Stakeholder Perspectives on Challenges in Integrating and Developing Infrastructure for Small Modular Reactors (SMRs) in Kuwait

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**Abstract**

Kuwait endeavors to reduce its reliance on oil in alignment with the Kuwait National Development Plan, diverting investments towards non-oil sectors. Concurrently, the nation is committed to mitigating greenhouse gas emissions. Recognizing the nuclear energy chain as a highly dependable and low-emission power source per unit, Kuwait deems it imperative to incorporate various low-carbon energy technologies, particularly nuclear power, to meet its climate policy objectives. Small Modular Reactors (SMRs) emerge as promising contributors to climate change mitigation and bolstering energy security. This study, an integral part of an ongoing research initiative, delves into the challenges associated with integrating and developing Small Modular Reactor (SMR) infrastructure in Kuwait, encompassing diverse stakeholder perspectives. Employing an empirical-qualitative approach, incorporating expert interviews and discussions, the research explores hurdles in nuclear infrastructure development, addressing regulatory frameworks, technical considerations, and the necessity for capacity-building. Notably, local political instability emerges as a significant risk, according to the majority of interviewed experts, directly influencing the development of a national nuclear program. This instability contributes to a lack of governance within various institutions across the country, posing both direct and indirect risks to the nuclear program's progress. The paper strives to provide decision-makers with a comprehensive understanding of these challenges for informed decision-making.

## INTRODUCTION

Climate change is a pressing global issue with wide-ranging consequences. In Kuwait, a country known for its arid conditions, climate change poses unique challenges, including increasing temperatures, greater water scarcity, and a growing demand for energy [1, 2]. To mitigate these challenges, reducing greenhouse gas emissions (GHGs) and carbon emissions is important [1-7]. Globally, major contributors to CO2 emissions include industrial operations and the combustion of fossil fuels. In 2021, the energy supply sector contributed approximately 34% of the total net anthropogenic greenhouse gas emissions, the industry sector accounted for 24%, the agriculture, forestry, and other land use (AFOLU) sectors contributed 22%, the transport sector was responsible for 15%, and the buildings sector contributed 6%. The burning of coal in coal-fired power plants has the potential to expedite global warming through CO2 emissions [8-11]. When measured in CO2 equivalents per kilowatt-hour (kWh), various power generation methods have differing levels of impact: coal (820), biomass combustion (740), natural gas (490), solar photovoltaic (48), geothermal (38), hydropower (24), and nuclear power plants (12). Therefore, nuclear power emerges as a viable solution since it generates energy with the least GHG emissions and can significantly reduce CO2 emissions.

Small Modular Reactors (SMRs) represent a promising paradigm shift in nuclear technology. SMRs offer numerous advantages, including reduced capital costs, enhanced safety features, and flexibility in deployment. The concept of SMRs has been successfully applied in military applications, serving as energy sources for warships and submarines in Russia and the USA[12, 13]. The modular design of these reactors simplifies on-site work, reduces construction durations compared to traditional reactors, enhances safety margins, and provides adaptability to different grid configurations. However, SMRs face challenges such as site selection, accommodating multiple units at the same location, and determining the number of reactors required to meet energy demands [14-16]. The competitiveness of SMRs is dependent upon the scale of production, with potential for competitive energy pricing due to their modular architecture for manufacturing, transportation, and assembly.

Kuwait's major energy sources primarily consist of oil and natural gas, resulting in substantial greenhouse gas emissions [17-19]. Factors such as population growth, industrial expansion, and the need for cooling systems in a hot desert climate put additional stress on existing resources[3, 20]. Therefore, SMRs offer a promising solution for Kuwait, as they can produce electricity and support desalination processes. Given Kuwait's heavy reliance on desalination, which contributes to substantial carbon emissions, SMR cogeneration technologies hold significant potential for the country.

Developing infrastructure for energy, renewable energy, and nuclear energy projects is of paramount importance for Kuwait[19]. These projects have the potential to transform the energy landscape, reduce carbon emissions, enhance energy security, and improve the resilience of infrastructure. Nonetheless, they also come with various challenges and risks, particularly for a nation relatively new to nuclear power and SMR technology. Implementing nuclear power in general, and SMR technology in particular, in Kuwait demands careful consideration and thorough risk assessment. The construction of SMR infrastructure represents a novel and substantial endeavor for Kuwait, characterized by its complexity, size, and impact. As mega projects, they entail inherent risks related to resource allocation, technological challenges, and financial considerations. Identifying, assessing, and managing these risks effectively is essential to ensure the successful implementation of SMR technology in Kuwait [17, 18].

