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Assessing the Economic Viability of Small Modular Reactors in Cambodia's Evolving Energy Mix

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Abstract: Cambodia's economy has grown steadily over the past two decades, leading to a sharp increase in electricity demand across residential, commercial, and industrial sectors. At the same time, the country continues to face challenges related to energy affordability, dependence on imported power, and the need for a stable electricity supply to support economic development. This paper explores the economic potential of introducing nuclear power into Cambodia's energy mix, with a particular focus on small modular reactors (SMRs) as a more flexible and scalable technology option. The study begins by analyzing Cambodia's current electricity generation profile, highlighting the heavy reliance on hydropower, imported fossil fuels, and rising but still limited contributions from solar energy. While hydropower has enabled some degree of energy independence, seasonal variation and climate risks make it unreliable as a sole baseload provider. In contrast, nuclear energy offers a steady, low-emission supply of electricity that can operate continuously, independent of weather or fuel market fluctuations. Through a review of cost data and levelized cost of electricity (LCOE) comparisons, the study finds that nuclear power—despite its higher initial investment—can become cost-effective over time due to low operating costs and long plant lifespans. The paper also considers broader economic benefits, including job creation during construction and operation, foreign direct investment opportunities, and support for industrial growth through more reliable and affordable energy. Given Cambodia's current technical capacity and financial resources, the paper emphasizes the importance of phased planning, international cooperation, and investment in human capital. Strategic partnerships with countries experienced in nuclear technology can help reduce costs and build local expertise. The findings suggest that nuclear energy has strong potential to complement Cambodia's renewable energy goals while addressing long-term affordability and supply stability. The paper concludes with key policy recommendations to help Cambodia assess and prepare for the possible integration of nuclear energy in its national energy strategy.

Keywords: *Nuclear Energy, Cambodia, Electricity Costs, Energy Planning, Economic Development, Small Modular Reactors*

I. Introduction

Cambodia's trajectory of economic growth and development over the past two decades has led to a substantial increase in national energy consumption. According to the Asian Development Bank (ADB), Cambodia's GDP grew by 5.0% in 2023, with projections reaching 6.2% by 2026 [1]. In contrast, the Economist Intelligence Unit forecasts a more moderate trajectory, estimating 4.2% growth in 2025 and 3.6% in 2026 [2]. Despite these varying projections, a consistent rise in energy demand is anticipated, posing critical challenges for the country's energy security and sustainability.

Cambodia's current energy landscape remains heavily reliant on hydropower and imported fossil fuels. Hydropower contributes significantly to domestic electricity generation, while fossil fuel imports, particularly from neighboring countries, fill the remaining gap. This dependency exposes the national energy supply to external market volatility, seasonal hydrological variability, and geopolitical risks, all of which affect price stability and supply reliability [3]. As a result, the Cambodian government has prioritized diversification of its energy mix, with growing interest in low-carbon, sustainable, and resilient energy sources.

Nuclear energy, as a high-density and low-emission power source, presents a compelling option for meeting future energy needs. Its ability to provide consistent baseload power complements intermittent renewable sources such as solar and wind. Furthermore, the development of nuclear infrastructure could stimulate industrialization, attract foreign direct investment, and foster national technical capacity through workforce development and international cooperation [4], [5].

Nevertheless, the pursuit of nuclear energy presents significant challenges, particularly for a developing country with limited institutional infrastructure and technical readiness. These challenges include high initial capital investment, stringent safety and security requirements, complex regulatory frameworks, and adherence to international non-proliferation agreements [6], [7]. Cambodia must carefully consider these factors when evaluating the feasibility of nuclear power as part of its long-term energy strategy.

At the regional level, ASEAN has increasingly promoted cross-border energy collaboration and sustainable energy transitions under the ASEAN Plan of Action for Energy Cooperation (APAEC) [8]. Cambodia's exploration of nuclear power aligns with these regional goals but will require coordinated efforts in policy development, regulatory readiness, capacity building, and stakeholder engagement.

This paper examines the dual dimensions of nuclear power in Cambodia, its economic potential and the security challenges it presents. Through comparative policy analysis, economic feasibility assessment, and a review of international best practices, the study provides insights and recommendations for a balanced, secure, and forward-looking approach to nuclear energy development in the Cambodian context.

