Review Paper

Economics, cost-effective and financial Small Modular Reactors

‘‘Mamoon khan’’ ID (15628) ‘‘Aslam khan’’ ID (15622)

Abstract: The interest toward Small Modular nuclear Reactors (SMRs) is growing, and the economic competitiveness of SMRs vs large reactors is a growing technology. this paper firstly provides an overview of “*what we know*” and “*what we do not know*” about the economics and finance of SMRs. Secondly, the paper develops a research agenda. Several documents discuss the economics of SMRs, highlighting how the size is not the only factor to consider in the comparison; remarkably, other factors (co-sitting economies, modularization, modularity, construction time, etc.) are relevant. The vast majority of the literature focuses on economic and financial performance indicators (e.g. Leveloize Cost of Electricity, Net Present Value, and Internal Rate of Return) and SMR capital cost. Remarkably, very few documents deal with operating and decommissioning costs or take a program (and its financing) rather than a “single project/plant/site” perspective. Furthermore, there is a gap in knowledge about the cost-benefit analysis of the “modular construction” and SMR decommissioning.

Introduction: Small modular reactors (SMRs) are a type of nuclear fission reactor which are smaller than conventional reactors. Advanced Small Modular Reactors (SMRs**)** are a key part of the Department’s goal to develop safe, clean, and affordable nuclear power options. The advanced SMRs currently under development in the United States represent a variety of sizes, technology options, capabilities, and deployment scenarios. These advanced reactors, envisioned to vary in size from tens of megawatts up to hundreds of megawatts, can be used for power generation, process heat, desalination, or other industrial uses. SMR designs may employ light water as a coolant or other non-light water coolants such as a gas, liquid metal, or molten salt. Advanced SMRs offer many advantages, such as relatively small physical footprints, reduced capital investment, ability to be sited in locations not possible for larger nuclear plants, and provisions for incremental power additions. SMRs also offer distinct safeguards, security and nonproliferation advantages. Many Member States are focusing on the development of small modular reactors, which are defined as advanced reactors that produce electricity of up to 300 MW(e) per module. These reactors have advanced engineered features, are deployable either as a single or multi-module plant, and are designed to be built in factories and shipped to utilities for installation as demand arises.

There are about 50 SMR designs and concepts globally. Most of them are in various developmental stages and some are claimed as being near-term deployable. There are currently four SMRs in advanced stages of construction in Argentina, China and Russia, and several existing and newcomer nuclear energy countries are conducting SMR research and development. Economics and finance are two sides of the same coin, and the appraisal of a certain technology needs to consider both. Consequently, both economic and financial studies are reviewed in this paper. The amount of documents published about SMR economics and finance so far is relatively large, the information is disorganized, and most of the quantitative studies do not follow a standardized approach, making a proper comparison in most of the cases impossible. This paper aims to provide, through a Systematic Literature Review (SLR), an overview of *what* we know and what we do not know.

Issues: Since SMRs do not have the same economies of scale as larger reactors, they may produce electricity at a higher cost per kilowatt hour than other energy sources, including existing commercial reactors. The Union of Concerned Scientists raises this point in a 2013 publication critiquing SMRs, which also contends that the inherent safety features of SMR concepts are untested. The lower capital investment required for SMR construction has also been called into question by the Institute for Energy and Environmental Research, which contends that construction of a modular nuclear plant would require costly early construction of shared facilities, such as a containment structure, intended for use with all planned reactor modules. The potential impact of SMR technologies on weapons proliferation is unclear. Proliferation concerns for reactors center on nuclear fuel—specifically, the requisite level of enrichment of enriched uranium fuel would pose a greater proliferation risk relative to typical nuclear power reactors, which use uranium enriched to about 5% of the fissile isotope U-235. In contrast, some advanced SMR concepts use 15-20% enriched uranium. The planned treatment of spent fuel for proposed SMR concepts varies, with some developers suggesting that sealed SMR cores could be manufactured, shipped to the site of the power plant, and shipped back to the manufacturer at the end of the core lifetime, still sealed. However, such systems could face technical barriers to safe transportation, and experts disagree on whether sealed cores would decrease the proliferation risk, since they would require relatively high enrichment levels. To date, the International Atomic Energy Agency (IAEA) identifies 40 small and medium-sized reactor designs under development. SMR concepts using coolants other than light (ordinary) water are less technically understood than water cooled concepts, and will require further research before commercialization.

