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Benefits of Multi-unit NPP Projects during Construction Phase with Full Life-cycle Cost Assessmen

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ABSTRACT

Analysis of Overnight Construction Costs of various Nuclear Powerplant projects with single and multiple units on site. Results expose benefits of multi-unit NPP projects, which statistically experiencing shorter construction times and overall lower costs of additional units on site. Additional analysis of cost assessment for operational NPPs provide inputs for comprehensive view of full life-cycle assessments of NPPs with extended long term operation projections.

This paper aims to provide an in-depth analysis of historical trends in nuclear power plant costs across different countries and eras. By examining the factors that have driven cost trends, such as R&D, economies of scale, economies of multiples, industrial learning, and regulatory stability, we seek to contribute to a broader understanding of nuclear energy economics. This study lays the foundation for a more holistic examination of cost dynamics within diverse national contexts.

Result can be beneficial for future nuclear projects, where demanding financial decision for multi-unit NPPs can be additionally supported with past results, present technology advancements and future development projections.

1 INTRODUCTION

1.1 Importance of Understanding Historical Nuclear Power Plant Costs

Brief Nuclear power has long been recognized as a pivotal source of clean and reliable energy, capable of contributing significantly to global energy demands while minimizing carbon emissions. However, the decision-making process surrounding nuclear power plant (NPP) construction and operation is influenced by numerous complex factors, among which cost considerations play a pivotal role. Gaining a comprehensive understanding of historical nuclear power plant costs is crucial for policymakers, energy economists, and industry stakeholders alike.

Understanding the cost dynamics associated with NPPs enables more informed decision-making processes across various dimensions. It facilitates the assessment of the economic viability of nuclear energy as a long-term energy solution, informs investment strategies, and guides policy formulation that can ensure sustainable nuclear power deployment. The economic aspects of nuclear energy are tightly interwoven with its technical, environmental, and societal dimensions, making cost analysis a critical component of the broader energy landscape.

1.2 Cost Drivers in Nuclear Energy Economics

The cost of a nuclear power plant is a multi-faceted parameter influenced by a range of variables and drivers. The concept of "cost drivers" refers to the underlying factors that influence the financial aspects of NPP construction and operation. These drivers can vary significantly over time, leading to distinct "eras" that characterize the dominant influences on cost trends.

While construction cost constitutes a substantial portion of the overall nuclear power plant cost, it is essential to recognize that other factors also contribute to the overall cost landscape. Operational and maintenance costs, fuel expenses, operational efficiency, and capacity factors are among the key determinants of nuclear power plant economics. This holistic view is critical for capturing a comprehensive understanding of the cost drivers and trends that shape nuclear energy economics.

In the context of nuclear power plant construction, it's observed that when multiple reactors commence construction simultaneously at a site, they are unlikely to be completed simultaneously. This divergence is due to construction management strategies aimed at optimizing equipment and labour resources. Consequently, subsequent reactors are often completed approximately one year after their predecessors, forming a predictable pattern that correlates with the assigned numerical unit identifiers.

2 UNDERSTANDING NUCLEAR POWER PLANT COST COMPONENTS

2.1 Introduction to Literature Review

In the realm of nuclear energy economics, a wealth of literature has emerged to explore the multifaceted landscape of nuclear power plant costs and their underlying drivers. This chapter undertakes a comprehensive review of existing literature to uncover insights into the complex interplay between various cost components, including overnight costs, labour expenses, and particularly the pivotal role of borrowing costs, i.e., interest rates. Moreover, it identifies gaps within the current literature, highlighting the necessity for a more comprehensive analysis that embraces not only the Levelized Cost of Electricity (LCOE) but also the vital concept of the Full Cost of Electricity (FCOE).

2.2 Overnight Construction Costs and Beyond

Overnight Construction Costs (OCC), representing the initial investment required to construct a nuclear power plant, constitute a substantial portion of the total cost picture. Existing literature has extensively explored methods of estimating overnight costs, considering factors such as reactor technology, project scale, and regulatory environment. The exsisting research papers often focus onto capital expenditures, construction timelines, and technology-specific variations. However, a comprehensive understanding necessitates an exploration of costs throughout the plant's life cycle, encompassing operational and maintenance expenditures, fuel costs, and decommissioning expenses.

