Federal Ministry
Agriculture and Forestry, Climate
and Environmental Protection,
Regions and Water Management
Republic of Austria

Nuclear Economics and Finance

Nuclear power plants are amongst the most expensive construction projects of any kind. And many cost estimates do not even include all of the costs, like decommissioning, final nuclear waste disposal, and insurance against major accidents. Some of the main selling points of nuclear—a continuous rather than variable power source, low-carbon, dispatchable, and generating heat that can be used for other purposes—are all attributes that are under pressure from a wide range of other, increasingly innovative competitors, in particular new renewables.

Overview

Amongst the top-ten of a "list of most expensive buildings" in the world, nuclear power plants feature prominently with seven projects.[1] Nuclear power is under increasing competitive pressures not limited to generation but extending to other components affecting the cost and reliability of the service as well, for example sufficiency, efficient use or demand response, electric-vehicle-to-grid integration, or electricity storage to address the variable output of wind and solar. Already experience shows that solar photovoltaics (PV) plus storage can provide a competitive service option. Long-term commercial contracts pairing solar, wind, and storage are already being struck.

Geopolitics Drive Nuclear Finance, Not Economics

While a reliable comprehensive, global overview of credit data is not available, partial data indicates strong credit support especially from Russia and China for overseas projects.

[1] Wikipedia, "List of most expensive buildings", see en.wikipedia.org/wiki/List_of_most_expensive_buildings. This reference is for illustrative purposes only and does not reflect endorsement of methodology or completeness.

Advantageous financing conditions are key to the relative success of both countries. According to a former OECD Nuclear Energy Agency (NEA) official, "China and Russia are in the process of putting the West's nuclear industry out of business".[2] However, there seems to be a trend towards an increasing role for Export-Import Banks and various international development banks to finance nuclear projects. State intervention has been increasing in many countries for some time. Some estimates indicate that already roughly 45 percent of global nuclear capacity is fully state-owned.[3]

Operating Reactors Face Continued Competitive Pressure, Receive State Support

In recent years, operating reactors have been facing financial challenges in many countries. Unplanned outages have reduced output, and aging reactors or unexpected problems have sharply driven up plant maintenance, repair, and reinvestment costs, particularly in France and Japan.

Nuclear generation has also suffered from climate-related impacts, such as cooling water availability, heat sink capacity, and storm events. While the effect on overall output remains limited until now, climate-related disruptions of nuclear generation have increased eight-fold over the past 30 years and can have significant impact on available capacity for limited periods of time.

Competition from low-price natural gas, and increasingly wind and solar, represents serious economic risks for nuclear. For example, in Finland, surging production from renewables and negative wholesale power prices forced curtailment of generation at the much-delayed Olkiluoto-3 reactor, just one month after it commenced commercial operation. Similar restrictions have been implemented at Spanish reactors.

Arguing that plant closures would drive up carbon emissions, the industry has labelled closures as premature and has lobbied for – and increasingly often successfully obtained – large subsidies to support operating uneconomical plants. In the U.S., state-level taxpayer-

---

[2] Geoffrey Rothwell, "Projected electricity costs in international nuclear power markets", Energy Policy, Vol 164, May 2022, pp.3–5,
see sciencedirect.com/science/article/abs/pii/S0301421522001306?via%3Dihub.
[3] Mycle Schneider, Antony Froggatt, et al., "World Nuclear Industry Status Report 2023", December 2023, see worldnuclearreport.org/-World-Nuclear-Industry-Status-Report-2023-.html

funded subsidies were granted to 19 reactors; these last from five to 12 years and are estimated to exceed US$15 billion by 2030. In addition, the Civil Nuclear Credit (CNC) program funds a national pool of US$6 billion in subsidies to keep economically distressed reactors from closing.

