Effect of Policy and Regulatory Consistency in SMR Investment: A Real Options Approach

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1. Introduction

Unlike traditional gigawatt-scale nuclear power plants, Small Modular Reactors (SMRs) are designed for modular deployment and megawatt-scale power production. Their scalability enables more flexible integration into national or dispatched energy systems. However, SMR investments are confronted with substantial uncertainty. High upfront capital expenditures, long construction durations, uncertain licensing approvals, and policy volatility all contribute to complicating investment decisions.

Conventional economic evaluation methods or indicators such as Net Present Value (NPV) or Levelized Cost of Electricity (LCOE) assume deterministic cash-flows and immediate, irreversible investment. However, these methods fail to capture the economic value of flexibility—the option to defer or abandon an investment when faced with uncertainty. As a result, they may underestimate the viability of emerging technologies like SMRs, which are embedded in highly uncertain policy and regulatory environments.

Real Options Valuation (ROV) provides a more suitable framework for such cases. In an ROV framework, investment is treated as an option rather than a fixed commitment. Within this framework, decision makers can wait (defer) for more favourable conditions, expand under hopeful scenarios, or abandon under unsatisfactory environments. This approach can explicitly account for uncertainty, a concept well established in real options theory [1,2]. In economic evaluation of SMRs, this means the ability to strategically delay construction until electricity prices are profitable, policies are favourable, and larger subsidies are granted.

This study therefore develops a simulation-based ROV framework to evaluate SMR investment under regulatory and policy uncertainty. Specifically, it applies the Least Squares Monte Carlo (LSM) method to quantify both NPV and ROV across a range of scenarios including policy consistency, licensing uncertainty, SMR-specific regulation, and investor type (public versus private). By doing so, this paper highlights the economic values of regulation design and policy stability in assessing financial viability of SMRs.

2. Methodology

2.1 Conceptual Framework

In this framework, the investment decision for SMRs is not modeled as a one-time "now or never" choice. At each decision point, the investor can:

- Invest immediately,
- Keep the investment option alive for later (Defer), or
- Cease consideration (Abandon) [3, 4].

This model incorporates three categories of uncertainty:

- Electricity market conditions – modeled as a geometric Brownian motion (GBM) for electricity price, with volatility representing market risk.
- Policy support consistency – represented as a Markov switching process between subsidy "ON" and "OFF" states, with transition probabilities α (OFF→ON) and β (ON→OFF).
- Licensing approval time – modeled as a lognormal random variable. The introduction of SMR-specific regulation is represented by reducing both the mean and variance of this distribution, reflecting faster and more predictable approval.

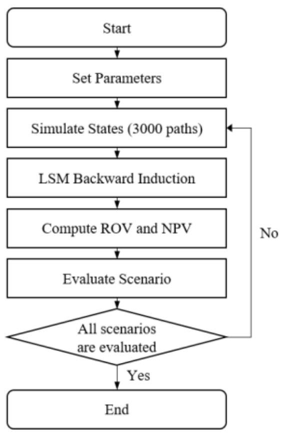

Fig. 1. System Flowchart

Table I: Parameters

Parameter	Description	Value
T , dt	Simulation horizon, time step	15 years, 1 year
r, r_private	Discount rate (public), discount rate (private)	6%, 8.5%
Plant net capacity	The maximum amount of electrical power a power plant can deliver to the grid after accounting for the electricity it consumes for its own operations	77 MWe [5]
CAPEX	Capital expenditures per kW	4,844 $/kW [5]
OPEX	Operating expenditures per MWh	22 $/MWh [5]
Capacity factor	The ratio of actual electricity generated to the maximum possible output over a specific period	90% [6]
Power Price	Initial power price	75 $/MWh [6]
μ_power	GBM drift of power price (Long-term trend)	0
σ_power	GBM volatility of power price	0.3
Subsidy_on	Price multiplier when subsidy regime is ON	*1.6
Subsidy_off	Price multiplier when subsidy regime is OFF	*0.85
α_on	OFF→ON transition probability of policy	0.45
β_off	ON→OFF transition probability of policy	0.06
μ_licensing	Log-mean of licensing delay (years)	1.61 (log(5.0))
σ_licensing	Log-sigma of licensing delay	0.45
SMR_reg_μ	Factor reducing licensing period mean under SMR-specific regulation	0.7
SMR_reg_σ	Factor reducing licensing period variance under SMR-specific regulation	0.7
Construction period	Construction period to commercial operation	4.5