Global nuclear cost experience make their case by many lessons learned: from the importance of reactor standardization, multi-unit builds, and regulatory stability [1].

2.3 The Limitation of LCOE Analysis

Most of the existing literature predominantly relies on the Levelized Cost of Electricity (LCOE) as a standard metric to assess the economic viability of nuclear power projects. While LCOE offers valuable insights into the cost dynamics of energy generation, its focus on comparing different energy sources fails to encompass the entirety of nuclear power plant economics. LCOE analysis often overlooks the financial intricacies associated with borrowing costs, operational efficiency, and capacity factors, thereby providing an incomplete view of the true costs involved.

2.4 Interest Rates and Borrowing Costs

Arguably, one of the most impactful factors influencing nuclear power plant economics is the cost of borrowing money, reflected in interest rates. Literature has recognized the substantial impact of interest rates on project financing, project economics, and the overall feasibility of nuclear energy projects. Studies typically analyses the implications of fluctuating interest rates on project viability, stressing the need for stable and favourable financing conditions. The role of interest rates in shaping cost trajectories is of paramount importance and requires in-depth analysis within the broader cost framework.

2.5 The Need for a Comprehensive Analysis: Full Cost of Electricity (FCOE)

Acknowledging the gaps inherent in a narrow LCOE analysis, the literature comparing various clean energy sources such as Wind, Solar and Nuclear increasingly calls for a more comprehensive approach that incorporates the Full Cost of Electricity (FCOE). FCOE extends the analysis beyond the point of electricity generation, encompassing all costs throughout the plant's life cycle, from construction to decommissioning. This approach inherently considers interest rates, operational efficiency, capacity factors, and other dynamic factors that impact the financial bottom line. The literature recognizes FCOE's capacity to provide a more accurate representation of nuclear power plant economics and underscores its significance in shaping energy policy and investment decisions.

3 STRATEGIC DECISION MAKING FOR A NEW MULTI-REACTOR NPP

The decision to build a new nuclear power plant (NPP) is a significant undertaking that requires careful preparation and strategic decision making. Ordering and building multiple reactor units within a nuclear power plant with high inspection standards and rigorous licensing procedures offer significant advantages in terms of safety, regulatory compliance, and operational efficiency. These benefits contribute to the overall success and sustainability of multi-reactor NPPs, ensuring safe and reliable nuclear energy production for years to come.

3.1 Meeting Growing Energy Demand

Multi-reactor NPPs provide the advantage of scalability. As energy demand increases over time, additional reactors can be added to the same site, minimizing the need for new construction projects at separate locations.

Planning for a multi-reactor facility allows for better alignment with long-term energy demand projections. It ensures that the NPP can adapt to changing electricity needs without major infrastructure overhauls.

3.2 Operational Efficiency in Resource Optimization and Redundancy

Multi-reactor NPPs can optimize the use of resources, including personnel, fuel, and maintenance schedules. Shared resources lead to more efficient operations and cost savings.

Having multiple reactors on one site enhances operational redundancy. In case of maintenance, unexpected shutdowns, or other issues affecting one reactor, others can continue to generate electricity, reducing the risk of supply disruptions.

3.3 Streamlined Licensing and Regulation

Preparing for and making strategic decisions about multiple reactors on a single site can lead to more efficient regulatory approval processes. Regulators may be more inclined to grant licenses for multi-reactor projects due to economies of scale and safety benefits.

Maintaining consistent safety and operational standards across multiple reactors simplifies compliance efforts and ensures that lessons learned from one reactor can be applied to others resulting in enhanced Consistency in Compliance.

Over time, nuclear projects have become more expensive due to an increasing complexity of technology, more efficient control mechanisms and more safety measures [3].

