Nuclear Regulation’s Impact on Financial Viability of Nuclear Power Plants

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Nuclear projects are notoriously capital intensive and take several years to build, usually in the range of 6-10 years, though there are cases of both shorter and longer timelines than these. The shorter ones are seen in East Asia, and the longer ones usually in Western Europe and the US. Because of the long timelines and the sheer size of the endeavor of constructing such a project, capital costs and financial costs incurred during construction accounts for about 70% of the LCOE, as can be seen in Figure 1. (IAEA, 2024). Thus, the economics of a nuclear plant are rendered sensitive despite the upside of long operations, as the impact of design, pre-construction, and construction variables have a tremendous impact on the final electricity cost to the consumer, and the competitiveness of nuclear energy in the electricity market. A statement to this sensitivity is the fact that a 1% change in the cost of capital (interest rates) of a project can lead to a 10% change in the LCOE. With such levels of sensitivity, changes - whether positive or negative - can have winning or detrimental impact on the outcome of a project.

Regulations, nuclear safety, and security measures and assessments are necessary to ensure the proper deployment and operations of plants. The inherent energy density and instability of fissile material poses a risk that must be acknowledged and respected for safe deployment of nuclear energy. That said, regulatory processes - as with any industry - are bureaucratic and often lengthy, with multiple examples of delays when it comes to nuclear projects.

The task at hand here is to gain an image of the impact that regulations have on the economics and financial viability of nuclear power plants. There are direct costs of regulations, which are the costs of regulatory assessment, etc., and indirect, which are cost increases associated with delays and other factors impacting the economics of a project. Indirect costs are particularly interesting, as this - if proven to be - is an area of inefficiency. Comparatively, direct costs are necessary, though they could also be reduced by improving e.g. the efficiency of assessments.

As we’ll explore in-depth, regulations can have an impact on a project’s financial viability in several ways; 1) it can cause delays in a project’s timeline, which has an impact on the financial costs, construction cost, and the net present value of a project, 2) unanticipated changes can arise post-design approval and during construction.

Direct costs of regulations

Though international standards and recommendations from entities such as the IAEA exists, these still remain nothing but guidelines. The sovereignty of nuclear regulations is country-specific, where each nation is responsible for establishing its own nuclear regulator, and thus their own regulations. This reduces the overall scalability of innovation and new designs for the industry, as one would have to perform multiple safety reviews and assessments when wanting to deploy a design across multiple nations, where several of the safety reviews are mere duplicates, in cases where the regulations are similar between nations (Carson, 2023). One example of this is Westinghouse's deployment of the AP1000 reactor design, which had to be individually assessed by multiple regulators for approval in France, UK, and the US, each being a process that takes years to complete. (Office for Nuclear Regulation, 2024).

While regulatory design review costs vary by nation, The World Nuclear Association presents estimations for indicative costs. Around $60mn must be paid to the regulatory body per reactor per country, and reactor vendor support costs fall between $180mn to $240mn per design per country. Thus, the independent review of a reactor design by four different countries, the direct costs for the assessment process alone could fall on more than $1bn, prior to considerations of how design changes will impact the supply chain, construction timelines, and operational safety through experience sharing. The World Nuclear Organization reports that these costs increased on an inflation-adjusted basis over the last 15 years (Carson, 2023).

This is only parts of the direct costs of regulations, as these consider only the costs in the process of design approval, not the direct cost incurred during construction by the accounts of (e.g.) supervision and site inspection by the regulator.

The degree to which regulations impact project timelines

A significant part of regulation's impact on a nuclear project's financial viability comes through alterations of a project's timeline, whether anticipated or unanticipated. Thus, before getting into impact on costs, it is important to establish to what extent nuclear regulations affect timelines and cause delays for nuclear power plant projects. Extended timelines and delays may have an impact on the escalation of costs, e.g. by keeping the workforce active for a longer time, though this impact can be somewhat difficult to measure. In addition to this, extended timelines during construction directly increases the financing cost. Importantly, whether direct impact on cost is present or not due to extended schedules, it does affect the overall value of the project, by the principles of opportunity cost and time value of money. Therefore, it is especially important to assess regulations' impact on project timelines separate from the escalation of costs.

