World Nuclear Performance Report 2023

WORLD NUCLEAR ASSOCIATION

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Preface

Globally, the world's nuclear reactors generated more than 2500 terawatt hours (TWh) of electricity for the sixth year running. Nuclear generation supplies around one-quarter of the world's clean electricity, second only to hydropower. However, with output totalling 2545 TWh, generation in 2022 was just over 100 TWh lower than in 2021.

Three events in Europe contributed much to this reduction. First, a programme of welding repairs, as well as other outages, reduced generation by 81 TWh in France. Second, the closure of three of Germany's remaining six reactors at the end of 2021 deprived that country of a source of reliable low-carbon generation and prolonged its continuing use of fossil fuels. Third, the war in Ukraine resulted in the shutting down of the six units at the Zaporizhzhia nuclear power plant.

In combination, these three events resulted in a reduction of electricity output in France, Germany and Ukraine of 134 TWh, compared to 2021. Looking forward, nuclear generation is expected to recover in France over the next two years as reactors return to service. However, the shutdown of the last three reactors in Germany in April 2023 and the ongoing conflict in Ukraine will continue to impact overall nuclear generation in Europe.

In contrast to Europe, nuclear electricity generation in Asia increased by 37 TWh last year. Over the last ten years nuclear generation in Asia has more than doubled and has now overtaken nuclear generation in West & Central Europe. With three-quarters of the reactors that are under construction in the world in Asia, this is a positive trend that is set to continue.

Elsewhere, in Africa, North America and South America, nuclear generation last year was little changed from in 2021.

At the same time, nuclear generation should be increasing much more rapidly if we are to achieve global goals of decarbonization and provide reliable and secure access to clean energy to everyone, everywhere.

Realizing this will require us to maximize the operation of our existing nuclear power plants, as well as increasing the rate of construction of new reactors.

This edition of *World Nuclear Performance Report* breaks down the amount of generation by the ages of nuclear reactors in each country. With some reactor operators now targeting 80 years of operation, there is plenty of scope for many reactors in operation today to be contributing to meeting net-zero goals in 2050.

Six new reactors were connected to the grid in 2022: two reactors in China, and one each in Finland, Pakistan, South Korea and the United Arab Emirates. Construction started on eight reactors: five in China, two in Egypt and one in Turkey. These additions are welcome, but a far faster rate of construction and commissioning will be needed, at least a tripling of nuclear capacity worldwide, to achieve net-zero greenhouse gas emissions by 2050.

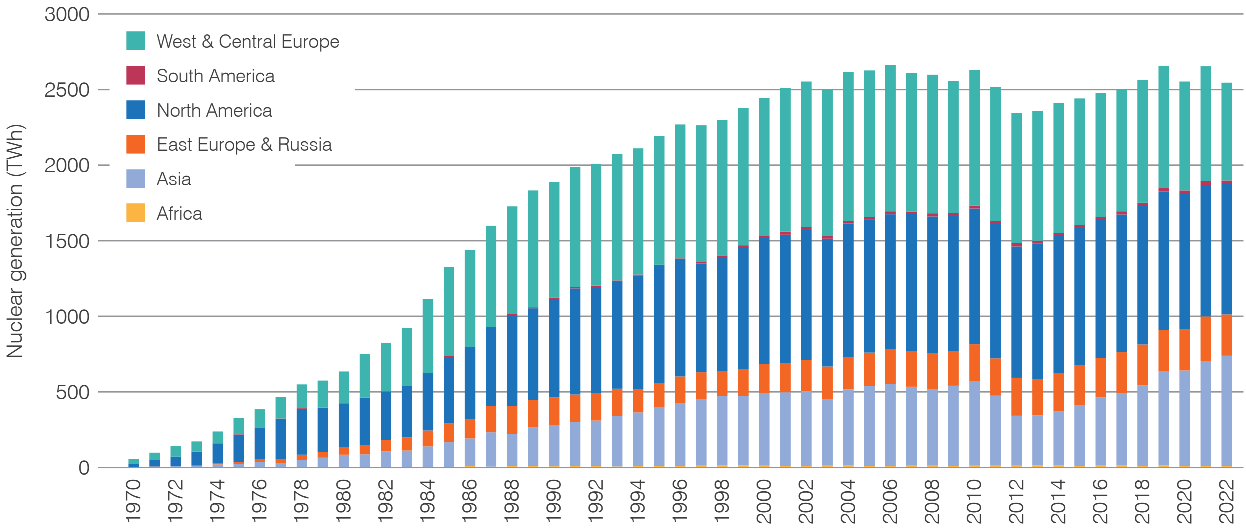
Sama Bilbao y León
Director General
World Nuclear Association

1 Nuclear Industry Performance

Global highlights

Nuclear reactors generated a total of 2545 TWh in 2022, including an estimated 59 TWh output for Ukraine. This is down 108 TWh from 2653 TWh in 2021. Excluding Ukraine, nuclear generation was 2487 TWh in 2022, down 85.4 TWh on the equivalent total in 2021.

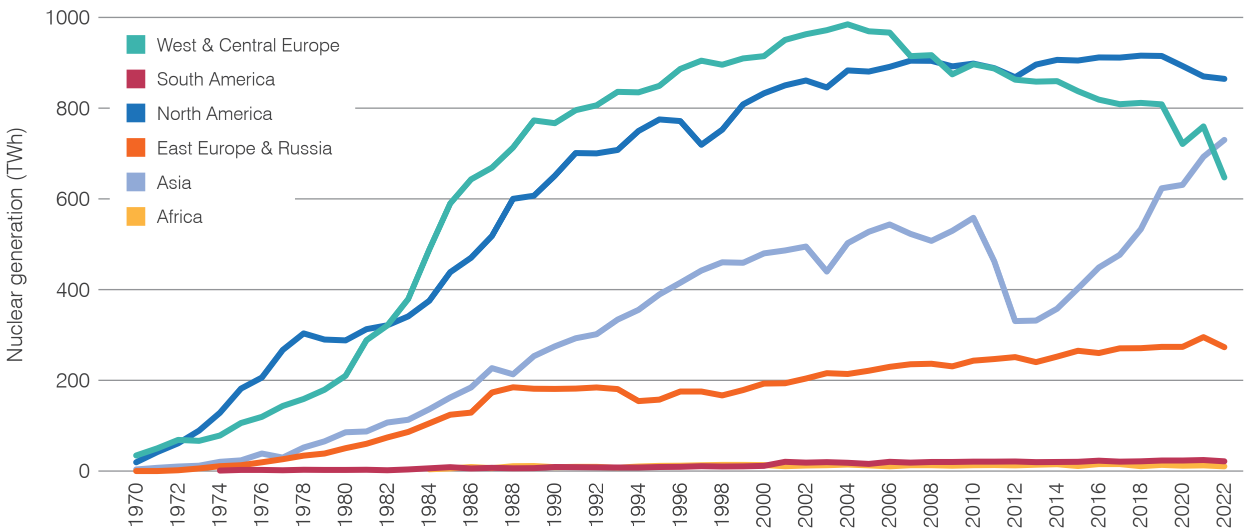
Figure 1. Nuclear electricity production



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

In 2022 nuclear generation increased by 37 TWh in Asia. There were minor decreases in South America and in Africa, but output was still within typical levels for these regions over recent years. Closure of Palisades contributed to the 6 TWh decline in output in North America. Output declined by 22 TWh in East Europe and Russia, a reduction similar to the estimated fall in generation in Ukraine. Generation declined by 112 TWh in West and Central Europe; this reduction can be attributed to the 34 TWh reduction in output in Germany, as reactors closed down, and the 81 TWh reduction in output in France, due to a high number of reactor outages.

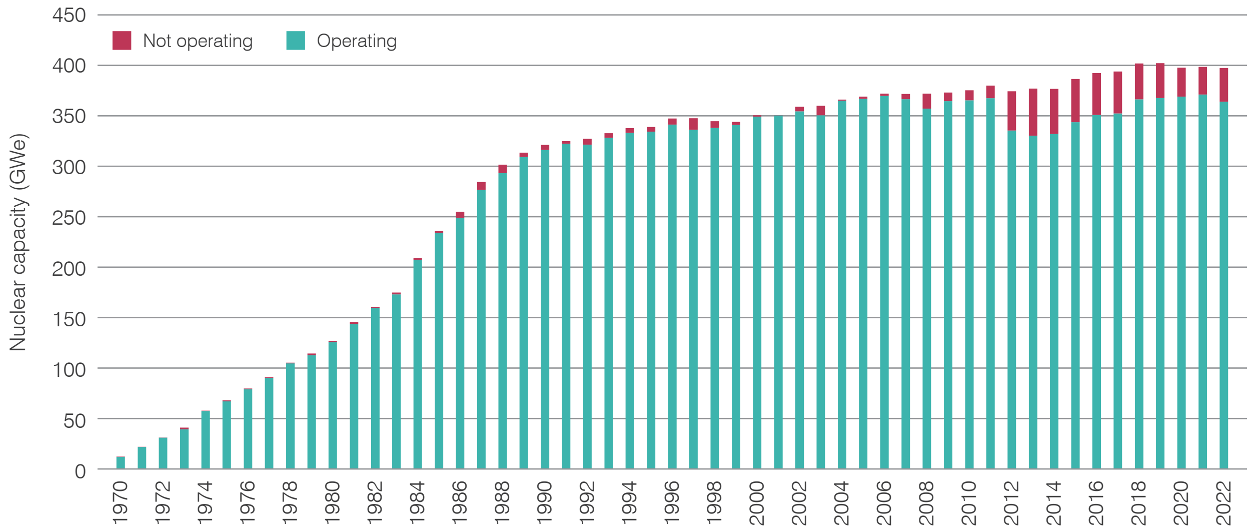
Figure 2. Regional generation



Source: World Nuclear Association, IAEA PRIS

In 2022 the end of year capacity of operable nuclear power plants was 394 GWe, up 5 GWe on 2021. The total capacity of reactors that produced electricity in 2022 was 363 GWe, down 7 GWe from 2021. In most years, a small number of operable reactors do not generate electricity, for example if they are undergoing extended outages. In recent years the figure has been higher, as reactors in Japan await approval to restart following the Fukushima Daiichi accident in 2011.

Figure 3. Nuclear generation operable capacity (net)



Source: World Nuclear Association, IAEA PRIS

The total number of operable reactors at year-end 2022 was 437, up one from 2021. Just over 70% of all operable reactors are pressurized water reactors (PWRs), with all but two of the 36 reactors that have started up between 2018 and 2022 being PWRs.

Table 1. Operable nuclear power reactors at year-end 2022 (change from 2021)

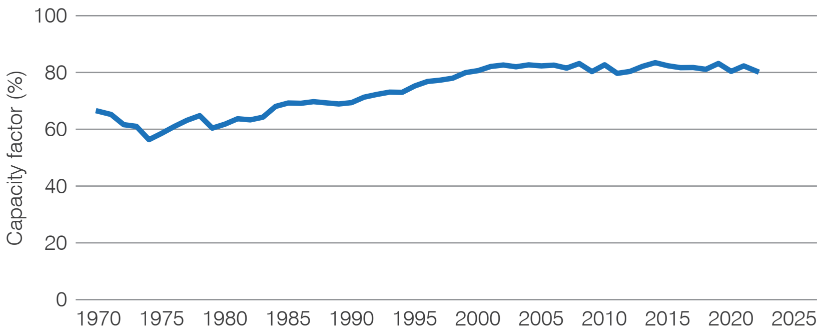
	Africa	Asia	East Europe & Russia	North America	South America	West & Central Europe	Total
BWR		20		33		8	61
FNR			2				2
GCR						8 (-3)	8 (-3)
HTGR		1					1
LWGR			11				11
PHWR		23		19	3	2	47
PWR	2	104 (+5)	40	61 (-1)	2	98	307 (+4)
Total	2	148	53	113	5	116 (-3)	437 (+1)

Source: World Nuclear Association, IAEA PRIS

Operational performance

In 2022 the global average capacity factor was 80.5%, down from 82.3% in 2021, but still continuing the trend of high global capacity factors seen since 2000. Capacity factors in this section are based on the performance of those reactors that report electricity generation in any one calendar year.

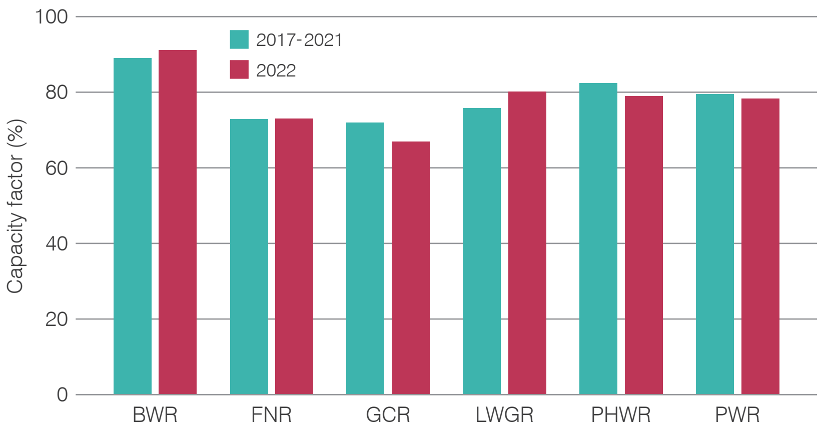
Figure 4. Global average capacity factor



Source: World Nuclear Association, IAEA PRIS

In 2022, capacity factors for different reactor types were broadly consistent with those achieved in the previous five years. On average, BWR reactors achieve the highest capacity factors consistently.

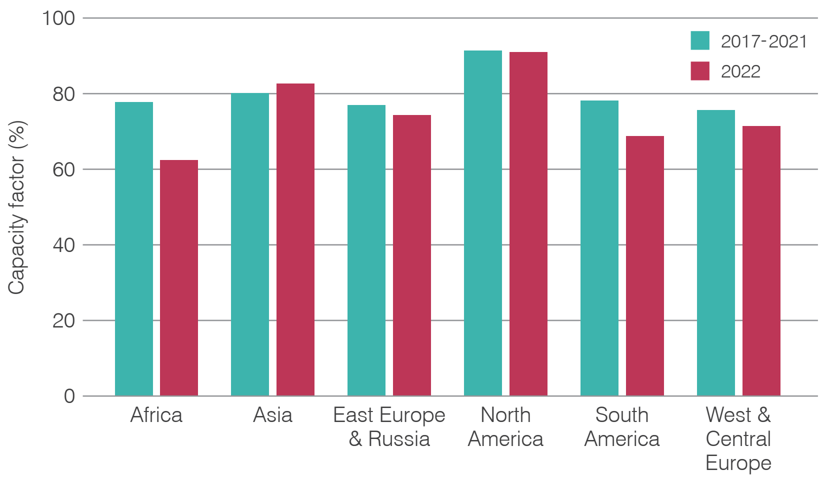
Figure 5. Capacity factor by reactor type



Source: World Nuclear Association, IAEA PRIS

Capacity factors in 2022 for reactors in most geographical regions were also broadly consistent with the average achieved in the previous five years, with North America maintaining the highest average capacity factors. Capacity factors for Africa are determined by the performance of the sole nuclear power plant operating there, South Africa's Koeberg.

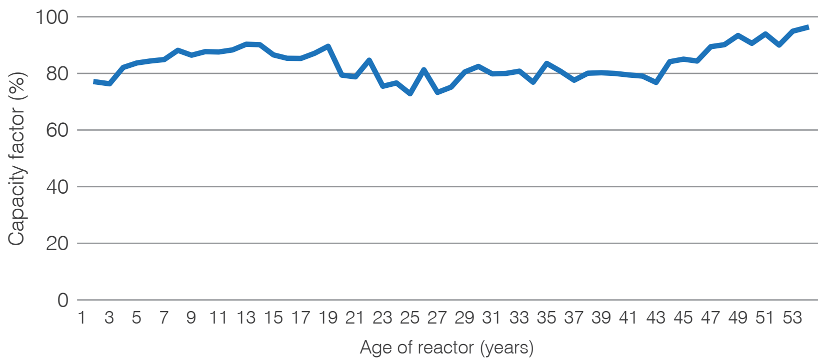
Figure 6. Capacity factor by region



Source: World Nuclear Association, IAEA PRIS

There is no overall age-related decline in nuclear reactor performance, although there is some variation, with lower average capacity factors for those reactors between 25 and 35 years of operation and higher than average capacity factors for those reactors exceeding 45 years of operation.

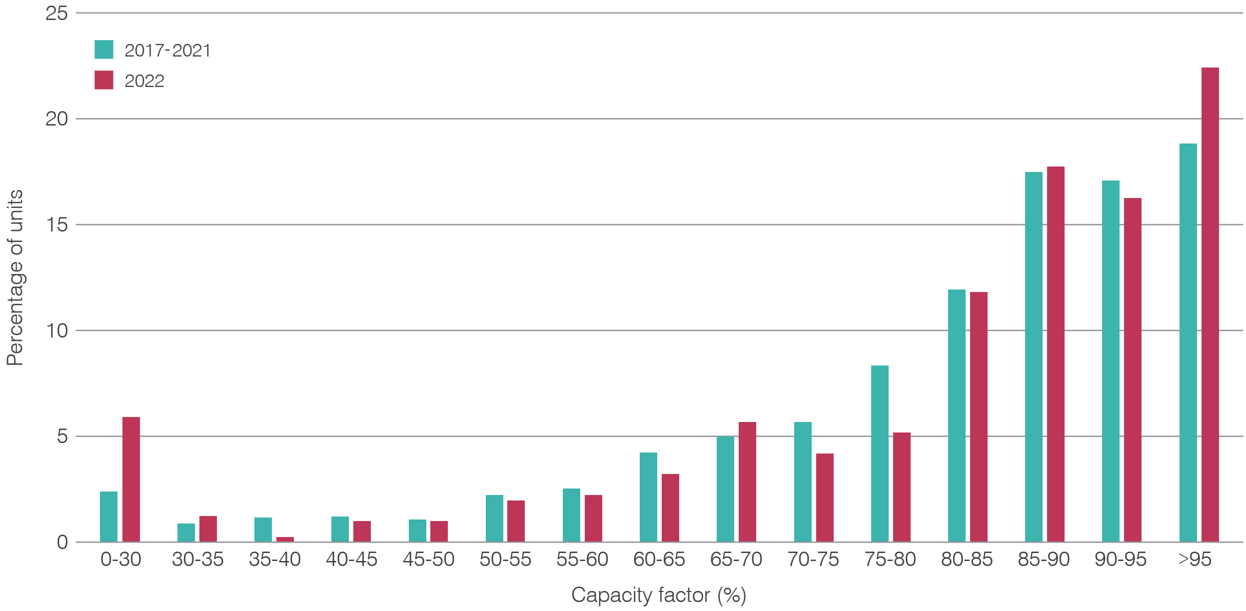
Figure 7. Mean capacity factor 2018-2022 by age of reactor



Source: World Nuclear Association, IAEA PRIS

The spread of capacity factors in 2022 is broadly similar to the average of the previous five years. Just over two-thirds of reactors have a capacity factor greater than 85%.

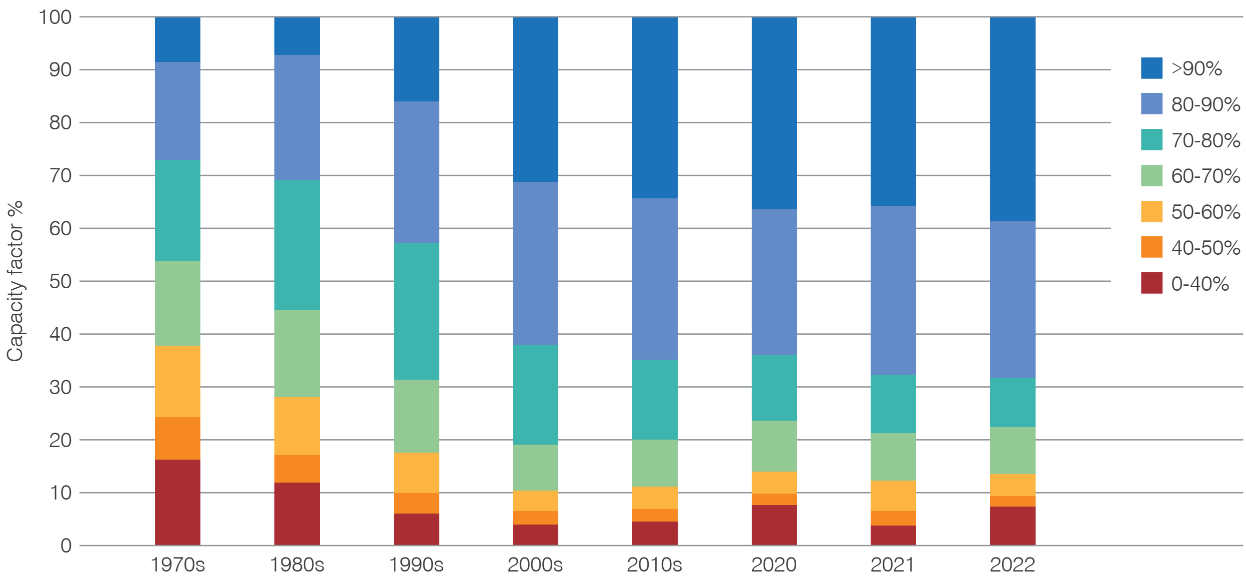
Figure 8. Percentage of units by capacity factor



Source: World Nuclear Association, IAEA PRIS

There has been a steady improvement in average capacity factors in each decade since the 1970s. The high capacity factors achieved in the 2010s have continued from 2020 onwards.

Figure 9. Long-term trends in capacity factors



Source: World Nuclear Association, IAEA PRIS

New construction

In 2022 construction began on eight large PWRs. Five reactors commenced construction in China, two at the El Dabaa site in Egypt and one, the fourth unit at Akkuyu, in Turkey.

Table 2. Reactor construction starts in 2022

	Location	Model	Process	Design net capacity (MWe)	Construction start date
Tianwan 8	China	VVER V-491	PWR	1100	25 February 2022
Xudabao 4	China	VVER V-491	PWR	1100	19 May 2022
Sanmen 3	China	CAP1000	PWR	1163	28 June 2022
Haiyang 3	China	CAP1000	PWR	1161	7 July 2022
El Dabaa 1	Egypt	VVER V-529	PWR	1100	20 July 2022
Akkuyu 4	Turkey	VVER V-509	PWR	1114	21 July 2022
Lufang 5	China	HPR1000	PWR	1100	8 September 2022
El Dabaa 2	Egypt	VVER V-529	PWR	1100	20 November 2022

Source: World Nuclear Association, IAEA PRIS

With eight construction starts in 2022, and six reactor connections to the grid, the total number of units under construction at the end of 2022 was 60, two more than at the end of 2021.

Table 3. Units under construction year-end 2022

	BWR	FBR	PHWR	PWR	Total
Argentina				1	1
Bangladesh				2	2
Belarus				1	1
Brazil				1	1
China		2		20	22
Egypt				2	2
France				1	1
India		1	3	4	8
Iran				1	1
Japan	2				2
Russia		1		2	3
Slovakia				2	2
South Korea				3	3
Turkey				4	4
Ukraine				2	2
United Arab Emirates				1	1
United Kingdom				2	2
United States of America				2	2
Total	2	4	3	51	60

Source: World Nuclear Association, IAEA PRIS

Six reactors were connected to the grid for the first time in 2022. This included Olkiluoto 3 in Finland, where construction of the first-of-a-kind EPR began in 2005. Much shorter construction times were achieved for the other five reactors, with construction of the Karachi 3 HPR1000 (Hualong One), in Pakistan, taking just 69 months.

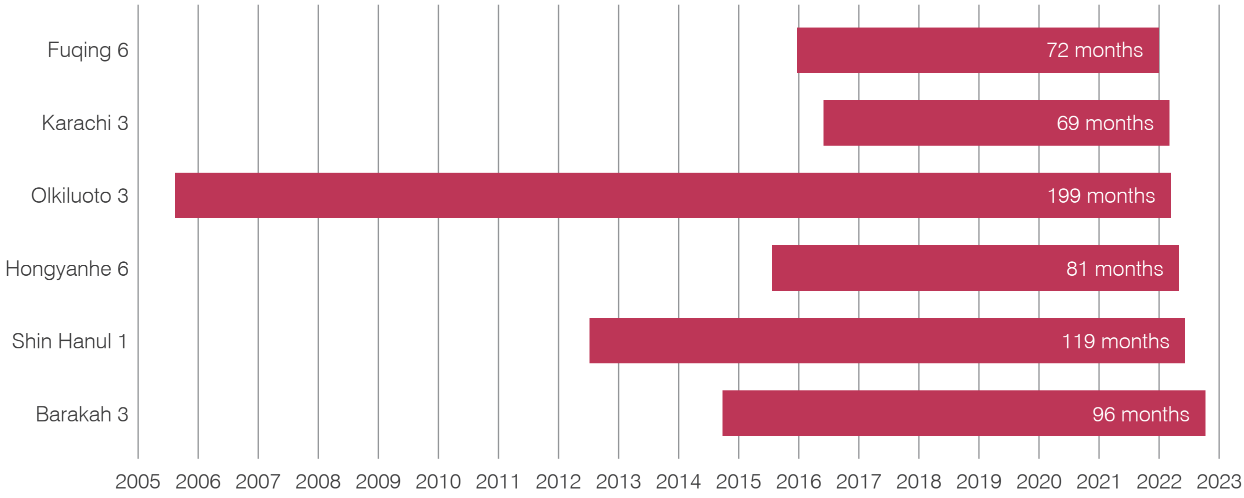
Table 4. Reactor grid connections in 2022

	Location	Design Net Capacity (MWe)	Model	Reactor Type	Construction Start	First Grid Connection
Olkiluoto 3	Finland	1600	EPR	PWR	12 August 2005	12 March 2022
Shin Hanul 1	South Korea	1340	APR-1400	PWR	10 July 2012	9 June 2022
Barakah 3	United Arab Emirates	1310	APR-1400	PWR	24 September 2014	8 October 2022
Hongyanhe 6	China	1061	ACPR-1000	PWR	24 July 2015	2 May 2022
Fuqing 6	China	1075	Hualong One	PWR	22 December 2015	1 January 2022
Karachi 3	Pakistan	1014	HPR1000	PWR	31 May 2016	4 March 2022

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. In contrast, the first-of-a-kind construction at Olkiluoto 3 took an exceptional 199 months.

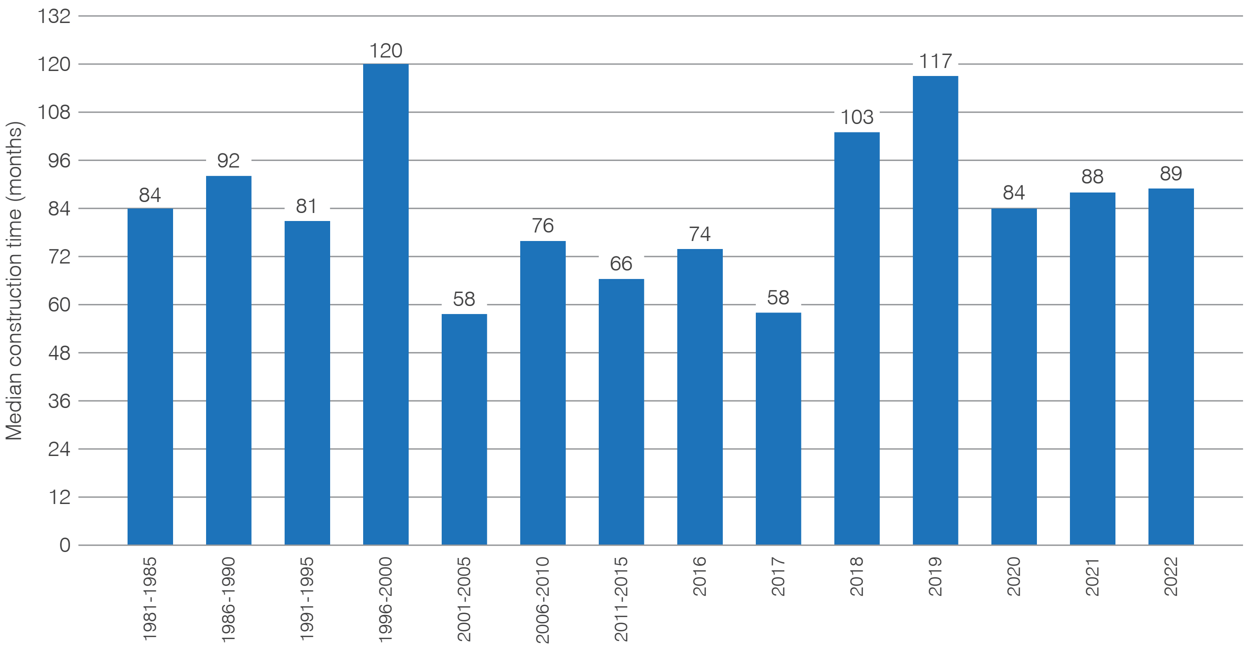
Figure 10. Construction times of new units grid-connected in 2022



Source: World Nuclear Association, IAEA PRIS

Despite the large variation in reactor construction times, the median construction time for reactors grid-connected in 2022 was little changed from that in 2021, being one month longer, at 89 months.

