- Standardisation: The lower power output of SMRs reduces the need to adapt to local site conditions, raising the level of design standardisation compared with large reactors.
- Modularisation: Smaller SMR size means that transporting their modules would be easier than for large reactors. As illustrated in Figure 32, the degree of modularisation increases considerably for power outputs of less than 500 megawatts of electrical capacity ($MW_e$). This trend could be improved with more aggressive modularisation techniques tailored to the logistical constrains and transport standards of each country. It is estimated that 60-80% factory fabrication levels are possible for SMRs (with power outputs below 300 MWe) (Lloyd, 2019). This would also facilitate the implementation of advanced manufacturing techniques such as electron beam welding and diode laser cladding by 2025 (EY, 2016). Others, such as powder-metallurgy hot isostatic pressing and additive manufacturing, are at lower technology readiness levels but significant progress is being made (EPRI, 2018).
- Harmonisation: Having access to a global market is necessary to foster series-production economies, but this is possible only with regulatory and industrial harmonisation.

Box 17: **SMR definition, classification and key design features**

SMRs are generally defined as reactors with power outputs of between 10 $MW_e$ and 300 $MW_e$ that integrate higher simplification, modularisation, standardisation and factory-based construction in their design to maximise the economic advantages of series production. The various modules can be transported and assembled on-site, with the shorter lead times enhancing construction predictability and savings.

SMR designs can be classified in a number of ways (NEA, 2011), as they involve a variety of coolants and fuel arrangements at different technology readiness levels (TRLs) and licensing readiness levels (LRLs):

- Light-water (LW)-cooled SMRs: Some vendors are using the well-stablished LW-cooled technology to propose Gen-III designs with unique features thanks to the lower power output.
- Generation-IV or advanced SMRs: Some SMRs integrate alternative coolants (other than light or heavy water) and fuel arrangements into their designs, producing more revolutionary concepts. They are essentially based on the six systems selected by the Generation IV International Forum (GIF) in 2000[59] and could also offer additional economic advantages thanks to higher outlet temperatures, among other qualities. Advanced materials and their qualification are key research and collaboration areas.
- Micro Modular Reactors (MMRs): More recently, smaller concepts of less than 10 $MW_e$ have been proposed. They are capable of semi-autonomous operation and have improved transportability compared to other SMR concepts. They involve a wide range of technological approaches including Gen-IV systems and even heat pipes.[60]

Around 50 SMR concepts were under development in 2018: 50% LW SMRs and the other 50% Gen-IV (IAEA, 2018). The LW SMRs are at a higher TRL, as they take advantage of experience accumulated with the existing fleet of water-cooled reactors and therefore encounter fewer regulatory uncertainties. It is important to mention that while the term SMR has been adopted around the world to refer to all small reactor designs, there are significant differences among the major types, particularly in their degree of modularity.

59. Sodium-cooled fast reactor (SFR); very-high-temperature reactor (VHTR); supercritical water-cooled reactor (SCWR); molten salt reactor (MSR); lead-cooled fast reactor (LFR); and gas-cooled fast reactor (GFR).

60. Heat-transfer devices that combine the principles of both thermal conductivity and phase transition to effectively transfer heat between two solid interfaces. They are extremely simple, as the coolant flows by means of capillary action, centrifugal force or gravity within the tube. They are also being tested in experimental nuclear-propulsion aerospace applications (NASA, 2018).

Box 17: **SMR definition, classification and key design features** *(cont'd)*

Although simplification, modularisation and standardisation were described in Chapter 4 as potential strategies to reduce the costs of large projects, the size of Gen-III reactors, and the layering of their auxiliary systems impose several design constraints that may limit the applicability of these approaches. The impact of size is particularly acute for simplification and modularisation, but small nuclear cores have advantageous features that counteract these technical limitations (Ingersoll, 2009):

- Enhanced passive or gravity-driven mechanisms: The lower power output and higher surface-to-volume ratio offered by smaller cores increases the efficiency of passive safety systems for both normal and off-normal operating conditions. Many LW SMR designs have a very large water capacity to cool reactor systems even under extreme circumstances.
- Integral designs: An integral system incorporates all the components of the nuclear steam supply system (NSSS) into a single vessel. This is viable with small cores, as otherwise the size of the vessel would be prohibitively large.
- Reduced inventories: The total quantity of radionuclides that could be potentially dispersed in accidental conditions – referred to as the source term – is roughly proportional to the power level. Smaller inventories may enable reduced shielding in various systems and components, thus simplifying the design. Smaller inventories may also permit emergency planning zones (EPZs) to be smaller, which would increase siting flexibility.

SMR features also allow for below-grade siting, providing more protection from natural (e.g. seismic or tsunami, depending on the location) or man-made (e.g. aircraft-impact) hazards.

Nevertheless, regulator experience with some of these new design features may be limited. These innovations may also introduce new safety issues that will have to be assessed in more detail. Regulatory uncertainty is even higher with Gen-IV designs, as current licensing regimes may require some adjustments.

