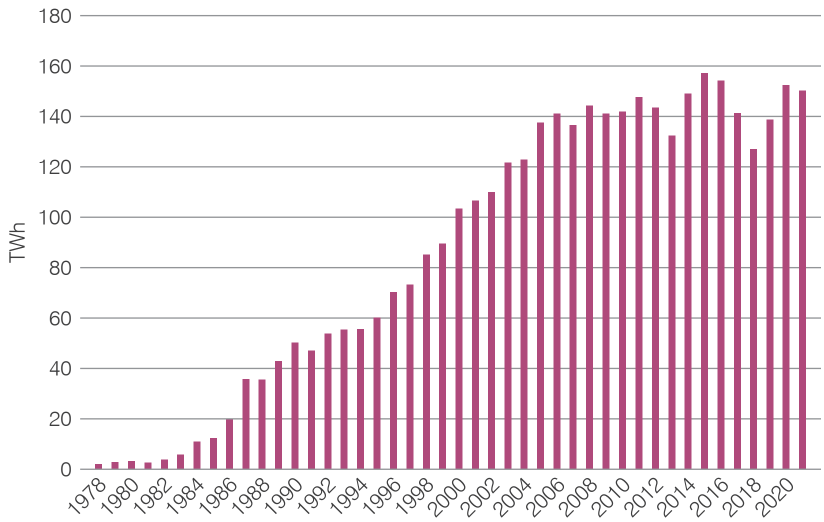
Wide support for nuclear power has been maintained despite the previous president's policy. In a September 2021 poll of 1000 adults on behalf of the Korean Nuclear Society, 72.1% of respondents supported the use of nuclear power.

Operable Reactors	Nuclear Share of Generation	Reactors Under Construction	Lifetime CO_2 Avoided



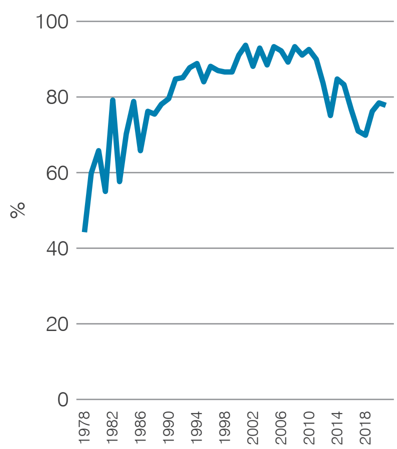
24,431 MWe	28.0 %	5360 MWe	$MtCO_2$ cf. coal

Nuclear electricity production



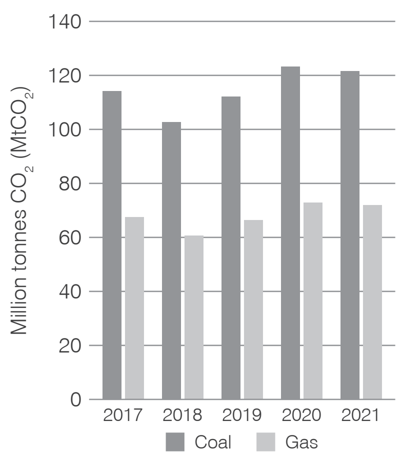
Source: World Nuclear Association, IAEA PRIS

Average nuclear capacity factor



Source: World Nuclear Association, IAEA PRIS

Emissions avoided cf. fossil fuels generation



Source: World Nuclear Association, IAEA PRIS

Spain

Spain has seven operable nuclear reactors at five sites across the country. With a combined capacity of 7121 MWe, the units generate about 20% of the country's electricity. All seven reactors were connected to the country's grid during a period of just seven years in the 1980s.

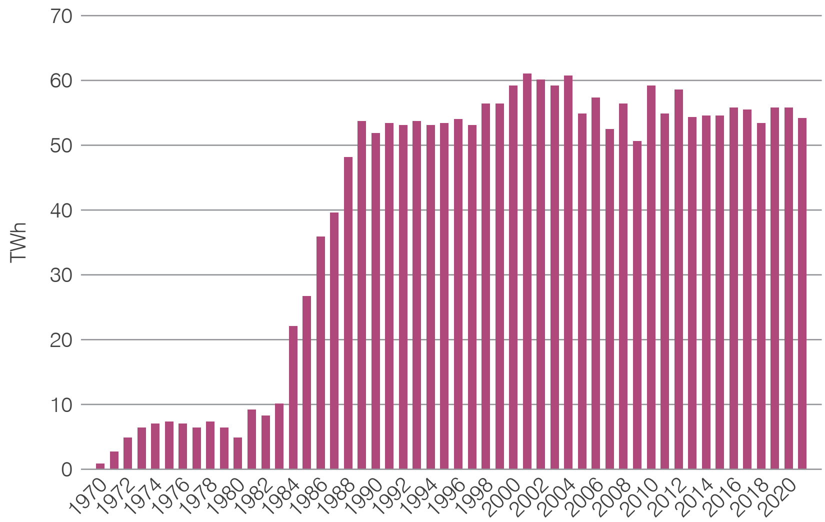
Until 2011 it was planned that operation of Spain's reactors would end in the 2020s as operating lifetimes would be limited to 40 years. That restriction has since been removed and the reactors currently in operation are now expected to close over the next 13 years.

Spain aims to generate all its electricity from renewable sources by 2050. In a review of the country's energy policy in May 2021, the IEA said that it should consider the usefulness of nuclear energy, including for non-electricity applications, for diversifying technical options to achieve long-term carbon neutrality.

Operable Reactors	Nuclear Share of Generation	Reactors Under Construction	Lifetime CO_2 Avoided

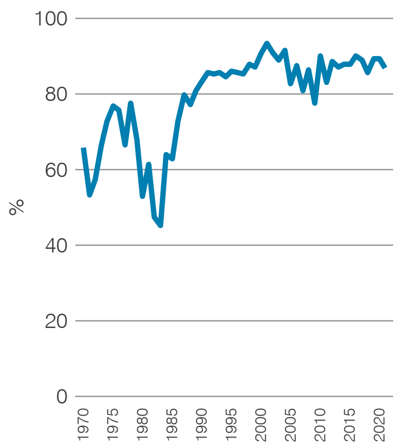
7121 MWe	20.8 %	0 MWe	$MtCO_2$ cf. coal

Nuclear electricity production



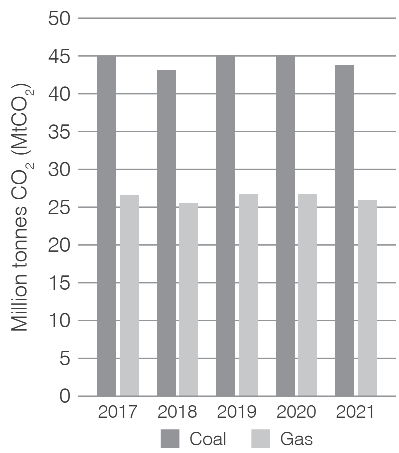
Source: World Nuclear Association, IAEA PRIS

Average nuclear capacity factor



Source: World Nuclear Association, IAEA PRIS

Emissions avoided cf. fossil fuels generation



Source: World Nuclear Association, IAEA PRIS

Sweden

There are six operable reactors in Sweden, at Ringhals, Oskarshamm and Forsmark.

