

ENERGY TRANSITION FOR THAILAND'S CLEAN ENERGY FUTURE VIA SMALL MODULAR REACTORS (SMRS)

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Abstract

Thailand's energy transition towards low-carbon electricity generation has become increasingly important for global climate change mitigation. Besides renewable energy, nuclear power is recognised as a viable solution for providing low-carbon and reliable baseload electricity. Thailand has considered nuclear power development for several decades; however, the country has not yet implemented a commercial nuclear power plant due to uncertain national policies, high investment costs, limited public acceptance, and safety concerns. This paper introduces Thailand's power system profile and the draft Power Development Plan 2024 (PDP2024), particularly the potential of nuclear power in enhancing national energy security and supporting decarbonisation goals. An overview of the status of nuclear power in Thailand and its potential contribution to a clean energy future is presented by focusing on small modular reactors (SMRs) as a promising option. The paper also describes the regulatory organisations and institutional framework relevant to SMR deployment. In addition, the national policies, feasibility studies and public acceptance related to SMR deployment will be further reviewed.

1 Introduction

Global electricity demand has been markedly increasing due to population growth and ongoing industrialisation. According to the International Energy Agency (IEA), electricity demand by 2050 is expected to expand significantly across multiple policy scenarios, i.e., the Stated Policies Scenario (STEPS), the Announced Pledges Scenario (APS), and the Net Zero Emissions by 2050 Scenario (NZE) [1]. The rising electricity demand has affected the global energy crisis, which reflects persistent imbalances in the energy trilemma: energy security, energy equity, and environmental sustainability. As one approach to balancing the energy trilemma, sustainable electricity generation will depend on low-carbon energy sources, particularly renewable energy and nuclear power to replace unabated coal and natural gas. Despite the benefits of decarbonisation, some renewable energy sources such as solar and wind have a constraint on the intermittent energy production; thus, reliable baseload generation to maintain grid stability is necessary. The Intergovernmental Panel on Climate Change (IPCC) Working Group III contribution to the Sixth Assessment Report (AR6) emphasises that limiting global warming to 1.5°C requires a rapid and diversified energy transition [2]. Among the mitigation pathways presented in the AR6, nuclear energy, one of the reliable and low-carbon energy sources, plays a role in a low-carbon electricity system by complementing renewable energy sources such as

solar and wind to reduce greenhouse gas (GHG) emissions. However, the deployment of conventional large-scale nuclear power plants remains constrained by high upfront capital costs, long construction periods, and public acceptance challenges. To overcome these limitations, small modular reactors (SMRs) become a promising option. The International Atomic Energy Agency (IAEA) identifies that SMRs offer higher flexibility and advanced passive safety systems. Their modular designs can reduce construction and installation times, simplify on-site assembly, and enable economies of serial production, thereby lowering upfront capital costs [3, 4]. Furthermore, the OECD Nuclear Energy Agency (NEA) notes that the incremental deployment of SMRs could contribute to meeting future electricity demand and supporting grid reliability and reduce financial risks for investors [5]. As a result, these advantages make SMRs a resilient and cost-effective option for facilitating the net-zero energy transition. Although SMRs have gained global attention, no SMRs have yet been deployed in Southeast Asia due to concerns regarding technical and safety issues, economic viability, and public acceptance [6].

This paper introduces Thailand's power system profile and the draft Power Development Plan 2024 (PDP2024). It also reviews the status of nuclear power and the possibility of SMR deployment for enhancing national energy security and supporting the decarbonisation transition.

2 Overview of Thailand's Power System

Thailand's power sector faces the critical challenge of balancing growing electricity demand with global climate commitments. To move from a fossil fuel-dependent system to a low-carbon energy system, national energy policies have undergone important strategic reforms to energy transition. In 2022, the Ministry of Energy assigned the Energy Policy and Planning Office (EPPO) to develop Thailand's National Energy Plan (NEP), a principal framework guiding the country's energy transition, and promoting energy security, clean and sustainable energy development [7]. The NEP aligns with the country's latest Nationally Determined Contribution (NDC 3.0) submitted in 2025, which aims to reduce net GHG emissions by 47% compared with 2019 levels. This target is consistent with the 1.5-degree pathways and a goal of net-zero emissions by 2050 [8]. The NEP agrees with other key national policy frameworks, as follows:

- the 20-Year National Strategy (2018–2037),
- the Master Plans under National Strategy (Revised Edition) (2023–2037),
- the 13th National Economic and Social Development Plan (2023–2027), and
- the National Security Policy and Plan (2023–2027).