Threatened by bankruptcy, the largest nuclear operator in the world, the French utility EDF, has been fully renationalized in 2023. The French government has also been lobbying successfully to allow the possibility of accessing various E.U. financing mechanisms to subsidize its existing nuclear fleet. The Belgian government has agreed in principle to share the economic risk of a planned ten-year lifetime extension of two reactors beyond the previously agreed closure date of 2025 by setting up a joint company with utility Engie-Electrabel. To accelerate the restart of reactors shut down since 3/11, the Japanese government is also considering subsidies that would guarantee income to winning bidders for the subsequent 20 years.

Newbuild Economics

The OECD-Nuclear Energy Agency's overnight cost estimates for Light Water Reactors (LWR) vary by a factor of two from US$2,157–4,250/kW. An independent assessment from the Technical University Berlin based on an 88-reactor database found much higher values, including about US$6,000/kW for mean overnight costs for LWRs.

Overnight cost analyses are seriously limited for the assessment of nuclear competitiveness: the exclusion of financing and other costs, although financing is frequently recognized as a significant cost component; the limited number of real cases to serve as reference; the frequent assumption for nth of a kind implementation supposing learning effects through the building of a series of units, but without clearly defining the number n, which can range from five to a few hundred (in the case of so-called Small Modular Reactors or SMRs).

The production scales of nuclear's main competitors are in entirely different orders of magnitude. The installed base of wind turbines is more than 300,000 globally, with more than 25,000 installed in 2022 alone. Solar PV module (each panel has multiple modules) production translates to a unit count in the hundreds of millions per year, with well-documented associated learning effects and cost reductions.

The most advanced SMR design in the U.S., NuScale, terminated a six-module project to be implemented for a conglomerate of Utah municipalities, in early November 2023. Cost estimates had spiked to US$20,000/kW, much higher than real costs of the most expensive recent large reactors. Despite massive federal subsidies, estimated to exceed US$4 billion, the projected cost of electricity appeared too high for most candidate municipalities.

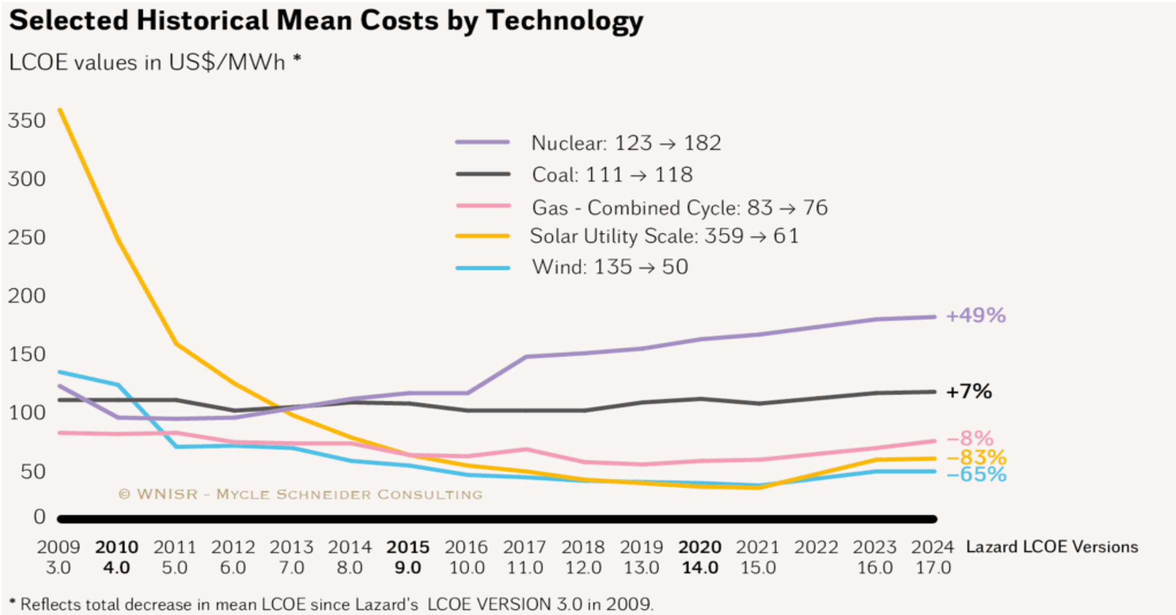
Trends in Nuclear Cost Estimates Over the Lifetime of a Plant

Levelized Cost of Energy (LCOE) assessments incorporate not only construction expenses (overnight costs) but also operating and maintenance costs, build times, productivity, and discount rates[4] to generate an average cost per unit of energy produced over the plant's lifetime. With increasing discount rates, nuclear becomes less and less competitive with other energy policy options.

