

FINANCING AND INSTITUTIONALIZING MICRO-NUCLEAR REACTORS IN PAKISTAN: A POLICY FRAMEWORK

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Abstract

Pakistan faces a long-running energy crisis. Electricity is expensive and unreliable and this has slowed the country's economic growth. At the same time, Pakistan has real experience with civilian nuclear power. It currently operates six reactors. Their combined capacity is about 3,262 megawatts. This paper looks at a newer technology: micro-nuclear reactors. These are small, factory-built reactors. Most generate 20 megawatts of electricity or less. A few designs reach up to about 50 megawatts. The paper asks a simple question. What financing models could bring micro-reactors to Pakistan? And what policy steps would make that adoption last? The paper reviews four financing pathways. These are public-private partnerships, green bonds and climate finance, international technology transfer, and power purchase agreements. It also places micro-reactor financing inside a wider climate and nuclear-diplomacy framework. This includes carbon markets, diplomatic bargaining, institutional reform, and public awareness campaigns. The paper argues that micro-reactor adoption is financially and technically possible for Pakistan. But success depends on sequencing. Financing must be paired with regulatory modernization and stronger institutions. The paper closes with a set of policy recommendations for Pakistani decision-makers.

INTRODUCTION

Pakistan's energy problems are not new. Electricity has long been expensive and inconsistent. This has held back economic growth. It has also limited Pakistan's ability to share in the region's rising prosperity (Dawn 2024). At the same time, Pakistan has a real record in civilian nuclear power. The country operates six nuclear reactors. All six were built by the China National Nuclear Corporation (CNNC). Together, they produce about 3,262 megawatts of electricity (World Nuclear Report 2025). This fleet includes two

Hualong One reactors near Karachi, known as K-2 and K-3. It also includes four CNP-300 units at Chashma. In 2023, nuclear power supplied 17.4 percent of the national grid. That is up from 16.2 percent the year before (Dawn 2024).

A newer nuclear technology is now drawing global attention. Micro-nuclear reactors are compact, factory-built systems. They are designed to serve decentralized and off-grid energy needs. Designs such as Westinghouse's eVinci and Radiant Industries' Kaleidos are leading examples. Both show how nuclear power can move beyond large,

centralized grids. They can reach remote areas, mission-critical sites, and off-grid communities (PowerMag 2024; U.S. Department of Energy 2025).

This paper asks two questions. First, what financing models could support micro-reactor development in Pakistan? Second, what policy architecture would let Pakistan institutionalize this technology as part of a climate-resilient, human-security-oriented energy strategy?

Methodology

This paper uses a qualitative, document-based policy analysis. It does not run new experiments or collect primary field data. Instead, it draws on secondary sources. These include government and regulatory documents, international agency reports, industry news, and academic literature. The sources cover three areas. The first is the technical status of micro-reactor designs internationally, especially eVinci and Kaleidos. The second is Pakistan's existing financing and regulatory institutions. This includes the Public-Private Partnership Authority, the Pakistan Nuclear Regulatory Authority (PNRA), and past green bond issuance. The third is the wider climate finance and nuclear diplomacy literature. The analysis proceeds in three steps. First, it maps the global micro-reactor landscape. It also clarifies how micro-reactors differ from small modular reactors (SMRs) more broadly. Second, it evaluates four financing pathways against Pakistan's existing institutional track record. Precedent projects are

used as evidence of feasibility. They are not treated as guarantees of transferability. Third, the paper applies securitization theory, drawn from the Copenhagen School of security studies, to explain why financing alone is not enough (Buzan, Wæver, and de Wilde 1998; Heinrich and Szulecki 2018). Securitization theory holds that an issue becomes a security priority when it is framed, accepted, and acted on as an existential concern by relevant audiences. Applied to energy, this means public trust and institutional credibility matter as much as technical feasibility. This framework is used to structure the discussion and policy recommendations. It is not used to generate new primary data. All monetary figures are reported in the currency and year stated in the original source.

Results

What Are Micro-Nuclear Reactors, and How Do They Differ from SMRs?

