Hindawi Publishing Corporation
Science and Technology of Nuclear Installations
Volume 2014, Article ID 803698, 8 pages
http://dx.doi.org/10.1155/2014/803698

Research Article

An Evaluation of SMR Economic Attractiveness

Sara Boarin and Marco E. Ricotti

Department of Energy, Nuclear Engineering Division-CeSNEF, Politecnico di Milano, Via La Masa 34, 20156 Milano, Italy

Correspondence should be addressed to Marco E. Ricotti; marco.ricotti@polimi.it

Received 27 February 2014; Accepted 16 July 2014; Published 5 August 2014

Academic Editor: Shengqiang Li

The nuclear "renaissance" that is taking place worldwide concerns the new build of GW size reactor plants, but smaller GenIII+ NPP (Small Modular Reactors, SMR) are on the verge to be commercially available and are raising increasing public interest. These reactor concepts rely on the pressurized water technology, capitalizing on thousands of reactor-years operations and enhancing the passive safety features, thanks to the smaller plant and equipment size. On the other hand, smaller plant size pays a loss of economy of scale, which might have a relevant impact on the generation costs of electricity, given the capital-intensive nature of nuclear power technology. The paper explores the economic advantages/disadvantages of multiple SMR compared to alternative large plants of the same technology and equivalent total power installed. The metrics used in the evaluation is twofold, as appropriate for liberalized markets of capital and electricity: investment profitability and investment risk are assessed, from the point of view of the plant owner. Results show that multiple SMR deployed on the same site may prove competitive with investment returns of larger plants, while offering, in addition, unique features that mitigate the investment risk.

1. Introduction

Some GenIII advanced designs that are planned for deployment or currently under construction have emphasized their passive safety features and design simplifications [1]; nevertheless, further enhancements in passive safety are possible by reducing the plant scale below the GW power size. Following IAEA definition, the category of small and medium sized reactors encompasses the designs below 700 MWe [2], but novel design layout and concepts are made possible by smaller sizes (i.e., from 350 MWe downwards) [3–5]. The interest by the investors community for the Small Modular Reactors (SMR) option [6] and the proactive development effort by vendors recommend an in-depth analysis of the economics of this reactor category.

Currently only two SMR class reactors are under construction in the world: the Russian KLT-40s and the Argentinean CAREM, but other projects are in an advanced stage of development or under licensing, with some sites already identified for their deployment.

For the purpose of the economic evaluation, this paper excludes those cases where SMR are the only technically viable deployment option, such as scattered population, remote areas, and sites with physical limitation to the overall power installed (e.g., limited water resources and grid capacity).

On the contrary, when SMR are considered as an alternative option to GW-scale NPP, economic analysis shall investigate the rationale of such an investment case. For a correct comparison, the same total power installed on the same site is considered: LR shall be compared with multiple SMR with equivalent overall capacity at site level. In this case, SMR exploit the so-called "Economy of Multiples," that counterbalances the loss of "Economy of Scale." The latter is the economic paradigm that drove the design evolution towards larger and larger power capacity along the civil nuclear era, up to the current French EPR (1,600 MWe). Economy of scale holds as a hard fact in the nuclear capital-intensive industry (Figure 1). With this considered, SMR must be able to bring new specific benefits able to recover economic competitiveness and to offer attractive or protective conditions to investors.

In this study, the assessment of the economic competitiveness of SMR is approached with a twofold perspective:

(i) investment profitability: the value created by the investment project, given specific scenario conditions, is measured and related to the investment effort;

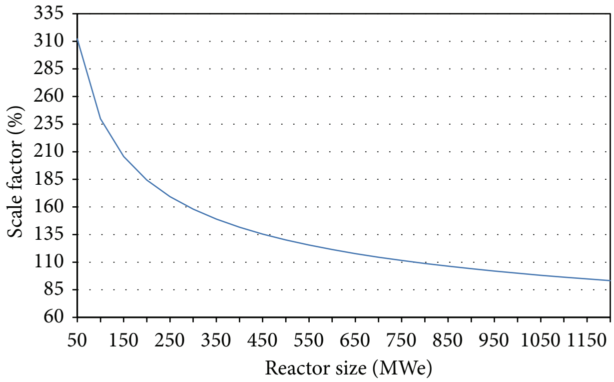

FIGURE 1: Economy of scale curve.

