



CASE
for Southeast Asia

On behalf of:



Federal Ministry
for the Environment, Climate Action,
Nature Conservation and Nuclear Safety



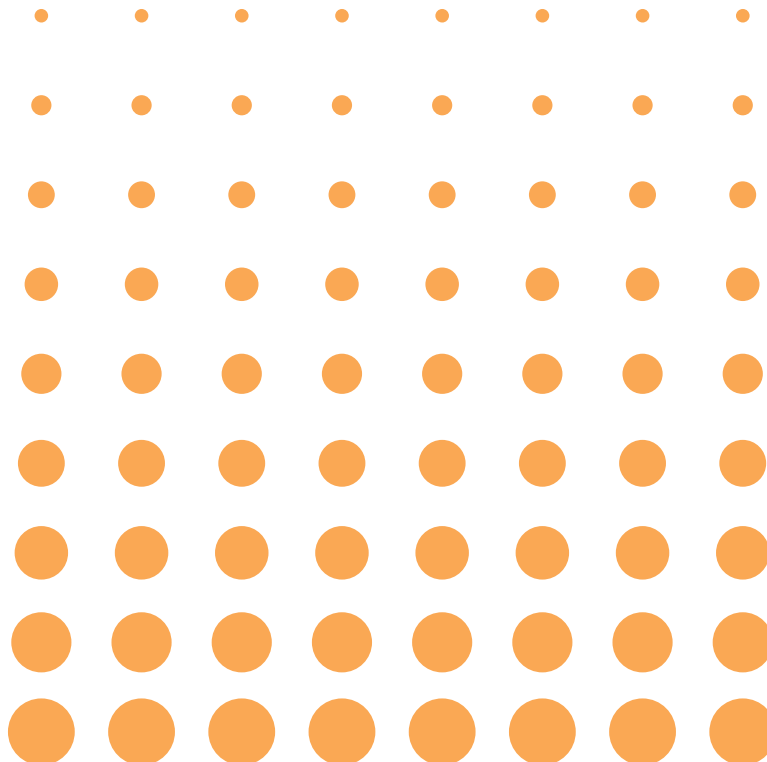
INTERNATIONAL
CLIMATE
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of the Federal Republic of Germany

EMERGING TECHNOLOGIES SERIES

Nuclear Small Modular Reactors for Southeast Asia

October 2026





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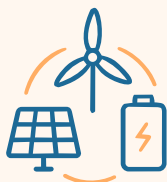
Nuclear Small Modular Reactors (SMRs) could offer firm, zero-carbon power in the future, but they remain a long-term prospect, not a near-term solution. No SMR is commercially available today, and even optimistic forecasts place commercial deployment in the mid-2030s, with meaningful capacity only expected after 2040.

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The economics of SMRs remain unproven, with costs currently far higher than alternatives. First-of-a-kind units are projected to cost several times more than large reactors or solar-plus-storage. The anticipated cost reductions depend on factory-based manufacturing at scale. However, this has not yet materialised across more than 80 existing competing designs.

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Southeast Asia's clearest near-term decarbonisation gains lie in solar, wind, grid modernisation and storage. These technologies are proven, cost-competitive and available today. They have already achieved the modular, mass-production cost declines that SMRs are still waiting to demonstrate.

4



Governments can decide to build the institutional foundations for SMRs now, without committing to deployment. Legal frameworks, regulatory capacity and technical expertise require more than a decade to build and strengthen energy governance regardless of whether SMRs are ultimately built. Early, low-cost preparation therefore preserves optionality rather than committing to a technology choice. Where resources are scarce, building the capacity needed to integrate renewables and modernise grids should take priority.

1. Introduction



After years of largely sitting on the margins of global energy policy conversations, nuclear energy has re-entered national energy agendas worldwide.

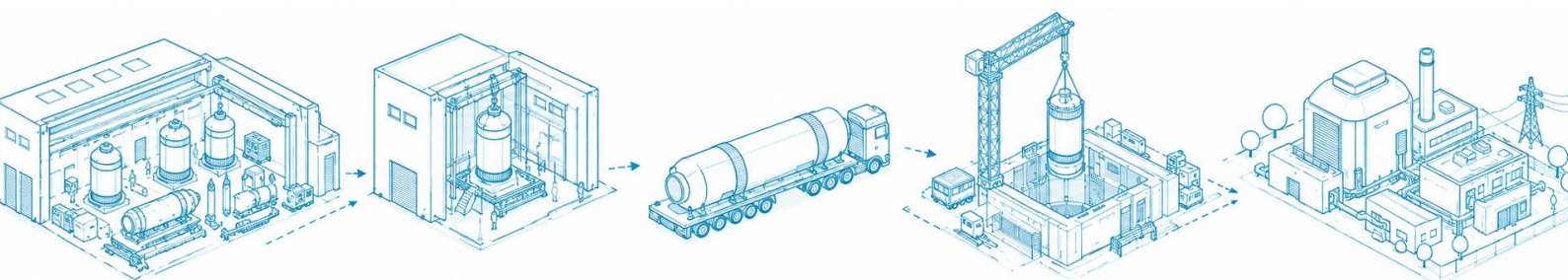
Three strategic pressures are converging. First, the sheer scale of new electricity demand—including from industrialisation, electrification and the sharp growth of data centres—has made any form of reliable and energy-dense generation capacity harder to ignore. Second, renewed energy security considerations: two energy crises in a decade have sharpened governments' anxiety about depending on imported fossil fuels and put a premium on supply diversification. Third, the urgency of decarbonisation: the Paris Agreement and national net-zero commitments continue to encourage governments to think seriously about every available source of low-carbon power.

Meanwhile, a new generation of nuclear reactor designs, in particular small modular reactors (SMRs), promises lower upfront capital costs than larger nuclear reactors, greater siting flexibility and the ability to be deployed to smaller or less stable grids where conventional large reactors are not viable (IAEA 2024c). Private sector interest, including from major technology companies seeking to power data centres with clean and firm electricity, has generated significant commercial momentum.

Southeast Asia is emblematic of these dynamics. Over the past few years, every major economy in the Association of Southeast Asian Nations (ASEAN)—Singapore, Thailand, the Philippines, Malaysia, Indonesia and most recently Vietnam—has announced its intention to consider nuclear in its future energy plans. These announcements remain expressions of intent rather than firm commitments for now, and most target deployment in the mid-to-long-term. Yet, such announcements from across the region signal renewed interest in the technology, one that justifies a closer assessment of its potential advantages and shortcomings.