Micro-reactors are a subset of the broader small modular reactor (SMR) category. A conventional nuclear reactor typically produces around 1,000 megawatts of electricity (MWe) or more per unit. International bodies generally define SMRs as reactors with an output of up to 300 MWe (World Nuclear Association 2026a). Micro-reactors sit at the smallest end of that range. Most definitions place them at 20 MWe or below. A few sources extend the ceiling closer to 50 MWe (U.S. Energy Information Administration 2026; World Nuclear Association 2026a). Table 1 sets out the main differences between the two categories

Table 1. Micro-reactors compared with small modular reactors (SMRs)

Dimension	Micro-Reactors	Small Modular Reactors (SMRs, broader category)
Typical electrical output	Usually 20 MWe or less; some definitions extend to about 50 MWe	Up to 300 MWe per module
Relationship between the two	A subset of SMRs	Broader category; includes micro-reactors as its smallest tier

Physical size and transport	Roughly container-sized; can be shipped by road, rail, or air as a complete unit	Larger; factory-built and modular, but not typically road-transportable as one piece
Grid role	Off-grid, remote, backup, or microgrid use	Can serve centralized grid roles as well as remote or industrial sites
Refuelling interval	Often five to eight-plus years without refuelling (e.g., eVinci, Kaleidos)	Varies by design; generally longer construction and deployment cycles
Typical use cases	Remote communities, military bases, disaster relief, diesel-generator replacement	Grid-scale power, industrial parks, larger district heating schemes
Example designs	Westinghouse eVinci, Radiant Kaleidos	NuScale, Rolls-Royce SMR, China's HTR-PM

Source: compiled by the author from World Nuclear Association (2026a), U.S. Energy Information Administration (2026), IAEA (2025b),

Two designs show where the technology currently stands. Westinghouse's eVinci is built to deliver up to 5 MWe. It uses passive heat-pipe cooling with very few moving parts. It can run for eight years or more without refuelling (PowerMag 2024). Radiant's Kaleidos is a 1.2 MWe high-temperature, gas-cooled design. It is built to run for about five years between refuelling cycles. It is also designed to replace diesel generators (U.S. Department of Energy 2025). Both are being tested through the U.S. Department of Energy's Demonstration of Microreactor Experiments (DOME) program at Idaho National Laboratory. Westinghouse, Radiant, and Ultra Safe Nuclear Corporation received an initial USD 3.9 million in October 2023 for early engineering work. A further USD 5 million followed in November 2024. This funded detailed engineering and safety analysis. The first fuelled reactor experiments are expected as early as spring 2026 (U.S. Department of Energy 2025; World Nuclear News 2024). Radiant has separately raised USD 160 million in venture funding. This points to real private-sector confidence in the technology (World Nuclear News 2024).

Micro-reactors run largely on their own. They also cost little to operate. Because of this, they could replace diesel and gas generators in several sectors. Likely candidates include agriculture, healthcare, construction, mining, and data centres. Diesel power is expensive in these settings. It is also environmentally damaging. Micro-reactors could also support water purification, district heating, disaster recovery, and remote or military power needs. They are best understood as a complement to utility-scale nuclear and renewable power. They are not a replacement for either.

Why Pakistan Needs Micro-Reactors?

Pakistan's energy crisis is structural, not seasonal. Chronic shortfalls, an ageing transmission grid, and heavy reliance on imported fuel expose the economy to price shocks and foreign-exchange pressure. Micro-reactors offer three advantages that set them apart from both utility-scale nuclear power and variable renewables.

- **Decentralized deployment.** Micro-reactors can power remote or off-grid areas, disaster zones, and military sites. They do not depend on an already-stressed national grid.

- Diesel displacement. Mining, agriculture, and data centres rely heavily on costly, high-emission diesel power. These sectors stand to gain the most from a like-for-like replacement.

- Fuel-cycle independence. eVinci and Kaleidos units can run for five to eight-plus years without refuelling. This removes the logistical burden of constant fuel deliveries, a burden that is especially heavy in Pakistan's more remote regions. Integrating micro-reactors could strengthen Pakistan's energy security. It could also reduce the country's ecological footprint and support more sustainable growth. However, financing remains the central obstacle. Micro-reactor projects need substantial upfront capital. Pakistan's regulatory environment is also built around large, centralized reactors, not small, distributed ones. Section 3.3 evaluates four financing pathways that could help close this gap.