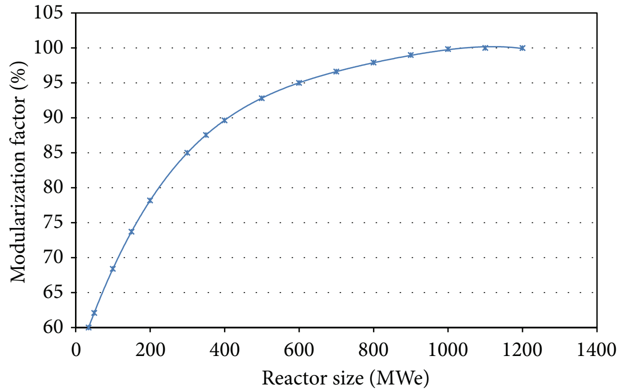

FIGURE 2: Modularization factor depending on the NPP size in terms of output power.

(ii) investment risk: the risk-mitigation features of SMR and LR are considered and analysed.

2. Method and Tool

The economic competitiveness of SMR has been assessed by means of a software simulation tool developed by Politecnico di Milano—Nuclear Reactors Research Group: the integrated model for competitiveness assessment of SMR (INCAS) [7]. INCAS is a MATLAB-based code able to calculate investment scenarios in NPP deployment. The INCAS code is based on a discounted cash flow (DCF) analysis that is performed over a given investment scenario. Results provide the calculation of key economic performance indicators.

Internal rate of return (IRR) and Profitability Index (PI) have been assumed as a key indicators of investment profitability. The levelized cost of electricity (LCOE) that represents the unit generation cost of electricity attained by a specific LR or SMR plant measures cost effectiveness. In a DCF model, LCOE is calculated as the minimum electricity price that is able to grant a threshold investment profitability (in terms of IRR); this means that, by selling electricity at LCOE, the plant manager is able to cover all operating and capital costs, including a target capital remuneration (IRR).

The INCAS code is able to account for a self-financing capability of the project: if a multiple NPP fleet is deployed through a staggered schedule, the cash flows from the sale of electricity by early units may be reinvested in the construction of late NPP units. This self-financing capability allows decreasing the up-front capital requirements and may be relevant when total power installed is fractioned into multiple smaller units.

In this work, a stochastic approach is used to include the scenario uncertainties in the analysis. The statistical estimate of probability distributions of the relevant output is calculated by means of Monte Carlo simulation.

3. Input and Assumptions

Among the economic benefits of multiple, smaller NPP units, some apply in the construction cost mitigation [10].

(i) Modularization: the NPP is conceived for the fabrication of separate modules. This fosters standardization and factory fabrication, and parallelization of activities is enabled. A smaller plant equipment size enhances the scope of modularization. A number of SMR units I backlog enable a miniserial production. Expected benefits are higher quality and cost savings of shop-build as compared to stick-build.

(ii) Learning effect: the higher the number of NPP built on the same site is, the higher the cost effectiveness of construction and assembling activities on site is, due to learning accumulation and best practice achievement by the manpower.

(iii) Cositing economies: economy of scale increases the unit cost of output product because it allocates the fixed costs on the first plant unit. Cositing economies account for the redistribution of site-related fixed costs on the whole SMR fleet.

(iv) Design savings: unique design and layout features are enabled by the smaller physical size of plant equipment. SMR design may result leaner and be simplified, with lower active components. On a stand-alone basis, the mere plant design should represent a cost-saving feature of SMR as compared to LR.

In Figures 2, 3, and 4 the above-mentioned features are represented against the power size of a single NPP. On the contrary, "Design savings" are strictly related to a specific reactor concept: for this reason they can be quantified based on the detailed engineering of a specific plant layout and are not applicable to different design with the same size. No design saving curve can therefore be sketched. On the contrary, with a reverse approach, design saving factors of different SMR sizes have been estimated in order to bring their profitability in line with LR. It has been calculated [20] that this factor strongly depends on the reference unit overnight cost assumed [€/MWe], because the higher the loss of economy of scale to recover, the higher the design enhancements and simplifications (i.e., "Design saving factor") to recover the investment profitability. It may be calculated that,