Methodology: This paper provides an SLR combining the methodologies detailed in The selection process of the documents includes two sections. Section A deals with documents extracted from the scientific search engine Scopus, and section B deals with reports published by key stakeholders (e.g. International Atomic Energy Agency).
Section A has three main stages. The first stage is the identification of relevant keywords related to the research objective. Several discussions with experts and several iterations led to this list:

-SMRs: "small modular reactor", "small medium reactor".

-Economics and finance: "economic", "economy", "cost", "finance", "financing".

-Construction: "construction", "modularisation", "modularization", "modularity", "fabrication", "prefabrication", "factory".

-O&M: "operation", "operating", "maintenance", "O&M".

-Decommissioning: "decommissioning", "end of life", "shut down", "removal", "site restoration", "dismantling".

SMR fuel cost is a relatively small percentage of the total cost [19,25], and given the same technology, it is not differentiable between large and small reactors. Therefore, studies about the fuel cost are excluded from the analysis.
In the second stage, strings with the Boolean operator *AND*/*OR* are introduced in Scopus:

1) *“*small modular reactor*” OR “*small medium reactor*” AND “*economic*” OR “economy” OR “*cost*” OR “*finance*” OR “*financing*” (search date: 11/01/2019).*

2) *“*small modular reactor*” OR “*small medium reactor*” AND “*modularization*” OR “*modularisation*” OR “*modularity*” OR “*construction*” OR “*fabrication*” OR “*prefabrication*” OR “*factory*” (search date: January 10, 2019).*

3) *“*small modular reactor*” OR “*small medium reactor*” AND “*operation*” OR “*operating*” OR “*O&M*” OR “*maintenance*” (search date: 14/01/2019);*

*4)“*small modular reactor*” OR “*small medium reactor*” AND “*decommissioning*” OR “*end of life” OR “*shut down*” OR “*removal*” OR “*site restoration*” OR “*dismantling*” (search date: January 10*, 2019).*

Scopus was chosen because of the scientific merit of the indexed literature. A timeframe was not selected a priori because all the documents have been published after 2004 (therefore it is 2004–2019). The selection step used the aforementioned strings (applied to title, abstract or keywords) and retrieved 763 documents (excluding 14 non-English documents).

The third stage is the filtering characterised by the following two steps:

1) A careful reading of the title and abstract of each document to filter out documents not related to the research objective or duplication. After the first step, 640 documents were removed leaving 123 documents.

2) A careful reading of the introduction and conclusion of the 123 documents retrieved after the first step to filter out documents not related to the research objective. After the second step, 58 documents were removed, leaving 65 documents.

The distribution of the final retrieved documents is:

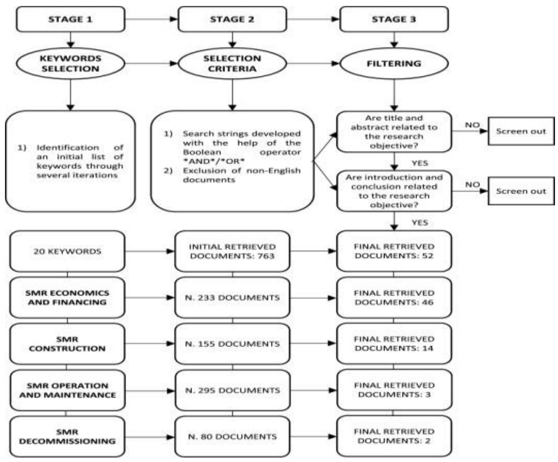
-SMR Economics and finance: 46 documents;

-SMR Construction: 14 documents;

-SMR O&M: 3 documents;

-SMR Decommissioning: 2 documents.

