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Tackling Indonesia's Nuclear Power Euphoria

How to Reconcile Nuclear's Technical Promise With Market Realities

Executive Summary

Indonesian nuclear power supporters often promise that nuclear will be an affordable, safe and sustainable solution for the problem of over-reliance on fossil fuel. Yet, 70 years after the first nuclear power developments were announced, the technology is quickly losing market share as global power markets pivot toward more cost-competitive renewables and storage solutions. As old generation large-scale nuclear units face decommissioning, there is little consensus about how long it will take for newer small-scale nuclear technologies to be economically viable nor how long-standing safety and waste disposal risks will be addressed.

Despite the steady erosion of nuclear power's competitive potential, key South East Asian energy ministries continue to be lobbied by nuclear advocates. In growing power markets like Indonesia, decisionmakers are facing a barrage of pro-nuclear media coverage as the nuclear industry floods the market with panels and webinars focused on the potential of nuclear power. Many of these offerings are sponsored by lobbyists for the international backers of new small modular reactor (SMR) technologies, who are actively engaging with governments and utilities around the region.

Nuclear is quickly losing market share as global power markets pivot to more cost-competitive renewables.

Determining the suitability of nuclear for the Indonesian power market will be a challenging task that will require honest and deep engagement by senior policymakers to ensure there is a high degree of accountability. There are a number of complex technical and market issues that must be considered when it comes to nuclear. The shortlist includes technology reliability, safety and safeguards, the geographic conditions of South East Asia, the prospects for waste treatment and permanent disposal, fuel availability, affordability and the risk of persistent cost overruns and frequently overlooked shut-down costs. An objective review of these factors will be required to avoid questions about policy missteps in the future, particularly in the case of a country like Indonesia which is grappling with a costly effort to repair long-neglected operational problems at PT Perusahaan Listrik Negara (PLN), the national power company.

In addition to looking at the technology's fundamentals, policymakers should commit to a transparent study of the projects that sit behind this nuclear push. It's notable that one of the most prominent projects being discussed is backed by an untested early-stage thorium nuclear venture that has never built nor operated a nuclear facility of any sort anywhere in the world. The focus on this project, as well as more mainstream offers from long-time nuclear players like Rosatom and EDF, underscores the importance of committing to stakeholder consultation at the outset. Traditional nuclear technology poses unique long-duration risks that should be evaluated according to international standards along with the many enthusiastic claims that are being made about the technical and economic viability of newer technologies.

This last point is crucial in light of PLN's severe financial and operational problems. While some project advocates may see an opportunity to use the country's 23% renewable target for 2025 as a soft target for new technology options, it is always important to look at any project in PLN's pipeline from multiple angles given the long life of PLN's existing baseload coal power assets. Advocates need to be reminded that claims about technical viability must be balanced against an assessment of project-level financial viability and long-term market viability in Indonesia's baseload-heavy system. Even if nuclear could be proven to be technically viable for Indonesia at some point in the future, the economics are likely to be inconsistent with the more flexible opportunities now offered by established renewable solutions.

The average cost overrun for a nuclear power plant was US$1.3 billion per project with construction delays adding 64% more time than initially projected.

Perhaps one of the most persistent risks associated with nuclear stems from project delivery risks. Research has shown that an estimated 97% (175 out of 180 projects examined) of nuclear power projects exceed their initial budgets. The average cost overrun for a nuclear power plant was US$1.3 billion per project with construction delays adding 64% more time than initially projected.[1] Hard to estimate nuclear waste disposal costs also complicate the cost estimation process—typically raising project costs as political risk factors crystallize. The inability of leading nuclear nations to find safe and affordable solutions for high-level nuclear waste disposal leaves expensive back-end cost issues on the table.

[1] Ramana, M.V. Eyes Wide Shut: Problems with the Utah Associated Municipal Power Systems Proposal to Construct NuScale Small Modular Nuclear Reactors. September 2020.

The economics of nuclear power in Indonesia are also blurred by the fact that under existing regulations, nuclear accident liabilities for nuclear owners/operators are capped at a maximum of IDR 4 trillion (US$276 million) for power plants with capacity of more than 2000 MWe. It is cut in half as the capacity decreases. This means smaller nuclear reactors would be liable for only a fraction of potential accident costs.

These open-ended cost issues make it hard to evaluate claims about the market viability of nuclear power in Indonesia's cost-sensitive market. This is particularly true when most established nuclear nations are pivoting away from commitments to new nuclear power facilities as more flexible renewable plus storage options reshape power sector economics.

Indonesia is blessed with having many renewable energy resources. Currently only 2.5% of Indonesia's 400GW renewable energy potential has been utilized. That means that new technology options such as nuclear must compete with the deflationary cost curve in evidence with increasingly low-cost and low-risk renewable power solutions. New innovations to support grid flexibility such as demand response and storage are providing a cost-effective alternative to baseload-heavy planning disciplines. This trend raises questions about how small-scale nuclear reactors will fit into a more diverse power market where more cost-competitive renewable options could under-cut untested technologies that are years away from realizing scale economies.

Currently only 2.5% of Indonesia's 400GW renewable energy potential has been utilized.

PLN's struggle with cost under-recovery due to its inability to increase tariffs in the face of lower-than-expected demand growth should also increase pressure on policymakers to define realistic cost parameters for any new technologies. This is a lesson that PLN should have embraced to minimize further risk of baseload lock-in. PLN is already struggling with serious financial consequences of long-dated power purchase agreements (PPAs) that rob the system of the ability to pivot to more cost-effective dispatch options.

PLN is actually not oblivious to these conditions. A recent announcement made by PLN pledging to become carbon neutral by 2050 actually paints a more realistic picture about how PLN sees the role of nuclear in Indonesia's energy transition scenarios. Although there were very little details presented in the scenarios, both the 2045 and the 2050 charts show nuclear only entering the energy mix in 2040 instead of earlier, which would have been preferred by nuclear advocates. In the follow up presentation to the Parliament days later, the PLN net zero goal was set back to 2060, but the starting point for nuclear remains in 2040. In PLN's own word "Nuclear will enter in 2040 to maintain system's reliability as the development of nuclear technology becomes safer and more secure." [2]

If a decision is reached to move ahead with pilot stage nuclear projects, policy makers and the government will also need to establish rigorous new governance mechanisms to provide oversight of the nuclear value-chain to ensure safety, security, and safeguards. This process should include regulations covering all nuclear life cycle phases from uranium and thorium mining processes, fuel transportation, power plant construction, operations, decommissioning, waste management, storage and permanent waste disposal. A separate initiative will be required to develop a reliable third-party liability insurance scheme, which is currently non-existent in Indonesia.

All of this policy work —the technical evaluation, the regulatory preparation, and the financial support—will place a serious burden on a government already taxed by the response to the COVID-19 pandemic and efforts to revitalize the financially constrained PLN. To date, Indonesia's nuclear advocates have done little to address the issue of how a pivot toward nuclear would place stress on the existing power system. Until these issues have been acknowledged and fully addressed, the safe path for Indonesia for now, would be to pause and set realistic goals for its power development strategy.

[2] PLN presentation in a Parliament's hearing, 27 May 2021

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Background

South East Asia's Nuclear Track Record

Southeast Asia's (SEA's) rapid industrialization and rising power demand has turned the region into a target for power equipment manufacturers of all stripes. For decades, fossil fuel (coal, oil, and natural gas) has dominated the region's energy mix, increasing greenhouse gas (GHG) emissions. Scientific findings now highlight GHG's social and economic threats emphasizing the need for a large-scale cleaner energy alternative to fossil fuel[3]. Proponents of nuclear technology have stepped into this debate, often proposing nuclear as part of the solution for a sustainable energy supply, giving it labels such as emissions-free, reliable, safe, and an affordable source of baseload power.

SEA's nuclear power development has been modest. So far, there are no commercial nuclear plants operating in the region, only a handful of operating research plants with a total capacity of 37.8MW.

Table 1: List of Operational TRIGA Reactors (SEA)

Country	Facility Name	TRIGA Type	Power		First Criticality
			Steady State (kW)	Pulsing (MW)	
Indonesia	TRIGA Mark II, Bandung	Mark II	2000	n.a.[a]	19/10/64
Indonesia	Kartini-PTAPB	Mark II	100	n.a.[a]	25/01/79
Malaysia	TRIGA Puspati (RTP)	Mark II	1000	1200	28/06/82
Thailand	TRR-1/M1	Conversion	2000	1200	07/11/77
Viet Nam	The Dalat Nuclear Research Reactor	Mark II	250	n.a.[a]	04/03/63
Research Reactors Converted from MTR To UZrHX Type Fuel (SEA)					
Country	**Facility Name**	**Original TRIGA Fuel Type (Nominal wt% U–235U Enrichment)[c]**		**Steady State Power after Conversion (kW)**	**Original TRIGA Conversion Startup**
Thailand	Office of Atoms for Peace	8.5-20		2000	1977
Philippines	Philippines Nuclear Research Center[b]	30–20		2000	1988
Other Research Reactors (SEA)					
Country	**Facility Name**	**Type**	**Coolant**	**Steady State (kW)**	**Criticality**
Philippines	Research Reactor-1[b]	POOL, MTR	Light water	1000000	26/08/63
Indonesia	GA SIWABESSY MPR	POOL, MTR	Light water	30000	29/07/87
Viet Nam	The Dalat Nuclear Research Reactor	POOL, MTR	Light water	500	1984

[a] n.a.: not applicable. [b] Decommissioned.

Sources: IAEA. Technical Report Series no 482: History, Development and Future of TRIGA Research Reactors. 2016; IAEA. Research Reactors Details: Indonesia. 2009; IAEA. The Role of a Research Reactor in the National Nuclear Energy Programme in Vietnam: Present and Future.

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[3] IEA. Southeast Asia Energy Outlook 2019 – Analysis - Retrieved October 20, 2020.

At present, amongst SEA's nuclear frontrunners, Malaysia, Thailand, and Vietnam have decided to indefinitely postpone their nuclear plans due to economic viability problems and politically sensitive safety concerns. Malaysia's former Minister of Energy, Science, Technology, Environment and Climate Change, Yeo Bee Yin even announced in early 2020 that the Malaysia Nuclear Power Corporation would be shut down.[4] The decision was echoed by her successor, Minister Khairy Jamaluddin, who designated nuclear as off the table for Malaysia, and chose to develop more renewables instead.[5]

Interest in nuclear power has a long track record in Indonesia reflecting the country's deep bench of technocrats and a long history of interest in advanced technologies that could, in theory, offer opportunities for global market leadership. Law No. 10/1997 on nuclear energy showed how this openness to sophisticated technology fits comfortably with the potential scale of economy and the need for new solutions to the country's growth challenges. So far, however, more practical market realities have always taken priority over unchecked technology optimism.

Indonesia is not unique in attracting a range of nuclear suitors. As the large-scale nuclear industry enters its sunset days in developed markets, it is only natural that the nuclear power sector would scour the globe for a last round of opportunities. At the same time, a handful of new nuclear proponents are romancing the remaining new partners who might be convinced to underwrite the development costs. This alluring combination of old giants and new entrepreneurs has triggered an urgent push for nuclear as a "new and cleaner" energy source that could be prioritized as part of Indonesia's planning process to meet its 23% renewable target by 2025.

In addition to lobbying efforts by conventional nuclear sponsors, Indonesia has recently been the focus of an aggressive push by backers of small modular reactor (SMR) technology in particular a venture offering an untested thorium molten salt reactor (MSR).