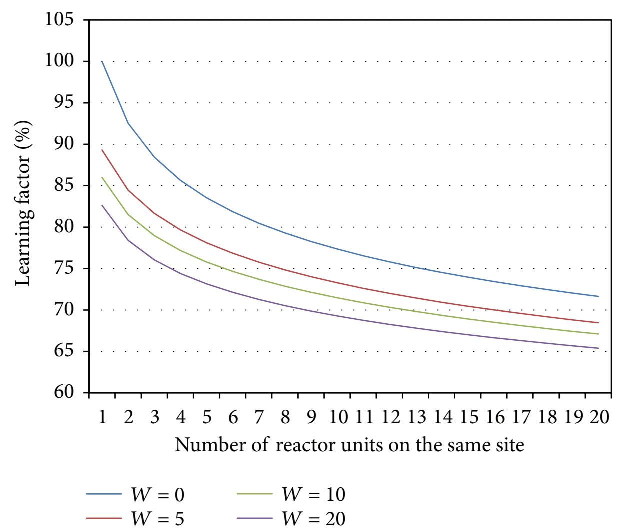

Figure 3: Learning factor depending on number of reactors built on site (learning on site) and parametric to the number of reactor plants of the same type built worldwide (worldwide learning, W).

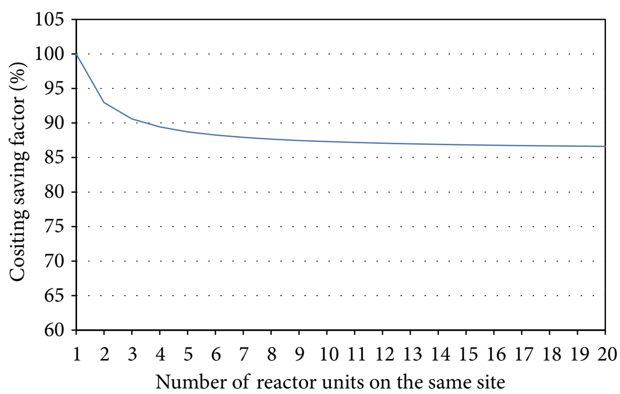

Figure 4: Cositing economies: site-related, fixed cost sharing by multiple units on the same site.

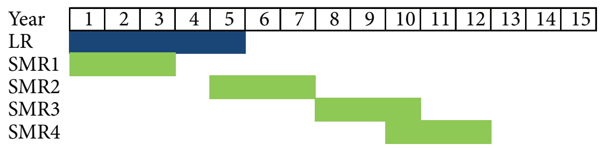

Figure 5: Construction schedules: reference scenario.

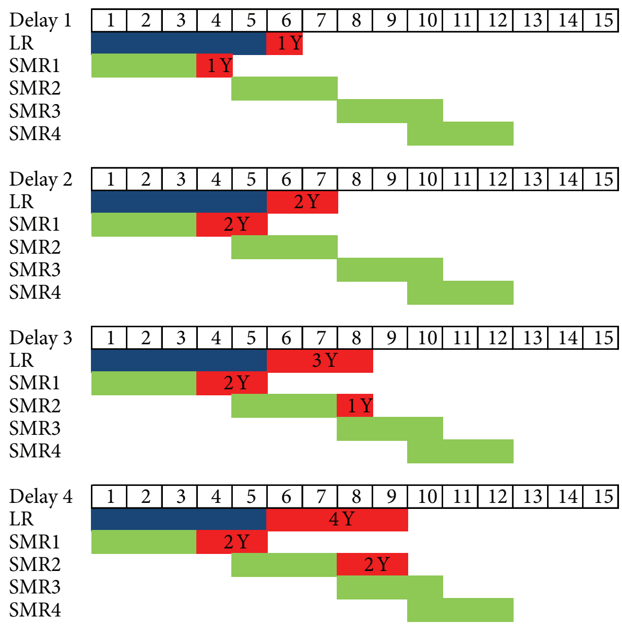

Figure 6: “Intrinsic” delay in the construction schedule considered in the sensitivity analysis: in red, the years of delay in the construction.

with construction costs ranging in 3000–5000 €/KWe, 350–150 MWe plants need design savings up to 10% in order to be competitive with larger units lays, while for the smallest plants (e.g., 50 MWe) this factor must increase up to 17%. Design saving factors of this order should be achievable [21]. In this work, a design saving factor of 10% has been allowed to a 300–350 MWe SMR over the unit construction cost of a LR.

All of the above-mentioned economic features are assumed as a framework model for the economic analysis of SMR and allow decreasing the construction costs of multiple SMR, thus recovering the loss of economy of scale.

In the following, case-study scenarios with a single, stand-alone LR and multiple power-equivalent SMR are analysed, in order to assess the economic rationale of smaller scale NPP with commercially available large scale NPP of the same technology.

Key technical and economic assumptions are listed in Table 1, while deployment schedules considered in the analysis are represented in Figures 5 to 7, with a reference scenario and 6 possible construction delay case studies.

