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Nuclear energy
Challenges and opportunities

Foreword

Welcome to the first report produced by the Credit Suisse Center for Sustainability (CfS).

The CfS is a new pillar of the Credit Suisse Research Institute (CSRI), our in-house think tank, which studies long-term economic developments that have a global impact on the financial services industry and beyond. In its publications, the CfS aims to produce thought leadership on forward-thinking and emerging sustainability themes, and discuss challenges and opportunities faced by our planet and society by drawing on the insights from senior Credit Suisse and external experts. These sustainability themes are an important part of the global dialogue that is needed to lead the bank and our clients into a sustainable future.

This inaugural CfS report tackles a topic of emerging importance related to the so-called energy transition. In this case, we consider the role of nuclear energy and its ability to support the transition toward more sustainable sources of power generation. As the global economy looks to deliver on the pressing commitments set out by the Paris Agreement, nuclear energy has been thrust into a debate around what constitutes safe, secure and reliable power on one side, and whether future investment is either politically or economically viable on the other.

The pursuit of sustainability practices within the financial services sector has the potential to support clients in their approach toward a just transition alongside the reduction and removal of greenhouse gas emissions. In navigating the opportunities and challenges we face, I trust you will find this report, and those that follow, an informative and interesting contribution to the global debate about our future.

Emma Crystal
Chief Sustainability Officer, Credit Suisse

At Credit Suisse, we strive to lead the bank and our clients into a sustainable future through the pursuit of a meaningful transition that achieves net-zero carbon emissions across our financing, supply chain and own operations by 2050. This approach is underpinned by interim science-based goals for key sectors by 2030. In support of our goal, we have also committed to providing CHF 300 billion of sustainable finance by 2030.

For more detail on Credit Suisse's approach to sustainability, visit: credit-suisse.com/sustainability

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For more information, contact:
Richard Kersley
Executive Director of EMEA Securities Research and Head of Global Product Management, Credit Suisse
richard.kersley@credit-suisse.com

Nannette Hechler-Fayd'herbe
Chief Investment Officer for the EMEA region and Global Head Economics & Research of Credit Suisse
nannette.hechler-fayd'herbe@credit-suisse.com

Emma Crystal
Chief Sustainability Officer, Credit Suisse
emma.crystal@credit-suisse.com

Authors:
Peter Babkevich
peter.babkevich@credit-suisse.com

Bahar Sezer Longworth
bahar.sezer@credit-suisse.com

Eugene Klerk
eugene.klerk@credit-suisse.com

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Nuclear energy: Where do we stand?

Peter Babkevich

Whether nuclear power should be central to the energy transition is a source of debate. Although nuclear energy has the potential to generate vast quantities of low-carbon electricity and is evolving with the goal of making the industry safer and less costly, it is not without its drawbacks. Construction of nuclear power plants has been plagued by cost overruns, long lead times and delays, which remain a barrier to nuclear power adoption.

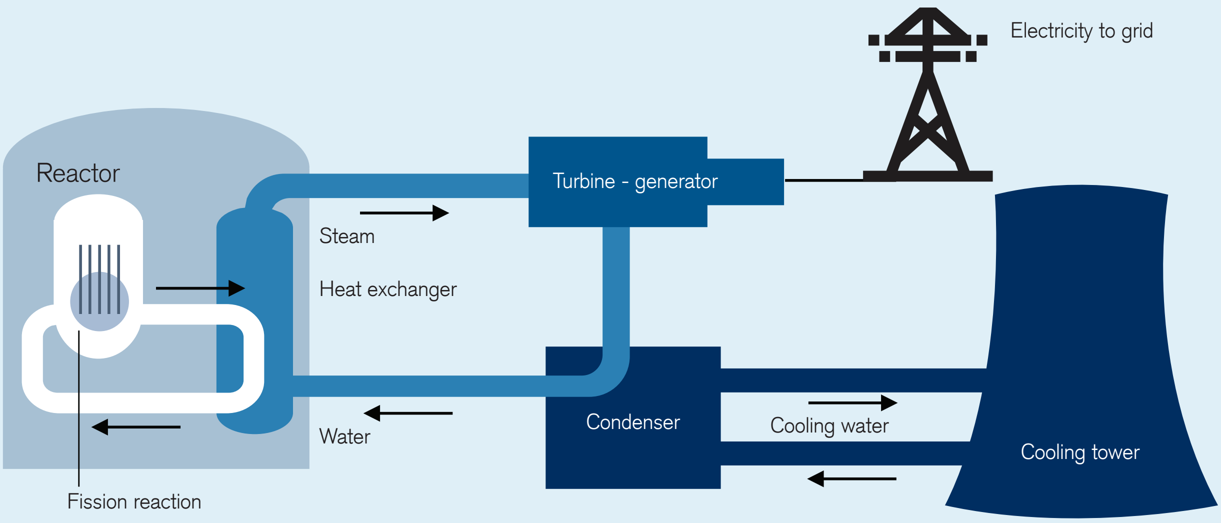
In its latest report, the Intergovernmental Panel on Climate Change (IPCC) states that unless there are immediate, rapid, and large-scale reductions in the greenhouse gas (GHG) emissions, meeting the 1.5 °C will be beyond reach. The electricity sector is the dominant contributor to the energy sector CO2 emissions, accounting for about 36% of them. Yet, as the world becomes increasingly electrified, the demand for electricity is set to increase dramatically. According to the International Energy Agency (IEA) Net Zero roadmap, electricity generation will increase by 160% between 2020 and 2050[1]. It is largely agreed that renewables, with their costs falling across all geographies, will play the main role in the energy transition. However, as nuclear is a low-carbon energy source, it too may have a role to play. Both the IPCC and IEA Net Zero roadmaps project that the share of electricity from nuclear is set to diminish from the 10% currently to 8% by 2050, but double in absolute terms. In many countries with advanced economies, there is an increasing push to extend the lifetime of aging reactors beyond their original design, rather than build new nuclear power plants. The main growth of nuclear power is expected to be in the Asia-Pacific (APAC) region, where two-thirds of the future nuclear reactors are going to be built[2].

Current technology

Harnessing nuclear fission allows nuclear reactors to generate very large amounts of energy from relatively little fuel: one kilogram of coal can provide eight kilowatt hours (kWh) of heat energy, but one kilogram of uranium-235 (U-235) releases around 24,000,000 kWh.

1. “Net Zero by 2050 – A Roadmap for the Global Energy Sector,” IEA, 2021
2. “Nuclear Power Reactors in the World,” IAEA, 2021

Figure 1: Fission – technology of current nuclear power plants



Source: Credit Suisse

This heat is used to turn water into steam, which drives turbines to generate electricity for the grid (see **Figure 1**). Vast quantities of cooling water are needed for this process, which is typically discharged back in the water supply, but at a higher temperature with potentially adverse effects on aquatic life. The uranium fuel rods sit in a circulating water bath, that has no contact with the external environment.

Advanced reactors

Pressurized water reactors (PWRs) and boiling water reactors (BWRs), collectively called light water reactors (LWRs), provide 88% of today's nuclear power. These include Generation II commercial reactors built from 1970 to 1990; and Generation III evolutionary improvements on the Generation II reactors. Advanced reactor designs include light-water-cooled small modular reactors (SMRs) and non-water-cooled reactors – Generation IV systems. These concepts have been proposed to tackle some of the challenges of nuclear technology, i.e. increase safety, reduce construction and maintenance time, and reduce waste and nuclear proliferation.

Fusion reactors

While fission is the process of releasing atomic energy by splitting heavy atoms, fusion creates energy by fusing lighter atoms together, which then releases energy. They may sound similar and create energy in a similar way, but the two technologies and expertise needed are almost entirely different, so that little knowledge can be transferred between the two. Fusion has several important advantages over conventional nuclear power. It does not use radioactive uranium and the radioactive waste produced is low-level and short-lived, with far fewer disposal issues. The technology cannot be readily used for atomic weapons and it can be turned off instantly without risks of meltdowns or emissions of radioactive particles into the environment.

Research into fusion began around the same time as nuclear fission, but it remains to be commercialized. The major problem with fusion has been engineering the right conditions for fusion to occur in perpetuity. The major publicly funded, large-scale international fusion flagships projects – the International Thermonuclear Experimental Reactor (ITER) and the DEMOnstration power plant (DEMO) – are not expected to produce electricity for the grid before 2050. In recent years, start-ups have emerged that are trying to cut the development time by using different technological methods to achieve a fusion breakthrough. These privately funded companies, mostly located in the USA, have received considerable attention. Although they are helping to drive the field forward and have made some important advances, net-energy output to the electric grid (2030 is the companies' goal) is unlikely in the near future because the technology is still very young and past developments have shown that the companies have been unable to meet their timelines. Although we expect a breakthrough to come from the private sector sometime before 2050, it is unlikely to aid the world in decarbonizing the energy sector today.

Light-water SMRs

SMRs are reactors that produce less than 300 MW of electricity – about a third of a conventional nuclear reactor. The advantages offered by proponents of SMRs are (1) the cost and time

savings through modularized production processes and (2) the increased safety of reactors that could be placed closer to densely populated areas.

SMRs offer reduced and more predictable timescales, while also producing less power. There are arguments that SMRs can be made cost-effective by mass production. We believe it would take many years of industrial experience and the production of many units before such savings could be demonstrated. Warning signs to the contrary are (1) spiraling upward cost projections for NuScale's SMRs from an initial USD 1,718 per kW in 2003, then USD 5,500 per kW in 2015 and to USD 8,500 per kW in 2020[3], and (2) historically, cost decreases have not necessarily followed from first-of-a-kind reactors. The trend in the past has been to build increasingly larger power plants to benefit from economies of scale. Whether SMRs can reverse this trend is far from certain.

SMRs largely share the water-based design used in the larger conventional reactors, but with self-sustained passive cooling, with the reactor located underground. This is used as an argument to reduce the safety regulations applied to them. As a result, (1) SMRs could be closer to populated areas by virtue of their greater safety, (2) emergency planning zones (in the USA) could be reduced, thus allowing more flexibility in site locations, and (3) the number of specially trained armed security staff could be decreased to reduce operating costs. However, a change in regulations to approve this is unlikely to come soon and public skepticism about having nuclear power plants next door is unlikely to change.

Molten salt reactors
Conventional nuclear reactors produce uranium fuel rods and use water as cooling. Control rods are inserted into the reactor to stop the reaction. A molten salt reactor (MSR) instead uses molten salt as both fuel and coolant where the fuel is dissolved in the salt. Commonly a "plug" system is incorporated. If the temperatures of the reaction become too high, the plug dissolves and the fuel is dumped into a series of storage vessels, which stops the reaction. This has the advantage of not having to rely on the operation of pumps, so it is inherently safer. The benefit to the reactor is that it can be refueled while the plant is operational.

However, the concept has some important challenges to overcome. The core temperatures are more than double those of conventional light water reactors. This leads to more challenges in the material and design of the vessel. While the online refueling saves some time, it is the maintenance that is most time-consuming in

3. "Why Small Modular Nuclear Reactors Won't Help Counter the Climate Crisis," Environmental Working Group, 2021

Photo by Monty Rakusen, Getty Images

conventional nuclear power plants, which is unlikely to be positively improved with this design. Conversely, there is twice as much neutron damage in MSRs, which may reduce the lifetime of the components and increase the frequency of repairs. There are also questions about the corrosion damage of the molten salt. According to an MIT review[4], MSRs are at an early stage of technological maturity and are not expected to be commercialized before 2050. Therefore, they are not likely to help reach net-zero in the near term.

Sodium fast reactors

Sodium fast reactors (SFRs) are one of the most technologically mature advanced nuclear concepts. First built in 1951, they have more recently seen a resurgence with startups trying to develop this technology. Water is replaced by sodium in SFRs. The advantage of using sodium instead of water is that it does not slow down the neutrons from the fission reaction, but at the same time can carry heat effectively away from the reactor. The higher reactor temperature of around 550 degrees Celsius versus 300 degrees Celsius in conventional nuclear power plants allows for potentially higher electricity generation efficiency. The fast reactor is more effective at splitting heavier elements, including plutonium into lighter, shorter-lived radioactive elements, potentially reducing long-term radioactivity from high-level nuclear waste.[5]

Most SFRs today are small and have inherent passive safety features that may not be viable in larger sodium systems. Liquid sodium can react violently with air or water. SFRs built in France, Russia and Japan have suffered from corrosion and sodium leaks, resulting in fires. The other potential problem with SFRs is the positive void coefficient (the increase in the rate of fission and heat generation that would occur following a loss of coolant, which can result in dangerous reactor state). The culmination of safety hurdles that escalated costs of this reactor design meant it was not adopted in the USA and elsewhere.

Research into thorium

There have been many reports and considerable discussion in the media about using thorium to replace uranium in the fuel cycle. Although thorium offers a few theoretical advantages over the U-cycle, these are limited and the technology was abandoned many decades ago due to its relatively high costs. The U-cycle has been well researched and improved over many decades, so that switching to thorium would imply almost starting from scratch to gain only marginal benefits.