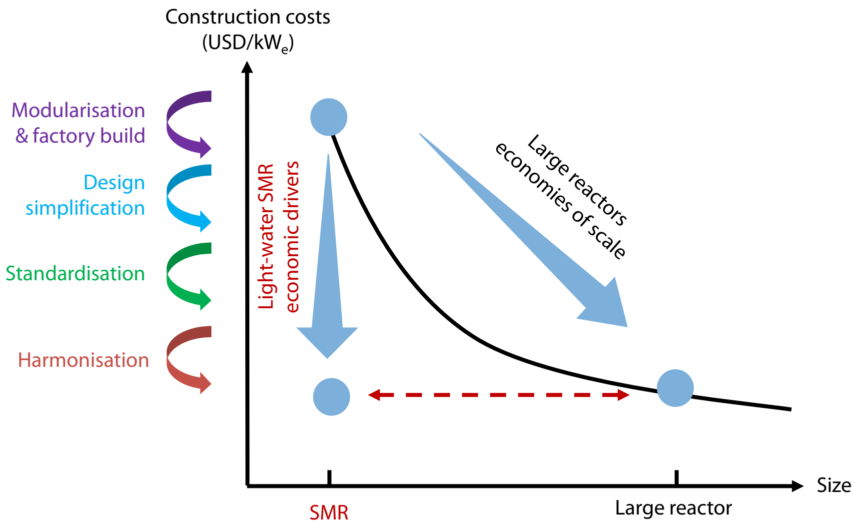
The cost reduction potential of these drivers for large reactors has already been covered in this report. In fact, SMRs (like any new nuclear product) can follow the same learning curve as the one illustrated in Figure 17 and may exploit the same cost reduction approaches. However, the series effect, simplification, standardisation, modularisation and harmonisation will carry more relative importance in order to counterbalance the lack of economies of scale compared to contemporary large reactors. The potential of these strategies to reduce costs has been well documented in other industries, such as shipbuilding and the aircraft industry, in which serial manufacturing has produced learning rates of 10-20% (NNL, 2014). Nevertheless, these practices still need to be proven for SMRs.

Furthermore, the timely deployment of this technology will also require new licensing regimes. Current licensing frameworks typically rely on an extensive experience base with large single-unit LW reactors and proposed LW-based SMRs have similar operating conditions and fuel arrangements, which should facilitate licensing. However, limited experience with these novel designs poses challenges in demonstrating and approving their safety case. Moreover, the introduction of alternative fuels and/or coolants (i.e. Gen-IV SMRs) will translate into greater deviations from previous regulatory paradigms and may require more flexible licensing approaches (Sainati, Locatelli and Brookes, 2015).

Consequently, attaining economic benefits for SMRs will require a co-ordinated effort by the various stakeholders, a dedicated policy and regulatory framework and, most importantly, a global market. Regulators will therefore need to determine how they can work together to devise more streamlined and harmonised regulatory frameworks to create a true global SMR market; experience gained through initiatives such as the MDEP, CORDEL and NSQA could prove useful in this process. It is also imperative to appropriately estimate the size of this market to establish a robust supply chain (i.e. key partnerships) and sustainable construction know-how that results in competitive capital costs (Lyons, 2020).

Finally, it is important to note that, beyond the potential cost savings described above, SMRs also offer a different value proposition in terms of financing, ancillary services, and off-grid and non-electric applications that could also improve their economic performance (NEA, 2019). Unfortunately, these prospects are outside the scope of this study.

Figure 34: **SMR economic drivers that help compensate for diseconomies of scale**




## 5.3 **Long-term industrial performance and design development**

Previous sections of this report address numerous construction cost reduction opportunities for nuclear systems in several areas (i.e. technology, organisation, regulatory) that allow for the main underlying risks to be contained and even mitigated. They tackle both direct and – more importantly – indirect costs, the latter being determined by governance, including project management.

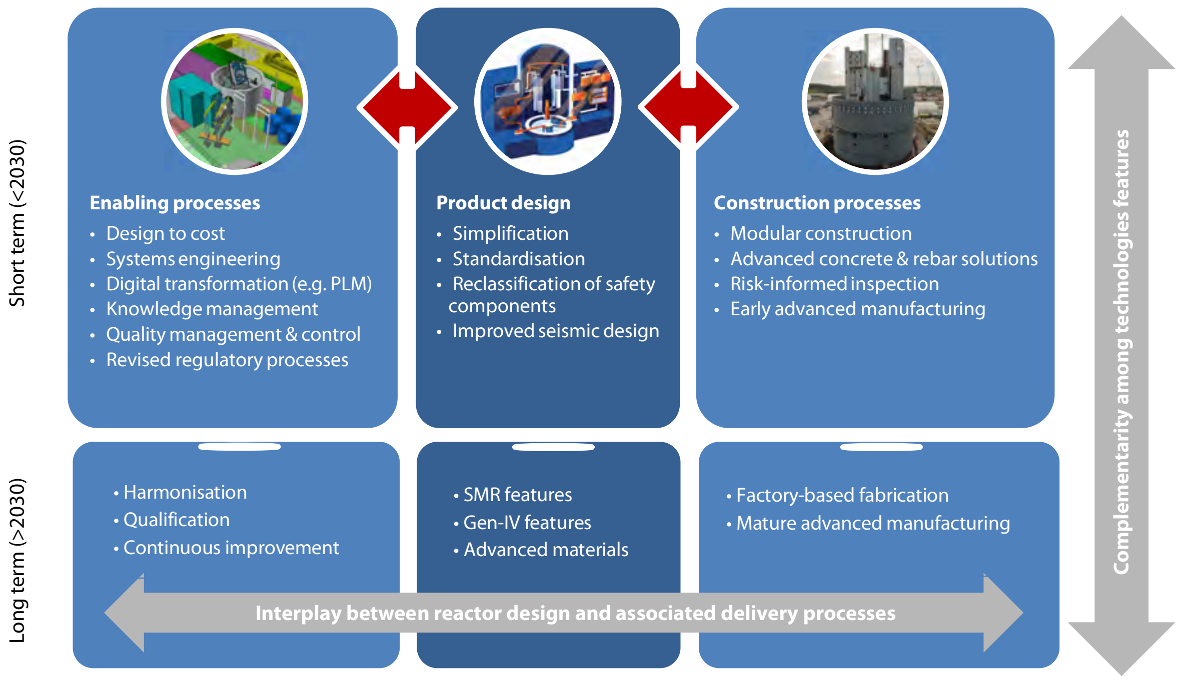
Specific recognition has been given to the dichotomy between product (i.e. design) and process, in light of strong evidence that rising nuclear construction costs have consisted largely of indirect costs in the past ten years (see Figure 12). Delivery processes therefore warrant special attention.