Considering the overlap of the documents (i.e. some documents are related to more than one search string), the total number of documents to be analysed is 52 (see the list in Appendix 1). Fig. 1 summarizes the selection process for section A.



In the selection process for section B, the documents were searched specifically on the IAEA (International Atomic Energy Agency) and NEA (Nuclear Energy Agency) websites (section: publications) excluding non-serial publications (i.e. lecture notes). IAEA and NEA were selected because they are two leading organizations in the nuclear field and publish high-quality reports. Three keywords related to SMRs were used to search documents: “SMR”, “Small” and “Modular” (search date: March 22, 2019).

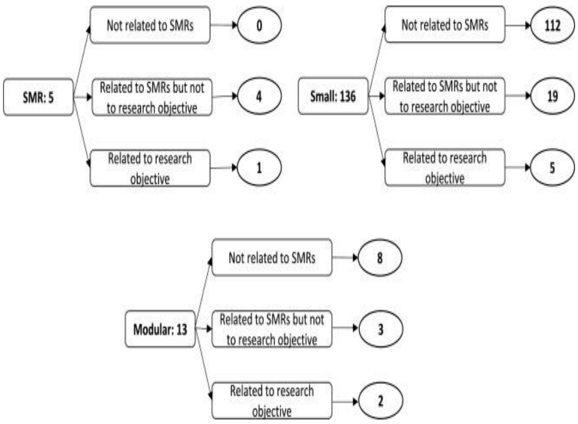
The distribution of the retrieved documents is:

-“SMR”: 5 (4 IAEA documents and 1 NEA document);

-“Small”: 136 (129 IAEA documents and 7 NEA documents);

-“Modular”: 13 (11 IAEA documents and 2 NEA documents).

The filtering stage has the same two steps of section A. Fig. 2 shows the results.



After the check for duplication, four documents are related to the research objective: [[26], [27], [28]], and [29]. Following discussions with stakeholders, other five documents were added: [[30], [31], [32], [33]], and [34]. Most of the selected documents are published in journals (45.9%), and nine documents (14.75%) are published by organizations/companies/working groups. The remaining ones are conference papers: ICONE[1] (16.39%), ICAPP[2](13.11%), SMR[3] (4.92%), ASEE[4] (1.64%), ICST[5] (1.64%), and one book (1.64%). The research objective “to identify the state-of-the-art about economics and finance of land-based SMRs and the most relevant gap in knowledge” determined the choice of information to retrieve from the selected documents. The main themes that emerged from the analysis of the selected documents determined the organization of the information in the following sections.

Economics and finance of SMRs

3.1. Introduction to the terms used in this paper

This section provides a brief overview of the terms mainly used in the next sections.

3.1.1. Life-cycle costs

In the nuclear sector, the life-cycle costs (or generation costs) are commonly divided into four groups: capital cost, operation and maintenance costs, fuel cost, and decommissioning cost [9].

3.1.1.1. Capital cost

Capital cost is the sum of the “overnight capital cost” and the Interest During Construction (IDC) [35]. [10] defines the “overnight capital cost” as *“the base construction cost plus applicable owner’s cost, contingency, and first core costs. It is referred to as an overnight cost in the sense that time value costs (IDC) are not included”* (Page 25). [10] defines the “base construction cost” as *“the most likely plant construction cost based on the direct and indirect costs only”* (Page 19). Examples of owner’s cost are land, site works, project management, administration and associated buildings [36]. Capital cost represents the biggest percentage of the life-cycle cost of a nuclear power plant, and typical values are in the region of 50–75% [8].