2.2 Flow of the Algorithm

The computational sequence is illustrated in Figure 1, and parameters are given in Table I. It shows the logical flow from parameter setting, stochastic simulation of states, LSM-based decision-making, and scenario evaluation.

2.3 Scenario settings

To study the impact of economic, policy, and regulatory uncertainties on investment decisions, eight scenarios were examined.

The first scenario is the baseline public scenario, where 6% discount rate of is adopted. This represents the perspective of a public utility or public company seeking to invest in SMRs. The second scenario is the baseline private scenario, which applies a higher discount rate of 8.5% to capture the private investor's opportunity cost of capital. The comparison between these two baselines highlights the divergence in investment timing between public and private decision-making frameworks.

Scenarios three and four address policy consistency. In scenario three (policy more consistent), the probability of switching between subsidy-on and subsidy-off regimes is reduced. This adjustment reflects a more stable and predictable policy environment, which lowers uncertainty about future support conditions. In scenario four (policy less consistent), these transition probabilities are increased, producing greater volatility in policy. This contrast allows us to evaluate how policy stability influences both the option to defer and the timing of exercise.

Uncertainty in licensing duration is investigated by modifying the variance of the licensing process. In scenario five (reduced licensing deviation), the standard deviation of licensing time is reduced by 20%, reflecting a more predictable licensing approval. On the other hand, in scenario six, the variance is increased by 20%, reflecting greater uncertainty in the time required for regulatory approval. These cases illustrate how regulatory uncertainty affects the economic value of waiting.

Finally, the SMR-specific regulation scenarios seven and eight consider the adoption of a licensing framework tailored to SMRs. In this case, both the mean and variance of the licensing period are reduced by 30%, representing the potential for regulatory reform to accelerate approval timelines and reduce uncertainty.

These eight scenarios span public and private perspectives, policy credibility, and differences in regulatory predictability.

Table II: Simulation Results by Scenarios

No.	Scenarios	Avg. First Investment Time (years)	NPV (Million USD)	ROV (Million USD)	Option Premium (Million USD)
S1	Baseline public case	5.05	-108.9	0.3	109.2
S2	Baseline private case	4.97	-117.9	0.2	118.1
S3	Policy more consistent	5.06	-106.1	0.4	106.5
S4	Policy less consistent	5.04	-113.4	0.3	113.7
S5	Licensing deviation reduced by 20%	4.83	-108.0	0.0	108.0
S6	Licensing deviation increased by 20%	5.31	-108.5	1.0	109.5
S7	SMR-specific regulation adopted	3.42	-81.2	0.4	81.6
S8	SMR-specific regulation + private inv.	3.29	-109.6	0.2	109.8

3. Results

Table II summarizes the results of scenario-based simulations, comparing NPV, option premium, and average first investment time. In this study, option premium is defined as the difference between ROV and NPV, representing the added value of managerial flexibility. Table II summarizes outcomes of simulations across eight scenarios. A consistent finding is that all NPVs are negative, indicating that if investors were to start construction immediately upon licensing approval, the projects would not be financially viable. In contrast, all ROVs are positive except in scenario five. This is because the option to defer filters out unfavourable states. The option premium (ROV–NPV) quantifies this added flexibility.

In the baseline public case, average first investment occurs around 5.05 years after licensing approval. While the NPV without flexibility was significantly negative, ROV was positive. This difference demonstrates that the option to defer investment adds significant value under uncertainty. In contrast, private investment occurs slightly earlier (4.97 years), with reduced ROV, and increased option premium.