The company at the center of this push is ThorCon International Pte Ltd, a subsidiary of the United States-based ThorCon US, Inc, a start-up nuclear company that has been actively seeking support from the Indonesian government for an ambitious plan to develop a 500MW thorium molten salt reactor (TMSR) for either power generation or marine vehicle propulsion. In July 2019, this lobbying effort resulted in an agreement under which ThorCon will provide technical assistance to the

Indonesia has recently been the focus of an aggressive push by backers of small modular reactor (SMR) technology.

[4] Malay Mail. As 2020 comes a-knocking, wither Malaysia's nuclear power plan? 03 January 2020.
[5] Malay Mail. Khairy says nuclear energy 'not on the table' for now, focus on renewable energy sources. 14 August 2020.

Defense Ministry for an R&D on a 50MW TMSR pilot project.[6]

By contrast, in the Philippines, the debate revolves around whether to revive its long-built-but-never-commissioned 621MW Bataan power plant or to build a new one from the ground up. So far, the chief backer of this project, Rosatom, Russia's state-owned nuclear enterprise, has signed a Memorandum of Intent on cooperation with Philippine's Department of Energy to develop studies on SMR.[7]

This surge of activity has been accompanied by an effort to link the future of SMR nuclear projects to the rising fortunes of renewable energy. Indonesian nuclear advocates have pushed the idea of including nuclear as one of the 'new' sources of energy[8] in the draft Renewable Energy Bill. The stated goal of the Bill was to provide a stronger regulatory framework for accelerating renewable energy development in Indonesia. This process has opened the door to a diverse range of interests, including persistent efforts by nuclear advocates to insert technologies such as nuclear, and other high-cost fossil fuel processes such as coal capture and storage, and coal gasification into the draft Bill by designating them as 'new' sources of energy.[9]

This has resulted in an awkward dynamic. Understandably, many Indonesian policymakers lack the complicated technical and financial knowledge for nuclear power. As a result, they have struggled to provide the kind of oversight that is required to evaluate complex nuclear project proposals. To date, the discussion has been framed solely in terms of opportunities, with little attention paid to the need of disciplined governance habits that must be addressed before proceeding with any nuclear installation.

If the Indonesian scenario is representative of other ASEAN nations, it appears that the nuclear power information gap in South East Asia has permitted unconstrained optimism to dominate what should be a disciplined dialogue between energy stakeholders and recognized global experts. As a result, what's needed now is an up-to-date review of the nuclear power industry's track record.

Three Fundamental Challenges to the Viability of Nuclear Power in Indonesia

The debate on nuclear power should look at not only the opportunities presented by the fuel, but also the risks and liabilities attached to it. Discussions amongst policy makers, business interests and the common public have to be maintained at a level that is deep and honest, and communication on risks along with potential problems and solutions have to be based on scientific and market data. The claims on nuclear technical viability must be balanced against an assessment of project-level financial viability and long-term market viability especially considering Indonesia's current

[6] Jakarta Post. Thorcon, Defense Ministry to cooperate on thorium nuclear reactor. 28 July 2020.
[7] Powermag. Philippines taking new look at nuclear power. 1 October 2020.
[8] Indonesia considers nuclear as 'new' energy source, which is then often used in legal terms surrounding policy and regulations as 'new and renewable energy'.
[9] Jakarta Post. Stakeholders clash over nuclear in green energy bill. 29 September 2020.

baseload-heavy power system. This report provides an analysis on the three fundamental challenges for nuclear power viability in Indonesia relating to technological, financial and market structure.

Technological Viability

Nuclear technology was first developed during World War 2, circa 1940. In 2019, nuclear produced 2,657TWh of electricity or approximately 10.3% of global energy.[10] There are many types of existing nuclear technology, but the most common nuclear reactor technology designs currently being considered in South East Asia are:

Light Water Reactors (LWRs)

> *"Light water reactors (LWRs) are the most common Water Cooled Reactors (WCR) worldwide. WCRs were the cornerstone of the nuclear industry in the 20th century. Of the currently operating 442 reactors, 96 per cent are water-cooled. LWRs are divided into two types: Pressurized Water Reactors (PWRs), which produce steam for the turbine in separate steam generators; and Boiling Water Reactors (BWRs), which use the steam produced inside the reactor core directly in the steam turbine. All LWRs require fuel that is enriched in the fissile isotope, U-235."*[11]

Molten Salt Reactors (MSR)

> *"MSRs are characterized by the use of a fluoride or chloride salt as coolant. Two major design variants are being considered, characterized by solid or liquid fuel. The solid fuel option (often referred to as fluoride-cooled high-temperature reactors or FHRs) is more similar to other nuclear reactor concepts: salt is used to transfer heat from solid fuel to a secondary loop. In the liquid fuel design, instead, actinides are directly dispersed in the salt that, kept at high temperature (above 500°C), flows in and out of the reactor core. In the core, the salt is heated up by the fission reactions and heat is then transferred to a secondary loop when the fuel salt itself flows through the heat exchangers. Compared to light-water reactors, MSRs are expected be more economical because of higher power conversion efficiency, low-pressure containment, and absence of active safety systems."*[12]

Although initially developed in the 1950s, in 1965 a Molten-Salt Reactor Experiment (MSRE) was operated by Oak Ridge National Laboratory (ORNL), which lasted only four years and MSR development remained modest. As of 2020, there are no operational thorium reactors in the world.[13]

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[10] A Mycle Schneider Consulting Project. The World Nuclear Industry Report 2020. September 2020. p. 39.
[11] International Atomic Energy Agency. Water Cooled Reactors.
[12] Sabharwall, P. Heat transfer and computational fluid dynamics for molten salt reactor technologies. 2019.
[13] International Atomic Energy Agency. Molten Salt Reactors. Accessed March 2021.

Small Modular Nuclear Reactors (SMR)

> *"SMRs are often defined as advanced reactors that produce electricity of up to 300MW(e) per module. These reactors have advanced engineered features, are deployable either as a single or multi-module plant, and are designed to be built in factories and shipped to utilities for installation as demand arises. There are about 50 SMR designs and concepts globally. Most of them are in various developmental stages and some are claimed as being near-term deployable."*[14]

The recent interest in SMR was driven by a desire to reduce the total capital costs associated with nuclear power plants and to provide power to small grid systems. Many of the SMR designs in development simply shrink the systems of large-scale nuclear plants. In reality, Russia's state-funded floating SMR—Akademik-Lomonosov—the only SMR project currently in operation, took over 12 years to build (from the previous estimates of 3-5 years), at quadruple the costs.[15] The cost estimates for these two floating reactors were estimated at US$740 million in 2015, significantly more expensive than the most expensive Generation III reactors, and still it is likely to be underestimated.[16]

Table 1: Operable Nuclear Power Reactors at Year-End 2019

	Boiling water reactor	Fast neutron reactor	Gas-cooled reactor	Light water graphite-moderated reactor	Pressurized heavy water reactor	Pressurized water reactor	**Total**
Africa						2	**2**
South America					3	2	**5**
Eastern Europe and Russia		2		13		38	**53**
North America	34				19	64	**117**
Western and Central Europe	10		14		2	102	**128**
Asia	21				24	92	**137**
Total	**65**	**2**	**14**	**13**	**48**	**300**	**442**

Source: World Nuclear Association. World Nuclear Performance Report 2020.

Regardless of the reactor technology, both the old large-scale and new small modular reactors still present multiple technical risks in terms of safety and unresolved radioactive waste storage and disposal. It is particularly important for countries with unstable geological conditions, like Indonesia, to understand these

[14] International Atomic Energy Agency. Small Modular Reactors. Accessed March 2021.
[15] BBC. The countries building miniature nuclear reactors. 10 March 2020.
[16] A Mycle Schneider Consulting Project. The World Nuclear Industry Report 2020. September 2020. p. 29.

risks and the analytical claims that are common to the debate about how these risks can be mitigated and at what cost.

Safety, Security and Safeguard Issues Present the Biggest Potential Risk

While most thermal power technologies present a range of well-understood operating risks, nuclear power poses a unique constellation of safety, security, and safeguard risks that nuclear nations have struggled to manage with varying degrees of success. This reflects the complex technical issues and a persistent divergence between the assurances offered by technology advocates and the concerns of communities and stakeholders exposed to potential health risks.

Nuclear Reactor Accidents

The three major nuclear catastrophes known globally took place at Three Mile Island, Chernobyl, and Fukushima nuclear power plants. In the wake of these accidents, scientists at the Max Planck Institute for Chemistry found that the core meltdowns that occurred in Chernobyl and Fukushima were more likely to happen than engineers and policymakers had previously assumed. According to scientists, the probability of serious reactor accidents may be 200x more likely than previously acknowledged. On this basis, researchers have estimated that based on the current installed capacity of 440 active reactors globally, a major disaster might happen once every 10 to 20 years.[17]

Table 2: A Non-Exhaustive List of Publicly Acknowledged Accidents or Serious Incidents Resulting in Nuclear Reactor Shutdowns

Country	Reactor	Type	MWe Net	Years Operable	Shutdown
Germany	Greifwald 5	VVER-440/-213	408	0,5	11/1989
Germany	Gundremmingen A	BWR	237	10	01/1977
Japan	Fukushima Daiichi 1	BWR	439	40	03/2011
Japan	Fukushima Daiichi 2	BWR	760	37	03/2011
Japan	Fukushima Daiichi 3	BWR	760	35	03/2011
Japan	Fukushima Daiichi 4	BWR	760	32	03/2011
Japan	Monju	Prot FNR	246	1	2016
Slovakia	Bohunice A1	Prot GCHWR	93	4	1977
Spain	Vandellos 1	GCR	480	18	mid-1990
Switzerland	St Lucens	Exp GCHWR	6	3	1966
Ukraine	Chernobyl 4	RBMK LWGR	925	2	04/1986
USA	Three Mile Island 2	PWR	880	1	03/1979

Source: World Nuclear Associations.

[17] Max-Planck-Gesellschaft. Probability Of Contamination From Severe Nuclear Reactor Accidents Is Higher Than Expected. May 2012.

At the core of public concerns and financial liability risks is the fact that the impacts of a nuclear accident can last for thousands to millions of years, with a long list of detrimental environmental, social and economic impacts. Believed to be the worst nuclear accident in history, the Chernobyl disaster eventually affected three million people. Eighteen miles around the explosion site is now deemed too contaminated for people to live. Meanwhile 35 years after the explosion, nuclear scientists found a rising number of neutrons, a signal of fission reactions, smoldering again in uranium fuel masses across the reactor hall's basement. It is feared that the fission reaction could accelerate exponentially leading to an uncontrolled release of nuclear energy.[18]

The ultimate financial costs of the Chernobyl disaster are estimated at US$700 billion over the past 30 years according to Jonathan Samet, Distinguished Professor from the University of Southern California.[19] Meanwhile clean-up efforts of the Three Mile Island meltdown accident stretched over 14 years and costs over US$1 billion.[20]

The third major nuclear accident occurred in Fukushima in 2011, which had dramatic consequences for the power sector, prompting a global re-evaluation of the viability of nuclear power. The estimated cost of the clean-up ballooned to ¥21.5 trillion/US$200 billion from an earlier estimate of ¥11 trillion. The Japanese government decided to use taxpayer money to decontaminate the area, and some costs are expected to be passed on to consumers in the form of higher electricity prices.[21] Since then, most of Japan's nuclear power plants have been kept inactive, and though there have been talks of reopening the plants, the Japanese government has been slow to take it further due to community protests and political opposition. They have instead opted for an accelerated build out of coal, gas and renewable power plants.