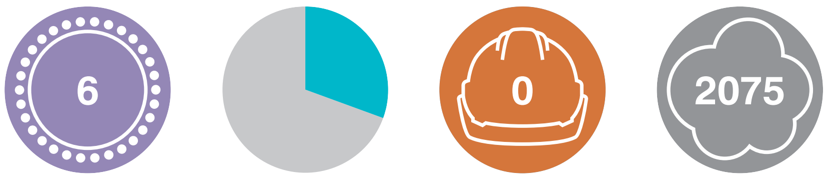
In January 2022 the Swedish government approved the construction of a final repository for used nuclear fuel in Forsmark. The decision makes Sweden only the second country (after Finland) to grant a construction licence for a commercial nuclear fuel repository.

Power company OKG signed an agreement with Linde Gas in January 2022 for the supply of hydrogen to be produced at the Oskarshamn nuclear plant. A facility at the Oskarshamn site uses electricity from the power plant to produce hydrogen through the electrolysis of water. During power operation, this hydrogen was added to the coolant of the plant's three reactors in order to reduce the risk of stress corrosion cracking of the reactor piping by reducing the amount of free oxygen in the coolant. As this hydrogen is now only required for unit 3 the plant now has an overcapacity for hydrogen.

In February 2022 the Swedish Energy Agency announced it had awarded a joint venture between Uniper Sweden and LeadCold funding of just over SEK99 million (US$ 10.6 million) to support the construction of a demonstration LeadCold SEALER (Swedish Advanced Lead Reactor) at the Oskarshamn site. This follows an announcement in February 2021 that Uniper Sweden, LeadCold and the Royal Institute of Technology were to work together to build a demonstration unit by 2030.

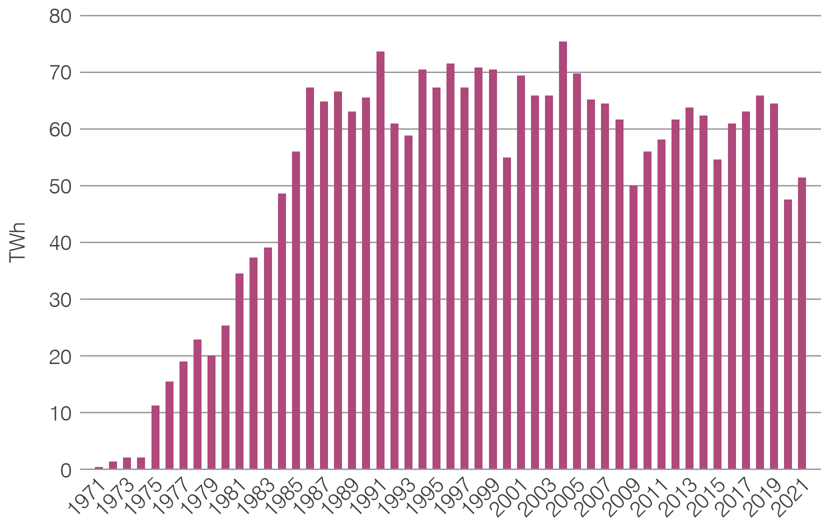
Separately, Kärnfull Next, a fully-owned subsidiary of Kärnfull Future, announced in March 2022 that it will collaborate with GE Hitachi Nuclear Energy on the deployment of the BWRX-300 in Sweden.

Operable Reactors	Nuclear Share of Generation	Reactors Under Construction	Lifetime CO_2 Avoided



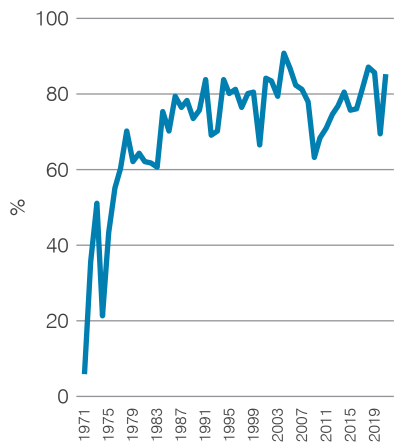
6885 MWe	30.8 %	0 MWe	$MtCO_2$ cf. coal

Nuclear electricity production



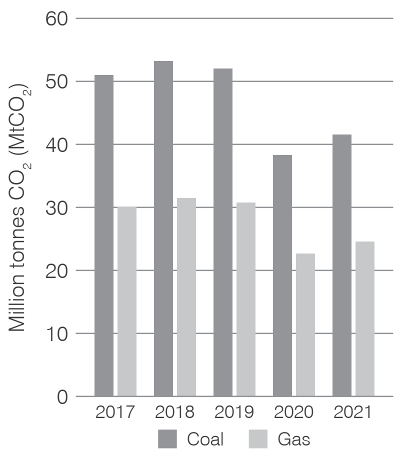
Source: World Nuclear Association, IAEA PRIS

Average nuclear capacity factor



Source: World Nuclear Association, IAEA PRIS

Emissions avoided cf. fossil fuels generation



Source: World Nuclear Association, IAEA PRIS

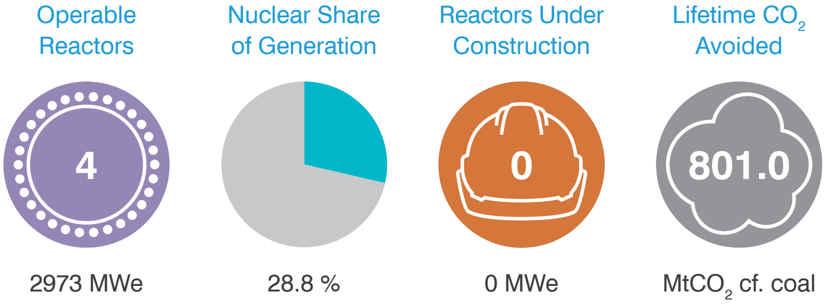
Switzerland

Switzerland has two reactors at Beznau, 30 km southwest of Zürich, one reactor at Gösgen, 40 km southwest of Zürich and one at Leibstadt, 35 km northwest of Zürich. A fifth reactor at Mühleberg ended generation in December 2019 after 47 years of operations.