In summary, the NEP adopts the following 5 key policy directions:

- 1) decreasing GHG emissions in the energy sector;
- 2) promoting investment in green energy;
- 3) advancing the 4D1E framework, i.e., digitalisation, decarbonisation, decentralisation, deregulation, and electrification;
- 4) enhancing energy sector competitiveness through increasing the proportion of renewable energy; and
- 5) developing energy infrastructure to support technological changes that cover electricity, natural gas, petroleum fuel, alternative energy, and energy conservation, as well as supporting the development of sub-plans under the national energy framework.

The following section provides an overview of Thailand's power system profile and the draft PDP2024, which is a key implementation framework under the NEP.

2.1 Thailand's power system profile

Thailand's electricity demand has steadily increased for several decades. Notably, the domestic power mix remains highly reliant on fossil fuels. According to the EPPO's electricity statistics from 2001 to 2024, natural gas is the dominant source of electricity generation, accounting for more than half of total generation [9]. The balance is supplied by imported electricity and electricity generated from hydropower and other renewable energy sources, as shown in Fig. 1 (a). Fig. 1 (b) illustrates long-term electricity growth of both the demand and supply sides in Thailand from 2001 to 2024. The electricity consumption and peak load showed an overall upward trend, reflecting the country's economic expansion and increasing reliance on electricity among all sectors, for example, industrial sector, business sector and so on. This growth was primarily driven by industrial and

commercial activities, along with rising temperatures and climate change. In response to high demand, electricity generation and total power system capacity also expanded significantly over the same period. The parallel growth of demand and supply indicates that the power system could meet the increasing electricity demand whereas maintaining adequacy and reliability. However, growing concerns over energy security such as the gradual depletion of domestic natural gas reserves in the Gulf of Thailand, increasing dependence on imported electricity, and fluctuations in global energy prices have prompted Thailand to source a more diversified and resilient energy mix.

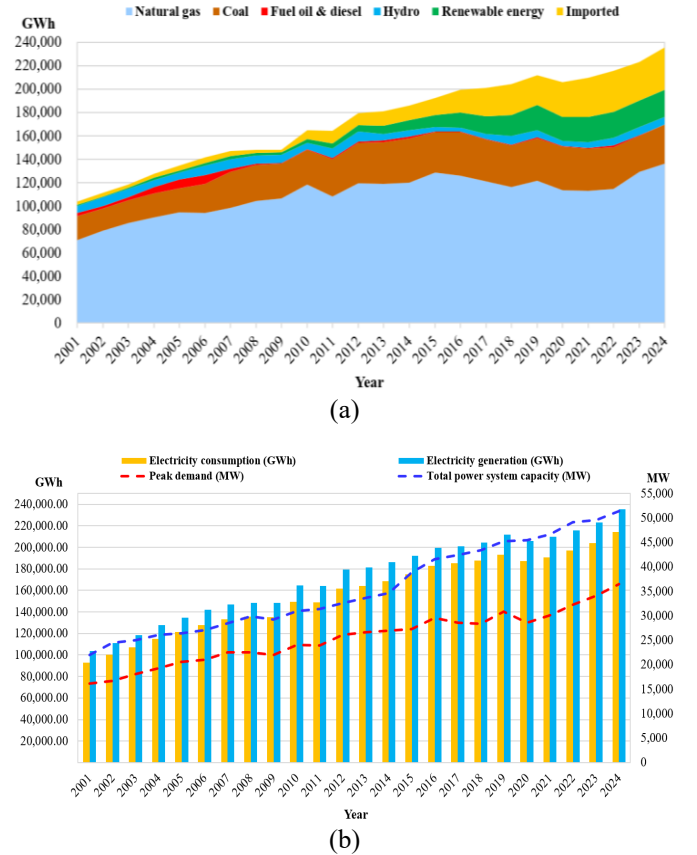


Fig. 1 Thailand's electricity statistics from 2001 to 2024 [9]: (a) electricity generation classified by fuel types; (b) electricity consumption, electricity generation, peak load, and total power system capacity.

2.2 Thailand's draft PDP2024

Thailand's current official power development framework is the PDP2018 Rev.1. However, a draft plan, PDP2024, has been developing under the NEP and is currently under review [10]. The PDP2024 serves Thailand's long-term electricity supply roadmap for 2024–2037. It aims at energy security, power system reliability, and cost-effectiveness, while simultaneously supporting decarbonisation and accelerating energy transition towards a cleaner energy mix. The rationale, concepts, principles, and policy directions of the draft PDP2024 are shown in Table 1.

Table 1 The strategic framework of Thailand's draft PDP2024 towards a low-carbon society and net-zero emissions [10].