4. "The Future of Nuclear Energy in a Carbon-Constrained World," MIT Energy Initiative, 2018
5. "Advanced Nuclear Reactors: Technology Overview and Current Issues," EveryCRSReport.com, 2019

Nuclear supply chain

The uranium lifecycle in a nuclear reactor starts from uranium ore that is mined; however, this cannot be used directly in a reactor. The ore undergoes a chemical conversion process before being fabricated into fuel rods. A key part of this process is the enrichment of uranium. Uranium occurs in nature as U-235 (0.7%) and U-238 (99.3%). However, to be used in most nuclear reactors, the U-235 proportion needs to be increased (enriched) to 3%–5%. This produces U-238 with trace amounts of U-235 as waste, called depleted uranium. In general, U-238 does not contribute to the release of energy in conventional nuclear reactors.

Mining and enrichment

According to the World Nuclear Association[6], Kazakhstan was by far the largest uranium producer in 2020, providing 41% of the world's supply. Russia is also one of the biggest miners and a dominant operator in the enrichment of uranium, supplying around 43% of the world's supply. With a few nations controlling much of the nuclear fuel supply, there is a danger that geopolitical shifts like the Russia-Ukraine war can result in supply-chain issues (see **Table 1**). This could compound with already falling load factors.

Falling load factors

To allow safe access, work on the reactor can cause lengthy shutdown periods during which no electricity is produced. Refueling a reactor lasts a few days and typically takes place once a year. Maintenance can take longer, depending on the work being carried out. According to data from the International Atomic Energy Agency (IAEA), the load factor (ratio of the energy produced over the nominal energy capacity in a time period) of nuclear reactors globally dropped to 74% in 2020[7]. This reduction in load capacity is likely due to (1) necessary upgrades following the Fukushima incident in 2011 and (2) additional maintenance to keep aging reactors running. With increasing global temperatures, nuclear power plants may see a need to curtail their power generation to stay within water discharge temperatures limits set for the aquatic environment. The unplanned capability loss (UCL) factor (ratio of unplanned energy loss over the nominal energy capacity in a time period) has remained unchanged globally at around 4.4% in the last two decades. However, this is highly country dependent. Between 2018 and 2020, the UK, Argentina and Belgium experienced UCLs of 22.2%, 19.6% and 15.1%, respectively[8]. The USA had one of the lowest UCLs of 1.2%. The cause of the large discrepancy between countries is unclear.

6. "World Uranium Mining," World Nuclear Association, 2021
7. "Load factor," PRIS, IAEA, 2022
8. "Unplanned Capability Loss Factor," PRIS, IAEA, 2022

Table 1: Uranium supply chain

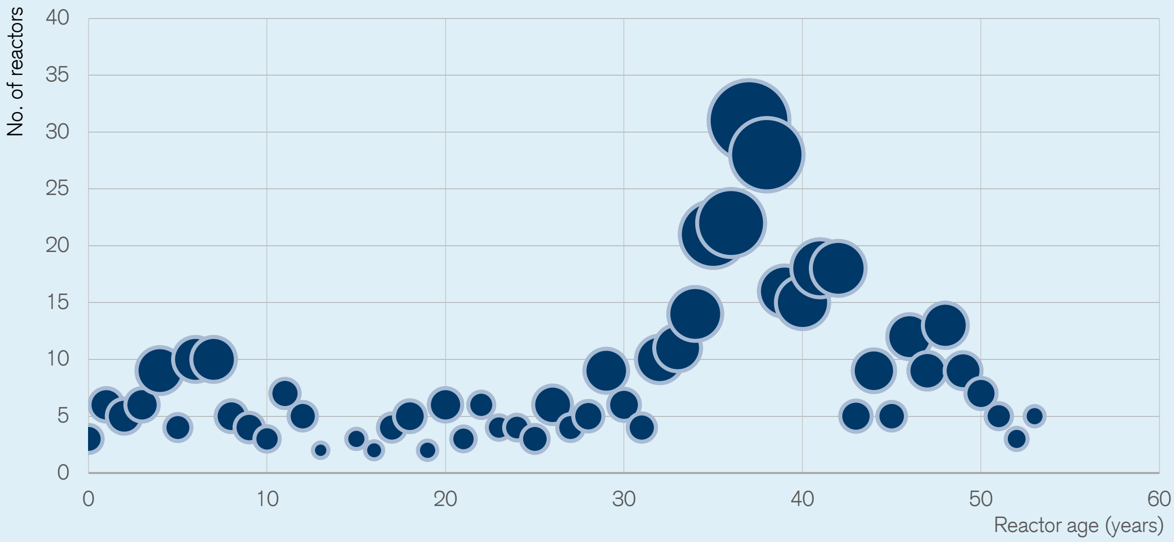
Country	Uranium mining (tonnes U in 2020)	% World	Country	Enrichment capacity (1,000 SWU/year* in 2020)	% World
Kazakhstan	19,477	41%	Russia	28,663	43%
Australia	6,203	13%	Germany, Netherlands, UK	14,900	22%
Namibia	5,413	11%	China	10,700	16%
Canada	3,885	8%	France	7,500	11%
Uzbekistan	3,500	7%	USA	4,700	7%
Niger	2,991	6%	Other	245	<1%
Russia	2,846	6%			
Other	3,416	8%			

*A separative work unit (SWU) is the standard measure of the effort required to separate isotopes of uranium (U-235 and U-238) during an enrichment process in nuclear facilities. Source: World Nuclear Association

Estimated nuclear capacity deficit of 400 GW
Nuclear power is split evenly between Europe, North America and Asia. There are currently over 400 nuclear power plants in operation around the world generating 367 gigawatts (GW) of power. A further 57 power plants are currently under construction and due to be operational by 2028. A further 213 plants are planned. Many of the future nuclear power projects are happening in Asia, where China is the main operator, accounting for just over half of the current nuclear energy in operation and in construction in APAC. India is building more nuclear power stations that will double its nuclear power. It also accounts for 23.3% of the planned future nuclear power projects in APAC. The majority of Japan's nuclear power production is currently suspended, with 24 reactors having been shut down since the Fukushima Daiichi incident in 2011. South Korea continues to operate its nuclear power plants, but, like Japan, no future plants are planned.

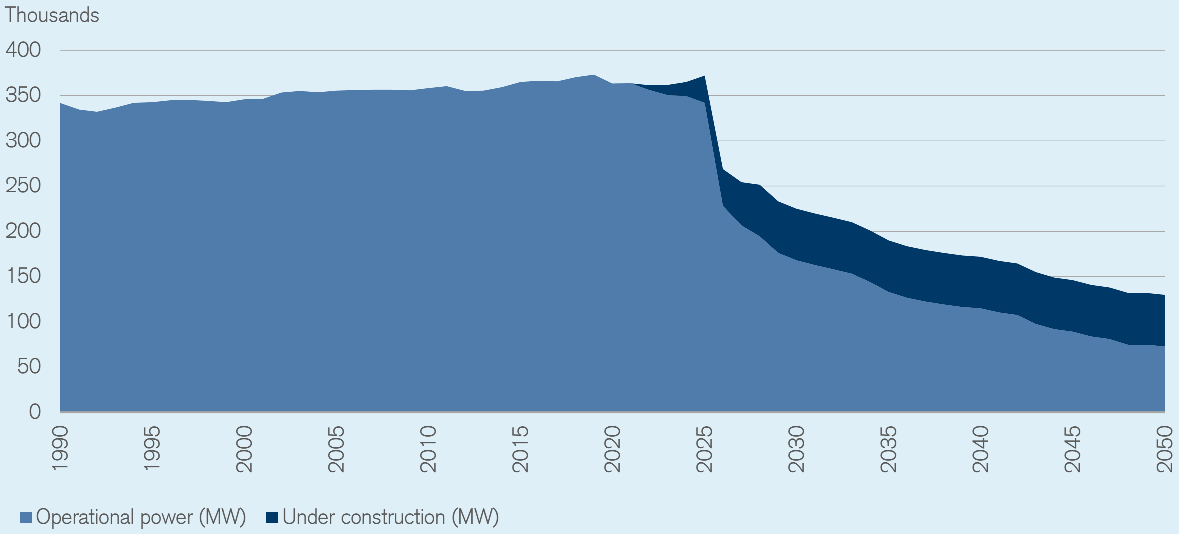
Based on the information currently available, we anticipate that, between 2025 and 2030, many existing power stations will reach their 40-year design lifetime and will need to be decommissioned, with a large quantity of electrical power supply going offline (see **Figures 2 and 3**).

Figure 2: Age distribution of nuclear reactors in the world



* The size of the bubbles represents the nuclear energy capacity (MW)
Source: IAEA

Figure 3: Trend in electricity supplied by nuclear reactors



Source: IAEA, Credit Suisse

The lifetime of the nuclear power plants can potentially be extended by the regulatory body provided the plant structure and components are adequately managed. In the USA, the extension period is up to 20 years[9]. The power plants that are currently under construction will mitigate a small portion of the reactors going offline. Despite the currently planned reactors, as it stands, the total nuclear power generation is expected to decline to around 345 GW by 2050. Based on the IEA Net Zero roadmap, this would imply the need to build an additional 400 GW of nuclear energy capacity – much more than many countries are currently planning to produce in the next three decades[10]. As the nuclear industry shifts towards APAC and given geopolitical concerns that are likely to emerge, there is a risk of a loss of expertise and a lack of qualified staff to develop and build new nuclear facilities in the future.

Construction time for nuclear power stations

Between 1960 and 1990, there was a rapid roll out of nuclear power stations. As the technology matured, larger reactors were built. However, the time to build these reactors increased, rather than decreased. Since 1990, the total number of nuclear reactors operating in the world has remained largely unchanged. The trend has been to build reactors of around 1,000 MW (usually several reactors operate at the same site). The average construction time for these reactors has decreased from 8.8 years in 1971–90 to 6.9 years in 2001–20. We find that it takes nearly 15 years to construct a nuclear reactor in the USA, compared to around six years in Japan and China (see **Table 2**).

The majority of Chinese reactors are very new, having been constructed since 2010. Unlike other countries, China has focused on building PWRs, which make up 94.3% of its reactors. However, this alone cannot explain the speed of China's power plant construction as Japan has built both PWRs and BWRs at the same pace, and Germany has built only PWRs since 1985, yet its construction times far exceed those of China.

9. "Going Long Term: US Nuclear Power Plants Could Extend Operating Life to 80 Years," IAEA, 2017
10. "Net Zero by 2050 – A Roadmap for the Global Energy Sector," IEA, 2021

Table 2: Construction time for nuclear power plants

Country	Power plants since 1985	Construction time (years)	Average capacity built (MW)
USA	23	14.7	1,160
UK	10	14.6	650
Russia	20	11.2	890
Germany	6	9.0	1,190
France	25	8.9	1,310
China	53	6.2	960
Japan	7	5.6	950

Source: IAEA, Credit Suisse

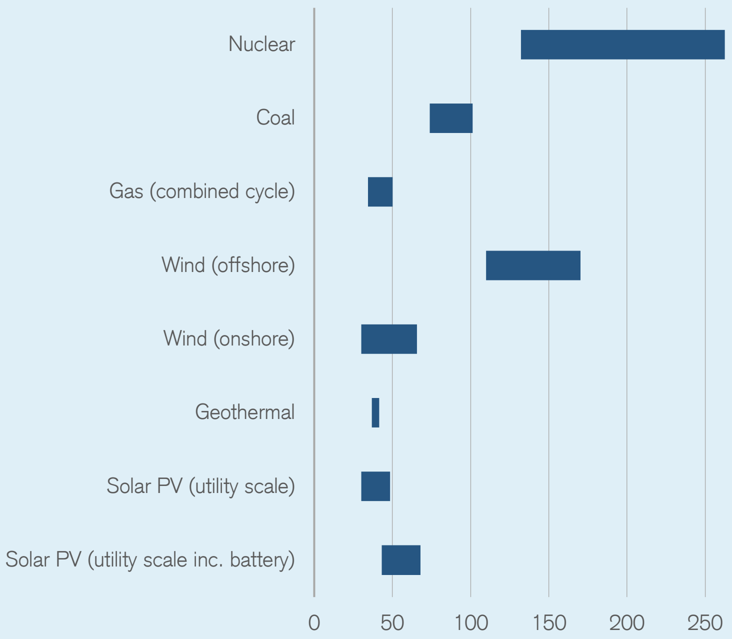
Costs

Levelized cost of electricity

The levelized cost of electricity (LCOE) is the net present value of the total lifetime cost of electricity divided by the net present value of the total electricity generated. We estimate the LCOE of nuclear energy to be USD 132–262 per megawatt hour (MWh, see **Figure 4**). Spending on fuel is assumed to make up 33% of the operating costs. We note that 60%–70% of the LCOE is due to the capital costs. We base our calculation on a 40-year operating time with overnight construction costs of USD 7,500–12,500 per kW, a load factor of 70%–90%, and include the decommissioning cost estimates. Many reported LCOE values underestimate the costs of building a nuclear power plant and the end-of-life costs, thus tending to underestimate the cost of nuclear power.