*Projects* are one-off temporary endeavours that aim to complete a number of tasks on time and on budget, to meet the expected requirements. Once they are completed, the project teams simply leave, taking their valuable experience with them most of the time. Conversely, *products* do not have an end date but a lifecycle and they are designed to create value and satisfy customer needs which may evolve over time. Consequently, products are more *permanent* compared to projects and require multidisciplinary teams to continuously integrate improvements and adaptations to customer specifications. They incorporate product-oriented "enabling" processes that foster the sophistication of the product, as well as of the associated fabrication/construction processes for their successful delivery. The various nuclear construction cost reduction drivers, with their potential timelines, can be categorised according to this framework (Figure 40).

The nuclear industry's long-term economic performance can be achieved through constant mobilisation of the various cost reduction enablers presented in Chapter 3, continuously improving designs by capitalising on learning gained from replications and new projects. However, the number of project orders must be large enough to drive continuous learning. Furthermore, the elements driving cost savings result from the interplay between design optimisation approaches and the enabling construction processes. This interplay is key, as the boundaries between product and process are sometimes blurred. For instance, modularisation is a construction process that also requires significant work in the design phase. Similarly, standardisation is not limited to the design phase but can be also interpreted as an enabling process, accelerating transactions with the supply chain.

At the same time, the product-oriented framework presented in Figure 35 is compatible with the development of different families of products (i.e. a product portfolio) at various maturity, growth and market share levels. It is therefore possible to create an optimised product portfolio wherein complementarities and synergies among products and processes can be explored. For instance, a mature product with well-established market shares could support other products that are at earlier stages of development and facing more risks.

Figure 35: **Cost reduction as interplay between product and process**




This approach is particularly interesting for SMR technology, as it involves numerous concepts at different TRLs and LRLs. Due to their innovative nature, SMRs may introduce additional technology and supply chain risks that do not necessarily exist with current large LW reactor designs.[61] To be credible options by the early 2030s, prototypes and demonstration units will be needed to prove the announced benefits of SMRs. From a cost perspective, these technologies should follow the same learning curve illustrated in Chapter 3, but the various cost reduction drivers will not carry the same weight (see Section 5.2).

Moreover, several learning factors, such as project management, construction advances and innovative organisational processes, are not technology-specific, meaning that SMRs should also benefit from progress made with large NPPs in the 2020s. This illustrates the complementarity between both technology families, with the next large Gen-III nuclear constructions playing an important role in the future success of SMRs.

61. LW rector-based SMRs incorporate non-traditional components such as helical coil steam generators, internal control rod drive mechanisms or new in-vessel instrumentation for which operational experience is limited. Plus, Generation-IV SMRs will include features that have never been tested before. Pilot facilities could help demonstrate these features and introduce the new technologies to the market, which is consistent with historical experience (NEA, 2019).

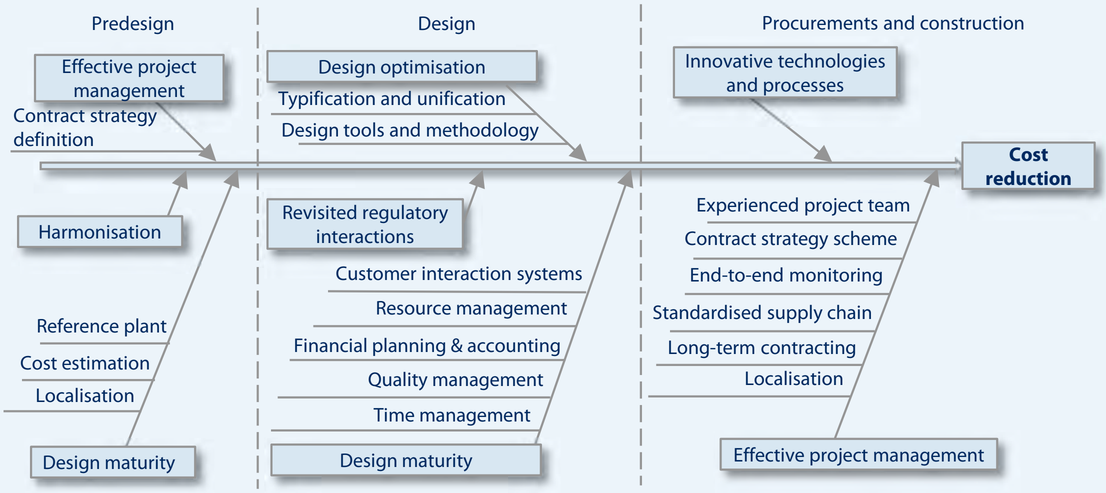
Countries at more advanced stages of nuclear construction learning are already working at continuously improving and optimising their product portfolios similarly to other sectors, Russia being a prime example (Box 18).