4 BENEFITS OF BUILDING MULTIPLE REACTOR NPP

Building and operating two reactors in a NPP compared to a single reactor offers several significant benefits. These advantages extend across various aspects, including economics, reliability, safety, and efficiency. The construction and operation of nuclear power plants require rigorous safety standards, thorough inspections, and adherence to strict licensing procedures.

4.1 Enhanced Safety and Redundancy

Two-reactor units inherently provide redundancy in safety systems. In the event of a safety issue in one reactor, the other can continue to operate safely, minimizing the risk of power interruptions and ensuring continuous electricity generation.

High inspection standards and rigorous licensing procedures necessitate robust emergency response plans. Having two reactors on the same site allows for coordinated and efficient emergency measures, benefiting from shared resources and expertise.

When multiple reactors are reported to have begun construction in tandem at a site, it is atypical for those reactors to be completed on or around the same date. This reflects the fact that NPP construction management usually economizes on equipment and labour by not performing the same tasks for both reactors at the same time [2].

4.2 Efficient Licensing and Regulatory Compliance

Building a two-reactor unit with comprehensive licensing can streamline the regulatory process. Regulators may be more inclined to approve a multi-reactor project when they are confident in the safety and oversight protocols in place.

Licensing multiple reactors on the same site encourages consistency in safety standards and regulatory compliance. Lessons learned from one reactor can be readily applied to the other, reducing regulatory hurdles and expediting approvals.

4.3 Economies of Scale and Cost Efficiency

Constructing two reactors simultaneously or in close succession often leads to economies of scale. Bulk procurement of materials, shared infrastructure, and synchronized construction efforts can significantly reduce costs per unit of capacity.

Corelation between Construction time and Overnight Construction cost (OCC) as well as Correlation Heatmap between data from Global-NPP-Database (until year 2016) [5] are presented on Figure 1.

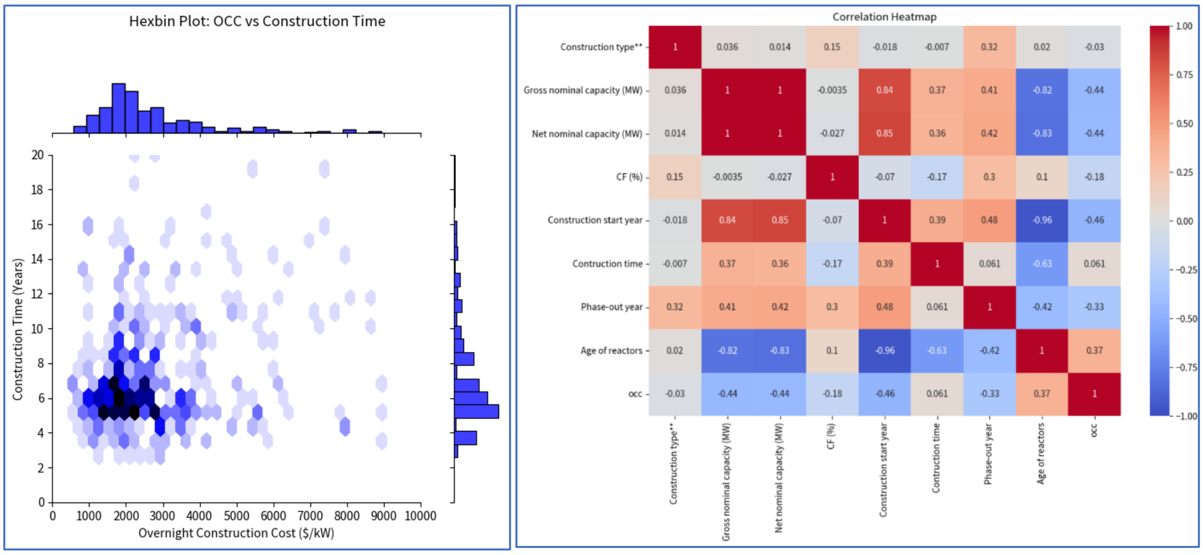

Figure 1: Construction time vs OCC (left) and Heatmap of data corelation (right) [5]

Majority of historic NPP constructions were bult in 5-7 years at a price between 1500$/kW and 3000 $/kW nominated in value of US $ in year 2010. Heatmap Correlation shows that younger NPP projects are larger and more expensive due to more and more strict regulation and legislation.