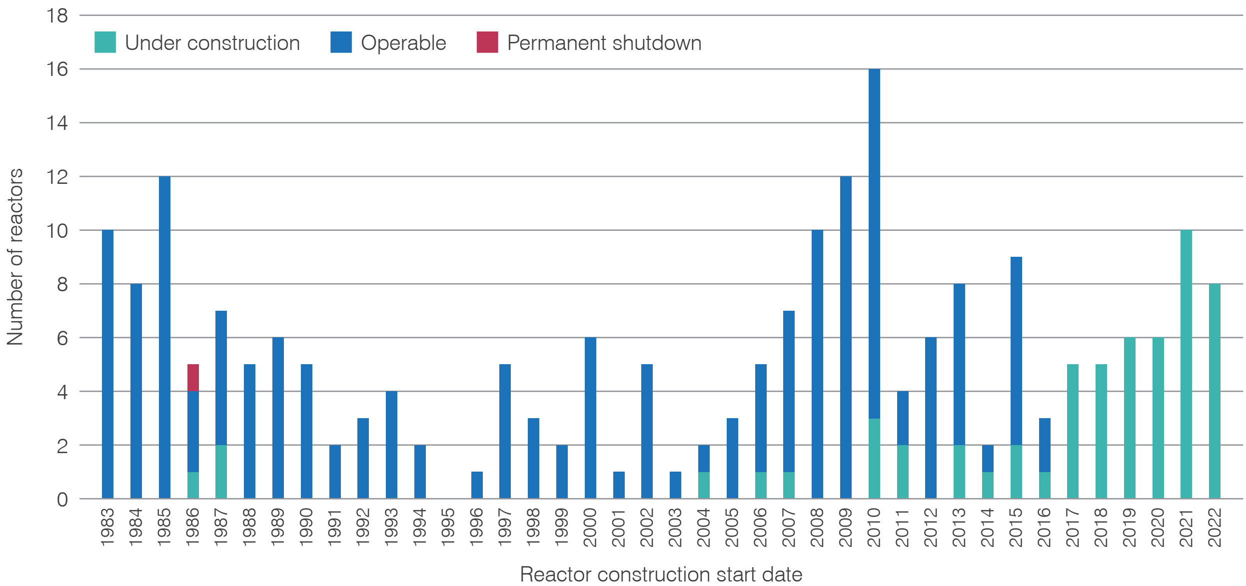
Figure 11. Median construction times for reactors since 1981



Source: World Nuclear Association, IAEA PRIS

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. Construction on Khmelnitski 3&4, Ukraine, started in 1986 and 1987, respectively, but there has been no active progress since construction was halted in 1990. Mochovce 4, in Slovakia, started construction in 1987, as did Mochovce 3, its sister unit. Mochovce 3 was grid-connected in January 2023.

Figure 12. Operational status of reactors with construction starts since 1983 as of 1 January 2023

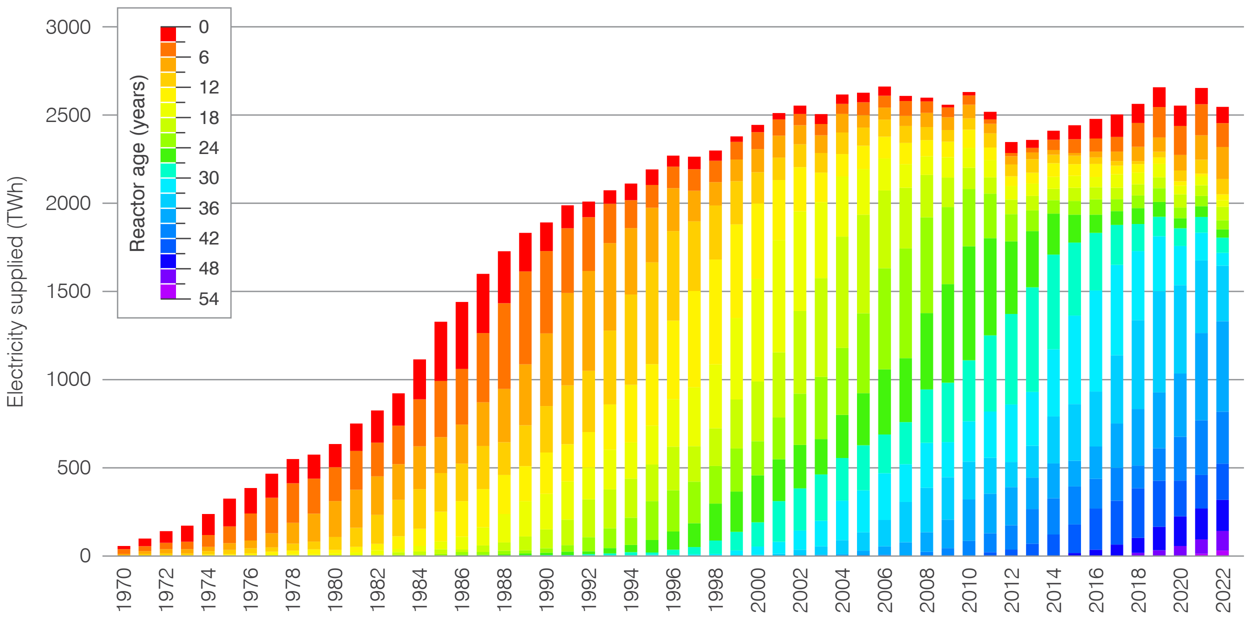


Source: World Nuclear Association, IAEA PRIS

Figure 13 shows total global electricity generation from nuclear power plants by age in each year since 1970. The ages of the reactors generating electricity in each year are indicated by the colours representing those ages in each bar.

The rapid expansion of nuclear generation in the 1970s and '80s is shown by the continued presence of the redder hues in the chart, indicating reactors in their first decade of operation. With the slowing of the pace of new reactor start-ups in the 1990s, the amount of red in each year's bar reduces. With increased construction and subsequent commissioning of reactors in recent years the amount of electricity generated by younger reactors has started to increase again, shown by the increasing amount of red in the bars over the last decade.

Figure 13. Total global nuclear electricity generation by age of reactor



Source: World Nuclear Association, IAEA PRIS

Five reactors were permanently shut down in 2022. The operation of the last three reactors in Germany, which were due to close in 2022 was extended, but all three plants finally closed in April 2023.

Table 5. Shutdown reactors in 2022

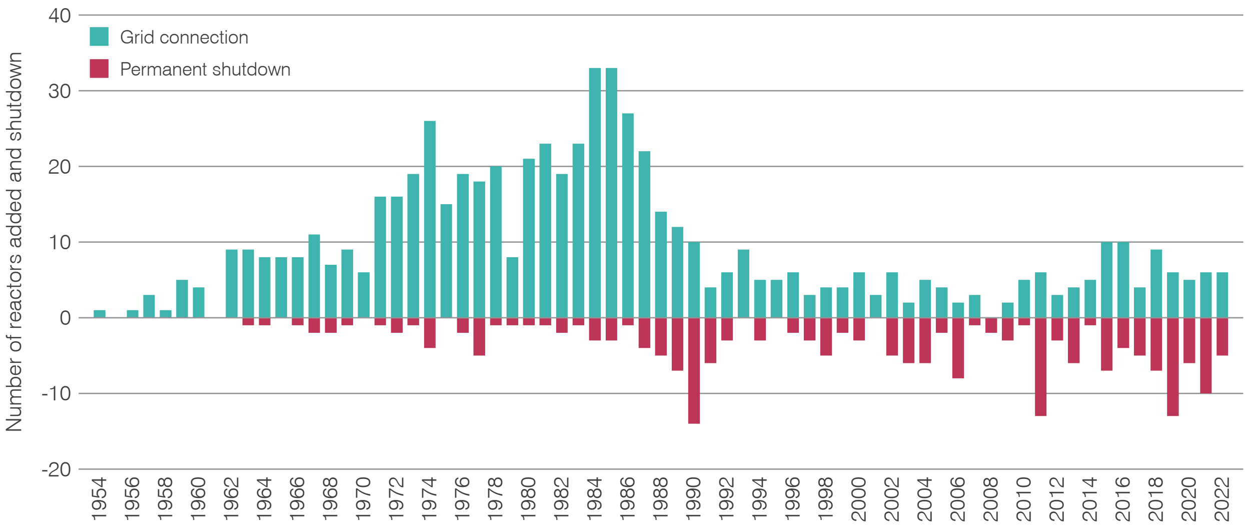
In 2022 the five reactors that were permanently shut down had a combined capacity of 3271 MWe.

Reactor Name	Location	Reference Unit Power (MWe)	First Grid Connection	Permanent Shutdown
Hunterston B2	UK	495	31 March 1977	7 January 2022
Palisades	USA	805	31 December 1971	20 May 2022
Hinkley Point B2	UK	480	5 February 1976	6 July 2022
Hinkley Point B1	UK	485	1976-10-30	1 August 2022
Doel 3	Belgium	1006	1982-06-23	23 September 2022

Source: World Nuclear Association, IAEA PRIS

With the start-up of six reactors and permanent shutdown of five, more reactors started operation than ceased operation for the first time in four years.

Figure 14. Reactor first grid connection and shutdown 1954-2022



Source: World Nuclear Association, IAEA PRIS

2 Case Studies

Commissioning Fuqing 5&6

Fuqing 5&6 (Image: FQNPC)

The Fuqing nuclear power plant, owned and operated by Fujian Fuqing Nuclear Power Company (FQNPC) consists of six GW-scale nuclear power units that have started up sequentially since August 2014. Units 1-4 are derived from the French M310 design and designated as M310+, and units 5&6 are CNNC's demonstration Hualong One units

The Hualong One have a number of similarities to units 1-4 at the Fuqing plant. Both designs are conventional three loop PWRs, with similar conventional island designs. At the same time, as a third-generation reactor design, the Hualong One employs passive as well as active safety systems to enhance defence-in-depth. Passive systems include containment heat removal, secondary side residual heat removal, and reactor cavity water injection.

The number of core fuel assemblies in the Hualong One is 177, increased from 157 in the M310+. The average linear power density is reduced while the rated power of the core is increased, which not only increases the power generation capacity of the nuclear power plant (1075 MWe net, compared with 1000 MWe) but also improves the safety margin of nuclear power operation.

The Hualong One technology has been developed by China National Nuclear Corporation (CNNC) on the basis of more than 30 years of experience in nuclear power research, design, manufacturing, construction and operation. As well as combining active and passive severe accident prevention and mitigation measures, the design incorporates feedback and improvements resulting from the March 2011 accident at the Fukushima Daiichi plant in Japan.

The first Hualong One – Fuqing 5 – was connected to the grid on 27 November 2020, setting a record construction time of 66.7 months for a first-of-a-kind third-generation nuclear power plant design. Fuqing 6 entered commercial operation on 25 March 2022, marking the full completion of the demonstration project.

Interviewee: Jia Yuqiang

Plant Manager of Fuqing 5&6, CNNC Fujian Fuqing Nuclear Power Company

Have there been any specific challenges during the commissioning process?

As the demonstration plant of the Hualong One, the commissioning of Fuqing 5&6 presented not only a heavy workload due to the first application of a large number of new technologies but also posed many challenges, including first-of-a-kind unit tests and new design verification.

The first unit test is a new commissioning test carried out only on the first unit of a new nuclear power reactor type. The first reactor test of Hualong One consists of five tests in total. Fuqing Unit 5 organically combined the front end and back end of the whole project through special test organization and management, commissioning, construction and installation, integrated design office, sand table deduction in advance, and so on, so as to find and solve problems in the first place, such as the rapid cooling and secondary side passive heat exchange capacity verification test, the use on-site simulator resources to verify test schemes and risk plans in advance, and check test results in advance. All the first unit tests were successful at the first attempt.

The new design concept of combined active and passive safety for the Hualong One creates challenges for the project integrity, the applicability of the commissioning scheme, and compliance of the commissioning results of the first unit. The commissioning team established a problem-oriented coordination mechanism and improved problem-solving efficiency through risk management, joint headquarters, and other management innovations.

At the same time, commissioning experience feedback for the previous unit at the site allowed for careful planning to be carried out. For example, differentiation analysis was carried out according to the design characteristics of Hualong One. This led to more than 60 differential adjustments of commissioning items and nearly 100 differential adjustments of acceptance standards compared with the M310+.

Improvements were continuously carried out; for example, during the commissioning of Fuqing 5, more than 20 verification and commissioning items were supplemented to ensure the comprehensive and high-quality completion of unit commissioning tasks.

How will the experience gained in the construction of these domestic demonstration plants benefit the construction of HPR1000 units in overseas projects in Pakistan and beyond?

Construction contractors can visit the Fuqing units to get a deep understanding of the design's technical characteristics and construction and operation experience. They can also receive on-the-job training in the relevant project management discipline.

The project management team have summarized the construction experience of domestic demonstration projects and issued the *HPR1000 Standardization Technical Manual* and *HPR1000 Standardization Management Manual*, which can be used as a reference for overseas construction contractors of such units.

For overseas units under construction, experienced project management personnel from domestic demonstration projects can be employed to provide onsite support services. Domestic demonstration projects can also provide remote services such as project management consultation and technical support for overseas construction contractors of HPR1000 units.

Staff at overseas units under construction can also establish cooperative relations with domestic demonstration plant staff to carry out activities such as engineering construction experience feedback, mutual visits of key personnel, overseas onsite observation and guidance, and benchmarking of the engineering construction system.

The Fujian Fuqing Nuclear Power Company is preparing for the establishment of an HPR1000 owners group, which can share information on HPR1000 construction, operation and maintenance, technical management, personnel training and other areas with all HPR1000 owners to jointly improve HPR1000 construction and operation performance.

Darlington Nuclear Refurbishment Project update

U3 Returned to Service – staff on the Turbine floor photo (Image: OPG)

The four CANDU 850 reactors at the Darlington nuclear power plant meet about 20% of Ontario's electricity needs and have been in operation since the early 1990s. In 2016 OPG commenced a 10-year refurbishment project of all four units, beginning with unit 2, that would extend the operating lifetimes of the reactors by 30 years. Work on units 2&3 has been completed, while refurbishment of units 1&4 continues.

Beginning in 2007, OPG conducted thorough station equipment assessments followed by extensive programme planning and preparation. This upfront investment of time and attention to detail resulted in an integrated 10-year long execution schedule (all four units will be returned to service before the end of 2026) and a committed total budget of C$12.8 billion.

In October 2016, OPG's team of project partners, industry experts, energy professionals, and skilled tradespeople shut down unit 2, the first of four Darlington reactors scheduled for refurbishment, and reconnected it to the power grid in June 2020 – an execution duration of 44 months. In addition to enabling unit 2 to operate for another 30 years, more than 4000 lessons learned were captured from the full evolution of the refurbishment of the reactor and associated unit systems.

Unit 3 refurbishment execution began in September 2020, incorporating the unit 2 lessons learned. Then in February 2022, execution commenced on unit 1 – the first time two units overlapped in execution during the refurbishment project.

Unit 3 was reconnected to the Ontario electricity grid on 17 July 2023 – after 34 months, 169 days ahead of OPG's commitment. On 19 July, unit 4, the final of the four Darlington reactors to be refurbished, was taken offline to begin its refurbishment outage.

Reactor details

Location	Bowmanville, Ontario, Canada
Reactor type	Pressurized heavy water reactor (PHWR)
Owner	Ontario Power Generation
Operator	Ontario Power Generation
Net capacity	4 x 878 MWe
Unit 1 construction/ grid connection	1 April 1982 / 14 November 1992
Unit 2 construction/ grid connection	1 September 1981 / 9 October 1990
Unit 3 construction/ grid connection	1 September 1984 / 14 February 1993
Unit 4 construction/ grid connection	1 July 1985 / 14 June 1993

Interviewee: Subo Sinnathamby

Senior Vice President, Nuclear Refurbishment

Four years later, has the project proceeded as expected?

The project has progressed better than expected. Executing a long-term mega construction project within an operating commercial nuclear station has required continued focus on safety and quality by the team to successfully drive the project forward. At more than halfway through the project execution phase (60% complete at the time of writing), it is the "OneTeam" culture within the OPG leaders and employees, our vendor partners and the tradespersons, focused on completing quality work that has kept this project ahead of schedule, with a far safer working environment than the average commercial construction site in Ontario.

A detailed schedule, effective implementation of lessons from the unit 2 refurbishment, along with strong risk mitigation plans, has allowed the team to overcome major challenges, including discovery and first of a kind execution.

In our 2019 case study, OPG identified many lessons learned from the execution of the unit 2 project. Has it been possible to apply these lessons learned in practice to the refurbishment of subsequent units?

As a learning organization, the Darlington refurbishment project team continuously gathers information throughout planning, tooling proofing, operation and maintenance, worker training, material management, work series execution and ultimately return-to-service evolutions. The information is assessed, lessons learned identified and then incorporated into the schedule of subsequent refurbishments. From the execution of unit 2, the team captured 4000 lessons learned to enhance the quality of work, safety to workers, and improve cost and schedule performance on subsequent units.

Effective implementation of these lessons learned through new execution strategies and innovation have resulted in greater than 20% performance improvement from unit 2 to unit 3 on safety, quality, and schedule. One key innovation for unit 3 based on lessons learned was modification of tooling to enable the pressure tubes and calandria tubes to be removed together, versus in series in unit 2, resulting in savings of 30 days and enhanced worker safety on each of the unit 3, 1 and 4 schedules.

Did the COVID-19 pandemic have any impact on the project and, if so, how were any challenges managed?

The Darlington refurbishment project was not immune to challenges brought on by the COVID-19 pandemic. The health and safety of all workers on OPG sites has and remains a top priority for us. The implementation of social distancing guidelines, enhanced disinfection and sanitizing of all work areas and enforcing screening protocols not only minimized the spread of the virus in our stations, but it also highlighted to our employees, workers, and community, OPG's commitment to maintaining a safe workplace.

Delaying the start of the unit 3 refurbishment by four months after the successful return-to-service of unit 2 was a carefully thought-out decision to ensure we had the appropriate measures to protect both the operational and project staff in this unprecedented environment. The time taken to put these measures in placed ensured there were no COVID-19 outbreaks on the project or schedule impact during execution.

New SMRs are planned to be built at Darlington. Congratulations. With the refurbishment project extending the operation of the existing Darlington units well beyond the potential start-up of the SMR, are there any benefits or challenges with constructing and operating a new reactor at an existing operating plant site?

OPG's track record in successfully operating nuclear generating stations and executing mega projects has paved the way for building new SMRs at the Darlington site. OPG has partnered with GE Hitachi, SNC Lavalin and Aecon to complete planning, design, and construction of four BWRX-300 SMRs on land adjacent to the existing Darlington station. Working with these three companies, OPG is leveraging decades of nuclear energy and large project experience, including lessons learned from the Darlington refurbishment project and OPG's operating experience, to build and operate SMRs.

Tianwan Nuclear Power Plant Steam Supply

The TNPP steam energy supply project (Image: CNNC Jiangsu Nuclear Power Station)

Tianwan nuclear power plant (TNPP) is located in Lianyun district, Lianyungang city, Jiangsu province. The plant is planned to consist of eight PWRs, with a total installed capacity of 9.1 GWe. Total investment is expected to be around CNY 150 billion ($21 billion).

At present, units 1-6 are in operation and units 7&8 are under construction. After these last two units are completed, annual electricity output will exceed 70 TWh, and the plant will have the largest installed operational capacity of any nuclear plant in the world.

In the TNPP steam energy supply project, steam (670 t/h, 270 °C, 6.0 MPa) in the secondary circuit of units 3&4 will be used as the heat source to heat the demineralized water provided by seawater desalinating equipment. The resulting steam at 248 °C and 1.8 MPa will then be provided at a rated flow rate of 600 t/h to users in the petrochemical engineering industry.

For this project, four sets of steam conversion equipment are used. Each set includes one superheater, one evaporator, one primary stage preheater, one secondary stage preheater, as well as a deaerator, primary feedwater pump, and secondary feedwater pump. Each set of steam conversion equipment has a designed capacity that covers 33% of the demand, but the four sets will run in a normal mode of 25% each. The steam conversion equipment can accommodate a wide range of operating conditions and can operate flexibly.

Interviewee: Zhang Xianggui

Deputy Plant Manager of Units 3&4, CNNC Jiangsu Nuclear Power Station

What advantages are there to the industrial users of steam from Tianwan, compared to using other sources?

In comparison with conventional fossil energy, nuclear energy is highly reliable, clean and low-carbon. From its design parameters, the TNPP industrial steam energy supply project can provide the petrochemical industry of Lianyungang city with 4.8 million tonnes every year. This could reduce coal use by 0.4 million tonnes per year, equivalent to a reduction in emissions of 1.07 million tonnes of CO_2, 184 tonnes SO_2 and 263 tonnes of NO_x.

What is the potential in China outside of Tianwan?

On 22 September 2020 President Xi Jinping promised in the United Nations 75th Session that our country would try its best to reach peak carbon dioxide emissions by 2030 and to achieve carbon neutrality by 2060. Consistent with this 'carbon peak & carbon neutrality' goal, nuclear energy, as a clean and efficient provider of baseload electricity, has been playing an important role in the national energy system. Development of nuclear energy will provide a foundation for the Chinese transition to a clean and low-carbon energy system.

At present, the nuclear heating projects of Shandong Haiyang and Zhejiang Qinshan have demonstrated good operational performance and social benefits. Fuqing and Sanmen are also planning to carry out modifications to supply industrial steam from nuclear energy.

The Tianwan steam supply project, as the first large-scale national project of industrial steam supplied by nuclear energy, will be ready to supply steam at the end of 2023. As well as demonstrate a green, efficient and harmonious use of nuclear energy, it is hoped that industrial steam supply from nuclear energy will become will be widely used in the future.

How are the operations of the industrial site affected by outages at the nuclear plant?

In the design of the Tianwan steam energy supply project, the operations at the industrial site during outages of the nuclear plant were taken into account. Four sets of steam conversion equipment are used for this project, and each one can be supplied with heating steam from both units 3 and 4. During normal operation, units 3 and 4 each provide the steam conversion equipment with 50% heating steam. With one unit offline, the other unit would provide 100% heating steam to the steam conversion equipment, guaranteeing a reliable steam supply to the users.

Supply is also maintained in the event that one set of steam conversion equipment needs to be repaired, as the other three sets can each transition to 33% of demand.

3 Country Pages

Chapter 3's Country Pages present summaries of recent developments and performance data for countries with reactors in operation, and updates on those new entrant countries with their first nuclear reactors under construction.

The information for the numbers of operable reactors and reactors under construction is correct as of 31 December 2022. A global update of reactor construction starts, grid connections and shutdowns to 31 July 2023 are listed in Chapter 4.

The Lifetime CO_2 Avoided data is calculated on the basis of the emissions of CO_2 that would have been released had the electricity supplied by nuclear generation in each country to 31 December 2022 had been generated by coal-fired power plants instead. The values for emissions avoided since 2016 compared to fossil fuels list emissions avoidance compared to electricity generation from both coal-fired or gas-fired plant.

As in Chapter 2, capacity factors are calculated based only on those reactors that generated electricity in each calendar year.

The electricity generation charts show total electricity generation for each year and subdivide this into electricity generation by reactors of different ages, based on the date of first grid connection.

Argentina

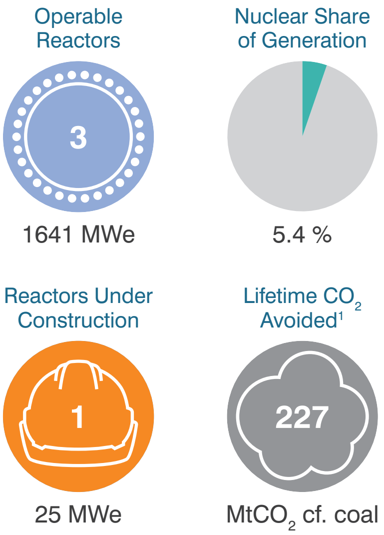
Argentina has two nuclear power plants: Atucha, about 100 km northwest of Buenos Aires; and Embalse, about 100 km south of Córdoba. The Atucha plant comprises two Siemens-designed pressurized heavy water reactors (PHWRs), unique to Argentina; and Embalse, a single Candu 6 PHWR unit from Atomic Energy of Canada Ltd (AECL).

A 30-month refurbishment project at Atucha 1, Latin America's first nuclear power reactor, is due to commence in 2024 – when the unit's current operating licence expires. This would allow Atucha 1 to operate for a further two decades.

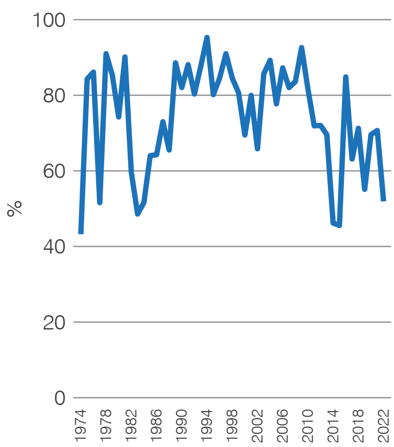
In August 2022 construction was completed on a dry fuel storage facility at the plant, which will store the used fuel assemblies from Atucha 1 in preparation for its refurbishment. Work on a second dry storage facility at the site is expected to commence in 2023.

Atucha 2, which started up in 2014, has been offline since October 2022, when a routine inspection revealed that one of the four internal supports of the reactor had become detached. Repairs began in June 2023 and were expected to take two months to complete.

Construction of the CAREM25 prototype SMR – also at the Atucha site – began in early 2014 but has been suspended several times. In October 2022 the country's National Atomic Energy Commission (CNEA) said that civil construction works on the reactor were expected to be finished by 2024, with initial criticality by the end of 2027.

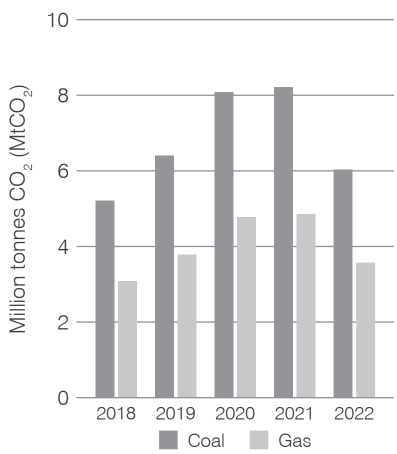


Average nuclear capacity factor



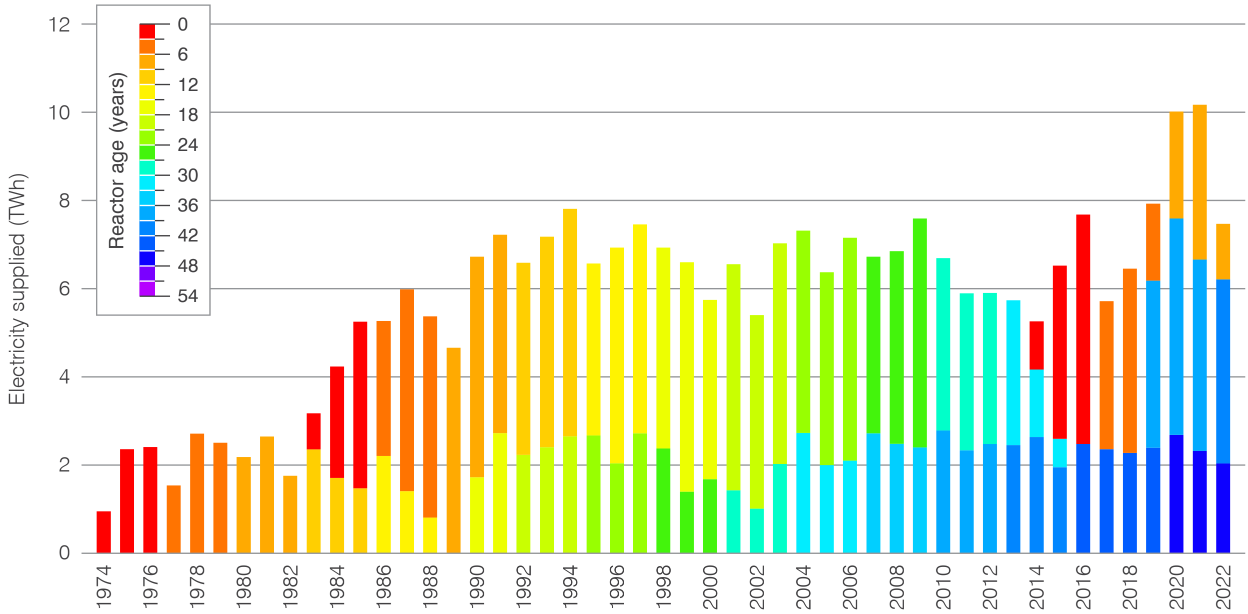
Source: World Nuclear Association, IAEA PRIS

Emissions avoided cf. fossil fuels generation[2]



Source: World Nuclear Association, IAEA PRIS

Nuclear electricity production



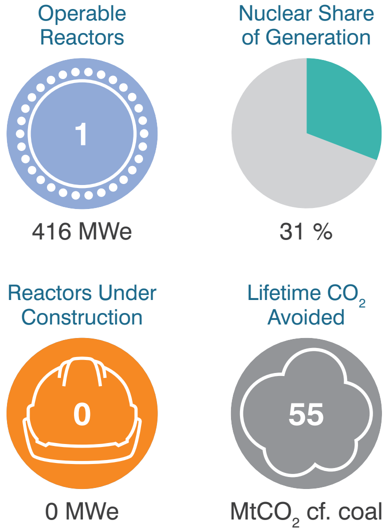
Source: World Nuclear Association, IAEA PRIS

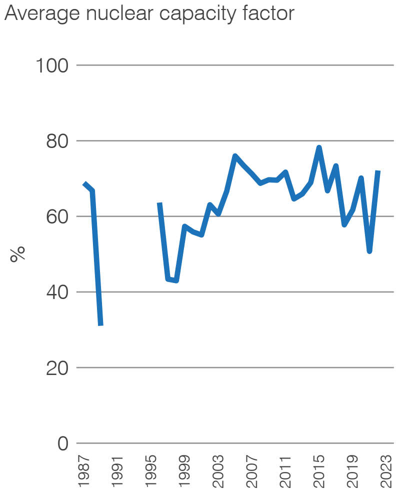
Armenia

Armenia has one nuclear power plant at Metsamor, 30 km west of the capital Yerevan, consisting of two VVER units. 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 following a major earthquake in the region earlier that year. Unit 2 was restarted in 1995 in the face of severe energy shortages.