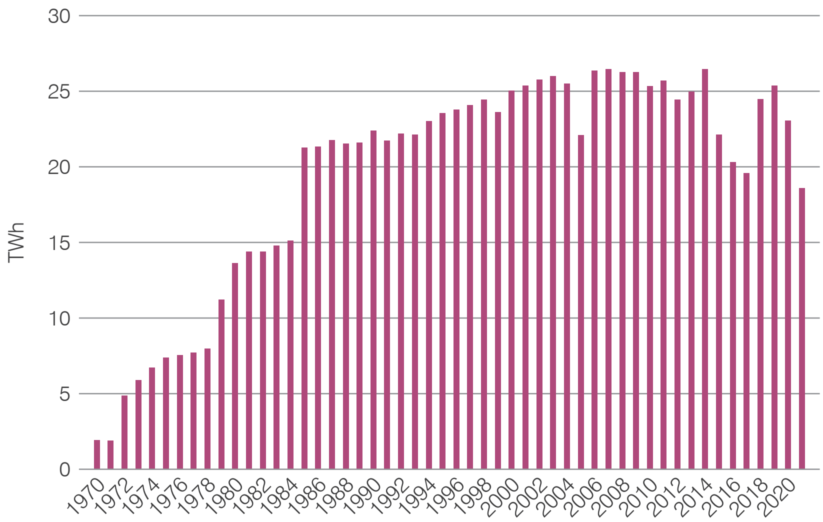
Switzerland voted to approve a revision to the country's energy policy that promotes the use of renewable energy sources and energy conservation in a referendum in May 2017. The revised Federal Energy Act also prohibits the construction of new nuclear power plants.

In October 2018, the IEA warned that Switzerland's phased withdrawal from nuclear power presented challenges for maintaining electricity security. In July 2021, media reports suggested that Switzerland's government was discussing delaying the scheduled closure of the country's nuclear units.

During the winter months Switzerland is reliant on imports of electricity from the EU. Concerns were raised after, in May 2021, Switzerland's Federal Council rejected the institutional framework agreement, a deal negotiated with the EU over seven years, that would have replaced Switzerland's existing electricity sharing agreements with the bloc.

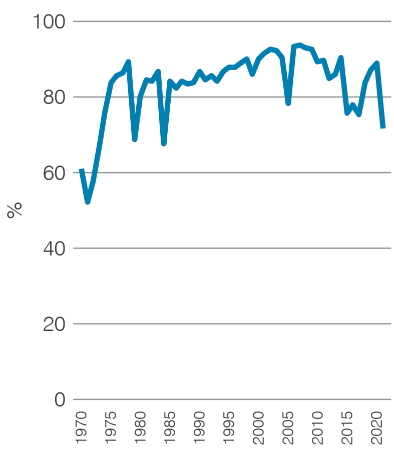


Nuclear electricity production



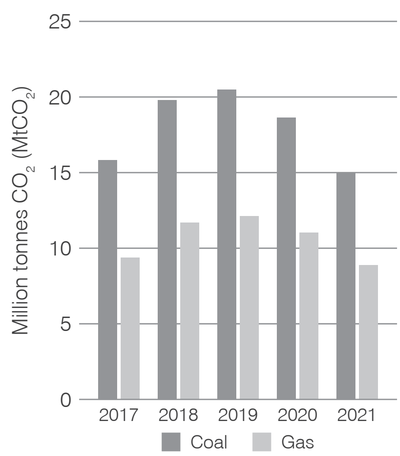
Source: World Nuclear Association, IAEA PRIS

Average nuclear capacity factor



Source: World Nuclear Association, IAEA PRIS

Emissions avoided cf. fossil fuels generation



Source: World Nuclear Association, IAEA PRIS

Turkey

Construction is continuing on the Akkuyu nuclear plant on Turkey's southern coast, 120 km southwest of Mersin.

The plant will comprise four 1114 MWe VVER-1200/V-509 reactors, based on the V-392M reactors at Novovoronezh II.

Construction commenced on unit 1 and unit 2 in April 2018 and 2019, respectively. In November 2020 Russia delivered the reactor pressure vessel for unit 1, which was installed in June 2021. Earlier in January 2021 GE Steam Power delivered the first of the four turbines to the plant. In March 2021 first concrete was poured for unit 3.

Operable Reactors	Nuclear Share of Generation	Reactors Under Construction	Lifetime CO_2 Avoided
0		3	0
0 MWe	0 %	3342 MWe	$MtCO_2$ cf. coal

The four units are expected to be connected to the grid over four years from 2023. When fully operational the plant will supply about 10% of Turkey's electricity needs.

In March 2021 the Akkuyu project secured two loans of up to US$200 million and US$100 million for a period of seven years from Sovcombank to help finance the project. The loans are being provided on special terms, including a reduced interest rate to recognize the project's sustainability credentials.

Earlier construction at Akkuyu. (Image: Akkuyu image bank, ROSATOM)

Ukraine

Ukraine's four nuclear power plants generate about half of the country's electricity. All 15 reactors, 12 of which were connected to the grid in the 1980s, are VVER units of Russian design.

In February 2022, Russia launched a military offensive against Ukraine. The resulting war has directly impacted nuclear facilities in the country, most notably Zaporozhye and Chernobyl.

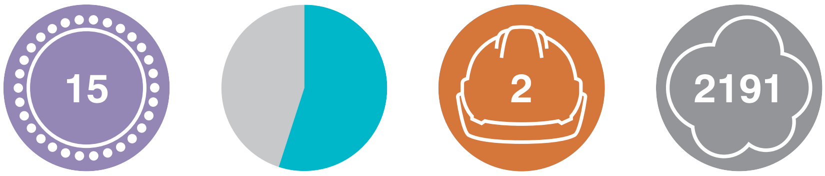
On 24 February Ukraine informed the IAEA that Russian forces had taken control of facilities at the Chernobyl nuclear power plant. Control of the site was returned to Ukrainian personnel over a month later on 31 March.

In the early hours of 4 March the Zaporizhzhia plant became the first operating civil nuclear plant to come under armed attack. Fighting between forces overnight resulted in a projectile hitting a training building. The six reactors were not directly affected. The site continued to be under Russian control as of June 2022.