### Box 18: Russia's long-term industrial performance and product design development

According to preliminary data from the forthcoming IEA/NEA *Projected Costs of Generating Electricity* 2020 report, the overnight costs of new nuclear construction in Russia are 54% below the OECD average. In fact, having accumulated more than 30 projects at home and abroad, Russia is already benefitting from a long-term industrial strategy. Stimulated by a constant inflow of projects, Rosatom, the state-owned company in charge of designing and constructing nuclear reactors, is leveraging experience from previous and ongoing projects to continuously refine its products and processes and drive down nuclear costs. Its long-term industrial strategy (Figure 36) provides insight into how, with a sufficient level of experience, the cost reduction opportunities explored in this report can be adopted at the various project stages:

- Pre-design: During this phase the first cost estimates are performed and the contract strategy is defined. The availability of a reference plant facilitates this process and increases the accuracy of the estimates. Localisation opportunities could be exploited, especially for commodities and non-safety-related equipment. Any progress in regulatory or industrial harmonisation should already be identified in this phase to minimise qualification and engineering work.
- Design: Based on the maturity of the design, sound quality control systems for design documentation as well as real-time time and resource management systems can be developed and supported by more advanced digital solutions. At the same time, design optimisations can be performed, in accordance with the desired cost target and by means of new design tools and methodologies, to streamline engineering efforts while increasing standardisation and reducing the risk that reworks will be required.
- Procurement and construction: Execution of the contract strategy could benefit from effective project management with experienced teams, and a standardised supply chain built on long-term contracting schemes while exploring localisation opportunities when possible. In this phase, several technical construction advances and innovative processes can be implemented to increase productivity, facilitate quick decision-making and ensure end-to-end monitoring and analysis of the execution of supply contracts and construction/installation works.

Figure 36: **Long-term industrial performance fishbone diagram**



Box 18: **Russia's long-term industrial performance and product design development** *(cont'd)*

Rosatom is using the experience it has gained with Gen-III large reactors and civil marine nuclear propulsion to develop other products. In December 2019, the floating Akademik Lomonosov SMR was connected to the grid. It is based on the LW-cooled KLT-40S concept, from the RITM reactors series (i.e. Russian civil marine nuclear propulsion reactors).[62] Six units of a new evolutionary concept, the RITM-200, have already been manufactured and installed in several icebreakers (Moskvin, 2019), and Rosatom is planning to extend this technology to land-based industrial applications. Two sites are being considered, with works to start by 2024 (NucNet, 2020b). This reflects Rosatom's strong product-oriented and long-term industrial vision in developing nuclear technology.

## References


EPRI (2018), *Advanced Nuclear Technology: Demonstration of Powder Metallurgy-Hot Isostatic Pressing*, www.epri.com/#/pages/product/000000003002010500/?lang=en-US.

EY (Ernst & Young) (2016), *Small Modular Reactors: Can Building Nuclear Power Become More Cost-Effective?*, March 2016, www.researchgate.net/publication/321715136_Small_modular_reactors_Can_building_nuclear_power_become_more_cost-effective.

IAEA (2018), *Advances in Small Modular Reactor Technology Developments*, IAEA, Vienna, https://aris.iaea.org/Publications/SMR-Book_2018.pdf.

Ingersoll, D.T. (2009), "Deliberately small reactors and second nuclear era", *Progress in Nuclear Energy*, Vol. 51, pp. 589-603.

ISO (2018), "New standard to improve safety in the nuclear sector", www.iso.org/news/ref2296.html.

Lloyd, C.A. (2019), *Modular Manufacture and Construction of Small Nuclear Power Generation Systems*, PhD thesis, University of Cambridge, www.researchgate.net/publication/337937287_Modular_Manufacture_and_Construction_of_Small_Nuclear_Power_Generation_Systems.

Lyons, R.E. (2020), *The Effect of Supply Chain Configuration on Small Modular Reactor Economics*, PhD thesis, University of Cambridge, https://doi.org/10.17863/CAM.49463.

Moskvin, A. (2019), "Rosatom SMR energy solution: Status and perspectives", presentation at the 139th Session of the Steering Committee of Nuclear Energy, Paris, 25 October 2019.

NASA (2018), "Space technology game changing development: The fission system gateway to abundant power for exploration", Kilopower fact sheet, www.nasa.gov/sites/default/files/atoms/files/ns_kilopower_fs_180111.pdf.

NEA (2015), *Nuclear New Build: Insights into Financing and Project Management*, OECD, Paris, www.oecd-nea.org/ndd/pubs/2015/7195-nn-build-2015.pdf.

NEA (2011), *Current Status, Technical Feasibility and Economics of Small Nuclear Reactors*, OECD, Paris.

NEI (2019), "President signs bipartisan bill to modernize nuclear regulation", www.nei.org/news/2019/president-signs-bill-to-modernize-nuclear.

NNL (2014), *Small Modular Reactors (SMR) Feasibility Study*.


62. Other concepts from the RITM reactor series are being operated in a lighter-aboard ship (KLT-40) and two icebreakers (KLT-40M).

NucNet (2020), "Rosatom wants licence for SMR construction to begin in 2024", www.nucnet.org/news/rosatom-wants-licence-for-smr-construction-to-begin-in-2024-3-2-2020.

Sainati, T., G. Locatelli and N. Brookes (2015), "Small Modular Reactors: Licensing constraints and the way forward", *Energy*, Vol. 82, pp. 1092-1095, www.sciencedirect.com/science/article/abs/pii/S0360544215000250.