For many countries in South East Asia, the technical challenges and governance burden have been a barrier to the acceptance of nuclear.

In the aftermath of the Fukushima accident, Germany committed to a complete exit from nuclear power by 2022.[22] France, known for its high reliance on nuclear as the primary source of electricity, followed suit. While not exiting completely, due to

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[18] Sciencemag. 'It's like the embers in a barbecue pit'. Nuclear reactions are smoldering again at Chernobyl. May 5, 2021.
[19] University of Southern California. New report examines financial costs of the Chernobyl nuclear power plant disaster. 24 May 2016.
[20] The Verge. Wasteland: the 50-year battle to entomb our toxic nuclear remains. 14 June 2012.
[21] The Japan Times, The cost of cleaning up Fukushima, 23 December 2016.
[22] International Business Times. Germany prepares to phase out nuclear power, but what will it cost? 20 March 2020.

long-standing policy based on energy security, France has chosen to reduce its reliance on nuclear power to 50% by 2035.[23] South Korea also reacted to the Fukushima disaster by adopting a nuclear phase-out plan. Under the phase-out policy, the number of nuclear plants will decrease from 24 this year to 17 by the end of 2030.[24] Globally, nuclear energy as a percentage of the total energy mix has declined from 17% in 1996 to only 10.5% in 2018.

These accidents have taken place despite the fact that the industry has been subject to high levels of regulation and oversight at both the country and global level. This regulatory imperative reflects the open-ended and catastrophic nature of the potential risks associated with nuclear technology. Nonetheless, governance remedies have not always proven effective due to bureaucratic failures, a history of cover-ups and the potential for unmanaged liabilities.

For many countries in South East Asia, the technical challenges and governance burden have been a barrier to the acceptance of nuclear. Indonesia recently faced the type of nuclear governance problem that is common to the sector. In an unresolved event in early 2020, a radioactive Cesium-137 nuclear waste site was found in an empty field near a BATAN housing complex in Serpong, Indonesia. Though the level of radiation found from the radioactive metal was considered low at 140 microsievert per hour,[25] the Indonesian Nuclear Energy Regulatory Agency (Bapeten) could not answer how this nuclear waste ended up in an open field near a housing complex.

The lack of public accountability in the wake of this event raises questions about how Indonesia would develop the governance capacity for managing new commitments to the nuclear industry. As rigorous oversight is absent from a credible and independent energy commissioner, Indonesia may face challenges developing the safety and safeguard guidelines that are required for safe operations of the commercial nuclear power. History has shown that it is precisely this type of robust oversight that becomes an important precondition for commitments to long-lived nuclear power assets.

Geography and Geology

Perhaps the over-riding risk associated with nuclear power in SEA relates to the region's vulnerability to seismic risk. The region is home to over 75% of the world's active and dormant volcanoes. It is known as "The Pacific Ring of Fire" for a reason: out of 452 known volcanoes, 28% are active volcanoes. Tectonic collisions have shaped the physical landforms of the region, making it susceptible to natural disasters, and home to 90% of the world's earthquakes.[26]

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[23] World Nuclear Association. Nuclear Power in France. September 2020.
[24] The Korea Herald. S. Korea to maintain nuclear phaseout scheme, scale back coal power generation. 28 December 2020.
[25] Tempo. Pemerintah sebut temuan radioaktif di Serpong sebatas pencemaran. 19 February 2020.
[26] Open Praxis. Opening World Regional Geography: A Case Study. 2020.

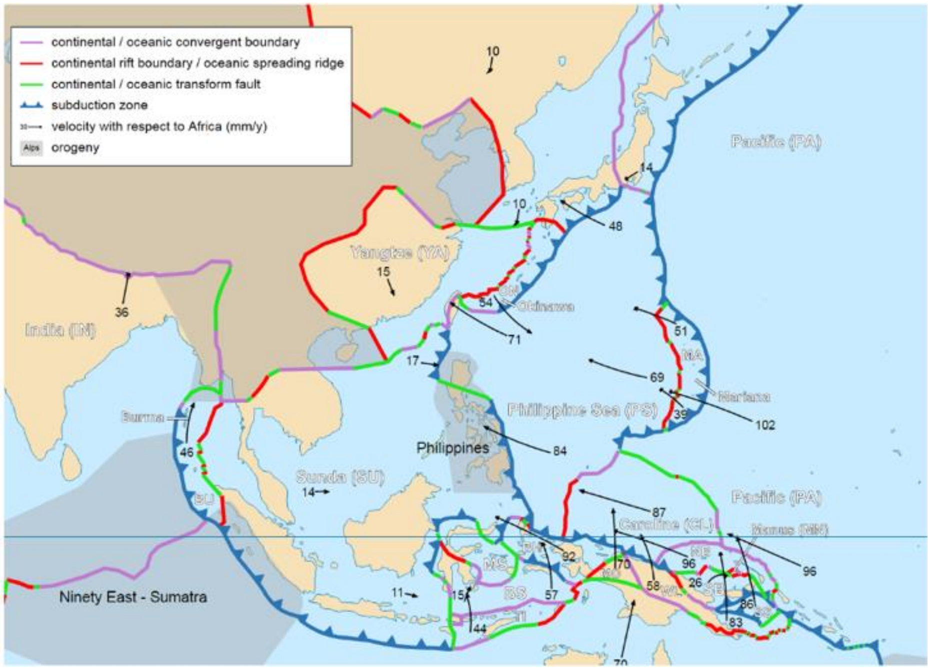
Indonesia has paid a profound human and economic price for its seismic vulnerability. Having 127 active volcanoes spread amongst its many islands,[27] Indonesia has experienced between 5,000 to 6,000 earthquakes every year since 2008.[28] The tectonic plates that define Indonesia's seismic situation are in constant motion, often resulting in earthquakes and sometimes tsunamis. Between 1990-2010 alone, Indonesia experienced 10 tsunamis, nine of which were lethal resulting in 170,000 deaths.[29] These geographical instabilities paired with annual climate-related weather disasters such as the massive floods that recently hit South Kalimantan claiming 15 lives and displacing 39,549 people,[30] and the devastating forest fires that burnt down approximately 2.1 million acres of land in 2019,[31] both present direct and indirect material physical risks to any planned nuclear power projects.

The over-riding risk associated with nuclear power in SEA relates to the region's vulnerability to seismic risk.

The risks associated with geological instability are not only important for operational safety reasons, but also for the safe disposal of nuclear waste. Ideally, nuclear waste is disposed in cooled water in deep geological repositories. With such unstable geological foundations, however, it will be difficult for Indonesia to find such repositories.

[27] LIPI. Indonesia miliki 127 gunung api aktif. 02 May 2012.
[28] CNN Indonesia. Gempa di Indonesia meningkat dalam 5 tahun terakhir. 01 December 2019.
[29] Bappenas. Narasi Rencana Pembangunan Jangka Menengah Indonesia. 28 June 2019.
[30] Antaranews. Massive flooding in South Kalimantan broke five-decade record: Jokowi. 18 January 2021.
[31] Reuters. Area burned in 2019 forest fires in Indonesia exceeds 2018 – official. 21 October 2019.

Figure 1: Map of Tectonic Plates in South East Asia



Source: Social Science. Natural Hazards in East and Southeast Asia.

The Legacy Nuclear Waste Disposal Issue

Despite 70-odd years of active R&D and operations, the leading nuclear nations have failed to arrive at a permanent solution for nuclear waste disposal. At every stage of nuclear power production, from uranium mining to reactor operation, radioactive materials are produced in large quantities, and solid high-level waste in particular remains dangerously radioactive for up to a hundred thousand years or more according to Joint Research Centre report for the European Commission.[32] For that reason, it is crucial for nuclear waste to be disposed of permanently and for nuclear nations to work collectively on safe solutions that will protect the health of future generations.

So far, the nuclear power industry has relied on short-term solutions such as storage pools and dry casks. Depending on each country's waste classification, about 0.2-3% volume of waste is considered high-level waste having 95% of the radioactivity, which requires cooling and shielding indefinitely. Around 7% by volume is known as intermediary waste, which is made up of reactor components and graphite. This is still highly dangerous, but current industry practice relies on storage in special canisters. The rest of the volume contains low or very-low level waste, which is comprised of scrap metal, paper, plastics, building materials and everything else that is involved in the operation and dismantling of nuclear plants. As of December 2013, as much as 22,000 cubic meters of solid high-level waste has accumulated in

[32] JRC Science. 2021. Technical assessment of nuclear energy with respect to the 'do no significant harm' criteria of Regulation (EU) 2020/852 ('Taxonomy Regulation'). European Commission.

temporary storage but not been disposed of (permanently stored) in 14 western countries, along with unknown amounts in China, Russia and at military stations.[33]

Table 3: Solid Radioactive Waste in Storage (m3), as of 31 December 2013

	VLLW	LLW	ILW	HLW
Africa	7,000	20,000	1,000	-
Eastern Europe	15,000	2,479,000	101,000	7,000
Western Europe	224,000	355,000	269,000	6,000
Far East	5,000	331,000	4,000	-
North America	2,105,000	248,000	84,000	8,000
Latin America	-	37,000	-	-
Middle East and South Asia	-	3,000	-	-
South East Asia and Pacific	-	5,000	1,000	-
Global Total	**2,356,000**	**3,478,000**	**460,000**	**22,000**

Source: IAEA Nuclear Energy Series. Status and Trends in Spent Fuel and Radioactive Waste Management. 2018.
Note: Possible differences are due to rounding.

The question of how to resolve the safe storage challenge has driven nuclear scientists and engineers in many countries to experiment broadly to identify practical strategies for permanent nuclear waste storage. "Investigations have explored the potential of shooting the waste into space; isolating it in synthetic rock; burying it in ice sheets; dumping it on the world's most isolated islands; and dropping it to the bottom of the world's deepest oceanic trenches. Yet most ideas have been "rejected and deemed as impractical, too expensive, or environmentally unacceptable."[34] Billions of dollars have been spent, yet there is no common, economically viable permanent solution to the waste disposal problem that currently exists.

Out of all the countries in the world, Finland is probably the one with the most advanced plans for nuclear waste handling. Finland was lucky to have found a deep geological repository for encapsulated used fuel at the Olkiluoto island in Eurajoki, which is 400 metres deep in two-billion-year-old igneous rock.[35] By contrast, the United States has been trying to find a permanent site for more than thirty years, and had begun construction in Yucca Mountain, Nevada, but pushback from local communities left the project on indefinite hiatus since 2011. For a seismically unstable country like Japan, the problem is even more severe. It has been unable to find a candidate site anywhere in Japan for more than a decade, while spent fuel has accumulated and storage space at the Rokkasho complex reached 70% of capacity in 2013.[36]

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[33] IAEA Nuclear Energy Series. 2018. Status and Trends in Spent Fuel and Radioactive Waste Management. p. 39.
[34] The Guardian. What should we do with radioactive nuclear waste? 1 August 2019.
[35] World Nuclear. Nuclear Power in Finland. Accessed in May 2021.
[36] The Japan Times. Editorial: Koizumi's nuclear power questions. 11 November 2013.

See appendix for a list of current and planned waste treatment by nuclear countries.

One strategy that can be used to reduce the amount of nuclear waste is to reprocess waste to recover residual uranium and plutonium from the spent fuel. Nuclear engineers would typically classify the nuclear fuel cycle into two types: ''once-through'' and ''closed.'' A ''once-through'' mode discharges spent fuel directly into disposal. Meanwhile reprocessing in a ''closed'' fuel cycle separates waste products from unused fissionable material and recycles it.