While the World Nuclear Association does not present specific intervals for the timeline of regulatory design review, ChatGPT reports that one design review process typically takes around 3-6 years, depending on the country (ChatGPT, 2025). The design review approval does not provide a construction or operating license. Thus, additional time will be added to the process, 2-4 years more depending on the national licensing process, prior to the construction

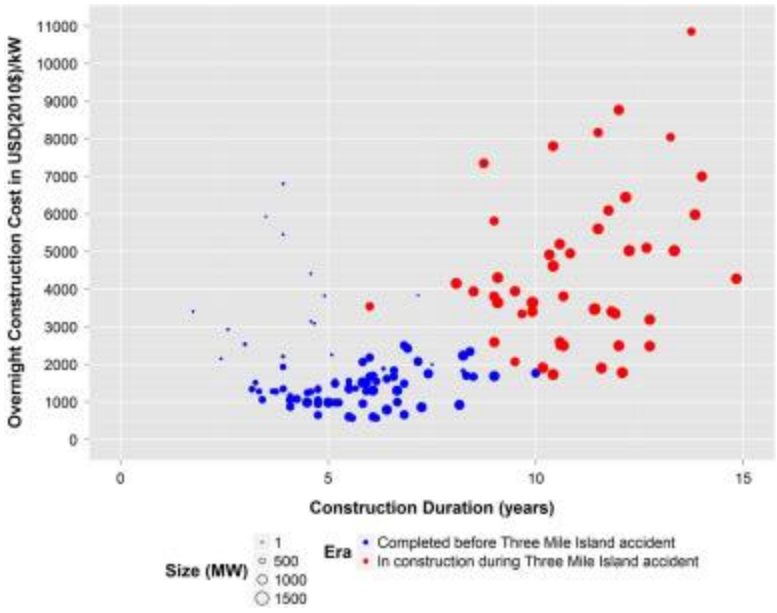
of the project can get underway. In practice, a construction schedule for a nuclear project on the scale of GW in the range of 6-10 years, an initial licensing period and environmental assessment in the range of 5-10 years prior to construction poses a significant hurdle to timely deployment. The extended timeline of a project posed by regulatory processes becomes even more pressing with the much sought after SMRs, with expected construction timelines to be on the order of 3 years (Carson A).

The industry often speaks of the long construction times, but tend to forget that this is coupled with a regulatory period of obtaining licensing, and performing environmental assessments that alone can extend as much as two business cycles. These regulatory processes alone can account for more than half of the time to operation from project initiation. Thus, the impact that regulation has on the project schedule is already significantly prevalent here - and even more so for SMRs - without accounting for regulatory impact during construction.

While multiple sources present statements of construction delays caused by regulation, I have come across few who present measurable impact. One study on the importance of advanced planning of manufacturing for the nuclear industry (Shykinov, 2016) reported that, as of 2014, of 60 reactors under construction globally, 75% were facing delays, of which eight reactors had been under construction for more than 20 years. Of the 37 last reactors having commenced operations across 9 countries between 2004 and 2014, the construction time ranged from 3.8 years to 26.3 years (Shykinov, 2016). That said, Shykinov does not attribute these delays to regulations specifically.

One study on the historical construction costs of global nuclear power reactors reports findings on the construction duration and cost of nuclear power reactors in the US, comparing the cost and duration by whether the operating license for the reactor was obtained before or after the Three Mile Island (TMI) incident. Reactors receiving licenses pre-TMI experienced mild duration escalation, while reactors completed post-TMI experienced median durations 2.2x higher, as can be seen in Figure 1 below. The study points to licensing, regulatory delays, and/or back-fit requirements to be significant contributors to the duration increase and increase in overnight construction costs (Lovering, 2016).