WNA (2013), *Aviation Licensing and Lifetime Management: What Can Nuclear Learn?*, WNA, London, www.world-nuclear.org/uploadedFiles/org/WNA/Publications/Working_Group_Reports/CORDELAviationReport.pdf.

# Part 3: Policy frameworks to deliver competitive nuclear projects, and policy recommendations

The overall nuclear policy framework is central to implementation of the construction cost reduction strategies identified in Part 2. Part 3 therefore addresses the key areas in which governments can support the delivery of future nuclear new-build projects, with Chapter 6 devoted to the financing framework and Chapter 7 offering key policy recommendations.

As already emphasised, financial costs are a central area for cost reductions, as they can make up more than 80% of capital costs. Having access to affordable financing therefore has a first-order impact on the levelised cost of electricity (LCOE) from nuclear power. The cost of capital is primarily driven by the risk premium expected by investors, which reflects the allocation of construction and market risks.

Today, the cashflow structure of nuclear projects, the associated perceived risks (founded largely on the recent poor construction performance record) and current electricity market conditions provide clear rationale for state commitment, regulation and, most likely, transitional financing in the early stages of the learning process. State financing can be provided in various forms: direct (i.e. equity, debt); indirect (market regulation, guarantees); or a combination of both. Financial support from foreign governments (e.g. through export credit agencies) could also have a positive impact.

While this government role in financing is particularly important for restarting nuclear programmes, it should be viewed as transitional, as industry maturity will reduce both risks and costs.

In best-performing countries, governments lead the nuclear construction programmes. They absorb the residual risks and provide positive and long-standing policy signals as well as the timely decision-making necessary for adequate industrial planning and optimisation. A nuclear power programme must be seen as a social contract among policymakers, industry and society, the primary beneficiaries of successful project delivery.

# 6. The role of financing frameworks to deliver cost-competitive nuclear new-build

As discussed in Chapter 2, the high fixed costs, low variable costs and 60-year operating lifetime of Gen-III nuclear reactors mean that the cost of capital has a first-order impact on the levelised cost of nuclear energy.

The cost of capital is determined primarily by the risk premium expected by investors, which reflects the allocation of construction and market risks. Today, the track record of delays and costs overruns for recent first-of-a-kind (FOAK) projects has heightened investors' risk perception and further policy interventions may be warranted to effectively allocate and mitigate these risks. This chapter outlines how to assess and allocate risks, particularly for post-FOAK projects, and discusses the support policies governments can implement.

The scale of these challenges means that cost and revenue risks may be considered more important for investment decisions than the cost estimates. Consequently, the core issue of "financing challenges" is not the financing *per se*, but rather the effective allocation and mitigation of risks, which will be reflected to a large extent in the financing conditions of the project.

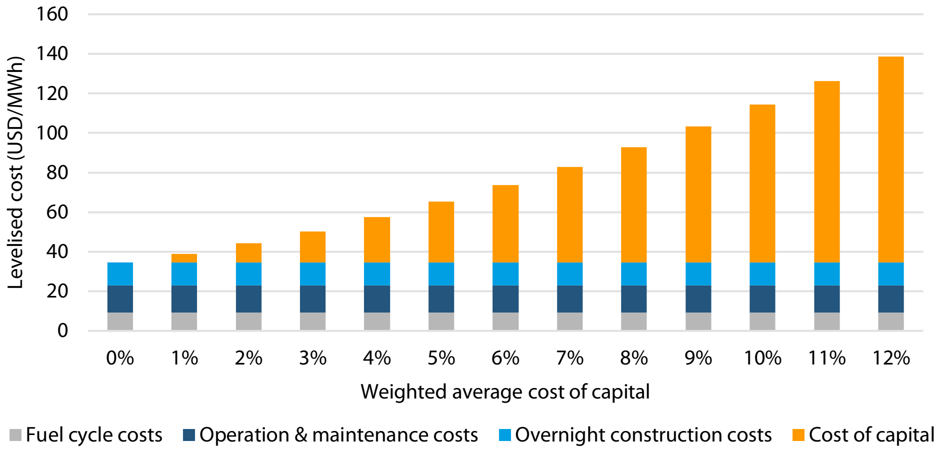
## 6.1 Financing conditions and nuclear power cost-competitiveness

Financing conditions directly affect the levelised cost of electricity (LCOE) and therefore the competitiveness of new nuclear construction. These conditions are strongly influenced by both the nature of the risks (with higher risks leading to a higher expected rate of return on investment, and therefore a higher cost of capital) and the organisational and ownership arrangements that allocate risks among stakeholders. Policy intervention plays a central role, as governments may decide to directly or indirectly carry a certain share of the risk. As discussed in Section 6.3.3., this can be arranged as part of policies to establish the conditions for developing low-carbon technologies, to ensure security of supply, or to correct for market failures. Strategies can also be introduced to transfer some of the risk to the final consumer.

Figure 37 illustrates the impact of the cost of capital on the LCOE of nuclear power: a 6 to 9% increase in the nominal weighted average cost of capital (WACC) raises the levelised cost by 50% in a reference scenario with an overnight cost of USD 4 500 per $kW_e$ and a lead time of seven years. Reducing the nominal WACC to 5-6% would be in line with the social discount rates typically used to assess public investments, such as infrastructure projects (NAO, 2017). Assuming a 2.5% inflation rate, this equates to a 3.5% real WACC – in line with normative estimates of the social discount rate (see footnote 68).