A study of LWR fuel-cycle costs recently performed by the Nuclear Energy Agency (NEA) of the Organization of Economic Cooperation and Development (OECD), concluded that the levelized fuel cost for the once-through LWR fuel cycle is approximately 14% less than for the reprocessing cycle.[37]

Despite adding more cost, some countries chose to reprocess their spent fuel to enhance self-sufficiency and to reduce the amount of storage needed for waste disposal. The United Kingdom and France are both heavily invested in fuel reprocessing plants, although the US does not reprocess its waste.

Each method for nuclear waste storage and treatment has vulnerabilities and risks that will continue to require long-term planning.

It should however be noted that reprocessing waste does not eliminate the need for storage and permanent disposal. The many technical challenges associated with reprocessing options pose an unacknowledged cost burden that must be factored into the full life-cycle costs of nuclear power. For example, a Japanese government report found reprocessing to be four times as costly as non-reprocessed nuclear power,[38] while a French government study in 2000 found that reprocessing spent fuel at their famous nuclear fuel reprocessing plant—La Hague—was twice as expensive as storing used fuel.[39]

Each method for nuclear waste storage and treatment has vulnerabilities and risks that will continue to require long-term planning, management, and investment. For example, all known storage methods still face complex problems associated with the risk of corrosion in the repository environment. These engineering risks should be acknowledged before policymakers address the right way to approach country-specific risks associated with technological malfunction, natural disaster, end-of-life costs, and terrorist attacks. These are all known risks associated with nuclear waste that have not yet been solved. In the meantime, despite a history of technological

[37] The National Academies of Sciences Engineering Medicine. Nuclear wastes: Technologies for separation and transmutation. 1996, p. 416.
[38] The Long Now Foundation. Just how big of a problem is nuclear waste? 9 December 2017
[39] Ecology Centre. Nuclear Redux. 15 November 2008.

optimism, the nuclear power industry does not have a solution for waste stored in older casks—some of which have begun leaking toxic waste.[40]

The new JRC Science Report found that there is a broad consensus amongst the scientific, technological and regulatory communities that deep geological repositories are the most effective, safe and feasible solution for the final disposal of high-level radioactive waste and spent fuel.[41] The most relevant and important question for Indonesian policymakers therefore is whether there is any stable geological structure several hundred meters below ground that exists in Indonesia? The implementation of the deep geological repository is important to ensure that radioactive waste will not harm the public and the environment.

The most important question for Indonesian policymakers is whether there is any stable geological structure several hundred meters below ground that exists in Indonesia?

Greenhouse Gas Emissions From Nuclear Power Plants May Be Comparable to Hydro and Wind Power, but Nuclear Still Comes With Radiological Risk

Nuclear proponents often claim that nuclear power is one of the cleanest energy sources in terms of its Greenhouse Gas (GHG) emissions. This may be true as various life cycle analyses (LCA) taken by scientists have revealed that GHG emissions from nuclear power plants are comparable to the emissions from renewable energy sources such as hydro and wind, and may even be lower than solar, in terms of non-radiological impact.

LCA presents a more comprehensive approach to accounting for emissions, by considering both direct and indirect emissions from electricity generation throughout the lifecycle of the power plant which includes fuel mining, fuel processing, construction, operation, and decommissioning of the plant. The respective GHG emissions for each energy source varies when several factors such as fuel, location and technical issues are considered.

In 2008, Benjamin K. Sovacool conducted a study comparing 103 lifecycle studies of greenhouse gas equivalent emissions for nuclear power plants, and found that "while the range for nuclear energy over the lifetime of a plant, reported from qualified studies examined, is from 1.4 g CO2e/kWh to 288 g CO2e/kWh, the mean

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[40] C&EN. As nuclear waste piles up, scientists seek the best long-term storage solutions. 30 March 2020.

[41] JRC Science for Policy Report. Technical Assessment of Nuclear Energy with respect to the 'do no significant harm criteria of Regulation (EU) 2020/852 ('Taxonomy Regulation'). European Commission. 2021, p. 11.

value is 66 g CO2e/kWh."[42] This is due to the reliance on existing fossil-fuel infrastructure plant construction, decommissioning, and fuel processing along with energy intensity and uranium mining and enrichment. He claimed "Thus, nuclear is in no way 'carbon free' or 'emission free', even though it is much better (from purely a carbon-equivalent emissions standpoint) than coal, oil, and natural gas electricity generators, but worse than renewable and small-scale distributed generators".[43]

In 2013 a study by Roberto Turconi, Alessio Boldrin, and Thomas F Astrup, evaluated 167 electricity generation technologies using LCA and the researchers found a wide range of lifecycle emissions for each technology (see Table 4).[44] It should be noted that solar, wind and nuclear power do not directly emit greenhouse emissions during the operational phase. Their lifecycle emissions occur mostly through plant construction, uranium mining and milling (for nuclear), metal mining, transport, and plant decommissioning. According to Poinssot, et.al, the main contributions for emission in nuclear are the reactors' operation (40%), the uranium mining activities (32%) and the enrichment (12%).[45]

Table 4: Life Cycle Assessment of Power Generation Technologies

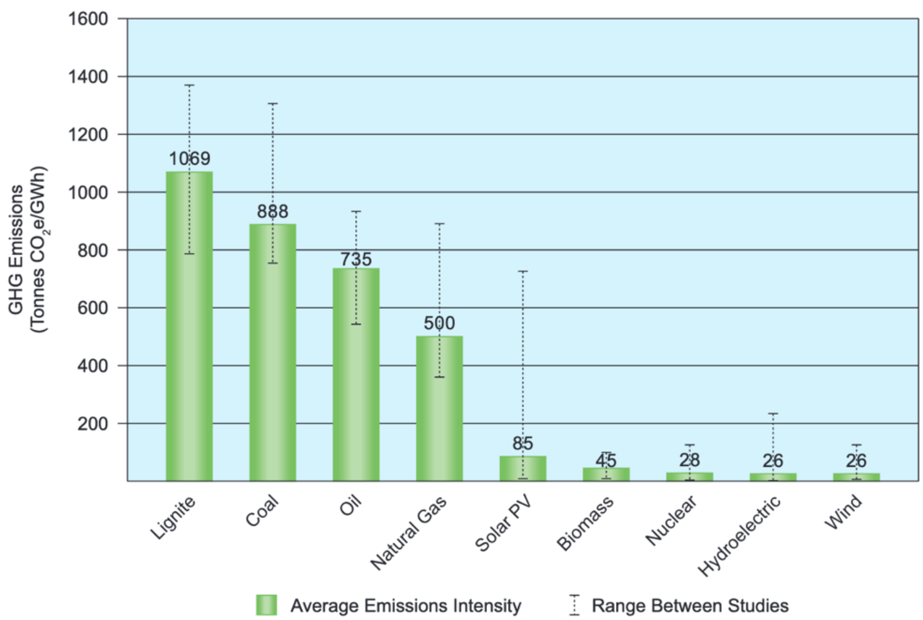
Technology	Lifecycle Emission kg CO^2e/MWh
Hard coal	660-1050
Lignite coal	800 – 1300
Natural gas	380 - 1000
Oil	530 – 900
Biomass	8.5 - 130
Hydropower	2-20
Solar energy	13 - 190
Wind	3 - 41
Nuclear (Turconi, Boldrin & Astrup)	3-35
Nuclear (Benjamin K. Sovacool)	1.4 - 288

Lifecycle emissions are 100-year carbon equivalent (CO2e) emissions that result from the construction, operation, and decommissioning of a plant.
Sources: Renewable and Sustainable Energy Reviews 2013.[46]

[42] Sovacool, B. K. Valuing the greenhouse gas emissions from nuclear power: A critical survey. Energy Policy. 2008. p. 2940–2945.
[43] *Ibid.*
[44] Turconi, R., Boldrin, A., & Astrup, T. Life cycle assessment (LCA) of electricity generation technologies: Overview, comparability and limitations. Renewable and Sustainable Energy Reviews. 2013. p. 555–565.
[45] Poinssot, C., Bourg, S., Ouvrier, N., Combernoux, N., Rostaing, C., Vargas-Gonzalez, M., Bruno, J. Assessment of the environmental footprint of nuclear energy systems. Comparison between closed and open fuel cycles. 2014. p. 199-211.
[46] Turconi, R., Boldrin, A., & Astrup, T. Life cycle assessment (LCA) of electricity generation technologies: Overview, comparability and limitations. Renewable and Sustainable Energy Reviews. 2013.

In March 2021, JRC Science conducted a technical assessment of nuclear energy for the European Commission (EC) with respect to the 'do no significant harm' criteria of the EU Taxonomy Regulation. One of the key conclusions reached was that based on a LCA study presented by the World Nuclear Association research in 2011, the non-radiological impacts of nuclear energy to humans and the environment are mostly comparable with hydro power and renewables. This includes impacts for not only greenhouse gases such as CO2, NOx and Sox, but also water consumption and potential thermal pollution of water bodies.

Figure 2: Lifecycle GHG Emissions Intensity of Electricity Generation Technologies



Source: JRC Science for Policy Report. 2021.[47]

However, JRC also acknowledged that nuclear power still comes with a radiological risk that other renewable sources do not have. The dominant lifecycle phases of nuclear energy that are significantly contributing to potential radiological impacts on the environment and human health are from uranium mining and milling (ore processing), nuclear power plant operation, and reprocessing of spent nuclear fuel.[48] The radiological risk that is unique to nuclear power hence made it fairly incomparable to other renewable sources.

[47] JRC Science for Policy Report. Technical Assessment of Nuclear Energy with respect to the 'do no significant harm criteria of Regulation (EU) 2020/852 ('Taxonomy Regulation'). European Commission. 2021 – taken from the World Nuclear Association Report. Comparison of Lifecycle Greenhouse Gas Emissions of Various Electricity Generation Sources. July 2011.
[48] Ibid., p. 7-13.

In relation to severe core melt down accidents, JRC stated that "severe accidents are events with extremely low probability but with potentially serious consequences and they cannot be ruled out with 100% certainty."

New Gen IV SMR Technology—A Work in Progress

The promise of Gen IV Small Modular Reactors (SMRs) technology has generated a lot of enthusiasm from nuclear experts and technocrats in recent years. SMRs offer faster construction times due to the fact that they can be built off-site and shipped to site. This would, in theory, significantly improve construction efficiency and reduce capital costs. Proponents also say it would be safer, with some reactor designs being self-contained and theoretically having the ability to shut itself down and remain cool for an unlimited time.