Figure 1: Overnight construction cost and duration of US nuclear reactors pre- (blue) and post- (red) Three Mile Island accident.



Source: (Lovering, 2016)

Escalation of construction costs

There are multiple ways in which construction costs can escalate beyond the expected overnight construction costs. Change in construction duration is a common factor among several of these. During construction, when a workforce that can be as strong as 1000 workers is engaged, prolonging the period in which such a workforce stays engaged has a direct cost impact. A one-month delay during peak construction can cause overnight construction costs to escalate on the order of $10s of millions.

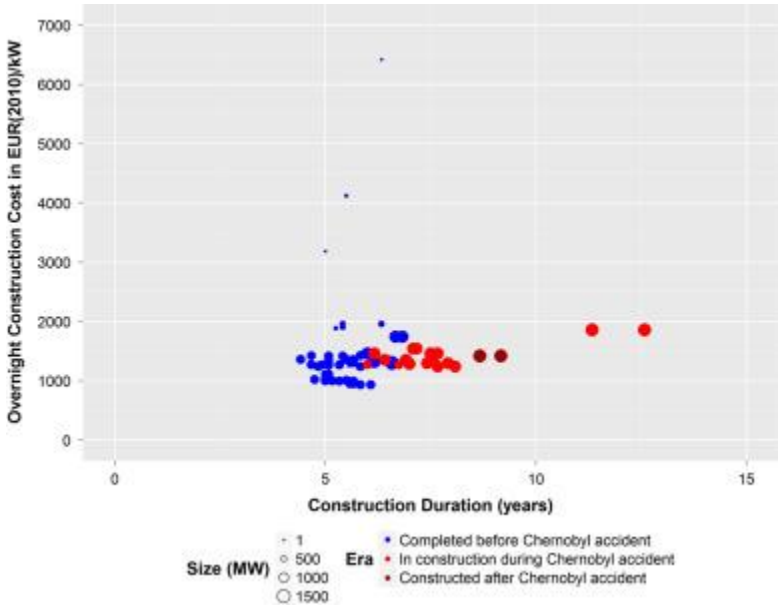
Moreover, extended timelines also lead to higher raw material cost, as these costs increase over time. The raw materials mostly impacted by this are concrete and steel, given the volume of each required to construct large infrastructure projects such as nuclear, for not to speak of the peculiar safety and security requirements, adding to the necessity for concrete and steel.

While there is a lack of information regarding the specific construction delay caused by regulations, there is a general consensus among multiple authors that regulations is a prevalent issue for delays, both for the project as a whole - as has been proven above - and for the construction process.

As can be seen in the figure above, it is not only the construction duration, but also construction costs that show a massive increase pre- and post-TMI accident in the US. In fact, post-TMI costs were 2.8x higher than for pre-TMI, an even greater increase than what is seen in terms of the prolonged construction duration. Lovering also points to regulations as a key contributor to this increase (Lovering, 2016). From 1971 to 1991 nuclear reactors in France show a moderate cost increase over the period, rising from €1000/kW to €1500-2000/kW. This is equivalent to

50-100% increase, or a 2% to 4% year-on-year escalation (Lovering, 2016). Figure 2 below shows the construction cost and duration for French nuclear before and the after the Chernobyl accident. While the impact is lower than the comparable example in the US with regards to the TMI accident, there is an observable increase in the overnight construction cost, and a considerable impact on duration. Similar cost escalations are seen in in multiple countries, with a particular exception of South Korea, as can be seen in Figure 3, while Figure 4 graphically represents the overnight construction cost of different countries, by the first non-demonstration reactor in each country.