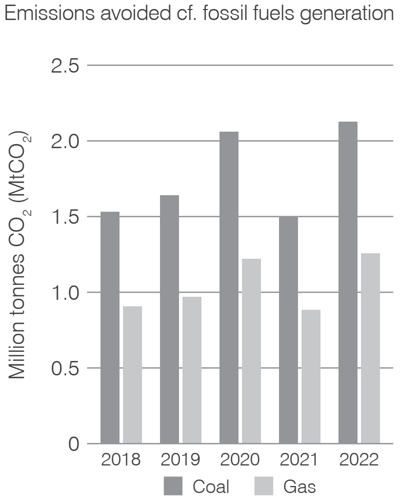
Following modernization of the unit's emergency cooling system, engine room, turbines and steam generators, as well as annealing of the pressure vessel, its operating lifetime was extended to 2026.

In March 2023, a further lifetime extension of ten years was announced – which would allow the unit to operate until 2036. Armenian prime minister Nikol Pashinyan met with Rosatom Director General Alexei Likhachev in May 2023 to discuss the lifetime extension work, which it was hoped would begin by the end of 2023. Construction of new Russian-designed nuclear power units in Armenia was also discussed during the meeting.

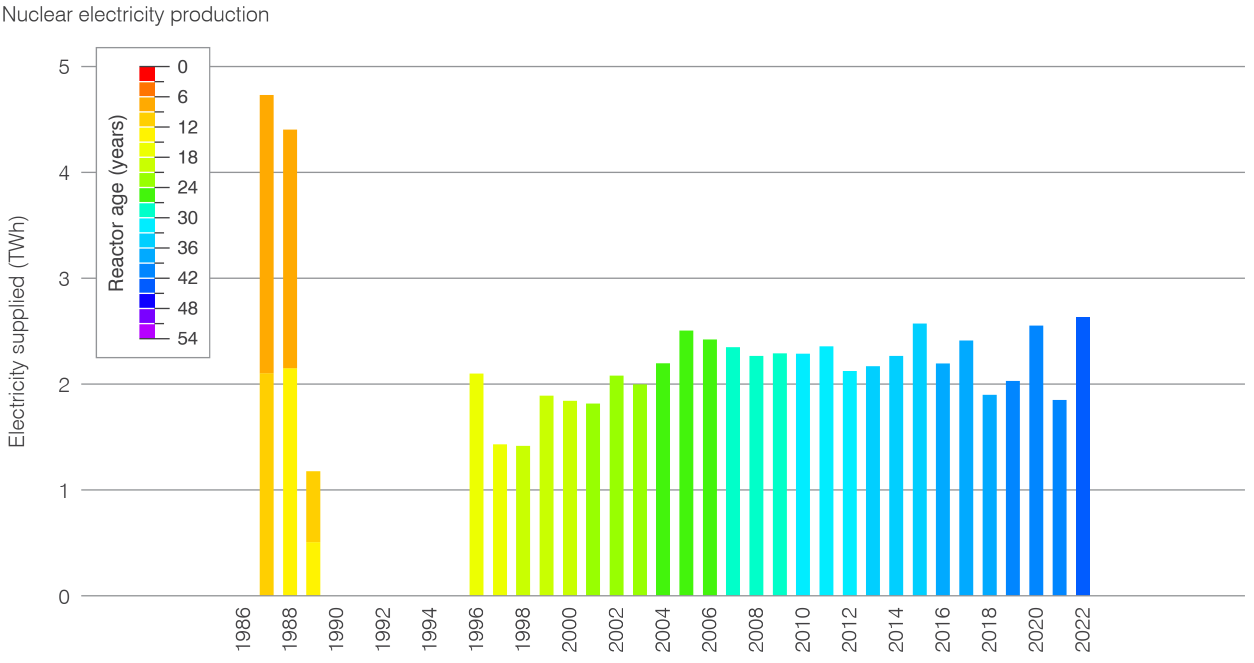




Source: World Nuclear Association, IAEA PRIS



Source: World Nuclear Association, IAEA PRIS



Source: World Nuclear Association, IAEA PRIS

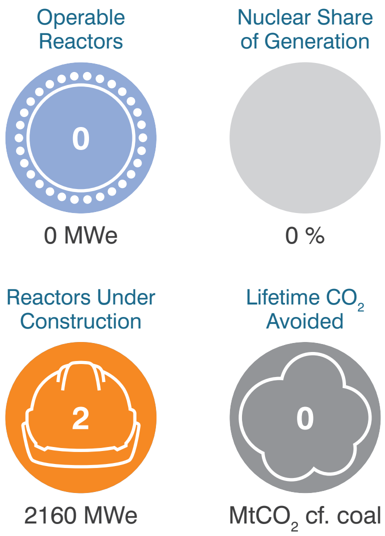
Bangladesh

Two VVER-1200s 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 designated as V-523, which are based on the V-392M reactors at Novovoronezh II in Russia. Once complete, the two-unit plant is expected to provide about 9% of the country's electricity.

In October 2022 the government announced that the construction of Rooppur was running approximately one year behind schedule due to issues stemming from the COVID-19 pandemic and Russia's invasion of Ukraine.

The same month, due to sanctions imposed on Russia, the Russian government issued a mandate to Bangladesh's government to repay the loans provided for the construction of the plant in Russian rubles instead of US dollars. In April 2023 the Bangladesh government opted to settle a $318 million pending repayment in Chinese yuan as international sanctions against Russian banks made payments in rubles impractical.



Work to install Rooppur 1's core barrel was completed in May 2023 (Image: Rosatom)

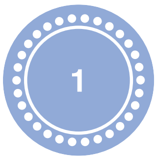
Belarus

Belarus has two VVER-1200 reactors, located at Ostrovets, about 120 km northwest of Minsk. These reactors were the first VVER-1200s to be built outside of Russia. Unit 1 was connected to the grid in November 2020 and unit 2 in May 2023.

Before the startup of the reactors, Belarus's electricity demand was met almost entirely by gas-fired generation, with most of the gas imported from Russia. When both units are fully commissioned, the plant should produce about 18.5 TWh of electricity each year, representing just under half of Belarus's total electricity requirements, and reducing annual demand for gas by 4.5 billion cubic metres.

In February 2023 the government announced plans to create an organization for radioactive waste management, which would implement a system of long-term storage and disposal of radioactive waste.

Operable Reactors



1110 MWe

Nuclear Share of Generation

11.9 %

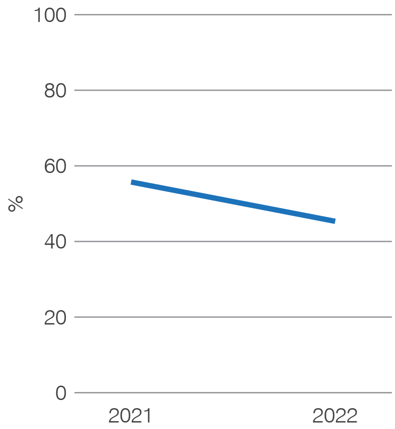
Reactors Under Construction

1110 MWe

Lifetime CO_2 Avoided

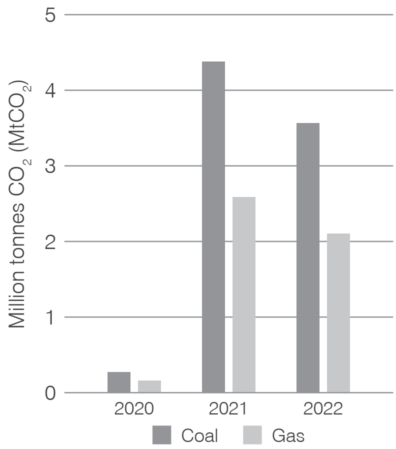
$MtCO_2$ cf. coal

Average nuclear capacity factor



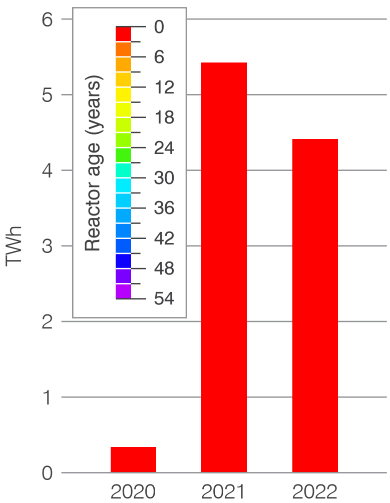
Source: World Nuclear Association, IAEA PRIS

Emissions avoided cf. fossil fuels generation



Source: World Nuclear Association, IAEA PRIS

Nuclear electricity production



Source: World Nuclear Association, IAEA PRIS

Belgium

Belgium has two 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.

Doel 3 was shut down as planned in September 2022. There had been calls to extend the reactor's operation, but operator Engie cited legal and logistical obstacles as an issue. Despite the government asking Engie to investigate extending the operating lifetime of Tihange 2 in July 2022, the unit was also permanently shut down at the end of January 2023 after 40 years of operation.

Events in Ukraine in early 2022 prompted a rapid reassessment of the country's policy to phase out nuclear energy by 2025, which had been reaffirmed in 2020 following the election of a new coalition government. Following the decision in March 2022 to extend the operation of Doel 4 and Tihange 3 to 2035, in February 2023 the government asked Engie to investigate whether Doel 1&2 and Tihange 1 could operate beyond their 2025 shutdown dates, so that they could be held in reserve for the winter months of 2025-2027.

In February 2023 RECUMO, a facility to recycle radioactive residues from the production of medical radioisotopes, began construction in Mol. The facility is scheduled to begin operation in 2026 and will process the current residues and those resulting from isotope production until 2038.

Operable Reactors

4934 MWe

Nuclear Share of Generation

46.4 %

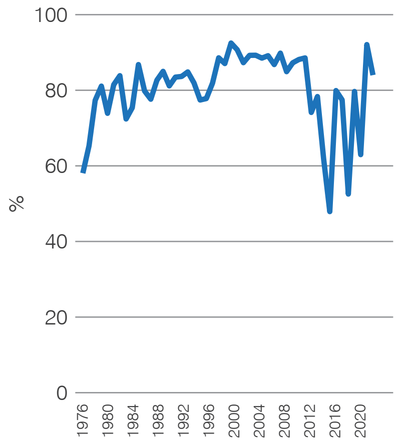
Reactors Under Construction

0 MWe

Lifetime CO_2 Avoided

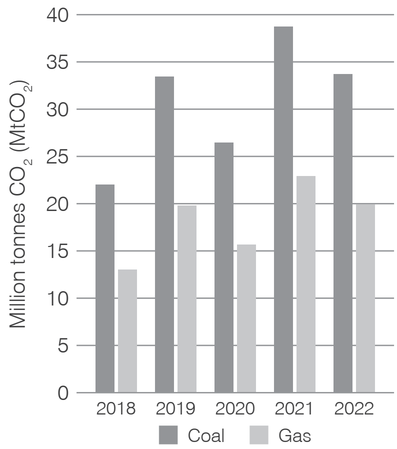
$MtCO_2$ cf. coal

Average nuclear capacity factor



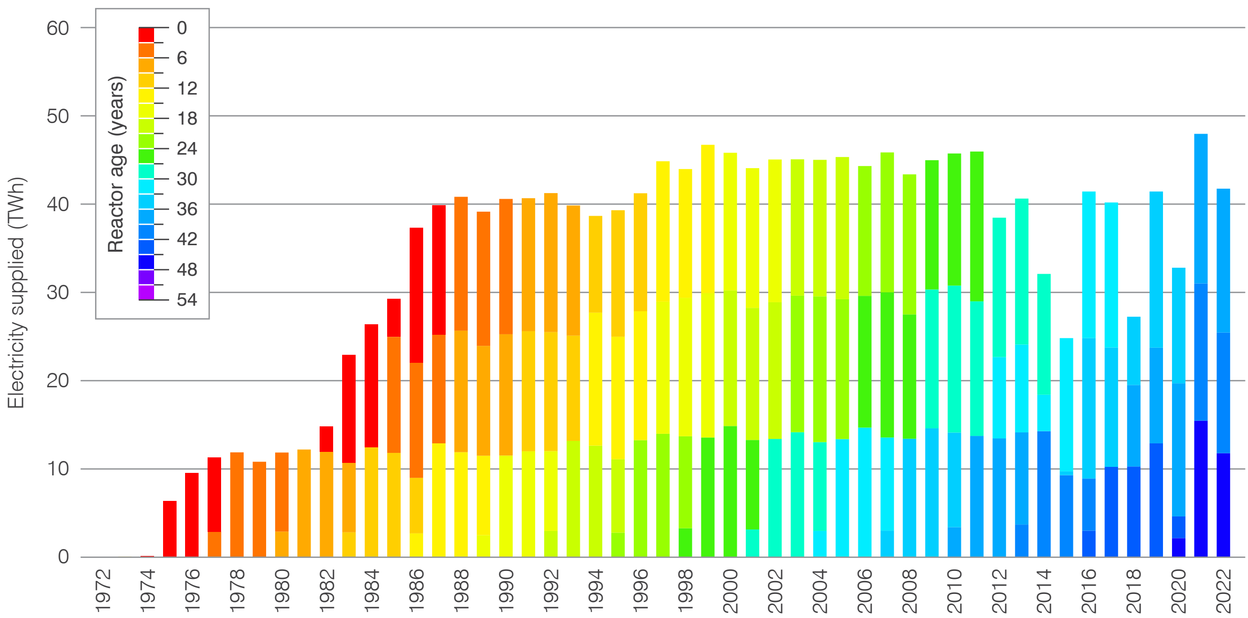
Source: World Nuclear Association, IAEA PRIS

Emissions avoided cf. fossil fuels generation



Source: World Nuclear Association, IAEA PRIS

Nuclear electricity production



Source: World Nuclear Association, IAEA PRIS

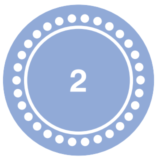
Brazil

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 1884 MWe and a third unit under construction.

Following many years of delay, construction of Angra 3 began in 2010 but has been suspended several times. Construction recommenced in November 2022 but was once again stopped in April 2023 following orders from the municipal government of Angra dos Reis.

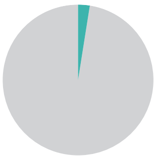
In December 2022 Indústrias Nucleares do Brasil (INB) signed a contract with Rosatom for the supply of 330 tonnes of uranium in the form of natural uranium hexafluoride to the Angra plant from 2023 to 2027. In May 2023, three contracts were signed with Westinghouse to cover the supply of advanced 16x16 fuel assemblies for Angra 1 reloads and to develop a project for the protective grid component of the fuel assembly, as well as INB supplying staff to move fuel in the USA.

Operable Reactors



1884 MWe

Nuclear Share of Generation



2.5 %

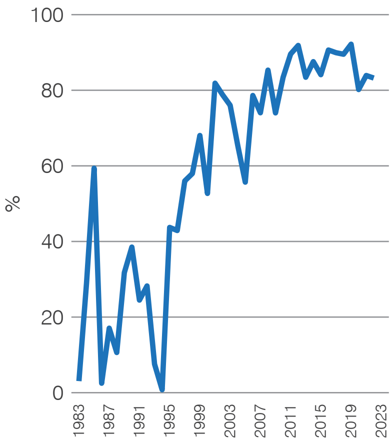
Reactors Under Construction

1340 MWe

Lifetime CO_2 Avoided

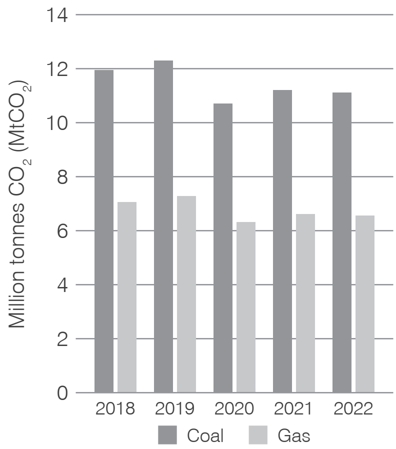
$MtCO_2$ cf. coal

Average nuclear capacity factor



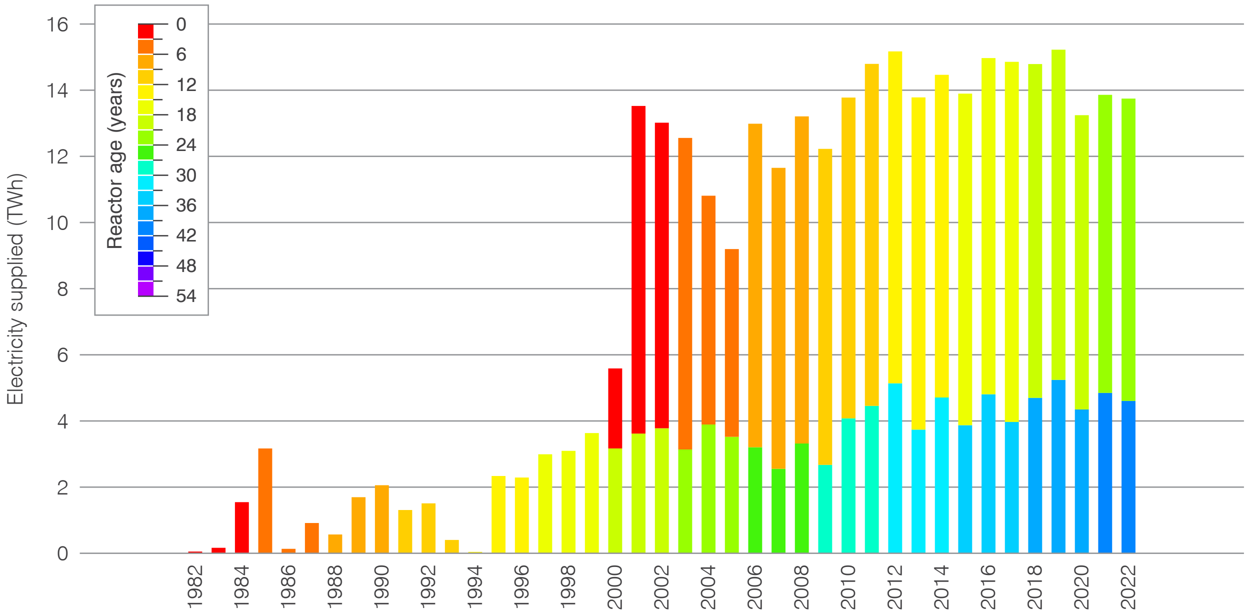
Source: World Nuclear Association, IAEA PRIS

Emissions avoided cf. fossil fuels generation



Source: World Nuclear Association, IAEA PRIS

Nuclear electricity production



Source: World Nuclear Association, IAEA PRIS

Bulgaria

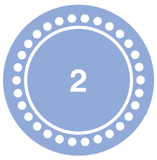
Bulgaria has one nuclear power plant, Kozloduy, located on the Danube River about 110 km north of Sofia. It has two operating VVER-1000 reactors, with a combined capacity of 2006 MWe. Four VVER-440 units were shut down in the 2000s as a condition of the country joining the European Union.

Events in Ukraine in early 2022 resulted in Bulgaria looking to secure an alternative to Russian-supplied nuclear fuel. Following a vote, in December 2022 the government signed a 10-year deal with Westinghouse to supply fuel for Kozloduy 5 and an agreement with Framatome to supply fuel for Kozloduy 6 between 2025-2034.

In January 2023 the energy minister set out an energy strategy that includes plans for two new reactors at Kozloduy and two at Belene. The strategy outlines the continued use of coal until 2030 before reducing its use to zero by 2038.

The same month, the National Assembly voted by 112 to 45, with 39 abstentions, in favour of a draft decision asking ministers to negotiate with the US government for a new AP1000 unit at Kozloduy.

Operable Reactors



2006 MWe

Nuclear Share of Generation

32.6 %

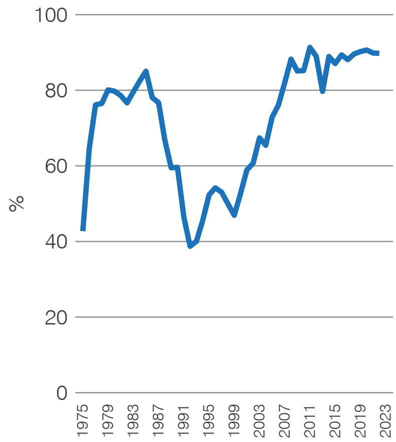
Reactors Under Construction

0 MWe

Lifetime CO_2 Avoided

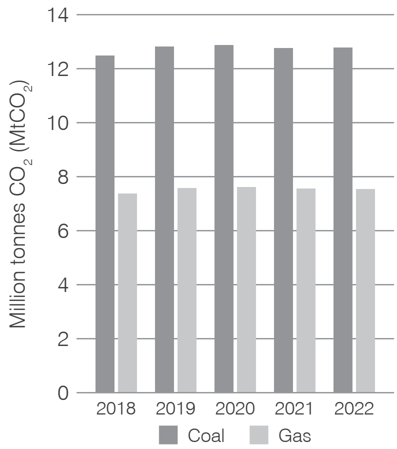
$MtCO_2$ cf. coal

Average nuclear capacity factor



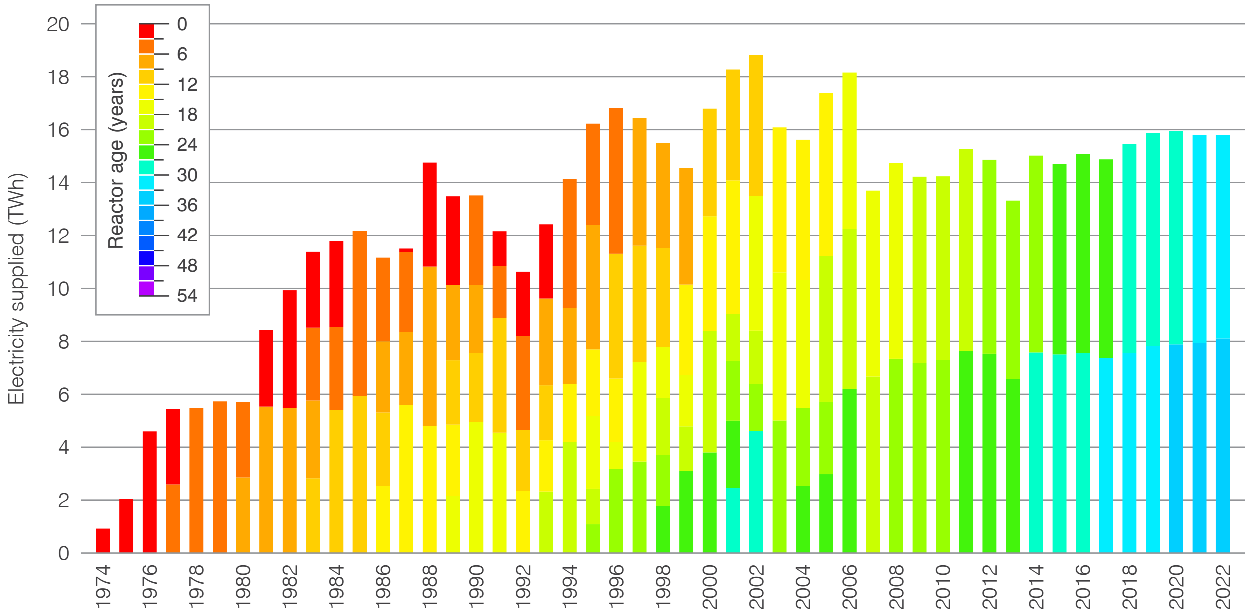
Source: World Nuclear Association, IAEA PRIS

Emissions avoided cf. fossil fuels generation



Source: World Nuclear Association, IAEA PRIS

Nuclear electricity production



Source: World Nuclear Association, IAEA PRIS

Canada

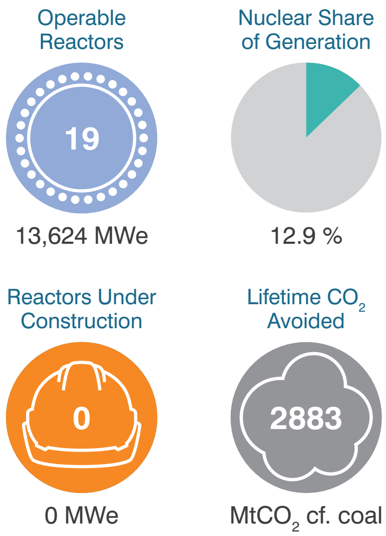
Nineteen reactors operate at four plants in southeast Canada, 18 of which are in Ontario and one in New Brunswick.

The Bruce nuclear power plant comprises eight units commissioned between 1977 and 1987. In 2015 it was decided that six of the units would be refurbished to extend their operation to 2064.

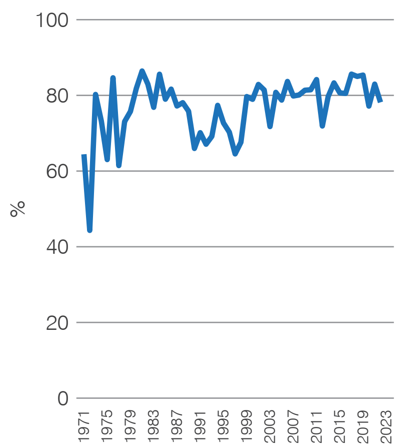
In May 2023 the first refurbished Bruce unit, unit 6, reached the major milestone of 'substantial completion', with refuelling work under way. In March 2023 the refurbishment of unit 3 began, with the reactor scheduled to come back online in 2026.

In 2015 Ontario Power Generation (OPG) decided on a full refurbishment programme for the Darlington plant to enable 30-year lifetime extensions for the four reactors. Unit 2 was taken offline in October 2016 and restarted in June 2020. Unit 3 was taken offline for refurbishment in September 2020, followed by unit 1 in February 2022. It is anticipated that unit 3 will resume operation by late 2023. Refurbishment of unit 4 is planned to commence in July 2023, with work on all four units on track for completion by 2026.

In January 2023 OPG, GE Hitachi, SNC-Lavalin and Aecon announced a six-year alliance to develop, engineer and construct a BWRX-300 at Darlington.