Meeting growing electricity demand while cutting emissions, strengthening energy security and keeping power affordable has become an urgent priority across Southeast Asia. Policymakers are weighing a range of low-carbon options to do so. With limited fiscal space and competing investment priorities, the choices governments make in the next few years will be consequential.

This brief explores where SMRs stand today, what deploying them would require and what that means for Southeast Asian stakeholders who are weighing nuclear as part of their clean energy transitions.



2. Technology outlook



SMRs are at the centre of the renewed interest in nuclear power. The term does not describe a specific technology but rather the combination of a relatively small generating capacity (between 20 and 300 MWe) with a serial and modular deployment philosophy. Where conventional nuclear reactors pursued vertical economies of scale, concentrating as much generating capacity as possible into a single large unit (on average around 1 000 MW), SMRs pursue what might be called horizontal economies of scale: standardised, factory-built units, produced repeatedly to a common design, with costs expected to fall as cumulative output grows. This logic is not new. It is precisely the dynamic that drove the dramatic cost reductions in solar photovoltaics (solar PV) and lithium-ion batteries over the past two decades, as mass manufacturing, accumulated experience and supply chain maturation pushed prices down by over 90 percent (IEA 2024, IRENA 2025).

In principle, SMRs could follow a similar trajectory. Each largely assembled unit can be transported to site, reducing construction time and risk. Over time, as governed by rising demand or the availability of financing, each unit can be added incrementally, module by module, to form a larger nuclear power plant complex. However, the economic case for SMRs depends on whether modular production can achieve repeatable commercial deployment at scale. In addition, nuclear power carries licensing, security and safeguards costs, so a meaningful share of its cost base sits outside the factory floor where learning curves operate.

Solar PV and battery technologies succeeded through massive and sustained deployment over many years, and this process has yet to truly begin for SMRs. Russia and China currently operate only two demonstration units, and while construction has broken ground on demonstration units in the US and Canada, no SMR is commercially available¹ anywhere in the world.

Applications

SMRs are attracting attention across a range of energy applications, ranging from grid (or off-grid)-scale power generation to high-temperature industrial heat, hydrogen production and desalination. The breadth of these expected applications drives much of the current excitement. Yet, what distinguishes SMRs is their smaller unit size and modular deployment, which should make them faster and easier to deploy.

In power systems, SMRs represent a potential source of firm, dispatchable, zero carbon generation that can run continuously and be controlled to meet system needs. As wind and solar shares grow, so does the need for flexibility to maintain resource adequacy, provide reserves and ensure frequency and voltage regulation. SMRs are one option among several being considered for this role, alongside storage technologies, improved grid operations and interconnection and demand side flexibility.

¹ By 'commercially available' this brief means a design offered off the shelf, at a predictable cost and schedule, to any customer, not a one-off demonstration project that happens to sell its output; two such demonstration units (in Russia and China) are already operating on that basis.

SMRs can deliver a wide range of grid services precisely because they are controllable thermal units. Some designs are being specifically engineered for flexible operation and load following, allowing output to ramp in line with net demand or market signals.² Using an SMR for load-following rather than near-continuous operation would, however, reduce its returns and raise its costs per kilowatt-hour, since the economics of a high fixed cost, low marginal cost technology like nuclear are optimised for base-load, near full output operation.

The combination of firm output and locational flexibility is what makes data centres a particularly attractive use case for SMRs. Their relatively flat, continuous electricity demand is a natural match for nuclear output, and major technology companies are already exploring or signing long term power purchase agreements with prospective SMR projects. The possibility of co-locating SMRs with data centres and emerging digital-industrial clusters may furthermore reduce grid congestion and could help defer costly transmission investments.

A key advantage of SMRs in the power sector is their high-power density. This allows SMRs to be situated close to demand centres, including in industrial zones or on brownfield thermal plant sites, reducing the need for large new land areas or distant resource regions. Data centres exemplify this: a single SMR could in principle provide a substantial share of a campus' load from one small site, whereas matching the same continuous demand with distributed renewables would require much larger land areas and additional grid reinforcement. Repurposing retiring coal or gas stations can also exploit this density characteristic by reusing existing infrastructure, such as grid connections at sites already integrated into the transmission network.

High energy density also interacts with fuel characteristics: because fuel costs account for a small share of total nuclear generation costs, swings in fuel prices have a much smaller impact on overall generation cost than they do for gas, even though uranium prices themselves have moved substantially in recent years, tripling between 2020 and their 2024 peak. For a new conventional large nuclear plant, fuel costs typically account for around 20 percent of the levelized cost of electricity, compared to around 75 percent for a combined-cycle gas turbine. A doubling of fuel prices would raise nuclear generating cost by about 9 percent versus a 66 percent increase for gas (IEA 2020). Equivalent operating-cost data is not yet available for SMRs, but the same fuel-cycle characteristics apply in principle, and longer refuelling cycles in some designs may reduce fuel price exposure further.

² Several SMR and advanced reactor designs are being developed for load following. Some propose using molten salt storage to decouple reactor output from grid delivery, while others propose leveraging SMR modularity to vary output by bringing individual modules online or offline.



Beyond electricity, the ability to supply heat across a range of temperatures, in addition to power, opens a set of applications where heat, rather than firm electricity, is the primary product. For example, in industrial contexts where decarbonisation is difficult to achieve through electrification alone, SMRs can in principle supply continuous process heat. The temperature requirements vary significantly across industrial processes, and not all SMR designs can meet them. Chemical processing and production offer an example: a chemicals manufacturer in the United States contracted four high-temperature gas-cooled SMR reactors, each rated at 200 MW, to supply both electricity and steam (NEA 2025). Some designs also propose using SMRs for district heating. Desalination has the most established precedent: large conventional reactors are already used for this purpose, and SMRs offer a smaller-scale variant. Hydrogen production is a further application, drawing on the same heat and electricity supply logic. Across all these uses, proximity to the industrial or processing site matters, since heat is costly to transport over distance, and the smaller footprint of SMRs makes co-location more feasible than with large reactors.

These applications are genuinely plausible, but every one of them depends on SMRs first becoming available at proven cost.