3.1.1.2. Operation and maintenance costs

Operation and maintenance (O&M) costs are the costs needed for the operation and maintenance of an NPP [37]. O&M costs include *“all non-fuel costs, such as costs of plant staffing, consumable operating materials (worn parts) and equipment,* repair and interim replacements, purchased services, and nuclear insurance. They also include taxes and *fees*, decommissioning allowances, and miscellaneous costs" [10] (Page 33).

3.1.1.3. Fuel cost

The fuel cost is the sum of all activities related to the nuclear fuel cycle, from mining the uranium ore to the final high-level waste disposal [38]. Examples of activities related to the nuclear fuel cycle are the enrichment of uranium, manufacture of nuclear fuel, reprocessing of spent fuel, and any related research activities [39].

3.1.1.4. Decommissioning cost

The decommissioning cost includes*: "*all activities, starting from planning for decommissioning, the transition phase (from shutdown to decommissioning), performing the decontamination and dismantling and management of the resulting waste, up to the final remediation of the site*"* [40] (Page 6).

3.1.2. Indicators of economic and financial performance

3.1.2.1. Levelised unit of electricity cost/Levelised Cost of Electricity

The levelized cost of the electricity for a power plant is usually termed "Levelised Unit Electricity Cost" (LUEC) or "Levelised Cost of Electricity (LCOE)"; it is one of the main indicators for policymakers. This indicator accounts for all the life cycle costs and is expressed in terms of energy currency, typically [$/kWh] [9,41,42].

3.1.2.2. Net Present Value and Internal Rate of Return

The most popular indicators to investigate the profitability of investing in a nuclear power plant are the Net Present Value (NPV) and the Internal Rate of Return (IRR) [9]. NPV measures the absolute profitability [$] and uses a discount factor to weight "present cost" versus the "future revenue" [43]. The discount factor depends on the source of financing and for many practical applications can be intended as the Weighted Average Cost of Capital (WACC). A low WACC gives similar weighting to present cost and future revenue (promoting capital-intensive plants, like NPP), while high WACC is weighted more towards the present cost respect to future revenues (promoting low capital cost solutions like gas plants). The IRR is a "specific dimensionless indicator", i.e. the value of WACC that brings the NPV to zero. The greater the IRR, the higher is the profitability of the investment [9,44].

Comparisons between the methodology:

The primary differences in SMRs compared to larger NPPs (e.g. advanced light-water reactors, ALWRs) are their small power output (typically below 300 MW per unit) and Modularity – in many SMR designs, the modules (which are intended to be produced in Factory conditions) could be complete reactor units. (Other equipment such as the Turbine-generator, condenser, the cooling system, etc., could also be produced as Modules.) These stand-alone modules could be transported to the construction site (Which could also involve factory-produced structures) and installed. Most SMR designs Benefit from a reduced number of structures, systems and components.
The economics of SMRs (capital costs, operation and maintenance [O&M] costs and Fuel costs) are not yet known. SMR vendors present the following advantages of small Modular reactors:

• SMR designers stress that their concepts offer enhanced nuclear safety and allow for the implementation of unique passive features.

• Many SMR designs benefit from a reduced number of structures, systems and components, and from simplified power conversion systems.

• Because of the smaller upfront investment required for one unit, plants with SMRs are expected to be easier to finance.

• Plants with multiple SMR units offer better flexibility for utilities operating in the Markets with large shares of variable renewable generating resources, or operating in small grids. Most of the SMR designs have high potential for operation in load following regimes. In France and Germany, some nuclear power plants also operate in the load-following mode (NEA, 2011: 55).

• The transmission infrastructure requirements could be smaller for SMRs than for ALWR (because of lower electricity output). This makes them suitable for Deployment in a larger number of locations.

• In terms of human resource management of teams involved in operation and outage management, there are benefits in having several identical SMR units Instead of one large unit. In addition, multi-unit configuration helps to avoid a long outage period (if compared with ALWRs) through unit-by-unit maintenance and refuelling.

• The energy output of SMRs is well suited to existing heat and water distribution networks and thus SMRs could offer higher potential for cogeneration, such as water desalination and district heating.