Many renewable sources of energy, such as solar, wind, hydro and, increasingly geothermal, are more cost-competitive than nuclear. However, the LCOE as a measure does not take into account the fact that nuclear energy, gas and coal are dispatchable sources of energy available 24/7, while renewables are not. When storage costs are included to make renewable energy similarly available, we should include the cost of batteries. According to analysis by IEA[11], combining utility-scale solar PV with battery storage increases the costs to USD 43–70 per MWh. We note, however, that (1) by building renewable generating overcapacity, demand for expensive batteries could be reduced as argued by Rethink X[12]; (2) prices of batteries, wind and solar energy have been rapidly decreasing – a trend which is likely to continue through economies of scale and efficiency improvements; and (3) other energy storage technologies are available or being developed. We anticipate that the combined renewables and storage costs will continue to decrease.

Figure 4: Levelized cost of electricity (USD per MWh)
Estimates based on new supplies entering service in 2027



Source: "Levelized costs of new generation resources in the annual energy outlook 2022," IEA, 2022, Credit Suisse

Capital costs breakdown and outlook

Even before building a nuclear power plant, the project owner must perform feasibility studies and prepare for regulatory approval, which takes time and effort. The construction is a complex project involving site preparation, assembly, and testing. Both pre- and construction activities are thus time-consuming, labor-intensive, and expensive. The capital costs can be broken down into (1) construction (including engineering, procurement), (2) owner's costs, contingencies, and (3) interest during construction (IDC)[13] as follows:

Construction costs: Across the different regions, of the total costs, supervisory and quality assurance costs are around 15%–20%; while close to 50% of the capital costs are from civil work to prepare the site, excavations, foundations, cooling towers, and installation of the plant equipment[14]. Therefore, any potential modularization of the component-manufacturing process is unlikely to substantially improve the time and cost.

Owner's costs: Some of the costs borne by the owner include general administration, project management, site selection, regulatory approval, public relations, taxes and legal fees, as well as preoperational costs.

Contingencies: The means of dealing with unexpected circumstances are included as experience shows that all risks and changes cannot be accounted for at the start of the project. The number of contingencies evolves as the project matures and the uncertainties are reduced over time. Projects with a low level of maturity include contingencies of 30%–50% that drop to 10%–15% at advanced stages of the overnight construction costs.

11. "Levelized costs of new generation resources in the annual energy outlook 2022," IEA, 2022
12. "Rethinking Energy 2020-2030", RethinkX, 2020
13. "Financing France's New Nuclear Build", SFEN, 2022
14. "Sources of Cost Overrun in Nuclear Power Plant Construction Call for a New Approach to Engineering Design," Joule, 2020

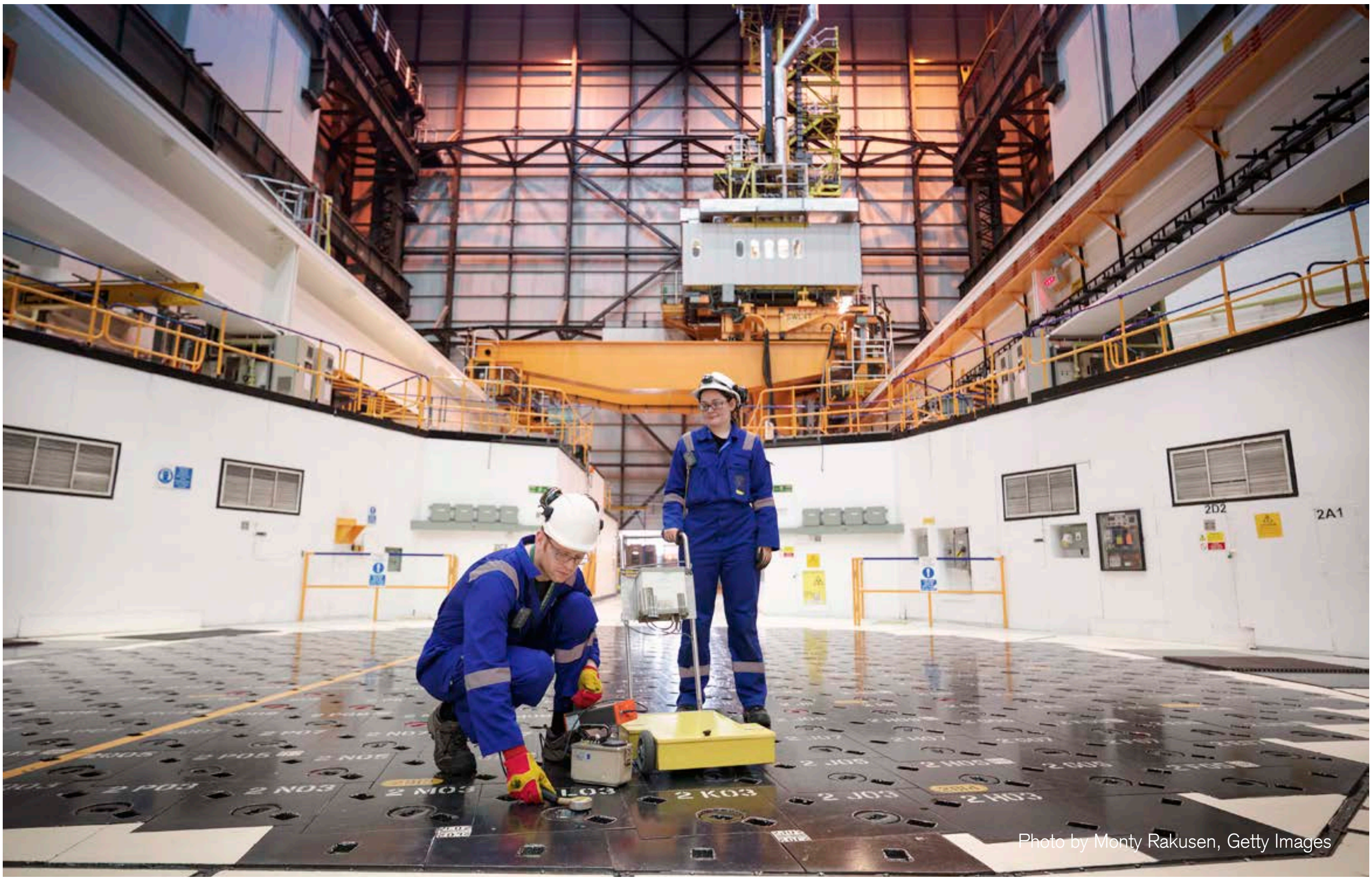


Photo by Monty Rakusen, Getty Images

Interest during construction: The ownership structure of a nuclear power plant drives the financing decisions. According to the OECD Nuclear Energy Agency, this can take various forms, e.g. a sovereign model, where the state funds the project and the taxpayer carries the project risks; a corporate model, where utility companies with strong balance sheets can finance large projects through equity and debt financing; or a project-finance model, which is the same as the corporate model, but where a separate legal entity is created (see **Table 3**).

The latter is the most common approach, but the options are not mutually exclusive and can be combined. The government can therefore play an important role in providing financial support directly as well as indirectly through long-term power purchase agreements and setting up favorable regulatory and policy frameworks. Electricity generation and repayment only occur once the power plant is up and running, which means investors have to wait a decade before seeing a return on their investment. The weighted cost of capital (WACC) for nuclear power is usually around 7%–8%. In comparison, due to the lower risks involved, the WACC values for wind and solar energy are 4%–7% and 3%–6%, respectively[15].

15. "World Energy Model," IEA, 2021

Table 3: Portion of IDC in the total investment costs

Cost of capital	Construction period		
	3 years	5 years	10 years
3%	5.8%	8.6%	15.3%
7%	12.8%	18.7%	32.4%
10%	17.6%	25.5%	43.0%

Source: Adapted from "Unlocking Reductions in the Construction Costs of Nuclear: A Practical Guide for Stakeholders," OECD/NEA, 2020

Decommissioning: Older nuclear power plants were designed for a production life of 40 years, although some of these have been extended and, conversely, some have been shut prematurely as in Japan and Germany. New reactors are designed for 60 years of operations. When the power plant is decommissioned, the fuel rods are removed, but the reactor remains radioactive. The common approach is to wait a decade to allow radioactivity to decay to lower levels before demolition. The building decommissioning is split into phases. The preparatory work takes 2–5 years, followed by 2–7 years for

dismantling, three years for decontamination, and then conventional demolition work taking around two years[16].

Therefore, the total decommissioning time can take 10–20 years. The spent fuel is stored in water tanks for several years before it is put in storage. In the USA, nuclear generators pay a levy to the government of 0.1cents/kWh, but have no liability for fuel disposal. In the UK and most of Europe, the companies are responsible for the spent fuel even though they are dependent on state policies[17]. The decommissioning costs vary from around USD 500 million to USD 3,000 million[18] for 1,000 MW reactors.

Cost trends: Experience shows that the construction of nuclear power plants is often over-budget and delayed. Of the 20 reactors completed in 2018–20, 16 reactors were at least a year overdue[19]. Reactors in the USA, Europe and Asia that had an initial construction time of 4–5 years were completed in 8–17 years with released construction costs that were typically double the projected budget[20]. An MIT study of nuclear power costs in the USA[21] identified that the cost overruns are due to tightening safety regulations and declining labor productivity. The former could be explained by re-engineering processes that need to be carried out during construction due to regulatory, quality or project-owner demands. An assumption in many cost projections of nuclear power is that the costs should decline as the industry gains experience in designing reactors.

However, others dispute that nuclear power could ever realize the level of scale and standardization necessary to achieve economies of scale. The MIT group examined the construction costs of four designs of nuclear reactors to find that the first one built was the least expensive. Its analysis further showed that, between 1976 and 1987, 72% of the cost increase was due to construction support activities, such as engineering, administration and construction supervision, rather than the hardware costs.

Construction costs in Germany, France and Japan increased over the years, although not as fast as in the USA[22]. India saw a small increase in costs whereas South Korea's construction costs decreased slightly over the same time period. One of the main methods proposed to reduce nuclear energy costs is the modularization of components to reduce capital costs. However, this is unlikely to significantly alter the assessment. Equipment costs make up a small proportion of the overall construction costs. While the greatest benefit would potentially be the time-saving reduction, this is not a substantial economic factor. Experience in the USA has shown that 10%–15% cost savings through modularization can be achieved[23].

> “
> ## Experience shows that the construction of nuclear power plants is often over-budget and delayed

In contrast, over the last decade, the development of solar and wind has seen a substantial reduction in costs as the capacity was scaled up. Coal has seen little change over the same period and is unlikely to do so as (1) there is little room to improve the efficiency of coal power plants, and (2) the cost of coal that makes up the significant portion of the LCOE is unlikely to change in the long run. The cost of electricity from gas has an LCOE of USD 34–50 per MWh, having declined in the last decade. However, this is largely driven by the price of gas, which saw a peak in 2008 and has been declining rapidly due to increased supply from fracking until recent months. Since the LCOE of gas power stations is highly dependent on the gas price, recent gas price volatility would imply LCOE of gas is likely much higher than these

16. “Costs of Decommissioning Nuclear Power Plants,” OECD, 2016
17. “How should investors value nuclear liabilities?,” JBS, 2008
18. “New cost study now available for Mühleberg Nuclear Power Plant decommissioning and waste disposal,” BKW, 2016
19. “The World Nuclear Industry Status Report”, 2021
20. “Unlocking Reductions in the Construction Costs of Nuclear,” Nuclear Energy Agency, 2020
21. “Sources of Cost Overrun in Nuclear Power Plant Construction Call for a New Approach to Engineering Design,” Joule, 2020
22. “Historical construction costs of global nuclear power reactors,” Energy Policy, 2020
23. “The Future of Nuclear Energy in a Carbon-Constrained World,” MIT Energy Initiative, 2018

estimates. Furthermore, it is highly unlikely that gas power plants will increase in efficiency and thus it is unlikely that the cost of electricity from gas is going to decline in the future.

Nuclear energy is expensive and can take decades from conception to a built power plant. The main expenses are the initial construction costs, particularly civil engineering. In most countries, the costs of building nuclear power plants have only increased over the years and delays and cost overruns are common. As many nuclear power plants are reaching the end of their design life, there is interest in adapting regulations and prolonging their operations. However, as nuclear power plant structures are gradually destroyed by radiation, there is some skepticism about the viability of these plants and the additional costs for maintenance. Renewables, on the other hand, offer electricity at a lower cost. Solar PVs typically have lifetimes of 25–30 years. However, the solar panels do not stop working after this period. Typical degradation rates are around 1% per year, so that PVs can still generate 74% and 67% of their nominal electricity output after 30 and 40 years, respectively. Wind turbines are specified for 20-year operation, which can also be extended. However, potentially additional investment cycles would be needed for wind farms to operate for a similar length of time as nuclear power plants.

Security

In this section, we examine some of the risks associated with the nuclear power plant technology. The main dangers are associated with the handling of the uranium fuel and the stability of the reactor operation under non-ideal conditions. We note that nuclear technology today is, within acceptable limits, safe.

Nuclear waste

Every year, around 50,000 tons of uranium ore are mined. The enrichment process to create the fuel results in large quantities of U-238 (depleted uranium) that needs to be discarded. Assuming all fuel is enriched to 3.3% U-235, this would correspond to around 40,000 tons of depleted uranium that would need to be discarded. In the USA, this is primarily stored at the enrichment facility[24]. Depleted uranium is very dense and extremely hazardous if ingested or inhaled[25], but not very radioactive and can be disposed of as low-level radioactive waste. It can be used for aircraft counterweights and military applications (radiation shielding, armor and ammunition).