II. Energy mix evolution in Cambodia

Cambodia's energy mix has transformed significantly over the past two decades as the country transitioned from energy scarcity and high dependency on imported fuels toward a more diversified domestic generation strategy. In the early 2000s, Cambodia relied heavily on imported diesel and electricity from neighboring countries such as Vietnam, Thailand, and Lao PDR, which exposed the national power system to high costs and external supply risks [3], [9]. Between 2010 and 2020, the country embarked on an ambitious expansion of domestic hydropower capacity, with major projects such as Kamchay (193 MW), Lower Se San II (400 MW), and Stung Tatai (246 MW) contributing to a significant shift in the energy mix [10], [4]. By 2019, hydropower accounted for nearly half of Cambodia's electricity generation, reducing reliance on imports and enabling broader electrification [8], [11]. However, dependence on hydropower also introduced vulnerabilities due to seasonal water flow variation and climate-related droughts, underscoring the need for a more resilient and balanced generation portfolio [12].

To address these limitations and secure stable power supply, Cambodia diversified into coal-fired generation, particularly in coastal provinces like Sihanoukville, and expanded cross-border energy trade agreements. By 2023, coal accounted for approximately 32% of electricity generation, while imports provided 15–20% of national supply, depending on seasonal demand. As illustrated in Figure 1, Cambodia's electricity mix in 2022 remained dominated by hydropower and coal, with solar and imports making up smaller but growing contributions. Imports from Lao PDR grew substantially—from 6.65 million kWh in 2011 to over 2.7 billion kWh in 2022—while Vietnamese exports peaked at 1.2 billion kWh in 2022 before tapering as domestic capacity improved. Thailand also supplied intermittent volumes throughout the decade. This import trend is documented in Figure 2, which tracks national grid and cross-border electricity flows from 2011 to 2024.