For many years, and particularly following the annexation of Crimea by Russia in March 2014, the Ukrainian government has looked to the West for both technology and investment in its nuclear plants. In June 2022, Energoatom signed a contract with Westinghouse to build nine AP1000 units.

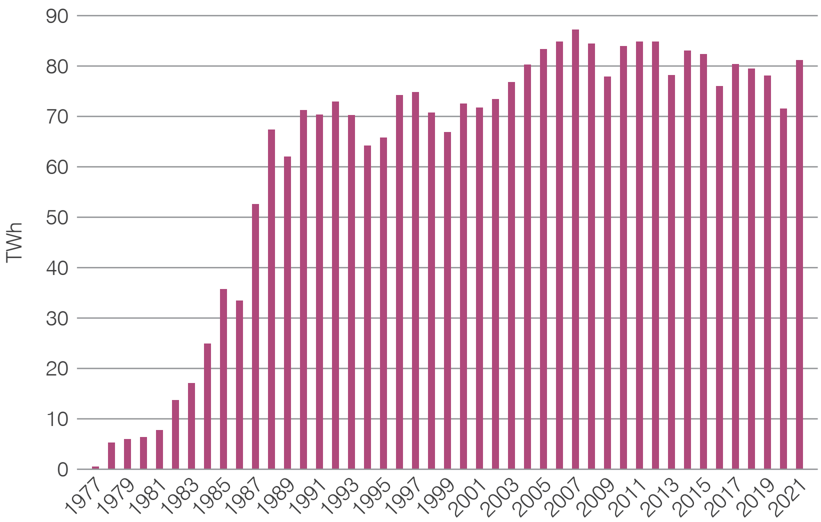
In January 2022 the government approved a Ministry of Energy plan that aims to make Ukraine self-sufficient in uranium by 2027.

Operable Reactors	Nuclear Share of Generation	Reactors Under Construction	Lifetime CO_2 Avoided



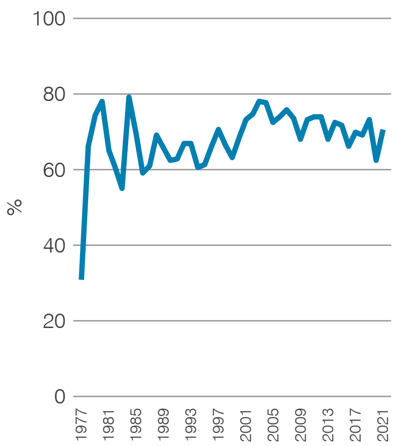
13,107 MWe	55.0 %	2070 MWe	$MtCO_2$ cf. coal

Nuclear electricity production



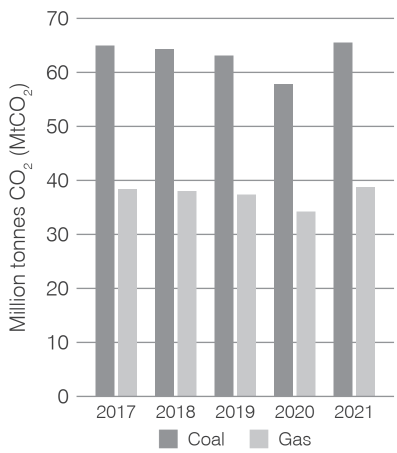
Source: World Nuclear Association, IAEA PRIS

Average nuclear capacity factor



Source: World Nuclear Association, IAEA PRIS

Emissions avoided cf. fossil fuels generation



Source: World Nuclear Association, IAEA PRIS

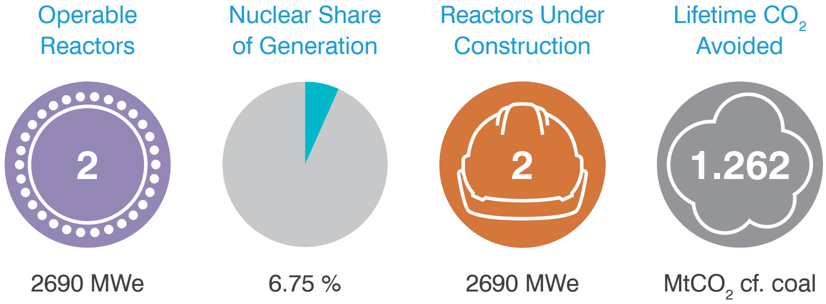
United Arab Emirates

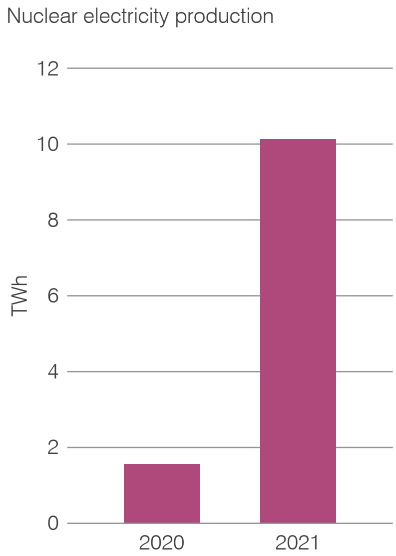
The United Arab Emirates has two operable nuclear power reactors at its Barakah nuclear power plant, which is located on the Gulf coast in the Al Dhafrah region, 250 km west of Abu Dhabi. The first unit achieved grid connection in August 2020, followed by the second in September 2021.

Construction of a third unit at the site was completed in November 2021 and it is expected to start up in 2023. A fourth reactor is under construction at the site.

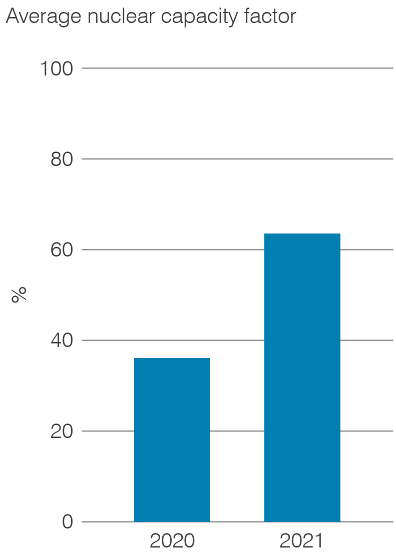
Once all four units are operational, the plant will supply 25% of the UAE's electricity.