Financing Pathways

- ***Public-Private Partnerships (PPPs)***

Public-private partnerships give the government a proven route to work with private investors. Private capital would provide the upfront investment. The public sector would provide regulatory support and risk-sharing guarantees. Pakistan's PPP framework has matured over the past decade. The federal Public-Private Partnership Authority (P3A) was created under the Public Private Partnership Authority Act of 2017 (RIAA Barker Gillette PK 2025; Public-Private Partnership Authority [Pakistan] 2026). Models already used in Pakistan include build-operate-transfer (BOT), build-own-operate-transfer (BOOT), and design-build-finance-operate-transfer (DBFOT).

These have financed major projects. Examples include the Lahore-Islamabad Motorway overlay, in operation since 2016, and the Lahore-Sialkot Motorway, in operation since 2017, both built on a BOT basis (RIAA Barker Gillette PK 2025).

These precedents show that Pakistan can structure and run large, multi-year infrastructure PPPs. That institutional capacity could be adapted

to micro-reactor projects. This would require nuclear-specific risk allocation and liability rules built into contracts from the start.

- ***Sovereign Green Bonds and Climate Finance***

Pakistan is one of the countries most exposed to climate change. This gives it a case for issuing sovereign green bonds to attract international clean-energy investors. The clearest example is the Indus Bond. The Water and Power Development Authority (WAPDA) launched it on 28 May 2021. It was Pakistan's first Green Eurobond. The ten-year, dollar-denominated bond raised USD 500 million at roughly 7.5 percent interest.

It financed the Diamer-Bhasha and Mohmand dam projects (Dawn 2021). The bond was oversubscribed by about six times. It attracted close to USD 3 billion in orders from investors including Goldman Sachs, BlackRock, and Fidelity (Dawn 2021; Institute of Strategic Studies Islamabad 2021). The Indus Bond financed hydropower, not nuclear infrastructure. Even so, it shows that Pakistani parastatal entities can access international green-capital markets on their own credit standing. That template could, in principle, extend to a dedicated clean-nuclear bond. International climate-finance mechanisms under the UN framework may also offer grants or low-interest loans. This would require framing and reporting micro-reactor projects as low-carbon, climate-mitigation infrastructure.

- ***International Collaboration and Technology Transfer***

Bilateral agreements are likely to remain central to Pakistan's nuclear financing strategy. Pakistan has a limited domestic reactor-manufacturing base. It is also excluded from Nuclear Suppliers Group markets, since it has not signed the Nuclear Non-Proliferation Treaty. China has been Pakistan's main nuclear partner since the 1970s. It has supplied all six of Pakistan's operating reactors through CNNC (World Nuclear Report 2025). Construction of Chashma-5 began in December

2024. It is a 1,117 to 1,200 MWe Hualong One unit. It is also the first non-Russian nuclear newbuild construction start anywhere in the world in five years.

The deal is estimated at USD 3.4 to 4.8 billion, financed mainly through Chinese credit (World Nuclear Report 2025; IAEA 2025a). PNRA issued the construction license for Chashma-5 in December 2024. This came after a review of the plant's safety, radiation protection, and waste-management submissions (Pakistan Nuclear Regulatory Authority 2026a). Chashma-5 is a utility-scale project, not a micro-reactor. But it shows the depth of the Pakistan-China nuclear financing relationship. It suggests a plausible channel through which micro-reactor technology and concessional financing could also be pursued. Deeper engagement with the IAEA's small modular reactor working groups could further build Pakistan's credibility as a responsible actor in nuclear innovation.

- **Power Purchase Agreements (PPAs)**

A further option is structuring power purchase agreements. Industrial off-takers, such as textile manufacturers, mining operators, and military facilities, would commit to buying power from micro-reactors over a fixed term. This gives private investors the financial predictability they need before committing capital to first-of-a-kind nuclear infrastructure. Pakistan already has a PPA track record in renewables. The Sindh Engro Coal Mining Company signed a private PPA for a 5 MW solar system on a fifteen-year take-or-pay basis. COMSATS University Islamabad contracted a 300 kW solar PPA with DCH Solar Giga on a build-own-transfer basis. More broadly, the Central Power Purchasing Agency already manages standardized energy-purchase agreements for solar, geothermal, wind, and hydropower producers on behalf of WAPDA-owned distribution companies. This institutional and contractual base could extend to micro-reactor generation with modest adaptation.