At a holistic level, however, it is important not to consider financing conditions per se as a lever to reduce the cost of nuclear power, as they simply reflect the underlying industrial organisation and government/public participation choices that designate risk allocation and mitigation. The financing framework is therefore defined by the organisational and ownership structures at the project level, as well as by the national and international contexts that determine the available sources of financing. For this reason, the overall policy framework should especially be considered, as government intervention can play a significant part in carrying and mitigating some of the risks associated with nuclear construction, as well as in addressing the higher risk perception associated with recent FOAK projects.

Figure 37: **LCOE of a new nuclear power plant project according to the cost of capital**




Note: MWh = megawatt hour. Calculations based on OCC of USD 4 500 per kilowatt of electrical capacity (/kWe), a load factor of 85%, 60-year lifetime and 7-year construction time

Box 19: **Addressing risk perception for nuclear new-build projects**

The recent delays and cost overruns of nuclear new-build projects have raised risk perception for potential investors, but also for society as a whole. This directly affects risk premiums and, therefore, the cost of financing.

Furthermore, the higher cost of financing resulting from greater risk perception can further reinforce the perception of nuclear construction risks for future projects, creating a cycle in which nuclear technology competitiveness is hindered well into the future.

Addressing risk perception requires, first and foremost, effective mitigation of construction risks by delivering upcoming new-build post-FOAK projects without significant delays or cost increases. At the same time, government commitment, regulation and financial support (at least transitional) are essential to attract private investment in long-lived assets such as nuclear power plants (NPPs).

Lastly, greater engagement between nuclear new-build developers and the financial sector can further mitigate the misperception of risk. This is especially important in the early developmental stage to put the project on the right track, especially for reputational risks, which are hard to quantify.

## 6.2 Construction risks: Allocation and mitigation priorities

Identifying and addressing risks during construction is standard procedure in the process of financing infrastructure projects.

A variety of risks from project planning through execution can impact new nuclear plants and directly or indirectly lead to construction costs overruns. Indeed, understanding and appraising these risks is often a key factor in investment decisions, more important than cost estimates. Today, the track record of recent FOAK projects and the broader specificities of nuclear projects are making this assessment particularly sensitive.

The sensitivity of nuclear projects arises from a combination of factors: the scale of investments; the long lead times; and the complexity of the decision-making process involving multiple interested stakeholders. It is therefore critical to address risks – particularly construction risks – early in the development phase, with all the relevant stakeholders, to support a robust and sound decision-making process as well as address potential risk perception issues.

### 6.2.1 *Nuclear construction risks and key mitigation priorities*

Construction risks can be divided into three broad categories:

- Technology risks are associated with reactor design, particularly design maturity, but also with the integration of new technologies.
- Organisational risks relate largely to project management but also the capabilities of the supply chain to meet quality assurance standards and to manufacture key components.
- Policy framework risks include policy issues related to safety regulation, the financing framework and political support. These risks need to be considered as early as possible, but some will persist after commissioning.

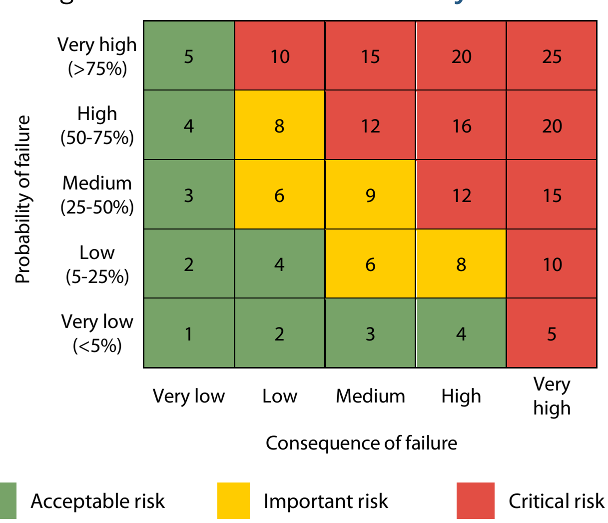
In addition, post-construction risks across the project lifetime will also need to be assessed using the same approach (IAEA, 2017; NEA, 2008). These risks can impact costs and, just as importantly, future revenues:

- Market risks: lack of long-term revenue certainty (prices and quantities), including $CO_2$ price trajectory (e.g. functioning of carbon markets).
- Operational risks: plant performance, reactor availability, fuel supply.
- Liability risks: insurance and insurability, nuclear liabilities, natural disasters and force-majeure circumstances.
- Waste management and decommissioning risks.

Once identified, the appraisal of these risks typically relies on a well-formalised process wherein each risk is defined in terms of origins, probability of occurrence, and potential consequences. Consequences of construction risks fall primarily into two categories – delays and costs overruns – but non-completion is also possible, particularly if there is a change in political support. Sub-optimal performance once the plant is operating may also be an issue.

The risk assessment process is therefore project-specific and can be summarised in a risk criticality matrix (Figure 38), then integrated into a dedicated document – a project risk register (PRR) – by the developer. This document is central to discussions with key stakeholders, within the industry and at the government level to establish the contractual framework. It is also vital for discussions with the various institutions involved in financing: current/future equity shareholders, debt-provider financial institutions, and guaranteed providers such as export credit agencies (ECAs).

Figure 38: **Illustrative risk criticality matrix**



Risk mitigation priorities will need to be assessed based on the PRR. Affecting this process are the short-term costs reduction opportunities explored in Chapter 3, which are intrinsically linked with risk mitigation priorities for future post-FOAK projects (Table 5). For example, risks related to design could be mitigated largely by starting construction only when a high level of design maturity has been achieved, especially once a reference plant has already been built and licensed by the same regulatory authority. Similarly, project management challenges could be further addressed by using new digital tools such as product lifecycle management (PLM) and systems engineering.