In September 2021 Abu Dhabi Department of Energy (DoE) has issued a regulatory policy for implementing a clean energy certificates scheme that it said would cater to a growing appetite among businesses and consumers to contribute to the fight against climate change. The scheme provides an accreditation system based on internationally recognized standards and lays the foundations for a market for trading renewable and nuclear energy attributes.

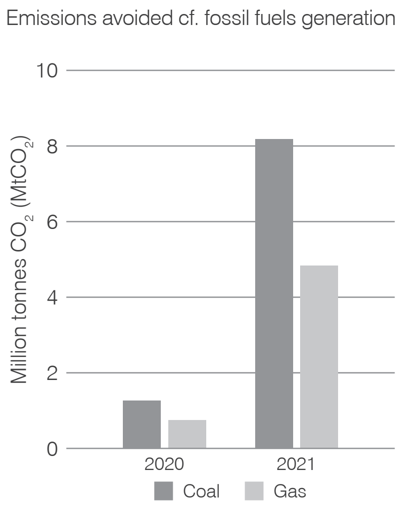




Source: World Nuclear Association, IAEA PRIS



Source: World Nuclear Association, IAEA PRIS



Source: World Nuclear Association, IAEA PRIS

United Kingdom

The United Kingdom (UK) has 11 operable reactors at seven sites, ten of which are advanced gas-cooled reactors (AGRs), with one PWR at Sizewell. Most existing capacity is to be retired by the end of the decade, but the first of a new generation of nuclear plants is under construction at Hinkley Point, in southwest England.

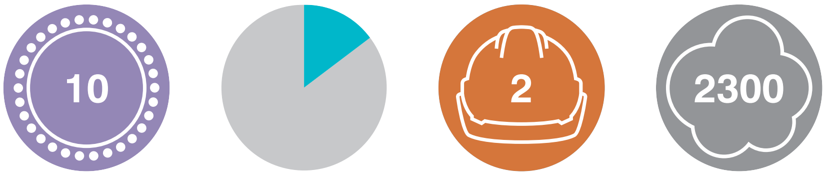
The UK government published its Energy Security Strategy in April 2022. The strategy sets out an ambition to construct eight new reactors, in addition to SMRs, to meet about 25% of the country's electricity demand by 2050.

The Energy Security Strategy, whilst prompted by events in Ukraine, followed a series of positive developments for nuclear in the UK. In October 2021 the UK government set out the Nuclear Energy (Financing) Bill, which would see the regulated asset base (RAB) model used to fund future nuclear power stations in the UK. Days later, the UK government announced up to £1.7 billion in direct government funding for a large-scale nuclear power plant in its autumn budget and spending review.

In May 2022 EDF announced a one-year delay to its project at Hinkley Point C and increased its cost estimate by £500 million to between £22-23 billion. This brings the total delay to the initially announced in-service dates to 18 months. The company said that the 18-month delay was mainly due to the impact of the COVID-19 pandemic.

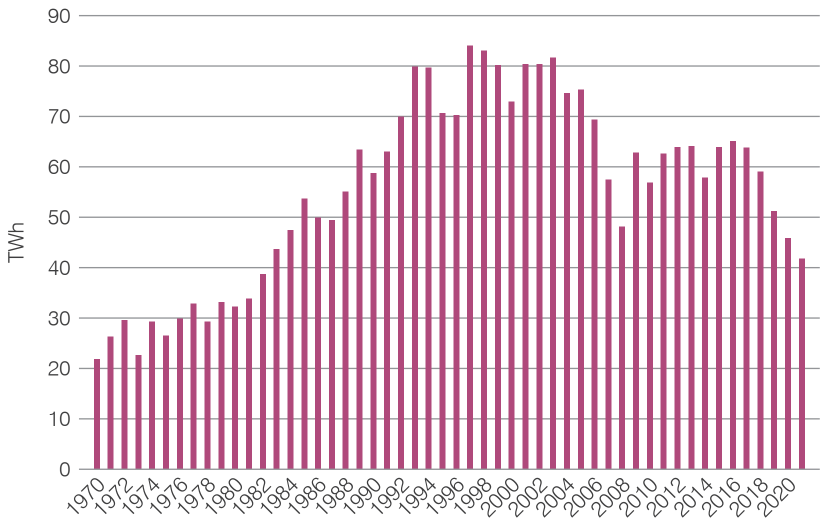
In November 2021 Rolls-Royce submitted its SMR design for assessment by the UK nuclear regulator. It was accepted for review in March 2022.

Operable Reactors	Nuclear Share of Generation	Reactors Under Construction	Lifetime CO_2 Avoided



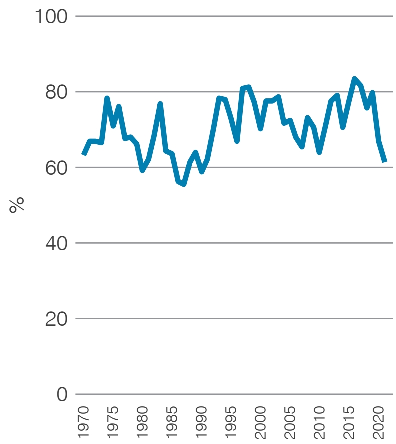
6368 MWe	14.8 %	3260 MWe	$MtCO_2$ cf. coal

Nuclear electricity production



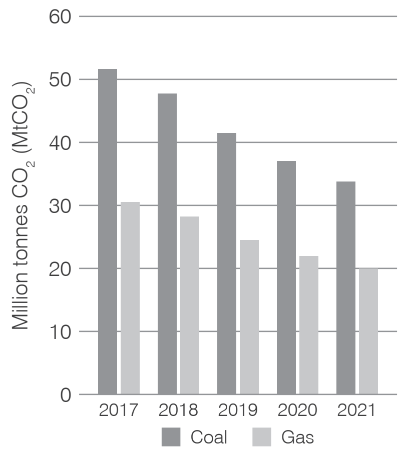
Source: World Nuclear Association, IAEA PRIS

Average nuclear capacity factor



Source: World Nuclear Association, IAEA PRIS

Emissions avoided cf. fossil fuels generation



Source: World Nuclear Association, IAEA PRIS

United States of America

The USA has 92 operable reactors with a combined capacity of 94.7 GWe.

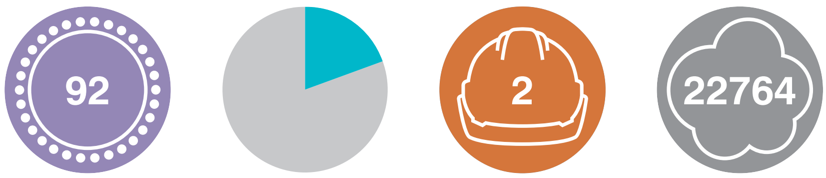
Two AP1000 reactors are under construction at Vogtle in the state of Georgia. Georgia Power now expects to start up unit 3 in the first quarter of 2023, followed by unit 4 in the fourth quarter.