State of development

Nuclear power plants rank among the most complex engineering systems ever built, integrating precision mechanical, thermal, electrical and instrumentation-and-control systems that must operate reliably under extreme conditions for decades. That complexity is mirrored in the diversity of SMR designs currently under development. More than 80 are in active development globally, spanning four broad technology families that differ in scale, coolant chemistry, fuel type, operating temperatures and safety approaches (IAEA 2024b, NEA 2025, WNA 2026b); see Figure 1. These new SMR designs draw on more than 60 years of operational experience with conventional nuclear. Most of them incorporate passive safety systems and carry smaller radioactive inventories than large reactors, both factors that IAEA and vendors argue generally reduce the likelihood and severity of accidents (IAEA 2024c).³ Independent safety reviewers (e.g. Union of Concerned Scientists 2021) are less convinced, arguing that novel coolants and fuel forms introduce their own failure modes that a smaller inventory does not automatically offset.

³Passive safety systems work using natural forces like gravity and convection, rather than pumps, motors, or backup power. This means they can continue to cool the reactor and keep it safe even if electricity or human intervention is unavailable.

Technology families

▶▶ **Water-cooled reactors** draw on the same basic technology as most of the world's existing reactor fleet, making them the most mature type and closest to deployment. Operating at relatively modest temperatures, they are suited to power generation, desalination and district heating. They operate at high pressure, and many incorporate passive safety systems that rely on gravity and natural convection rather than active pumping for emergency cooling. A marine variant that can be mounted on barges or vessels extends deployment to coastal and remote locations.

Only one water-cooled SMR is currently operational: Russia's barge-mounted floating plant, supplying heat and power to a remote Arctic community since 2020. Further projects are under construction in China and Russia, with first power generation targeted around 2030 (WNA 2026b). In the United States, the first Western SMR to receive full regulatory approval saw its flagship project cancelled in 2023 after projected costs escalated sharply and customer commitments fell short (Schneider 2025).

▶▶ **High-temperature gas-cooled reactors** use an inert gas such as helium as a coolant rather than water, which allows them to operate at significantly higher temperatures and enables a wider range of industrial heat applications. Their fuel is specifically engineered to retain radioactive material even under extreme conditions, providing an additional layer of protection over conventional fuel designs (NEA 2022).

Operational experience with this type remains limited. China has one demonstration plant in commercial operation since 2023, and several designs are under development in the United States and elsewhere, but none has yet reached construction (WNA 2026b).

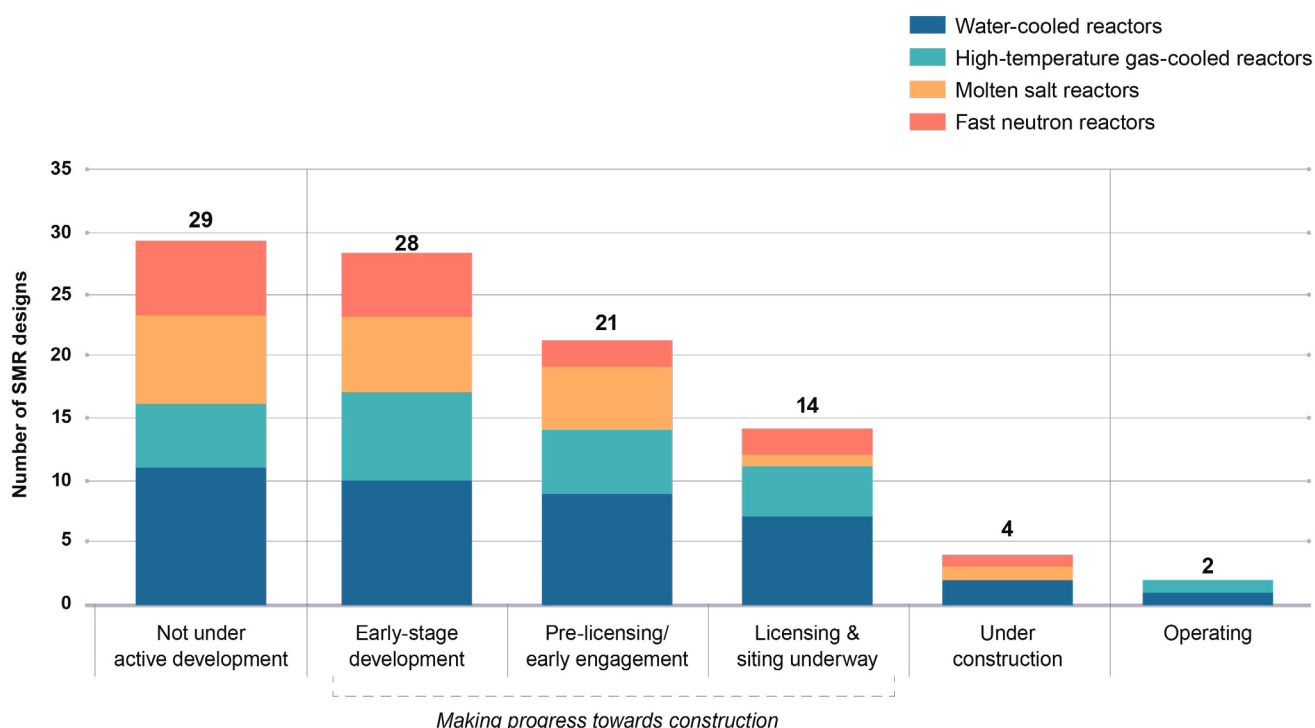
▶▶ **Molten salt reactors** operate using a fuel that has been dissolved directly into liquid salt, which helps reduce some of the failure risks associated with conventional solid fuel designs. These reactors operate at low pressures and high temperatures. The low operating pressure seeks to eliminate another failure mode common to water-cooled reactors, while high operating temperatures make them suitable for industrial heat applications. They represent the most significantly novel design of the four types (IAEA 2023).

Molten salt reactors remain at an early stage of development. The only design to have reached construction is a demonstration unit in the United States, which started construction in 2024 but will not generate electricity — its purpose is to test the technology's viability for industrial heat production. Most other designs remain at the conceptual or detailed design stage (NEA 2025).

Fast neutron reactors are cooled using liquid metal and are distinguished by their potential to run on spent fuel from conventional reactors in a closed fuel cycle, which could reduce nuclear waste volumes and improve long-term fuel security. The technology has operated at large scale, most notably in Russia, for decades, but has not translated into commercial SMR-scale deployment. Liquid metal coolants are chemically reactive and add significant engineering complexity, and the closed fuel cycle requires reprocessing infrastructure that few countries possess (WNA 2026a).