Financing for multi-reactor units can be more attractive to investors and lenders due to the spreading of risk across multiple units. This can result in lower interest rates and financing costs, making the project more financially viable.

4.4 Improved Operational Efficiency

Two-reactor units can optimize resource allocation, including personnel, fuel management, and maintenance schedules. Shared resources lead to more efficient operations and cost savings.

Operating two reactors on the same site allows for a concentrated pool of operational expertise. Personnel can share knowledge and best practices, leading to improved operational performance and safety.

5 BENEFITS OF OPERATING MULTIPLE REACTOR NPP

One of the primary advantages of a two-reactor NPP is its ability to maintain continuous power generation. In the event of maintenance, refuelling, or unexpected shutdown of one reactor, the second reactor can continue supplying electricity to the grid without interruption, contributing to grid stability.

5.1 Improved Load Following

Two-reactor NPPs have the flexibility to adjust their power output to match varying electricity demand more effectively. This load-following capability contributes to grid reliability, especially in regions with fluctuating energy requirements.

5.2 Lower Operating Costs of Multiple Reactor Unit

Operating a multi-reactor plant offers several cost-saving advantages such as continuous operation in the event of maintenance or unplanned outages in one reactor, the remaining reactor(s) can continue to operate, ensuring a reliable power supply and reducing downtime.

A two-reactor NPP can benefit from economies of scale. Shared infrastructure, maintenance teams, and support staff can reduce per-unit operating costs compared to two separate single-reactor facilities. Procuring and managing fuel for two reactors on the same site can be more efficient and cost-effective. Bulk purchasing and centralized fuel management can lead to cost savings.

O&M cost is a strong function of number of units operating on a site. U.S. engineering consulting firms estimated that an additional unit will require 60% of the first unit staff, which gives a 2-unit and 4-unit AP1000 an O&M cost of $11 and $9/MWhr$_e$, respectively [4].

5.3 Optimized Maintenance and Outage Scheduling

Operating two reactors enables the sharing of resources such as emergency response teams, equipment, and spare parts. This resource sharing can expedite response times during emergencies and improve overall safety.

Coordinating maintenance schedules for two reactors allows for synchronized shutdowns, minimizing downtime, and optimizing the use of maintenance personnel and resources.

With two reactors, the NPP can maintain a higher overall availability, ensuring that a larger portion of its capacity is online and generating power, contributing to higher revenue generation.

5.4 Total generating costs of US NPPs

Approximately 80 percent of the electricity generated from nuclear power in the U.S. comes from plants with multiple reactors. The economies of scale allow plant operators to spread costs over more generation, resulting in a lower total generating cost. In 2021, the average total generating cost at multiple-unit plants was $27.18 per MWh compared to $37.43 per MWh for single-unit plants (expressed in 2021 dollars).

The average total generating costs for an operator with only one plant was $31.28 per MWh compared to $28.56 per MWh for owners of multiple plants in 2021. Operating costs were the primary driver for the decline in costs for both one-plant operators or multiple-plant operators [4].

Category	Plants / Sites	Fuel	Capital	Operations	Total Generating (Fuel + Capital + Operating)
All U.S.[2]	55	$5.55	$5.50	$18.07	**$29.13**
Plant Size					
Single-Unit	20	$5.46	$7.19	$24.78	**$37.43**
Multiple-Unit	35	$5.57	$5.11	$16.50	**$27.18**
Operator					
One Plant	12	$5.77	$5.52	$19.99	**$31.28**
Multiple Plants	43	$5.49	$5.50	$17.56	**$28.56**

USA NPP 2021 Cost Summary ($/MWh) [4]

This highlights comparison of average total generating costs show substantial cost savings of approximately -27.38% for multiple-unit plants compared to their single-unit counterparts. This cost differential underscores the economic viability and efficiency of multi-reactor nuclear power facilities.