• Modularity of construction and small-sized units allow easier decommissioning.

According to the estimates available today, if the competitive advantages of SMRs are realised, SMRs are expected to have lower absolute and per kWe total construction costs than ALWRs. This would be possible if SMRs were produced in large numbers, through optimised supply chains and with smaller financing costs. According to vendors' estimates, most SMR designs require the construction of five to seven plants to get the most out of supply chain establishment and learning. The size of the SMR market (determining the possibility of factory production) is thus particularly important for achieving the desired level of competitiveness.

Variable costs (O&M and fuel costs) for SMRs most likely will be higher than for ALWRs. Fuel costs are expected to be higher because of smaller core sizes and a less efficient use of the fuel. O&M costs will depend on the capability of the SMR designer to prove to the nuclear regulators that security and operation requirements could be achieved with fewer personnel than for ALWRs. However, for multi-unit plants with several SMR units, O&M costs per MWh are likely to decrease, although this will depend on regulatory requirements.

Consequently, if SMRs are produced in series in factory conditions, they are likely to be cheaper to build than ALWRs in terms of both absolute and per kWe total construction costs, although they will have higher variable costs. In economics terms, SMR costs are therefore situated between those of coal and large nuclear plants.

There is a market for SMRs in national energy mixes with large shares of renewables.
This can be seen from the analysis of the residual load curve (with generation of electricity by variable renewables subtracted), which would allow for an energy mix to be obtained that minimises the total cost of electricity generation. This approach demonstrates that the optimal share of SMRs in the total nuclear capacity increases when large shares of variable renewables are introduced (leading to reductions of capacity factors of traditional baseload sources, such as nuclear and coal). Although these values are not universal and greatly depend on the energy system under consideration, and the actual economic characteristics of the SMR, this example indicates that there is a potential market for SMRs with a strong development of variable renewables.
The share of SMRs in nuclear new build in 2020-2035 could be estimated by using the arguments summarised above and applying them to different countries.

Results: Not a single "truly modular" SMR has been built so far. Economic and financial reasons are strongly hindering SMR development. However, there are plenty of studies about SMR economics and finance. Through an SLR, this paper aims to provide an overview of what we know and what we do not know about the economics and finance of land-based SMRs, and to suggest a research agenda. Instead of a traditional narrative review, an SLR has been performed to provide a holistic perspective and allow repeatability. One of the limitations of an SLR is the inclusion of papers of different perspectives (still published in respectable journals). Furthermore, more recent papers are, in principle, considered equal to older references that might have less up-to-date information and theories. The exclusion of certain papers because of the authors disagree on or consider too old is an arbitrary choice. The strength of an SLR is the high scientific rigour allowing a full reproducibility of the work. One or more option-based papers leveraging an arbitrary choice of references and data can be considered a follow up from this work.

As highlighted by the words "Small" and "Modular", SMRs present three main peculiarities with respect to large scale traditional reactors: smaller size, modularization, and modularity. SMR size has three main implications: loss of the "economy of scale", for the same power installed more units can be built fostering phenomenon like the industrial learning, and the reduction of the up-front investment per unit. This latter makes SMR investment particularly attractive considering the multi-billions up-front investment of LRs. Modularization has several implications: working in a better-controlled environment, standardization and design simplification, reduction of the construction time, logistical challenges. Modularity allows having a favorable cash flow profile, taking advantage of the co-sitting economies, cogeneration for the load following of NPPs, a higher and faster industrial learning, and better adaptability to market conditions. Furthermore, the interest in SMRs is growing because of the different applications: electrical, heat, hydrogen production, and seawater desalination.

Suggestions:

Although the economics of SMRs are not fully known, there is a large potential for these
Technologies that can represent an alternative way forward for nuclear power development. In the high-case scenario, up to 21 GWe of SMRs could be globally added by

2035. Actual SMR market development will strongly depend on the successful deployment of prototypes and FOAK plants. To achieve the ambitious goals of SMR development, the following recommendations are being made:

• Governments and industry should work together to accelerate the construction of SMR prototypes that could demonstrate the benefits of this technology. Governments willing to develop nuclear power should consider supporting International collaboration and common R&D on SMRs, and work on national and International licensing frameworks for small nuclear reactors.