At SMR scale, fast neutron reactors remain the furthest from commercial deployment of the four families. Russia has the most advanced example, a demonstration unit currently under construction with operations targeted around 2027. Most other designs remain at a conceptual stage (NEA 2025).

Figure 1:
More than 60 SMR designs are under development globally, spanning four different technology families



Sources: 'Not under active development' and pipeline stages (NEA 2025). Under construction and operating (WNA 2026b). Notes: 'under construction' means first concrete poured. Research reactors excluded. CAREM25 excluded (abandoned December 2024, WNISR 2025).

Across all four SMR design types, no single design has emerged as a dominant standard. And within each family, multiple competing designs remain in development. This reflects a sector that remains relatively far from reaching the technological maturity required for large-scale commercial deployment, as the economics of serial production typically only take hold once a clear winning design, or small set of designs, has emerged. Regulatory frameworks in most countries were built around water-cooled reactor technology and are not well-suited to assessing the more novel concepts. This adds time and uncertainty to already long development timelines. The most optimistic credible scenario places the first commercial SMRs at scale in the mid-2030s, with meaningful deployment more likely a post-2040 story (IEA 2025). The commercial case for SMRs rests fundamentally on modularity and serial production and the expectation that standardised, factory-built units will drive down costs. Whether that dynamic materialises is the central economic question facing the sector.

3. From development to deployment: conditions for commercial viability



The costs of going first: scaling SMRs from demonstration to serial deployment

Nuclear power has long been, and remains, expensive to build, and large reactor projects are capital-intensive, slow and highly sensitive to financing conditions. As a result, they have often required strong public support, whether through loan guarantees, favourable financing or state ownership. Costs also vary widely by context. Countries with more continuous construction experience, including China and South Korea, have generally been better able to preserve supply chains, regulatory familiarity and project know-how, while countries that paused construction for long periods have found it harder to restart without major cost and schedule problems. Recent reactor projects in the UK and the United States have shown how severe overruns can become when new builds face unfamiliar supply chains, licensing complexity and execution risk. For countries with no nuclear construction history, the economics are even more uncertain because they must build institutional capacity, regulation and supply chains at the same time as the plant itself.

SMRs are proposed, in part, as a response to this problem by offering a different cost model. Unlike large reactors, which are largely custom engineered for each site, SMRs are designed for factory fabrication and repeated deployment, with costs expected to decline over time as learning accumulates, designs are standardised, and supply chains mature.

This cost logic depends on scale. The first unit of any new design, i.e., the first-of-a-kind, or FOAK, is the most capital-intensive, time-consuming and financially risky to build. The nth-of-a-kind, or NOAK, represents the point at which serial production has matured sufficiently for the economics to become competitive. Reaching NOAK requires a sustained pipeline of orders, which in turn requires investor confidence in costs that developers cannot prove until they build sufficient units.

The current state of the sector compounds this challenge. As noted in the previous section, more than 80 SMR designs are under active development globally, spanning four technology families. No single design has yet reached the volume of deployment needed to demonstrate NOAK economics, and the fragmentation of the design landscape means that the limited pool of potential orders is distributed across competing concepts rather than concentrated behind a single standardised design. In effect, the sector faces multiple simultaneous FOAK projects, each attempting to establish the commercial credibility that serial production requires.

On overnight capital cost, first-of-a-kind SMRs currently sit at around \$18 000–\$19 700/kW,⁴ well above roughly \$9 700/kW for conventional large reactors⁵ and \$2 500–\$3 500/kW for utility-scale solar paired with four-hour battery storage, though the latter does not provide equivalent firm output without significantly more storage capacity. This corresponds to electricity generation costs (LCOE)⁶ of about \$229–248/MWh for a FOAK SMR, compared to an average of \$143/MWh for conventional large nuclear reactors (\$60/MWh for Korea, \$214/MWh for a recent UK project), and \$119–162/MWh for a solar power plant with 4-hour storage.

These costs are expected to fall as deployment scales, though the pace and extent of that decline remain uncertain. Optimistic bottom-up engineering studies model what a mature, NOAK SMR industry could achieve, rather than forecasting when that maturity would be reached. One study, for example, estimates that SMRs could reach an overnight capital cost of \$4 300–\$6 400/kW under NOAK assumptions (Asuega et al. 2023). Meanwhile, the IEA ties its cost targets to an explicit horizon, judging that costs need to fall to around \$4 500/kW in the US and Europe (and \$2 500/kW in China) by 2040 for SMRs to achieve cost-competitive, large-scale deployment (IEA 2025). This would put the generation costs of SMR in the long-term to \$83–105/MWh (\$64/MWh in China), at a similar or even lower range of large reactor. Whether, and how quickly, first-of-a-kind projects converge toward these levels is an open question.

⁴ Projected overnight cost for first-of-a-kind SMRs, based on Canada's Darlington project (Graham & Hayward 2025)

⁵ Large reactors, recent projects. ~\$9 700/kW is the average of the six projects, which range from ~\$2 700/kW (Korea) to ~\$15 700/kW (UK) (IEA 2025).

⁶ These figures rest on a common set of assumptions: a 7% weighted average cost of capital, interest during construction compounded from the midpoint of the build period (5 years for SMRs, 8 years for large reactors, 1.5 years for solar+storage), a 60-year economic life for both nuclear technologies against 25 years for solar+storage, capacity factors of 90% for nuclear and 24% for solar+storage (considering an inverter-loading ratio of 1.7), and fixed O&M, fuel and decommissioning costs of \$180/kW-yr, \$13/MWh and \$1/MWh for SMRs, \$140/kW-yr, \$9/MWh and \$1/MWh for large reactors, and \$25/kW-yr, \$0 and \$0 for solar+storage. These are illustrative, not sourced or verified against the report's own figures, and the numbers move meaningfully with WACC and capacity-factor choices.

Solar PV overcame a similar dynamic through policy-driven demand aggregation. First, feed-in tariffs in Germany and then support for large-scale deployment in China created sustained and predictable demand that drove manufacturing scale-up and steep cost declines. Nuclear presents a more complex case, given that regulatory approval must be repeated independently in each jurisdiction and potential customers are far fewer than those who drove solar and wind deployment.

