

Security and Safeguard of Small Modular Reactors: Assessing Potential Risk for SMR Deployment in Southeast Asia

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Abstract

The potential deployment of small modular reactors (SMRs) can be one of the drivers toward decarbonized electricity. With the growing electricity demands, SMRs can provide clean electricity for the grid and other commercial operations. Southeast Asia is one of the emerging economies facing challenges in energy security and decarbonization. SMR could represent a strategic option, but their potential deployment in Southeast Asia has not been thoroughly assessed. Small and modular reactors have several features designed to improve the safety and security of the plant. However, the decrease in size and smaller facilities may cause undesirable consequences once a security incident happens. As several ASEAN countries have close geographical proximity, an incident in Southeast Asia could lead to severe transboundary impacts. Therefore, this paper is trying to assess the potential challenges to ensure the readiness of ASEAN in deploying SMR. Robust security and safeguard systems should be in place before SMR is in operation in the region. All relevant stakeholders should address the importance of answering security and safeguard challenges of SMR.

Introduction

Over the last few years, nuclear energy has been actively discussed as a key contributor to achieving sustainable development scenarios and net-zero emissions (IEA 2022a). Renewable and nuclear energy can be the answer to increasing energy demand and reliance on fossil fuels. To achieve IPCC target of 1.5°C by 2100, nuclear generation must increase by 59-106% by 2050 (IPCC 2019). Countries are looking at nuclear power to meet net-zero goals including countries from Southeast Asia region. The Association of South East Asian Nations (ASEAN) is a region consisting of one-tenth of the world's population, with electricity demand projected to grow 4.1% per year, reaching 1589 Mtoe in 2045 (ASEAN Centre for Energy 2023). The current energy mix of ASEAN's primary energy supply is still based on coal and fossil

fuels. Carbon emissions are projected to be roughly equivalent to the world's fifth-highest emitter in 2040 (ASEAN Centre for Energy 2023).

As ASEAN countries are looking for a solution to enable decarbonization, several countries are exploring the potential for nuclear power generation. Even though there is no operational nuclear power plant in the region, several ASEAN Member States (AMS) have explored the feasibility of introducing nuclear power plants. Indonesia, Malaysia, Philippines, Thailand, and Vietnam are the AMS with experience developing nuclear power programs (ASEAN Center for Energy 2020). The development of small modular reactors technology can lower the barrier of entry to building a nuclear power plant, as it has a lower capital cost and can be deployed as smaller or serial units, which could be a favorable option for ASEAN (Nian et al. 2022). SMRs could be a suitable option for ASEAN countries, as several SMRs developer also mentioned ASEAN as the potential deployment site (World Nuclear News 2023a; 2022; 2023b). This paper will assess the possible implication of the potential SMRs introduction in the region, especially in the security and safeguards context.

ASEAN Member-states' interest in pursuing nuclear power

Status of ASEAN energy mix

Energy demand in Southeast Asia has increased steadily, averaging 3% a year over the past two decades. Governments across Southeast Asia have published net zero emissions and carbon neutrality targets, which will need an aggressive energy transition approach. The need to decarbonize the power generation cost and lower electricity costs makes it a technology choice to be deployed in the region. Nuclear power can provide baseload and increased grid reliability, supporting the utilization of ASEAN interconnection grids. Figure 1 shows the IEA assessment of the potential trajectory of the ASEAN energy system. In the sustainable development scenarios, nuclear power and renewable are introduced and expanded as early as possible to cut back the shares of coal, oil, and natural gas.