	Description
Rationale	The draft PDP2024 concerns: - Economic growth after COVID-19 that lowered than expected, resulting in excess electricity supply. - Change in electricity demand patterns due to the growth of Independent Power Supply (IPS), and new energy technologies such as solar rooftop and electric vehicles (EVs). - Direction of global clean energy and CO₂ reduction trends.
Concepts	The draft PDP2024 is formulated based on: - Global clean energy trends. - Thailand's NEP in achieving carbon neutrality by 2050. - Thailand's NDC in achieving GHG reduction target and net-zero emissions by 2065, in line with COP26 commitments.
Principles	This draft PDP follows the below key principles: - Power security and system reliability. - Optimal economic scheduling for power systems. - Sustainable ecology and power system efficiency.
Policies	The draft PDP2024 is related to the following policies: - Clean energy and alternative technologies for CO₂ emission reduction in 3 categories: - Fossil fuel power plants: Promote hydrogen co-firing with natural gas in combined cycle power plants to reduce CO₂ emissions. - Clean energy power plants: - Renewable power plants, i.e., solar, wind, biomass, biogas, waste-to-energy. - Pumped storage hydropower. - Nuclear power plants, i.e., small/micro modular reactors (SMRs/MMRs). - Other alternative technologies: - Battery energy storage systems (BESS). - Demand response (DR) and distributed energy resources (DER). - Modern technologies on smart grid development for achieving carbon neutrality goals through improved efficiency, flexibility, and integration of clean energy sources.

Under the draft PDP2024, Thailand's contracted power generation capacity is projected to increase from 53,868 MW in 2023 to 112,391 MW by 2037. This expansion includes 77,407 MW of added capacity, while 18,884 MW of existing capacity will be retired. At the same time, peak demand

under the business-as-usual (BAU) scenario is projected to reach approximately 56,133 MW by 2037, reflecting progressive electricity demand growth. For energy security and decarbonisation goals, the draft PDP2024 emphasises increasing the proportion of clean energy in power generation mix. By 2037, clean energy aims to increase approximately 51% of total electricity generation, consisting of renewable energy sources (such as solar, floating solar, domestic and imported hydro), and nuclear power as illustrated in Fig. 2. The 0.04% demand response (DR) of the total mix is included in the draft PDP2024, but it is not presented in Fig. 2. The PDP reflects Thailand's initiative to diversify its energy mix and reduce dependence on fossil fuels.

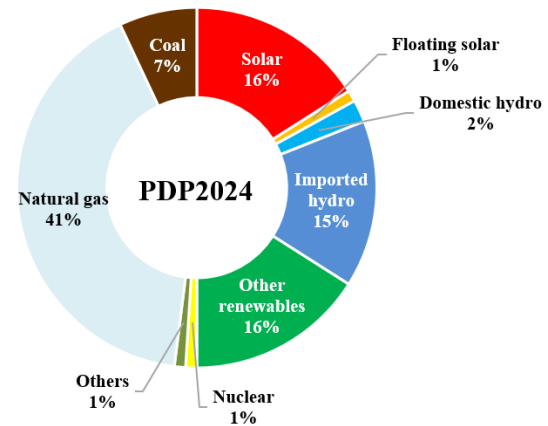


Fig. 2 Proportion of electricity generation classified by fuel types in the draft PDP2024 [10].

3 Status of Nuclear Power in Thailand

To meet Thailand's growing electricity demand while enhancing energy security and supporting decarbonisation goals, nuclear power is considered a promising solution. In fact, nuclear power has been recognised a low-carbon and reliable baseload electricity source as it emits the lowest GHG, estimated at approximately 5.1–6.4 g CO₂eq/kWh, compared with wind power, solar technologies, and hydropower, respectively [11]. Nuclear power development in Thailand has undergone multiple revisions and delays; however, it has been incorporated in the PDPs [10]. While nuclear energy has not yet been deployed for electricity generation in Thailand, nuclear technology has been utilised in several non-power applications, involving medicine, agriculture, industry, and nuclear-related research.

Thailand first considered nuclear power generation in 1966 through a proposal to construct a 600 MW boiling water reactor (BWR) at Aow Pai in Chonburi Province [12]. The nuclear power project was postponed indefinitely after the discovery of natural gas resources in the Gulf of Thailand in 1978. In 2007, nuclear power was reconsidered into PDP2007 and continued to incorporate in subsequent PDPs, including the draft PDP2024, although it was excluded from PDP2018 Rev.1. Table 2 summarises the plans of nuclear power capacities specified in the final revision of Thailand's PDPs.

Table 2 Plans of nuclear power capacities in Thailand's PDPs [10, 12].