In September 2021 Exelon Generation (now Constellation Energy) announced it was preparing to refuel its Byron and Dresden nuclear plants after the Illinois Senate passed an energy package that allows the state to procure carbon mitigation credits from nuclear plants. Both plants were scheduled to be shut down absent of legislative support.

The bipartisan Infrastructure Investment and Jobs Act includes US$62 billion to deliver a "more equitable clean energy future" including by preventing the premature retirement of existing nuclear plants and investing in advanced nuclear projects. In February 2022 the US Department of Energy announced its US$6 billion Civil Nuclear Credit Program, which would allocate credits to operating reactors that are at risk of shutting down due to economic factors.

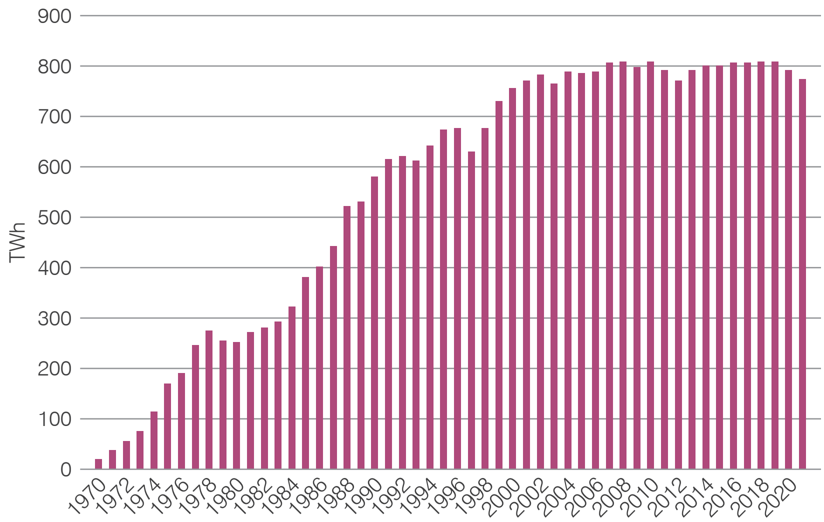
In California, Diablo Canyon, which provides 8% of the state's electricity, remains at risk of premature shutdown. A poll in May 2022 found strong support local to the plant and state-wide for extending its operation. In November 2021 a study by Stanford University, Massachusetts Institute of Technology and LucidCatalyst concluded that delaying the plant's retirement would reduce power sector carbon emissions, reduce reliance on gas, save billions in power system costs and bolster system reliability.

Operable Reactors	Nuclear Share of Generation	Reactors Under Construction	Lifetime CO_2 Avoided



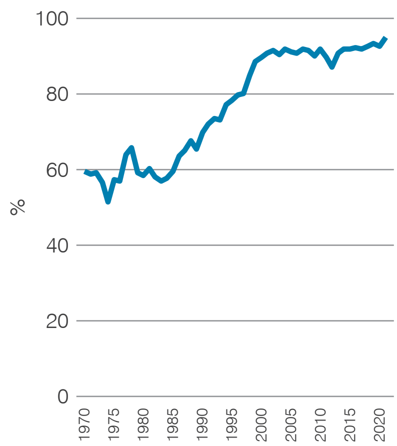
94,718 MWe	19.6 %	2234 MWe	$MtCO_2$ cf. coal

Nuclear electricity production



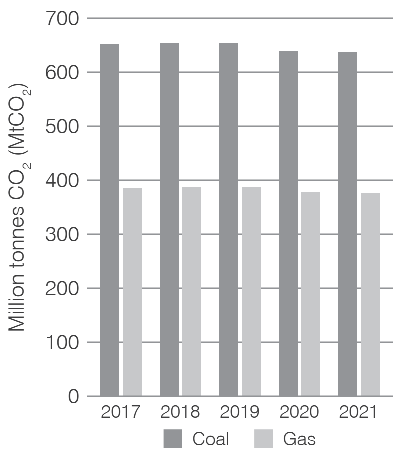
Source: World Nuclear Association, IAEA PRIS

Average nuclear capacity factor



Source: World Nuclear Association, IAEA PRIS

Emissions avoided cf. fossil fuels generation



Source: World Nuclear Association, IAEA PRIS

4 | Nuclear Reactor Global Status

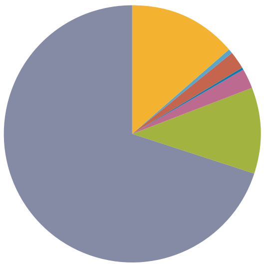
1 July 2022

Operable Reactors

440

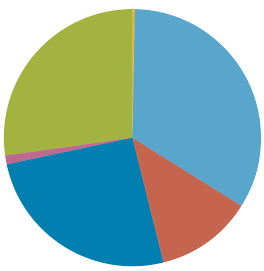
394,312 MWe

Operable Reactors by Type



BWR	61	LWGR	11
FNR	2	PHWR	48
GCR	10	PWR	307
HTGR	1		

Operable Reactors by Region



Africa	2
Asia	148
East Europe & Russia	53
North America	113
South America	5
West & Central Europe	119

Grid Connections 1 January - 30 June 2022

Reactor name	Model	Type	Net Capacity (MWe)	First grid connection	Location
Fuqing 6	HPR1000	PWR	1075	1 January 2022	China
Karachi 3	HPR1000	PWR	1014	4 March 2022	Pakistan
Olkiluoto 3	EPR	PWR	1600	12 March 2022	Finland
Hongyanhe 6	ACPR-1000	PWR	1061	2 May 2022	China
Shin Hanul 1	APR-1400	PWR	1340	9 June 2022	South Korea

Construction Starts 1 January - 30 June 2022

Reactor name	Model	Type	Net Capacity (MWe)	Construction start	Location
Tianwan 8	VVER V-491	PWR	1100	25 February 2022	China
Xudabao 4	VVER V-491	PWR	1100	19 May 2022	China
Sanmen 3	CAP1000	PWR	1157	28 June 2022	China