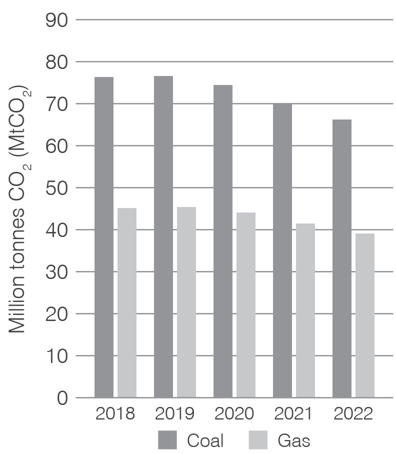


Average nuclear capacity factor



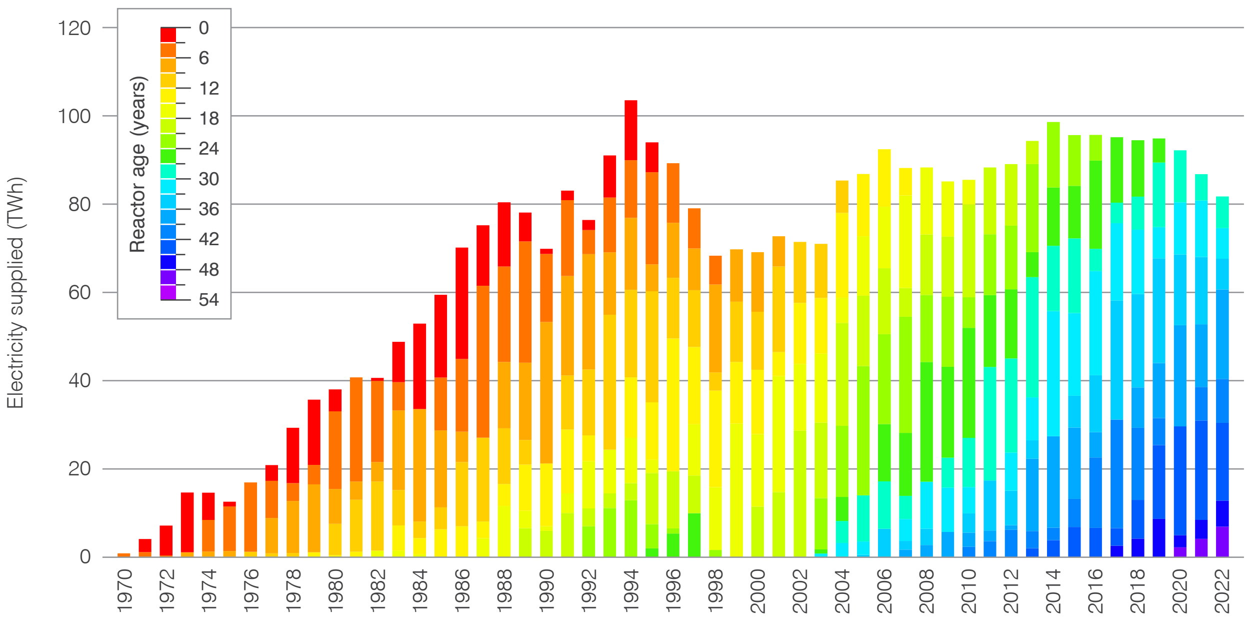
Source: World Nuclear Association, IAEA PRIS

Emissions avoided cf. fossil fuels generation



Source: World Nuclear Association, IAEA PRIS

Nuclear electricity production



Source: World Nuclear Association, IAEA PRIS

China, mainland

Mainland China has 55 operable reactors with a total capacity of 53 GWe, primarily at sites along its southeast coastline. It also has 23 reactors under construction as of June 2023, totaling 24 GWe

In January 2023 the first Hualong One reactor in China, unit 3 at Fangchenggang, was connected to the grid. The unit began construction in December 2015.

Four CAP1000 reactors have commenced construction: Sanmen 3&4 in June 2022 and March 2023; and Haiyang 3&4 in July 2022 and April 2023, respectively.

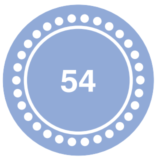
A 1100 MWe Hualong One reactor started construction at Lufeng 5 in September 2022.

In February 2023 construction began on a 23 km-long heating pipe network that would transport nuclear-generated heat from the Haiyang plant. The project is planned to be put into operation before the end of 2023 and would provide up to 9.7 million gigajoules, enough to meet the needs of one million residents.

The country's first industrial heating project from a nuclear power plant was completed in December 2022. The Zhejiang Haiyan Nuclear Energy Heating Demonstration Project uses residual thermal power from the Qinshan plant in winter to supply 288,000 gigajoules of heat to public facilities, residential communities and industrial parks in Haiyan County.

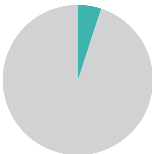
In November 2022 CNNC began construction of China's first nuclear generation-supported pumped hydro storage project, with power from the Zhangzhou plant.

Operable Reactors



52,181 MWe

Nuclear Share of Generation



5 %

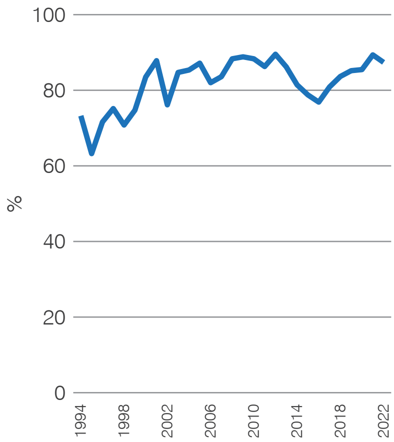
Reactors Under Construction

22,084 MWe

Lifetime CO_2 Avoided

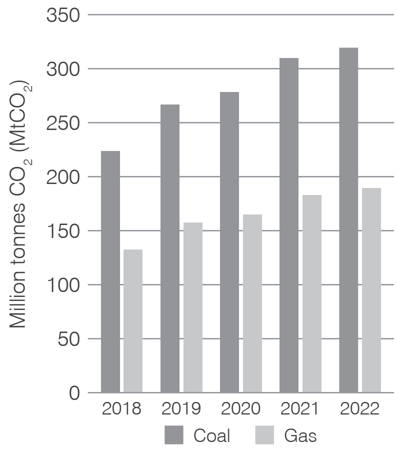
$MtCO_2$ cf. coal

Average nuclear capacity factor



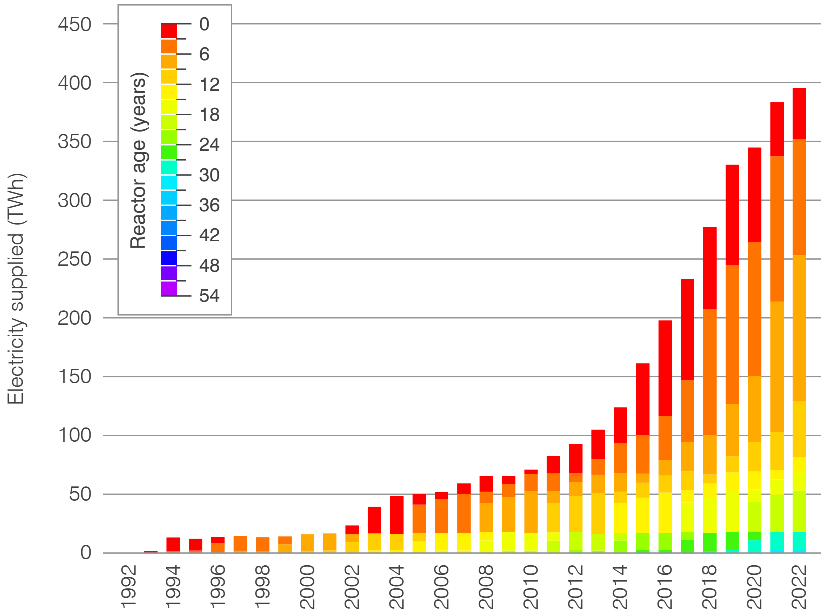
Source: World Nuclear Association, IAEA PRIS

Emissions avoided cf. fossil fuels generation



Source: World Nuclear Association, IAEA PRIS

Nuclear electricity production



Source: World Nuclear Association, IAEA PRIS

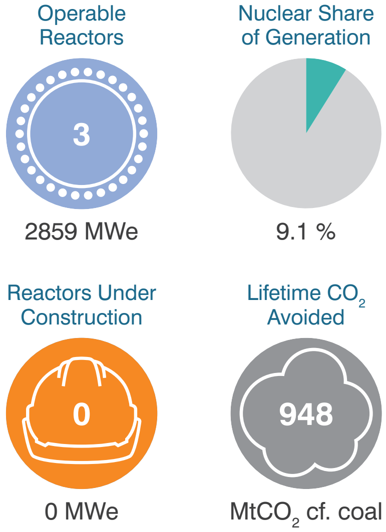
Taiwan, China

Taiwan has two operable nuclear power reactors with a combined capacity of 1874 MWe located at Maanshan, on the southern coast of the island. The reactors' operating licences expire on 27 July 2024 and 17 May 2025, respectively.

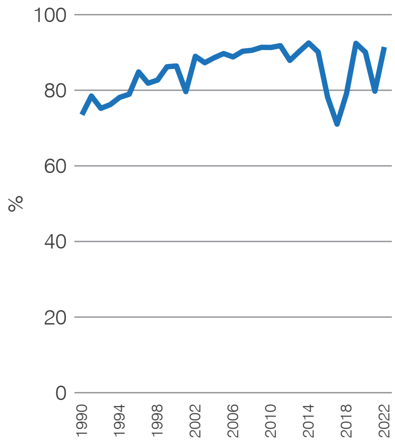
Taiwan's Democratic Progressive Party (DPP) was elected to government in January 2016 with a policy of creating a "nuclear-free homeland" by 2025. Under this policy, the island's six power reactors that were then operable would be decommissioned as their 40-year operating licences expire. Shortly after taking office, the government passed an amendment to the Electricity Act, bringing its phase-out policy into law.

Although this amendment was later removed following a referendum held in November 2018, the government said no nuclear plants would receive licence extensions. In July 2021 Taipower announced the closure of unit 1 at the Kuosheng plant, followed by unit 2 in March 2023.

The government aims for an energy mix of 20% from renewable sources, 50% from liquefied natural gas and 30% from coal.

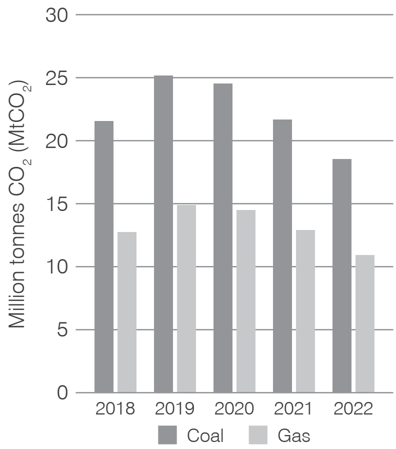


Average nuclear capacity factor



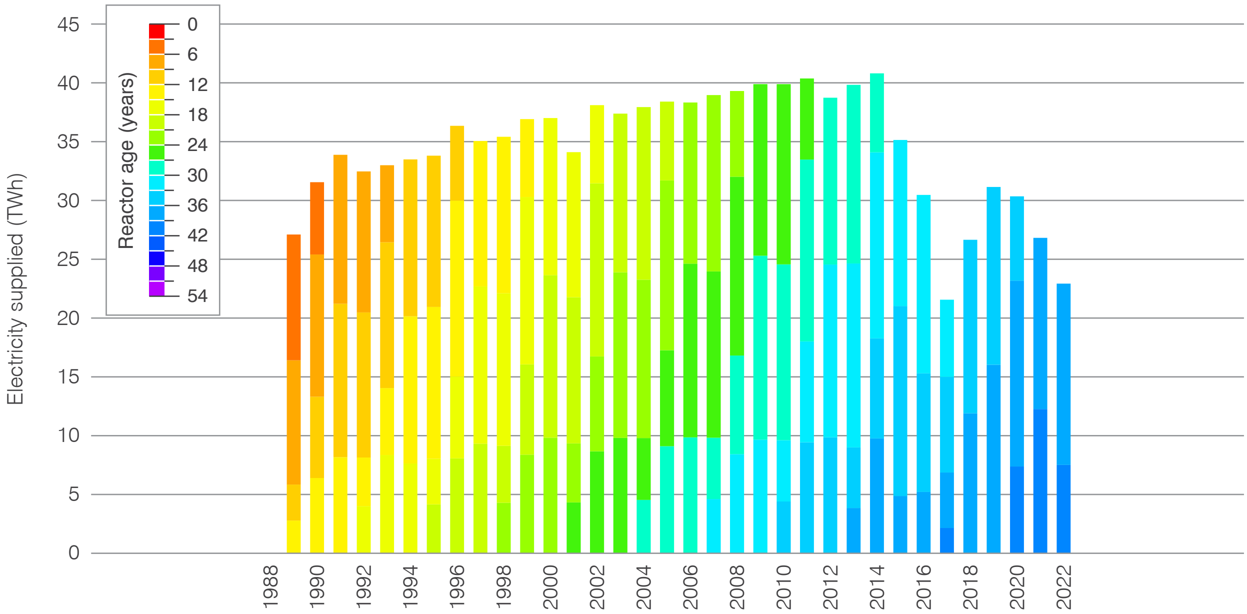
Source: World Nuclear Association, IAEA PRIS

Emissions avoided cf. fossil fuels generation



Source: World Nuclear Association, IAEA PRIS

Nuclear electricity production



Source: World Nuclear Association, IAEA PRIS

Czech Republic

The Czech Republic has six operable reactors: two VVER-1000 units at Temelin, 100 km south of Prague; and four VVER-440 units at Dukovany, 30 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. In February 2023 Czech utility CEZ announced that it planned to invest around $100 million into Dukovany 4 to extend the unit's operational lifetime to 60 years, to 2047.

In November 2022 three vendors – EDF, Westinghouse and Korea Hydro and Nuclear Power – submitted initial bids to build a new reactor at Dukovany. Final bids are expected by September 2023.

The country is also planning the construction of its first SMR, with Temelin a potential site. In February 2023 CEZ identified the coal-fired power plants at Dětmarovice and Tušimice as the preferred locations for a second and third SMR, with CEZ hoping to get the sites up and running by the second half of the 2030s. The country has committed to phasing out coal power generation by 2033.

In March 2023 CEZ signed an agreement with Westinghouse for the supply of VVER-440 fuel assemblies to Dukovany from 2024. This followed a similar agreement made in April 2022 for Westinghouse and Framatome to supply Temelin.

Operable Reactors

3934 MWe

Nuclear Share of Generation

36.7 %

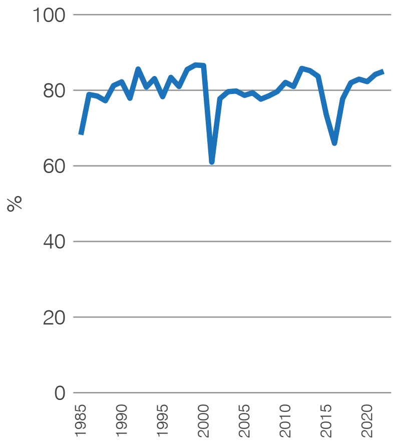
Reactors Under Construction

0 MWe

Lifetime CO_2 Avoided

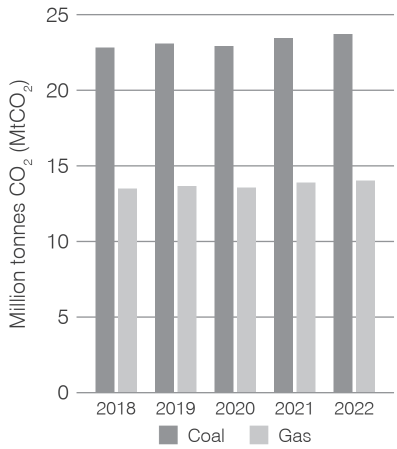
$MtCO_2$ cf. coal

Average nuclear capacity factor



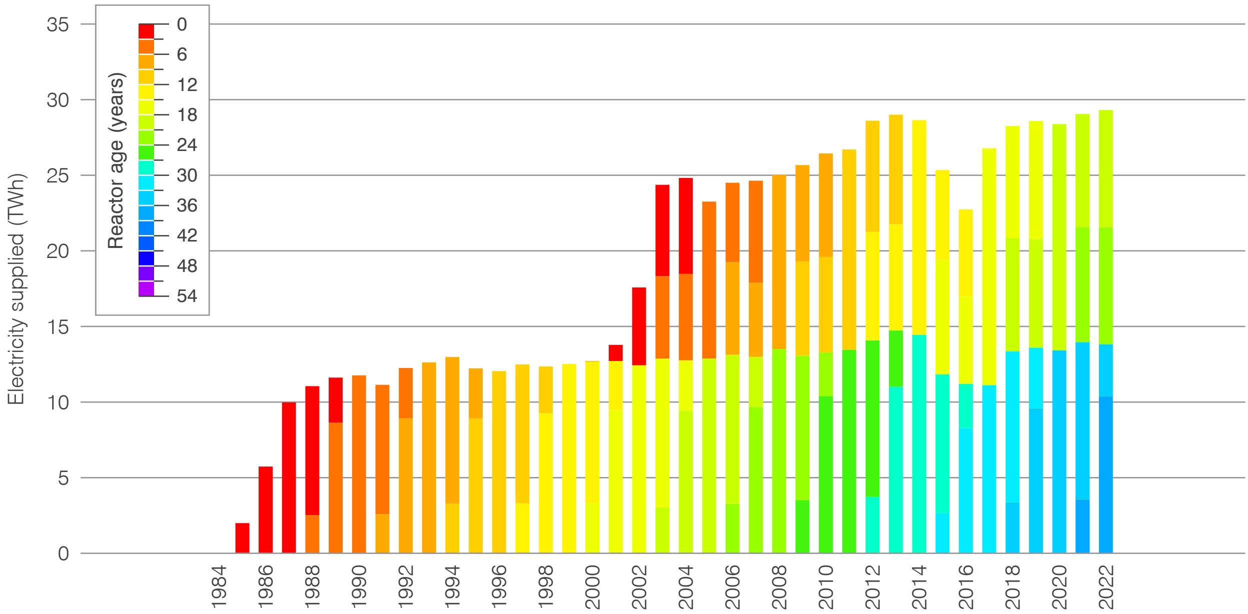
Source: World Nuclear Association, IAEA PRIS

Emissions avoided cf. fossil fuels generation



Source: World Nuclear Association, IAEA PRIS

Nuclear electricity production



Source: World Nuclear Association, IAEA PRIS

Egypt

Three VVER-1200 units are currently under construction in Egypt at El Dabaa, on the North Mediterranean coast, 140 km west of Alexandria. A fourth unit is also planned, with significant desalination capacity.

In November 2015 an intergovernmental agreement was signed with Russia to build and operate the four reactors, including fuel supply, used fuel, training and development of regulatory infrastructure. In April 2019 the Nuclear Power Plants Authority (NPPA) received a site approval permit for the El Dabaa site from the Egyptian Nuclear Regulation and Radiological Authority (ENRRA).

Construction of El Dabaa 1 commenced in July 2022, followed by unit 2 in November 2022 and unit 3 at the beginning of May 2023.

Operable Reactors

0

0 MWe

Nuclear Share of Generation

0 %

Reactors Under Construction

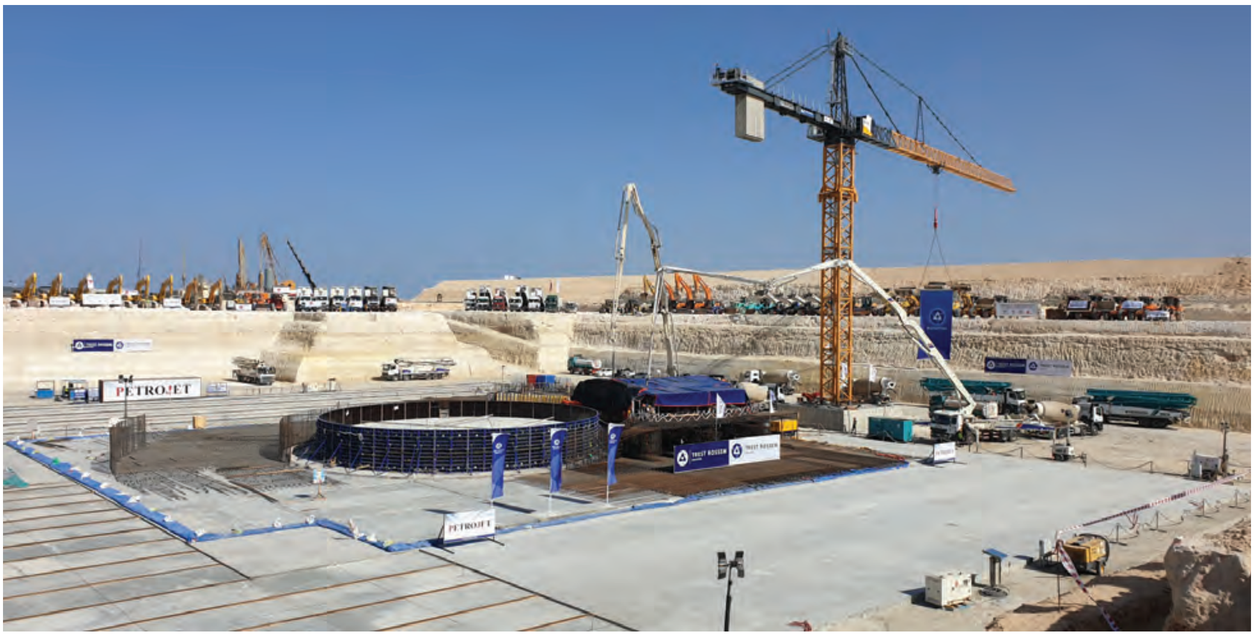
2

2388 MWe

Lifetime CO_2 Avoided

0

$MtCO_2$ cf. coal



Start of construction of unit 2 at El Dabaa (Image: Rosatom)

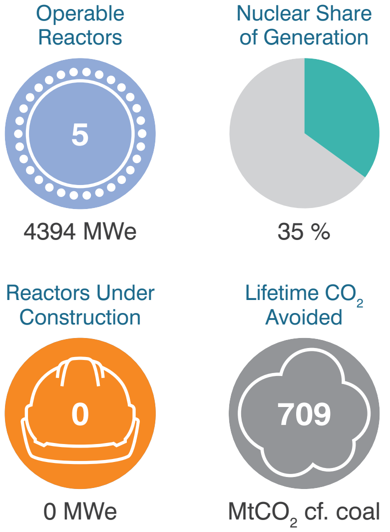
Finland

Finland has two nuclear power plants: Loviisa, a two-unit VVER-440 plant, located 80 km east of Helsinki; and Olkiluoto, about 220 km northwest of the capital, with twin BWR units and an EPR.

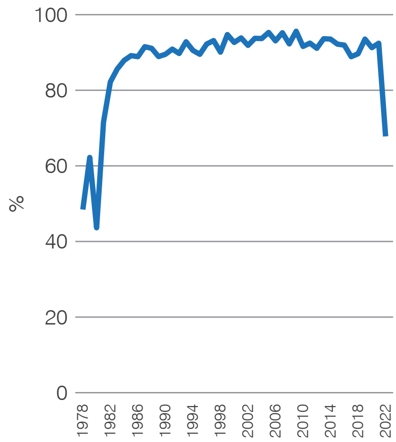
Construction of Olkiluoto 3 – Europe's first EPR – commenced in May 2005 . First criticality was eventually achieved in December 2021, with first power in March 2022. Following an extended test phase – during which damage to the impellers of all four of the feedwater pumps had to be repaired – regular electricity production commenced in mid-April 2023.

In February 2023 the Finnish government approved Fortum's operating lifetime extension request for an additional 20-year term, which would extend the operation of Loviisa 1&2 until the end of 2050. The units started up in 1977 and 1980, respectively.

A contract for Rusatom Overseas to supply a VVER-1200 reactor at Hanhikivi on the coast of Bothnian Bay, near Pyhäjoki, had been signed by the Fennovoima consortium in December 2013. Following Russia's invasion of Ukraine, Fennovoima announced in May 2022 that it was terminating the contract. This was later ruled unlawful by the Dispute Review Board (DRB) and Fennovoima has since initiated international arbitration proceedings.

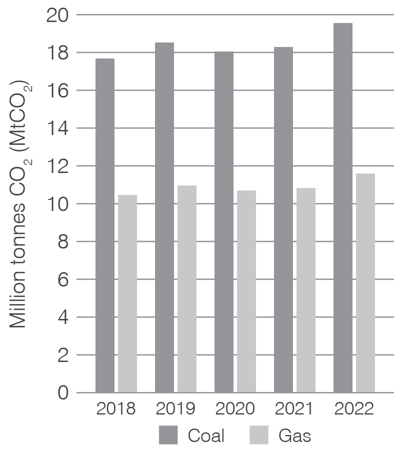


Average nuclear capacity factor



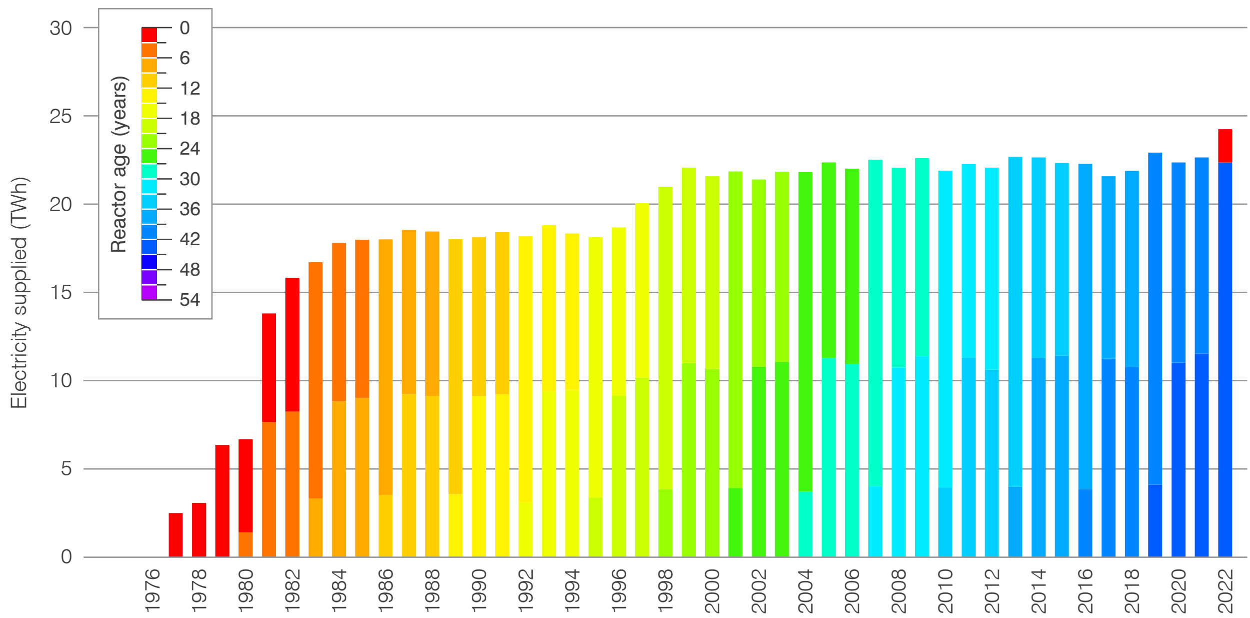
Source: World Nuclear Association, IAEA PRIS

Emissions avoided cf. fossil fuels generation



Source: World Nuclear Association, IAEA PRIS

Nuclear electricity production



Source: World Nuclear Association, IAEA PRIS

France

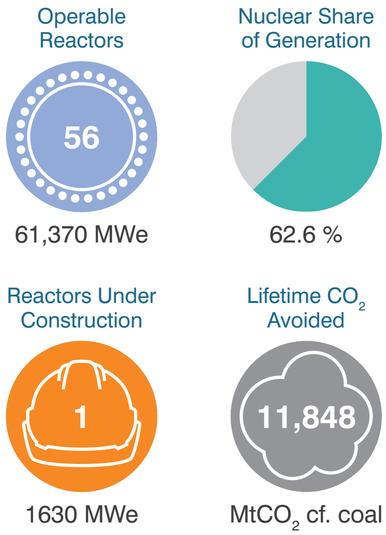
France has 56 operable reactors with a total capacity of 61,400 MWe at a variety of coastal and inland sites throughout the country. An EPR is under construction at the Flamanville plant in Normandy on the northwest coast.

In January 2023 the government approved a draft bill that included the removal of the objective to reduce the nuclear share of France's electricity production to 50% by 2035.

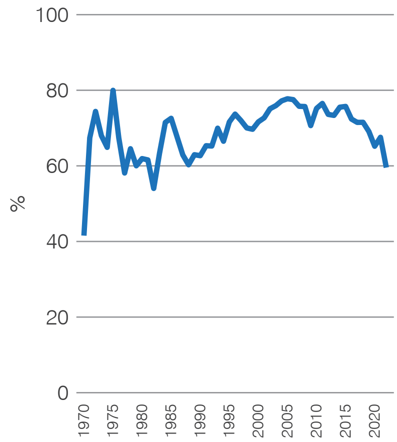
In March 2023 France’s Parliament formally approved the government’s nuclear investment plan to construct six EPR-2 units at three sites at an estimated cost of €52 billion.

The full renationalization of EDF was completed in June 2023. The utility’s finances have recently been adversely impacted by generic stress corrosion issues at several nuclear plants. The problem was first discovered in December 2021, when maintenance checks on the primary circuit at Civaux 1 revealed corrosion near the welds on pipes of the safety injection system. Similar faults were soon discovered at other units, requiring the need for checks across much of the country’s nuclear fleet. Due to the resulting outages, in February 2023 EDF posted a record annual loss of €17.9 billion ($19.0 billion) for 2022.

In July 2022 France's nuclear safety regulator, the Autorité de Sûreté Nucléaire, approved of EDF’s inspection and repair strategy for all of its reactors for the years 2023-2025.