A conventional BWR or PWR will use a fuel rod for around six years. Most power stations use fission of U-235 to generate electricity. Several reactions take place such that, by the end of the useful life of the fuel rods, they still contain 93% of the original uranium. However, some lighter-than-uranium elements (5.2% of the spent fuel) and heavier-than-uranium elements (1.2% of the spent fuel) are created, some of which are hazardous. These include strontium-90 (Sr-90), which is carcinogenic when ingested, caesium-137 (Cs-137), which can cause acute radiation sickness and death, and plutonium-239 (Pu-239), which remains radioactive for thousands of years[26].

> “
> ## Costly lessons learned have improved the safety of nuclear reactors

Owing to the dangers and long-lived nature of the radioactive waste, its safe storage for several hundred thousand years is of paramount importance. Every year, around 10,000 tons of nuclear waste are created worldwide. Currently, 263,000 tons of spent fuel are in interim storage facilities worldwide, according to the IAEA estimates[27]. In the USA, almost all nuclear waste is stored onsite at the power stations in specialized containment vessels. Attempts to dispose of nuclear waste at the Yucca Mountain purpose-built nuclear waste facility faced strong opposition in the USA and the project’s future is uncertain and likely to be entirely abandoned[28]. The near-finished nuclear waste facility in Finland cost EUR 818 million and will eventually store 6,500 tons of spent fuel. Based on IEA and IPCC projections, by 2050 we would have used up 40% of the known and inferred uranium deposits and generated an additional 300,000–340,000 tons of spent fuel.

24. “FAQ About Depleted Uranium Deconversion Facilities,” US NRC, 2015
25. “Depleted Uranium,” US EPA, 2021
26. “Physics of Uranium and Nuclear Energy,” World Nuclear Association, 2022
27. “Final resting place,” Science, 2022
28. “Current Status of the Yucca Mountain Project,” Eureka County, Nevada - Nuclear Waste Office, 2019

In practice, waste processing, which can separate out some of the more harmful elements, is not carried out in most countries as it adds additional expenses. France uses a centralized facility in La Hague where the fissile uranium and plutonium are removed from the other waste and made into a new fuel. This process adds 6% in costs to electricity in France[29]. Half of the processing is carried out for spent fuel imported from other countries. The UK, Japan, India and Russia all have some level of reprocessing that helps to reduce the nuclear waste. However, since a spent fuel rod contains U-235 at almost natural abundance level and enrichment means that for every one kilogram of U-238 used in the reactor, approximately 3.7 kilograms of (depleted) U-238 must be disposed of as waste, the benefits of reprocessing can be overstated.

Nuclear weapons

Atomic bombs: Only certain isotopes of atoms can be used as a viable weapon-making material – other heavy atoms cannot easily undergo a chain reaction. The fissile nuclei are U-233, U-235, Pu-239, and Pu-241. However, the bottleneck to creating nuclear weapons is not the supply of the material, but the processing needed to have sufficient pure fissile material, requiring expert knowledge and equipment. Nuclear reactor fuel rods contain 3%–5% U-235 (the rest being non-fissile U-238) enriched uranium. At the end of the fuel rod, its U-235 content is close to naturally occurring uranium of around 0.7%. However, the production of nuclear weapons requires a U-235 content higher than 20%. This would mean acquiring several tons of the starting material and then processing it. Therefore, risks of spent fuel being used for nefarious purposes in this way seem very low and would more likely require a more coordinated, state-sanctioned effort.

Radiological weapons: Instead of creating a large explosion, radioactive substances are hazardous to life when ingested or inhaled. Obtaining the right materials would be challenging, but to construct a radiological weapon requires minimal technical knowledge or skill. The region that would be affected would be substantially smaller than that of a nuclear weapon detonation, but the risk is much higher of nuclear waste (or other radioactive materials) being used in this way.

Nuclear disasters: It is of paramount importance that a nuclear reactor is cooled sufficiently to avoid a thermonuclear meltdown.

- Natural disasters: Nuclear power plants are built with attention to withstanding adverse natural disasters. According to the IAEA, around 20% of nuclear reactors worldwide are operating in areas of significant seismic activity. At Fukushima Daiichi, the power plant met its design specifications, but did not foresee and

29. "Recycling Nuclear Fuel: The French Do It, Why Can't Oui?," The Heritage Foundation, 2007

plan for the huge tsunami that followed. Nuclear power plants are also vulnerable to damage to the infrastructure from other natural phenomena, including hurricanes, tornadoes, flooding, etc., that can expose flaws in the plant design. Such events have caused dangerous incidents and near misses from failed backup systems in the USA.

- Man-made disasters: One of the first commercial nuclear power plants to find itself in an area of military operations was Krsko, Slovenia in 1991 and more recently Zaporizhzhiya in Ukraine in 2022. Although disaster was averted in these cases, no nuclear power plant can be expected to withstand a military strike against it. However, provided the power plant has advanced warning of such actions, it can be shut down beforehand to mitigate some of the risks. While some nuclear reactors are built to withstand the crash of an aircraft, there is no precedence for the consequences of such an event.
- Human error: It takes 18–25 months and around USD 30,000 in fees to train a nuclear power plant operator. Automated safety systems exist to ensure that reactor operations remain stable. Reactors are better designed to avoid instabilities such as those that occurred in the Chernobyl reactor and personnel are better trained with simulations.
- Malign actions of parties with access to reactor operations: Regular psychological evaluation of nuclear radiation workers is carried out. Automated systems are also in place to safeguard the operations of the reactor. The case of Dr Abdul Qadeer Khan who stole nuclear secrets for uranium enrichment to help in Pakistan's and allegedly North Korea's nuclear weapons programs highlights the importance of safeguarding the enrichment processing. To build an enrichment facility from scratch is a complex endeavor and requires a large-scale, national strategy rather than a few small actors. Provided the enrichment facilities are secured, based on the nuclear proliferation discussion above, nuclear weapon construction can be averted. It is not possible to reduce the risk of nuclear energy to zero from man-made or natural factors, but costly lessons learned have improved the safety of nuclear reactors. Redundancy systems and high spending on safety factors will only ever increase.

Security staff
In the USA, the Nuclear Regulatory Commission (NRC) requires that nuclear power reactors have 24-hour armed response forces of at least ten people to protect the facility against potential attacks. Security staffing costs amount to 15%–25% of the operating and maintenance (O&M) costs and make up 20%–30% of the total workforce. The reactor's security with physical barriers and access restriction is based on three levels of increasing security as you move closer to the reactor and vital systems. Access to a nuclear power plant requires various background checks including criminal and credit records, psychological assessments, education and work history, and drug testing.

Greenhouse gas emissions

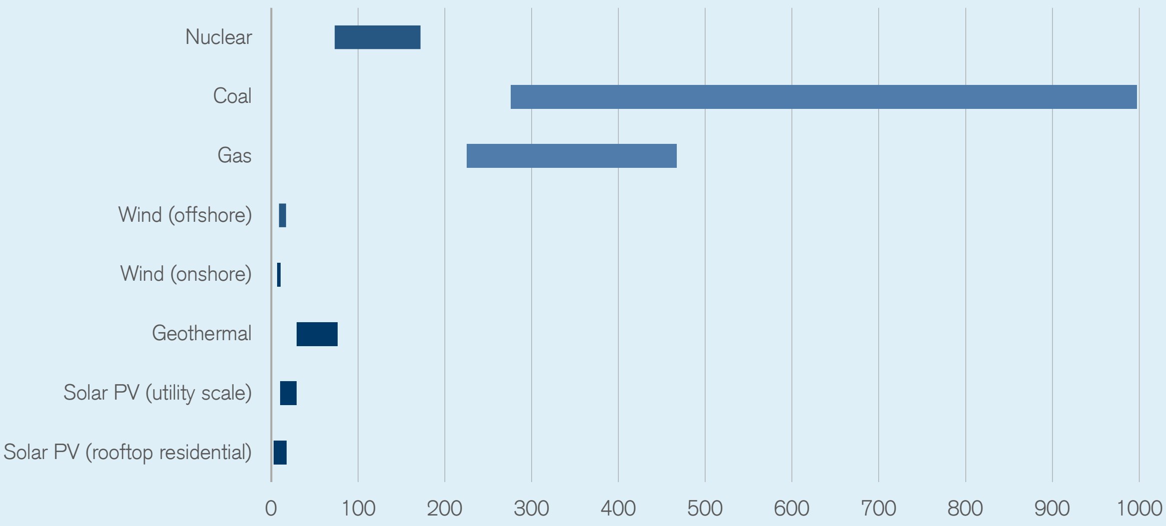
Nuclear energy is often advertised as being emission-free. This statement needs careful evaluation. Compared to coal and gas power plants, nuclear energy offers significant potential to reduce greenhouse gas (GHG) emissions. However, its emissions are still substantially higher than solar and wind renewable energy (see **Figure 5**). During the construction phase, there is no energy being produced by the plant – its capacity is taken up by other sources, such as gas power plants. At the same time, there are significant emissions from the construction site. The construction emissions are due to the large quantities of cement needed to build the power plant, including the deep foundations around the reactor in case of meltdown and the surrounding infrastructure. Once built, the emissions of nuclear power plants are low – there is vapor from the steam generation emitted, which contributes around 4.4 g-CO2/kWh, and emissions from mining uranium ore that need to be considered.

If we compare solar power to nuclear power, electricity can be generated as additional capacity is added. The construction time is much less (we assume around three years) and overall emissions are lower than from nuclear power plants. We assume that gas is used to provide the electricity needed during the construction phase. In this scenario, we find that the carbon payback for nuclear energy comes much later, with a breakeven in carbon emissions 11–25 years after the start of construction. For solar, the breakeven in carbon emissions comes after 1–6 years. Onshore wind takes 1–4 years and offshore wind takes 1–6 years for a breakeven in carbon emissions. However, as the lifetime of wind farms is around half that of nuclear, it would correspond to a breakeven of approximately 2–12 years.

Therefore, the modularity of solar power makes it much more effective for decarbonizing the electricity grid than nuclear power. The situation can be improved for nuclear energy through the use of SMRs, adding capacity more gradually to the grid. However, in absolute terms, it would be unlikely to be better than solar power.

Figure 5: Greenhouse gas emissions (g CO_2/kWh)

Lifecycle and opportunity cost emissions due to delays from background electric power grid



Source: "100% Clean, Renewable Energy and Storage for Everything," Jacobson, 2021, Credit Suisse

Conclusions

- Nuclear energy can generate vast quantities of energy 365 days a year around the clock.
- Nuclear technology and the current storage of spent fuel are relatively safe, but there is no clear strategy for long-term storage of nuclear waste in most countries.
- The security problem arises principally from the enrichment process, which can also be used to produce nuclear weapons. These facilities and personnel must be safeguarded.
- Geopolitical shifts may raise supply chain issues or increase costs as substitute suppliers of fuels and services are used.
- A substantial number of currently operating nuclear reactors are coming to the end of their operating life in the next 5–10 years.
- In the near term, most of the nuclear power roll out will take place in APAC, particularly in China.
- There is a strong discrepancy between the construction times in European countries and the USA compared to APAC. Construction in China typically takes half of the time as in the USA.
- The high economic costs of nuclear energy are unlikely to disappear any time soon. SMRs do not appear to be a viable means of reducing costs.
- When building nuclear power plants, cost savings are best achieved by optimizing how plants are constructed and by accelerating the construction process to reduce interest payments.
- Historically, the cost of nuclear power plant construction has increased, mainly due to the non-hardware-related increase in costs. In contrast, renewable energy from solar and wind power has seen a dramatic decrease in costs as the technology has been scaled up in the last decade to be more cost-competitive than nuclear and fossil fuels. However, the storage capacity and transmission infrastructure required to make renewables as dispatchable as nuclear power must be taken into account.
- Nuclear fuel is not infinite – at current usage rates and based on data from the OECD Nuclear Energy Agency (NEA) including yet-to-be discovered deposits, it would last 300 years. However, if we factor in doubling or tripling of electricity demand by 2050 due to increased electrification, this decreases potential supply to 100–150 years. Also, if we were to increase the share of electrical supply from nuclear power above the current 10% to 20%–30%, this would decrease potential reserves to around 50–75 years.
- Reprocessing spent fuel can help to reduce the demand for mining uranium, but this still creates large quantities of depleted uranium as waste for disposal.
- Although nuclear energy contributes to lower GHG emissions, it is still significantly higher than renewable sources of energy due to (1) emissions during the construction phase, and (2) long construction times of a new nuclear power plants during which fossil fuel power plants are used to generate electricity.

Photo by Alexandra Lande, Shutterstock

The EU Taxonomy: A framework for nuclear?

Bahar Sezer-Longworth

The EU Taxonomy Regulation aims to improve transparency on sustainability, avoid greenwashing and redirect capital flows toward activities in line with the EU's climate and environmental goals. In February 2022, the European Commission recognized the "transitional" role of certain gas and nuclear activities in its "green" rulebook, and the European Parliament eventually did not object to the Commission's proposal in July 2022. The inclusion of nuclear could provide a tailwind for the industry, despite historical wavering on the environmental impacts of the energy source.