Resolving the FOAK-NOAK paradox therefore requires sustained commitment to multiple sequential builds over many years, supported by long-term financing, licensing frameworks, supply chains, workforce development and fuel availability. China currently holds the strongest position to generate the order volumes required, while Russia, the United States, Canada and several European countries⁷ maintain programmes at smaller scale and with greater uncertainty. Whether these programmes collectively generate sufficient volume to demonstrate competitive SMR economics remains the sector's central open question.

The need for new regulatory frameworks

Most existing nuclear regulatory frameworks were developed for large, water-cooled reactors — the technology that has dominated the sector for six decades. Novel SMR designs, particularly molten salt and fast neutron concepts, present safety and security cases, fuel cycles and operational characteristics that these frameworks were not designed to assess (see section 4 below). Regulatory bodies in leading nuclear countries — including the United States, Canada, and the United Kingdom — are actively developing new licensing pathways for advanced reactor designs, but these processes are at an early stage and add significant time and cost uncertainty to any project.

The absence of international harmonisation compounds the problem further. Each jurisdiction conducts its own independent licensing process, meaning that approval in one country provides limited relief in another. Efforts are underway, including through the International Atomic Energy Agency (IAEA)'s Nuclear Harmonisation and Standardisation Initiative, to develop more common frameworks, but meaningful convergence remains distant (IAEA 2024a, NEA 2025). For developers seeking to build across multiple markets, the regulatory burden is effectively multiplied with each new jurisdiction.

⁷ Mainly: France, the UK, Czechia, Poland, Sweden and Romania; and to a lesser extent Italy, Netherlands and Finland.

Supply chains

The supply chains required to manufacture and operate SMRs remain underdeveloped, and in some critical areas do not yet exist at commercial scale. The most widely discussed bottleneck is fuel. It is important to distinguish the fuel used in the water-cooled SMR designs closest to deployment, which generally use the same low-enriched uranium 3–5 percent as most of the world's existing reactor fleet, to the more advanced non-water-cooled designs, many of which require high-assay low-enriched uranium, or HALEU, enriched to between 5–20 percent uranium-235.

Russia is currently the only country with commercial-scale HALEU production capacity, and as of early 2025, more than half of SMR designs planning to use HALEU had not progressed beyond non-binding agreements on fuel supply. In the United States, domestic HALEU production totalled around 900 kilograms in 2024 (Office of Nuclear Energy 2025), against projected annual demand exceeding 50 metric tons by 2035 (Shenk 2025). The problem mirrors the FOAK-NOAK paradox: without committed reactor orders, fuel suppliers cannot justify the capital investment required to scale production; without assured fuel supply, reactor orders remain cautious. Long-term offtake agreements are starting to break this cycle in isolated cases, but only a handful of SMR developers have moved beyond non-binding agreements (NEA 2025). Government-funded demonstration projects, such as the US Department of Energy's co-funded HALEU enrichment facility, have also begun to add capacity independent of private offtake commitments (Office of Nuclear Energy 2025). HALEU also raises a security question distinct from supply (see section below).

Even for water-cooled designs that run on conventional uranium fuel, supply concentration is a concern. Russia controls around 46 percent of global enrichment capacity, while Kazakhstan accounts for over 40 percent of global uranium mining output (WNA 2026c). Since Russia's invasion of Ukraine, this structural dependency has become a point of concern, with European and North American governments accelerating efforts to diversify enrichment capacity (Skoczek-Wojciechowska 2023).

Beyond fuel, broader supply chain gaps are widely acknowledged. The availability of enough manufacturers of nuclear-specific equipment has been identified as a potential major bottleneck to any rapid expansion of nuclear power, which led the European Commission to establish a dedicated industrial alliance in 2024 specifically to identify gaps in the European SMR supply chain (European Commission 2026).

These supply-side constraints narrow the menu of SMR options. Whether any of them materialise into operating plants, however, depends less on reactor design than on political commitment and on the institutions that can carry a programme from feasibility to operation.