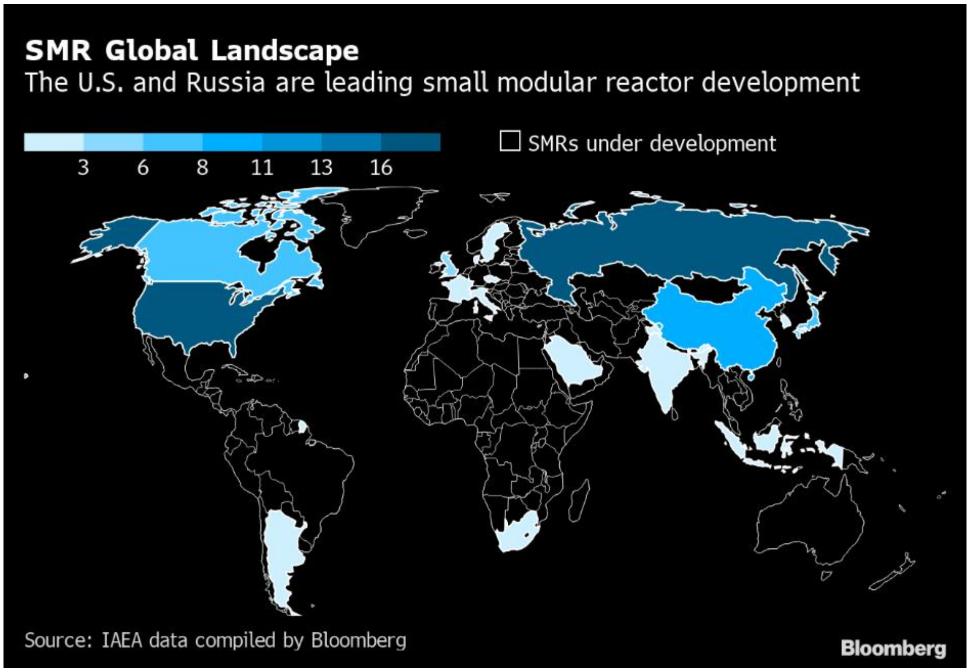
Opponents of nuclear power argued that SMRs suffer from many of the same problems as large reactors, most notably safety issues and the unresolved problem of what to do with long-lived radioactive waste.[49] Critics also say that SMR economies of scale will be limited because each reactor will need its own control and safety system. Others say that having an array of smaller reactors increases the risk of spreading radioactive material more widely and increases radiation and security risks.[50]

Opponents of nuclear power argued that SMRs suffer from the same problems as large reactors, most notably safety issues and the unresolved problem of what to do with long-lived radioactive waste.

Currently, there are at least 67 designs of SMRs recorded by the International Atomic Energy Agency around the world, all of which are still in conceptual designs and not operational, except for the Russia Akademik-Lomonosov. Big names like Rolls-Royce Holdings, Fluor Corp-NuScale Power, Terrestrial Energy USA Inc. and TerraPower have been pouring investment into the technology.[51]

[49] BBC. The countries building miniature nuclear reactors. 10 March 2020.
[50] Reuters. EDF and Westinghouse in talks to develop SMR nuclear reactor. 17 September 2019.
[51] Bloomberg. Atomic heat in small packages gives big industry a climate option. 5 December 2020.

Figure 3: SMR Global Landscape Led by the US and Russia



Source: Bloomberg. Atomic hit in small packages gives big industry a climate option. December 5, 2020.

NuScale Power, the leading US-based SMR reactor developer is the closest to bringing its technology across the finish line, but even they have not yet received full design certification from the US Nuclear Regulatory Commission. NuScale submitted their design certification application in 2017, and three years later it is still not yet certified.[52] Meanwhile the estimated cost of the NuScale reactor has been consistently increasing, from US$3.0 billion in 2015 to US$6.1 billion in 2020. Even with a strong parent company like Fluor Corporation, NuScale still relies upon large subsidies from the US taxpayers – through the investment of the US Department of Energy for its development costs.[53]

[52] Office of Nuclear Energy. NRC approves first U.S. Small Modular Reactor Design. September 2020.
[53] Ramana, M.V. 2020. Op.cit. p. 4.

ThorCon Power—The Company Behind the SMR Nuclear Push in Indonesia

ThorCon Power, a small venture SMR developer is still in the design-phase according to their website. Their aim is to build a first phase of 500MW thorium-fueled molten-salt reactor technology SMR which would go up to 3 GW in the future. They have signed an agreement with Indonesia's state-owned shipbuilder, PT PAL to conduct a feasibility study on building the reactors. The plan is to begin construction in 2023 and finish by 2026. PAL would be working with South Korea's Daewoo Shipyard & Marine Engineering to build the reactors. ThorCon also has already been in talks with state-owned tin miner, PT Timah to supply the thorium.

Currently ThorCon managed to sign a memorandum of intent to develop a study with the Indonesian Defense Ministry for an under-50MW TMSR pilot project. Through this cooperation, they hope they will be able to work together with Bapeten to receive clearance and a type of license citing that the design is safe for similar future power plants. It is worth noting, however, that Indonesia is the only country where ThorCon has an active project.

With untested technology and no history of gaining design certification from an experienced nuclear authority, it is difficult to assess the likelihood that ThorCon can see this project through to completion. ThorCon would obviously need strong financial backing from a more seasoned engineering company. Even then, without subsidies (or financial incentives) from the government, it is unlikely that the company would survive to achieve its goal to provide "a cheap and reliable electric power to support economic development".

According to M.V. Ramana, a nuclear physicist at Princeton who has written about the history of SMRs, "There are definitely niches that SMRs can fill, but there is uncertainty over whether the market will ever be large enough. There are going to be a few reactors that are built. The question is whether there will be the next customer after they see the cost and time it has taken to get the first unit online."[54]

The Indonesian Batan nuclear facilities' director Dandang Purwadi also expressed pessimism about the chances that ThorCon's technology would be operational by 2040, as "we have to wait around 10 years for the technology to mature, then take 10 years to build the facility."[55]

The risk for Indonesia's policymakers is that they lack an accountable framework for assessing the claims of SMR developers. Moreover, the narrow focus on technical promise has not been expanded to include a more practical analysis of the financial

[54] Bloomberg. Atomic heat in small packages gives big industry a climate option. December 5, 2020.
[55] Jakarta Post. This company wants to build Indonesia's first commercial nuclear power plant. February 20, 2020.

viability of these projects in the context of other technology options in the RUPTL. None in the current group of SMR technology providers have actually progressed to full commercial operations, except one 70MW floating SMR in Russia. As a result, the risk of extended delays and cost overruns should be acknowledged in order to ensure that policymakers can accurately determine whether Indonesians would be willing and able to absorb these development risks.

Reliability of Fuel Supply

Nuclear is powered by one of the rarest mineral resources Uranium235 (^{235}U), the primary element of nuclear fission that would channel acute energy. A thimble-sized ceramic cylinder boasts the same energy as 1,780 pounds of coal, 149 gallons of oil, or 17,000 cubic feet of natural gas.[11] The only fissile element found in nature, the supply of U235 is finite. Meanwhile, Thorium232 (^{232}Th) introduced as a nuclear fuel complimentary to U, is fertile. It requires a fissile driver to transmute into uranium233 (^{233}U).

Indonesia does not have significant resources of either U or T. In fact, no SEA country is on the list of top 10 countries possessing U and T resources. Indonesia only has enough uranium supply to run 6-7 years of 1000 MWe according to BATAN.[56]

If nuclear power was to be integrated into the region's energy mix, all nuclear SEA countries would require assistance from external countries that have adequate U and T resources and mining technology to maintain the life of the nuclear plant. Instead of being energy independent, this could translate to energy dependency.

Table 6: World Uranium Resources

Countries	Tonnes	% of the World
Australia	1,818,300	30%
Kazakhstan	842,200	14%
Canada	514,400	8%
Russia	485,600	8%
Namibia	442,100	7%
South Africa	322,400	5%
China	290,400	5%
Niger	280,000	5%
Brazil	276,800	5%
Uzbekistan	139,200	2%

Source: World Nuclear Association.

[56] Bastori, I & Birmano, MD. "Analisis Ketersediaan Uranium di Indonesia untuk Kebutuhan PLTN Tipe PWR 1000 MWe". Jurnal Pengembangan Energi Nuklir, vol. 19, no. 2, 2017. p. 95-102.

Table 7: World Thorium Resources

Countries	Tonnes	% of the World
India	846,000	13.3%
Brazil	632,000	9.9%
Australia	595,000	9.3%
USA	595,000	9.3%
Egypt	380,000	5.9%
Turkey	374,000	5.8%
Venezuela	300,000	4.7%
Canada	172,000	2.7%
Russia	155,000	2.4%
South Africa	148,000	2.3%

Source: World Nuclear Association.

Economic and Financial Viability

The Complex Nature of Nuclear Power Projects Drives Upside Cost Risks

Nuclear power plants have extremely high upfront capital investment costs, which often increase during the project period due to construction delays and cost overruns. Recent research indicates that an estimated 97% (175 out of 180 projects studied) of nuclear power projects exceed their initial budgets, with an average US$ 1.3 billion cost overrun per project, and 64% more time than projected.[57] The median construction time for nuclear reactors in 2019 was 117 months[58], while solar took a maximum of 24 months, and wind 36 months to deploy.[59]

Many times, cost overruns result in financial jeopardy for the project owners. As a result, governments have often been forced to step in and use public monies to provide direct subsidies and other incentives, just to get the projects across the finish line. Typically, these struggling projects seek to pass the burden of cost overruns on to ratepayers. This was the case for Hinkley Point C project (HPC) in the UK, when in June 2017 the UK National Audit Office (NAO) condemned the UK government's deal to support the project through consumer energy bills. The government's deal for HPC has "locked consumers into a risky and expensive project with uncertain strategic and economic benefits," as stated by NAO.[60]

[57] Ramana, M.V. 2020. Op.cit. p. 11.
[58] World Nuclear Association. World Nuclear Performance Report 2020. August 2020.
[59] European Commission. PV Status Report 2019. 2019.
[60] National Audit Office. Hinkley Point C. 23 June 2017.

In unregulated power markets that are now benefitting from lower generation costs due to the energy transition, competition from deflationary modular renewable options have made it difficult for nuclear to compete with other energy options.

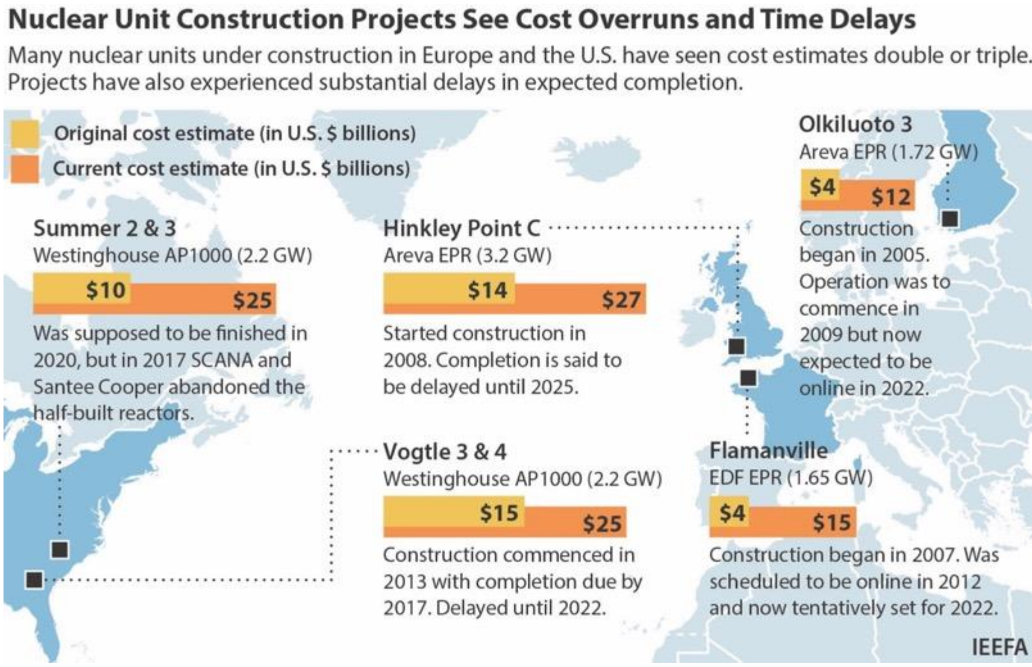
The compounding costs of nuclear power plants are usually a result of:

- Inaccurate cost estimate – underestimating construction time schedule.
- Specific design requirements requiring highly qualified specialists.
- Longer time needed to satisfy strict licensing, especially for those without standardized design.
- Strict safety regulations sometimes require additional passive-control systems, high insurance premium, and additional security systems for emergency situations.[i]
- Compounding financing costs as a result of the construction delays
- Design changes of lawsuits causing further delays which will increase financing charges.
- Untimely and expensive political and regulatory risks; especially in countries with inconsistent policies – commonly seen in developing nations.

i. Bulletin of the Atomic Scientists. Why nuclear power plants cost so much – and what can be done about it. 20 June 2019.