Static scenario analysis does not allow catching the complexity of dynamics that drives the relevant variables nor the uncertainty about their evolution and the forecast capability over a very long time horizon. Sensitivity analysis allows assessing the impact of relevant input parameters on the economic performance. This is the case of possible delay in the construction schedule. A construction delay is an event capable of deeply puzzling the economics of a NPP investment project. For this reason, SMR competitiveness versus equivalent LR has been tested against four possible construction delay scenarios, each of them with the same delay, in terms of total number of years on the project (from 1 to 4 years).

As shown in Figure 6, the construction delay on each SMR unit is shorter and/or it applies on the first SMR units only: in other words, it does not affect the whole investment cost, as it does in the case of the single LR. This is reasonable to argue that the construction delay must in some way be proportional to the construction duration and that it is considered very improbable that mistakes and project management mismatches—causing the delay—would

Table 1: Scenario input data to INCAS test cases.

Input	LR	SMR	Notes
Plant operating lifetime (years)	60	60	Same technology enhancement and reliability [8] assumed for LR and SMR.
Estimated construction period (years)	5 [9]	3	Reduced construction time for SMR due to reduced size and assuming design simplification [10].
Overnight construction cost (€/kWe)	4000	Estimated from LR capital costs [10]	LR [11–13].
Operation and maintenance cost (€/MWh)	9 [14]	10.8	SMR O&M cost estimated from LR [15] (SMR/LR ratio = 1.2x).
Fuel cycle cost (€/MWh)	6.7 [8]	6.7	Same fuel cost for SMR: longer core life, but higher enrichment and poorer neutron economy (leakages).
Decontam. & decommissioning sinking fund (€/MWh)	3	5.9	SMR decommissioning cost estimated from LR cost [16, 17] (SMR/LR ratio = 2x).
Electricity price (€/MWh)	80	80	
Plant availability	93%	95%	Based on estimations for GenIII/GenIII+ LR [1] and SMR [18].

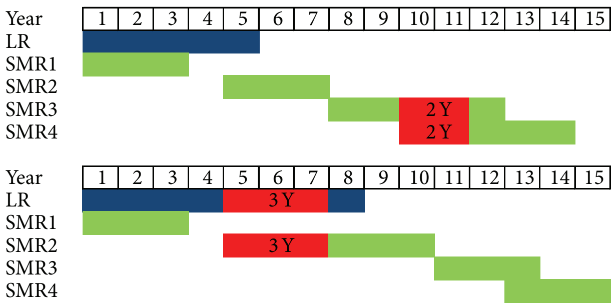

Figure 7: Two examples of how “external” delays may affect the construction schedule of LR/SMR: in red, the years of delay in the construction.

replicate in the same manner on all the units of a fleet made of NPP of the same type. Generally, it may be assumed that a sort of learning process might improve, correct, and optimize the information and the operations in the construction process, in a way that the possible delay might decrease from the early to the later deployed units. The same effect would apply to a LR fleet, but, given a total generation capacity installed on a site, the number of SMR units would always be higher than equivalent LR. These considerations apply as far as “intrinsic” delay events are concerned, that is to say delay events that may arise from the procurement, the project management, the assembly, and construction activities.

Unexpected “external” events may also be the cause for construction delays. These events may happen randomly in time and cause a stop in the NPP construction. This is the case, for example, of a political climate change, the withdrawal of a public support to the investment project, a political halt due to adverse public opinion, and the consequence of a natural disaster (like the recent Fukushima event). This kind of delay is not proportional to the construction duration of a NPP and happens randomly in time, with a random duration.

In this work, the effect of “intrinsic” construction delay has been investigated by means of a sensitivity analysis, while “external” delay events have been analysed by means of a Monte Carlo simulation.

It has been considered that one of such delay events may happen randomly during the investment period, producing a delay in the schedule of a NPP under construction and shifting onwards the construction of NPP that have not been started yet. Whenever it begins, the “external” delay event may affect one or more SMR units, depending on the specific construction plan and staggered units. The maximum duration considered for the “external” delay event is three years.

Along with construction delay, Monte Carlo analysis is a suitable tool to investigate the impact of general scenario uncertainty on the economic competitiveness. The key investment-case parameters have been considered stochastic and distributed according the probability distribution functions (PDF) indicated in Table 2.

4. Results and Discussion

4.1. Cost Effectiveness. In the reference case, with 7% cost of debt and 10% cost of equity, cost effectiveness of LR is sensibly higher than SMR in terms of LCOE (i.e., lower LCOE).