Regulatory and Governance Gaps

Micro-reactors typically generate under 20 MWe. This gives them flexibility and passive-safety features that set them apart from larger SMRs, which remain better suited to centralized grid roles. Even so, deployment faces real regulatory hurdles. Licensing frameworks built for large, centralized reactors do not easily fit micro-reactors' distributed model, smaller footprint, and factory-built supply chain. Streamlining licensing, re-evaluating emergency-planning zones for smaller thermal outputs, and strengthening independent oversight are all necessary steps.

Pakistan's regulator, PNRA, was established in 2001. It is responsible for reactor licensing, safety inspection, and oversight of radioactive materials (Wikipedia 2026c; Islamabad Policy Institute 2025). PNRA's licensing experience, most recently shown in the Chashma-5 construction license, points to real regulatory capacity. But that capacity has been built around large, centralized plants. A distinct micro-reactor licensing track, informed by international collaboration and IAEA guidance, would be needed. This would help avoid diluting safety and non-proliferation commitments while still pursuing faster deployment timelines.

Growing private-sector interest internationally is also pushing regulators worldwide to speed up approvals. This carries a real risk. Oversight capacity may not keep pace with commercial pressure. Several micro-reactor designs use higher-enrichment fuels. This raises proliferation-sensitivity concerns. Those concerns require strict domestic and international controls.

Climate and Diplomacy Policy Tools

Financing alone is not enough. It needs a matching policy architecture that places nuclear energy, including micro-reactors, inside Pakistan's wider climate and foreign-policy strategy. Nuclear power is among the lowest-carbon electricity sources available. It emits no greenhouse gases during generation. Across its full life cycle, independent reviews place nuclear emissions in a similar range to wind power. This is well below solar, coal, and gas (World Nuclear Association

2026b; Earth.Org 2022). One United Nations-linked assessment placed nuclear's lifecycle footprint as low as roughly 5 to 6 grams of CO₂-equivalent per kilowatt-hour. Coal-fired power, by comparison, runs into the hundreds of grams (Earth.Org 2022). Nuclear power is also far less waste-intensive than coal. A large coal plant produces vastly more solid waste each year than an equivalent nuclear reactor (World Nuclear Association 2026b). Five policy instruments can help turn this advantage into a coherent national strategy.

- **Carbon Markets**

Domestic carbon markets are central to meeting the targets in Pakistan's Updated Nationally Determined Contribution (NDC) of 2021. That NDC commits Pakistan to a 60 percent shift toward renewable energy in its power mix. It also commits to a 30 percent shift to electric vehicles by 2030 (UNFCCC 2021; NDC Partnership 2026). Carbon markets allow the trading of carbon credits. They offer a cost-efficient way to cut emissions. They could extend financial incentives to clean-energy projects, including micro-reactors, provided market design protects environmental integrity and vulnerable communities.

- **Diplomatic Bargaining**

Pakistan can use its long-standing strategic partnerships, particularly with China, and potentially with Iran and Saudi Arabia, to negotiate nuclear-technology transfer and investment. This should be framed around climate resilience, not strategic deterrence. Pakistan has not signed the Non-Proliferation Treaty. This limits its access to formal international nuclear trade. Even so, it can stress the civilian, peaceful character of its nuclear ambitions. It can also seek collaboration through platforms such as the Shanghai Cooperation Organisation, where China, Russia, and Pakistan each bring distinct nuclear capabilities.

- **Institutional Reform**

Establishing a dedicated nuclear policy wing for peaceful purposes would give Pakistan's energy and environmental governance more institutional clarity. Such a wing would develop legislation and standards for peaceful nuclear applications. This would cover energy, medicine, and research, in line with international best practice. It would also coordinate directly with the IAEA. This would reinforce Pakistan's credibility as it pursues technology transfers and climate financing.

- **Public Awareness and Capacity-Building**

Working with the IAEA's Peaceful Uses Initiative, Pakistan should launch awareness campaigns. These should highlight the peaceful use of nuclear technology in energy, healthcare, and agriculture. Such programmes can draw scientific talent. They can build public understanding and strengthen confidence in nuclear energy. Under securitization theory, this kind of audience acceptance is a precondition for expanding any civilian nuclear programme (Buzan, Wæver, and de Wilde 1998).