IEEFA research has examined a number of projects that demonstrate how the economics of new nuclear power have eroded competitive markets. Even in highly regulated markets, nuclear power is increasingly seen as an expensive energy option, often viable only with significant public commitments to long-term subsidies or taxpayer support. Well-known examples of extended delays and multi-billion dollar cost-overruns for high profile new nuclear power projects are summarized on the following page.

Table 8: Nuclear Projects Blow Outs



Source: IEEFA.

It is worth noting that Mizuho Securities USA LLC is projecting a further 7-month delay for Vogtle unit 3 & 4 in response to an increase in Covid-19 cases in the United States. The project is currently expected to incur an additional US$2 billion in cost overruns.[61]

One final element of the operating cost equation that cannot be ignored is the cost and availability of affordable insurance. As a result of the disasters at Fukushima, Chernobyl, and Three Mile Island, it has become more difficult, expensive, and time-consuming to build a nuclear reactor because of rising insurance premiums and strict regulations. The nuclear waste stalemate has also added significantly to the insurance risk associated with these projects.

In countries with a longstanding nuclear footprint such as the US, the UK, and Europe, insurance for nuclear is pooled under one mutual insurance associations such as Overseas Nuclear Electric Insurance Limited (NEIL) in the US; EMANI and ELINI[62] based in Europe, or the UK's Nuclear Risk Insurers Limited. These pool of insurances are set up by the nuclear industry themselves. However, it is understood that individual operator liability had to be curtailed and risk had to be socialized beyond a certain level. In the end, the state usually needs to accept responsibility as an insurer of last resort.

[61] S&P Global Market Intelligence. Wall Street braces for further delays, cost overruns at Vogtle nuke project. January 13, 2021.
[62] European Mutual Insurance for Nuclear Installations (EMANI), focused on physical damage, and European Liability Insurance Mutual (ELINI), focused on liability, respectively.

It is worth noting that no such insurance platform is known to exist yet in Indonesia. Before jumping into a nuclear development spree, it is strongly advised that policy makers ensure the needed underlying insurance framework is prepared well in advance.

The Cost of Decommissioning and Nuclear Waste Disposal in Indonesia Cannot Be Estimated With Any Certainty

Decommissioning nuclear power plants, which includes defueling, deconstruction, and dismantling, are technically complex processes. Despite the increasing number of nuclear facilities reaching the end of their operational lifetimes or are already closed, decommissioning nuclear facilities remains under-researched globally. As of mid 2020, only 20 units of reactors have been fully decommissioned out of the 189 that have been closed[63].The rest are either still awaiting or in various stages of decommissioning.

Country case studies by the World Nuclear Industry Status Report 2020 shows that both duration and costs of decommissioning have been largely underestimated. Ironically, the ongoing decommissioning projects suffer the same long delays and cost increases problems as the nuclear construction projects. This lack of global decommissioning experience makes it almost impossible for new nuclear proposals to accurately predict the total cost of energy.

In addition to the risks associated with decommissioning, there is also a long-term cost burden of managing nuclear waste disposal and storage that must be added into the cost calculus. These costs are frequently ignored when initial project costs are endorsed but the long-term cost of treatment, storage, and permanent disposal should be addressed by policymakers at the outset. Without this analysis, it is difficult, if not impossible, to evaluate power options on a like-for-like basis.

The challenges in finding suitable storage options can be meaningful. For example, the US, with the largest number of active nuclear reactors in the world, has been trying to construct a multibillion-dollar nuclear waste handling project since 2002 at Hanford Vit Plant, and Yucca mountain was chosen as a repository for the 90,000 metric tons of highly radioactive waste. Yet, these projects are still far from finished. Without a geologic repository solution, US taxpayers are currently paying an estimated US$6 billion annually to address the legacy high-level waste from the Manhattan

Other nuclear power leaders have only just begun to determine the full cost of potential decommissioning and waste storage solutions.

[63] A Mycle Schneider Consulting Project. The World Nuclear Industry Report 2020. September 2020. p. 220.

Project, according to researchers at Stanford University.[64]

Other nuclear power leaders have only just begun to determine the full cost of potential decommissioning and waste storage solutions. Germany set aside €23.6 billion of state-owned fund to pay for the interim storage and disposal of nuclear waste, and €38 billion to decommission the 17 reactors.[65]

In January 2012, France's Court of Audit released a report that estimated that the future costs of decommissioning all of France's nuclear facilities and disposing the radioactive waste would be as much as €79.4 billion. EDF's estimates of the total cost was not far behind at €75 billion. As of end 2016, EDF has set aside €19.6 billion provisions for waste management of spent fuel and long-term radioactive waste in France, and €16.4 billion for decommissioning and last cores. Yet in January 2017, a French parliamentary committee reported that the cost of decommissioning is "likely to be greater than the provisions", the technical feasibility is "not fully assured" and the dismantling work will take "presumably more time than expected." It questioned the basis of EDF's estimates of €75 billion total cost.[66]

The unfortunate conclusion from these examples is that no country has been able to ring fence the ultimate disposal cost of its nuclear waste, because none have found a real working solution to the question of permanent storage. Finland is often cited as the only country that is realizing a permanent nuclear waste repository solution. A deep geological repository in Olkiluoto is currently undergoing construction with an estimated construction cost of US$ 555 million[67], and around €3.5 billion (US$ 3.9 billion) to operate for 100 years.[68] The plant is planned to be operational by 2022.

No country has been able to ring fence the ultimate disposal cost of its nuclear waste.

The financial impact of the nuclear waste issue has been acknowledged in previous power sector planning efforts by PLN. Since the RUPTL 2015-2024 and subsequent RUPTLs, PLN has raised a red flag concerning the cost of waste management citing "the unclear capital cost of radioactive waste management and decommissioning, as well as cost related to nuclear liability."[69] Having raised the issue, however, since the 2018 RUTPL, PLN passed the decision about the viability of nuclear power to the

[64] Stanford Earth: School of Earth, Energy, and Environmental Science. The steep costs of nuclear waste in the US. 03 July 2018.
[65] World Nuclear Association. Nuclear Power in Germany. Updated March 2021.
[66] World Nuclear Association. Nuclear Power in France. Updated January 2021.
[67] NS Energy. Onkalo nuclear waste disposal facility. Accessed February 2021.
[68] The New York Times. On nuclear waste, Finland shows US how it can be done. 9 June 2017.
[69] PLN. RUPTL 2015-2024.

government and policymakers, instead of taking full control of the risk analysis and planning decisions.

Indonesian Regulations on Nuclear Accident Liability—Is Comparable to Global Standards, but With Caveats

Law no 10/1997 on nuclear energy stipulates that each nuclear operator in Indonesia would be liable to a maximum of IDR 900 billion (USD$64 million) for any nuclear accident occurring on site or during fuel or waste transportation. This amount was updated by a Government Regulation no 46/2009 to IDR 4 trillion (USD$276 million).[70]

The set nuclear accident liability amount is notably comparable to the global standard set by the Convention on Supplementary Compensation for Nuclear Damage (CSC) and the Protocol to Amend the Vienna Convention (RVC) in 1997. These protocols set the nuclear operator's liability at a minimum 300 million Special Drawing Rights (SDRs)—a unit of account used by the International Monetary Fund based on a basket of weighted currencies— or about EUR360 million.

As a comparison, the catastrophic accidents at Chernobyl and Fukushima cost USD$259 billion and USD$166 billion, respectively, most of which was paid for by the public.[71]

It is worth noting that there are caveats embedded within the nuclear liability regulations. One of the clauses in the Nuclear Bill stipulates that nuclear owners are not liable for any nuclear accident that occurs as a direct result of international or non-international armed conflict or natural disasters of extraordinary magnitude beyond the required safety design limits set by the Supervisory Agency. In the explanation chapter of the Law, the 'extraordinary natural disasters' include earthquakes of seismic category S1 and S2.

Category S1 seismic entails the maximum earthquake that can occur once during a nuclear operational lifetime (such as the 50 years cycle), and S2 is the maximum earthquake that can occur at the location exceeding the plant's life (such as the 1,000 years cycle). In theory, all nuclear installations need to be designed to withstand the S1 and S2 earthquakes. In practice, however, this might be hard to prove, considering no record of earthquake magnitude was found in

The catastrophic accidents at Chernobyl and Fukushima cost USD$259B and USD$166B, most of which was paid for by the public.

[70] BAPETEN. Peraturan Pemerintah no 46/2009.
[71] Gilbert, Alexander, Sovacool, Benjamin K, Johnstone, Phil and Stirling, Andy. Cost overruns and financial risk in the construction of nuclear power reactors: a critical appraisal. Energy Policy, 102. 2017. p. 644-649.

Indonesia, even by the Indonesian Meteorology Climatology and Geophysics Council (BMKG).

Considering the unstable geographical location of Indonesia, this clause presents a high risk for taxpayers when so-called 'natural disasters' inevitably take place.

There is not a clear explanation in the Law nor the Government Regulations regarding the Central Government's responsibility as the last resort, should the third party liability amount exceeds the insurance coverage.

In addition, a follow up regulation issued by President Susilo Bambang Yudhoyono through Presidential Regulation no 74/2012 confirmed the liability limit increase up to IDR 4 trillion (USD$276 million). This regulation further breaks down the liability limit into types of reactors. Apparently the IDR 4 trillion is the upper limit for commercial reactors with more than 2000 MWe energy. Those having installed capacity of 1500 – 2000 MWe are capped at IDR 2 trillion (USD$142.8 million); 1000 – 1500 MWe capped at IDR 1 trillion (USD$71.4); 500 – 1000 MWe capped at IDR 500 billion (USD$35.7 million), and any commercial reactor below 500 MWe will have their liability capped at IDR 250 billion (USD$17.8 million).[72]

The segregation of liability limit gives favours to the SMRs economics as they would only be liable for a much smaller amount compared to traditional large-scale units. Although when it comes to unforeseen catastrophic event, a small reactor's accident with core melt down would still cause a significant impact to people and the environment.

Market Viability

Perhaps the biggest challenge that nuclear advocates must address is how nuclear will actually fit into Indonesia's already very stressed power market. Over the past two years, over-capacity and baseload lock-in have emerged in the key Java-Bali grid and PLN's financial position remains quite vulnerable. Given the long timelines for nuclear development, it will be crucial for policymakers to consider how the structure of Indonesia's power market will evolve in the future as cost-competition from other sources of energy change the market. Given the demanding requirements for successful nuclear development, it is particularly important to stress test any planning assumptions to assess the potential risk that new nuclear assets might become stranded, as other more competitive options emerge.