4. What an SMR programme requires

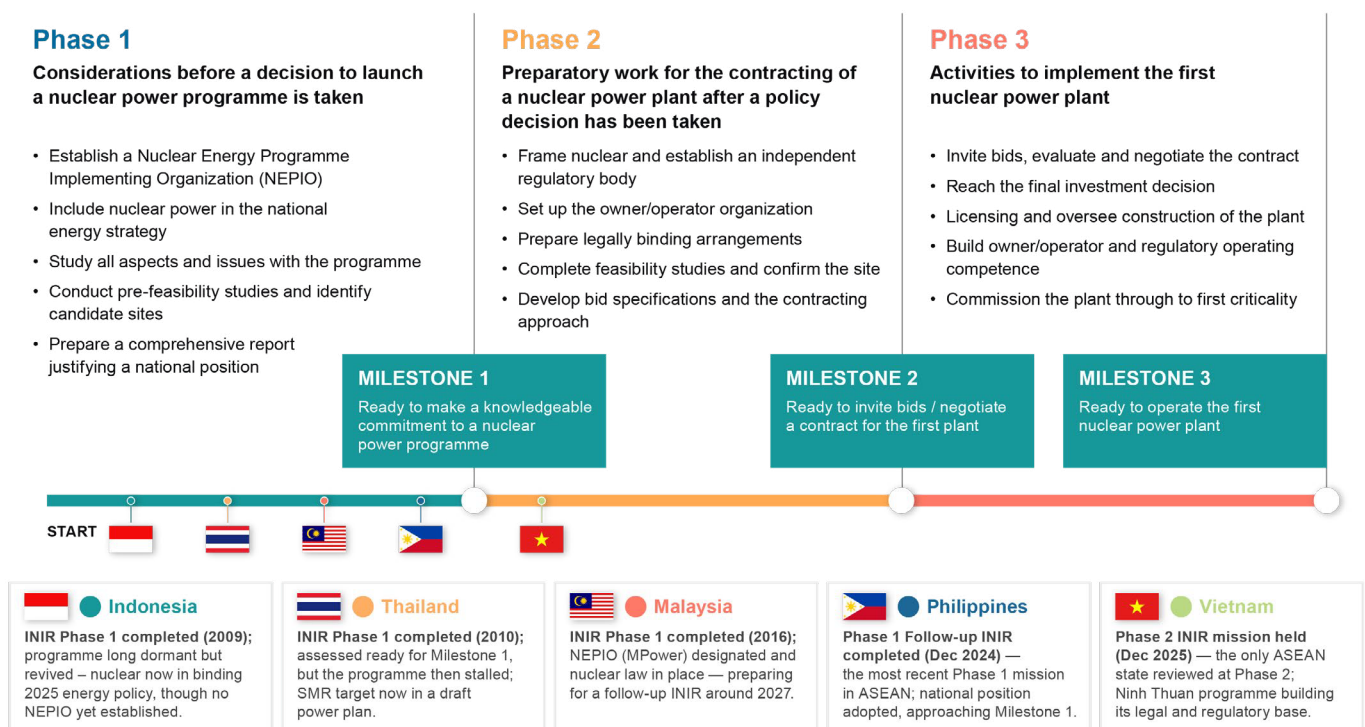


Nuclear programmes operate on timescales that far exceed normal planning horizons. A first plant typically takes 10-15 years from a formal decision to the first megawatt-hour, and the full programme lifecycle, including decommissioning, extends to a century or more, and tens of thousands of years for spent fuel and high-level waste disposal. The institutional and governance groundwork required to reach even the first decision can take years.

The IAEA has developed the Milestones approach, a phased framework for building the institutional, legal, technical and human foundations of a nuclear power programme and for clarifying the long term commitments such a programme entails (Figure 2). It divides the process into three phases, each ending with a formal readiness assessment. For a country with no prior nuclear experience, completing all three phases typically takes 15-20 years. While the Milestones approach is not embedded in a treaty obligation, and therefore not legally binding, the framework is highly influential and sets a de facto standard for countries seeking to deploy their first nuclear power plant. The IAEA supports member countries in assessing their readiness to introduce nuclear power through an Integrated Nuclear Infrastructure Review (INIR) (IAEA 2020).

Figure 2:

The IAEA Milestones Approach - ASEAN member states are in the early phases of institutional readiness



The IAEA Milestones Approach comprises three phases and three milestones toward a first nuclear power plant — with five ASEAN states placed by their most recent INIR mission. Positions are indicative; the IAEA sets no fixed timelines. Source: (IAEA 2024a)

The sections below discuss the principal institutional and governance considerations this process involves.

Political commitment

Nuclear programmes depend on political commitment sustained across decades. This encompasses an explicit government decision to pursue nuclear energy as part of a national energy strategy, sustained budgetary support across multiple cycles and continuity mechanisms that allow the programme to survive changes in government. While smaller unit size may reduce some upfront capital requirements, it does not compress the institutional timelines or reduce the governance requirements of the programme around the reactor. The commitment required to deploy an SMR is the same in kind, if not always in scale, as that required for a large reactor. Without a government willing to back the first unit through cost and schedule uncertainty, the learning curve that underpins the long-term cost case never begins.

Legal framework and Regulatory Capacity

Translating political commitment into a functioning programme requires a set of institutional and governance prerequisites. The first is a national legal framework, which establishes the rights, responsibilities and liabilities of all parties involved. This includes nuclear liability legislation, regulations governing the safe use of nuclear material and adherence to key international treaties and safeguards agreements. Safeguards are the system of verification measures administered by the IAEA to confirm that nuclear material is not diverted to non-peaceful purposes and are a legal obligation for all states operating nuclear programmes.

A national regulatory body is responsible for translating the legal framework into operational oversight — licensing reactor designs, inspecting construction and operation, enforcing compliance with safety standards and verifying adherence to safeguards agreements. Its independence from political and commercial pressures is a major source of credibility, but that credibility also depends on technical competence and effective implementation. Where regulatory processes are predictable and technically credible, they provide the stable foundation that vendors, financiers, and the public rely on; where they are not, licensing becomes unpredictable, financing risk increases, and the consistency that SMR deployment depends on is undermined. Building a regulator with genuine technical depth takes years, requiring specialist expertise that is scarce in most countries and internal processes capable of assessing complex and novel safety cases.

The specialist expertise that a regulatory body requires is part of a broader workforce challenge. Nuclear programmes depend on a range of highly specialised skills: nuclear engineers, reactor operators, safety analysts, radiation protection specialists and project management professionals with nuclear sector experience. Beyond construction, operating plants safely over decades, managing waste and eventually decommissioning facilities all demand additional technical, legal and organisational capabilities that few countries currently possess at scale. These skills develop through university programmes, technical training institutions and sustained engagement with experienced nuclear operators, and building this pipeline takes years. The IAEA advises that specialist expertise be in place well before construction begins, and some practitioners estimate that developing nuclear experts with genuine operational depth typically takes 10 to 20 years (IAEA 2024a, Viet Nam News 2025).

In countries that have paused nuclear construction for decades, these skills have often atrophied as experienced staff retire and nuclear construction roles disappear, forcing new projects to relearn basic lessons.

In the end, SMR projects draw on the same pools of expertise: smaller units require the same depth and breadth of skills required to keep reactors within safety limits and to manage their end of life obligations. As such, these fixed costs are highest in programmes planning only a few units. Importing overseas experts can help offset the capability gap but adds cost and creates potential dependencies. For example, the UAE, often cited as the fastest modern newcomer, reached first-reactor operation about 13 years after its 2008 nuclear policy by using a turnkey contract with an experienced Korean vendor and a largely expatriate workforce, building domestic capability alongside the project rather than in advance. Pooling regulatory or training capacity regionally is a viable and interesting alternative, though such coordination would require significant political buy-in.

Safety culture, i.e., the organisational values, behaviours and practices that prioritise safety at every level of a programme, is inseparable from the workforce that carries it. It develops through training and experience over time and cannot be sourced from a vendor alongside the reactor. The passive safety features increasingly incorporated into SMR designs reduce reliance on active intervention in the event of an incident, but cannot replace this broader organisational dimension or effective regulatory oversight, especially as SMR designs become more novel.

Physical and cyber security

Nuclear governance frameworks distinguish safety (preventing and mitigating accidents) from security (preventing malicious acts such as theft, sabotage and cyberattack). The IAEA groups these as the “3S”: safety, security and safeguards (IAEA, 2023b). A regulator with credible safety oversight does not automatically have the distinct expertise, in physical protection engineering, security-cleared personnel and cyber-informed design review, that security requires. Most newcomer countries need to build this capacity deliberately rather than assume it follows from safety regulation.