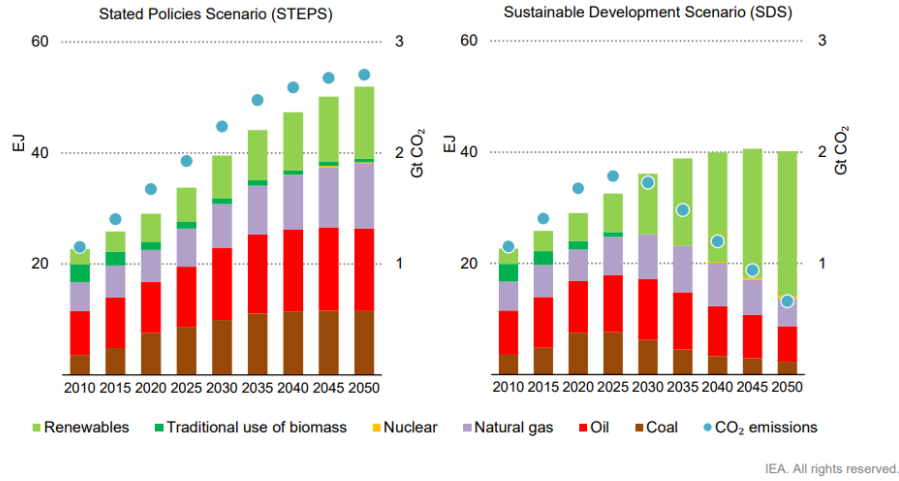


Figure 1. Total energy supply and CO2 emissions, 2010-2050 (International Energy Agency 2022)

Singapore, Philippines, Vietnam, and Indonesia are seen as potential adopters of nuclear power (Toh Jun Shen et al. 2022). 2030-2035 is targeted as the likely target timeframe to start introducing nuclear energy in the region. Hence, the utility and policymakers need to assess the necessary policy implications of the developments of SMR technology in the region. This includes the possibility of theft or sabotage of facilities, concerns about potential proliferation, regulatory oversight, and the potential security and safeguards risks and risk mitigation strategies.

Interest in nuclear power

There is no operational nuclear power plant in the region. ASEAN member states are still pursuing all the requirements to enable the introduction of nuclear power and SMR in the future. The summary of the potential SMR adopters and proposed design are shown in Table 1. The degree of development varies among each country and SMR developers.

Table 1. Potential countries deploying SMRs and proposed SMRs design

Country	Nuclear power policy	Proposed SMR Design	References
Indonesia	Planning to open first nuclear power plant by 2035 reaching 8 GW of capacity by 2050	ThorCon MSR (USA), NuScale (USA), PeLUit/RDE (Indonesia)	(IEA 2022b; World Nuclear News 2023a; IAEA 2022)
Vietnam	proposed developing nuclear energy on a small-scale post-2030	SEABORG CMSR (Denmark)	(Vietnam plus 2022; World Nuclear News 2023b)

Philippines	Since 2014, the Ministry of Energy has expressed a strong interest in developing an NPP with an SMR option. In January 2022, the country has conducted a feasibility study on SMRs.	NuScale (USA), iSMR (South Korea)	(President of the Philippines 2022)
Malaysia	focus on other nuclear applications such as in food and advanced polymer processing	N/A	(Madsen 2021)
Thailand	2 GW of nuclear power as indicated in the Power Development Plan 2015-2036	N/A	(Energy Policy and Planning office 2015)
Singapore	Assessed that nuclear energy was viable and could be developed for domestic generation capacity by 2040	N/A	(Energy 2050 Committee 2022; World Nuclear News 2022)

Potential growth of nuclear power and demand for nuclear fuel in Southeast Asia

Based on those interests and varying degrees of nuclear power development among ASEAN countries, we assessed which countries are more likely to deploy SMRs based on nine main indicators. Each indicator is then assigned a value from 1 (less likely to obtain SMR) to four (most likely to obtain SMR). The assessed indicators include (1) national energy demand, (2) SMR-specific demand, (3) financial sufficiency, (4) physical infrastructure sufficiency, (5) climate change motivation, (6) energy security motivation, (7) governmental participation, (8) experience with nuclear technology, (9) availability of national scientist and engineers. The result of the assessment is shown in Table 2.