The reason lies in the fact that economy of scale is not fully recovered by the benefits and cost savings of multiple SMR. The overnight cost of the SMR fleet shows a decrease on the back of learning and cositing economies that brings the construction cost of the last unit in line with the cost of a single LR (Figure 8), but, on average, the whole SMR fleet bears higher construction cost on a unit base that affects its LCOE.

Nevertheless, if the target remuneration for the equity capital (i.e., cost of capital) is increased to 15%, the cost effectiveness of the two alternative investment options is brought in line with each other. The same trend is confirmed with increasing cost of debt, meaning that multiple SMR are more cost effective with high cost of capital (Figure 9).

The rationale of this outcome lies in the shorter construction period of each SMR module, that accounts for lower financial interests capitalization. Interest during Construction (IDC) is accounted over the invested capital during

Table 2: Scenario input data for Monte Carlo simulation.

Input	PDF	LR	SMR
Overnight construction cost (€/kWe)	Triangular	2000; 4000; 3000 (min; max; most likely)	Estimated from LR capital costs [10]
"External" delay in construction schedule	Uniform	0; 36; 18 months (min; max; mean)	0; 36; 18 months (min; max; mean)
Plant availability	Triangular	80%; 95%; 95% (min; max; most likely)	80%; 95%; 95% (min; max; most likely)
Operation and maintenance cost (€/MWh)	Uniform	6.3; 11.7; 9.0 (min; max; mean)	120% of LR
Fuel cycle cost ($/MWh)	Uniform	4.7; 8.6; 6.7 (min; max; mean)	4.7; 8.6; 6.7 (min; max; mean)
Decontam. & decommissioning sinking fund ($/MWh)	Uniform	1.4; 2.6; 2 (min; max; mean)	200% of LR
Electricity price (€/MWh)	Triangular	50; 90; 70 (min; max; most likely)	50; 90; 70 (min; max; most likely)
Financial interest rate	Uniform	6.0%; 8.0%; 7.0% (min; max; mean)	6.0%; 8.0%; 7.0% (min; max; mean)

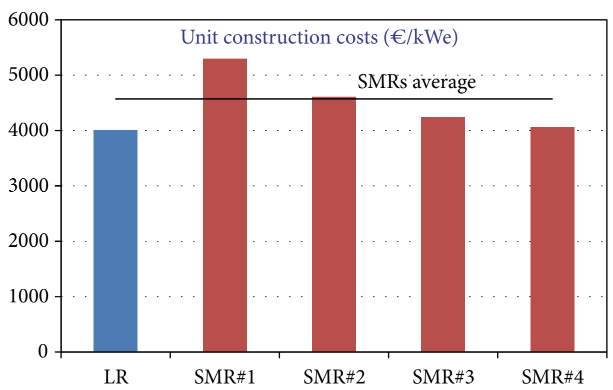

Figure 8: Unit construction costs in reference scenario [22].

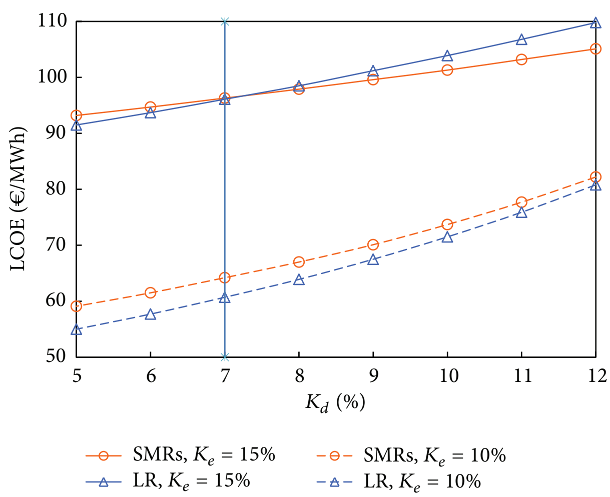

Figure 9: LCOE trend with increasing cost of debt (K_d) and different cost of equity (K_e) (adapted from [23]).

the construction period and may end up by representing a relevant part of the Total Capital Investment Cost. If construction period is shorter for SMR, then the incidence of financial interests accumulated during the construction period on overnight construction costs is lower. Financial interests are included as a component in the electricity generation cost and thus the higher the interest expenses, the higher the LCOE and the longer the payback time of the NPP investment. In other words, SMR show a better financial behaviour and for this reason, their performance improves on LR when capital costs are higher (Figure 9 with $K_d > 7\%$ and $K_e = 15\%$). This feature is particularly valuable in liberalized (capital and energy) market conditions, where capital costs are higher, compensating for higher investment risk.