Further, nuclear LCOE estimates span a wide range even when the same discount rate is assumed. Asset-management firm Lazard concluded that aside from natural gas peaking plants at discount rates of 5.4 percent or less, nuclear always turned out always the most expensive resource on an LCOE basis. At a 7.7 percent discount rate, nuclear came out at US$182/MWh versus US$50/MWh for wind and US$61/MWh for solar PV. Adding storage or other "firming" costs – thus making solar and wind as reliable as gas or nuclear – would increase total costs only to US$67–177/MWh for unsubsidized wind and US$75–162/MWh – depending on the power market, all below the average newbuild nuclear cost estimates.[5]

[4] The discount rate is the minimum rate of return expected to be gained on an investment considering its specific risk profile, thus higher investment risk, higher discount rate.
[5] Lazard, "LCOE+ Levelized Cost of Energy+", June 2024.

Figure 1: Average costs of the technologies over the course of history. Sources: WNISR with Lazard LOCE Versions, 2024



Missing and Underestimated Costs

Beyond the generating station, nuclear power plants require fuel sourcing, conversion, enrichment, assembly manufacturing that are more expensive and more complex components than for other forms of electricity generation. Decommissioning – not only of the power plant but also of the fuel chain facilities – as well as waste management costs should be part of the cost assessments. Earmarked funds need to be of appropriate scale and carefully invested to meet needed targets when needed.

Decommissioning cost estimates vary widely, and empirical data are limited. In the U.S. for example, reactor decommissioning estimates span a range of US$510–2,148/kW.[6] Nuclear waste management costs per kWh for SMRs are likely to be higher still than in the case of large reactors.

Moreover, there are different cost categories that are connected to the nuclear power sector, but these are difficult to be quantified and therefore their allocation to the nuclear

[6] Callan Institute, "2023 Nuclear Decommissioning Funding Study", December 2023.

power sector is complex, such as emergency preparedness and response structures, knowledge management, science and education or security and safeguards.

Insufficient Liability Coverage for Nuclear Accidents

Inadequate or subsidized insurance to cover offsite damages from accidents at nuclear power plants or fuel chain facilities, or during transportation, is common worldwide. Taking reactor accidents as an example, liability requirements for offsite damages are set nationally. Additional funds may be provided by national governments once the operator liability limit is reached; and then by a third level of coverage provided by series of international treaty agreements (which include the Paris Convention, Vienna Convention, various Joint Protocols and Supplementary Conventions). However, even the total coverage in the U.S., which has the largest liability pool in the world for nuclear accidents, is well below expected damages from even a moderate accident. For example, the Japanese Government's cost estimate of the 2011 Fukushima accidents at US$223 billion is more than sixteen times the total U.S. insurance pool of US$13.6 billion.

Future New Market Claims

Emerging market services that are supposed to help make the economics of nuclear work include hydrogen production, water desalination, supplying industries in need of high-temperature process heat, and behind-the-perimeter uses such as data centres and crypto mining. Most of these uses involve capital-intensive customers generally relying on 24/7 production to be economic. A nuclear operator would need to allocate a fixed percentage of production to that user rather than sell intermittent power surpluses. Thus, the alternative markets would compete with existing clients, not supplement them.

Overall, the economic outlook for nuclear will remain challenging. Research, development and deployments will rely primarily on government money, absorption of risks, and direct ownership. It is likely that by the time cost improvements could occur, technological developments in competing generating technologies, energy storage, demand side management, and energy efficiency will have moved the economic costs down still further and the reactors will remain too costly to ever gain a significant share in the market.

Last update: 2024