Our study shows that Vietnam has the highest potential for deploying small modular reactors, followed by Indonesia, Singapore, Thailand, Malaysia, and the Philippines. High-scoring countries both have high value in experience with nuclear technology. Those countries also tend to have comparably higher GDP and supporting infrastructure, making it more favorable to pursue SMRs.

Table 2 SMR Prospects of ASEAN Countries

Country	Real GDP	Rural Population	Existing Desalination Plant	Energy Intensive Industry	S&P Ratings	Total Electricity Output	Infrastructure Rank	CO ₂ Emissions	Energy Security	Uranium: Identified Resources	Increased Share of Renewable Energy	Government Effectiveness Indicator	Experience with Nuclear Technology	Human Capital Readiness	Total (highest to lowest prospects)
Vietnam	4	3	1	4	3	4	3	1	3	3	4	3	4	3	43
Indonesia	4	2	1	1	3	4	3	1	1	3	4	3	4	3	37
Singapore	4	1	4	3	4	1	4	1	4	1	1	4	1	4	37
Thailand	4	2	1	3	3	4	3	1	4	1	1	3	3	3	36
Malaysia	4	1	1	3	4	3	4	1	3	1	1	3	2	4	35
Philippines	3	3	1	2	3	3	3	1	4	1	3	3	2	3	35

Potential security and safeguards implication of SMR deployment in the region

Security-by-design (SeBD) and safeguard-by-design (SBD) are essential in ensuring the region's secure deployment of small modular reactors. SeBD and SBD methodologies should be applied early in the design process. Both concepts will play an integral role in ensuring effective security and safeguards in designs, minimizing overlapping features, and minimizing potential security and safeguards burdens. Regulatory bodies in the ASEAN Member States shall be involved in the process in the event of possible deployment in the country. Assessing safety, security, and safeguards (3S) risk in a more integrated manner in the early design process will help alleviate some concerns about the potential risk of deployment in the region.

In the policy sphere, ASEAN Member States have been consistent in their stance on the critical importance of nuclear disarmament (Caballero-Anthony and Trajano 2022). ASEAN Network of Regulatory Bodies (ASEANTOM) has achieved considerable progress in the regional cooperation on nuclear safety and security in the region. The work of ASEANTOM in nuclear security and peaceful use of nuclear energy is important, especially in preventing nuclear security incidents such as illicit possession and trafficking of nuclear materials in the region. ASEAN Member States are well aware of the importance of nuclear security, as nuclear explosive devices and radiological disperse devices by non-state actors may pose a serious threat in the region. In the deployment of SMR, the role of ASEANTOM need to grow, especially in terms of capacity building on the security and safeguard of SMR.

ASEAN Member States (AMS) also has been a parties to global nuclear parties and conventions, including nuclear security and safeguard related treaties. The list of the treaties that have been signed/ratified by AMS is shown in Table 3. ASEANTOM should play an important role in strengthening the region's current nuclear security and nonproliferation norms.

Table 3. Participation of ASEAN Member states in key nuclear agreements (Caballero-Anthony and Trajano 2022)

	Safeguards Additional Protocol	Convention on Physical Protection of Nuclear Materials (CPPNM)		Nuclear Terrorism Convention (ICSANT)	Comprehensive Nuclear-Test-Ban Treaty (CTBT)	Convention on Nuclear Safety (CNS)	Joint Convention on Spent Fuel and Radiological Waste	Convention on Early Notification of a Nuclear Accident	Code of Conduct on the Safety and Security of Radioactive Sources (Political Commitments/non-legally binding)
		2016 CPPNM Amendment	1980 CPPNM only						
Brunei					✓				
Cambodia	✓		✓	signed	✓	✓		✓	
Indonesia	✓	✓	✓	✓	✓	✓	✓	✓	✓
Laos	signed		✓		✓			✓	
Malaysia	signed			signed	✓			✓	✓
Myanmar	signed	✓	✓		✓	✓		✓	✓
Philippines	✓	✓	✓	signed	✓	Signed	signed	✓	✓
Singapore	✓	✓	✓	✓	✓	✓		✓	✓
Thailand	✓	✓	✓	✓	✓	✓	✓	✓	✓
Vietnam	✓	✓	✓	✓	✓	✓	✓	✓	✓

Sources: IAEA, 2021; CTBO, 2021; UN Treaties Collection, 2021.