4.2. Risk and Returns. Sensitivity analysis over possible delays in the construction schedule shows that multiple SMR are a robust investment project in terms of cost effectiveness, towards this kind of events.

While the cost of equipment is fixed, other construction costs are sensitive to time increase: for example, workforce on the site yard, financial costs, cranes and auxiliary equipment rent fees, and so forth.

As said, based on the assumptions, in the case of multiple SMR, delay and consequent extra-costs affect only a portion of the Total Capital Investment Cost, since only some but not all the SMR units may be concerned. In the case of LR, the whole capital investment cost is affected by the construction delay, in its sensitive cost items. As a consequence, in case of construction delay, the increase in the LCOE is sharper for LR, while multiple SMR are an intrinsically safer investment option towards this unfavourable event (Figure 10).

The economic competitiveness of multiple SMR versus LR has been investigated under uncertain scenario conditions and tested against construction delays of "external" nature.

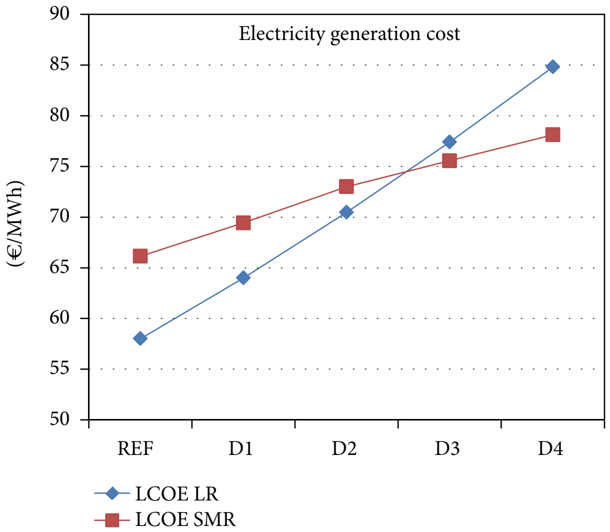

FIGURE 10: LCOE sensitivity with increasing delay in construction schedule [22].

TABLE 3: Profitability Index (PI) for multiple SMR and stand-alone LR in deterministic/stochastic scenarios [19].

	Deterministic scenario		Stochastic scenario	
	LR	SMR	LR	SMR
PI [%] (min; max)	1.31	1.23	1.06 (0.23; 2.36)	1.12 (0.17; 2.90)
Std deviation of PI	—	—	0.29	0.37

The values of PI of the two alternative investment projects are the same magnitude and are substantially in line with each other (Table 3). Given the uncertainty span over the cost/price estimates for input parameters, it may be concluded that the two projects grant the same level of investment profitability. This result is a very significant one, if one considers the effect of economy of scale on smaller NPP: it means that multiple SMR have features able to partially compensate for the loss of economy of scale.

Nevertheless it is interesting to notice that, compared to deterministic scenario, results are reversed in stochastic simulation, where investment profitability of SMR appear better than LR (Table 3). In deterministic scenario, the value of Profitability Index is higher for the LR project, but it is lower than SMR under stochastic conditions. This result is interesting as far as it highlights a trend and shows the robustness of multiple SMR against uncertain scenario conditions. This behavior is mainly due to an intrinsic lower exposure of multiple NPP to an "external" delay event: staggered deployment grants the possibility to defer the construction of later units after the end of the "external" delay event, without incurring in cost overruns. Multiple SMR represent an intrinsic investment modularization in a way that only a fraction of the total investment (some of the units) might be affected by a random delay event. Figure 11 shows that the cost overruns in stochastic scenario are more limited for multiple