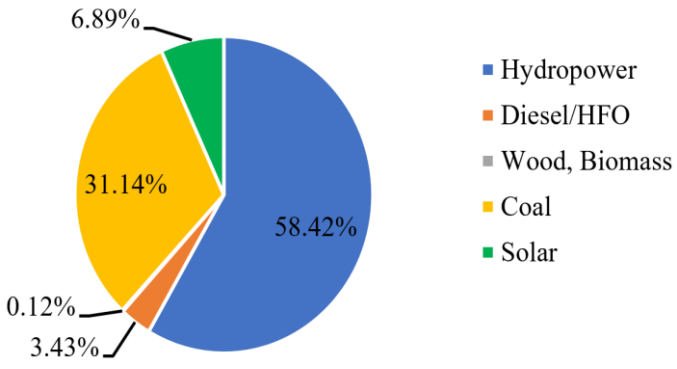

Figure 1 Electricity mix produced in Cambodia in 2022

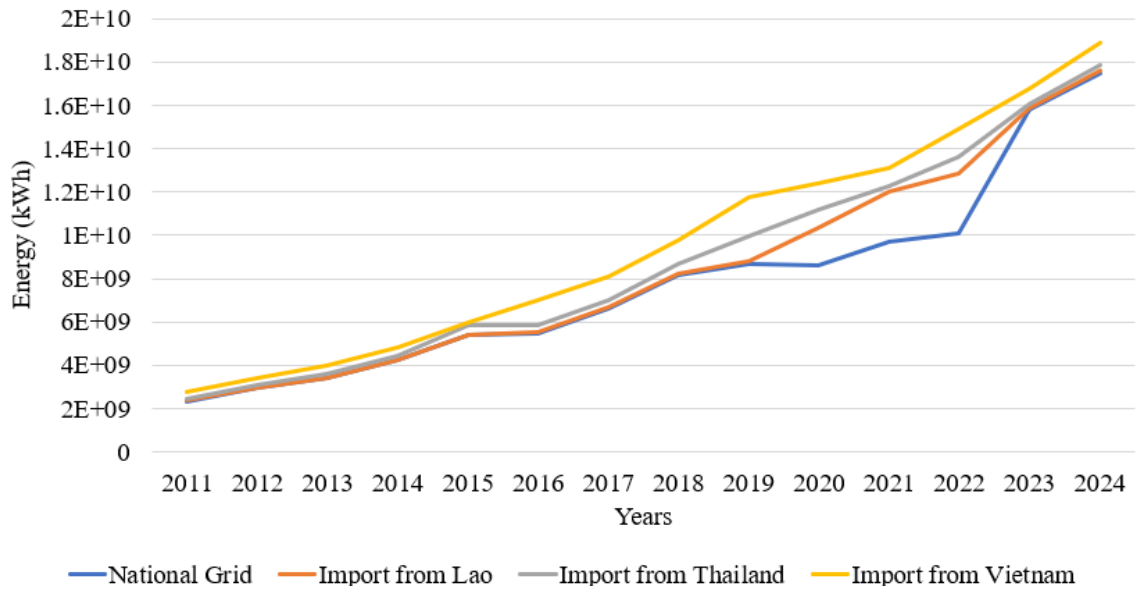

Figure 2 Electricity Supply in Cambodia (2011–2024): National Grid and Imports from Lao PDR, Thailand, and Vietnam

Simultaneously, the Cambodian government intensified efforts to promote renewable energy, particularly solar photovoltaic (PV), driven by falling global technology costs and international development assistance. By 2023, more than 300 MW of grid-connected solar capacity had been installed, representing around 7–8% of the country's total installed capacity. Despite these advancements, integration of intermittent renewable sources remains constrained by insufficient grid flexibility, limited energy storage infrastructure, and regulatory gaps. Overall, the evolution of Cambodia's energy mix reflects a deliberate policy orientation toward diversification, resilience, and alignment with regional initiatives such as the ASEAN Plan of Action for Energy Cooperation (APAEC). Looking ahead, the government's strategic priorities include accelerating renewable energy deployment, reducing reliance on fossil fuels, and exploring nuclear energy as a low-carbon, stable baseload option that supports both national energy security and long-term climate goals.

Electricity prices in Cambodia remain among the highest in the region. Industrial tariffs in Phnom Penh range from $0.14 to $0.18 per kWh, while rural consumers often pay above $0.20 per kWh. These high costs are driven by reliance on fuel imports, expensive infrastructure investments, and limited economies of scale. In this context, nuclear power emerges as a potential long-term solution. Its ability to provide consistent, low-carbon, baseload electricity can help reduce costs, stabilize supply, and support Cambodia's industrial and economic development. The next section analyzes the economic feasibility of nuclear power under Cambodia's current and projected energy conditions.

III. Economic Feasibility of Nuclear Energy in Cambodia

As Cambodia explores future energy pathways to support its growing economy, nuclear power emerges as a potential long-term option. This section presents a comprehensive economic analysis of nuclear energy's feasibility in Cambodia, focusing on capital and operational costs, fuel economics, competitiveness compared to other energy sources, and broader economic impacts. The discussion emphasizes small modular reactors (SMRs), which are better suited for Cambodia's current grid size, technical capacity, and financial scale.

3.1 Capital Investment Requirements

Conventional large-scale nuclear power plants typically involve capital costs exceeding USD 6 billion and capacities of over 1,000 MW, which are unsuitable for Cambodia's current grid [13]. Instead, SMRs offer a more feasible solution, providing flexible capacity between 50 MW and 300

MW, with capital costs ranging from USD 3,000 to 6,000 per kilowatt installed [14]. A 100 MW SMR would require an investment of approximately USD 300–600 million, a figure that could be achievable through international cooperation and blended financing models [15], [16].

These smaller-scale units can be constructed more quickly and in stages, reducing financial risk and allowing adaptation to growing demand. Cambodia can leverage bilateral agreements with technology providers from countries like Russia, China, or South Korea, who often offer Build-Own-Operate (BOO) models that shift the initial capital burden to the vendor [17].

3.2 Operational Costs and Fuel Economics

Once operational, SMRs have relatively low and stable operation and maintenance (O&M) costs, typically ranging from USD 10–20 per MWh [18]. Fuel costs make up a small proportion of total generation costs, and uranium's high energy density enables long fuel cycles, reducing refueling frequency [19]. One gram of uranium-235 can produce up to 24,000 kWh of energy [20], whereas coal provides only 8 kWh per gram [4].