The decline in costs for both types of operators was primarily driven by operating expenses at a cost advantage of approximately -8.69% for owners of multiple plants compared to single-plant operators.

6 FULL LIFE-CYCLE COST ASSESSMENT FOR TWO-REACTOR NPP

While assessing the costs of a single-reactor NPP is undoubtedly crucial, substantial benefits can be shown while conducting a Full Life-Cycle Cost Assessment (FLCCA) for two-reactor NPPs. A FLCCA provides a holistic understanding of the financial dynamics involved in nuclear energy generation, spanning the entire lifespan of the facility, from construction to decommissioning. This comprehensive analysis brings multifaceted advantages that extend far beyond the initial investment considerations.

6.1 Informed Decision-Making

One of the paramount advantages of a FLCCA is its ability to facilitate informed decision-making. For two-reactor NPP projects, which are inherently complex and entail substantial financial commitments, this holistic assessment offers decision-makers unparalleled clarity. It ensures that strategic choices align with the long-term vision of the project, reducing the risk of unforeseen financial challenges and optimizing the allocation of resources.

6.2 Life-Cycle Cost Risk Mitigation Strategies

By accounting for the full spectrum of costs, a FLCCA enables precise risk assessment and the development of robust mitigation strategies. Decision-makers can proactively address financial risks, reducing the likelihood of cost overruns and ensuring the project remains on a stable financial footing.

Investors and lenders gain confidence in the project's stability and profitability when presented with a comprehensive FLCCA. This confidence can lead to more favorable financing terms and conditions, ultimately reducing the cost of capital for the project. Project managers armed with the insights from a FLCCA can make more informed decisions throughout the NPP's life cycle. This includes optimizing operational efficiency, managing costs effectively, and responding to unforeseen financial challenges proactively.

6.3 Regional Investment Sharing and Strategic Benefits

An essential aspect of FLCCA for two-reactor NPPs is recognizing the high upfront investment required for such projects. However, this initial financial commitment can be shared regionally with other countries, fostering international collaboration in energy infrastructure development. Sharing costs can lead to cost efficiencies and promote diplomatic ties through mutually beneficial endeavors.

Beyond cost considerations, two-reactor NPPs provide strategic regional benefits. The ability to generate 24/7 clean power contributes to energy security, ensuring a stable and uninterrupted energy supply. Moreover, such NPPs stabilize energy prices, protecting consumers from the volatility associated with other energy sources. Grid stability, a critical factor in modern energy systems, is enhanced, reducing the risk of blackouts and ensuring the reliable operation of interconnected power networks.

7 CONCLUSION

Strategic decision making and preparation for a new multi-reactor NPP offer numerous benefits over single-reactor projects. These advantages include scalability to meet energy demand, operational efficiency, economic benefits through economies of scale, streamlined licensing and regulation, and enhanced safety measures. Considering these factors is crucial for long-term planning and the successful deployment of nuclear energy to meet future electricity needs.

Building a two-reactor unit with high inspection standards, rigorous licensing, and a commitment to safety offers several significant advantages over a single-reactor facility. These benefits include enhanced safety through redundancy, streamlined regulatory processes, economies of scale, lower financing costs, and improved operational efficiency. These advantages underscore the importance of comprehensive safety measures and meticulous planning when considering multi-reactor nuclear power projects.

Operating a two-reactor NPP offers numerous advantages in terms of continuous power generation, grid stability, safety through redundancy, cost efficiency, optimized maintenance scheduling, and streamlined regulatory compliance. These benefits underscore the value of multi-reactor facilities in meeting electricity demand reliably and economically while maintaining the highest safety standards.

Full Life-Cycle Cost Assessment for two-reactor NPPs offers multifaceted advantages that transcend the boundaries of traditional financial analysis. It empowers stakeholders with the knowledge needed to make informed decisions, fosters sustainability, enhances financial transparency, secures the future of clean, reliable, and safe nuclear energy generation, and promotes regional collaboration in energy infrastructure development. Such an assessment is not merely a financial exercise; it is a strategic imperative for the responsible and sustainable deployment of nuclear power.

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