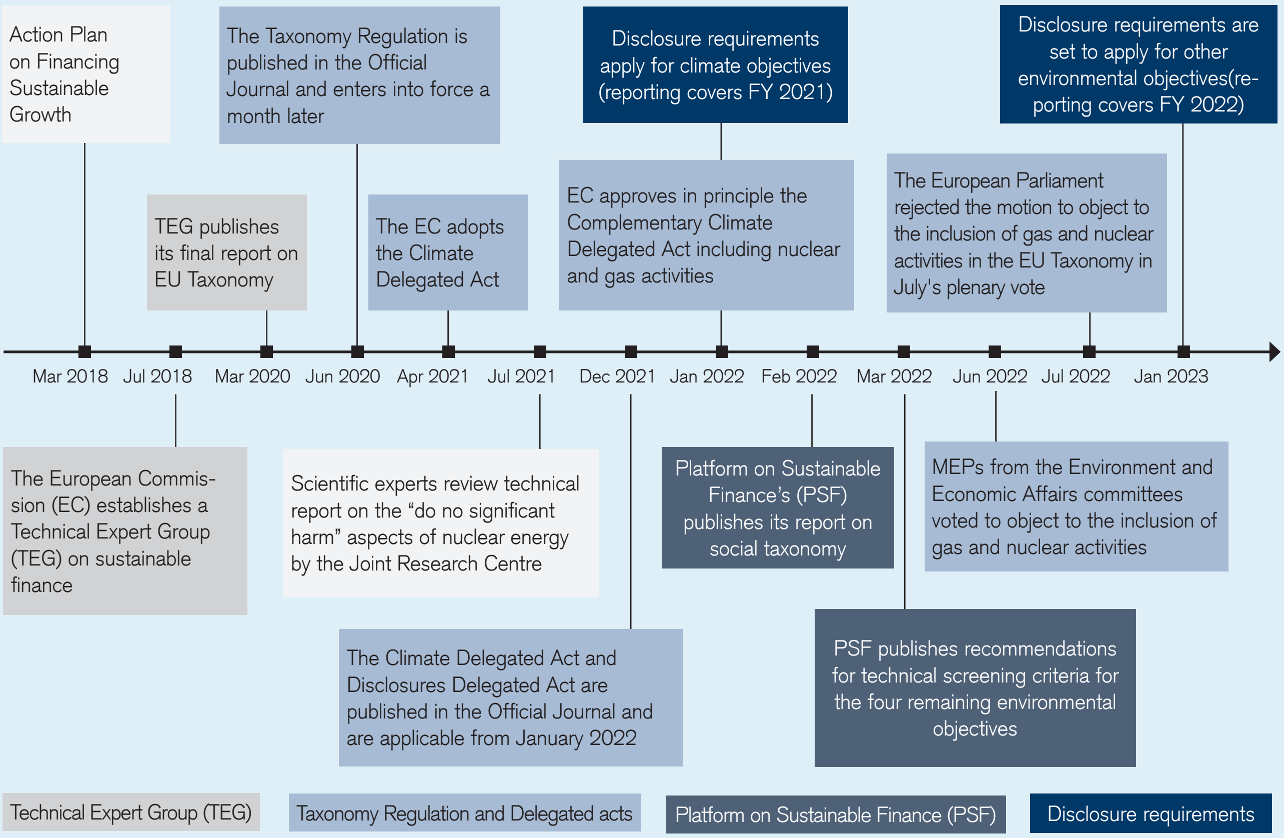
The EU's rulebook for "green" or sustainable activities

The Sustainable Finance Framework and the EU Taxonomy

In 2020, the European Commission pledged to cut greenhouse gas (GHG) emissions by 55% by 2030 based on 1990 levels as part of the overall 2030 Climate Target Plan and the commitments made in the European Green Deal. The acceleration in the reduction of GHG emissions to reach the European Union (EU) climate objective was further supported by the proposals in the "Fit for 55" package. To meet the climate and energy targets set for 2030, however, the EU faces a serious financing gap of EUR 350 billion per year. To reach the broader environmental objectives, an additional investment of EUR 100–150 billion per year is required.

To improve transparency, avoid greenwashing (where companies give a false impression of how their products are environmentally friendly) and redirect capital flows toward green activities, lawmakers have increasingly focused on the development of regulatory regimes focusing on sustainability. Over the past years, the EU has established a Sustainable Finance Framework to support the flow of private finance toward activities that help with the transition to a carbon-neutral economy. One of the main pillars within the EU's Sustainable Finance Framework and an important piece of environmental, social and governance (ESG) legislation is the EU's rulebook for green or sustainable activities,

Figure 1: A timeline of the EU Taxonomy regulation



Source: Credit Suisse, European Commission

commonly referred to as the EU Taxonomy. The role of the EU Taxonomy is two-fold. First, it aims to prevent greenwashing and provide a common language and definition of economic activities in line with the EU's climate and environmental goals. Second, it also aims to increase and redirect capital flows in order to close the investment gap needed to transition toward a carbon-neutral economy.

The EU Taxonomy contains a list of economic activities with technical screening criteria to determine whether an economic activity makes a substantial contribution to an environmental objective and is taxonomy-aligned. It is important to highlight that the EU Taxonomy does not prescribe a mandatory list of activities to invest in, nor does an economic activity that is not taxonomy-aligned mean it is by definition unsustainable or environmentally harmful. Delegated Acts[1] will be treated like living documents that will be regularly updated and further drafts will be released as they incorporate additional economic activities. Moreover, there is an existing proposal to extend the environmental taxonomy beyond green to classify a wider array of economic activities to address the "binary classification" problem.

A timeline on the EU Taxonomy and its inclusion of nuclear power

The **EU Taxonomy Regulation** was published in the Official Journal of the European Union in June 2020 and entered into force a month later. The **Climate Delegated Act**, which is the first Delegated Act under the EU Taxonomy Regulation, was published in the Official Journal on 9 December 2021 and has been applicable since January 2022. It defines the technical screening criteria for activities in the sectors that are most important in delivering on climate change adaptation and mitigation. The criteria defined under the current Climate Delegated Act will cover the economic activities of around 40% of EU-domiciled listed companies in sectors that are responsible for almost 80% of direct GHG emissions in Europe, according to the European Commission. In total, 13 sectors are covered, including energy, forestry, manufacturing, transport and buildings.

In February 2022, the Commission approved in principle the **Complementary Climate Delegated Act**, which recognizes the

1. Delegated Acts are non-legislative acts adopted by the European Commission that serve to amend or supplement the non-essential elements of the legislation.

Table 1: The EU Taxonomy's six environmental objectives

	Environmental objectives	Delegated Act	Applicable from
1	Climate change mitigation	Climate Delegated Act and Complementary Climate Delegated Act (focusing on nuclear and gas energy activities)	January 2022 (first Climate Delegated Act) and January 2023 (Complementary Climate Delegated Act)
2	Climate change adaptation		
3	The sustainable use and protection of water and marine resources	The Commission will review the published recommendations by the Platform on Sustainable Finance and make its own proposal for a Delegated Act towards the end of 2022	Targeted for January 2023
4	The transition to a circular economy		Targeted for January 2023
5	Pollution prevention and control		Targeted for January 2023
6	The protection and restoration of biodiversity and ecosystems		Targeted for January 2023
A Delegated Act supplementing Article 8 of the Taxonomy Regulation ("Disclosures Delegated Act") specifies the content, methodology and presentation of information to be disclosed by financial and non-financial companies in relation to the % of Taxonomy-aligned economic activities in their business, investments or lending activities.			January 2022

Source: European Commission, Credit Suisse

"transitional" role of certain gas and nuclear activities in meeting the EU's climate change mitigation objective. The European Parliament and the Council were given four months to scrutinize the text. In June 2022, during the scrutiny period, members of the European Parliament's Environment and Economic Affairs committees voted to object to the inclusion of gas and nuclear activities in the list of environmentally sustainable economic activities. Although the European Parliament eventually voted in favor of the Commission's proposal during the plenary session on 6 July, the objection provided a telling insight into the political divide among legislators. In July 2022, the European Parliament plenary voted on the motion of objection with 328 votes against, 278 in favor and 33 abstentions. This means that Parliament does not object to the Commission's proposal to classify certain nuclear and natural gas activities as sustainable under the EU Taxonomy. In the absence of objection from both the European Parliament and Council, the Complementary Delegated Act will be deemed approved and passed into law.

Despite historical wavering on the environmental impacts of nuclear power, the proposed inclusion of nuclear activities in the EU taxonomy could provide an impetus for new investment in the sector, thus ultimately providing a tailwind for the nuclear industry as well as for investors who already have nuclear holdings or plan to start increasing investments in nuclear energy.

Figure 2: Four conditions that an economic activity must meet for taxonomy alignment

1 Make a substantial contribution to at least one environmental objective

2 Do no significant harm to any other environmental objective

3 Comply with the technical screening criteria

4 Comply with minimum social and governance safeguards

Source: Platform on Sustainable Finance, Credit Suisse

Finally, a **Disclosures Delegated Act**, which took effect in January 2022, specifies the content, methodology and presentation of information that financial and non-financial companies need to disclose. Under Article 8 of the Taxonomy Regulation, companies that are subject to the Non-Financial Reporting Directive (NFRD) have to report on how and to what extend their activities are associated with taxonomy-aligned economic activities in their non-financial statements or consolidated non-financial statements.

Taxonomy alignment

Figure 2 shows that an economic activity is considered to be taxonomy-aligned if (1) it makes a substantial contribution to at least one of the six environmental objectives, (2) it causes no significant harm to any of the other five objectives, (3) it complies with the technical screening criteria, and (4) it meets a set of minimal social safeguards (e.g. OECD Guidelines on Multinational Enterprises and the UN Guiding Principles on Business and Human rights).

The technical screening criteria for a "substantial contribution" to an environmental objective are meant to ensure that an economic activity has a positive environmental impact or substantially diminishes negative impacts on the environment (e.g. reducing GHG emissions), whereas the technical screening criteria for "do no significant harm" ensure the economic activity does not prevent any environmental objectives from being reached (i.e. has no significant negative impact on them). For each environmental objective, the EU Taxonomy defines two types of substantial contributions that can be considered taxonomy-aligned:

- Own performance: Economic activities that make a substantial contribution based on their own performance (i.e. they can be performed in a way that is environmentally sustainable).
- Enabling activities: Economic activities that enable a substantial contribution to be made in other activities (i.e. an economic activity that manufactures or creates a component that improves the environmental performance of another activity).

The Taxonomy Regulation also recognizes "Transitional activities." These are activities for which low-carbon alternatives are not yet available, but that have a level of emissions in line with the best performance in the corresponding sector.

Table 2: Disclosure obligations based on the type of sustainability claim

Fund	Description	Taxonomy disclosures
Article 9 ("dark green")	Financial products that have sustainable investment as their overarching objective.	Must complete Taxonomy disclosures where the investment concerns activities that contribute to an environmental objective.
Article 8 ("light green")	Financial products that promote environmental or social characteristics, but not as their overarching objectives.	Must complete Taxonomy disclosures where environmental characteristics are promoted.
Article 6	All other financial products.	Must complete Taxonomy disclosures or carry a disclaimer stating "the investment(s) underlying this financial product do not take into account the EU criteria for environmentally sustainable investments."

Source: EU Technical Expert Group on Sustainable Finance

Table 3: What should companies report and by when (for the previous calendar year)?*

Date	Non-financial companies		Financial companies	
	Taxonomy eligibility	Taxonomy alignment	Taxonomy eligibility	Taxonomy alignment
As of January 2022	X		X	
As of January 2023	X	X	X	
As of January 2024	X	X	X	X
As of January 2025	X	X	X	X**

*Taxonomy-eligible activities are listed in the Delegated Acts specifying the technical screening criteria. Taxonomy-aligned activities meet the following criteria: (1) contribute substantially to at least one environmental objective, (2) do no significant harm to any other environmental objective, (3) comply with the technical screening criteria, and (4) comply with minimum social safeguards.
**Credit institutions include taxonomy alignment of their trading book and fees and commissions for non-banking activities.

Source: European Commission, Credit Suisse

Photo by Santiago Urquijo, Getty Images

What are the disclosure requirements and who is in scope?

The Taxonomy Regulation sets out three main groups of users:

1. Financial market participants who offer financial products in the EU as environmentally sustainable investments or investments having similar characteristics.
2. Large financial and non-financial companies that are already required to provide a non-financial statement under the Non-Financial Reporting Directive.
3. The EU and Member States.

Financial market participants
The proposed inclusion of nuclear activities in the EU Taxonomy will impact funds that currently have holdings or plan to increase investments in nuclear power. The Taxonomy Regulation requires that, for each financial product in scope, investors will be required to disclose:

- How and to what extent they have used the Taxonomy in determining the sustainability of the underlying investments.
- What environmental objective(s) the investments contribute to.
- The proportion of underlying investments that are taxonomy-aligned, expressed as a percentage of the investment, fund or portfolio.