Figure 2: Overnight construction cost and construction duration of French nuclear reactors, completed pre (blue) and post (red) Chernobyl accident



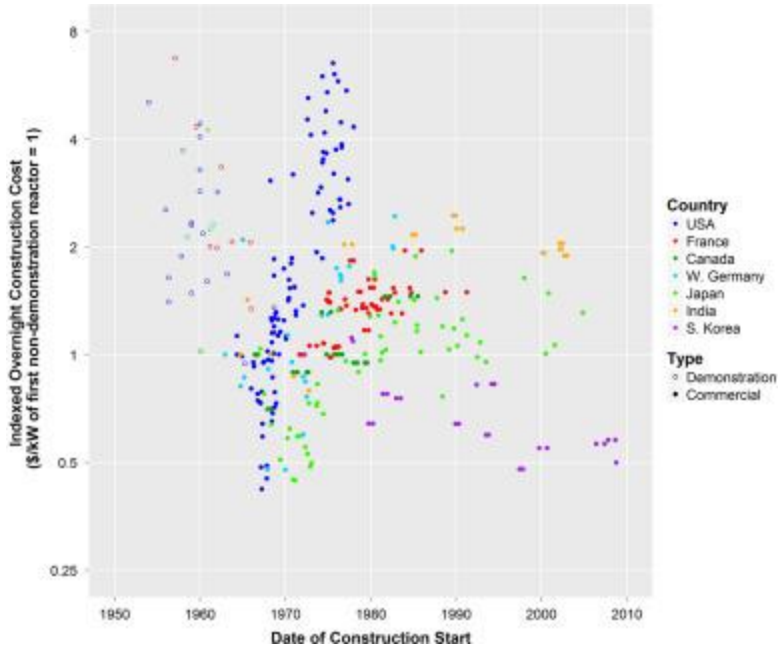
Source: (Lovering, 2016)

Figure 3: Summary of historic cost trends by country

Country	Era (defined by time period in which reactors began construction)	Annualized rate of change in OCC (%/yr)	Total change in OCC by era (%)
USA	1954–1968, 18 demonstration reactors	−14%	−81%
	1964–1967, 14 turnkey reactors	−13%	−33%
	1967–1972, 48 reactors completed pre-TMI	+23%	+190%
	1968–1978, 51 reactors completed post-TMI	+5 to +10%	+50 to +200%
France	1957–1966, 7 gas-cooled reactors	−17%	−82%
	1971–1991, 59 light-water reactors	+2 to +4%	+50 to +100%
Canada	1957–1974, 6 reactors	−8%	−77%
	1971–1986, 18 reactors	+4%	+60%
West Germany	1958–1973, 8 reactors	−6%	−63%
	1973–1983, 18 reactors	+12%	+200%
Japan	1960–1971, 11 imported reactors	−15%	−82%
	1970-1980, 13 foreign designs	+8%	+100%
	1980–2007, 30 domestic reactors	−1% to +1%	−17% to +33%
India	1964-1972, 5 imported reactors	−7%	−38%
	1971-1980, 8 domestic reactors	+5%	+150%
	1990–2003, 6 domestic reactors+2 imported	−1%	−10%
South Korea	1972–1993, 9 foreign designs	−2%	−25%
	1989–2008, 19 domestic reactors	−1%	−13%

Source: (Lovering, 2016)

Figure 4: Comparison of overnight construction cost trends by country



Source: (Lovering, 2016)