Uranium markets are also less volatile than those for coal and gas, enabling more predictable pricing over the reactor's lifetime [21]. For Cambodia, which currently relies heavily on imported fossil fuels and electricity, this stability offers a substantial economic advantage.

3.3 Levelized Cost of Electricity (LCOE) and Competitiveness

The Levelized Cost of Electricity (LCOE) is a key metric for comparing energy sources. Recent international studies estimate the LCOE of SMRs between USD 80 and 120 per MWh [13], depending on local conditions and financing terms. Cambodia's current industrial tariffs range from USD 140 to 180 per MWh, suggesting nuclear power could offer long-term savings.

While solar PV presents a lower upfront LCOE (USD 70–100 per MWh), its intermittent nature and lack of storage infrastructure limit its reliability as a baseload power source (ADB, 2023). In contrast, nuclear energy offers stable, high-capacity output that can complement renewables and reduce the need for imported electricity.

IV. Results and Discussion

To facilitate direct comparison of electricity generation technologies, Table 1. Estimated Levelized Cost of Electricity (LCOE) Ranges for Major Power Generation Options in Cambodia summarizes the estimated LCOE (Levelized Cost of Electricity) ranges for nuclear SMRs, coal, solar PV, and hydropower based on international and regional data sources. These comparisons show that SMRs, while more capital-intensive upfront, can become competitive under the right financing conditions, especially when factoring in their baseload capacity and minimal fuel price exposure. In contrast, solar PV appears cheaper per kWh but incurs additional grid and storage costs when used as a primary energy source.

Table 1 Estimated Levelized Cost of Electricity (LCOE) Ranges for Major Power Generation Options in Cambodia

Energy Source	**LCOE Range (USD/MWh)**	**Notes**	**Source & Basis**
Nuclear (SMR)	80–120	Higher CAPEX, high reliability, low operating costs	IEA & NEA (2021), World Nuclear Association (2023); global average for new SMRs with financing variation [13]
Solar PV	70–100	Includes imported coal and transport costs	ADB (2023), IEA (2020); unsubsidized LCOE for utility-scale solar in Southeast Asia [22]

Coal	100–140	Excludes storage; intermittency limits baseload reliability	IEA & NEA (2021); includes imported coal logistics cost in Cambodia
Hydropower	50–80	Seasonal variability, highly site-dependent	Based on ADB & World Bank data for Cambodia and Lao PDR; depends on season and flow [23]
Liquefied Natural Gas	70-110	Dependent on LNG price volatility; cleaner than coal but imported	EA (2020), ADB (2018); combined-cycle gas turbine costs in Southeast Asia
Industrial Tariff (Cambodia)	140–180	Current retail rate paid by industrial users (non-subsidized sector)	Directly cited in Section II (based on EDC, ADB, World Bank reports)

Based on current estimates, as indicated in Table 1, the Levelized Cost of Electricity (LCOE) for Small Modular Reactors (SMRs) is projected to range between USD 80–120/MWh (IEA & NEA, 2021). In contrast, the prevailing industrial electricity tariffs in Cambodia fall between USD 140–180/MWh. This indicates a potential long-term economic gain of USD 20–100/MWh if nuclear generation replaces imported or fossil-based electricity. At first glance, SMRs appear less competitive than solar PV (USD 70 to 100 per MWh) and natural gas combined-cycle plants (USD 70 to 110 per MWh). However, these apparent advantages diminish significantly once intermittency costs (in the case of solar) and fuel price volatility (in the case of natural gas) are internalized. Cambodia lacks large-scale storage systems and flexible grid infrastructure, making continuous nuclear baseload power a more dependable supply source for industrial and commercial sectors that require stable, high-quality electricity. Moreover, reliance on imported liquefied natural gas (LNG) exposes Cambodia to global market fluctuations, adding economic and supply security risks over the long term.

Capital Expenditure (CAPEX) plays a central role in evaluating the feasibility of nuclear power projects. For a 100 MW Small Modular Reactor (SMR), the total capital cost in Cambodia is estimated at USD 300–600 million, translating to USD 3,000–6,000 per kilowatt installed (WNA, 2023). This range is higher than solar (USD 1,000–1,500/kW) or coal (USD 1,500–2,500/kW), primarily due to the specialized infrastructure, safety systems, and technology licensing involved in nuclear power.