Table 5: **Key risk categories and mitigation priorities**

| Risk category | | Principal risks | Risk mitigation priorities |
|---|---|---|---|
| **Technology risks** | **Design** | - Implications of design misspecification:<br>• redesign during construction<br>• licensing amendments<br>• equipment replacement and rework | - Design maturity before start of construction<br>- Early supply chain involvement to integrate requirements<br>- Systems engineering and new digital tools<br>- Reduce rework: better anticipate the impact of design modifications on the rest of the plant<br>- Get it right the first time |
| | **Integration of new technologies** | - Impacts on the construction schedule and/or plan due to regulatory approval or constructability issues | - Integrate constructability requirements when considering new technologies<br>- Use proven technologies unless a case can be made for the risks vs. benefits of a new technology<br>- Early supply chain involvement |
| | **Nuclear quality assurance standards** | - Challenges for the supply chain to meet nuclear quality assurance standards (including verification/validation) leading to extensive rework | - Near term: oversight during construction and consolidation of the nuclear supply chain<br>- Long term: innovative reactors with simpler nuclear heat supply systems to simplify the safety case and associated quality assurance processes |
| **Organisational risks** | **Project management** | - Poor planning/scope definition and division<br>- Inefficient resource allocation<br>- Inefficient oversight and low reactivity to change during construction<br>- Costs overruns and results non-consistent with specifications | - Proactive early supply chain engagement<br>- Delegate authority to project manager for faster on-site decision-making<br>- Procurement strategy incentives<br>- Incentives to increase workforce productivity and encourage on-time completion<br>- Develop a process to encourage adaptability to specification changes<br>- New digital tools: use PLM to improve traceability and knowledge management of requirements and modifications |
| | **Supply chain capabilities** | - Lack of manufacturing expertise/knowledge in critical areas<br>- Lack of manufacturing capabilities for large components, leading to bottlenecks | - Long-term nuclear new-build perspective to support supply chain mobilisation<br>- Supply chain co-ordination with vendors at the international level to prevent bottlenecks<br>- Comprehensive knowledge management strategy |
| **Policy framework risks** | **Political support** | - Uncertainties regarding the government's position on nuclear:<br>• politicisation of the nuclear agenda<br>• change of government policy | - Establish and maintain broad national and local political consensus on the role of nuclear power<br>- Political leadership to absorb residual risks<br>- Legal and contractual cover for political risks |
| | **Licensing framework** | - Unpredictable licensing/regulatory framework<br>- Unstable licensing/regulatory framework | - Outcome-focused dialogue between vendor and regulator to ensure proper interpretation of requirements<br>- Regulator awareness of cost implications for industry and regulator to find best approaches to meet required safety objectives |
| | **Financing** | - Unexpected changes in financial conditions (interest rates, taxes, exchange rates)<br>- Insurability of nuclear liabilities according to regime<br>- Unavailability of funding | - Allocation of technological, organisational and governance risks to those best equipped to mitigate them<br>- Legal framework for liabilities<br>- Contract strategy aligned with financier requirements |

Reviewing risk mitigation priorities emphasises that near-term technical and organisational construction risks decrease significantly when standardised reactors are built in standardised series using a proven design and supply chain; policy framework risks are also likely to be reduced. However – as the next section highlights – these risks are only partially owned by the industry, with the government playing a central role in their mitigation, especially through providing political support and long-term energy policy and financing frameworks.

### 6.2.2 *Allocating construction risks among stakeholders*

The general principle for efficiently allocating project risks is to allocate them as much as possible to the stakeholders best placed to mitigate them. The various construction risks are typically allocated to two types of stakeholders: i) the risk owners that have primary risk mitigation responsibility; and ii) other stakeholders of key importance for effective mitigation (Table 6).

Table 6: **Typical stakeholder allocation of key construction risks**

| Risk categories | | Risk stakeholders | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Industry | | | | Other stakeholders | | | |
| | | Plant owner | Vendor | Project team | Supply chain | Government | Society | Safety authority | Financiers |
| Technological | Design | x | **x** | x | | | | | |
| | Integration of new technologies | | x | **x** | x | | | | |
| | Nuclear quality assurance standards | x | x | **x** | x | | | x | |
| Organisational | Project management | x | x | **x** | | | | | |
| | Supply chain capabilities | | x | **x** | x | x | | | |
| Policy framework | Political support | x | | | | **x** | x | | |
| | Licensing framework | x | | | | **x** | x | x | |
| | Financing | x | | | | **x** | | | x |

Notes: **x** = primary risk owner; x = other key risk mitigation stakeholders.

For most of the categories, risk allocation is reflected in several complementary contractual arrangements (IAEA, 2017):

- Ownership arrangements: The ownership structure of the future NPP is of critical importance, as it determines the commercial and contractual arrangements of the investment decision. For example, under a state-owned model the government directly finances the project, meaning that it will explicitly or implicitly carry a large share of the project's construction risks.
- Procurement arrangements: Under fixed-cost contracting, risks related to supply chain capabilities tend to be allocated at the level of the supply chain. As highlighted in the discussion on recent FOAK projects in Chapter 3, issues may also arise when contracts are incomplete and can trigger a lack of risk allocation certainty. This can lead to litigations, resulting in additional costs and delays.

- Financial arrangements: Certain "pure" financial risks, such as exchange-rate variation, can be addressed through financial instruments applied at the level of international financial markets. These includes financial products to mitigate changes in commodity prices or the foreign exchange rates.