Permanent Shutdowns 1 January - 30 June 2022

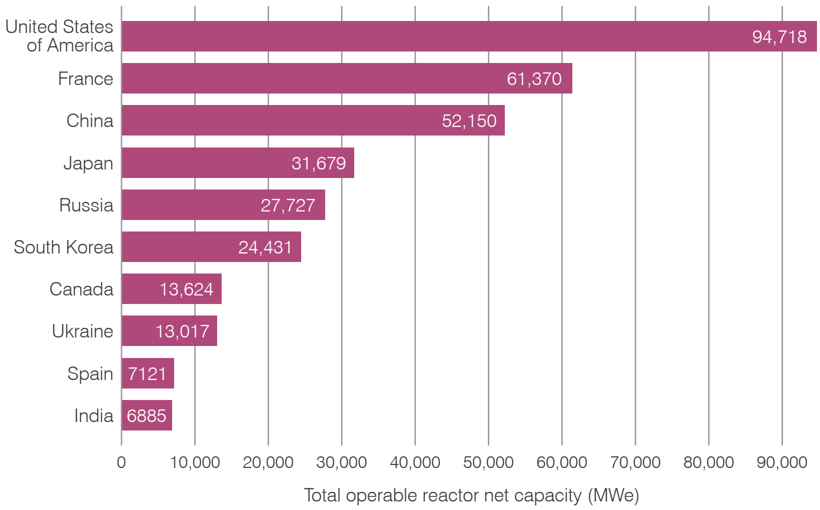
Reactor name	Model	Type	Net Capacity (MWe)	Permanent shutdown	Location
Hunterston B2	AGR	GCR	495	7 January 2022	UK
Palisades	CE (2-loop) DRYAMB	PWR	805	20 May 2022	USA

Long-term Shutdowns*

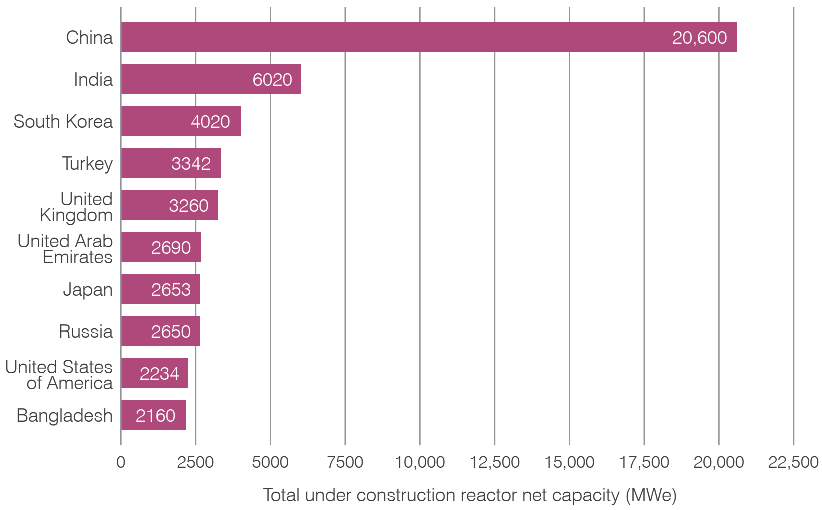
Reactor name	Model	Type	Net Capacity (MWe)	Permanent shutdown	Location
Rajasthan 1	Horizontal Pressure Tube	PHWR	90	9 October 2004	India

*A long-term shutdown date of 9 October 2004 was applied retrospectively in June 2022. Data for periods prior to June 2022 elsewhere in this report categorize the reactor as operable.

Top 10 Countries Installed Capacity



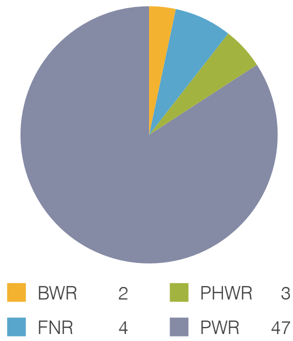
Top 10 Countries Capacity Under Construction



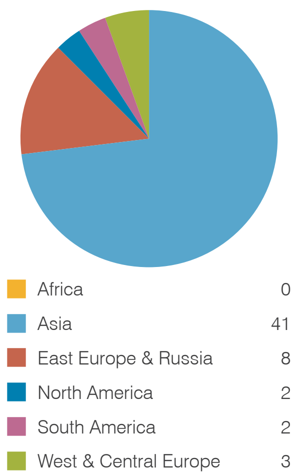
Under Construction

57,666 MWe

Under Construction by Type



Under Construction by Region



5 Director General's Concluding Remarks

Sama Bilbao y León
Director General
World Nuclear Association

In 2021 the world's nuclear reactors bounced back from the economic downturn resulting from the COVID-19 global pandemic and generated 100 TWh more electricity than in 2020.

Every additional megawatt-hour of nuclear generation helps in the fight against climate change and every reactor helps provide secure and reliable electricity.

But nuclear's achievement in 2021 has to be put in the context of the much broader political, environmental and energy challenges facing the world today.

The Russian invasion has brought incredible hardship to the people of Ukraine. In addition to the direct consequences of the war, the broader impacts on global energy supply have been profound.

The fragility of the fossil fuel supply chain has been made plain. Fossil gas prices have sky-rocketed, and with them so have electricity prices.

Worse may be yet to come, as electricity and heating demand is expected to rise later in the year as the Northern Hemisphere moves into winter.

Promises of action and signs of hope at COP26

The COP26 climate change conference in Glasgow saw a renewed global commitment to tackle climate change. More than 100 countries have now set a target to achieve net-zero emissions.

On the floor of the conference hall nuclear delegates, including a fantastic delegation of Nuclear4Climate representatives, sensed that nuclear energy was being embraced as a vital part of climate change action to a much greater extent than only a few years ago.

While I was in Glasgow it seemed that a day didn't go by without a major announcement from one of our member companies, or another government committing to nuclear energy as part of their climate change mitigation strategy.

But the harsh reality is that, despite this enhanced commitment to nuclear and other low-carbon technologies, the growth in energy demand seen as the global economy began to recover from the COVID-19 pandemic was primarily met through an increase in the use of fossil fuels.

A confused response

An apparent revelation for policy-makers worldwide has been the realization that decarbonization needs to happen at the same time as we ensure energy independence, reliability and security of supply.

Over the last six months we have seen a series of announcements from governments seeking to reduce their reliance on fossil fuels, and gas imports in particular. An accelerated transition away from fossil fuels has prompted a series of commitments aimed at accelerating the deployment of low-carbon technologies, including nuclear energy.