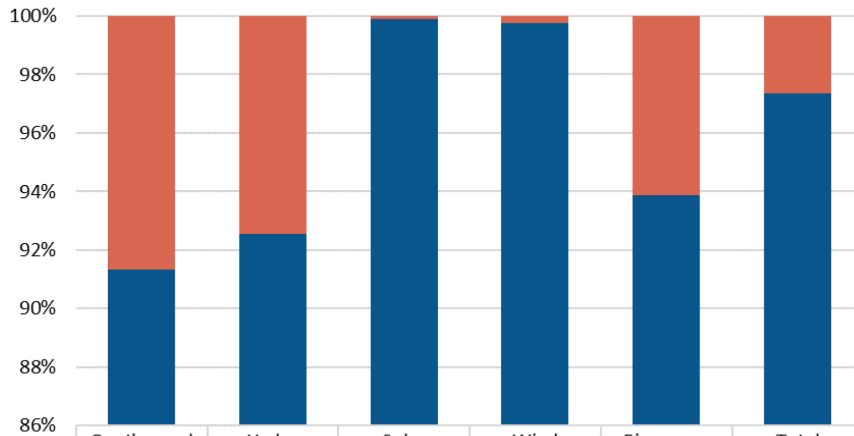
Competition From Renewables

The fact that Indonesia has an abundance of different types of renewable energy sources, makes the case for nuclear even less attractive. From hydro to geothermal, or solar to wind, and not to mention biomass, Indonesia has approximately 400 GW of untapped renewable energy potential. Currently only 2.5% of that potential had been utilised. Hypothetically, those resources alone can easily fill the demand trajectory for Indonesia's power sector which is forecast to reach 118-127 GW in

[72] ESDM. Presidential Regulation no 74/2012.

2025, and 205-267 GW in 2038 years.[73]

Figure 4: Indonesia’s Renewable Energy Potential vs Installed Capacity



	Geothermal	Hydro	Solar	Wind	Bioenergy	Total
Current Installed Capacity (MW)	2,271	6,051	232	154	2,132	10,839
Potential (MW)	23,966	75,091	207,898	60,647	32,654	400,256

Source: Installed capacity is taken from MEMR Infographic 2021. RE potential is taken from DEN. Bauran Energi Nasional 2020.

What is important to note here is that PLN already has proven and reliable technology options available to meet the 2025 or 2030 Paris Agreement target. The already mature hydro technology and civil construction knowledge for hydro power is long known and proven in Indonesia. Some golden hydro sites are even able to produce power at very low costs and competitive to coal. The new government-backed geothermal exploration program is meant to help lower the project’s risk which in turn will lower production costs. The global trend of annual double-digit deflation of solar, wind and battery storage cost should give PLN plenty of choices to increase intermittent renewable energy mix into its system.

It would arguably make more sense for PLN to find a way to optimize system operations and enhance the cost effectiveness of projects with known technology. Given the ongoing improvements in renewable technology cost curves, a new focus on providing a conducive business environment for renewable energy industry in Indonesia would be more consistent with PLN’s medium-term financial priorities.

Adding an Inflexible High Cost Nuclear Into the Mix Could Worsen PLN’s Financials

Traditionally, nuclear power plants are designed to run continuously as baseload power at a very high capacity to recoup its large capital costs. This means privately owned nuclear power plants will need to be contracted on a certain capacity to the

[73] Forecast is based on the National Electricity General Plan 2019-2038, with the lower target includes energy efficiency measures.

utility, regardless of whether the produced power is being absorbed by the grid.

Numerous reports by IEEFA have highlighted how capacity payment contracts for coal IPPs have paralyzed PLN from being able to manage a more efficient dispatch order[74]. Having locked itself with capacity payment contracts with approximately 26.6 GW of coal and 3.6 GW of gas IPPs[75], PLN's financials will be more at risk if it starts adding big chunks of inflexible power such as nuclear to its system without much of the needed demand growth. The low power demand condition is magnified with the Covid-19 pandemic, as a second and third wave is expected to prolong economic slowdown.

In fact, the Minister of Energy and Mineral Resources, Arifin Tasrif conceded to the House of Representatives during a joint working meeting with the Commission VII on 19th January 2021, that should the ambitious 35GW program go ahead and be completed by 2029, with the current economic projection, PLN will likely have 40 – 60% of reserve margin in its system. This means there will be around 7GW of unused power in PLN's systems. This was based on the ministry's study of revising the country's economic growth to 4.6—5%, lower than the previous assumption of 7%.[76]

There is a mismatch between what the nuclear power advocates want to achieve with what PLN will be able to offer.

Indonesia's vertically integrated market structure and the complex nature of PPA contracts gave little room for PLN to renegotiate contractual agreements with IPP. All nuclear power plant owners, be it the traditional large scale PWR or the small modular SMR, would understandably ask for such fixed capacity payment contracts. Technically there may be ways to enable nuclear power plants to be flexible, but plant owners would inevitably choose to dispatch nuclear plant as baseload, so that the required steady stream of cash flow needed by the plant owner to repay debt is guaranteed.

There is an apparent mismatch between what the nuclear power advocates want to achieve with what PLN will be able to offer. At the moment and for the foreseeable future, Indonesia does not need more baseload power, especially for islands with grid systems that are already experiencing overcapacity. Although the COVID-19 crisis is not the fundamental cause of PLN's financial problems, it has shown how overoptimistic planning and stringent contracts could lock-in utility with obligation to pay unneeded power. It is therefore very understandable, if PLN at this stage of

[74] IEEFA. Running Out of Options: Six Questions for PLN. October 2020.
[75] Data processed from PLN Annual Report 2019.
[76] Harian Terkini. Kementrian ESDM: Indonesia akan kelebihan pasokan listrik hingga 60%. 22 January 2021

the game, is not looking into the possibility of having another inflexible high-cost power into the mix.

The recent pledge announced by PLN to become carbon neutral by 2050 actually paints a clear picture of how PLN sees the role of nuclear power in Indonesia’s energy transition scenario[77]. It looks like PLN sees nuclear as a viable option to decarbonize PLN’s grid systems, a view that is in line with the plan of other utilities globally. However, it is worth noting that in all of PLN’s net zero scenarios—be it the 2045, 2050, or 2060—nuclear is planned to start only in the year of 2040, not earlier in this decade like most SMR nuclear advocates would have preferred. The unexpected announcement reflects PLN’s realistic expectation on nuclear power development in Indonesia. It also pretty much dismisses the SMR euphoria that we have seen in recent media publications.

In a follow up presentation to the Parliament a few days later, PLN claimed that nuclear power is planned to start in 2040 to “maintain system’s reliability as the technology is expected to become safer by then”. Behind the claim, PLN actually understands the real market viability challenge that nuclear power faces in the wake of less-cost less-risk renewables options. In addition, PLN management also seemed to be fully aware of its own financial struggle with overcapacity and inflexible PPA contracts.

Conclusion

When it comes to commercial nuclear power build up in Indonesia, deep engagement efforts need to be taken with high-level of honesty and credibility by all parties. Truthful communication and discussion between policy makers, PLN and BATAN/BAPETEN technocrats, private business interests, and the general public need to happen to ensure a high degree of accountability on such a complex matter. Recognizing the potential role for nuclear to decarbonize Indonesia’s power system means the opportunities should be presented along with the risks and liabilities that come with it.

This report aims to provide an unbiased and technology-agnostic review of the three fundamental challenges for nuclear power visibility in Indonesia. In its analysis, IEEFA found that technological viability of nuclear needs to be challenged against financial viability of specific projects and the long-term market viability for nuclear power against the rise of deflationary and low risk renewable and storage alternatives. The vertically integrated market structure of Indonesia’s power system should also be at back of mind whenever nuclear is considered as a baseload option, especially with the current PLN’s worsening financial condition.

From the technical point of view, the technology reliability, safety and safeguard issue present the most potential risk for the general public. Considering the high technical complexity of nuclear technology, a new governance mechanism and rigorous oversight by a credible and independent energy commissioner is crucial to

[77] Mongabay. Indonesia Says No New Coal Plants from 2023 (After the Next 100 or so). May 12, 2021.

have to ensure safety, security and safeguard throughout the overall nuclear value-chain. This is something that Indonesia currently does not have and will need to establish as soon as possible should the decision be reached to move ahead with the nuclear pilot project installations. Failure to do so could result in serious safety consequences that could be fatal for Indonesians.

When it comes to financial viability, perhaps the most prominent risk relates to project delivery risks. Most of the new nuclear power constructions have experienced significant delays and exceeded their initial budgets. This very typical cost overrun risk must be taken into serious consideration every time PLN receives a project proposal from a nuclear proponent. On top of that, the open-ended cost issues relating to the cost of decommissioning and permanent waste disposal need to be brought to attention to all related stakeholders, especially the general public, well in advance of any nuclear power construction.

Indonesian citizens need to know the total cost of having nuclear in their power system.

Indonesian citizens need to know the total cost of having nuclear in their power system. They also have the right to know how the government and policy makers would handle the problematic high-level waste of nuclear. It would not be fair to pass these kinds of liabilities and risks to our next generation, without proper risk communication to the general public.

IEEFA acknowledges that the smaller, easily dispatchable, and walk-away safe promise of the new Gen-IV SMR technology offer is promising, IF and when the technology reaches commercial stage. Until such technology is proven to be technically and financially feasible, Indonesia's safest option is to pause and set a more realistic net zero scenarios with resources and technologies that are already readily available with less cost, less risk, and less future liabilities.

Appendix

Nuclear Power Plants							
Country	Active Reactors		Decommissioned Reactors		Current Waste Treatment	Waste Handling / Plan	Occurring Waste Treatment Cost
	Units / Reactors	MWe Installed	Units / Reactors	MWe Installed			
The United States	95	96,772	38	16,944	Over 90,000 metric tons of highly radioactive nuclear waste remained in casks mainly where it's generated - at the power plants and processing facilities. Many are known to be leaking. The US does not reprocess its spent fuel. Reactors remained on-site pools for a few years until the fuel cools and radioactivity starts to fall. Then the fuel rods are placed in stainless-steel canisters, which are welded shut and packed inside reinforced concrete silos.	Proposed repository beneath Yucca Mountain in Nevada. Received strong opposition from local community and has been discussed for years with changes in the US leadership.	Multibillion dollar project at Hanford Vit Plant under construction since 2002. Yucca mountain construction began in 1990, but pushback from Nevadans left the project on indefinite hiatus since 2011.
France	57	62,250	13	4,671	Centre de l'Aube operated by Andra	Preferred site selected. The establishment of a plan for 500m underground rock laboratory in eastern France situated in clays and known as the Industrial Centre for Geological Storage (Cigéo). The structure will comprise hundreds of storage tunnels covering a total area of 25km2 and will last for a century.	The energy minister set the cost for repository project at €25bn in 2016, figure is hefty and, at this stage, is purely an estimate.