Compared with scenario 3 where policy is more consistent, less consistent policy produces an average investment time of 5.04 years but a higher option premium indicating investors facing policy instability see more value from the option to defer, as flexibility allows them to adapt to adverse policy changes.

Varying the standard deviation of the licensing period had a measurable impact. When licensing uncertainty was reduced, the average investment time shortened to 4.83 years. In this case, ROV is zero as when regulatory risk is minimal, the option to defer loses power and investors tend to exercise investment quickly. In contrast, when licensing uncertainty increased, the average investment time extended to 5.31 years. The ROV rose sharply, producing a relatively large premium. This highlights that uncertainty in regulatory timelines amplifies the value of investment flexibility.

With a more SMR-specific regulation and therefore reduced licensing time, the average first investment time was reduced significantly to 3.42 years. It indicates the value of waiting is diminished. Instead, early investment becomes more attractive. When combined with the private investor case, the investment occurred even earlier (3.29 years). This confirms that regulatory certainty, coupled with higher discount rates, strongly brings about earlier investments.

4. Discussion

The contrast between NPV and ROV underscores the limitations of deterministic economic evaluation of SMRs. While NPVs are negative, ROV can be positive because it has the option to defer. This demonstrates the importance of flexibility under uncertainty.

Public investors apply lower discount rates, making the value of waiting larger. On the other hand, private investors with higher discount rates invest earlier once licensing approvals occur, since the cost of waiting is relatively higher.

The most impactful scenario is the application of SMR-specific regulations. Reducing both the mean and variance of licensing approval time reduces the risk of excessively late approvals and advances investment. Since licensing approval is a strict prerequisite for investment, earlier and more predictable approvals directly translate into earlier average investment times.

Interestingly, policy consistency has limited influence on average investment timing, though it affects overall option value. This is because impact of policy enters through revenue multipliers after commercial operation starts, and its volatility influences payoff magnitude more than timing. Investors can simply wait through unfavourable policy states until conditions improve, which reduces the effect of policy consistency on the first investment year.

Licensing period variance has a more clear effect on timing. Higher variance increases the likelihood of late approvals, pushing investment timing, while lower variance allows more projects to invest earlier. This gating effect explains why licensing period variance is more influential for timing than policy consistency.

Finally, the fact that most ROVs are positive while NPVs are negative confirms the central insight of real options theory: flexibility under uncertainty can change unprofitable projects in deterministic evaluations to viable opportunities. For SMRs, this highlights the importance of regulatory reform and risk-sensitive evaluation in ensuring project investment.

5. Conclusion

This study applied a LSM-based real options framework to SMR investment under regulatory and policy uncertainty. The analysis shows that while NPVs are negative across scenarios, ROV can be positive due to the option to defer.

Results demonstrate that:

- Public and private investors differ in timing due to discount rates,
- SMR-specific regulation significantly accelerates investment,
- Policy consistency has limited effect on timing but influences overall project value, and
- Licensing variance strongly affects average investment timing.

From a policy perspective, these findings imply that regulatory clarity and predictable approval processes are as important as direct subsidies in fostering SMR deployment. Reducing licensing uncertainty is itself a form of policy support, effectively increasing option premiums and accelerating investment.

While this research contributes to both nuclear economic analysis and policy debates, this study has several limitations.

First, while the present framework models uncertainty in licensing, policy support, and electricity prices, it does not yet incorporate carbon pricing mechanisms, technology learning effects, or long-term fuel cycle economics. Extending the model to include such factors would provide a more comprehensive assessment of SMR economics.

Future work could explore stochastic optimization methods and interactions among multiple stakeholders, including regulators, utilities, and private investors. Addressing these aspects will further strengthen the policy relevance of real options analysis for SMR investment planning. by showing how regulatory design directly shapes financial viability under uncertainty.

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