- **Blended Climate-Auction Financing**

Pakistan could also draw on the World Bank's climate-auction financing model. This model has three parts. First, competitive auctions set price guarantees for future climate results, at the minimum price the private sector needs (World Bank Group 2014; World Bank Group 2026). Second, funds are only disbursed after independent verification of climate results. This ensures observable progress comes before payment. Third, public and private actors explicitly share risk. Applied to micro-reactor financing, this structure would let Pakistan attract private capital while limiting public exposure to construction and performance risk.

- **Ministerial Coordination**

None of these instruments work in isolation. Effective delivery needs coordinated engagement between the Ministry of Planning, Development and Special Initiatives and the Ministry of Climate

Change and Environmental Coordination. Together, these ministries should sequence and implement a unified framework. This framework should link climate strategy, energy planning, and nuclear governance.

Discussions

The evidence here points to a specific conclusion. Pakistan's constraint on micro-reactor adoption is not a lack of viable financing instruments. PPPs, green bonds, technology transfer, and PPAs are all functioning already within Pakistan's existing infrastructure-finance system. The real constraint is the absence of an integrated framework. That framework needs to sequence financing alongside regulatory modernization.

Consider a hypothetical example. A green bond issuance without a dedicated micro-reactor licensing track would raise capital for a project that could not clear regulatory approval on a competitive timeline. Diplomatic bargaining for technology transfer is unlikely to succeed on its own, either. It needs a domestic institutional counterpart, such as the proposed nuclear policy wing. That body would need to credibly represent Pakistan's civilian nuclear intentions to international partners and financiers.

This points to a layered sequencing logic. Regulatory modernization and institutional reform should come before, or alongside, large-scale financing mobilization. They should not follow it. Public awareness programmes function as a precondition for durable public acceptance of nuclear expansion. This aligns with the securitization-theory literature on nuclear energy. That literature finds that public trust and regulatory credibility, not technical risk alone, determine the long-term viability of nuclear policy (Buzan, Wæver, and de Wilde 1998; Heinrich and Szulecki 2018).

This analysis has limits. It relies on secondary and open-source data. Cost estimates for Pakistani precedent projects, such as Chashma-5 and the Indus Bond, come from third-party reporting rather than official government audits. Micro-

reactor designs referenced here, including eVinci and Kaleidos, remain in the testing and demonstration phase internationally. Neither has reached full commercial deployment anywhere in the world yet. Any Pakistan-specific financing estimate would need updating once a design is selected and a site is identified.

Conclusion and Policy Recommendations

Micro-nuclear reactors offer Pakistan a technically credible and increasingly commercially proven route to address chronic, decentralized energy shortfalls. They can also contribute to national and global decarbonization goals. The financing instruments already exist within Pakistan's institutional experience. Public-private partnerships, green bonds, technology-transfer relationships with China, and power purchase agreements all require adaptation, not invention. The binding constraint is not capital availability. It is the absence of a coordinated regulatory, institutional, and diplomatic framework. That framework needs to sequence capital toward a first-of-a-kind micro-reactor deployment. Pakistan already has the institutional experience to structure billion-dollar utility-scale nuclear financing, as shown by Chashma-5. It has also shown it can independently access international green-capital markets, as shown by the Indus Bond. Given this, the case for micro-reactor adoption rests less on feasibility and more on political will and institutional sequencing. This is, in effect, a securitization of nuclear energy policy. It treats climate-resilient, decentralized power not as a peripheral technical option, but as core to Pakistan's human security and sustainable development.

Based on this analysis, the paper recommends the following steps:

- Pakistan should establish a micro-reactor-specific licensing track within PNRA, adapted from IAEA guidance on small and micro reactor

regulation, before large-scale financing is mobilized.

- Pakistan can pilot a dedicated green bond or sukuk issuance earmarked for clean-nuclear infrastructure, building on WAPDA's Indus Bond precedent.
- Pakistan must negotiate a micro-reactor technology-transfer and financing pilot with China through the existing CNNC relationship. This pilot should be kept distinct from utility-scale projects such as Chashma-5, and used to test decentralized deployment in an off-grid or mining application.
- The government should extend the existing PPA framework, already used for solar and wind, to micro-reactor generation for industrial and military off-takers.
- Pakistan could establish the proposed nuclear policy wing for peaceful purposes, so that it can serve as an institutional counterpart for climate-linked nuclear diplomacy and IAEA engagement.
- The Ministry of Planning, Development and Special Initiatives and the Ministry of Climate Change and Environmental Coordination should jointly oversee and sequence implementation.

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