Each construction project is distinct, particularly when introducing new concepts into a country[19]. This is especially true for the integration and construction of SMRs for nuclear power, a technology not yet adopted in countries like Kuwait. This study aims to investigate the risks and challenges associated with integrating this technology from the perspective of stakeholders. Identifying these challenges and risks is a critical first step towards innovation and change. Understanding these factors is essential for several reasons, including the unique and critical risks associated with megaprojects, such as design changes and construction quality issues [17, 18].

The construction industry, one of the largest globally, faces various risks that can cause significant delays and cost overruns. Policymakers, nuclear power companies, and energy analysts worldwide are increasingly interested in SMRs due to their potential as a competitive, low-carbon technology component of future integrated energy systems. Despite this interest, Kuwait has yet to adopt SMRs. This research paper seeks to explore the challenges and risks that could influence this decision.

This paper is part of ongoing research exploring the challenges and risks of integrating Small Modular Reactors (SMRs) into Kuwait's energy infrastructure. The aim is to provide insights that inform decision-making and support Kuwait's climate and energy security goals. By identifying these risks, the research will help Kuwait transition to a sustainable and resilient energy future, reduce its carbon footprint, and address climate change. Additionally, it will pave the way for future projects of similar magnitude, contributing to the country's long-term energy and environmental sustainability.

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## Methodology

This study employed a qualitative descriptive method to investigate the significant risks of integrating nuclear power systems, specifically Small Modular Reactor (SMR) technology, into Kuwait’s energy sector. Data were gathered through structured face-to-face interviews with construction professionals, enabling an in-depth understanding of the respondents' perspectives. The qualitative research approach focuses on how phenomena are perceived, understood, and experienced by individuals [18, 21, 22]. This method allows for the collection of rich, detailed insights directly from the respondents, rather than relying on the researcher's assumptions. This paper is part of an ongoing research project aimed at gaining a comprehensive understanding of these risks through the perspectives of experts and stakeholders. A systematic approach was used for collecting and analysing qualitative data to achieve this goal. A combination of convenience and purposive sampling techniques was used to select participants. Convenience sampling addressed time and logistical constraints while ensuring data quality. Purposive sampling intentionally selected participants who could provide the most relevant and comprehensive insights. The interview questions were carefully designed to align with the research objectives. Pilot tests were conducted with industry experts to refine the questions, ensuring they were clear, appropriately lengthy, and comfortable for participants.

## Finding Results and discussion

To effectively integrate new technology or techniques into an industry, it's crucial to address and ensure successful implementation and integration. In the examination of risks associated with the integration of nuclear power technology into Kuwait's industrial landscape, a comprehensive understanding demands rigorous scrutiny. Utilizing qualitative research methodologies, the study seeks to identify key insights into the strengths of the integration process and to formulate strategies for mitigating potential obstacles Figure 1 presents the risk categories identified through these interviews. As illustrated, six distinct risk categories emerged: financial, social, technical, political, environmental, and strategic. These categories are the result of a qualitative analysis that identified a total of 38 specific risk factors, detailed in Table 1. Each risk factor highlights a particular concern or challenges relevant to the integration of Small Modular Reactors (SMRs) in Kuwait.



*FIG. 1. Categorization of Output Risks Derived from Interview Findings.*

The findings reveal a variety of risks encompassing various dimensions (FIG 1). Delving into economic aspects shows the elaborate interaction among economic practicality, financial approval complexities, technological investments, and the looming specter of cost overruns. Sociocultural factors illuminate the challenges of garnering public acceptance, bridging awareness gaps, and navigating cultural nuances. Operational and technical considerations underscore potential deficiencies in infrastructure, skill gaps in the workforce, and the imperative of adherence to nuclear project regulations. Regulatory and governance challenges scrutinize the volatility of governmental policies, the intricacies of regulatory approval processes, and the persistent threat of political interference. Environmental and safety issues delve into the complexities of waste management, the implementation of safety protocols, and the necessity of comprehensive environmental impact assessments. Lastly, strategic risks underscore the significance of proactive measures in addressing economic shifts, collaboration obstacles, and fostering innovation within the framework of nuclear technology. The ensuing discourse dissects each dimension of these risks, elucidating their ramifications and proposing strategic mitigation strategies to ensure the seamless integration of nuclear power systems in Kuwait.