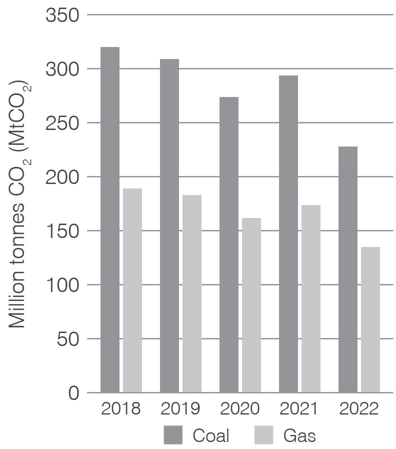


Average nuclear capacity factor



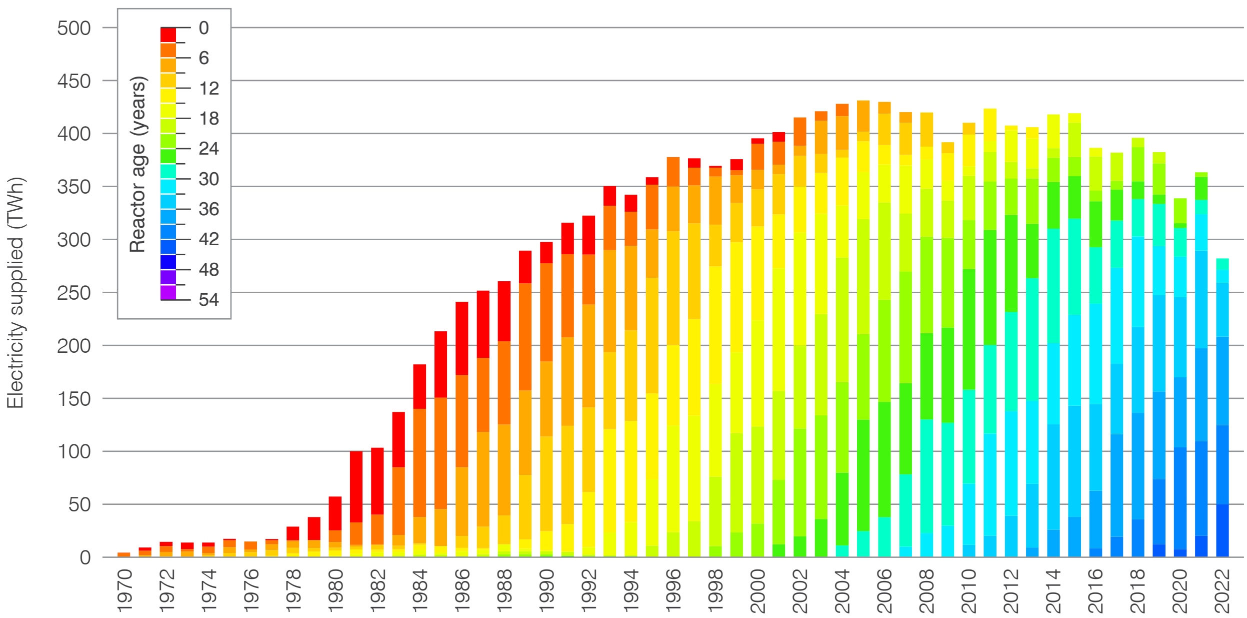
Source: World Nuclear Association, IAEA PRIS

Emissions avoided cf. fossil fuels generation



Source: World Nuclear Association, IAEA PRIS

Nuclear electricity production



Source: World Nuclear Association, IAEA PRIS

Germany

Germany has no nuclear power after closing its final three reactors – Neckarwestheim 2, Isar 2 and Emsland – in April 2023.

The three reactors had been due to close at the end of 2022, but the Russia-Ukraine war prompted a reappraisal of this plan. Following a 'stress test' conducted by the country's power grid transmission operators, in October 2022 it was decided that the reactors were to continue operating until mid-April 2023.

Operable Reactors

3

4055 MWe

Nuclear Share of Generation

5.8 %

Reactors Under Construction

0

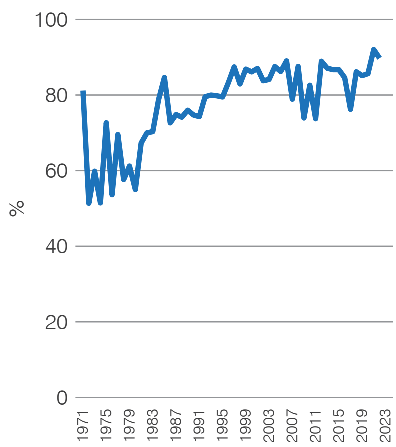
0 MWe

Lifetime CO_2 Avoided

4193

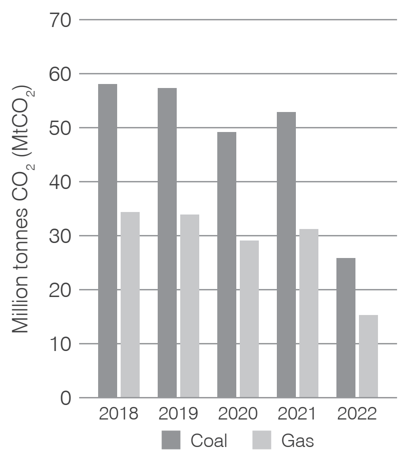
$MtCO_2$ cf. coal

Average nuclear capacity factor



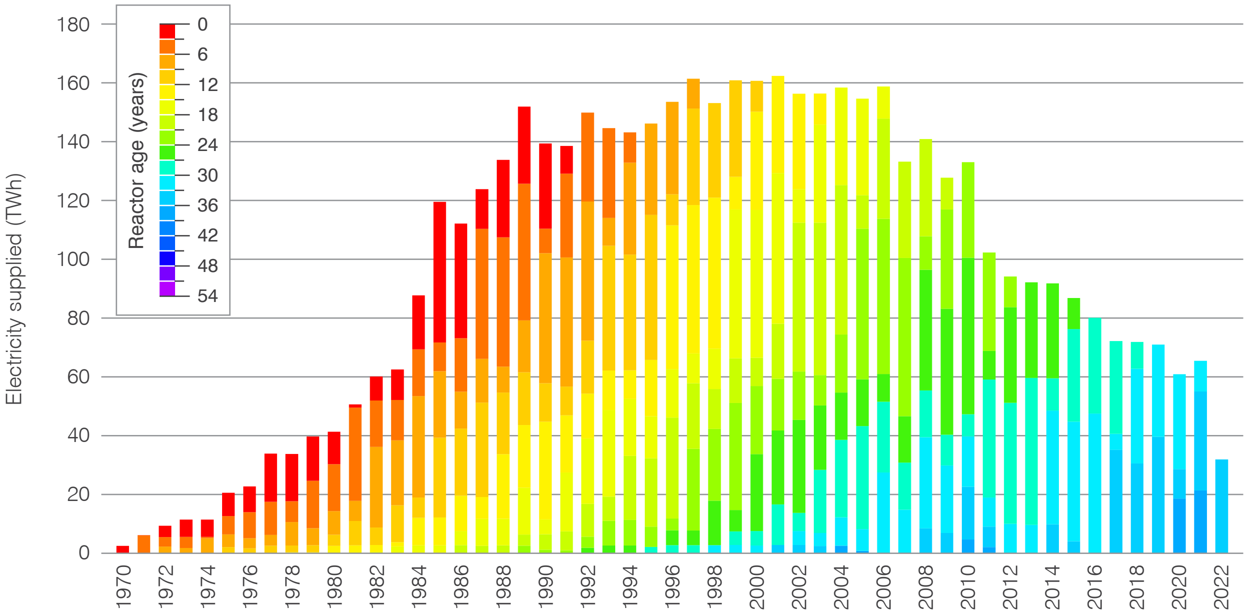
Source: World Nuclear Association, IAEA PRIS

Emissions avoided cf. fossil fuels generation



Source: World Nuclear Association, IAEA PRIS

Nuclear electricity production



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 1916 MWe. The plant generates around half of the electricity produced in Hungary, but supplies around a third of electricity demand as the country relies heavily on imported electricity.

All four units started up in the 1980s, and would have originally reached the end of their service lifetimes between 2012 and 2017 but received 20-year licence extensions. In December 2022 the Hungarian parliament approved plans to extend the operating lifetime of the four units for an additional 20 years. The legislation received overwhelming support with 170 votes in favour, eight against, and one abstention. This decision allows the state to prepare for operating the Paks plant into the 2050s.

In August 2022 the Hungarian Atomic Energy Authority (HAEA) issued a construction licence for two VVER-1200 units at Paks II, to be built by Rosatom.

In April 2023 the government announced its intention to proceed with the construction of Paks II despite the conflict between Russia and Ukraine and the European Union's sanctions against Russia. Although details were not made public, it was announced that an amendment to the construction and financing of the Paks II project was agreed with Rosatom. The following month, the European Commission approved the amended contract.

Operable Reactors

1916 MWe

Nuclear Share of Generation

47 %

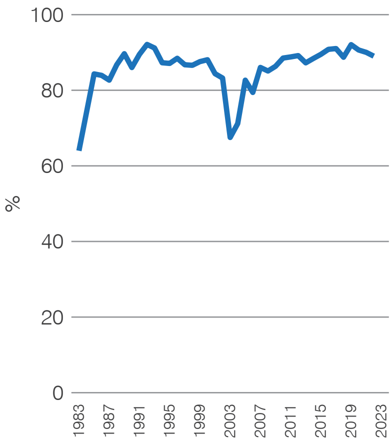
Reactors Under Construction

0 MWe

Lifetime CO_2 Avoided

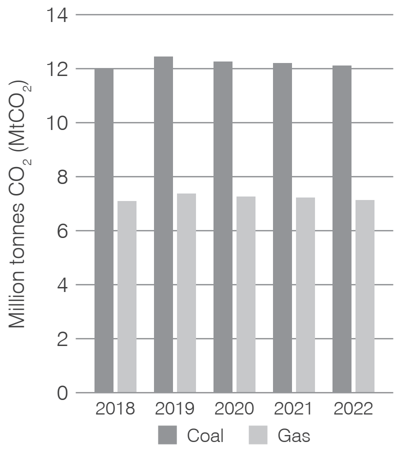
$MtCO_2$ cf. coal

Average nuclear capacity factor



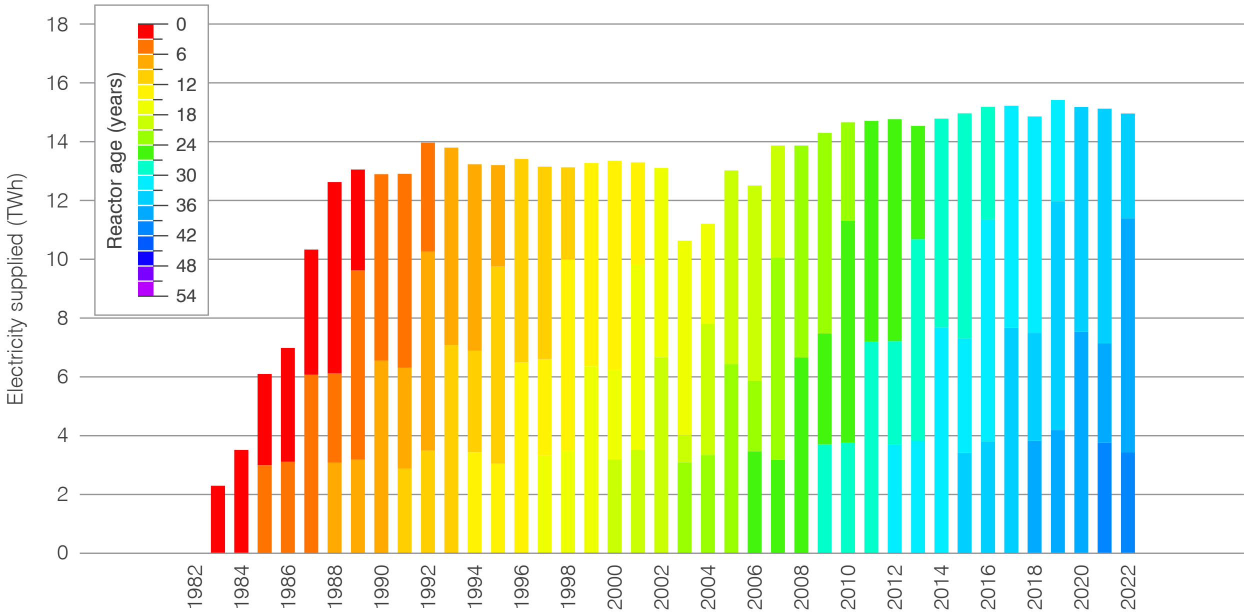
Source: World Nuclear Association, IAEA PRIS

Emissions avoided cf. fossil fuels generation



Source: World Nuclear Association, IAEA PRIS

Nuclear electricity production



Source: World Nuclear Association, IAEA PRIS

India

India has 22 reactors at seven nuclear power plants located both inland and along the coast. The majority of reactors are indigenously-designed pressurized heavy water reactors (PHWRs).

In April 2023 the government announced plans to increase nuclear capacity from 6780 MWe to 22,480 MWe by 2031, with nuclear accounting for nearly 9% of India's electricity by 2047.

Two VVER-1000 reactors at the Kudankulam nuclear power plant, located in Tamil Nadu, began commercial operation in 2013 and 2017, respectively. Four additional VVER-1000 units are under construction at the site: units 3&4 began construction in 2017; unit 5 in June 2021; and unit 6 in December 2021. All four units are expected to be completed by 2027.

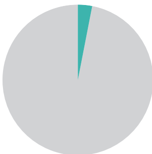
Kakrapar is an indigenously-designed plant in India's Gujarat state with three operating reactors and one under construction. Unit 3 – India's first PHWR-700 – was connected to the grid in January 2021 but has still not reached commercial operation (as of June 2023). Units 3&4 began construction in 2010 and 2011, respectively.

Two further PHWR-700 units are under construction at Rajasthan 7&8 and in May 2023 a 'supplementary joint venture agreement' was signed between NTPC – the country's largest power company – and Nuclear Power Corporation of India Ltd (NPCIL) for the development of six PHWR-700 units: two at Chutka in Madhya Pradesh and four at Mahi Banswara in Rajasthan.

Operable Reactors

7182 MWe

Nuclear Share of Generation



3.1 %

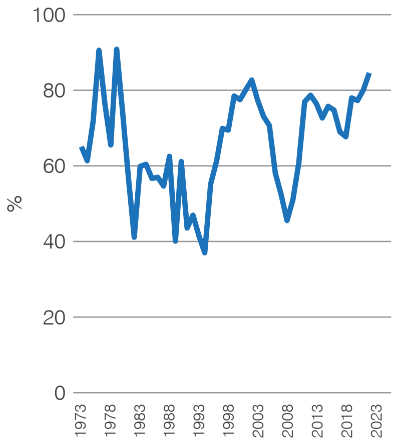
Reactors Under Construction

6028 MWe

Lifetime CO_2 Avoided

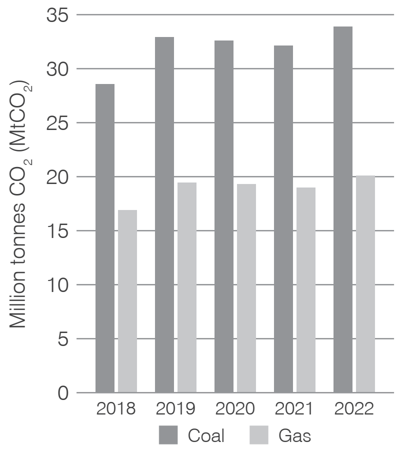
$MtCO_2$ cf. coal

Average nuclear capacity factor



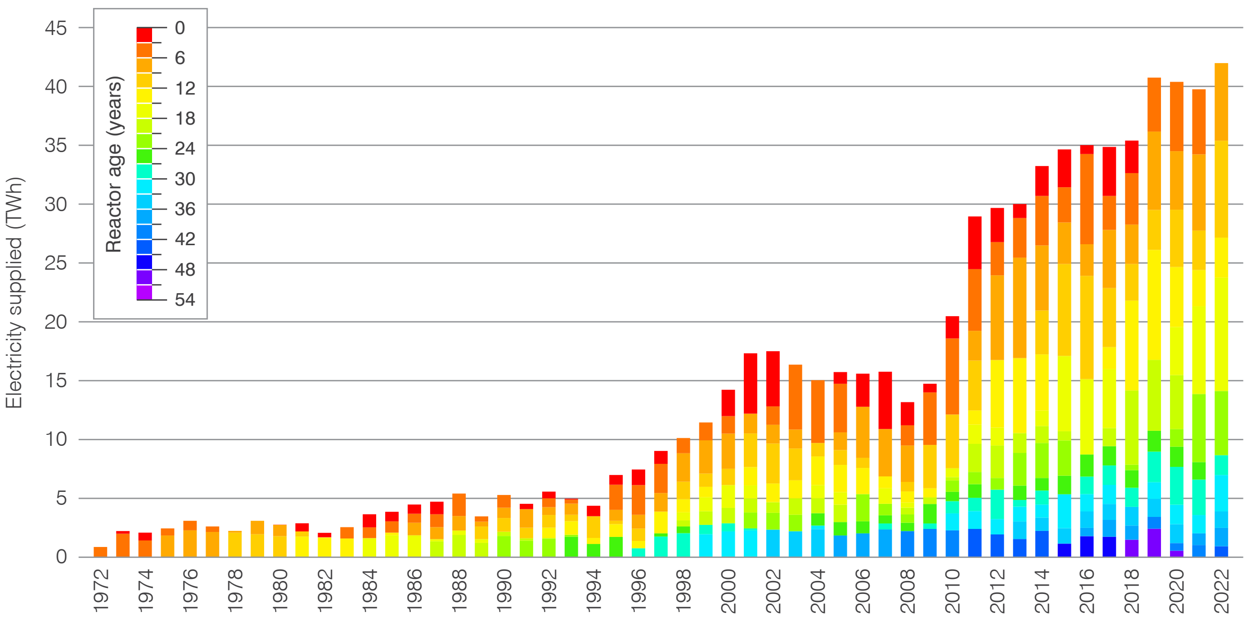
Source: World Nuclear Association, IAEA PRIS

Emissions avoided cf. fossil fuels generation



Source: World Nuclear Association, IAEA PRIS

Nuclear electricity production



Source: World Nuclear Association, IAEA PRIS

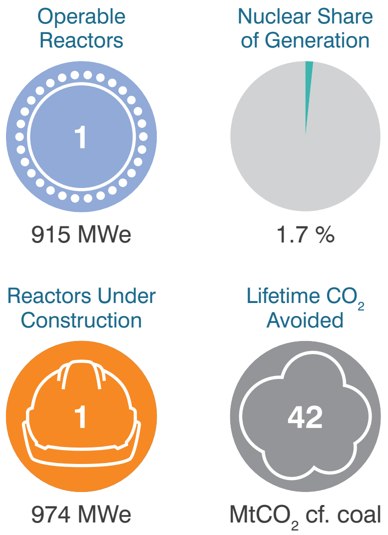
Iran

A single VVER-1000 unit is in operation in Iran on the Persian Gulf coast at the Bushehr site, about 180 km southwest of Shiraz.

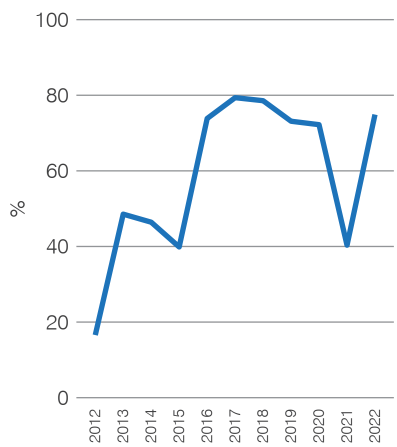
Construction commenced on a second VVER-1000 at Bushehr in 2019 and is expected to start up in 2024. A further VVER-1000 was due two years later, but construction has not yet started. In August 2022 work commenced on the country's first nuclear-powered desalination plant, located at Bushehr, with a capacity of 70,000 m³/day.

Since 2002 Iran has been the subject of IAEA inquiries concerning its possible development of nuclear weapons. In December 2022 the United Nations reported that no progress had been made on the implementation of the 2015 Joint Comprehensive Plan of Action (JCPOA), with Iran still enriching "worrying quantities" of uranium.

In February 2023 France, Germany, the UK and the USA called on Iran to comply with all its international obligations under its Comprehensive Safeguards Agreement. The following month, Iran agreed to enhance its cooperation with the IAEA, including the reinstallation of monitoring cameras at enrichment sites.

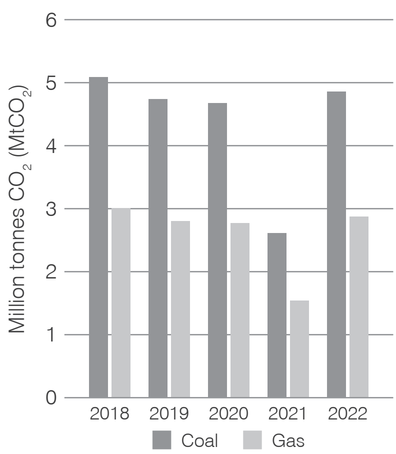


Average nuclear capacity factor



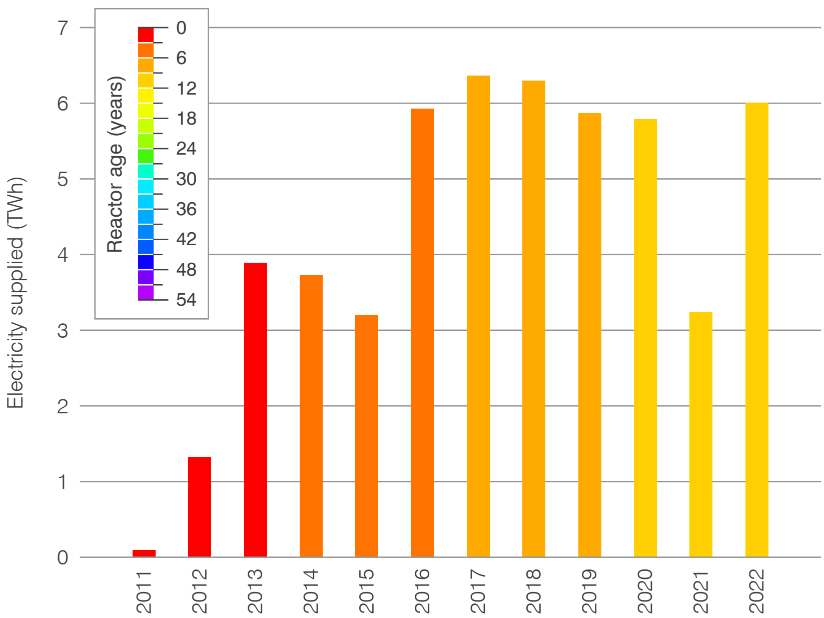
Source: World Nuclear Association, IAEA PRIS

Emissions avoided cf. fossil fuels generation



Source: World Nuclear Association, IAEA PRIS

Nuclear electricity production



Source: World Nuclear Association, IAEA PRIS

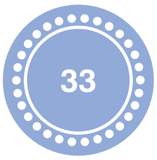
Japan

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. Only ten (9500 MWe) of the country's 33 operable reactors have since restarted as of June 2023.

In September 2022, the Ministry of Economy, Trade & Industry (METI) outlined plans to maintain the 60-year cap on reactor operating lifetimes. However, the years when reactors remained idled – in the wake of the 2011 Fukushima accident – would not be included in the calculation. In February 2023 the cabinet approved a new policy enabling nuclear reactors to operate beyond the 60-year limit, with lifetime extensions approved once every ten years after a reactor has attained 30 years of operation.

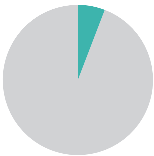
In December 2022 the government adopted a policy maximizing the use of existing reactors by restarting as many of them as possible, whilst also developing advanced reactors to replace those that are shut down.

Operable Reactors



31,679 MWe

Nuclear Share of Generation



6.1 %

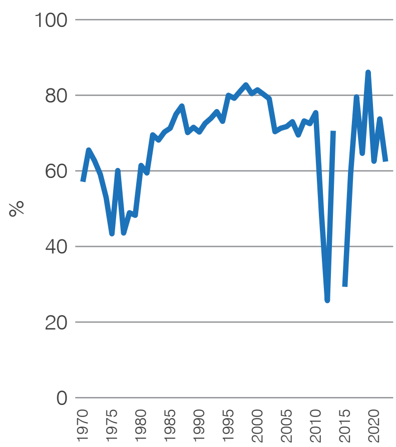
Reactors Under Construction

2653 MWe

Lifetime CO_2 Avoided

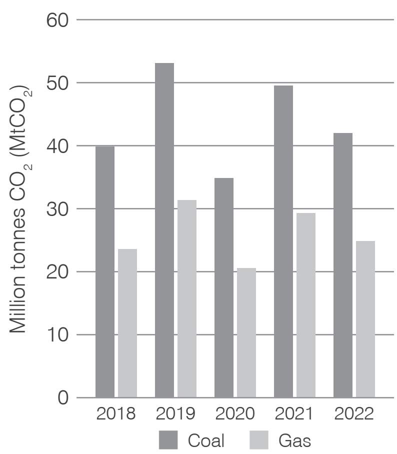
$MtCO_2$ cf. coal

Average nuclear capacity factor



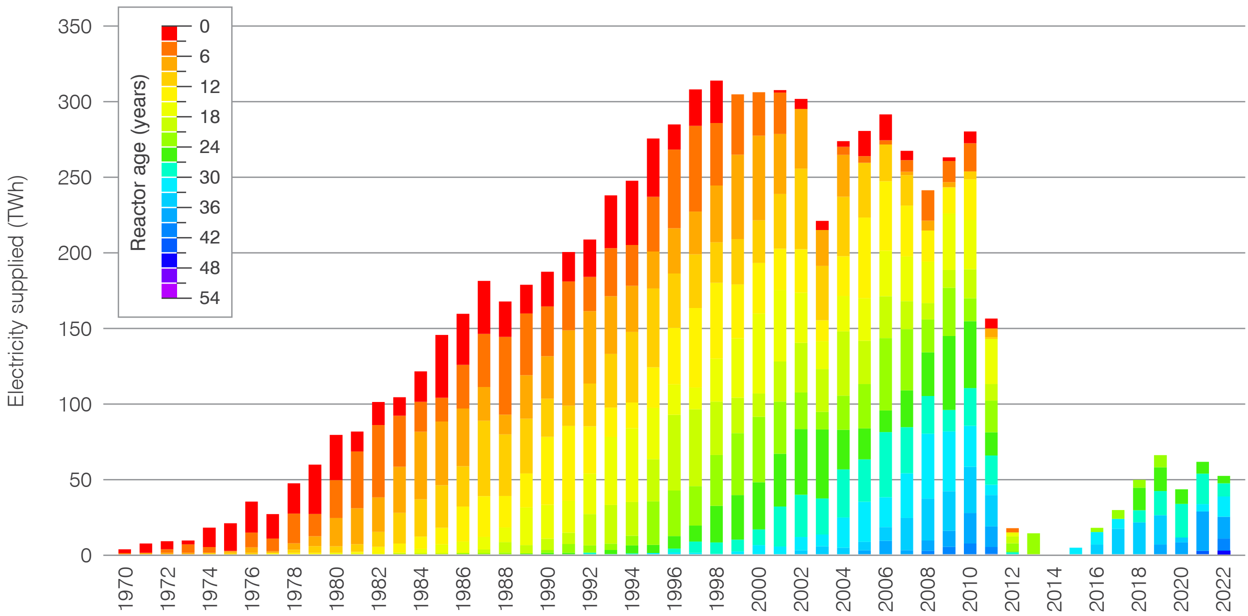
Source: World Nuclear Association, IAEA PRIS

Emissions avoided cf. fossil fuels generation



Source: World Nuclear Association, IAEA PRIS

Nuclear electricity production

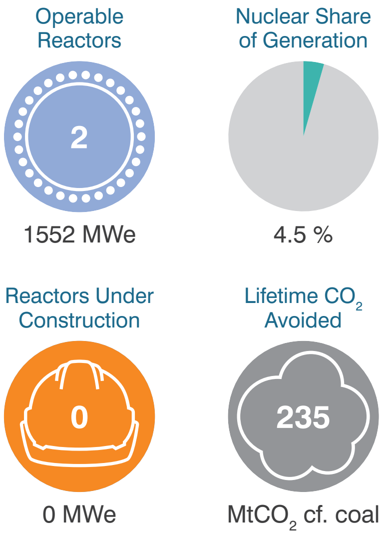


Source: World Nuclear Association, IAEA PRIS

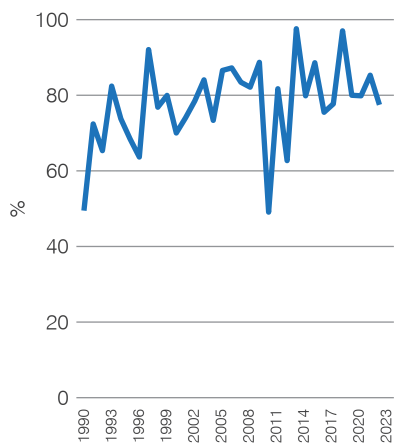
Mexico

Mexico has two operable nuclear reactors located on the east coast of the country, 290 km east of the capital, Mexico City. Laguna Verde 1 began commercial operation in 1990 and unit 2 in 1995.