• SMR vendors and potential customers should work closely with nuclear regulators to allow early resolution of various issues of SMR development (including validation of innovative safety features and solutions) and factory assembly. In the case of overseas deployment of SMRs, both nuclear and non-nuclear regulatory authorities (e.g. export control agencies) should be associated with this process.

• SMR vendors and customers should work together to estimate the economics of small nuclear power plants, taking into account the role that SMRs could play in the new energy mixes, in particular when large shares of variable renewables are present. Detailed SMR market assessments should be performed, taking into account realistic estimates of SMR economics and the capabilities of the supply chain. These results must be carefully drafted for policymakers and the public

Conclusions:

SMRs are currently being developed around the world, and they are believed to have a potential for broadening the ways that nuclear power is developed. This study focuses on light water SMRs that are expected to be deployed in the 2020s.
Not a single “truly modular” SMR has been built so far. Economic and financial reasons are strongly hindering SMR development.Small modular reactors (SMRs) are small reactors with unit power output below 300 MWe(with larger plant capacities) that can be built as modules in factory facilities.

SMRs target traditional markets (on-grid deployment), in which case they must compete with other energy sources or niche applications in remote or isolated areas, or on islands that require small-sized units and where electricity that is produced with nonnuclear sources of power has a high cost.

SMR vendors present the following advantages of small modular reactors:

• SMR designers stress that their concepts offer enhanced nuclear safety and allow for the implementation of unique passive features.

• Many SMR designs benefit from a reduced number of structures, systems and components, and from simplified power conversion systems.

• Because of the smaller upfront investment required for one unit, plants with SMRs are expected to be easier to finance.

• Plants with multiple SMR units offer better flexibility for utilities operating in markets with large shares of variable renewable generating resources, or operating in small grids. Most SMR designs have high potential for operation in load following regimes. In France and Germany, some nuclear power plants also operate in the load-following mode (see NEA, 2011: 55).

• Transmission infrastructure requirements could be smaller for SMRs than for advanced light water reactors (ALWRs) because of lower electricity output, which makes them suitable for deployment in a larger number of locations.

• In terms of human resource management of the teams involved in operation and outage management, there are benefits in having several identical SMR units instead of one large plant. In addition, multi-unit configuration helps to avoid a long outage period (if compared with ALWRs) through unit-by-unit maintenance and refueling.

• The energy output of SMRs is well suited to existing heat and water distribution networks, and thus SMRs could offer higher potential for cogeneration, such as water desalination and district heating.

• Modularity of construction and small-sized units facilitates decommissioning.

While the economics of SMRs, capital costs, operation and maintenance (O&M) costs and fuel costs are not yet known, SMR designers argue that per kW over night cost of SMRs could be lower than the overnight cost of ALWRs. This would be possible if SMRs were produced in large numbers, had optimized supply chains and had smaller financing costs. The number of SMR orders, which determines the economics of building Production facilities, is thus particularly important for achieving SMR competitiveness.

According to the estimates available today, if the competitive advantages of SMRs are realized, SMRs are expected to have lower absolute and per kW total construction costs
than ALWRs.

There is a market for SMRs in national energy mixes with large shares of renewables.

This can be seen from the analysis of the residual load curve (with generation of electricity by variable renewables subtracted), which would allow for an energy mix to be
obtained that minimizes the total cost of electricity generation. This approach demonstrates that the optimal share of SMRs in the total nuclear capacity increases
when large shares of variable renewables are introduced (leading to reductions of capacity factors of traditional base load sources, such as nuclear and coal). Although these
values are not universal and greatly depend on the energy system under consideration,
and the actual economic characteristics of the SMR, this example indicates that there is a
Potential market for SMRs with a strong development of variable renewables.

