Production costs uncertainties of SMR-concepts - A model-based Monte Carlo analysis

Björn Steigerwald, TU Berlin, +491741820003, bs@wip.tu-berlin.de
Ben Wealer, Christian von Hirschhausen DIW Berlin, TU Berlin, bw@wip.tu-berlin.de
Martin Slowik, Uni Mannheim, slowik@math.uni-mannheim.de

Overview

The role of nuclear power in a future low-carbon electricity system is still debated intensively. In this debate, supposedly new reactor technologies are gaining more attention, especially the so-called small modular reactors (SMR) (Chu 2010). SMR concepts are nuclear power plants with relatively low power ratings (e.g., up to 300 MW_{el}, see Pistner and Englert (2017), Pistner et.al. (2021), Mignacca and Locatelli(2020), Boarin et.al. (2021)). They are currently re-emerging in the debate about large scale decarbonization of the energy sector because of the failure of nuclear power plants with higher power output (e.g., 1,000 – 1,600 MW_{el}) to become cost-competitive (Lloyd, Lyons, and Roulstone 2020; Wealer et al. 2021). The value proposition of SMR developers and national energy and defense administrations is that SMR concepts could overcome their disadvantage of size through increased productivity by – among others – mass production, learning, or co-siting (Rothwell 2016; Boarin et al. 2021). In this paper we analyze the competitiveness of SMR concepts by combining investment and production theory with Monte Carlo simulations of uncertain parameters.

Methods

We analyze the costs of SMR concepts employing publicly available costs and recent cost theory, to evaluate an investment decision with the help of Monte Carlo simulation of economic indicators (Wealer et al. 2021). First, we collected a unique economic dataset for SMR concepts from different manufacturers (Pistner et al. 2021). Following Lloyd et.al. (2020) and Rothwell (2016), we recalculate cost with:

$$Cost_{SMR} = (Cost_{LR} * \left(\frac{Size_{SMR}}{Size_{LR}}\right)^{n}) * (1-x)^{d}$$

with LR for values for large reactors (Nuclear power plants > 300 MW), SMR respresenting values associated with nuclear powerplants < 300 MWe, and n for the scaling effect (estimated between 0.2 and 0.7). Furthermore “costs”got described in USD/MWe, and “Size” in MWe. We identify investment intervals subject to both scaling factors driving cost and learning effects reducing cost. Calculations are based on public available costs of the AP1000 of the Voigtle Nuclear Power Plant described by Wealer et.al (2021). As a second step, in order to incorporate uncertainty, we simulate certain economic parameters (electricity wholesale market prices, investment costs, load factor) within the previously calculated cost ranges. Lastly, we determine the net present value by Mont Carlo simulations.

Results

Our results for unified distributed investments in SMR concepts with wholesale electricity prices from 2020, suggest that the lack of competitiveness attributed to large nuclear reactors with their uncertainties shown by Wealer et.al. (2021), also applies to current SMR concepts. Furthermore, we can assume through recalculation that it would take a quantity of around 1000 SMR reactors to reach a breakeven (Figure-1). This in contrast to a previous, much lower, estimations (Litvag 2014). Figure-2 additionally shows a preliminary best case scenario for one production doubling of SMRs, which is actually a negative NPV ((Mignacca and Locatelli 2020), (Pannier and Skoda 2014), (EEX 2021)).

Conclusions

Our results suggests that the lack of competitiveness attributed to large nuclear reactors also applies to current SMR concepts with a low capacity. Moreover, predictions suggest no commercial success in the long term as neiter scale- and learning effecs nor modularization are able to compensate missing economies of scale. Additional uncertainty analysis should be developed to be able to evaluate current SMR concepts more holistically.