But at the same time those governments face the difficult task of ensuring continued energy supplies in the complex geopolitical here and now. In Germany, Austria, Netherlands and the UK coal power plants on the verge of closure are being brought back online to shore up electricity supplies. And in India and China the pace of new coal power plant construction has picked up again.

Whilst it was hoped that the economic stimulus packages put in place to aid the economic recovery from the COVID-19 pandemic would lead to a clean energy system, we have actually seen a rebound for fossil fuels. And long-term plans for a more secure low-carbon future are having to wait in line behind short-term shifts to any energy form available, clean or dirty.

Nuclear for secure and clean energy

Faced with the current energy crisis and the long-term threat of climate change there is an even-more urgent need to maximize the huge contribution to decarbonization and energy security of nuclear reactors currently operating worldwide.

Many of the closures of nuclear reactors over the last five years have resulted not from technical requirements, but from political decisions or economic pressures. At a time when every kWh of clean secure energy is precious, and extending the operating lives of existing nuclear plants should be incentivized, misguided political dogma is making things worse.

Earlier this year we saw Palisades NPP close down despite securing a licence to operate until 2031 and having the potential to operate for years beyond that.

Germany's three remaining reactors, Emsland, Isar 2 and Neckarwestheim 2 have a combined capacity of 4GWe, perform well, with high capacity factors frequently in excess of 90%, and together avoid the emissions of 25 million tonnes of carbon dioxide each year. Being barely more than 30 years old, these reactors could supply clean and reliable electricity well into the second half of this century, but will be permanently shutdown at the end of 2022.

In contrast, the Belgian government has approved the extended operation of two reactors, Doel 4 and Tihange 3, although it is to be seen whether this will represent a practical economic proposal.

With an average age of just over 30 years, many of the world's operating reactors have the potential to be in operation far longer than new solar panels and wind turbines coming online this year. It is vital that governments, regulators and industry all take steps to ensure that action is taken to proceed with long-term operation wherever it is feasible to do so. This will reduce reliance on fossil fuels, enhance energy security, and deliver what the IEA has concluded is the lowest cost form of additional clean, low-carbon electricity generation.

Invest in a sustainable, secure and prosperous future

Our existing nuclear fleet can continue to make a massive contribution to energy security and climate change mitigation. But establishing the net-zero economy that will be needed to avoid the worst impacts of global climate change, and that so many governments have set targets to achieve, will require a total transformation of our energy system including a far greater contribution from nuclear energy.

Nuclear energy will play a major role in making possible a net-zero world of abundant energy for everyone. It will generate electricity for both large and small grids, provide district heating and cooling, supply process heat to industry, produce hydrogen, and so much more. As the only energy source that can produce low-carbon electricity and low-carbon heat, it can be a game changer for the deep decarbonization of the entire global economy.

In the last few months we have had announcements from many new and existing nuclear countries, including Argentina, Bangladesh, Bulgaria, Canada, Czech Republic, France, Egypt, Netherlands, Poland, Romania, Ukraine and United Kingdom, setting out their plans for new reactors large and small.

It is essential that these plans are delivered on in full and expanded upon, so the pace and scale of new nuclear construction accelerates worldwide. We need to lay down human, physical, commercial and institutional infrastructures that will allow the global nuclear sector to truly scale up fast to meet the urgent and massive decarbonization needs.

Only if this is achieved will everyone have equitable access to the secure and reliable energy and electricity supplies they need to live well, and be able to preserve an environment fit to live in.

Abbreviations and Terminology

AGR	Advanced gas-cooled reactor
BWR	Boiling water reactor
CO_2	Carbon dioxide
COVID-19	Disease caused by the SARS-CoV-2 coronavirus
CORDEL	Cooperation in Reactor Design Evaluation and Licensing
ESG	Environmental, Social, and Governance
EU	European Union
FNR	Fast neutron reactor
FOAK	First of a kind
g	gram
GCR	Gas-cooled reactor
GWe	Gigawatt (one billion watts of electric power)
HTGR	High temperature gas-cooled reactor
IAEA	International Atomic Energy Agency
IPCC	Intergovernmental Panel on Climate Change
LWGR	Light water-cooled graphite-moderated reactor
MoU	Memorandum of understanding
MWe	Megawatt (one million watts of electric power)
PHWR	Pressurized heavy water reactor
PRIS	Power Reactor Information System database (IAEA)
PWR	Pressurized water reactor
SMR	Small modular reactor
TWh	Terawatt hour (one trillion watt hours of electricity)
VVER	Vodo-Vodyanoi Energetichesky Reaktor (a PWR)
HTR	High-temperature reactor
COP	Conference of the Parties
NGO	Non-governmental organization

Definition of Capacity Factor

Capacity factors are calculated as the percentage obtained by dividing a reactor's actual electricity output by the output expected if the reactor operated constantly at 100% of its net capacity.

When calculating capacity factors, those reactors that do not generate any electricity during the calendar year are not included.

For reactors that start-up or shut down during a calendar year the capacity factor for that year is calculated based on the electricity output that would have been generated where they to operate at 100% output for the fraction of the year in which they were in an operable status.

Geographical Categories

Africa
South Africa, Egypt

Asia
Armenia, Bangladesh, China mainland and Taiwan, India, Iran, Japan, Kazakhstan, Pakistan, South Korea, Turkey, United Arab Emirates

East Europe & Russia
Belarus, Russia, Ukraine

North America
Canada, Mexico, USA

South America
Argentina, Brazil

West & Central Europe
Belgium, Bulgaria, Czech Republic, Finland, France, Germany, Hungary, Italy, Lithuania, Netherlands, Poland, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, UK

Further Reading

World Nuclear Association Information Library
https://world-nuclear.org/information-library.aspx

World Nuclear Association Reactor Database
https://world-nuclear.org/information-library/facts-and-figures/reactor-database.aspx

The Nuclear Fuel Report: Global Scenarios for Demand and Supply Availability 2021-2040 (published September 2021)
https://www.world-nuclear.org/our-association/publications/global-trends-reports/nuclear-fuel-report.aspx

The World Nuclear Supply Chain: Outlook 2040
https://www.world-nuclear.org/our-association/publications/global-trends-reports/world-nuclear-supply-chain-outlook-2040.aspx

World Nuclear News
https://world-nuclear-news.org

International Atomic Energy Agency Power Reactor Information System
https://www.iaea.org/PRIS/home.aspx

World Nuclear Association is the industry organization that represents the global nuclear industry. Its mission is to promote a wider understanding of nuclear energy among key international influencers by producing authoritative information, developing common industry positions, and contributing to the energy debate, as well as to pave the way for expanding nuclear business.

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