However, SMRs offer distinct economic advantages that can justify the higher upfront investment. These include a lifespan of up to 60 years, very high capacity factors (>90%), low variable operating costs, and minimal exposure to fuel price volatility. Unlike fossil fuel plants, where fuel can make up 30–50% of costs, nuclear fuel contributes only about 5–10%.

The capital-heavy nature of nuclear power makes it especially sensitive to financing conditions. To assess this, a sensitivity analysis was conducted to evaluate how different financing models impact the LCOE. The analysis assumes a 100 MW SMR with a capital cost of USD 450 million, a 90% capacity factor, and a 60-year operational life. Three financing scenarios were examined:

Scenario 1: Commercial Lending – Assumes 7% annual interest over 20 years. Under this condition, the LCOE is estimated at approximately USD 120/MWh.

Scenario 2: Concessional Lending – Assumes 3% annual interest over 30 years, typically offered by development banks or through sovereign guarantees. This reduces the LCOE to about USD 95/MWh.

Scenario 3: Vendor BOO (Build-Own-Operate) – Involves vendor financing with deferred capital recovery and an effective interest rate of 0–2% over 40 years. This results in the lowest estimated LCOE, ranging from USD 80–85/MWh.

Table 2 Sensitivity Analysis of SMR LCOE Under Different Financing Scenarios in Cambodia

Financing Scenario	Interest Rate	Duration	LCOE (USD/MWh)
Commercial Lending	7%	20 yrs	120
Concessional Loan	3%	30 yrs	95
Vendor BOO	0–2%	40 yrs	80–85

These findings demonstrate the crucial role financing terms play in determining nuclear cost competitiveness. Under concessional or vendor-backed financing, the LCOE for nuclear SMRs in Cambodia can fall within the range of 80–95 USD/MWh. This is below the average cost of electricity from coal (100–140 USD/MWh) and closely aligns with that of solar PV (70–100 USD/MWh). While solar appears cheaper at first glance, its cost-effectiveness depends on backup systems and storage due to intermittency. Nuclear, in contrast, delivers baseload power continuously and without dependence on weather, offering greater reliability. Therefore, with favorable financing and operational assumptions, nuclear power becomes economically viable relative to both coal and solar in Cambodia's context.

V. Conclusion

Cambodia's growing energy demand, combined with the need for a reliable and low-emission power source, makes nuclear energy a promising strategic option. This paper evaluated the economic feasibility of introducing Small Modular Reactors (SMRs) into Cambodia's energy mix, using cost analysis, financing models, and comparative benchmarking with other energy sources.

The results indicate that although nuclear power involves higher capital expenditures compared to solar and coal, its long operational life, high capacity factor, and low fuel cost volatility contribute to competitive long-term costs. Sensitivity analysis showed that with favorable financing, such as concessional loans or vendor-supported Build-Own-Operate (BOO) models, the Levelized Cost of Electricity (LCOE) for SMRs can fall below USD 90/MWh, making nuclear energy cost-competitive with fossil-based generation and aligned with the average costs of solar PV when reliability is accounted for.

In a BOO model, a foreign vendor or private entity finances, builds, and operates the nuclear power plant while selling electricity to the host country through a long-term power purchase agreement. This arrangement reduces the financial burden on the Cambodian government and utilities, allowing access to advanced technology without requiring upfront capital investment.

Furthermore, nuclear energy offers advantages in fuel import substitution, price stability, job creation, and regional economic development. These benefits support Cambodia's broader goals of energy independence, industrial expansion, and low-carbon transition. However, several prerequisites must be addressed, including the development of a nuclear regulatory framework, capacity building, financing strategy, and international cooperation mechanisms.

In conclusion, nuclear power, particularly through the deployment of SMRs, presents a viable long-term investment for Cambodia's energy future. Policymakers should prioritize feasibility studies, institutional preparedness, and regional partnerships to enable a gradual but effective integration of nuclear energy. As Cambodia moves toward diversifying its energy mix, SMRs offer not only a clean and stable energy source but also a catalyst for industrial and technological advancement.

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