Plan	Period	Description
PDP2007 Rev.2	2008–2021	Nuclear power projects were formally introduced as a part of long-term electricity generation plan, with the final revision targeting approximately 2,000 MW (1,000 MW $\times$ 2 units).
PDP2010 Rev.3	2012–2030	Due to the Fukushima accident in 2011, the planned nuclear power capacity in PDP2010 Rev.2 was reduced from 4,000 MW to 2,000 MW (1,000 MW $\times$ 2 units), with delays in nuclear power projects.
PDP2015	2015–2036	Nuclear power projects remained a part of PDP2015, having targets of approximately 2,000 MW (1,000 MW $\times$ 2 units)
PDP2018 Rev.1	2018–2037	Nuclear power projects were excluded.
PDP2024 (Draft)	2024–2037	The draft PDP2024 reconsidered nuclear power projects through the SMRs. The plan proposed approximately 600 MW by 2037 (300 MW $\times$ 2 units) to enhance energy security and support clean energy future.

In Thailand and other countries, where commercial nuclear power has not yet been deployed, issues such as policy uncertainty, the high capital costs and economic viability of nuclear power projects, and limited public acceptance remain major barriers. In addition, concerns regarding the long-term management of high-level radioactive waste from nuclear power plants and the legacy of past severe nuclear accidents require transparent and science-based communication strategies. In response to these challenges, SMRs have gained increasing attention in Thailand's draft PDP2024 [10] due to their potential advantages over conventional large-scale nuclear power plants, e.g., greater deployment flexibility, lower upfront capital requirements, and enhanced safety features. As a result, SMRs are increasingly viewed as a potential pathway for integrating nuclear energy into Thailand's long-term energy transition strategy.

4 SMRs

Like conventional large-scale nuclear power plants, SMRs generate electricity through nuclear fission. This process occurs when neutrons collide with the nuclei of nuclear fuel, primarily uranium-235, initiating a fission chain reaction that releases a large amount of thermal energy. The generated

heat is then used to produce steam, which drives a steam turbine to generate electricity.

This section outlines the classification of SMRs, followed by their global deployment status and the possibility of SMRs in Thailand.

4.1 Classification of SMRs

SMRs typically have a power capacity of up to 300 MW per unit [3, 4]. They can be classified according to their reactor technologies and coolant systems, ranging from conventional water-cooled reactors, including light water reactors (LWRs) and heavy water reactors (HWRs), to advanced designs such as gas-cooled reactors (GCRs), high-temperature gas-cooled reactors (HTGRs), liquid metal-cooled fast reactors (FRs), and molten salt reactors (MSRs). The IAEA classifies SMR technologies into 6 categories based on reactor technologies, deployment environment, power scale, and intended applications, as shown in Table 3.

Table 3 Classification of SMRs [3, 4].

Type	Characteristics
1. Land-based, water-cooled SMRs	- Mature technology prevalent in large-scale nuclear reactors - Coolant: Light water and heavy water
2. Marine-based, water-cooled SMRs	- Barge-mounted floating power units - Flexible offshore deployment - Coolant: Light water
3. Gas-cooled SMRs	- High-temperature heat output ($\geq 750^\circ\text{C}$) for efficient electricity generation, industrial applications and cogeneration - Coolant: Helium
4. Liquid metal-cooled, fast-neutron SMRs	- Fast neutrons with liquid metal coolants - Potential for waste reduction - Coolant: Sodium, pure lead, lead-bismuth eutectic
5. Molten salt SMRs	- Enhanced safety - Low-pressure single-phase coolant systems - High efficiency - Flexible fuel cycles - Coolant: Molten salt
6. Microreactors	- Designed to generate electrical power typically up to 10 MW - Suitable for niche markets, e.g., microgrids, remote areas, disaster recovery, and critical service restoration - Coolant: Light water, helium, liquid metal, molten salt

4.2 Global deployment status of SMRs

The global deployment status of SMRs can be monitored from the Small Modular Reactor (SMR) Global Project Tracker by the World Nuclear Association (WNA), which provides information on SMR projects worldwide [13]. The platform offers project type, project status and technology

information via an interactive map-based interface. At present, two commercial SMR projects are operating [4, 13], as indicated below:

- Russian Federation: The Akademik Lomonosov floating nuclear power plant utilises two 35-MW KLT-40S pressurised water reactors (PWRs) for electricity generation. It entered commercial operation in May 2020, supplying district heating and electricity to Pevek in Chukotka. The facilities completed their first refuelling cycle in 2023.
- China: The high-temperature gas-cooled reactor-pebble bed module (HTR-PM) at the Shidaowan site entered commercial operation in December 2023. The plant generates 200 MW of electricity by coupling two reactor modules to a single power turbine.