In July 2020 the Mexico energy ministry approved a 30-year extension of the operating licence for Laguna Verde 1. This would allow the reactor to operate until 2050. In August 2022 Laguna Verde 2 was granted an extension to its operating licence, to April 2055.

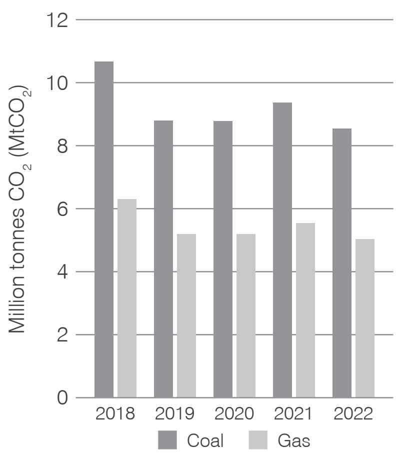


Average nuclear capacity factor



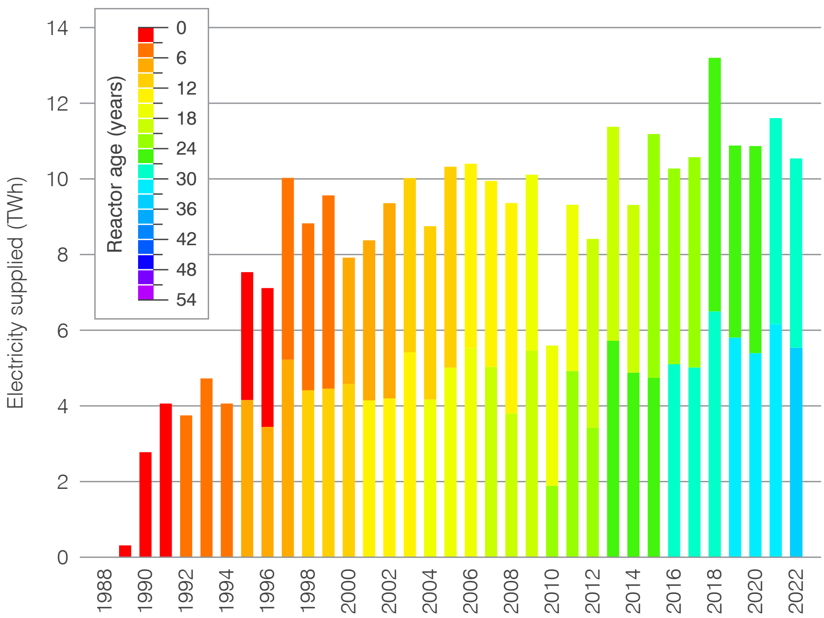
Source: World Nuclear Association, IAEA PRIS

Emissions avoided cf. fossil fuels generation



Source: World Nuclear Association, IAEA PRIS

Nuclear electricity production



Source: World Nuclear Association, IAEA PRIS

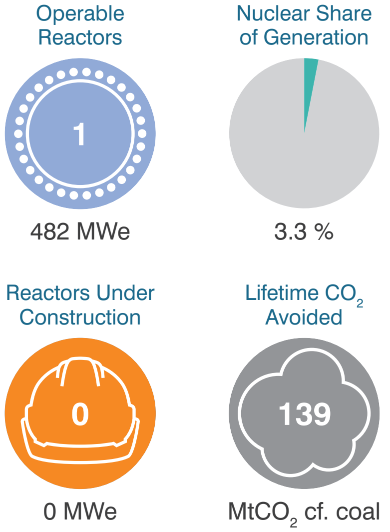
Netherlands

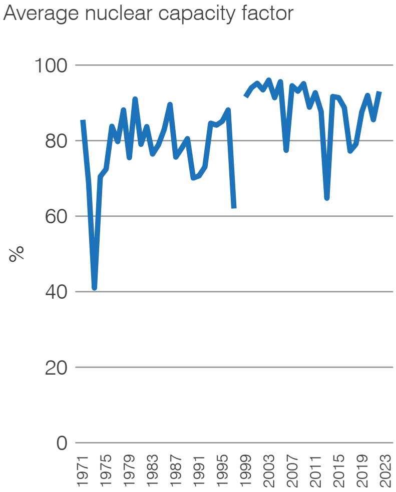
A single 485 MWe PWR is operating at Borssele, about 70 km southwest of Rotterdam.

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.

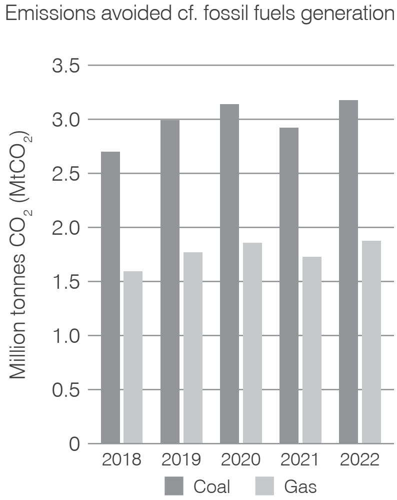
In April 2023 the government announced its draft Climate Fund for 2024, which includes €320 million for the development of nuclear energy. Of this funding, €10 million would go towards studies over the period 2023-2025 regarding the operating lifetime extension of the Borssele plant; €117 million has been allocated for studies on the construction of two new reactors; €65 million would go towards investment in nuclear skills; and €65 million would be used to support the development of SMRs.

Plans to extend the operating lifetime of the Borssele plant beyond its 2033 licence expiration were first considered in December 2022, with technical studies carried out by the Authority for Nuclear Safety and Radiation Protection. The same month, the government earmarked the Borssele site as the most suitable location for the construction of two new reactors. However, it said that a final decision on the location would not be made before the end of 2024. Preliminary plans suggest that the reactors would have a capacity of 1000-1650 MWe, providing 9-13% of the country's electricity, and could be completed by around 2035.

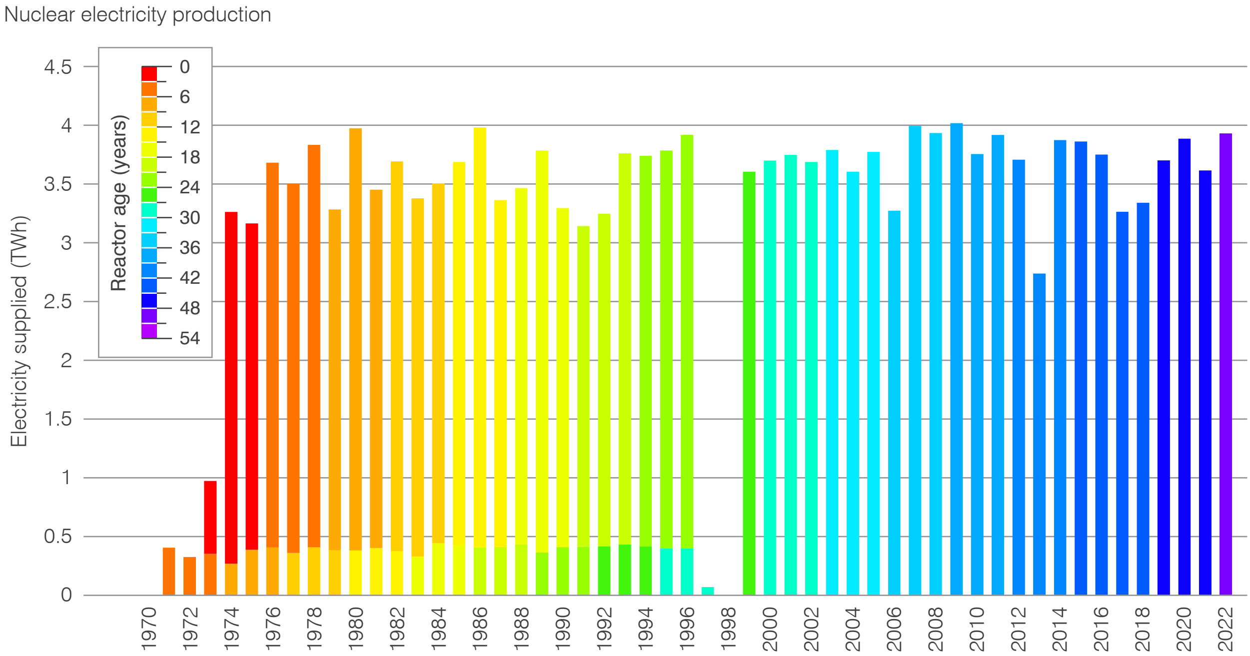




Source: World Nuclear Association, IAEA PRIS



Source: World Nuclear Association, IAEA PRIS



Source: World Nuclear Association, IAEA PRIS

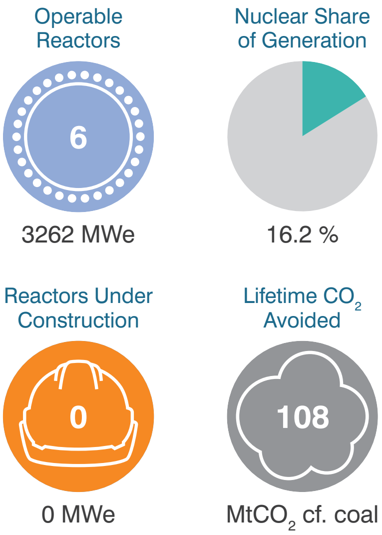
Pakistan

Pakistan has six operating nuclear power reactors supplied by China at two sites: Chashma, inland 210 km southwest of Islamabad; and Karachi, on the coast about 100 km southwest of Hyderabad.

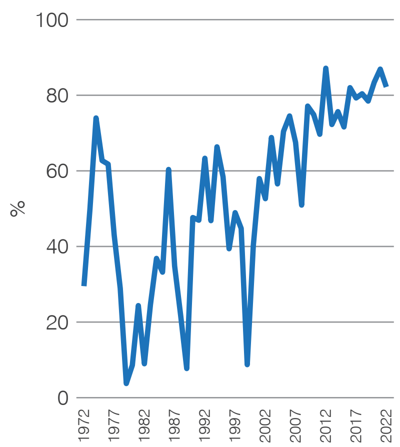
The four units at Chashma are CNP300 models, based on the Qinshan 1 reactor in China. The first reactor came online in 2000 and the fourth unit in 2017.

A construction agreement for an additional unit at Chashma was first signed in November 2010. Following an environmental assessment in 2020, the Pakistan Atomic Energy Commission (PAEC) announced in February 2023 that it had signed the final contracts for the construction of a HPR1000/Hualong One PWR at unit 5 of Chashma. The reactor will be built by China National Nuclear Corporation, which will also supply 85% of the estimated $3.7 billion required for the construction.

Karachi hosts two Chinese-designed HPR1000 units. 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 and commercial operation was in April that year.

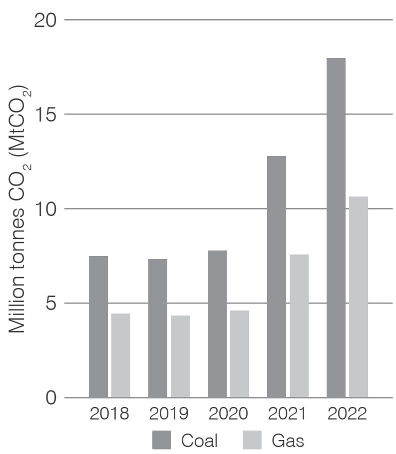


Average nuclear capacity factor



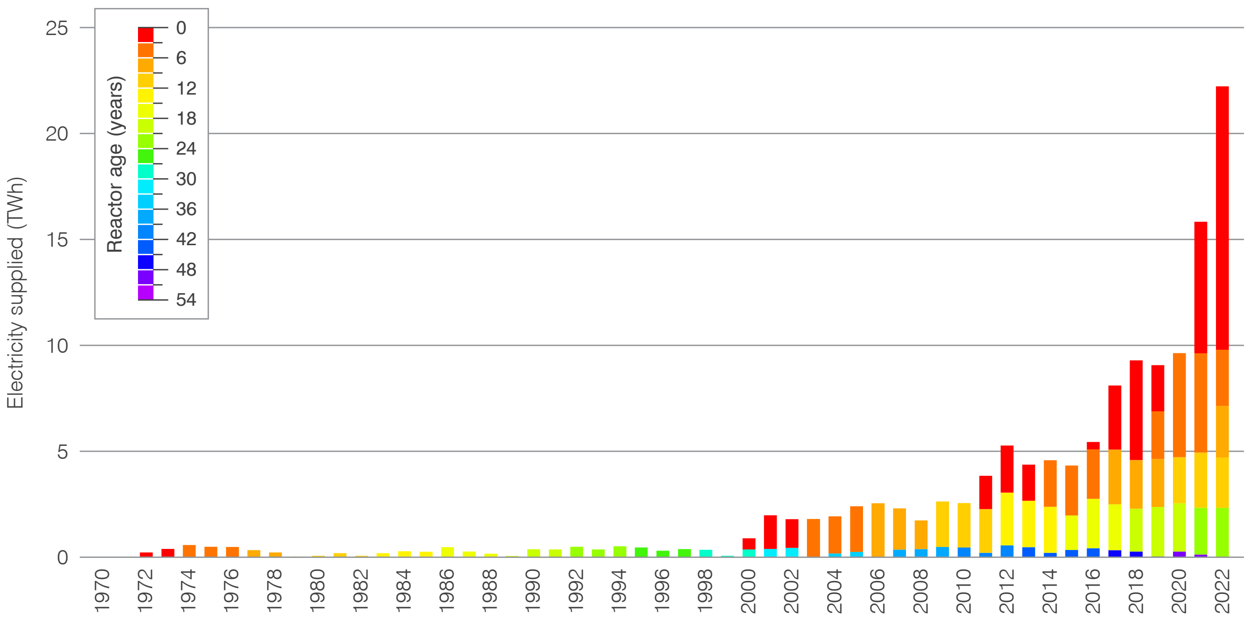
Source: World Nuclear Association, IAEA PRIS

Emissions avoided cf. fossil fuels generation



Source: World Nuclear Association, IAEA PRIS

Nuclear electricity production



Source: World Nuclear Association, IAEA PRIS

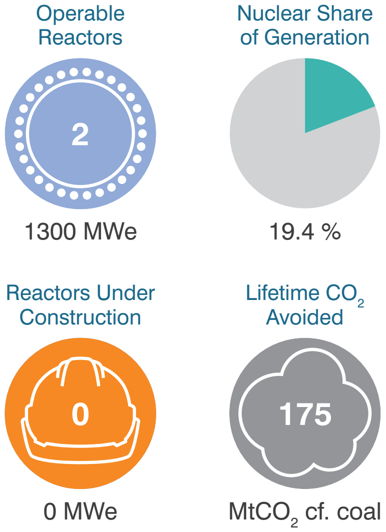
Romania

Two CANDU-6 PHWRs operate at the Cernavoda plant, 150 km east of Bucharest. In addition to electricity, the plant provides district heating to the adjacent town of Cernavoda.

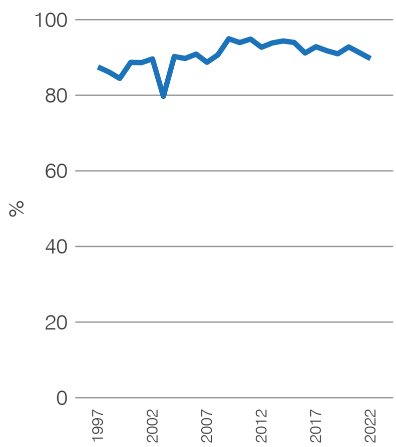
Cernavoda was originally planned to be a five-unit plant. In December 2022 the Romanian government adopted a draft law covering a state support agreement with Societatea Nationala Nuclearelectrica (SNN) subsidiary EnergoNuclear relating to the estimated €7 billion ($7.4 billion) project to complete Cernavoda 3&4.

A three-phase project to upgrade unit 1 began in 2017. The second phase, due to last from February 2022 to 2026, covers the provision of the financial resources, negotiating and granting engineering, procurement and construction contracts, assessing, preparing and scheduling the activities to be carried out and obtaining all the authorizations necessary to start the project. The third phase, scheduled for 2027 to 2029, starts with the shutdown of unit 1 and includes all the work required on it and its recommissioning. The work would allow the reactor to operate for an additional 30 years, to 2060.

In December 2022 RoPower and NuScale Power signed a contract for the front-end engineering and design work for a VOYGR-6 SMR plant at Doicești in Romania's Muntenia region. In May 2023 the USA, along with multinational public-private partners from Japan, South Korea and the United Arab Emirates, announced funding for the project.

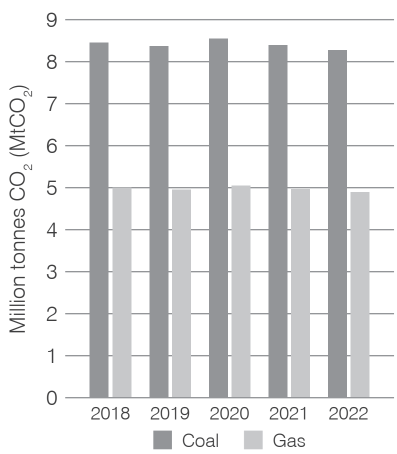


Average nuclear capacity factor



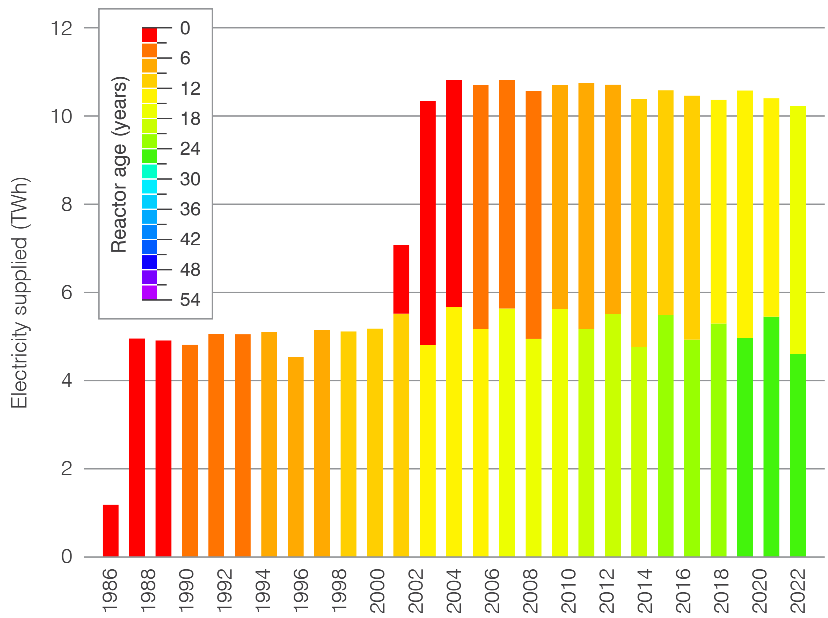
Source: World Nuclear Association, IAEA PRIS

Emissions avoided cf. fossil fuels generation



Source: World Nuclear Association, IAEA PRIS

Nuclear electricity production



Source: World Nuclear Association, IAEA PRIS

Russia

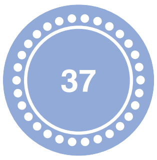
There are 37 operable reactors in Russia, with the majority in the west of the country. An additional three reactors are under construction: two VVER-1200 units at the Kursk power plant, and a demonstration lead-cooled fast reactor, BREST-OD-300, in Seversk.

As of June 2023, a total of 19 VVER reactors were under construction outside of Russia in Turkey (4), Iran (1), India (4), Slovakia (1), Bangladesh (2), China (4) and Egypt (3).

Domestic progress has also been made with the second generation of floating nuclear power plants, known as Optimized Floating Power Units (OFPUs), which use two RITM-200M reactors derived from those for the latest icebreakers. In early September 2022 Atomenergomash signified the start of construction of the first four OFPUs through a keel laying ceremony.

Russia is also proceeding with the development of the third-generation LK-60 nuclear-powered icebreakers under Project 22220 for use in the Western Arctic year-round and in the eastern Arctic in summer and autumn. The first three icebreakers in the fleet – *Arktika, Sibir* and *Ural* – are already operating in Russia's northern sea route. There are currently two icebreakers – *Yakutia* and *Chukotka* – under construction and in February 2023 an agreement was signed between Baltic Shipyard and Atomflot for the construction of two more nuclear-powered icebreakers.

Operable Reactors



27,727 MWe

Nuclear Share of Generation

19.6 %

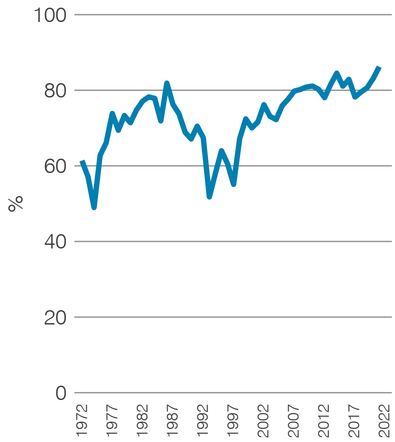
Reactors Under Construction

2700 MWe

Lifetime CO_2 Avoided

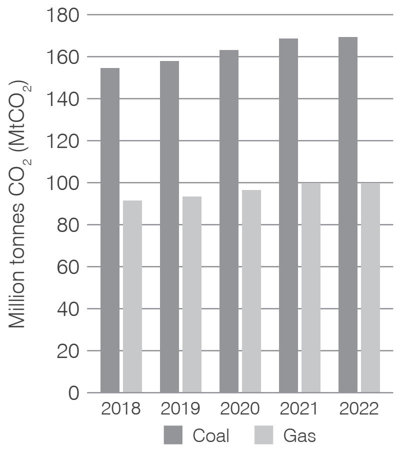
$MtCO_2$ cf. coal

Average nuclear capacity factor



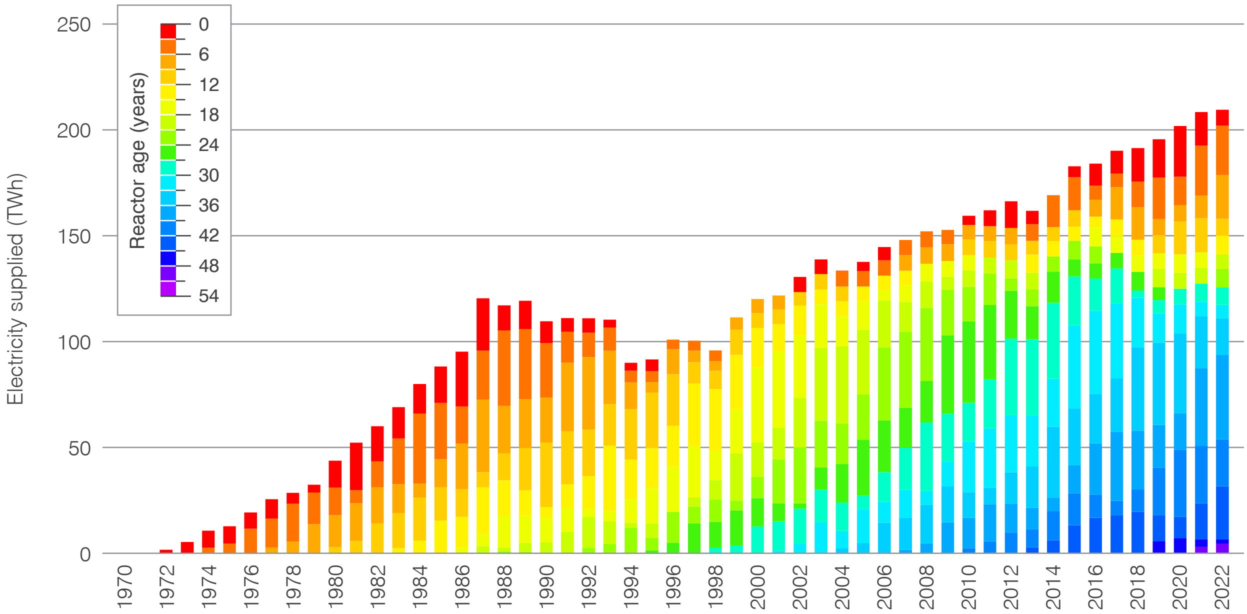
Source: World Nuclear Association, IAEA PRIS

Emissions avoided cf. fossil fuels generation



Source: World Nuclear Association, IAEA PRIS

Nuclear electricity production



Source: World Nuclear Association, IAEA PRIS

Slovakia

Slovakia has two nuclear power plants with VVER-440/V-213 reactors: two at Bohunice V2, 140 km northeast of Bratislava, and three at Mochovce, 100 km east of Bratislava, with unit 4 at that site under construction. Two VVER-440/V-230 units at Bohinice V1 were shut down in 2006 and 2008 as a condition of Slovakia's membership of the EU.

After reaching first criticality in October 2022, Mochovce 3 was connected to the grid at the end of January 2023.

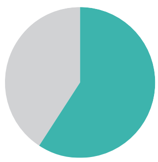
At the Bohunice plant, decommissioning of the two V1 reactors started in 2012, and the reactors were fully dismantled by the end of July 2022. Plans for a new reactor, unit 5, were first announced in 2008 for a 1000-1600 MWe unit, with Czech utility CEZ as the 49% joint venture partner, with the remaining share held by state-owned Javys. The formal joint venture JESS (Jadrová Energetická Spoločnosť Slovenska, Slovakia Nuclear Energy Company) agreement was signed the following year. Although in March 2022 CEZ said the project was effectively stalled, in February 2023 JESS applied to Slovakia's Nuclear Regulatory Authority for a siting permit for Bohunice 5.

In June 2023 Slovenské Elektrárne signed a memorandum of understanding with France's Framatome on the development of European nuclear fuel for VVER-440 reactors.

Operable Reactors

1868 MWe

Nuclear Share of Generation



59.2 %

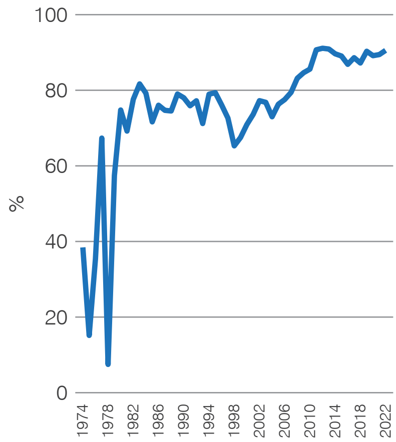
Reactors Under Construction

440 MWe

Lifetime CO_2 Avoided

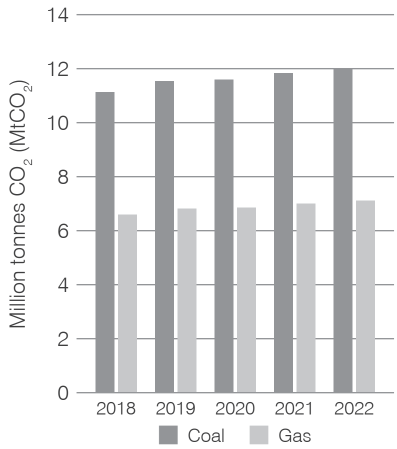
$MtCO_2$ cf. coal

Average nuclear capacity factor



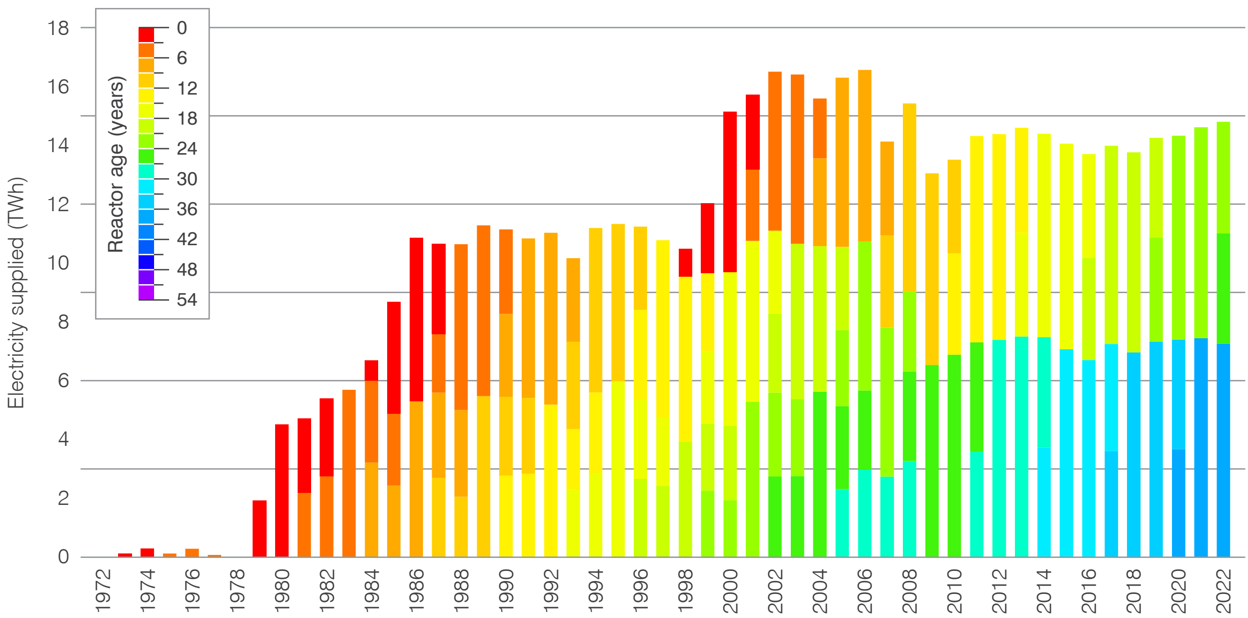
Source: World Nuclear Association, IAEA PRIS

Emissions avoided cf. fossil fuels generation



Source: World Nuclear Association, IAEA PRIS

Nuclear electricity production



Source: World Nuclear Association, IAEA PRIS

Slovenia

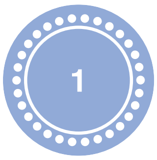
Slovenia has a single reactor operating at Krško, about 40 km northeast of Zagreb. It is a two-loop Westinghouse PWR with a net capacity of 688 MWe.