We note that the taxonomy-related disclosures for financial market participants are part of a broader sustainability-related disclosure regime set out in the Sustainable Finance Disclosure Regulation, which came into effect on 10 March 2021. The regulation defines three types of funds based on their sustainability approach with varying levels of disclosure requirements (see **Table 2**).

Large financial and non-financial companies
The Disclosures Delegated Act requires large financial and non-financial companies to provide information to investors about the environmental performance of their assets and economic activities. Large financial and non-financial public-interest companies with more than 500 employees, including listed companies, banks and insurance companies, which are subject to the Non-Financial Reporting Directive, are required to make disclosures. Around 11,700 companies are currently in scope.

The proposal for the Corporate Sustainability Reporting Directive extends the scope to all large companies and all companies listed on regulated

markets except listed micro-enterprises. In addition, it will also cover non-European companies generating a net turnover of EUR 150 million in the EU, and which have at least one subsidiary or branch in the EU. A large company must meet at least two of the following criteria: (1) a balance sheet total of EUR 20 million, (2) a net revenue of EUR 40 million, and (3) an average number of 250 employees during the financial year. Nearly 50,000 companies will be in scope.

Key performance indicators

Companies should demonstrate the breakdown of the key performance indicators (KPIs) based on the economic activities and environmental objectives in scope, including transitional and enabling activities. Non-financial companies are required to disclose the proportion of their turnover, capital expenditure ("CapEx") and operating expenditure ("OpEx") that is taxonomy-aligned. The KPIs in scope for financial companies such as banks, investment firms, asset managers and insurers are based on the proportion of taxonomy-aligned economic activities in their financial activities (e.g. lending, investment and insurance). If "economic activity A" (15% of turnover) makes a substantial contribution to climate change mitigation and does no significant harm to the other five environmental objectives, and meets the minimum social safeguards (e.g. UN Guiding Principles on Business and Human Rights), the company can disclose that 15% of its turnover is taxonomy-aligned or green.

The EU Taxonomy and nuclear power

What is the rationale for including nuclear activities in the EU Taxonomy?

(1) Nuclear power as a low-carbon source of energy: Data from the International Energy Agency (IEA)[2] shows that nuclear power is the second-largest source of global low-carbon electricity generated today, with over 400 reactors in operation providing 2700 terawatt-hours (TWh) of electricity in 2018. This accounts for 10% of the global electricity supply. Moreover, the IEA asserts that, over the past 50 years, the use of nuclear power has avoided emissions by over 60 gigatons, which is equivalent to two years' worth of global energy-related emissions.

Figure 3 shows the low carbon footprint of nuclear power in comparison to other sources of electricity generation, whereby nuclear energy produces a similar amount of grams of carbon dioxide equivalent per kilowatt-hour of electricity generated (gCO2/kWh) as wind power and considerably less than solar power.

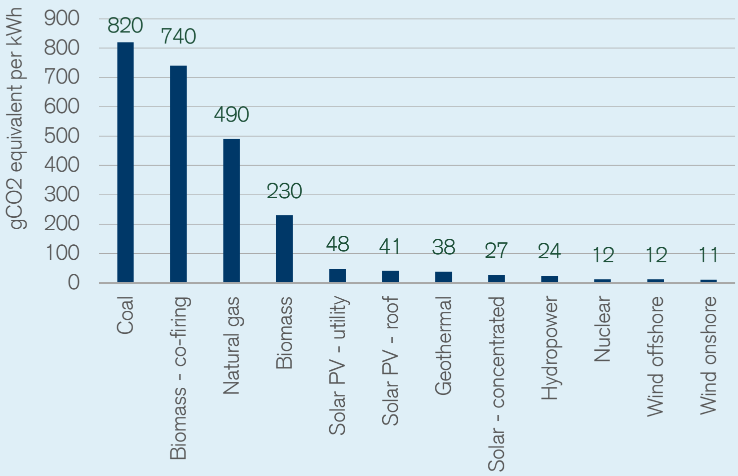
2: "Nuclear Power in a Clean Energy System," IEA, May 2019

(2) Reliance on nuclear power for electricity generation: Eurostat data[3] shows that, in 2020, 13 EU member states generated 683,512 GWh of gross nuclear energy production. This makes up a quarter of the EU's total electricity production.

France accounted for the largest share of total EU nuclear energy production at 52% (353,833 GWh), followed by Germany at 9% (64,382 GWh) and Spain at 9% (58,299 GWh). A more detailed evaluation of the energy mix within

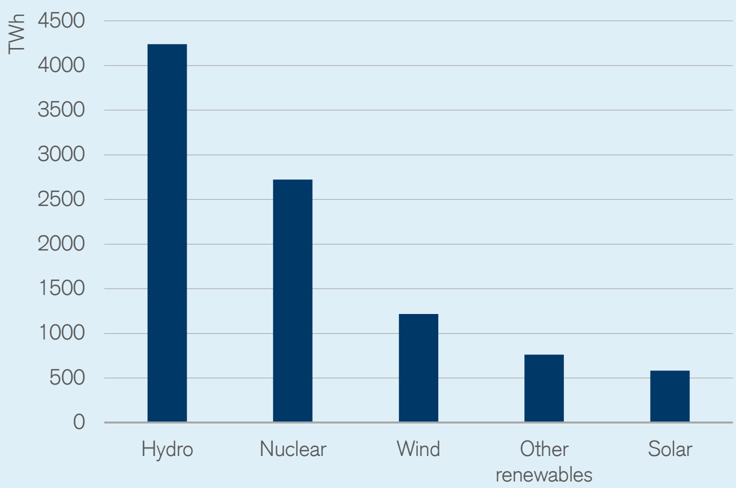
3. "25% of EU electricity production from nuclear sources," Eurostat, January 2020

Figure 3: Average life-cycle carbon dioxide-equivalent emissions for different electricity generators



Source: World Nuclear Association, Intergovernmental Panel on Climate Change

Figure 4: Global low-carbon power generation by source, 2018



Source: International Energy Agency

individual member states shows that France generated almost 70% of its energy from nuclear sources in 2020, followed by Slovakia at 54%. As highlighted in the Eurostat data, this figure stood at 46% in Hungary, 41% in Bulgaria, 39% in Belgium, 38% in Slovenia, 37% in Czech Republic, 34% in Finland, 30% in Sweden, 22% in Spain, 21% in Romania, 11% in Germany and 3% in the Netherlands.

At the start of 2020, 13 EU members had 109 reactors in operation out of the roughly 440 reactors operating globally in 32 countries. During 2020, however, two nuclear reactors were permanently shut down in France and one in the Netherlands[4]. This corresponds to a 10% fall in nuclear generation in 2022 – the largest fall since at least 1990, according to Ember Climate[5]. The organization forecasts that nuclear generation will continue to decline as countries intensify efforts to phase out nuclear power (by 2022 for Germany, 2025 for Belgium, 2030 for Spain, and a reduction in France to half of its electricity mix by 2035). We note that the IEA's Sustainable Development Scenario (SDS)[6] projects the EU's nuclear power generation to remain relatively flat on an absolute basis over the next 30 years, but fall from around 25% of total generation in 2020 to around 12% of total generation in 2050 as renewables account for the lion's share of growth.

The debate around nuclear power and the Taxonomy

"Do no significant harm" criteria: Nuclear energy was not included in the Climate Delegated Act for various reasons. Although the European Commission recognizes nuclear power as a low-carbon energy source similar to other international organizations (e.g. the IPCC, OECD, UN, etc.) and that it can contribute to climate change mitigation, it also acknowledges that the other environmental impacts (i.e. nuclear waste) of nuclear are less conclusive. In particular, the "do no significant harm" criteria with respect to other environmental objectives such as the circular economy and waste management, biodiversity and pollution. In 2020, the Commission launched an in-depth analysis assessing the issues surrounding nuclear power.

Following the scientific review, the Commission adopted the Complementary Climate Delegated Act in February 2022, in which certain gas and nuclear energy activities are recognized for their "transitional role" in achieving the objective of climate change mitigation. The Commission's latest stance is that nuclear energy mainly produces low-level radioactive waste, for which there are disposal facilities that have been in operation for decades, while high-level radioactive waste accounts for just 1% of total nuclear waste.

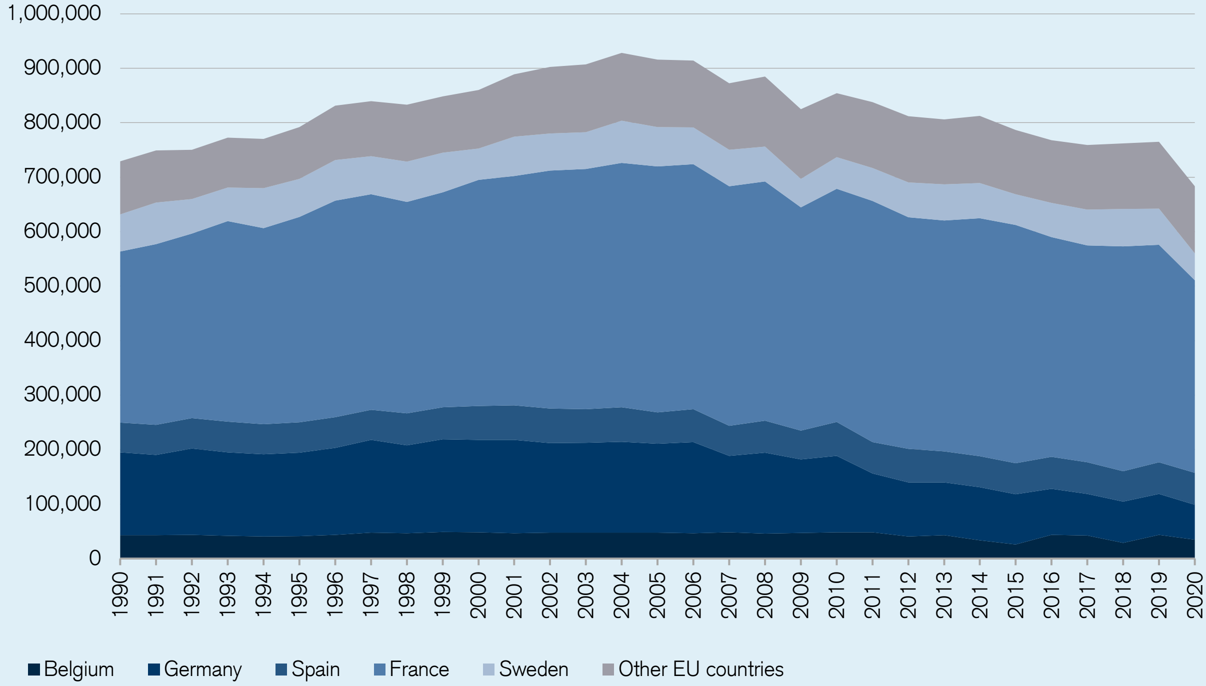
Political divergence: Divergence of opinion in the political landscape has significantly focused on the EU Taxonomy's inclusion of nuclear energy. In October 2021, ten EU countries, including Finland, France and Poland, signed a statement that is strongly in support of the use of nuclear energy. According to the statement, nuclear energy already accounts for half of Europe's low-carbon electricity production[7] and is a stable and independent source of energy. By contrast, during the UN Climate Change Conference (COP26), Germany, Luxembourg, Austria, Portugal and Denmark released a joint statement in which they argue that nuclear power is incompatible with the EU Taxonomy Regulation's "do no significant harm" principle. The countries state that the inclusion of nuclear energy in the taxonomy would permanently damage its credibility and usefulness.

> "Nuclear energy already accounts for half of Europe's low-carbon electricity production

Further political discord unfolded in January 2022 when the Commission launched consultations on the draft text of Complementary Climate Delegated Act. According to Reuters (21 January 2022), Austria's climate and energy minister confirmed that Austria would take legal action if the Commission were to proceed with its draft plan to label nuclear energy as a sustainable investment[8]. In February 2022, Germany's vice chancellor also raised the possibility of a lawsuit if the European Commission were to proceed with its plans regarding nuclear power (Euractiv,

4. Eurostat, op cit
5. "EU Power Sector in 2020," Ember, January 2021
6. "Sustainable Development Scenario (SDS)," IEA , World Energy Model, 2021
7. https://energy.ec.europa.eu/topics/nuclear-energy/nuclear-safety_en
8. https://www.reuters.com/article/eu-regulation-energy-taxonomy-idUSA5N2LS00I

Figure 5: Gross nuclear electricity production in the EU, 1990–2020



Source: Eurostat

8 February 2022)[9]. However, officials told POLITICO (13 May 2022) that Germany would vote against the Taxonomy proposals, but would not take legal action[10].