Physical protection requirements scale with the number of sites as well as with total capacity. A fleet of SMRs sited close to demand centres, industrial zones and data centres (see Applications, in Section 2) implies more perimeters, more guard forces and more potential targets than the same generating capacity concentrated in one or two large plants. Vendors have proposed cutting SMR security-force requirements relative to large-reactor norms, on the reasoning that smaller radioactive inventories need less protection; independent reviewers regard this as unproven, and the appropriate standard remains an open regulatory question even in countries with mature nuclear programmes. SMR designs also lean more heavily on digital instrumentation and control than most of today’s large-reactor fleet, and regulators including the US NRC are still developing cybersecurity-by-design guidance specific to advanced reactors; no equivalent guidance yet exists in Southeast Asia.

Waste management and environmental protection

Because spent fuel and other high-level nuclear wastes remain hazardous for periods extending to 100 000 years or more, waste management is fundamentally an institutional and environmental question rather than a reactor-design detail. Decisions about who is responsible for spent fuel and other radioactive waste, how long-term liabilities are funded, and where different waste streams will be stored or disposed of all require dedicated governance arrangements, public consent and environmental assessment specific to the design and site chosen. Some SMR designs may produce more complex or unfamiliar waste streams than today’s large reactors, which would demand new packaging, licensing and repository strategies. Around the world, most high-level waste remains in interim storage while countries work toward deep geological repositories; a handful of programmes are under development, but globally no country yet has a fully operational permanent repository for high-level waste.

The preparation process described above is long and carries real costs in time, resources and institutional attention that could be directed elsewhere. It is also partly compressible: while much of the groundwork can proceed alongside early project development rather than in strict sequence, a reactor cannot be built until the legal framework, an independent regulator and credible licensing capacity are in place. Institution-building and construction may overlap, but the institutions must lead.

Still, the decision to begin building institutional capacity for nuclear energy is not the same as a decision to build a reactor. The process is staged, with each phase ending in a formal readiness assessment. Foundational work to develop domestic institutions is worth beginning even before committing to a project. The governance frameworks, regulatory capacity and technical expertise accumulated along the way have applications beyond nuclear, and a country that has worked through the early phases is better placed to make an informed decision when technology and economics eventually mature.

5. Assessing the potential for SMRs in Southeast Asia



Southeast Asia's engagement with nuclear energy spans more than five decades, though it remains without an operating power reactor. Several ASEAN states explored nuclear power in response to the oil shocks of the 1970s and rising electricity demand in the decades that followed. The most advanced effort was the Philippines' Bataan Nuclear Power Plant, a 620 MW facility completed in the early 1980s but never fuelled or operated, following the 1986 political transition, post-Chernobyl safety concerns, and independent seismic and volcanic-hazard reviews flagging its proximity to Mount Natib and an active fault line. The siting lesson is directly relevant to any future SMR programme in the region: the Philippines and Indonesia both sit on the Pacific Ring of Fire, and siting criteria will need to screen for seismic, volcanic and typhoon exposure alongside the institutional criteria discussed below.

Other countries—Indonesia, Vietnam, Thailand and Malaysia—developed plans and conducted feasibility studies during the 1980s and 2000s, but repeatedly deferred or cancelled commitments, particularly after Chernobyl and again after Fukushima in 2011. In parallel, several countries built research reactors and developed regulatory capacity for non-power nuclear applications, creating pockets of technical expertise without full power reactor programmes.

Since around 2015, and more sharply after 2020, a combination of rising electricity demand, decarbonisation pressure and gas price volatility has returned nuclear to policy agendas across the region, increasingly with SMRs in view. Vietnam's parliament voted in 2024 to restart its long-deferred Ninh Thuan nuclear project; Indonesia has announced plans for up to 10 GW of nuclear capacity by 2040 (Viet Nam News 2025); the Philippines is targeting its first nuclear plant around 2032 and assessing both SMRs and a potential revival of Bataan (PIA 2024); Thailand and Malaysia are pursuing feasibility studies and SMR cooperation agreements (Bernama 2026, EGAT 2025). These announcements reflect genuine policy intent, though even optimistic assessments suggest that ASEAN's first commercial nuclear generation is unlikely before the 2030s (NEA 2025).

Applications in context

The applications for which SMRs are considered most promising globally—grid-scale power, industrial heat, data centres and off-grid supply—all have some relevance in Southeast Asia, though the fit is uneven. Grid-scale power is the least straightforward case, because the region has abundant renewable potential and SMRs would have to compete against options that are getting cheaper and more competitive over time; their main attraction is therefore not cost, but the fact that they provide energy-dense, firm, dispatchable power in a form familiar to utility planning. Data centres are the most actively discussed use case, because the IAEA notes both strong interest from technology companies and rapidly rising data-centre electricity demand, while Southeast Asia's digital buildout makes that logic especially relevant. Off-grid and island supply is another plausible niche, particularly in Indonesia and the Philippines, where geography creates real demand for reliable distributed generation; here SMRs are technically relevant, though renewables-plus-storage are also advancing quickly.

Institutional context

Most countries in Southeast Asia are still at an early stage of the institutional preparation required for a nuclear programme. Against the IAEA Milestones framework, many remain in Phase 1 (consideration stage) or are only beginning Phase 2 (preparation stage), working through national positions, feasibility studies and the legal and regulatory foundations needed for eventual implementation (see Figure 2).

Two countries stand out as more advanced. The Philippines adopted a national position in 2022 and has started to advance its nuclear legislation. The country aims to establish the legal and regulatory framework for nuclear energy and start accepting nuclear project applications by the end of 2026, citing ambitious targets of 1 200 MW nuclear capacity by 2032, scaling up to 4.8 GW by 2050 (Esmael 2025). However, an IAEA mission review in December 2024 indicated that further work is needed to finalise the Philippines' nuclear power strategy and to complete necessary studies for future activities related to the electrical grid, industrial involvement and national legislation (IAEA 2024d).

Vietnam restarted its nuclear programme in 2024 after cancelling it in 2016 and has begun talks with foreign suppliers. Although Vietnam has advanced its preparations into Phase 2, the long suspension left it with significant rebuilding to do. An IAEA review of the programme identified the need to strengthen the legal and regulatory framework and to reinforce human resource capacity across all areas — reflecting the dispersal of trained personnel into other sectors after the 2016 cancellation, and a regulatory framework built for a programme that never reached construction (IAEA 2025).