China	47	45,498	-	-	China National Nuclear Corp. (CNNC) intermediate level wastes (ILW) and low level wastes (LLW): solidified and then put in stainless steel drums and stored in interim storage vaults in nuclear power plants for 5 years, followed by transported to disposal sites and buried safely in the shallow geological disposal depository 100~300m underground. High level wastes (HLW): similar to ILW and LLW though disposal depository is 500~1,000m below the ground, which requires long-term safety of more than 10,000 years.	Will expand its three disposal sites for low- and medium-level radioactive waste. Plans on high-level radioactive waste disposal earmarks site to store nuclear waste deep underground, soon begin on building the Beishan Underground Research Laboratory 400 metres (1,312 feet) underground in the northwestern province of Gansu.	No detailed official cost estimates for the reprocessing plants and disposal sites are publicly available. Though, suggested a capital cost for a 200 tHM/yr facility, equals to 11.3 billion in 2014 RMB ($3.2 billion in 2014 dollars). While the capital cost of 800 tHM/yr plant is estimate to be 34 billion in 2014 RMB ($9.6 billion in 2014 dollars).
Japan	33	31,679	23	12,851	As of March 31, according to Nuclear Waste Management Organization (NUMO) the total volume of spent fuel produced so far was equivalent to around 26,000 canisters of vitrified waste. Japan is only storing 2,492 canisters, with the remainder in France and the U.K. All waste will eventually have to be transported somewhere in Japan for final disposal.	Waste converted into a form of glass in a process called vitrification, placed inside stainless steel canisters and then into a cooling pool for a number of years, until the waste can be transferred to an underground final depository site. Plans call for construction of a storage area at least 300 meters underground, covering an area of between six and 10 square kilometers, with between one and two square kilometers of surface facilities. Around 1.23 million tonnes of water contaminated by 2011 Fukushima nuclear disaster is planned to be dumped in the	The total cost of an underground final depository site, consisting of technology development, surveys, land acquisition, construction, operations and management is estimated at ¥3.9 trillion.

Japan (continued)						Pacific Ocean in the near future. Although much of the water has been filtered, there are still questions of whether it will work as planned.	
Russia	38	29,203	8	1,232	Storage of nuclear waste in Russia is carried out mainly in temporary storage facilities. Total number is currently estimated at 140 industrial sites and 1,466 temporary storage points located in 43 regions of the country. Most of the waste is stored in metal or concrete containers, metal or concrete tanks, at ground level or underground, and in outdoor pools for liquid radioactive waste.	Existing program involves the establishment of at least 10 sites of final radioactive waste isolation in Russia by 2025. Deep geological disposal facilities in stable rock masses at between 250m and 1,000m deep for mined repositories, and between 2,000m and 5,000m deep for blast-holes. It is planned that these sites will be designed for the disposal of about 80,000m3 of solid radioactive waste material.	Investments in the implementation of the existing State program in Russia is expected to reach RUB 399 billion (US$6.6 billion), the majority of which will be provided from the Russian Federal Budget with extra-budgetary sources and private investments.
South Korea	24	23,231	2	1,237	Spent nuclear fuel is stored wet at NPPs and in wet storage at HANARO (High-flux Advanced Neutron Application Reactor) research site (KRR-1 fuel was returned to the U.S. in 1998). CANDU (CANada Deuterium Uranium) reactor fuel is stored for 6 years wet before transfer to dry storage.	Site selection for a final waste repository as prescribed by the 2016 National Policy on High Level Radioactive Waste Management is still in the preliminary stage, and will likely be completed around 2030, with operation beginning in the mid-2050s. The government has also considered disposal in another country's repository, as well as Pyroprocessing.	No detailed official cost estimates for the reprocessing plants and disposal sites are publicly available.

Canada	19	13,553	4	1,113	Used nuclear fuel bundles are removed from a reactor, they are placed in a water-filled pool where their heat and radioactivity decrease. After seven to ten years, the bundles are placed in dry storage containers, silos or vaults. Currently safely managed in facilities licensed for interim storage. These facilities are located at nuclear reactor sites in Ontario, Quebec, and New Brunswick, and at Atomic Energy of Canada Limited's sites in Manitoba and Chalk River Laboratories in Ontario.	Nuclear Waste Management Organization (NWMO) was established in 2002 under Ottawa's Nuclear Fuel Waste Act by Canada's nuclear electricity producers in Ontario, Quebec and New Brunswick. Currently investigating a geological repository site selection.	The estimated cost of this project is $23 billion.
Ukraine	15	13,107	4	3,515	Used fuel is mostly stored on site though some VVER-440 fuel continued to be sent to Russia for reprocessing under a 1993 arrangement. At Zaporozhe a long-term dry storage facility for spent fuel has operated since 2001, but other VVER-1000 spent fuel has been sent to Russia for storage, at a cost to Ukraine of over $100 million per year.	CSFSF near Chernobyl for VVER fuel, new storage facility will become a part of the common spent nuclear fuel management complex of the state-owned company Chernobyl NPP, though it will not take any Chernobyl fuel. Chernobyl ISF-2 for RBMK fuel, Used fuel from decommissioned RBMK reactors at Chernobyl nuclear power plant will be stored in a new dry storage facility being built a few kilometres from the plant, and not far from CSFSF.	CSFSF near Chernobyl for VVER fuel, US$ $460 million, including 'start-up complex' $160 million. ISF-2 has a fixed price of $411 million and was completed in 2019.

Germany	6	8,052	30	18,252	Utilities were the one responsible for interim storage of spent fuel, formed joint companies at facilities at Ahaus and Gorleben. Some are also stored on-site in dry casks. German reprocesses some of its high-level waste through vitrification process. Some of the low & intermediate level waste were disposed in the salt mine repository at Asse in Lower Saxony.	In 2017, the German government established the Bundes Gesellschaft für Zwischenlagerung mbH (BGZ) to enable the government to take over the intermediate storage and final disposal of radioactive waste. The salt dome at Gorleben was declared as the location for a national centre for disposal of radioactive wastes. It is currently being considered a possible site for geological disposal of high-level wastes.	23.6 billion Euro of state-owned fund to pay for the interim storage and disposal of nuclear wastes. This includes a 35% risk premium for increased costs. 38 billion euro for decommissioning the reactors.
United Kingdom	15	8,883	30	4,745	Spent nuclear fuel (SNF) from now-closed Magnox reactors is stored wet onsite before storage/reprocessing at the Magnox reprocessing plant. SNF from advanced gas-cooled reactors is dry-stored briefly before being stored wet on-site and transferred to central interim storage. Fuel from the single PWR is first stored in a pond and then put in a new dry independent spent fuel storage installation, constructed to keep up with the reactor's lifetime output.	Currently investigating a geological repository site selection for the HLW. LLW Repository at Drigg in Cumbria operated by UK Nuclear Waste Management (a consortium led by Washington Group International with Studsvik UK, Serco, and Areva) on behalf of the Nuclear Decommissioning Authority.	No detailed official cost estimates for the reprocessing plants and disposal sites are publicly available.

Sweden	7	7,738	6	3,231	the SFR final repository for short-lived radioactive waste at Forsmark, where the depth of the facility is 50m under the Baltic seabed – operated by the Swedish Nuclear Fuel and Waste Management Company (SKB)c.	Proposed plans for a final storage solution for all spent fuel from Sweden's nuclear power reactors, stored in 25 ton copper capsules, the nuclear waste is to be buried 500 meters underground.	According to the Swedish National Debt Office on September 30, 2019 total costs of the Swedish nuclear waste programme, from start to finish, will amount to about SEK 147 billion. SEK 53 billion has already been used to build and operate the existing plants and for research and development on the Swedish nuclear waste system and its construction. The remaining SEK 94 billion relates to future costs from 2021 and onwards.
Spain	7	7,121	2	1,067	Reactor fuel is stored temporarily in pools or, at the Trillo, Jose Cabrera and Asco sites, in dry Individualized Temporary Storage onsite. El Cabril LLW and ILW disposal facility operated by ENRESA.	Efforts are focused on constructing a centralized storage facility that will operate for 60 years; operational year is unknown.	As of April 2019 its funds were reported as about €5.8 billion.

India	22	6,255	-	-	The waste management in industrial and research facilities of DAE also are under AERB's purview. Solid waste: Solid waste generated from nuclear power plants after suitable conditioning are disposed off in Near Surface Disposal Facilities (NSDF) located within the exclusion zone boundary of nuclear power plants. Near Surface Disposal Facilities are designed and constructed to contain the radionuclides within the disposal system until the radionuclides decay to negligible activity level. Liquid waste: Low level liquid waste generated from nuclear power plants are discharged to the environment after suitable treatment and ensuring compliance with the regulatory limit. The treatment system essentially comprises chemical treatment, evaporation, ion exchange, filtration etc. Gaseous waste: Gaseous waste is treated at the source of generation. The gaseous wastes are discharged to the environment through 100 m high stack after filtration and dilution with continuous monitoring of radionuclides and compliance with the regulatory limits.	Working on a "deep geological repository" to permanently store its nuclear waste.	No detailed official cost estimates for the reprocessing plants and disposal sites are publicly available.

Belgium	7	5,930	1	10	Planned to be shut down by 2025. // ONDRAF/NIRAS (the Belgian Agency for Radioactive Waste and Enriched Fissile materials) is charged with radioactive waste management. radioactive waste is temporarily and safely stored mainly on the Belgoprocess site in Dessel (Province of Antwerp). The buildings are specifically designed in accordance with the type of waste they contain.	Belgium has yet to take a position on the final disposal of high-level and/or long-lived waste. "The current proposal only discusses the principle of geological disposal. How, where and when the repository would be built is not yet an issue."	No detailed official cost estimates for the reprocessing plants and disposal sites are publicly available.

Czech Republic	6	3,932	-	-	Liquid RAW (radioactive concentrate) from NPPs Dukovany and Temelín is immobilized in bitumen, ie. into a form complying with waste acceptance criteria for disposal. The main process equipment is a film rotor evaporator where the concentrate is mixed with bitumen and water is evaporated. The resulting product is filled into 200-liter drums. Solid waste is compacted into 200-liter drums or incinerated, melted and supercompacted abroad. Sludge and ion exchangers resins are treated by immobilization in aluminosilicate matrix using a portable device. Currently there are three radioactive waste disposal facilities (ÚRAO) at the territory of the Czech Republic in operation - ÚRAO Dukovany, ÚRAO Richard and ÚRAO Bratrství.	Aim of building a geological repository, work aimed at selecting potentially suitable sites began in 1992, but the final site has not yet been determined. Such a repository should commence operation in 2065.	No detailed official cost estimates for the reprocessing plants and disposal sites are publicly available.

Switzerland	4	2,960	2	379	Most of Switzerland's high-level waste is currently held in transport and storage casks at the Zwilag facility, with a smaller percentage at the interim storage facility at the Beznau nuclear power plant (Zwibez).	Planned deep geological repository, Nagra expects to submit the general licence application for the disposal facilities by 2024. A decision on the approval of the licence is expected around 2030 and is subject to an optional national referendum. The repository for LLW/ILW is planned to be in operation by 2050, with the one for HLW planned to be operational ten years later.	As of the end of 2015 this cost equated to around 5.6 billion Swiss Francs and was paid by the operators. Up to the end of the operation of the plants and for their post-operation, around 1.9 billion Swiss Francs will be added to this, which continue to be paid for by the operators.
Finland	4	2,764			Liquid radioactive waste (concentrate) and solid radioactive waste (after compacting) from the ÚJV Řež, a. s. are immobilized in cement in drums.	An underground research facility at 455m deep beneath the ground was constructed between 2004 and 2014 to verify the suitability of the Olkiluoto bedrock for the final disposal of highly radioactive waste. Construction of the encapsulation plant for the facility was started in September 2019, while Posiva plans to apply for an operating licence by the end of 2021.	The underground nuclear waste storage facility's investment is estimated £444 million ($555 million)
Others	30	17,735	17	8,025			
TOTAL	**436**	**386,663**	**180**	**77,272**			

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The Institute for Energy Economics and Financial Analysis (IEEFA) examines issues related to energy markets, trends and policies. The Institute's mission is to accelerate the transition to a diverse, sustainable and profitable energy economy. www.ieefa.org

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