What are the technical screening criteria?
Nuclear-related investments can be broken down into modifications/upgrades of existing facilities and new nuclear power plant projects. The two will be recognized by the EU Taxonomy until 2040 (date of approval by competent authority) and 2045 (date of approval of construction permit), respectively. Nuclear plants must be located in a country that already has disposal facilities for low-level waste in place and a detailed plan to have a disposal facility for high-level radioactive waste in operation by 2050, as well as make use of accident-tolerant fuel from 2025 onward. New projects must also use best-available existing technologies ("Generation III+"). We note there are only a handful of Generation III reactors operating in the world today, with the vast majority currently being Generation II reactors. **Table 4** provides more information on the type and net electrical power of reactors that are in operation in Europe. The text of the Complementary Climate Delegated Act also includes criteria for Generation IV reactors. Although those reactors are not yet commercially viable, research and development efforts are ongoing to develop technologies that use closed-fuel cycles and minimize waste. Finally, the Commission recognizes that the nuclear energy sector is subject to rapid technological development and deems it necessary for the technical screening criteria to be reviewed regularly.

9. https://www.euractiv.com/section/energy/news/germany-considering-lawsuit-against-eu-taxonomy
10. https://www-politico-eu.cdn.ampproject.org/c/s/www.politico.eu/article/germany-to-veto-eu-plan-to-label-nuclear-energy-as-green-european-commission/amp

What happens next?

The Climate Delegated Act entered into force on 1 January 2022 in relation to the climate objectives and legislation should enter into force on 1 January 2023 in relation to the other four environmental objectives. However, we note that the Commission still has to publish its own proposal for a Delegated Act for the remaining objectives. Reporting covers each previous financial year, which means that the first report related to climate change mitigation and adaptation is due in the course of 2022 for the financial year 2021. Companies that are currently subject to the NFRD are required to report on how and to what extent their activities are associated with taxonomy-aligned activities.

The Complementary Climate Delegated Act, which outlines the technical screening criteria for natural gas and nuclear power, was adopted on 9 March 2022 when the translations of the act into all EU official languages were made available. It was then transmitted to the European Parliament and the Council of the EU on 11 March for their scrutiny over a four-month period. The European

Table 4: Type and net electrical power of nuclear reactors operating in Europe

Country	Pressurized water reactor (PWR)		Boiling water reactor (BWR)		Gas-cooled reactor (GCR)		Pressurized heavy-water reactor (PHWR)		Totals	
Total	**No. 110**	**MW(e) 10735**	**No. 5**	**MW(e) 5352**	**No. 14**	**MW(e) 7725**	**No. 2**	**MW(e) 1300**	**No. 131**	**MW(e) 121752**
France	56	61,370							56	61,370
Ukraine	15	13,107							15	13,107
Belgium	7	5,942							7	5,942
Czech Rep.	6	3,934							6	3,934
Spain	6	6,057	1	1,064					7	7,121
Germany	5	6,825	1	1,288					6	8,113
Hungary	4	1,902							4	1,902
Switzerland	3	1,740	1	1,220					4	2,960
Bulgaria	2	2,006							2	2,006
Finland	2	1,014	2	1,780					4	2,794
Belarus	1	1,110							1	1,110
Netherlands	1	482							1	482
Slovenia	1	688							1	688
UK	1	1,198			14	7,725			15	8,923
Romania							2	1,300	2	1,300

Source: International Atomic Energy Agency

Parliament rejected the motion to object to the inclusion of gas and nuclear activities in the EU Taxonomy in July's plenary vote. In the absence of objection from both the European Parliament and Council, the Complementary Delegated Act will enter into force as of January 2023.

Conclusions

Over the past few years, lawmakers have increasingly focused on the development and delivery of regulatory regimes focusing on ESG criteria in order to improve transparency, avoid greenwashing and redirect capital flows toward more sustainable activities. One of the main pillars within the EU's Sustainable Finance Framework and an important piece of ESG-related legislation is the EU's rulebook for green or sustainable activities, commonly referred to as the EU Taxonomy. The role of the EU Taxonomy is two-fold. First, to prevent greenwashing and provide a common language and definition of economic activities in line with the EU's climate and environmental goals. Second, it also aims to increase and redirect capital flows in order to close the investment gap needed to transition toward a carbon-neutral economy. Despite the simple goal of regulators to improve transparency and avoid greenwashing, the ESG regulatory framework is becoming increasingly difficult to navigate.

The Complementary Climate Delegated Act recognizes the "Transitional" role of certain gas and nuclear activities in meeting the EU's climate objectives, which has led to well-publicized controversy and political discord. The European Commission's stance is, however, that nuclear energy mainly produces low-level radioactive waste, for which there are disposal facilities that have been in operation for decades, while high-level radioactive waste accounts for a minimal amount of total nuclear waste. Despite historical wavering on the environmental impacts of the energy source, the proposed inclusion of nuclear activities in the EU Taxonomy could provide impetus for new investment in the sector. Ultimately, this would provide a tailwind for the nuclear industry as well as for investors who hold nuclear investments or plan to start increasing investments in nuclear energy.


Photo by doug4537, Getty Images

Global expert perspectives

Interview with Dr. Sama Bilbao y Leon, Dr. Nina Skorupska and Andy Heiz

Nuclear power and where it belongs in the energy mix is hotly debated with valid arguments on both sides of the table. As policymakers and investors attempt to wade through the complex issues at hand, we have turned to the experts as we interview Dr. Sama Bilbao y Leon, Director General of the World Nuclear Association, Dr. Nina Skorupska, Chief Executive of the Renewable Energy Association, and Andy Heiz, Deputy CEO of the Axpo Group. The interviews were conducted in May 2022 by Dr. Nannette Hechler-Fayd'herbe, Chief Investment Officer for the EMEA region and Global Head Economics & Research of Credit Suisse.

Safety and security

Nannette Hechler-Fayd'herbe: There has been a lot of concern about different aspects of nuclear safety. Sama Bilbao y Leon, could you please tell us where we stand at the moment? How safe are nuclear power plants?

Sama Bilbao y Leon: Nuclear power plants are safe and robust industrial facilities in spite of what some people may think. Despite the two highly publicized events of Chernobyl and Fukushima, nuclear accidents are very rare. Nuclear energy is also one of the few industries that continuously retrofits any deficiencies that are found in any unit, anywhere in the world. These lessons learned have been shared among all the operators worldwide. This means that if a deficiency is found in a plant in France, for example, the way to fix that issue is going to be implemented worldwide. Beyond that, the future generation of nuclear units relies on even more advanced inherent safety mechanisms that are going to make these units more resilient and even safer.

How about nuclear waste?

In my opinion, the long-term management of used nuclear fuel and radioactive waste are two very different things. The storage then depends on whether a country pursues a "once through fuel cycle" policy (the fuel is used once in a reactor and then stored for the long term) or a recycling and

maximum energy extraction policy (the material is re-used). What most people call nuclear waste is in reality slightly used fuel, i.e. it still has 95% of its energy capacity. Such used nuclear fuel is mostly stored in the pools within the nuclear unit itself in interim storage facilities above ground which have a high degree of safety. Many countries are still looking at this material as a resource, not as a waste. But there is very little financial incentive to recycle or reprocess this material because current costs of uranium and the manufacturing of commercial fuel is still relatively cheap. Safety and security conditions of this interim storage are high. So there is not an enormous urgency to deal with this material immediately. As far as long-term management of real radioactive waste is concerned, there are geological repositories available in many countries of the world right now, e.g. Finland's repository will start operation in a couple of years and the ones in Sweden and France a few years later. The USA has a working repository for military nuclear materials called WIPP[1]. In other countries, where political decisions haven't been made about the long-term management of these materials, there is little political will to deal with this issue, primarily because it is not urgent.

Sama Bilbao y León is Director General of the World Nuclear Association since October 2020. She has more than 20 years of experience in nuclear engineering and energy policy having worked in industry, academia and international organizations. Sama holds a bachelor's degree in Mechanical Engineering and a master's degree in Energy Technologies from the Polytechnic University of Madrid. She also holds a master's degree and a PhD in Nuclear Engineering and Engineering Physics from the University of Wisconsin and an MBA from Averett University. She is one of the seven founders of the North American Young Generation in Nuclear.

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Nuclear power plants are safe and robust industrial facilities in spite of what some people may think

There seems to be a big difference in respect to the acceptability of nuclear energy in the East versus the West? What do you think are the reasons for this?

There is actually a lot of construction and interest in nuclear power all over the world, not only in the East. Currently 50 or more nuclear power plants are under construction in countries all over the world, not only China or India. Many of the more recent polls in France, the UK, Poland, the USA and Japan indicate that nuclear is seen as a key component of the long-term energy mix of these countries.

What about the security of the nuclear supply chain against the backdrop of a war in Europe – what types of new risks need to be considered?

Most countries in the world, particularly in Europe, have become acutely aware of the importance of energy independence and energy security. Nuclear energy is probably one of the energy sources that is most resilient to these global geopolitical situations as well as to weather and climate. Countries have already started planning how to become self-sufficient and we are seeing a lot of work in that area. So nuclear supply chains would certainly be affected, but we don't see this as a major problem because most nuclear power plants have enough fuel to operate for at least one year, most of them two years, and in some cases even more. So there is plenty of resiliency in the system to avoid worst-case scenarios, in our view.

1. Waste Isolation Pilot Plant

How would self-sufficiency affect the cost of nuclear energy?

Part of the reason why Russia has been supplying significant amounts of enrichment services and commercial services is because it could provide these services at a very low price, even though they do not have a lot of uranium mining. If the rest of the world decided to develop this infrastructure themselves, that would be an investment likely to result in higher prices for these services. But one has to consider that the cost of the fuel itself in the overall cost of electricity from a nuclear power plant is less than 10%. So, assuming the cost of enrichment and conversion were to double, the actual cost of the electricity would be increased by less than 5%, which is still relatively low.

The economics of nuclear power

Andy Heiz, as an electricity provider, what do you think about nuclear power and how would you compare it to other energy sources at your disposal?

Andy Heiz: We are of course looking at it from the perspective of a power generator who would have to make the investment and then carry a capital cost. Those are huge investments for any company. If you have to make an investment like that against the time horizon of up to six years, the political risks you're taking are enormous because, as we've experienced over the last 10–20 years, the opinion towards nuclear can change for the better or worse over such a period. This has political implications that will affect regulations and requirements, and a fortiori the economics of these plants. From that perspective, for us at Axpo, nuclear is not high on the priority list.

If the objective is to produce the cheapest kilowatt hour possible, PV (photovoltaics i.e. solar) might be the cheapest. But, if the objective is to secure winter supply 24/7 in a northern country through winter with solar, then the amount of battery storage and other infrastructure would have to be added and PV is not that cheap anymore. I know how people love levelized cost of energy (LCOE) ratios and then hold them up one against the other, but a solar kilowatt hour is not the same as a nuclear kilowatt hour because the nuclear kilowatt hour can be provided any time during the year, whether it's cold or hot outside, whether it's day or night. That's not the case with PV or wind. It is important to not compare them as they are different and will lead to wrong conclusions.

Andy Heiz is the Head of the Generation & Distribution business unit since 2014 and Deputy CEO and member of the Executive Board of Axpo Holding AG since 2019. Prior to joining Axpo, he worked for ABB as Head of Product Group Renewables and Head of Corporate Strategy. Previously, he covered various management roles for McKinsey & Company in the USA, for ABB Alstom Power in Malaysia and for ABB Power Generation in Switzerland. Andy holds a master's degree in electrical engineering from ETH Zurich and an MBA from INSEAD in Fontainebleau. He is a Board member of Axpo Power AG, President of Kernkraftwerk Leibstadt AG, Vice President of Kernkraftwerk Gösgen AG and member of the Commission of the Decommissioning and Disposal Fund for Nuclear Facilities.

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Countries need to put together economically efficient energy portfolios of different generation technologies

With energy, it's like with stocks in a portfolio – countries need to put together economically efficient energy portfolios of different generation technologies that balance costs and resilience depending on the endowment of a country.

What would you say is an ideal energy portfolio for a country like Switzerland?

It is really a matter of personal opinion, tradeoffs and politics. Therefore there is no right or wrong answer. For example, how do you trade off the use of the Alps with the impact it has on the environment? How do you trade off the risks of global warming against the risks of nuclear waste? Purely from a grid stability point of view, nuclear – especially when already existing – can be a good element in an energy mix. But if we are going to get out of nuclear, the key is to increase the capacity from dispatchable sources. We can do that by expanding hydro so that we could generate, for example, a lot of electricity from solar in summer and use it to fill the hydro storage for winter. But that would require significant additional hydro storage capacity. Or we could build combined-cycle power plants or winter natural-gas-based plants, or one day hydrogen-based plants. Of course, if it's natural-gas-based, you have the issue with global warming. But a certain amount of dispatchable energy sources that are available throughout the year are definitely needed in Switzerland. Aggressively relying on solar and wind alone would only work with a lot of battery capacity, which is really quite impossible in Switzerland.

Dr. Nina Skorupska is the CEO of the Association for Renewable Energy and Clean technologies (REA) since 2013. Previously she worked for 20 years for the multinational energy company RWE Group where her last role was CTO of the Dutch business. Before that she covered roles spanning fuel engineering and R&D, power station operations where she was Npower's first female power station manager, and trading. Nina holds a Bachelor of Science in Chemistry and a PhD in coal combustibility from Newcastle University. She is a Board member of Transport for London, REAL (REA subsidiary), and more recently Royal BAM Group NV. She also advises Carbon Trust, National Grid ESO and Energy Research Accelerator and others. Nina became Fellow of the Energy Institute (FEI) in 2015 and received her Commander of the Order of the British Empire in 2016 for her services to the renewable energy sector and for promoting diversity in the energy industry.