Combining the current institutional position of most countries in the region with the mid-2030s commercial availability timeline for SMRs, the most ambitious estimates of first deployment are more likely to fall in the late 2030s –2040s for the most advanced countries, and later for others.

Economics and dependency

SMR projects carry high upfront capital requirements, and the hoped-for advantage of modular, incremental deployment depends on a commercial model that has yet to materialise. For Southeast Asian governments, many of whom face tight fiscal budgets and higher borrowing costs than their Organisation for Economic Co-operation and Development counterparts who are currently pursuing SMRs, these capital requirements pose a more acute constraint. In practice, any early deployment of SMRs would require strong government involvement, whether through direct ownership, loan guarantees or long-term power purchase agreements.

The dependency issue extends beyond financing. SMRs will need to be imported, which includes a reliance on external suppliers and, depending on the technology, spent-fuel or waste arrangements. At present, Russia and China are the only countries with experience in operating SMRs, and could offer integrated financing and construction packages that can cover the bulk of upfront costs, while most Western vendors remain earlier in the deployment pipeline. Supplier choice would therefore determine not just the SMR type, but the financing structure, technology-transfer terms, and would likely be based on the foundations of a long-term strategic relationship. The latter involve overlapping energy, security and geopolitical considerations extending well beyond the remit of energy ministries.

Opportunity cost

The economics of SMR deployment cannot be assessed in isolation from competing investment priorities. Southeast Asia has abundant renewable potential that remains largely untapped. Scaling solar and wind power, expanding and modernising grid infrastructure and investing in storage and demand-side flexibility are all options available now and at demonstrated and falling cost. These investments address the region's near-term energy challenges directly and deliver value regardless of how the SMR story unfolds over the coming decades.

Nuclear, including SMRs, by contrast, requires a sustained governance commitment that includes institutional development, technical capacity and financing over many years before a single megawatt-hour is generated. The institutional groundwork that includes legal frameworks, regulatory capacity and workforce development typically takes 15–20 years under the IAEA Milestones framework, and most countries in the region are still in the early phases of that process. How governments sequence these competing demands, and what weight they assign to longer-term nuclear preparation relative to near-term energy transition investments, is a question each will need to work through considering its own circumstances and resource constraints.

Beginning institutional preparation has value independent of any eventual decision to pursue nuclear energy and preserves rather than precludes future options. Financial or political commitments to specific projects or suppliers, by contrast, are harder to reverse — and at a stage when technology costs and commercial models remain unproven, they transfer risk onto governments before the evidence base for those decisions is available.



Consideration 1:

Prioritise proven, near-term solutions

Southeast Asia's clearest near-term gains lie in scaling solar and wind, modernising grids and investing in storage and flexibility. Solar, wind and batteries are proven, cost-competitive and available today, having already benefitted from the modular, mass-production model that SMRs have yet to demonstrate. Modernised and more flexible grids underpin a clean, secure and resilient power system. They improve reliability and integrate more low-cost renewables while remaining a prerequisite for any potential SMRs or conventional nuclear in the future.



Consideration 2:

Treat SMRs as a long-term, high-uncertainty option

SMRs could provide firm, zero-carbon power in smaller, mass-produced units, but today remain a long-term prospect rather than a near-term solution. The technology remains commercially unavailable, and even optimistic forecasts place deployment in the mid-2030s at the earliest, with meaningful deployment only in the post-2040 period. This uncertainty is rooted in economics and an immature market. First units built are currently projected to cost several times more per kilowatt than either large reactors or solar-plus-storage. Further uncertainty remains in the costs of waste disposal, insurance and nuclear incidents and severe gaps in regulatory frameworks.



Consideration 3:

Build institutional readiness without committing to deployment

Southeast Asian countries can begin building the institutional foundations for SMRs now, at low cost and without committing to deployment. The legal and regulatory frameworks, technical knowledge base, and safety culture that SMRs require may take well over a decade to build. Much of this foundation, including integrated system planning, an empowered regulator, and technical expertise, will strengthen energy sector governance regardless of whether SMRs are ultimately deployed. Since moving first offers no strategic advantage, this readiness can be built gradually, leaving decisions on specific designs or suppliers until costs and commercial models are proven. Beginning this preparation preserves rather than precludes future options. Where regulatory and institutional resources are scarce, building the capacity needed to integrate renewables and modernise grids should take priority.



Consideration 4:

Monitor the global SMR market before committing capital

SMRs aim to cut technology costs through serial, factory-based production, but that model has yet to materialise. Prices will fall only as a sustained pipeline of orders generates cost reductions through learning. Yet, with more than 80 designs under active development, no single design has yet attracted the order volume that serial production requires. Southeast Asian countries should monitor how this progresses rather than making commitments and risking stranded investments.



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Analysis

Emerging Technologies Series: Nuclear Small Modular Reactors for Southeast Asia

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Published by

The project Clean, Affordable and Secure Energy for Southeast Asia (CASE), funded by the German Federal Ministry for the Environment, Climate Action, Nature Conservation and Nuclear Safety (BMUKN) via the International Climate Initiative (IKI)

Suggested citation

Agora Energiewende (2026): Emerging Technologies Series: Nuclear Small Modular Reactors for Southeast Asia. Clean, Affordable, and Secure Energy for Southeast Asia project.

About CASE

The project Clean, Affordable and Secure Energy for Southeast Asia (CASE) supports power sector transitions in Indonesia, Thailand, Viet Nam and the Philippines through evidence-based analysis and narrative change. The project supports decision-makers, industry leaders and consumers in enacting strategic reforms in the power sector in pursuit of the Paris Agreement goals and a just transition.

About Emerging Technologies Series

Nuclear Small Modular Reactors for Southeast Asia is the third part of the Emerging Technologies Series published by the project Clean, Affordable and Secure Energy for Southeast Asia (CASE). The series explores key topics in current energy policy discussions and aims to unpack common misconceptions around emerging technologies. Designed for policymakers, practitioners and energy transition stakeholders, each fact sheet provides a concise summary of current discussions and key facts to support informed decision-making in the region.

Acknowledgements

Special thanks go to the experts who reviewed drafts and provided feedback: Hanna Fekete (NewClimate Institute), Maximilian Heil and Palita Srichaisuphakit (GIZ), Dimitri Pescia, Ernst Kuneman, Intan Cinditiara (Agora Energiewende)