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| --- | --- | --- | --- | --- | --- |
| **Economic Risks** | **Sociocultural Risks** | **Operational and Technical Risks** | **Regulatory and governance Risks** | **Environmental and Safety Risks** | **Strategic Risks** |
| * Economic Viability * Financial Approval Challenges. * Technological Investment. * Cost Overruns. | * Public Opposition * Public Perception and lack of Awareness * Lack of Trust and Credibility * Media Influence | * Infrastructure Deficiency * Lack of regulatory Codes for Nuclear Projects * Advanced Construction and Engineering Techniques * Nuclear Waste Management * Lack of Specialized Workforce * Training Program Inadequacies * Long-term Maintenance Concerns * Bureaucratic Constraints * Land Allocation Issues | * Political Instability * Government Policies and Support * Regulatory Approval Processes * Political Interference | * Radioactive Waste Disposal * Accidents and Safety Concerns * Environmental Impact Assessment | * Economic Changes * Collaboration Challenges * Lack of Innovation * Research and Development Issues * The lack of an investment roadmap for future projects in Kuwait. * Lack of Educational Programs * Misuse of Nuclear Technology Perception * Inconsistent Government Policies * Lack of Government Endorsement * Dependence on Conventional Energy Sources * Security Concerns * Lack of Strategic Planning * Long-Term Vision and Goals * Geopolitics of nuclear technology and nuclear fuel |

Table 1. Key Risks in Integrating Nuclear Power in Kuwait

### Economic Risks

Addressing economic challenges and risks is paramount when integrating any new technology, including nuclear power plants, into an industrial landscape like Kuwait. Economic uncertainties, which encompass financial uncertainties external to the project and beyond the control of the project developer, can significantly impact the viability and success of construction projects. Integrating nuclear power plants into Kuwait faces significant economic and financial challenges. Stakeholders highlight concerns about the project's economic viability, questioning its ability to generate long-term positive returns on investment. Addressing these challenges requires an investment roadmap and support for Public-Private Partnerships to enhance funding and share risks. Government support is important to secure funding, streamline approval processes, and establish a regulatory framework. Effective project management and international collaboration are also critical to controlling costs, managing resources, and adopting advanced technologies, ensuring the project's success.

### Political and Regulatory Risks

Political risk within the construction industry, particularly concerning large-scale projects like the integration of Small Modular Reactors (SMRs), refers to potential uncertainties arising from political factors that could affect the project's feasibility and progress. Addressing political risk requires careful assessment, stakeholder engagement, and strategic management throughout the project lifecycle. Political and regulatory risks affect the feasibility and progress of integrating SMRs in Kuwait. Stakeholders identify four key risk factors:

* political instability,
* government policies and support,
* regulatory approval processes, and
* political interference.

Political instability can lead to delays and complicate decision-making. Stakeholders' feedback shows that consistent government policies are crucial for maintaining investor confidence. Regulatory approval processes pose potential hurdles due to possible delays and increased costs. Political interference can affect project continuity. To mitigate these risks, stakeholders recommend enhancing transparency, advocating for stable government policies, streamlining regulatory processes, and improving political communication. These measures aim to create a conducive policy environment and ensure efficient progress in nuclear project implementation.

### Strategic Risks

Strategic risk in construction, especially for large-scale projects like SMR integration, encompasses challenges that can impact long-term goals and project success. These risks stem from economic fluctuations, market shifts, technological changes, and competitive dynamics. Effective management involves thorough market analysis, adaptable planning, continuous monitoring of external factors, and proactive stakeholder engagement, ensuring project viability and alignment with evolving strategic objectives.

Derived from interview findings, the category of Strategic Risks in integrating nuclear power systems in Kuwait reveals stakeholder concerns. With 13 identified risk factors, worries include economic changes impacting project viability and coordination, requiring a resilient economic framework. Concerns about innovation hindering nuclear system implementation suggest the need for a robust research and development program to stimulate progress. Collaboration between research institutions and industry partners can address R&D challenges.

### Social and Cultural Risks

Sociocultural risk encompass public opposition due to safety concerns, lack of awareness about nuclear technology, cultural resistance to change, and conflicts with local customs and values. Addressing these risks requires comprehensive public engagement strategies, including educational campaigns, transparent communication about SMR safety, and efforts to align the project with local cultural values.

The category of social and cultural risks, emerging from interview results, reveals four significant risk factors. Stakeholders express concerns about potential public opposition to nuclear power plant applications in Kuwait, posing risks of delays, reputational damage, and approval challenges. Participants also highlight perceptions and lack of awareness regarding nuclear technology benefits and safety measures, hindering project acceptance and support.

Promoting nuclear energy development relies on public perceptions and acceptance, hindered by a lack of knowledge about nuclear energy. Building nuclear knowledge is crucial for shaping positive attitudes towards nuclear energy, regardless of a country's nuclear program status.