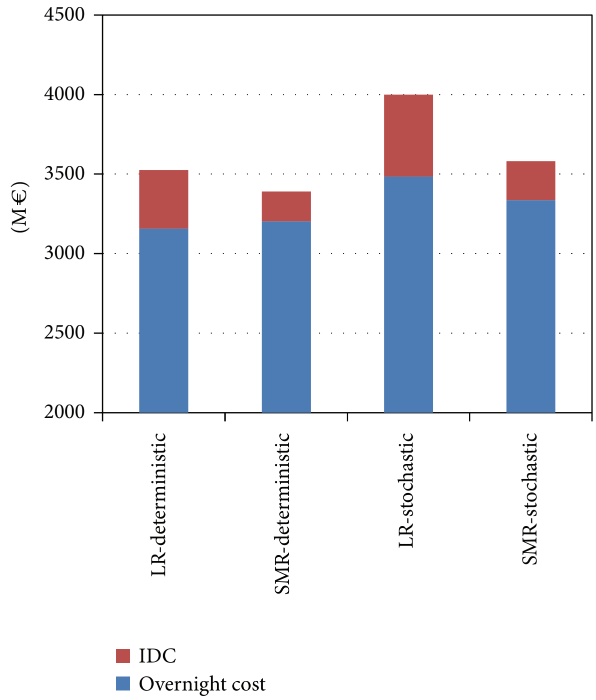

FIGURE 11: Total Capital Investment Cost (overnight cost + IDC) of SMR and LR under deterministic and stochastic scenario conditions.

SMR, accounting for lower capital expenditures. Financial interest (Interest during Construction, IDC) of SMR are half than LR's IDC. Considering the Total Capital Investment Cost (overnight construction cost + IDC), the gap between the four SMR and the stand-alone LR reduces in stochastic conditions as compared to deterministic scenario.

In addition, self-financing capability of multiple NPP and lower financial interest escalation during construction mitigate the possibility of a financial default in case of unfavorable scenario evolution (e.g., very low electricity price).

5. Conclusions

The premise of this work is the opportunity to investigate the economic competitiveness of SMR, considering the impact of a loss of economy of scale over the construction cost in a capital-intensive business, like nuclear power generation. Specific features of multiple GenIII+ SMR are analysed in order to understand at what extent they are able to compensate for this loss of economy of scale.

An investment case has been defined and simulated with the comparison of four SMR, deployed with a staggered schedule, and a stand-alone LR with equivalent power on site. The economic competitiveness of multiple SMR has been tested against a single equivalent LR under deterministic and stochastic scenario conditions, accounting for the possible uncertainty embedded in the market conditions or in the capability to estimate and forecast the cost/price values. Reasonable values for key investment parameters have been assumed and stochastic distributions have been considered to run Monte Carlo simulation of the possible investment scenarios.

In particular, specific assumptions have been elaborated to simulate possible delay events in the construction schedule of SMR and LR.

Results confirm that cost effectiveness of SMR, along with investment profitability, is in line and of the same order with LR's, provided that multiple units on the same site are deployed to exploit benefits from learning on construction process and cositing economies on fixed costs. On the other side, design modularization and simplification account for the cost reduction of each single SMR unit and help in meeting an acceptable investment return/LCOE targets.

Sensitivity analysis shows a better behaviour of multiple SMR versus LR against higher capital costs and construction delays. This "robustness" of the economic performance is confirmed by the Monte Carlo analysis. The rationale lies in the following.

(i) Protection against construction delays:

   (a) the possibility to learn from the past reduces the probability of an "intrinsic" delay in later SMR deployment;

   (b) investment modularization of SMR decreases the exposure of the whole SMR project to "external" delay events.

(ii) Better financial behaviour: shorter construction periods of SMR limit the financial cost escalation and allow to better cope with high capital costs and, in general, with construction delays and unfavourable scenario conditions.

Future developments of the SMR economic and financial analysis, to thoroughly investigate the competitiveness of such a new technology, will be devoted in addressing other important aspects of the SMR deployment path, such as the licensing process [24], the environmental implications, for example, the emergency planning zone reduction [25], and the impact on energy security [26]. In particular the licensing item will deserve specific attention, since it will be one of the first, key, and critical aspects in the deployment path also in terms of economic and market risks, due to potential delays and extra-costs.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

References

[1] T. L. Schulz, "Westinghouse AP1000 advanced passive plant," *Nuclear Engineering and Design*, vol. 236, no. 14–16, pp. 1547–1557, 2006.

[2] IAEA, "Approaches for assessing the economic competitiveness of small and medium sized reactors," IAEA Nuclear Energy Series NP-T-3.7, IAEA, Vienna, Austria, 2013.

[3] B. Petrovic, M. Ricotti, S. Monti, N. Čavlina, and H. Ninokata, "Pioneering role of IRIS in the resurgence of small modular reactors," *Nuclear Technology*, vol. 178, no. 2, pp. 126–152, 2012.

[4] J. Reyes and P. Lorenzini, *NuScale: A Modular, Scalable Approach to Commercial Nuclear Power*, Nuclear News, 2010.

[5] *Current Status, Technical Feasibility and Economics of Small Modular Reactors*, OECD-NEA, Paris, France, 2011.