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).

A decision-in-principle on a further unit at Krško – referred to as JEK 2 – was expected to be made in August 2023, with a decision on its construction in 2027.

In January 2023, the Ministry of the Environment approved a 20-year extension of Krško's operating lifetime. In April 2023 a used fuel dry storage facility was commissioned at Krško.

Operable Reactors



688 MWe

Nuclear Share of Generation

42.8 %

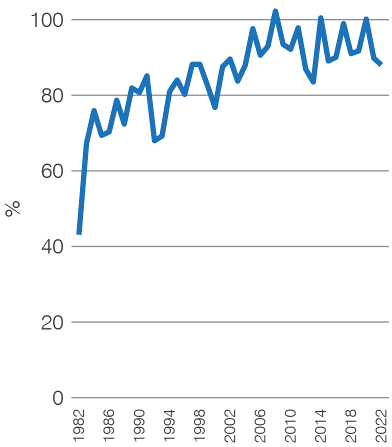
Reactors Under Construction

0 MWe

Lifetime CO_2 Avoided

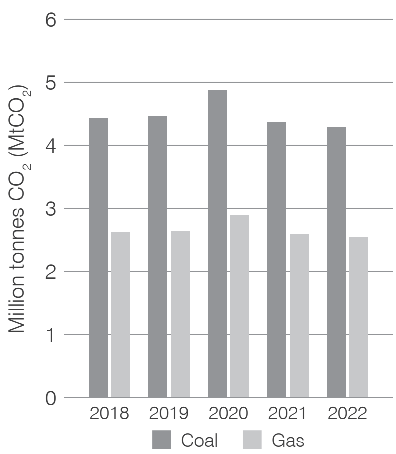
$MtCO_2$ cf. coal

Average nuclear capacity factor



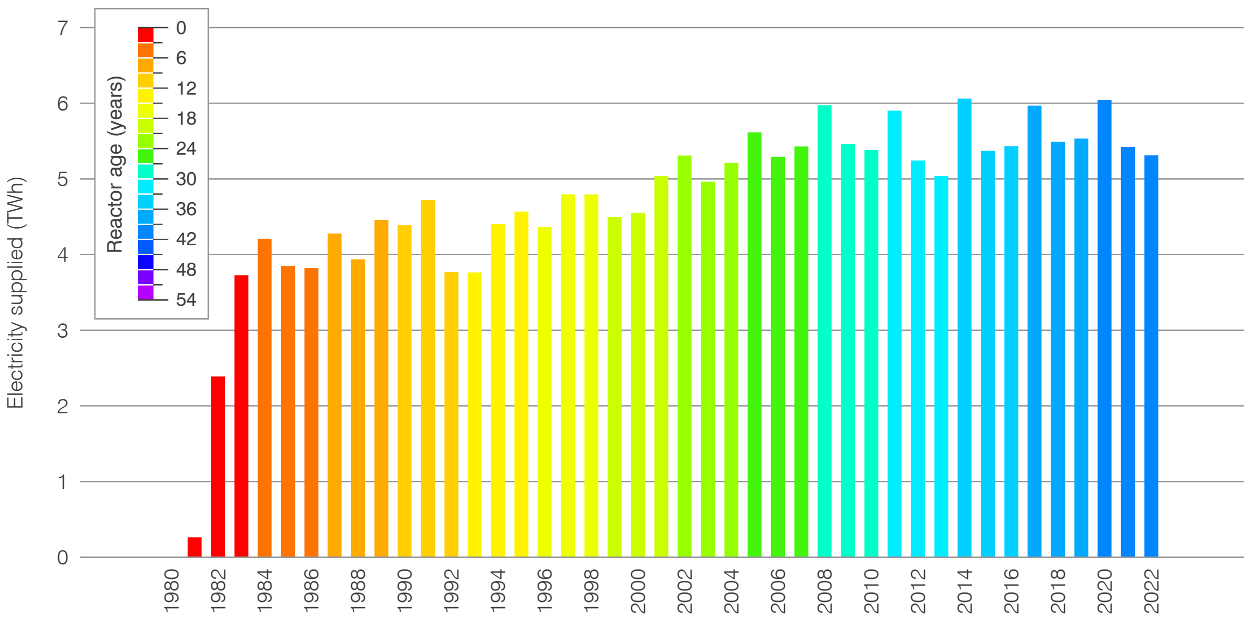
Source: World Nuclear Association, IAEA PRIS

Emissions avoided cf. fossil fuels generation



Source: World Nuclear Association, IAEA PRIS

Nuclear electricity production



Source: World Nuclear Association, IAEA PRIS

South Africa

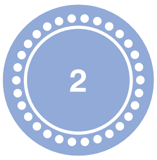
South Africa has a single nuclear power plant at Koeberg, 30 km north of Cape Town. The plant's two reactors, connected to the grid in 1984 and 1985, have a combined capacity of 1854 MWe.

In July 2022 Eskom submitted the safety case to extend the plant's operating lifetime by 20 years beyond its current licence term of 40 years, to 2045.

In February 2023 South African President Cyril Ramaphosa declared a national 'state of disaster' to tackle the electricity crisis in the country. The declaration enabled the government to take practical measures to address the economic damage caused by debilitating electricity shortages.

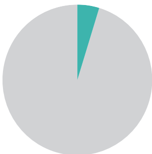
South Africa faces capacity challenges with the refuelling and the replacement of three steam generators at Koeberg 1, the first of which was removed in March 2023, after the unit entered a refuelling and maintenance outage in December 2022. Unit 1 was expected to remain out of service until June 2023. The steam generators of unit 2 are also planned to be replaced in the later part of 2023. With Koeberg 1 being offline, along with the extended outage of three units at the Kusile coal-fired power station, South Africa's power system was severely constrained in mid-2023, with the prospect of a high risk of load-shedding during the winter months of June, July and August.

Operable Reactors



1854 MWe

Nuclear Share of Generation



4.9 %

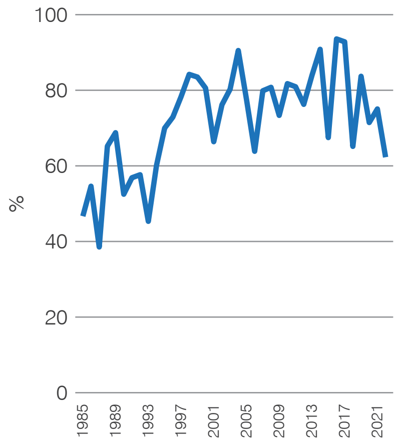
Reactors Under Construction

0 MWe

Lifetime CO_2 Avoided

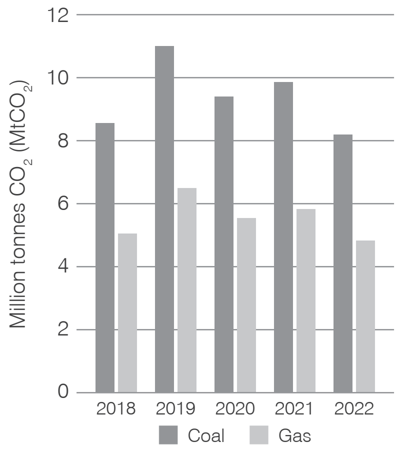
$MtCO_2$ cf. coal

Average nuclear capacity factor



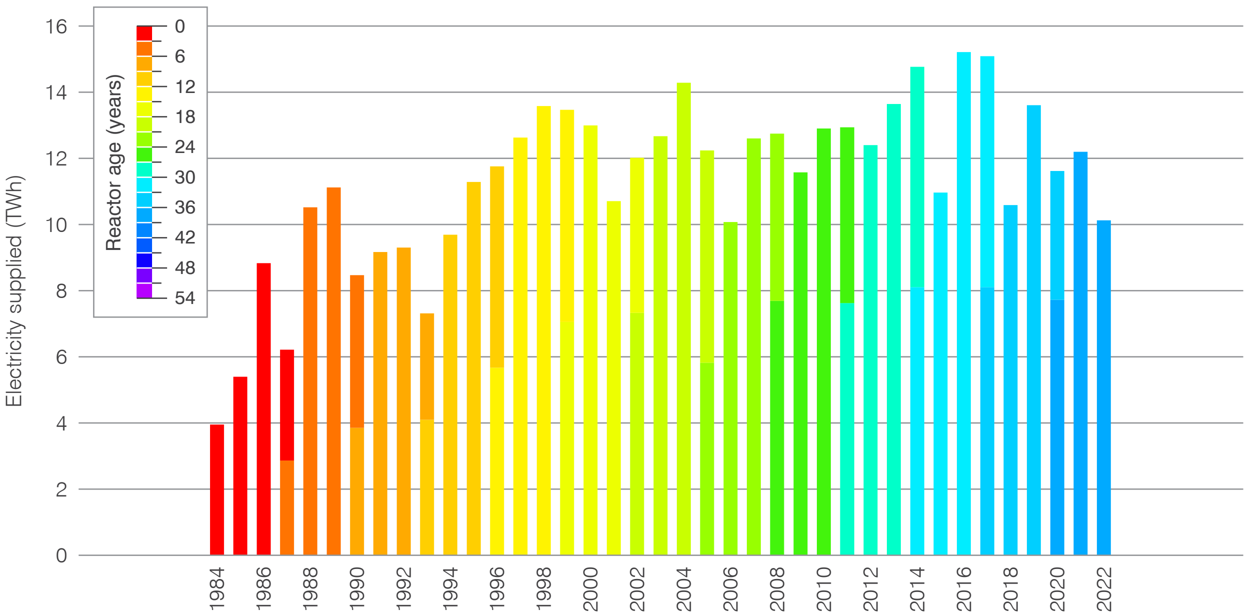
Source: World Nuclear Association, IAEA PRIS

Emissions avoided cf. fossil fuels generation



Source: World Nuclear Association, IAEA PRIS

Nuclear electricity production



Source: World Nuclear Association, IAEA PRIS

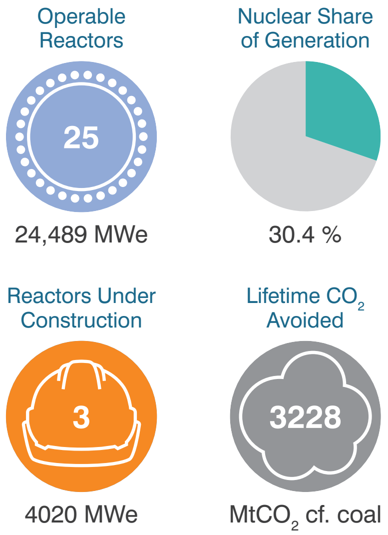
South Korea

There are 25 reactors operating in South Korea, providing more than a quarter of the country's electricity.

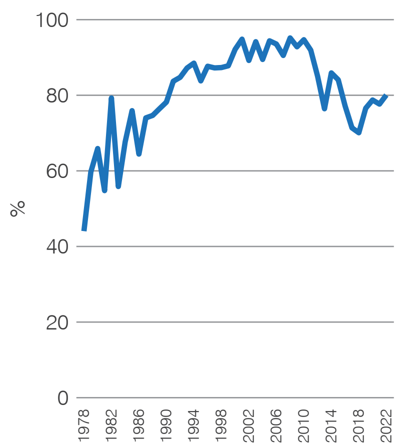
In March 2022 a new President, Yoon Suk-yeol, was elected on a platform that rejected his predecessor's policy of phasing out of nuclear energy. In August 2022 the Ministry of Trade, Industry and Energy (MOTIE) released an updated draft to the long-term energy plan, calling for an increase in nuclear capacity from 24.7 GWe in 2022 to 31.7 GWe in 2036. The plan includes the construction of six new reactors by 2033, along with operating lifetime extensions for existing reactors. In November 2022 the 10th framework plan envisaged nuclear energy increasing to 32.4% of total generation by 2030.

In December 2022 commercial operation of Shin Hanul 1 began, with unit 2 anticipated to be operational by September 2023. In February 2023 MOTIE announced that it was working to obtain the relevant approvals to enable Korea Hydro & Nuclear Power (KHNP) to restart preliminary construction on Shin Hanul 3&4 in September 2023.

Hanbit 4 returned to service in December 2022 having been taken offline for a "planned preventive maintenance" outage in May 2017. During the outage 'voids' were discovered in its containment building requiring repair. The five-year outage was also used to replace steam generators. Hanbit 3 was offline for similar repairs from 2018-2020.

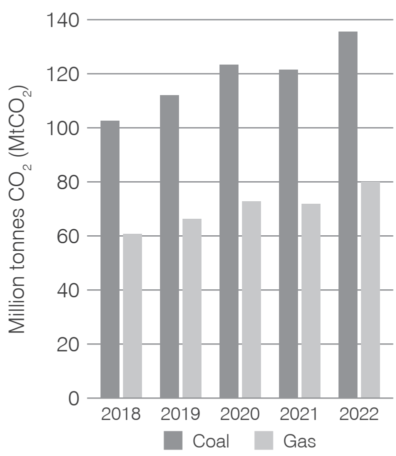


Average nuclear capacity factor



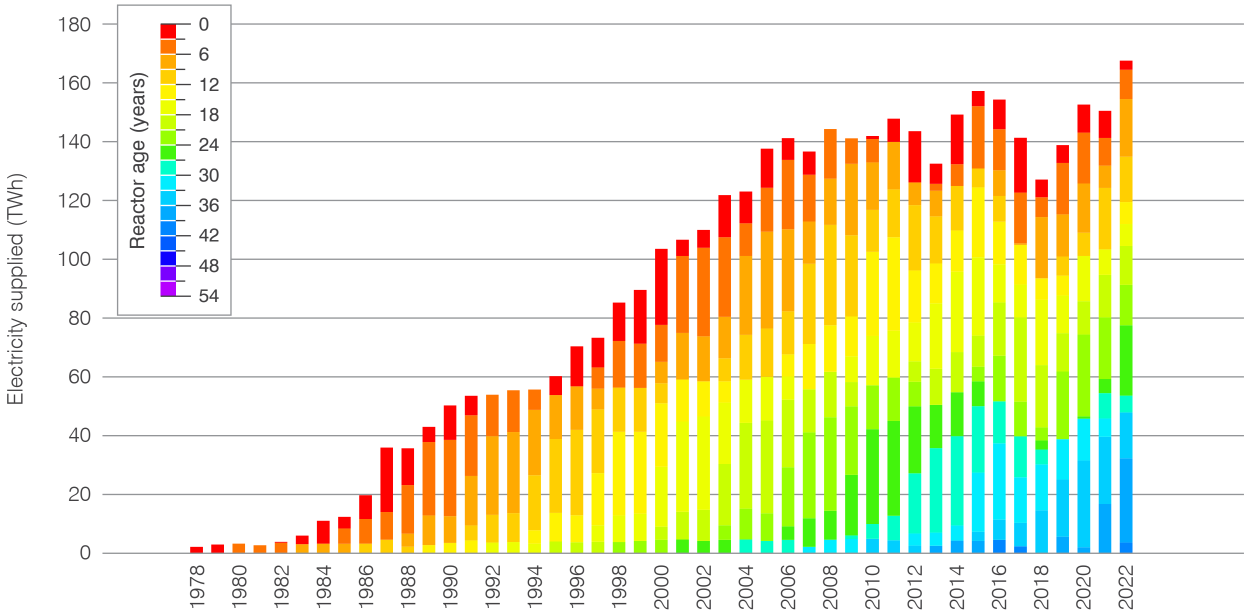
Source: World Nuclear Association, IAEA PRIS

Emissions avoided cf. fossil fuels generation



Source: World Nuclear Association, IAEA PRIS

Nuclear electricity production



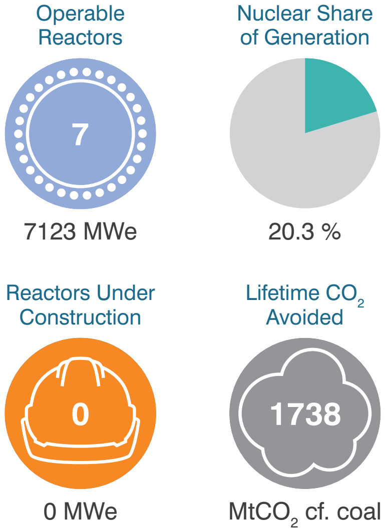
Source: World Nuclear Association, IAEA PRIS

Spain

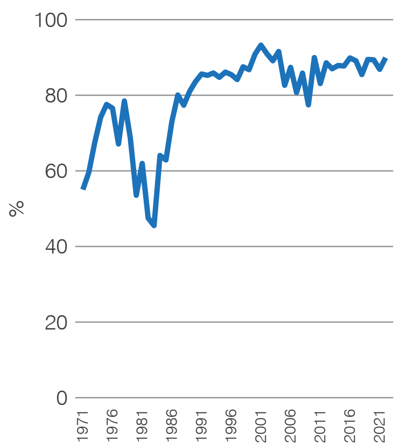
Spain has seven operable nuclear reactors at five sites across the country, all of which started up in the 1980s. With a combined capacity of 7123 MWe, the units generate over 20% of the country's electricity.

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 by 2035.

In July 2022 the first container holding used fuel from the Garoña plant was placed in the onsite interim dry storage facility.

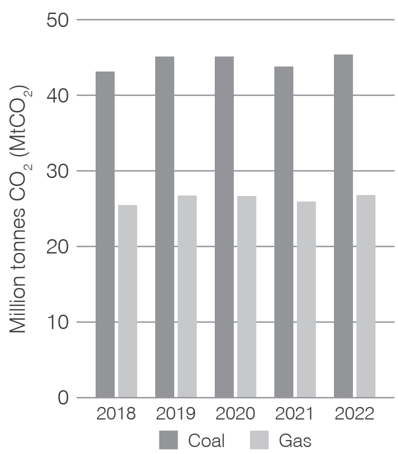


Average nuclear capacity factor



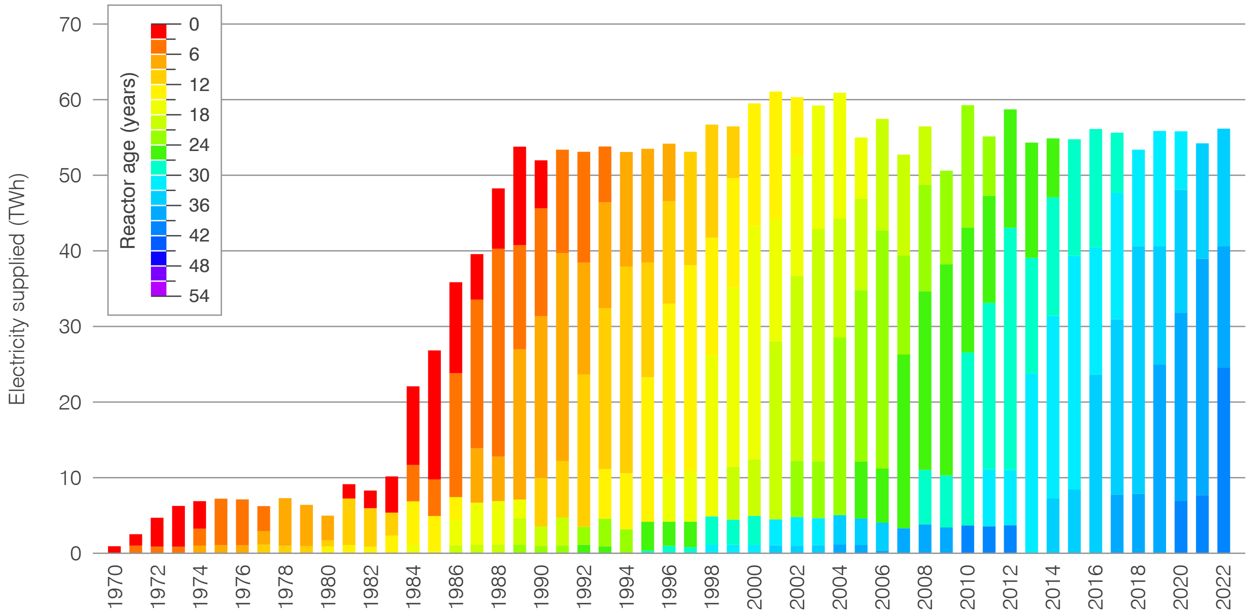
Source: World Nuclear Association, IAEA PRIS

Emissions avoided cf. fossil fuels generation



Source: World Nuclear Association, IAEA PRIS

Nuclear electricity production



Source: World Nuclear Association, IAEA PRIS

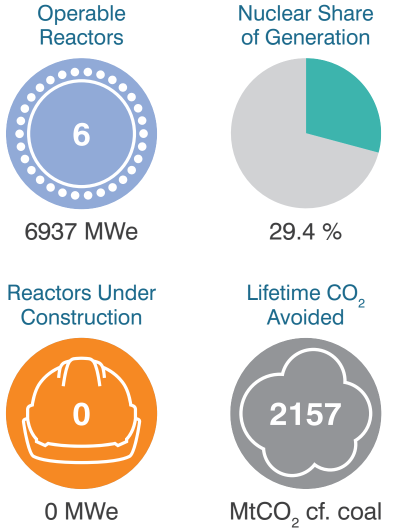
Sweden

There are six reactors operating in three locations in Sweden: Ringhals, 50 km south of Gothenburg; Oskarshamm, 220 km south of Stockholm; and Forsmark, 120 km north of Stockholm.

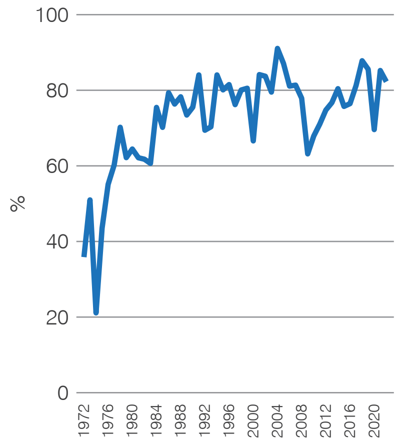
In October 2022 a pro-nuclear centre-right coalition government took office. During its first month in power, the government called on Vattenfall to investigate the possible restart of Ringhals 1&2 and to prepare for the construction of new reactors. In January 2023 the government announced that it was preparing legislation that would scrap both the country's limit of ten reactors and the requirement to only build new nuclear reactors at locations where they already exist. The proposed legislation is expected to be in place by March 2024.

In December 2022 Fortum and Kärnfull announced that they were exploring the development of SMRs in the country. In January 2023 Vattenfall announced that it was considering the option of installing SMR-based capacity at the Ringhals nuclear power plant.

In April 2023 Ringhals 4 restarted after being offline for eight months due to damage to the pressure vessel that occurred during routine maintenance.

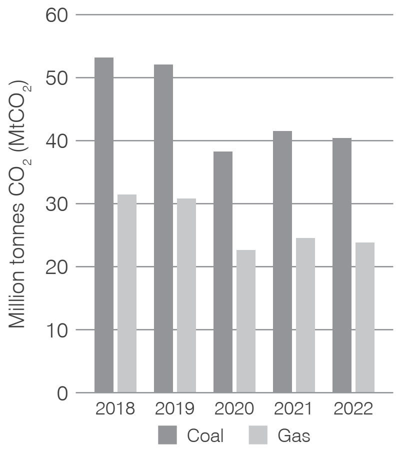


Average nuclear capacity factor



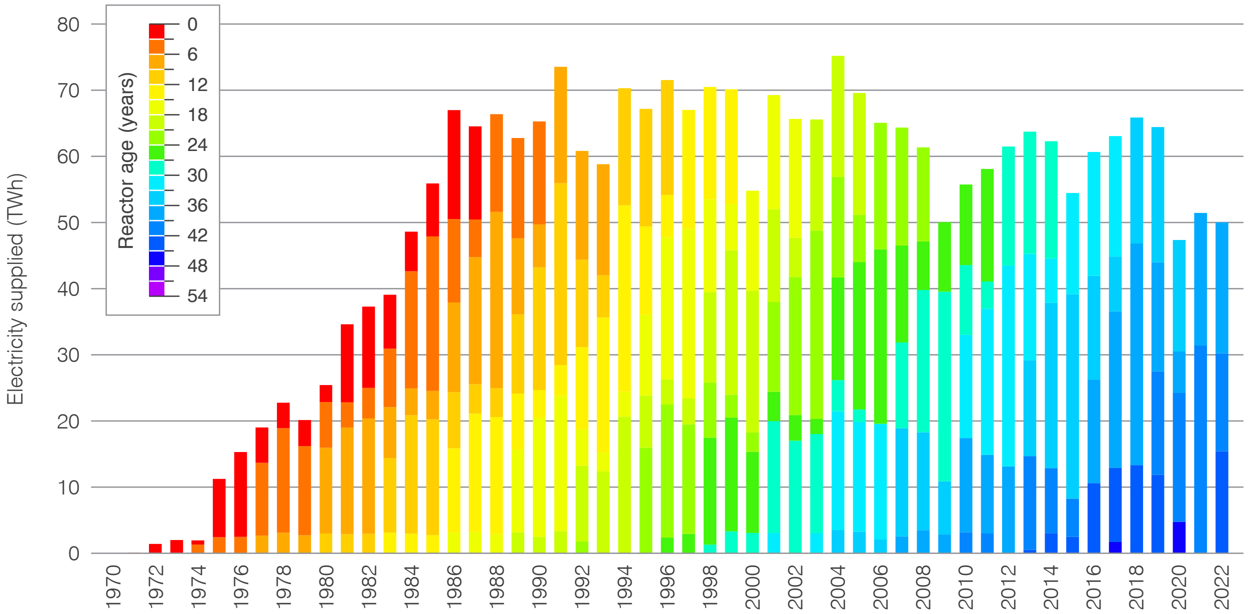
Source: World Nuclear Association, IAEA PRIS

Emissions avoided cf. fossil fuels generation



Source: World Nuclear Association, IAEA PRIS

Nuclear electricity production



Source: World Nuclear Association, IAEA PRIS

Switzerland

Switzerland has two reactors at Beznau, 30 km southwest of Zurich, one at Gösgen, 40 km southwest of Zurich and one at Leibstadt, 35 km northwest of Zurich. Together they generate up to 40% of the country's electricity. The country has a policy of gradual withdrawal of nuclear power: no new reactors are to be built, but existing reactors may remain in operation as long as the regulator considers them safe.

In September 2022 following a 14-year site selection process, Switzerland's national radioactive waste disposal cooperative Nagra proposed Nördlich Lägern in northern Switzerland as the site of a deep geological repository. The repository for low-level and intermediate-level waste is planned to be in operation by 2050, with the high-level waste facility planned to be operational ten years later.

