Supplement of

Future nuclear fission reactors – uncertainties, the effect of parameter choice and an application to small modular reactor concepts

Björn Steigerwald et al.

Correspondence to: Björn Steigerwald (bs@wip.tu-berlin.de)

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### Future Nuclear Fission Reactors – Uncertainties, the Effect of Parameter Choice, and an Application to SMR Concepts

**Abstract**
- Declining generation costs of renewable energy systems driving a paradigm shift in energy systems across the world. On the other hand, OECD countries still spend about 21% of total research and development expenditures on nuclear developments alongside the current discussion in recent literature about the role of new nuclear developments in combating the recent energy crisis and climate change.
- In this paper, we introduce the current state of knowledge about cost developments for high- and low-capacity reactors with an application of SMR concepts to draw a picture of the current understanding of the costs of future nuclear energy developments.
- In the case of SMR concepts we follow Roulstone et al. (2023) and introduce two different approaches in comparison of current manufacturer advertised costs for 15 concepts with sufficient available data. Finally, we apply the Monte Carlo method to benchmark the cost projections assumed by the manufacturers by varying production parameters in simulations of the net present value (NPV) and the levelized cost of electricity (LCOE).
- We conclude that any technology foresight has to take the case specifics into account as much as possible, including technological and institutional specifics, this also holds for SMR concepts. It seems to be that future nuclear technologies are not able to compete with renewable energy technologies.

### Cost Estimates for Future Technologies

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**High-Capacity Reactors**

**Water-cooled Reactors**
- Sodium Fast Reactors (SFRs)
  - Capital costs typically higher than current LWR, operation costs with a disadvantage due to the need for fuel reprocessing and higher cost of MOX fabrication, announced costs to be lower than current LWR.
  - High efficiency of the reactor system in the range of 45% compared to today’s LWR in the range of approx. 35% and possible savings in operation costs.
  - Potential advantage through its possibility for cogeneration and process heat production depending on the temperature, compared to LWR.
  - Reliable statements about investment requirements, construction times, operating costs, design life, and calculation are missing - there is no available experience.

**Low-Capacity Reactors**
- Molten Salt Reactors (MSR)
  - Potentially higher efficiency as a major advantage, especially through the use of the water-steam cycle (gas-cooled turbines) - the flexibility of this is still largely open at present.
  - Reliable information about investment requirements, construction times, operating costs, design life, and calculation are missing - there is no available experience.

**Supercritical Water Reactors (SCWR)**
- Potentially higher efficiency in the reactor system in the range of 45% compared to today’s LWRs and the open fuel cycle.
- Higher efficiency of MSR and possible savings in investment costs estimated at approx. 35% will result in cost advantages compared to today’s LWRs if the open fuel problems can be resolved at an acceptable level.

**Gas-cooled fast reactors (GFR)**
- Cost effects due to the more complex fuel assembly design cannot be estimated at the technology trial level, but can be assumed that these do not change the attractiveness substantially.

**Supercritical Systems (SCS)**
- Possible power regulation without the criticality condition, advantages exist over LWR and the other technology lines in the integration with other fluctuating energy sources.

**Very High Temperature Reactors (VHTRs)**
- Potential advantage through its possibility for cogeneration and process heat production depending on the temperature, compared to LWR.
- Higher efficiency of the reactor system in the range of 45% compared to today’s LWRs and the open fuel cycle.

**Decision**
- Roulstone et al. propose a simple model with
- for costs, a constant scaling parameter \( y \), a factor \( a = \gamma \frac{c}{c_{ref}} \) that considers the doubling in production with \( a = \gamma \frac{c}{c_{ref}} \) as the number of units produced and for the plant’s power output: \( P = P_{ref} \left( \frac{c}{c_{ref}} \right)^{1/a} \),

**Notes**
- Roulstone et al. propose a simple model with costs, a constant scaling parameter \( y \), a factor \( a = \gamma \frac{c}{c_{ref}} \) that considers the doubling in production with \( a = \gamma \frac{c}{c_{ref}} \) as the number of units produced and for the plant’s power output: \( P = P_{ref} \left( \frac{c}{c_{ref}} \right)^{1/a} \),

- \( \gamma \) tends to 0 if the number of units produced is not sufficiently small values of

**Simulation Results & Conclusion**
- Currently, nuclear energy has a share of about 10% in the global energy system and is associated in current literature with the problems of longer construction time and cost increases. The research expenditure of the OECD countries for energy technologies is 21% for nuclear energy.
- In the case of high-capacity future nuclear concepts, Roulstone et al. (2023) describe risks and cost uncertainties with a tendency to be able to compete against current water-cooled reactor designs.
- In the case of low-capacity reactor concepts, Steigerwald et al. (2023) assembled a large dataset consisting of both producers’ and other publicly available data. Different functional forms applied in literature were identified, together with significant gaps between current cost estimations by theory and manufacturer-advertised costs.
- A large-scale Monte Carlo analysis of potential net present values (NPV) and levelized costs of electricity (LCOE) finds that the majority of examined SMR concepts cannot deliver a positive NPV or an energy system competitive LCOE.
- The variance in the simulations can be in the largest part explained by the variance of the investment costs and the WACC, whereas the load factor and the electricity price play a minor role.
- In summary, neither high-capacity concepts nor low-capacity ones seem to be competitive with renewable technologies at present.

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