Note: A tick means that the country has not only signed the convention but also ratified it, thus becoming part of its legislative framework.

Key Challenges

Several challenges need to be addressed for the safe and secure deployment of SMR in Southeast Asia. Firstly, with the SMR deployment in ASEAN countries, the need for HALEU or other nuclear fuel will grow to support the reactor fleet. Growing HALEU, natural and enriched uranium needs in the region must be assessed rigorously to project the necessary security and safeguard measures. The HALEU needs may vary significantly depending on the type of reactor that Southeast Asian countries are trying to introduce into their national grid.

Secondly, due to cost concerns and a smaller physical footprint, the nuclear security approach applied to the large reactor may not be deemed compatible with the SMR. The transportation of the potential transportable small modular reactor (barge-mounted/truck-based microreactor) also needs to be accounted for. Hence, local regulations should be tailored to account for and strengthen physical protection and security to protect the power plant. Security-by-design robustness and reliability must be ensured if there is less staffing on-site.

Thirdly, the novel SMR design, operation modes, and deployment may impose unique safeguards challenges. For example, material handling is one of the potential SMR safeguards concerns as the presence of on-load refueled reactors may need safeguards considerations as significant quantities of nuclear

materials are transported to the site. Advanced nuclear fuel may also challenge current nuclear material accountancy and control, especially liquid fuels or pebble beds with online refueling capabilities.

Another issue that may arise from the SMR deployment in a new region like Southeast Asia is that it lowers the entry barrier for an aspiring nuclear power country. The good governance of nuclear regulatory bodies needs to be ensured to minimize the uncertainties regarding the global nuclear nonproliferation regime. Regulatory bodies shall propose an assessment methodology to assess the proliferation resistance and the physical protection aspect of SMRs.

Lastly, the preparedness of the regulatory framework in the ASEAN Member States also needs to be assessed. There is very limited international experience in regulating and licensing SMRs. Hence, key regulatory interventions will be required along the lifecycle of SMR. Regulatory frameworks for SMR security and safeguard need to be improved/established by ASEAN countries' regulatory bodies. The role of IAEA and strengthening regional cooperation will be crucial in this process. ASEAN already has a platform such as (NEC-SSN) and ASEAN Network of Regulatory Bodies on Atomic Energy (ASEANTOM). Ensuring that proper regulatory framework for SMR will be addressed in those for a is very crucial in maintaining the robustness of SMR security and safeguard in the ASEAN Member States

Conclusion

Small modular reactor (SMR) technology may play an essential role in the decarbonization and energy transition effort, including in Southeast Asia. However, several concerns may need to be addressed before the first nuclear power plant is deployed in the region. ASEAN Member States has no experience operating and regulating nuclear power plants. Hence, effort to ensure the security and safeguard of SMR deployment in Southeast Asia is important.

Any ASEAN Member-States interested in deploying SMR should ensure the safe and secure deployment of this technology. Security-by-design (SeBD) and safeguard-by-design (SBD) methodologies shall be implemented as early as possible in the design process. Proper safety, security, and safeguards (3S) risk assessment shall be conducted in the region as well. Under platforms such as ASEANTOM, regulatory bodies should prepare for the potential legal and regulatory issues concerning nuclear security and safeguard. The regulatory bodies in the region need to strike a balance between maintaining an adequate level of reliability and conservatism in the process to ensure safe and secure nuclear power development in the region.

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