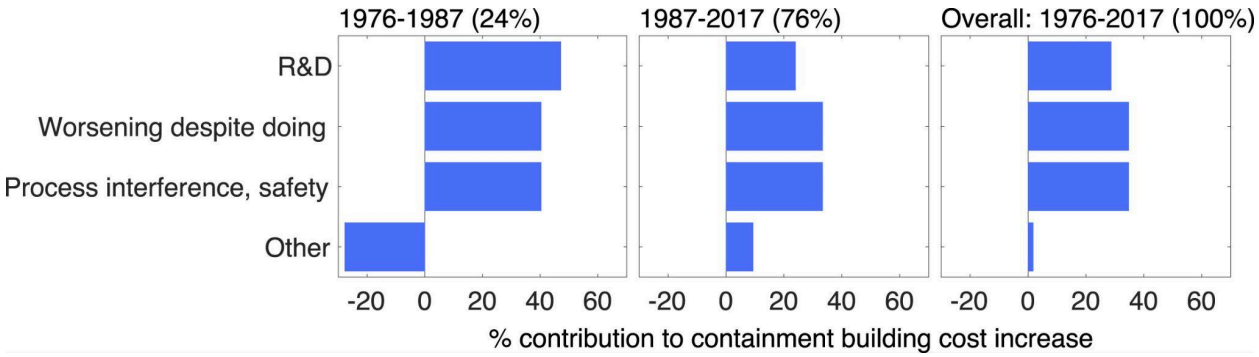
In studying the sources for cost overrun in nuclear power plant construction, Eash-Gates (2020) reports on how the overall trend of cost increase of nuclear plant construction - particularly in the US - was driven by the impact of different sources, overpowering the positive learning effects expected in the nuclear industry, that are typically associated with cost decline overtime. Several recent studies point out this unconventional effect where the nuclear industry has increased in cost on an inflation-adjusted basis, when industries and companies are expected to improve over time. This study first divided costs into direct and indirect costs, then further separating by different accounts. Direct costs are material, labor, and equipment costs, while indirect costs consist of construction support activities, such as engineering, administration, supervision, and others (Eash-Gates, 2020).

Indirect costs were associated with 72% of the cost increase seen over the period 1976-1987. When delving into the reasons for the increase in indirect expenses, the 1988 account from EEDB63 - the last year this database was updated, indicates regulation as a key cause. “Proliferation of safety regulations, codes, and standards; owner/designer reaction to the rapid appearance of these regulations, codes, and standards; rework caused by field interferences, constantly changing designs in response to new requirements, and inadequate engineering-to-construction lead times; extreme precision required in analyses, coupled with inflexible design and construction quality assurance requirements; management preoccupation with regulatory inspection, enforcement personnel site visits, and prudency reviews” are listed, along with low morale amongst workers, as an effect of the above causes (Eash-Gates, 2020).

Eash-Gates provides another assessment through dividing into three “high-level mechanisms”. Process Interference, Safety (PIS) relates to the effects posed by on-site NRC and other safety-related personnel occurring during the construction process, construction supervision,

and quality assurance and control by regulators interfering with construction workflows and impacting productivity. The two other mechanisms are Worsening Despite Doing (WDD), e.g. negative learning effects due to diminishing morale amongst workers, and Research and Development (R&D), relating to R&D processes, in addition to a category for Other, as a “catch all” category. The study particularly presents that the WDD related processes may be indirectly linked to safety regulation through complex project interactions, though the report does not further distinguish. Below is Figure 5, displaying the impact on cost increase for the containment building of nuclear projects through periods of time, expressed as a percentage of the total cost increase.

Figure 5: Containment Building cost increase by mechanism, through different periods - Joule



Source: (Eash-Gates, 2020).

As pointed out in the study, these results “...provide a starting point for quantifying the effect of safety regulations”. The mechanism directly related to regulations - PIS - contributed to roughly 30% of the cost increase seen from 1976 to 2017. That said, the study also points to regulations and safety-related considerations also having an indirect impact on WDD by slowing down productivity, and R&D through safety-related R&D activities (Eash-Gates, 2020).

Conclusion

The impact that regulations have on projects are already present when looking at the evidence of the direct costs, such as the cost of regulatory design review. It has been established that these costs fall on a several hundred million dollar scale for the approval of a reactor design in one country, given a fee of $60mn to the regulatory body per reactor per country and an additional $180-240mn in reactor vendor support costs per design per country. While one should not speak lightly of these costs, we must remember the sheer size of nuclear power plant projects in themselves, where construction cost can rise to tens of billions of dollars, as seen with the Vogtle plant.