In addition, it is noteworthy that technological and organisational risks tend to be owned by different stakeholders than policy framework-related risks.

Technology and organisational risks should generally be allocated within the nuclear industry, which includes the plant owner, the vendor, the project team and the supply chain as a whole. However, outcomes may often not be determined by a single company but by a concerted effort across the industry. For example, project management-related risks may primarily be the responsibility of the project team, but the interconnectedness of these activities means that the actions of the rest of the industry also affect the project. In addition, allocating part of these risks to the rest of the industry through incentive contracting can further support the concerted mitigation efforts needed. As highlighted in Chapter 3, incentives must be designed such that each contractor, and potentially each subcontractor, does not assume large risk margins, as this would raise overall costs.

Risks related to the policy framework will tend to be owned by the plant owner but will often be shared with the government. Again, this may vary from project to project: for instance, in the Hinkley Point C (HPC), specific contractual clauses were introduced in case policy changes affected the contract-for-difference mechanism. More generally, governments can support nuclear project financing through direct equity stakes, loans or loan guarantees. Similarly, licensing framework-related risks remain primarily with the industry (the plant owner or vendor), but – as highlighted in Chapter 4 – also benefit from co-ordinated efforts with the regulatory authority as well as the government to set up a framework that provides sufficient predictability and stability.

In parallel, governments should also be involved in market risk mitigation, particularly in liberalised electricity markets, to support long-term price signals.

Hence, beyond the specificities of each nuclear project, the efficient allocation and mitigation of policy-related risks generally requires close co-ordination between industry and the state.

## 6.3 Nuclear new-build financing frameworks

### 6.3.1 *The specifics of financing nuclear projects*

As highlighted in the previous section, risk identification and assessment underpins the financing framework. This mainly involves construction risks, but must also include risks once the plant is in operation as well as long-term liabilities.

Nuclear new-build projects are similar to other large infrastructure projects in that the scale, complexity and importance of political factors and social acceptance can significantly impact financing decisions. Nevertheless, nuclear projects also have a number of specific features that can reinforce these challenges (Pehuet Lucet, 2015).

First, private financial institutions such as equity funds have a limited credit time horizon (Offer, 2018), as they remain reluctant to invest in long-lived assets because policy uncertainty increases significantly beyond 10-15 years, rapidly raising risk premiums. In addition, new banking regulations were introduced following the 2008 financial crisis, requiring that banks improve their solvency ratios to comply with Basel-III regulations. These rules indirectly affect bank funding availability for long-lived assets such as nuclear projects, particularly because they are now required to put aside a percentage of equity as soon as they commit to lend money. Because these commitments prevent them from entering into other engagements during the tendering period, banks are less inclined today to finance long-term capital-intensive projects such as new NPPs.

Second, nuclear projects must comply with specific regulatory frameworks for safety and non-proliferation across the project lifecycle. This includes several layers of national and international norms and rules, such as IAEA guidelines, international treaties and conventions, and industry standards.

Third, in addition to general risk reviews, specific requirements have been added in the past two decades regarding environmental and social issues. Managing environmental and social risks has become a stringent obligation. The International Finance Corporation (IFC) Sustainability Framework and the Equator Principles (EPs) framework set the standards and references for addressing environmental and social risks in infrastructure projects.

All nuclear projects financed through international financial institutions are now governed by the EPs. This requires that they perform environmental and social-specific risk assessments, formulate action plans and report according to the EPs guidelines, through their lead bank.

### 6.3.2 *Ownership structures*

As explained above, the ownership structure of a nuclear new-build project is central to the series of contractual arrangements that underpin risk allocation and drive financing decisions. Three broad models are traditionally considered:

- Sovereign model: The state funds the project, either directly through the state budget or via public borrowing. This model implies that taxpayers carry the project risks unless they are explicitly transferred to consumers. Countries with low sovereign risk will be able to provide advantageous financial conditions, including for international projects, as projects can benefit from the state's credit rating.
- (Private) corporate model: Utilities with strong balance sheets can finance large projects by raising equity and borrowing money (debt); creditors may claim the loan against the company's overall assets. While the advantage of this financing model is its simplicity, it is also expensive and is accessible only to a handful of large corporations.
- Project-finance model: Project investment is financed through a combination of debt and equity as in the corporate-based model, but a project company is created to establish a legal separation from the sponsors' other assets. Hence, lenders have limited recourse beyond the revenues and/or assets of the project. As the debt remains in the project company, it does not appear on the investor's balance sheet.

In practice, these approaches are neither definitive nor exclusive. Ownership structures include hybrid formats that combine the attributes of the different approaches and/or complement them with specific support mechanisms that further shift risk to a specific stakeholder. The choice of structure is based largely on the project's economic environment, with the degree of electricity market unbundling and liberalisation particularly affecting interest in developing project finance. Similarly, competition rules may hamper the ability of the state to directly own and finance a nuclear project under a sovereign structure, at least without counterparties. Finally, interest in shifting risk from the investors to other parties can also be a strong determinant of project financing.

Table 7 summarises the financing models as well as market and construction risk allocation for selected Gen-III nuclear projects, revealing a number of important findings.

First, in recent years corporate finance has been implemented only for large (monopolistic) nuclear utilities in countries such as France and Korea.[63] In the rest of the world, project finance is the dominant approach. A notable exception is Finland, where the Olkiluoto 3 project was financed through a hybrid co-operative model (the Mankala model) with a pool of energy-intensive industries.

63. This also applies to Russia, which is not represented in Table 7.