[6] R. Smith, "Small reactors generate big hopes," *The Wall Street Journal*, 2010.

[7] S. Boarin, M. Massone, and M. E. Ricotti, *INCAS: INtegrated Model for the Competitiveness Analysis of Small-Medium Sized Reactors, Ver. 2.0-b0—User Manual*, Politecnico di Milano, 2012.

[8] Y. Du and J. E. Parsons, "Update on the cost of nuclear power," MIT-CEEPR Report, 2009.

[9] "Study of construction technologies and schedules, O&M staffing and Cost, decommissioning costs and funding requirements for advanced reactor designs," Dominion Energy, Bechtel Power Corporation and TLG Report, 2004.

[10] M. D. Carelli, P. Garrone, G. Locatelli et al., "Economic features of integral, modular, small-to-medium size reactors," *Progress in Nuclear Energy*, vol. 52, no. 4, pp. 403–414, 2010.

[11] D. Kennedy, "New nuclear power generation in the UK: cost benefit analysis," *Energy Policy*, vol. 35, no. 7, pp. 3701–3716, 2007.

[12] US DOE, "Assumptions to the Annual Energy Outlook 2009," DOE/EIA Report, 2009.

[13] H. Khatib, "Review of OECD study into 'Projected costs of generating electricity-2010 Edition'," *Energy Policy*, vol. 38, no. 10, pp. 5403–5408, 2010.

[14] J. Koomey and N. E. Hultman, "A reactor-level analysis of busbar costs for US nuclear plants, 1970–2005," *Energy Policy*, vol. 35, no. 11, pp. 5630–5642, 2007.

[15] M. Carelli, C. W. Mycoff, P. Garrone et al., "Competitiveness of small-medium, new generation reactors: a comparative study on capital and O&M costs," in *Proceedings of the 16th International Conference on Nuclear Engineering*, Paper no. ICONE16-48931, Orlando, Fla, USA, May 2008.

[16] "Decommissioning Nuclear Power Plants: Policies, Strategies and Costs," OECD Nuclear Energy Agency Report, 2003.

[17] G. Locatelli and M. Mancini, "Competitiveness of small-medium, new generation reactors: a comparative study on decommissioning," *Journal of Engineering for Gas Turbines and Power*, vol. 132, no. 10, Article ID 102906, 1 page, 2010.

[18] M. D. Carelli, L. E. Conway, L. Oriani et al., "The design and safety features of the IRIS reactor," *Nuclear Engineering and Design*, vol. 230, no. 1–3, pp. 151–167, 2004.

[19] S. Barenghi, S. Boarin, and M. E. Ricotti, "Investment in different sized SMRs: economic evaluation of stochastic scenarios by INCAS code," in *Proceedings of the International Congress on Advances in Nuclear Power Plants (ICAPP '12)*, Chicago, Ill, USA, June 2012, Paper 12322.

[20] S. Boarin and M. E. Ricotti, "Multiple nuclear power plants investment scenarios: economy of multiples and economy of scale impact on different plant sizes," in *Proceedings of the International Congress on Advances in Nuclear Power Plants (ICAPP '11)*, Nice, France, May 2011, Paper 11193.

[21] M. D. Carelli, B. Petrovic, C. W. Mycoff, P. Trucco, M. E. Ricotti, and G. Locatelli, "Smaller sized reactors can be economically attractive," in *Proceedings of International Congress on Advances in Nuclear Power Plants (ICAPP '07)*, Nice, France, May 2007, paper 7569.

[22] S. Boarin and M. E. Ricotti, "Construction delays and extra-costs on large and small nuclear projects," in *Proceedings of the 16th International Conference on Emerging Nuclear Energy Systems (ICENES '13)*, Madrid, Spain, May 2013.

[23] S. Boarin, G. Locatelli, M. Mancini, and M. E. Ricotti, "Financial case studies on small- and medium-size modular reactors," *Nuclear Technology*, vol. 178, no. 2, pp. 218–232, 2012.

[24] M. V. Ramana, L. B. Hopkins, and A. Glaser, "Licensing small modular reactors," *Energy*, vol. 61, pp. 555–564, 2013.

[25] F. C. V. Mancini, E. Gallego, and M. E. Ricotti, "Revising the emergency management requirements for new generation reactors," *Progress in Nuclear Energy*, vol. 71, pp. 160–171, 2014.

[26] I. N. Kessides and V. Kuznetsov, "Small modular reactors for enhancing energy security in developing countries," *Sustainability*, vol. 4, no. 8, pp. 1806–1832, 2012.