The share of SMRs in nuclear new build in 2020-2035 could be estimated by using the generic arguments regarding SMR competitiveness summarized above and applying those to different countries. Two scenarios are considered in this report: an optimistic High-case scenario (that assumes successful licensing of SMRs and establishment of their factory production and associated supply chain), and a more conservative low-case scenario in which SMRs are expensive to build and to operate, and thus only a limited number of projects are completed, including the prototypes and plants in remote/isolated areas.

In the high-case scenario (based on data from NEA/IAEA, 2014), up to 21 GW of SMRs could be added by 2035, representing about 3% of the total installed nuclear capacity in the world. Thus about 9% of nuclear new build in 2020-2035 could be SMRs in the high case scenario, and about 2.3% in the low-case scenario. These projections do not take into account the potential for further development of SMR technologies and regulatory frameworks that might lead to major changes in the NPP market. One of the key elements for SMR competitiveness is factory production. It is obvious that an assembly plant that does not operate at a sufficient level of volume will fail to achieve economic competitiveness. An important challenge for the factory assembly of SMRs is nuclear regulation. While all safety features of SMRs generally could be addressed within the existing regulatory framework, there are issues that must be resolved. In particular, current regulatory practices might not be fully compatible with a factory assembly mode, especially if the assembly process is automated. Regulators must adapt their methods of work to test the units to the greatest extent possible at the assembly stage and reduce the potential for rework. Other important regulatory issues include validation of enhanced passive safety systems and multi-modular deployment, size of the emergency planning zone and the staffing requirements for operation and security. This validation could be obtained with existing procedures, using a risk-informed approach similar to larger nuclear plants.

However, SMRs must demonstrate that they can meet safety requirements. Regulators and technical support organisations will need time and resources to form opinions on these options and innovations, and this process could lead to delays in SMR licensing.

Two case studies were considered in this report. The first case study focuses on SMR development in the United States. Several SMR designs have been actively developed in the United States, and the US DOE has made available USD 452 million in matching grants to the Babcock & Wilcox mPower design and to the NuScale SMR design in support of their design development and licensing programmes. Small reactors could be an interesting alternative for new electricity generation capacity in the United States, in particular to replace some of the retiring coal plants. About 60 GWe of coal plants in the United States were constructed before 1975 and have a capacity of between 50 and 300 MWe. However, although there is variation in the electricity prices across the United States, the average generation component of the electricity price is estimated to be USD2011 60/MWh when the natural gas price is about USD 4/MMBtu and it is likely to remain at this level for the next decade, according to projections by the US EIA. Despite the low level of electricity prices, about 3.5 GWe of SMRs could be deployed in the United States in the high-case scenario for the period 2020-2035. This will correspond to ~3.5% of the total nuclear capacity projected in the United States in 2035-2040. The low-case scenario corresponds to a pessimistic case in
which only the prototypes are constructed.

The second case study is on the Russian barge-mounted KLT-40S, currently under construction (scheduled to be completed in 2017), and intended to be deployed by 2019 in the Chukotka region (in north-east Russia). This project is based on the well-established technology of icebreaker-type nuclear reactors. According to the latest estimates, the cost of electricity produced by this first-of-a-kind plant is expected to be about USD 200/MWh.

Such high values are related to large staffing requirements (in total about 250 employees) motivated by the application of today's regulations in Russia. In addition, the fuel cost for such units is high, and maintenance of the barge and the coastal infrastructure requires a high level of resources.

Despite this high cost of electricity generation, the floating NPP is believed to be an adequate solution for bringing power to remote regions in Russia because the cost of alternatives, including power grid extension, is also high. Given the typical power demand of 50 to 100 MWe, estimates show that a 500- to 1 000-km grid extension is more expensive than deploying an SMR locally. In the future, up to seven floating NPPs (not necessarily of the same design) could be constructed in Russia, but the decision will be taken based on feedback from experience with the first unit.

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