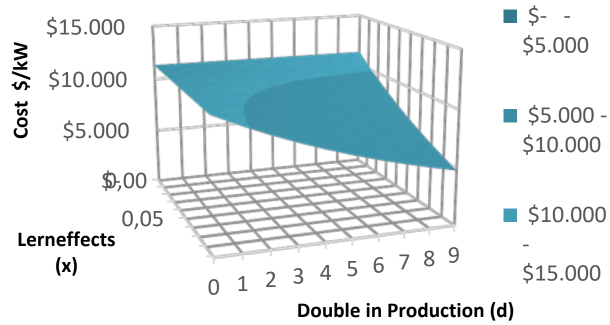

Figure 1 Influences between learning effects and mass - effects in SMR cost calculation

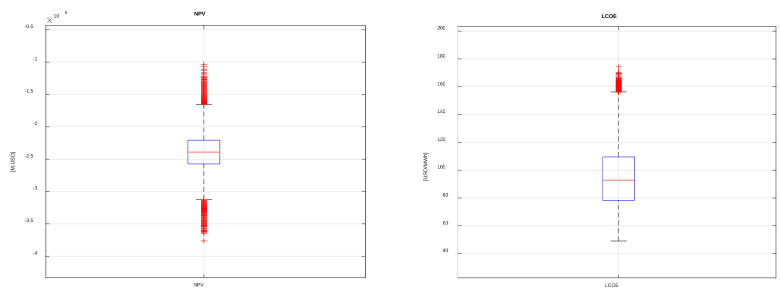

Figure 2 Preliminary result of best a first best case scenario for the NuScale concept

References

Boarin, S., M. Mancini, M. Ricotti, and G. Locatelli. 2021. 'Economics and Financing of Small Modular Reactors (SMRs)'. In *Handbook of Small Modular Reactors*, 2nd ed., 241–78. Kidlington (UK) and Cambridge (USA): Elsevier.

Chu, Steven. 2010. 'America's New Nuclear Option: Small Modular Reactors Will Expand the Ways We Use Atomic Power'. *Wall Street Journal*, 23 March 2010. https://www.energy.gov/articles/secretary-chu-op-ed-small-modular-reactors-wall-street-journal.

EEX. 2021. 'KWK - Price - Average Final Settlement Price of the Day Power Futures for the Market Area Germany at EEX per Quarter'. Leipzig, Germany: EEX. https://www.eex.com/fileadmin/EEX/Downloads/Market_Data/20210104_KWK.xls.

Litvag, Anya. 2014. 'Westinghouse Backs off Small Nuclear Plants'. *Pittsburgh Post-Gazette*, 2 February 2014. https://www.post-gazette.com/business/2014/02/02/Westinghouse-backs-off-small-nuclear-plants/stories/201402020074.

Lloyd, Clara, Robbie Lyons, and Tony Roulstone. 2020. 'Expanding Nuclear's Contribution to Climate Change with SMRs'. *Nuclear Future*, November, 39.

Mignacca, Benito, and Giorgio Locatelli. 2020. 'Economics and Finance of Small Modular Reactors: A Systematic Review and Research Agenda'. *Renewable and Sustainable Energy Reviews* 118 (February): 109519. https://doi.org/10.1016/j.rser.2019.109519.

Pannier, Christopher P., and Radek Skoda. 2014. 'Comparison of Small Modular Reactor and Large Nuclear Reactor Fuel Cost'. *Energy and Power Engineering* 06 (05): 82–94. https://doi.org/10.4236/epe.2014.65009.

Pistner, Christoph, and Matthias Englert. 2017. 'Neue Reaktorkonzepte. Eine Analyse des aktuellen Forschungsstands'. Darmstadt: Öko - Institut e.V. https://www.oeko.de/fileadmin/oekodoc/Neue-Reaktorkonzepte.pdf.

Pistner, Christoph, Matthias Englert, Christian Küppers, Ben Wealer, Björn Steigerwald, Christian von Hirschhausen, and Richard Donderer. 2021. 'Sicherheitstechnische Analyse Und Risikobewertung Einer Anwendung von SMR-Konzepten (Small Modular Reactors)'. Wissenschaftliches Gutachten im Auftrag des Bundesamtes für die Sicherheit der nuklearen Entsorgung (BASE) urn:nbn:de:0221-2021030826028. Darmstadt: Öko-Institut e.V.

Rothwell, Geoffrey. 2016. *Economics of Nuclear Power*. London, UK: Routledge.

Wealer, Ben, Simon Bauer, Christian von Hirschhausen, Claudia Kemfert, and Leonard Göke. 2021. 'Investing into Third Generation Nuclear Power Plants - Review of Recent Trends and Analysis of Future Investments Using Monte Carlo Simulation'. *Renewable and Sustainable Energy Reviews* 143: 110836.