Estimating Production Costs of Future Nuclear Fission Reactors – The Effect of Parameter Choice and an Application to SMR Concepts under Development ("small modular reactors")

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Overview

In this paper, we compare different approaches to forecasting cost trajectories for SMR concepts ("small modular reactors") that are in a rather early development stage. Following the mainstream definition, we define SMR concepts as nuclear power plants in which a single reactor has an electrical power output of less than 300 MW_e (or a thermal power output of less than 1000 MW_{th}), and which can be based on water-cooled, or other (non-water cooled) reactor designs (Pistner et al. 2021). The paper is structured in the following way: The section "Methodology and Production Models" explains the underlying theory of production and applies it to nuclear power plants; we also introduce the distinction between two theoretical approaches and the effect of different parameter choices on cost estimates. In Section 3, we present data on SMR concepts, assembled from both manufacturers and other publicly available sources, and discuss the range of parameters, mainly the scale effect and the learning effect. We also introduce a technology-based differentiation of SMR concepts, mainly conventional, light water-based reactors, and others. The data and parameters are fed into a Monte Carlo simulation to provide likely ranges for future production costs. Results are presented and discussed in Section 4, and Section 5 concludes and provides a research outlook.

Methods

In this paper, we compare and apply different approaches from production theory and define a numerical model of net present value and levelized cost of electricity based on 18 selected SMR development projects under way. The key question is whether these newly developed SMR concepts will be able to compete with nuclear power plants with larger capacities, e.g., because of cost advantages through learning effects (2), standardized design (3), modularization (4), co-siting economies (5), and other factors, such as better time-to-market (Figure 1). We apply two approaches used in the literature: the approach used by an SMR-research team around Professor Roulstone (Lloyd, Lyons, and Roulstone 2020) where the scaling factor is constant, and the more complex approach suggested by Rothwell (Rothwell 2018) that uses a more flexible form. Both differ in particular with respect to their treatment of the scaling factor.This paper explores the effects of different underlying models on estimating future production costs.

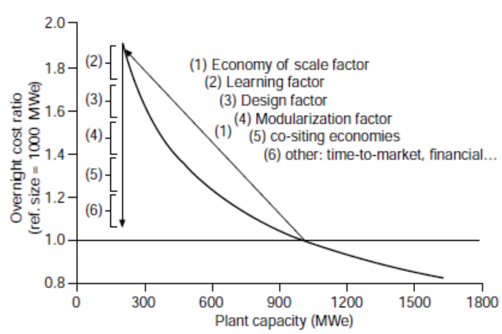


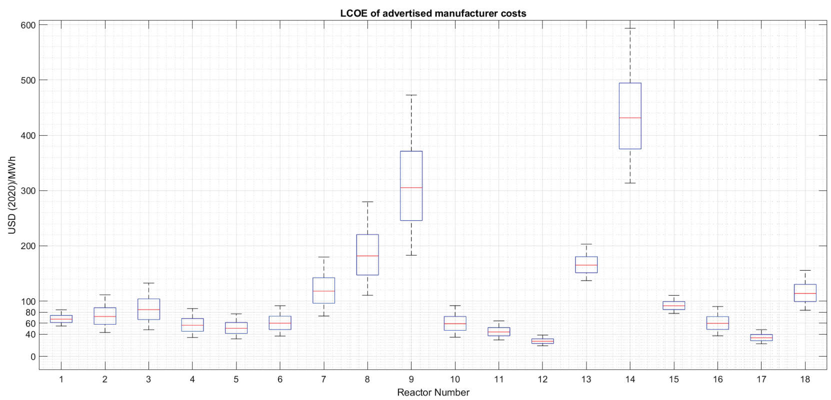
Figure 1: Production economics of an SMR concept

Source: (Boarin et al. 2021, 253).

In a second step, we apply the different approaches to estimate a range of potential production costs for 18 SMR projects for which sufficient data are available. These include one boiling water reactor, eight light water reactors, three high temperature reactors, three sodium fast reactors, two molten salt reactors, and one micro reactor.We then apply a Monte Carlo simulation to benchmark the cost projections assumed by the manufacturers, by varying investment costs, weighted average cost of capital (WACC), and wholesale electricity process in one million simulations. We also test whether the differences between the manufacturer estimates and ours differ between technology families of SMR concepts (i.e., light water, high temperature, or fast reactors). Here, we contribute to an intensifying debate in the literature on economics and finance of SMR concepts (Carelli and Ingersoll 2014; Mignacca and Locatelli 2020; Froese, Kunz, and Ramana 2020; Ingersoll and Carelli 2021).

Results

We find that the choice of the model has significant effects on the results: Notably, the latter approach allows for much lower cost predictions parameter ranges. The approach proposed by Rothwell (2018) suggests lower scaling factors for the entire range of the economies of scale, and even areas where this becomes negative, suggesting that nuclear reactors with lower power ratings may have a structural advantage. Second, our Monte Carlo analysis suggests a broad range of net present values and leveraged cost of electricity (LCOE): Surprisingly, the lowest LCOE is calculated for a high temperature pebble-bed reactor in South Africa, whereas some of the light water reactors feature higher LCOEs (Figure 2). The numerical results also confirm the importance of the choice of production theory and parameters.



Reactor Number	Reactor	Tyoe
1	BWRX-300	BWR
2	UK-SMR	PWR
3	SMR-160	PWR
4	SMART	PWR
5	Nuscale	PWR
6	RITM 200M	PWR
7	ACPR 50S	PWR
8	KLT-40S	PWR
9	CAREM	PWR
10	EM2	HTR/GFR
11	HTR-PM	HTR
12	PBMR-400	HTGR
13	ARC-100	SFR
14	CEFR	SFR
15	4S	SFR
16	IMSR(300)	MSR
17	SSR-W	MSFR
18	e-Vinci	MR

Figure 2 : Preliminary Result of computed LCOE calculation of manufacturer advertised costs

Source: own figure

Conclusion

Predicting future costs of technologies not yet developed is a complex exercise that includes many uncertain parameters and functional forms. Production theory provides some heuristic concepts such as “economies of scale” and “learning effects”, but the application of these concepts is not straightforward. Therefore, any technology foresight has to take as much of the case specifics into account, including technological and institutional specifics; this also holds for SMR concepts.

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