The Vogtle plant started out with an already high estimated price-tag of $14bn and expected commissioning in 2016 and 2017, and has exceeded €23bn, as reported in 2018, expected to be operational in 2021 and 2022 (IER, 2018). The two units finally became operational in 2023 and 2024 (EIA, 2024). While the specific direct regulatory costs for Vogtle are not present here,

the costs established above make up only about 1-2% of the total construction costs reported in 2018 (the real final construction cost not reported here).

The most significant impact of regulations comes through indirect costs and impact incurred on the project, though the specific cost impact is considerably more difficult to measure. We have uncovered that the construction time of a plant typically falls between 6 and 10 years, with a full range between 3.8 and 26.3 years. In addition to this construction time, what is often overlooked is the significant timeline of the project pre-construction. We found that the initial licensing and environmental assessment period, including the approval of reactor design review, typically fall between 5 and 10 years, potential more than doubling the time to commercial operation of the project. Even if the initialization of the project and the pre-construction period is not capital intensive to the same degree of during construction, increasing the time to commercial operation - i.e. when cashflow will finally be positive - by more than 2x significantly reduces the net present value of the project. This pre-construction period will be even more prevalent for SMRs, where expected construction time falls around 3 years.

Delays caused by regulations during construction is an area that should be studied more, though it is pointed out here that certain incidents such as that of the Three Mile Island caused construction duration to jump, with regulatory delays and back-fit requirements being the main causes. The same is true for overnight construction costs when comparing before and after the accident. As we have seen, of the cost increase of plants in the US between 1976 and 1987, 72% of the increase was attributed to a category of indirect costs, where regulations stood out as the main cause of the impact. The same study also found that in the period 1976-2017, regulations contributed about 30% of the cost increase on high-level mechanisms, while indicating that it likely indirectly impacted the cost increase in the two other categories relating to reducing productivity and R&D activities.

We have been able to quantify regulations' impact on time to commercialization, particularly for pre-construction activities. While we have not been able to quantify cost escalation and impact on duration during construction to the same degree, we have been able to paint a rough image of the prevalence of regulations on cost escalation. To conclude, regulations do negatively impact the economics and financial viability of nuclear power plants. It has 1) significant impact on the time from project initialization to commercialization, and 2) is one of the lead causes for cost escalation during construction. Moreover, the delays caused carry with an increase in financial cost, which, as we saw in the introduction, can impact the LCOE by 10% with a 1% increase in interest rate. Time increase will have the same impact on financial cost as directly increasing the interest rate. These factors further negatively influence the opportunity cost of a nuclear project, and thus the net present value of the project. These factors further ramp up the financial risk associated with investing in a nuclear power plant project, not just making it into an infrastructure project, but one that carries additional risks and costs.

Future topics

Following up in this report, it can add significant value to further quantify the cost and duration escalation during construction. Moreover, an assessment if the increase in financial costs due to delays in different stages of the project will help to understand not just that it is a considerable factor, but to quantify by how much regulations increase financial costs. I have also talked about the impact on net present value, which can be improved further by quantifying this as well. In aggregate, this will paint a better picture of the risk associated with a nuclear project, and how regulations add to this financial risk.

Quantifying regulatory impact on different accounts can be really difficult, as it is a wide topic with a lot of uncertainty and variables. One way to quantify regulations is by running case studies on different nuclear projects. Putting together multiple case studies could allow for a better understand of the general impact of regulations. Nevertheless, even a case study of one project - for example the Vogtle plant in the US or the Olkiluoto plant in Finland can significantly improve the understanding of the regulatory environment and how it impacts plant economics.

Here is an outline of suggested topics for further research:

- Increased financial costs due to regulations
- Regulations' impact on opportunity cost and NPV
- Increased risk due to regulatory uncertainty
- Case studies

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