Nina Skorupska, would you say the ideal energy mix is different for each region or country?

Nina Skorupska: Absolutely! Energy reliance always starts with the natural resources countries have and the whole infrastructure is then generally based on what they are endowed with. Therefore, everybody starts from a different point and evolves from there. Today, we see the benefits of countries like Norway who are now standing very firmly on a renewable platform. But that's on the back of decades of wealth created from oil and gas, and from exploration in the North Sea. Each nation must look for its own starting point.

The difficulty in Europe today is that, over the last 25 years, energy security and sources of dispatchable electricity have been based on open electricity trade. We have built an electricity market open trading system across Europe and gas networks. So countries are interconnected and interlinked. But, as nations are now starting to pursue individual greenhouse gas commitments, their energy strategies are determined more and more unilaterally and based on political decisions. European politicians who can be voted out every four or five years therefore focus primarily on the energy bill, the risks of blackouts and the attraction of industry, wealth and jobs in an area when it comes to their energy strategy. Pointing to a big nuclear power station for the next 60 years and 25,000 jobs can politically become more powerful than the more distributed, decentralized and democratized role of other renewables, for example.

Some emerging market nations like India have strongly growing populations and energy needs. Do the economics of nuclear power make sense for them?

India has a grid infrastructure, but it's not uniformly distributed across the country. And different states have different depths of infrastructure built. So, in a way, I see in India the best advantage and value for accelerating the ability to start to enjoying a modern life that we've all enjoyed in the countries we live in, i.e.

fresh water, secure electricity, lighting with renewables. There are vast tracts of land across all the different geographies of the continent and they could take advantage of the resources that they have, such as hydro and solar. The use of solar linked with a form of energy storage and whatever best suits the needs in each area is still by far the cheapest form of delivering a dispatchable form of power generation. So a decentralized, distributed microgrid approach would be the fastest and most cost-effective way of delivering what the different regions need.

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Energy reliance always starts with the natural resources countries have and the whole infrastructure is then generally based on what they are endowed with

For countries relying on fossil energy sources, after you accept that you no longer need fossil fuels and can use an existing grid infrastructure, the best and the quickest way is to repurpose the existing fossil fuel areas with bioenergy, energy from waste or advanced conversion technologies, combining that with carbon capture and storage. That still looks like a better answer to me than setting up and building a bespoke nuclear generation facility. But for a state that does not have any history of nuclear energy, I would argue that there are other solutions they can pursue.

Andy, in South Korea, the cost of building nuclear power plants has dropped significantly compared to Europe, the USA or Japan. What do you think are the key drivers?

Andy Heiz: There are probably a couple of key drivers. In Europe, we haven’t built that many nuclear plants recently, so there is a lack of expertise and experience. South Korea, in contrast, has definitely built more, therefore benefiting from more standardization and experience, and probably also from lower labor costs. Moreover, there are interest groups in Europe (at least in and around Germany and Switzerland) who don’t want nuclear power plants to be cheap. So they quite strategically drive up costs for nuclear facilities and increase capital costs.

Do small modular reactors (SMRs) change the economics meaningfully?

It depends on who you talk to. Companies building large-scale nuclear plants will tell you that the scale advantages of large nuclear power plants are so enormous that the SMR can never keep up with it. If you talk to the SMR people, they’ll tell you that mass manufacturing and standardization is going to beat economies of scale. I would say the jury is still out. And again, it’s probably not just a cost question. I find it difficult to imagine that people would want to have SMRs spread all over a country. They are still nuclear facilities, after all, and there is need for protection because they rely on nuclear fuel.

Sama, what about the perspective, especially now that we are all faced with high energy (electricity) prices?

Sama Bilbao y Leon: The International Energy Agency’s 2020 “Projected Cost of Electricity Generation” report concluded that long-term operation, meaning extending the life of the existing fleet of nuclear power plants, would have the lowest cost for low-carbon electricity. When looking at new nuclear power plants, the number one driver of costs is the interest rate on investment. In new nuclear, 76% of costs is due to the cost of capital. Therefore, for new nuclear projects to compete, a prerequisite is to have access to the same type of affordable financing that all other low carbon energy sources have.

For utilities to invest in nuclear projects, it is critical to have visibility and long-term transparency, as well as policymaker commitment to consistent policies. Low-carbon energy projects are basic infrastructure and the decisions cannot change every four or five years when governments change. In the UK, a specific financial framework was put together known as contracts for difference (CfDs). Because of high financial risk, investors were compensated for participating in the project with a large return on investment. The sense of confidence that investors have with a project (nuclear, hydro, wind or solar) is essential to incentivize enough capital to result in a low cost of electricity.


Photo by Dean Mitchell, Getty Images

Energy strategy and policymaking

Given the cost aspects, is the willingness and access to affordable finance for nuclear and other renewable projects there?

Andy Heiz: It is really a challenge because investments are made in wind and for maybe 20 years. When you develop your project, you get a power purchase agreement and you get financing, which basically carries you through the life of the project. So you have full certainty on how to model that economically. And that's also how you can get cheap financing. With nuclear power, where a plant's lifetime is probably more like 60–80 years, how are you going to get a guaranteed tariff even for 60 years? How are you going to get that guaranteed regulatory environment? How are you going to get fixed interest rates for 60 years? So it's just much harder to lock in the economics of such a long-term investment than it is in the case of wind and solar. And, of course, that creates uncertainty, which leads to high financing costs.

Sama Bilbao y Leon: This is perhaps where the EU taxonomy has not really done as good a job as it could have. When we are making these decisions, we really need to look at the lifecycle assessment of all the technologies. For example, if we are talking about energy or electricity production, we need to compare all the technologies that we use to produce electricity on the same basis, which is not something that is happening right now in the taxonomy. Policymakers need to forget political agendas and consider the entire spectrum of low-carbon technologies to analyze and understand how to produce energy, also beyond 2050. If you think about all the new renewables being built right now, their life will be over by 2050. So they will have to be rebuilt. These are things that we are not considering very well at the moment and, of course, where cost is not very well quantified as we plan forward.

Nina Skorupska: One important evolution in policymaking is the shift from a baseload focus (the minimum level of demand made on an electric grid over a span of time) to dispatchable generation (electricity dispatched on demand by power grid operators). How do

we deliver dispatchable electricity in a secure, reliable manner for powering heating and transportation in the future? In terms of a nation's energy security with a system based on single-direction flow (from electricity generation to the point of use), the traditional approach has been to have a lot more capacity on the system connected to the grid than needed. They tend to be able to run 24/7 and you would have a small open cycle gas turbine power plant ready to come on and off as quickly as possible, for example.

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> ## It's hard to put in place a coherent policy when you have to make so many compromises

With renewables, the classic way of describing them is intermittent. A lot of people believe that renewable generation is not reliable. But, today, we have much better power management systems, better use of data – we are able to model and predict when the sun is shining or the wind is blowing in different places. Today, we need power generation that can move with the different variables of sun, wind and storage. The developments in longer-duration energy storage are taking away that worry about having to pay for expensive 24/7 power generation to accommodate renewable energy generation.

What critical infrastructure does Europe need to invest in?

Andy Heiz: I would say stable, strong transmission so that you can balance across big geographic differences and some type of seasonal storage to move PV electricity from summer to winter via hydrogen or via pumped storage and a sufficient level of dispatchable baseload generation.

Sama Bilbao y Leon: I completely agree. Unfortunately, Europe in general, technologies like transmission and distribution for sure have been neglected. I believe the energy systems of the future will be different than today's energy systems. For example, electricity production, transmission and distribution will continue to exist, but we will see additional things like distributed grids to support remote areas or industrial facilities that may not need to be connected to the grid. We might see a coupling of different energy systems. I think that nuclear units are going to become much more multi-product – they will produce electricity whenever electricity is the high-priced product. For example, nuclear-generated hydrogen uses primarily heat (steam generated by nuclear) and is much more efficient than electrolizers used with solar PV or wind, which cannot produce heat.

Nina Skorupska: Looking at the fundamental infrastructure, like the grid networks for example, the regulatory way of rewarding the infrastructure owners and service providers is outdated. Technology is overtaking them and they cannot cope with the amount of decentralized distributed ways that power is used and produced anymore. We therefore need more investment and a change in the mindset of grid owners, operators and policymakers to accelerate and enable more digitalized power delivery.

How do you view China's effort in terms of infrastructure?

Sama Bilbao y Leon: While Europe needs to optimize and decarbonize, China needs to energize and generate energy in the most effective low-carbon manner, which is a slightly different approach. We will also witness a similar acceleration in the not-too-distant future in countries like India, for example. And we'll see the same thing in Southeast Asia and Africa.

Andy Heiz: In most of Europe, we can see different interest groups defending their own interests. So it's hard to put in place a coherent policy when you have to make so many compromises. We might even have to experience a shortage in Europe before things change. In places like India or China, people understand that if they are not progressing quickly, there will be a shortage in no time.

Would you expect nuclear capacity to increase more in emerging nations than in developed nations?

Andy Heiz: Two years ago, I would have said so. But, at least in Switzerland, there has been a shift in how people perceive nuclear energy over the last two years. The environment has become “nuclear friendlier.” In fact, people now realize that energy transition is not going to be as easy as they thought and cannot be done only with wind and solar. They now realize that electricity might become tight. If that realization becomes more prominent, I would not be surprised if Europe also starts building more nuclear facilities. France recently announced several new reactors

and the Netherlands is also thinking about it quite concretely. So there might be a slow revival in Europe, but I wouldn't be very surprised if it happens.

> "All the things that we currently enjoy need abundant round-the-clock energy 365 days a year

Sama Bilbao y Leon: I agree. The UK, France, Netherlands, Poland, the Czech Republic, Slovakia, Romania, Bulgaria and Slovenia are moving forward with brand new nuclear power plants. Many central and eastern European countries are very serious about expanding their nuclear power programs or starting new ones like in the case of Poland (Poland currently doesn't have any nuclear generation). Additionally, other regions such as Africa, Southeast Asia or South America are considering nuclear power. Nuclear energy provides a great opportunity to have abundant and affordable clean energy for everybody. If those countries want to achieve a quality of life similar to western Europe or North America, it can't be with one solar panel that is going to give them a light bulb and a cellphone charger. Quality of life means having access to refrigeration, fresh water, sanitation, education, health and industry. All the things that we currently enjoy need abundant round-the-clock energy 365 days a year. Certainly, nuclear energy will be one of the choices that some of those countries are going to consider.

What is the role of the consumer and demand?

Nina Skorupska: If we look at different smart technologies across people's homes, I am convinced that, if people are incentivized to do the right thing, they will, and this is where the transparency in the energy bill comes in – allowing people to decide when to use or produce their own energy via solar panels or be linked to a heat network for a larger community. I am sure that, in Switzerland and Germany, the role of community energy has grown and is now moving from being a hobby or a passion to becoming a viable investment tool. In the UK, if you look at some of the Facebook pages, communities are advising what's the best way to store solar energy at the best price. The closer the power generation is to the consumer, the better to save on efficiency, transmission and usage. Transparency is important in a market. There's a whole new generation of people who are interested in knowing more. So we need to have supportive organizations to help consumers know what's best for them.

Sama Bilbao y Leon: I fully agree. It should also be noted that electricity generation started as a bunch of small microgrids with small generators that produced power for a small circle of customers. In time, these microgrids coalesced into the grids of today, with larger and more efficient generators because the overall system was more reliable and cost effective – let alone more equitable as now everyone had access to electricity and not just those people who could afford to be a part of those small microgrids. I am not saying that this model may not work in some/many contexts, but the concept of the centralized grid seems like the most equitable and democratic way to ensure that everyone has access to abundant 24/7 affordable and clean electricity.

> "The closer the power generation is to the consumer, the better to save on efficiency, transmission and usage

Do you think the EU is heading in the right direction with the taxonomy and policymaking or do you see some areas of concern?

Nina Skorupska: I see many areas of concern because as soon as you get people in a room trying to define different things, vested interests come through, both political and commercial. I mean the acknowledgment that fossil gas is considered a green fuel has undermined everything I saw happening at the EU level. Nuclear fuel has its own safety storage challenges, but overall produces less greenhouse gases than everything linked with the production of fossil gas. In my experience, people only focus on the elements of the energy pathway that companies or politicians want them to see. One area we need to watch is greenwashing by oil and gas companies. I truly believe we need a mix of energy types that recognizes the role played by really good carbon capture, waste management, advanced conversion technologies, the balancing of sustainable bioenergy, the challenge for production of net-zero aviation fuel and marine fuel. All of these things are happening at the same time.

Nannette Hechler-Fayd'herbe is Chief Investment Officer for the EMEA region and Global Head Economics & Research of Credit Suisse. She has been with Credit Suisse since 1999, originally joining the group as the Head of Swiss Fixed Income and Credit Research at CSFB. She is a long-standing member of the Global Investment Committee and previously was a board member of the Credit Suisse Pension Fund Switzerland for several years and a board member of the International Capital Markets Association. She is now serving on the boards of the Department of Economics of the University of Zurich and the Institute of Economics of the University of St Gallen.

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