Operable Reactors

2973 MWe

Nuclear Share of Generation

36.4 %

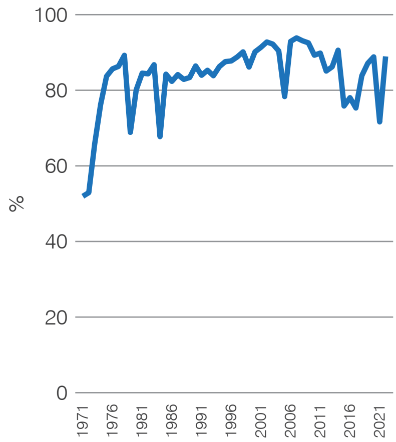
Reactors Under Construction

0 MWe

Lifetime CO_2 Avoided

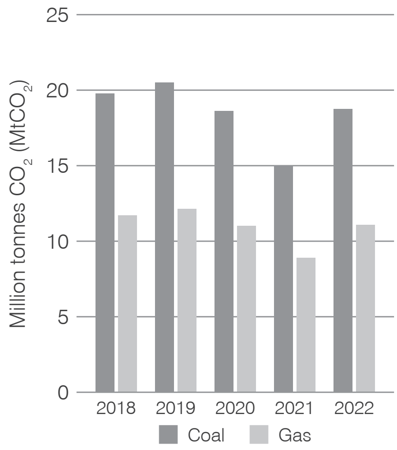
$MtCO_2$ cf. coal

Average nuclear capacity factor



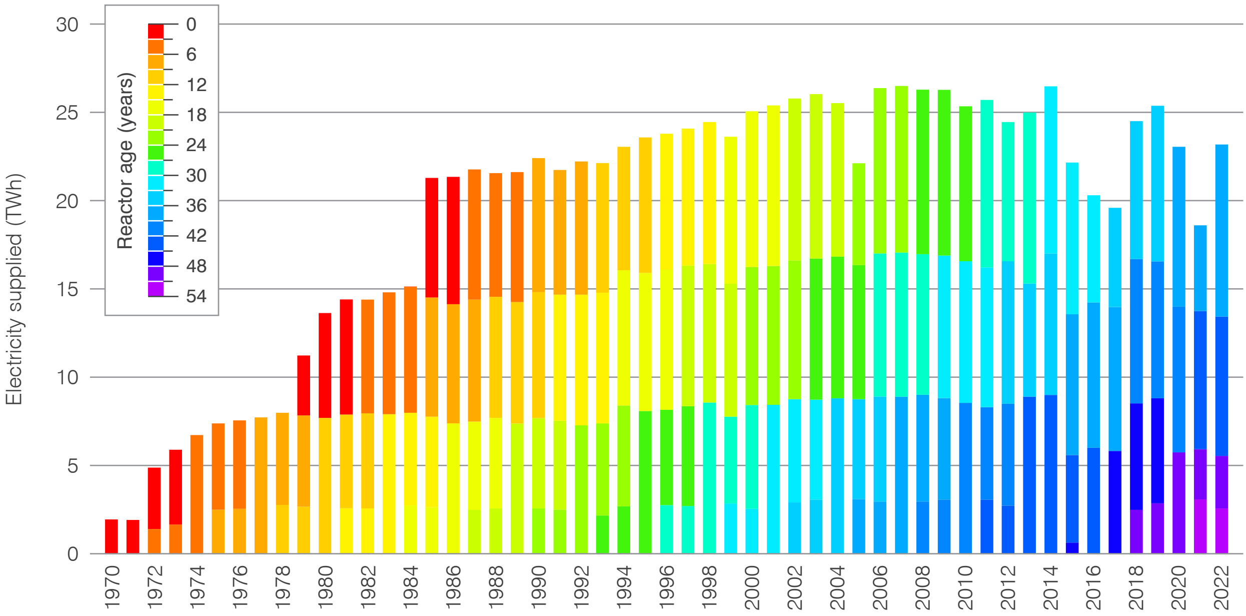
Source: World Nuclear Association, IAEA PRIS

Emissions avoided cf. fossil fuels generation



Source: World Nuclear Association, IAEA PRIS

Nuclear electricity production



Source: World Nuclear Association, IAEA PRIS

Turkey

The Akkuyu nuclear plant, under construction on Turkey's southern coast, 120 km southwest of Mersin, will comprise four 1114 MWe VVER-1200 reactors. The reactors are expected to come online between 2024 and 2028.

In November 2022 it was announced that the Turkish government had commenced studies into the potential construction of a third nuclear power plant.

In January 2023 KEPCO submitted a proposal for the construction of four APR-1400 reactors at an undisclosed site in the northern part of the country. This followed reports of discussions in late 2022 between KEPCO and the Turkish government on the development of four APR-1400 reactors at Sinop. In March 2023 state generation company EUAS established a nuclear-focused subsidiary known as TUNAS, tasked with "founding" the Sinop project. TUNAS plans to commence excavations at the site in 2023.

Operable Reactors
0
0 MWe

Nuclear Share of Generation
0 %

Reactors Under Construction
4
4456 MWe

Lifetime CO_2 Avoided
0
$MtCO_2$ cf. coal

Unit 3 under construction (Image: Akkuyu NPP)

Ukraine

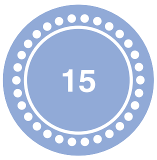
All 15 reactors in Ukraine are VVER units. Rovno and Khmelnitski are located in the west of the country, and South Ukraine and Zaporizhzhia in the south.

In February 2022 Russia launched a military offensive against Ukraine. The war has had an impact on energy systems across Ukraine, including nuclear facilities. Generation from nuclear has dropped significantly during the war, with all six units at Zaporizhzhia – which has been occupied by Russian military forces – being offline since September 2022. However, with overall electricity demand reduced, the share of electricity supplied by nuclear has remained at just over half.

In October 2022 Russian President Vladimir Putin issued a decree to transfer the Zaporizhzhia plant to Russian control. Ukraine's Ministry of Foreign Affairs described the statement as an "illegal attempt" to transfer operational control of the plant.

Since January 2023 teams of nuclear safety and security experts from the IAEA have been stationed at Ukraine's nuclear power plants and the Chernobyl site.

Operable Reactors



13,107 MWe

Nuclear Share of Generation

TBC %

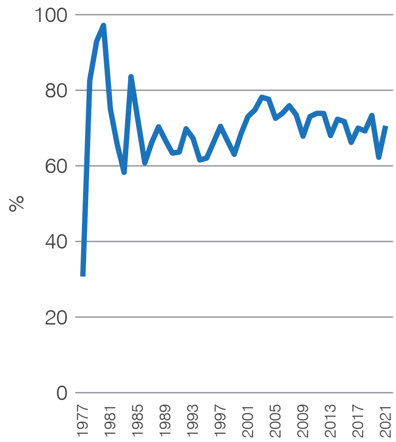
Reactors Under Construction

2070 MWe

Lifetime CO_2 Avoided

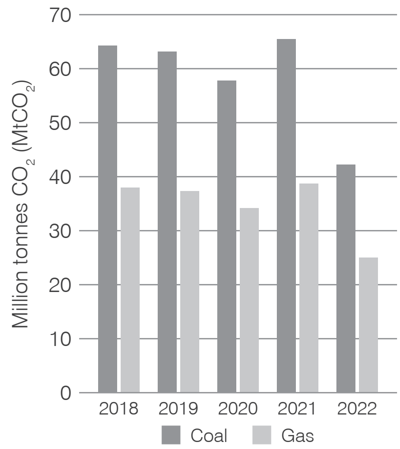
$MtCO_2$ cf. coal

Average nuclear capacity factor



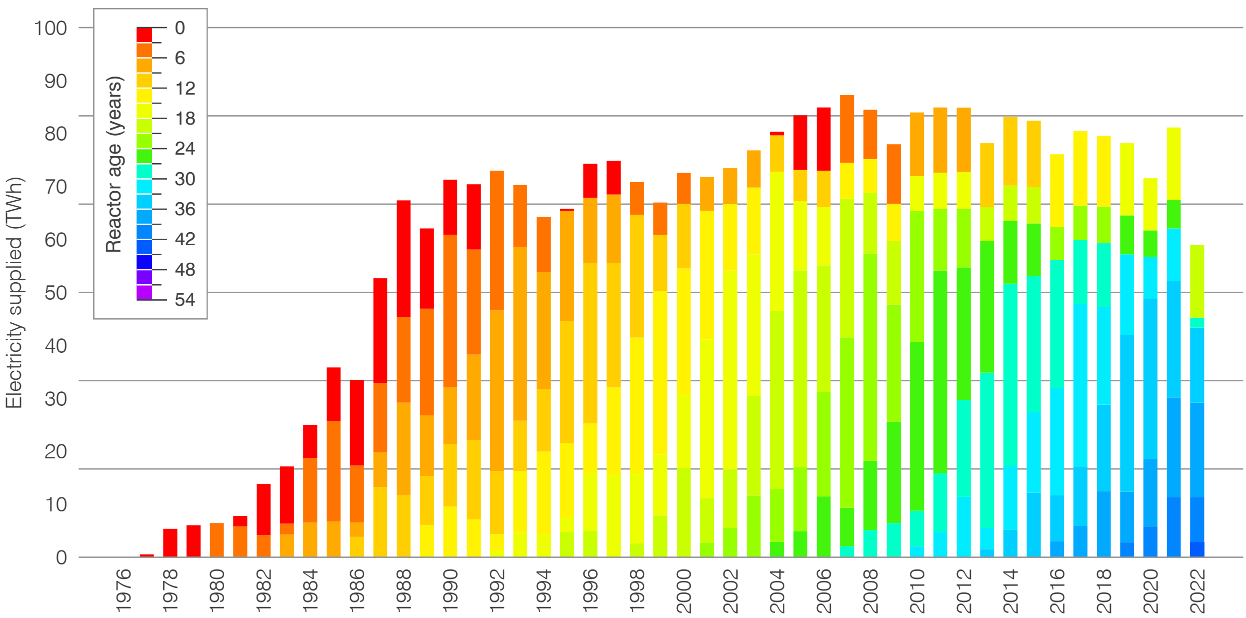
Source: World Nuclear Association, IAEA PRIS

Emissions avoided cf. fossil fuels generation



Source: World Nuclear Association, IAEA PRIS

Nuclear electricity production



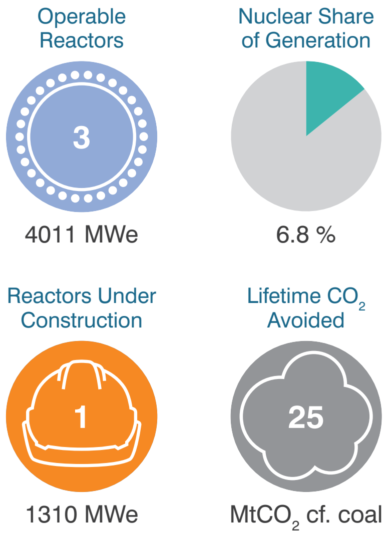
Source: World Nuclear Association, IAEA PRIS

United Arab Emirates

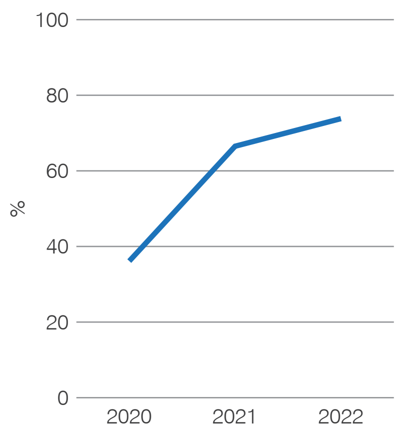
The United Arab Emirates has three operable nuclear power reactors at its Barakah nuclear power plant, located 230 km west of Abu Dhabi. It is the first nuclear power plant in the Middle East.

Barakah 1 produced first power in August 2020, followed by unit 2 in September 2021 and unit 3 in October 2022.

Construction of the fourth unit at the site began in September 2015. In June 2023 Barakah 4 initiated the final operational readiness testing and is expected to start operation later in 2023. Once all four units are operational, the plant will supply 25% of the UAE's electricity.

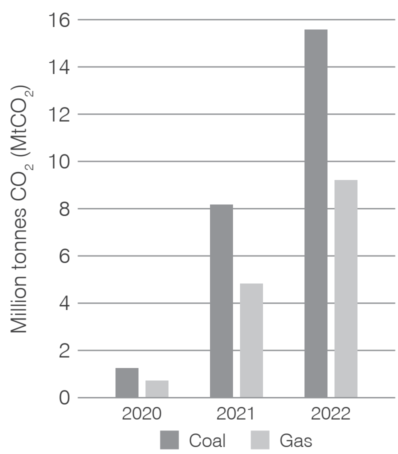


Average nuclear capacity factor



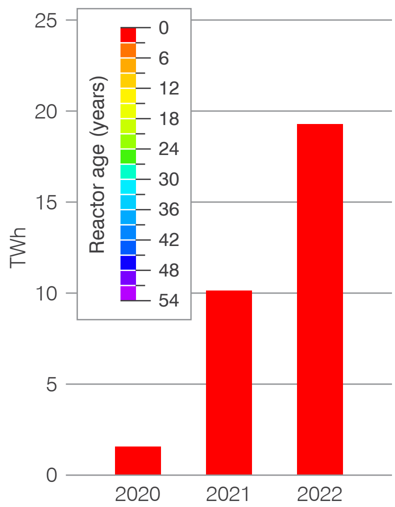
Source: World Nuclear Association, IAEA PRIS

Emissions avoided cf. fossil fuels generation



Source: World Nuclear Association, IAEA PRIS

Nuclear electricity production



Source: World Nuclear Association, IAEA PRIS

United Kingdom

The UK has nine operable reactors at seven sites; eight are advanced gas-cooled reactors (AGRs), with one pressurized water reactor (PWR) at Sizewell. The AGRs are due to be retired by the end of the decade. Two EPR units are under construction at Hinkley Point.

In April 2022 the Office for Nuclear Regulation began the generic design assessment (GDA) process for the 470 MWe Rolls-Royce SMR design. In November 2022 Rolls-Royce announced that it had identified four potential sites – Sellafield, Trawsfynydd, Wylfa and Oldbury – to deploy Rolls-Royce SMR plants, along with three possible sites to host its first factory for producing SMR components – Sunderland, Redcar and Deeside.

In November 2022 the government announced that the UK would invest $679 million ($815 million) and become a 50% partner with EDF in Nuclear New Build Generation (SZC) Ltd (NNB SZC), which aims to install and operate two EPR units at Sizewell C. It said the investment allowed for China General Nuclear's exit from the project. NNB SZC signed an early framework agreement in December 2022 with Framatome covering initial engineering and procurement activities.

In March 2023, the government announced the launch of 'Great British Nuclear', aimed at providing up to a quarter of UK electricity generation by 2050 from nuclear, as well as a competition for SMR funding.

Operable Reactors

5883 MWe

Nuclear Share of Generation

14.2 %

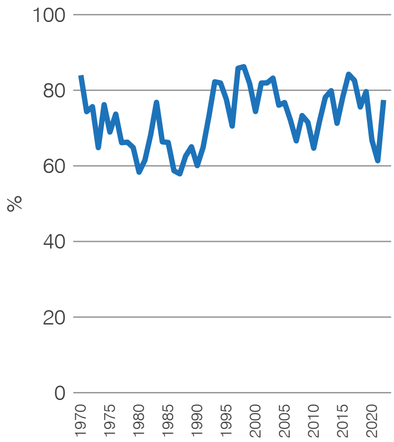
Reactors Under Construction

3260 MWe

Lifetime CO_2 Avoided

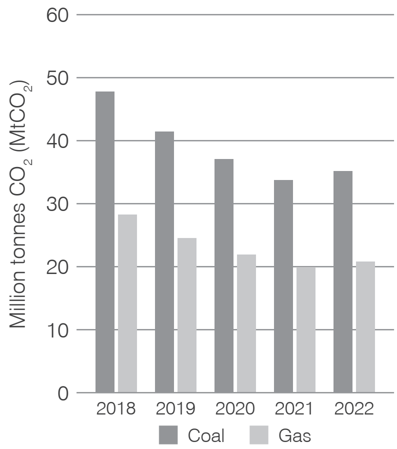
$MtCO_2$ cf. coal

Average nuclear capacity factor



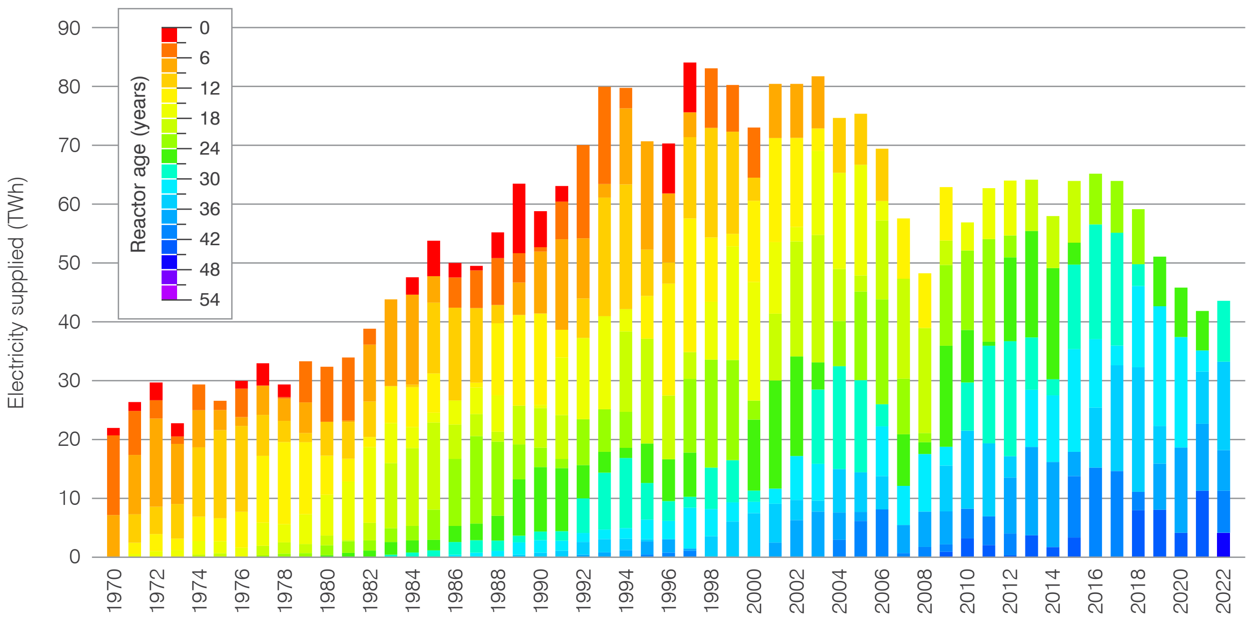
Source: World Nuclear Association, IAEA PRIS

Emissions avoided cf. fossil fuels generation



Source: World Nuclear Association, IAEA PRIS

Nuclear electricity production



Source: World Nuclear Association, IAEA PRIS

United States of America

The USA has 93 operable reactors with a combined capacity of 95,800 MWe, the largest nuclear fleet of any single country.

Vogtle 3, an AP1000, was connected to the grid in April 2023 and reached full power the following month. An additional AP1000, unit 4, is expected to commence operation early in 2024.

The Inflation Reduction Act was signed into law in August 2022. The Act provides support for existing and new nuclear development through investment and tax incentives for both large, existing nuclear plants and newer, advanced reactors, as well as high-assay low enriched uranium (HALEU) and hydrogen production.

In California, Pacific Gas & Electric Company (PG&E) had been planning to shut down the two Diablo Canyon units in 2024 and 2025. In August 2022 California Governor Gavin Newsom proposed to keep the plant operational for an additional five to ten years, extending up to $1.4 billion in loans to keep the two units online. Later that month, the California Assembly passed a bill enabling the plant to remain operational for up to five years longer than originally planned. In March 2023 the Nuclear Regulatory Commission approved PG&E's request to operate the two units beyond 2024 and 2025 on the condition that PG&E submits licence renewal applications by the end of 2023.

Operable Reactors

94,718 MWe

Nuclear Share of Generation

18.2 %

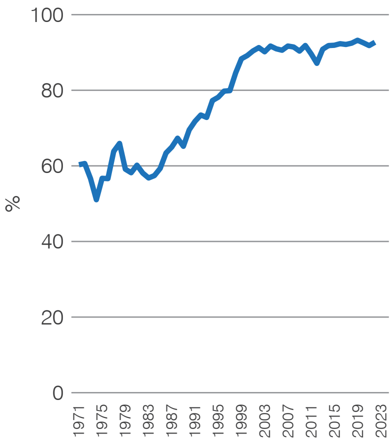
Reactors Under Construction

1117 MWe

Lifetime CO_2 Avoided

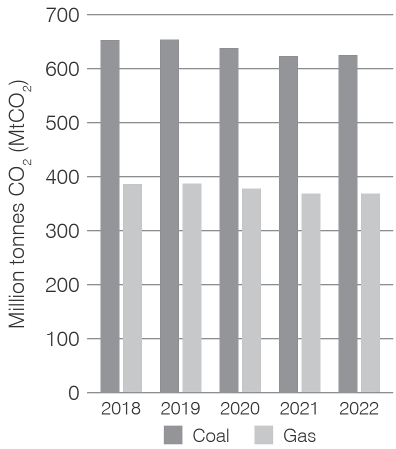
$MtCO_2$ cf. coal

Average nuclear capacity factor



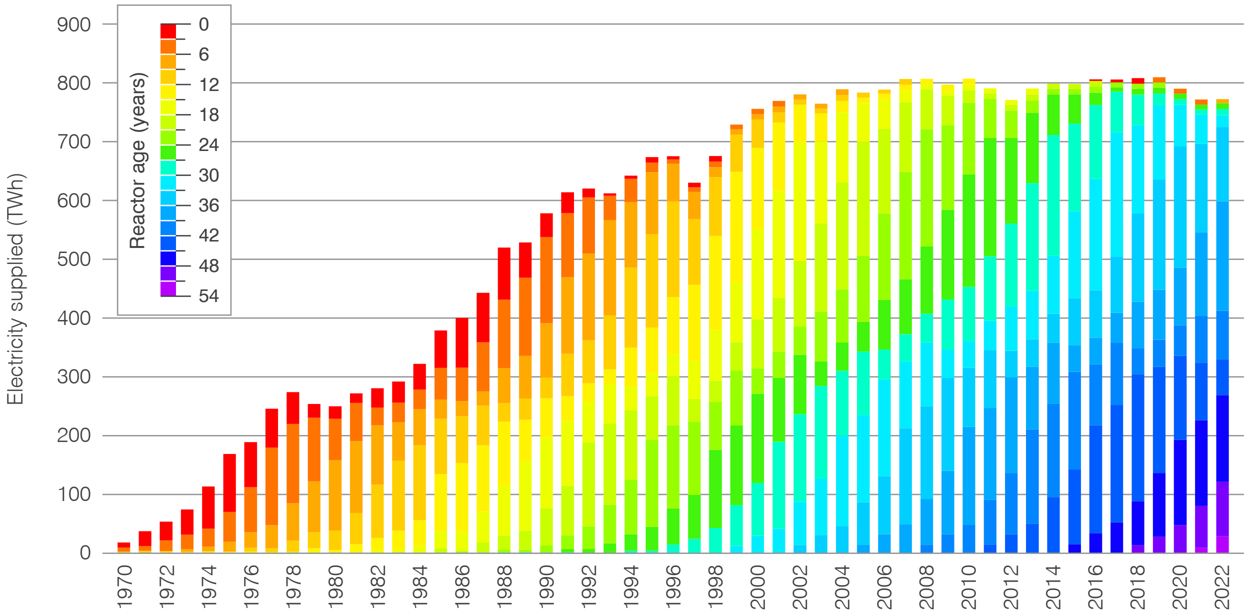
Source: World Nuclear Association, IAEA PRIS

Emissions avoided cf. fossil fuels generation



Source: World Nuclear Association, IAEA PRIS

Nuclear electricity production



Source: World Nuclear Association, IAEA PRIS

4 Nuclear Reactor Global Status

31 July 2023

Grid Connections 1 January - 31 July 2023

	Location	Model	Net Capacity (MWe)	Grid Connection
Fangchenggang 3	China	Hualong One	1105	10 January 2023
Mochovce 3	Slovakia	VVER V-213	440	31 January 2023
Vogtle 3	USA	AP1000	1117	1 April 2023
Ostrovets 2	Belarus	VVER V-491	1110	13 May 2023

Construction Starts 1 January - 31 July 2023

	Location	Model	Net Capacity (MWe)	Construction Start
Sanmen 4	China	CAP1000	1163	22 March 2023
Haiyang 4	China	CAP1000	1161	22 April 2023
El Dabaa 3	Egypt	VVER-1200/V-529	1100	3 May 2023

Permanent Shutdowns 1 January - 31 July 2023

	Location	Model	Process	Net Capacity (MWe)	Permanent Shutdown
Tihange 2	Belgium	W (3-loop)	PWR	1008	31 January 2023
Kuosheng 2	Taiwan, China	BWR-6	BWR	985	15 March 2023
Emsland	Germany	Konvoi	PWR	1335	15 April 2023
Isar 2	Germany	Konvoi	PWR	1410	15 April 2023
Neckarwestheim 2	Germany	Konvoi	PWR	1310	15 April 2023

5 Director General's Concluding Remarks

The turmoil in energy markets, which had begun even before the current conflict in Ukraine sent fossil fuel prices sky-high, has brought the issue of energy security to the fore, alongside the increasingly urgent requirements for rapid decarbonization to tackle climate change effectively, and the global sustainable development goal of providing access to affordable and clean energy for all.

An increasing number of governments are recognising the value of nuclear generation to address all of these challenges.

The European Nuclear Alliance of 14 EU member states have reaffirmed that nuclear technologies and renewable energies are complementary in achieving the EU's climate and energy security objectives and must, as such, be an integral part of the European energy transition.

In Asia, the South Korean government has reversed the phase-out policy of the previous administration, and released an updated draft to the long-term energy plan, calling for an increase in nuclear capacity. in Japan the government has adopted a policy maximising the use of existing reactors and developing advanced reactors.

In Africa, construction continues on the four reactors at Egypt's El Dabaa plant. When they enter service Egypt will become the second African country to operate a nuclear power plant. Other countries in Africa are intending to deploy nuclear energy, with Uganda, Nigera and Ghana already planning construction.

In North America, work to extend the operation of Canada's Candu reactors is progressing well, and plans are afoot for construction of several SMRs. In the USA, the start-up of the AP1000 units at Vogtle is underway, and investments and tax incentives included in the Inflation Reduction Act will reinforce the nation's commitment to maximize the use of its existing nuclear power plants, and encourage deployment of new nuclear technology.

But unless we can turn policies into action government commitments will remain as just good intentions. What can the industry do to ensure that it can grow and deliver at scale and speed?

In comparison to many other sectors, the nuclear industry comprises many relatively small companies. And, understandably, those companies working within the same sectors of nuclear energy are in fierce competition with each other.

But if the nuclear industry is to compete effectively for its place in a future energy mix, then those companies need to work together to make the case for nuclear energy globally. We need to develop our industry self-awareness, and scan the horizon together, looking for challenges and opportunities and developing joint strategies to make the most of both. Put simply, we will either succeed together, or fail separately.

One place where the industry must come together is the COP28 climate change conference that will take place later this year in Dubai. There are very loud and assertive voices at climate change conferences. The only way for the nuclear industry to be heard is if we present a cohesive vision of the important role that nuclear energy should play in a net-zero, clean energy future.

This is why World Nuclear Association is committed to bringing our member companies together from all corners of the world, so collectively we can make the case for nuclear energy. Because I believe that if we work together, the global nuclear industry can make a reality of the nuclear energy promise to decarbonize the entire economy in a cost-effective, secure and equitable manner.

Sama Bilbao y León, Director General
World Nuclear Association
July 2023

Background Information

Acknowledgement

World Nuclear Association is grateful to the International Atomic Energy Agency (IAEA) for access to its Power Reactor Information System (PRIS) database, used in the preparation of this report.

Ukraine

At the time of writing, performance data for reactors in Ukraine have not been provided to the IAEA PRIS database.

Estimates for output from Ukraine reactors is based on other data sources, such as overall electricity output from nuclear power plants in Ukraine published by the International Energy Agency, using Ukrainian electricity transmission system operator (UKRENERGO) data, for the period 1 January 2022 to 27 October 2022.

Other data assumptions

Data has not been published for Kakrapar 3, a 630 MWe PHWR-type reactor in India, which has been grid connected, but remains in a trial operation state. Electricity output data provided by the Indian government suggests that the plant produced less than 1 TWh in 2022. For the purposes of this report no electricity production is assigned to the reactor.

Data has not been provided for the Shidaowan HTR-PM reactor in China. No electricity output has been estimated for this reactor.

Reactor Statuses

The IAEA PRIS reactor database has a status type - *Suspended Operation* - differentiated from its *Operating* status. This status has been assigned to 23 reactors in Japan, which have not restarted since their outage after the 2011 accident at Fukushima Daiichi. It has also been assigned to four reactors in India: Madras 1, Rajasthan 1, Tarapur 1 and Tarapur 2.

World Nuclear Association uses the *Operable* status for reactors categorised by IAEA as *Suspended Operation* or *Operable*., with the exception of Rajasthan 1, which we consider to be in Permanent Shutdown status.

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 were they to operate at 100% output for the fraction of the year in which they were in an operable status.

Abbreviations

AGR	Advanced gas-cooled reactor
BWR	Boiling water reactor
CO_2	Carbon dioxide
COVID-19	Disease caused by the SARS-CoV-2 coronavirus
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
JCPOA	Joint Comprehensive Plan of Action
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)
WNN	World Nuclear News

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

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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