Several additional SMR projects are expected to enter operation soon, particularly in Argentina, China, the Russian Federation, and the United States.

4.3 Status and possibility of SMRs in Thailand

Thailand established a legal and institutional framework for the peaceful uses of nuclear energy under the Nuclear Energy for Peace Act 2016, and its amendment in 2019 [14]. For the future deployment of SMRs, several government and public organisations play key roles in policymaking and planning, regulation, research and development, and power generation (Table 4). These organisations include the National Energy Policy Council, the Nuclear Energy for Peace Commission, and other groups under the Ministry of Energy (MOE) and the Ministry of Higher Education, Science, Research and Innovation (MHESI).

Table 4 Roles and responsibilities of the government and public organisations for SMRs deployment in Thailand [14–16].

Key function	Roles and responsibilities
Policy-making and planning	National Energy Policy Council: Highest national energy policymaking body • Propose national energy policies and strategic plans, including the PDP, to the Cabinet for approval. • Provide policy direction for the development and deployment of SMRs under the national energy framework. Nuclear Energy for Peace Commission: National policymaking body for the peaceful uses of nuclear energy • Propose national policies and strategic plans for the peaceful uses of nuclear energy, for example, SMR development to the Cabinet for approval. • Approve nuclear safety standards and establish licensing principles and conditions. Energy Policy and Planning Office (EPPO): Principal energy planning agency under the MOE • Serve as the secretariat to the National Energy Policy Council. • Prepare national energy plan, including the PDP, for the National Energy Policy Council consideration. • Assess the roles of SMRs in the national energy mix and their potential contribution to the long-term PDP.
Regulation	Office of Atoms for Peace (OAP): National nuclear regulatory authority under the MHESI • Serve as the secretariat to the Nuclear Energy for Peace Commission. • License and regulate nuclear facilities, including future SMR facilities. • Regulate and oversee nuclear safety, radiation protection, nuclear security, and safeguards compliance.
Research and development	Thailand Institute of Nuclear Technology (Public Organisation) (TINT): Public organisation responsible for nuclear research and development under the MHESI • Conduct nuclear research and development such as technologies relevant to SMRs. • Provide specialised nuclear technology services independently of the regulatory authority.
Power generation	Electricity Generating Authority of Thailand (EGAT): State-owned electric utility supervised by the MOE • Responsible for electricity generation, transmission, and related infrastructure development. • Conduct SMR technical feasibility studies, infrastructure planning, and site selection activities aligned with the IAEA's milestones approach and its 19 infrastructure issues. These activities involve collaboration with international technology developers, assessment of grid readiness, and preliminary evaluation of potential deployment areas, particularly in high-electricity-demand regions in the northeastern and southern parts of Thailand.

Note: Roles and responsibilities are based on current institutional mandates and may evolve if Thailand further develops its framework for SMR deployment.

SMRs are considered as a part of the country's strategy in Thailand's draft PDP2024 to achieve carbon neutrality by 2050 and net-zero GHG emissions by 2065 [10]. The draft plan proposes the deployment of two SMRs with a combined generating capacity of 600 MW (300 MW × 2 units) with commercial target operation for 2037. While government organisations are responsible for policymaking and planning,

regulation, research and development, and power generation, private-sector participation is expected to support technology development, investment, and supply-chain management. To support renewable energy integration and Thailand's net-zero emissions goals, the Global Power Synergy Public Company Limited (GPSC), a company engaged in production and distribution of electricity, steam, industrial water and utility,

has initiated a feasibility study on Generation IV molten salt reactor-based SMRs. The study evaluates site suitability, technical requirements, and economic viability consistent with timeline of the draft PDP 2024 [16]. Likewise, academic institutions play supporting roles in Thailand's SMR development in research collaborations and human competency building relating to nuclear engineering, reactor technology and nuclear safety. Nevertheless, no SMR project has yet been approved for development in Thailand, and therefore its deployment remains contingent upon technology selection, regulatory readiness, grid integration, economic feasibility, ongoing public debate, and government approval processes.

5 Conclusion

Due to their smaller size and modular design, SMRs are increasingly considered a promising option for low-carbon electricity generation in Thailand. However, their successful deployment depends on several key enabling factors. The current status of national policies, feasibility studies, and public acceptance related to the long-term deployment of SMRs has been examined, together with other critical factors, including the establishment of comprehensive legal and regulatory frameworks, international cooperation, technology transfer, nuclear power plant-related infrastructure, the development of a skilled workforce, funding and investment, and the management of safety concerns.

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