Mitigation strategies include increasing public awareness through educational initiatives and outreach programs, integrating nuclear concepts into education, and fostering open dialogues and community forums. Collaboration with local cultural authorities and cultural awareness training for project teams are essential for aligning nuclear projects with cultural values and norms. Implementing these strategies is vital for fostering public acceptance and ensuring the success of nuclear power projects in Kuwait.

### Technical and Operational Risks

Operational and technical risks include infrastructure deficiencies, limited expertise in nuclear technology, and adherence to specific project codes. Challenges arise from the novelty of nuclear technologies and the lack of prior experience in managing similar projects in the region. Uncertainties about the availability of skilled labor, specialized equipment, and materials further compound these risks, potentially leading to project delays, cost overruns, and compromised safety standards.

From interview findings and illustrated in Figure 8, comprises ten key risk factors crucial for successful nuclear power plant projects in Kuwait. Stakeholders recognize the significance of these risks, acknowledging their potential to hinder implementation if not adequately addressed.

These risks present substantial challenges to project execution. Infrastructure deficiencies and the absence of specific codes for nuclear projects can lead to operational setbacks, undermining project efficiency. Inadequate training programs contribute to a scarcity of specialized workforce, potentially compromising personnel competence and project effectiveness. Long-term quality and maintenance concerns pose sustainability risks, while bureaucratic constraints and land allocation issues could cause delays and disrupt project execution.

Mitigation strategies involve integrated planning to align the country's master plan with future projects and ensure suitable land allocation for nuclear initiatives. Capacity-building initiatives and comprehensive training programs aim to enhance workforce skills and operational competence. Strengthening existing infrastructure is crucial for accommodating and preparing for nuclear projects while promoting transparency and economic infrastructure development supporting seamless integration into Kuwait's energy landscape. Addressing bureaucratic challenges through administrative process reforms and engaging in international collaboration and knowledge exchange further enhance project resilience and success.

### Environmental and Safety Risks

The Environmental and Safety Risks category, derived from interview findings, elucidates stakeholders' concerns regarding potential challenges associated with integrating nuclear power applications in Kuwait. There are three main risks identified in the Environmental and Safety Risks category. They are:

* radioactive waste disposal,
* accidents, safety and safeguarding concerns, and
* environmental impact assessment.

Stakeholders express apprehensions regarding the proper disposal of radioactive waste, citing concerns about environmental impact and potential health hazards. Safety issues and the risk of accidents during nuclear project implementation are also prominent concerns, emphasizing the need for robust safety measures to safeguard public safety and environmental well-being. Furthermore, stakeholders underscore the importance of conducting comprehensive environmental impact assessments before initiating nuclear projects, highlighting the potential adverse effects on the environment and ecosystems.

To mitigate these risks, stakeholders advocate for comprehensive radioactive waste management practices, adhering to international best practices for disposal and containment. They also emphasize the establishment of stringent safety protocols and continuous monitoring, recommending investments in advanced technologies and training programs to enhance safety measures throughout the project lifecycle. Additionally, stakeholders stress the importance of transparent and inclusive environmental impact assessments that consider local ecosystems and engage the community to address concerns and foster trust.

## CONCLUSION

The integration of Small Modular Reactors (SMRs) into Kuwait's energy infrastructure presents a significant opportunity to address the nation's dual objectives of reducing greenhouse gas emissions and enhancing energy security. The modular nature of SMRs offers advantages such as reduced capital costs, enhanced safety, and flexible deployment, making them suitable for Kuwait's energy and desalination needs. This study, through an empirical-qualitative approach involving expert interviews and stakeholder discussions, has identified numerous challenges and risks that need to be meticulously managed to ensure the successful deployment of SMRs. Our study results indicate that local political instability is a prominent risk factor, undermining governance and regulatory frameworks crucial for the development of a national nuclear program. This instability makes it harder to navigate the complex regulatory environment and affect the efforts to build a strong nuclear infrastructure. The economic, political, strategic, social, technical, and environmental risks associated with SMR integration necessitate comprehensive strategic planning and stakeholder engagement. By addressing these risks through robust management practices and informed decision-making, Kuwait can enhance the resilience and success of SMR projects. Furthermore, the study underscores the importance of aligning SMR integration with Kuwait's broader energy and sustainability goals. This alignment not only strengthens Kuwait's energy security but also positions the country as a proactive participant in the global transition towards sustainable energy solutions. By mitigating potential obstacles and leveraging the benefits of SMRs, Kuwait can make significant strides towards a sustainable and resilient energy future, contributing to its long-term environmental and energy sustainability.

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