Case study

Boosting renewable power with large-scale energy storage in Southeast Asia

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This publication has been funded by the Australian Government through the Department of Foreign Affairs and Trade and the Partnerships for Infrastructure (P4I) initiative. P4I partners with Southeast Asia to drive sustainable, inclusive and resilient growth through quality infrastructure. More information about P4I is available at partnershipsforinfrastructure.org.

Partnerships for Infrastructure acknowledges Aboriginal and Torres Strait Islander peoples as the traditional custodians of Country throughout Australia, and we pay our respects to Elders past and present. P4I also recognises early connections between Southeast Asia and the First Nations peoples of Australia.

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This case study explores the potential of pumped hydroelectric energy storage (PHES) as a key solution to support Southeast Asia's renewable energy transition. Australia, through Partnerships for Infrastructure (P4I), has led multiple initiatives in the region, working in collaboration with the Lao Ministry of Energy and Mines and Electricité du Laos; the Indonesian Ministry of Energy and Mineral Resources and PT Perusahaan Listrik Negara (PLN); Tenaga Nasional Berhad (TNB) and Sarawak Energy in Malaysia; and the ASEAN Centre for Energy. These collaborations draw on Australia's experience in PHES. Support includes access to the Australian National University's global atlas of potential PHES sites, expert input on strategic planning and feasibility studies, guidance on potential business models and sustainable finance pathways, and direct engagement with Australian policymakers, regulators, and engineering firms through study tours.

Other regional and bilateral programs of the Australian Department of Foreign Affairs and Trade that provide technical assistance on PHES include the Mekong–Australia Partnership and the Australia–Indonesia Climate and Infrastructure Partnership (KINETIK).

Cover image: P4I and the Australian National University (ANU) led a mission to Sarawak, Malaysia, bringing together Sarawak Energy, Sarawak government officials and the Australian High Commission to discuss the scope of future engagement and plan a PHES study tour to Australia for senior Sarawak officials. Source: P4I

ANU PHES experts, representatives from the Australian High Commission and P4I, and Sarawak government officials meet with Sarawak Energy representatives at their office in Kuching to discuss objectives and current challenges. Source: P4I

The challenges posed by an increasingly renewable grid

Electricity demand is set to grow rapidly in the coming decades in Southeast Asia, and variable renewable sources will meet an increasing share of that demand. Most countries in the region are committed to reducing fossil fuel reliance, increasing renewables in their energy mix, and achieving net-zero greenhouse gas emissions by 2050 or 2060.[1]

For example, Malaysia's National Energy Transition Roadmap outlines ambitious renewable energy targets of 40% by 2035 and 70% by 2050, with a focus on solar photovoltaic energy.[2] Similarly, in Indonesia, the government-owned utility PT Perusahaan Listrik Negara (PLN) released a 2021–2030 business plan that calls for 40.6 gigawatts of new generation capacity, with renewable energy sources making up half of this expansion.[3]

Renewables such as solar photovoltaic and wind energy have different generation patterns to traditional coal- and gas-fired plants, which will require distinct integration approaches for policymakers, regulatory bodies and utilities. One such area is managing the intermittent nature of renewables to maintain a reliable energy supply that can balance fluctuations in supply and demand. Renewable sources like solar and wind do not produce electricity consistently throughout the day – for example, when the sun is not shining or the wind is calm.[4] This is driving a rethink of how to plan, manage and operate power systems increasingly based on renewables, particularly in countries like Laos and Malaysia that are balancing renewable electricity exports with growing domestic demand.

'Guided by the Sarawak Post COVID-19 Development Strategy 2030, Sarawak is committed to addressing global climate challenges, aiming for net-zero emissions by 2050 while positioning itself as a regional powerhouse in renewable energy. With energy-intensive industries and a focus on electricity export strategies, Sarawak's power generation is predominantly powered by sustainable hydropower. To further diversify its renewable energy portfolio, Sarawak Energy, the state's power utility, is exploring alternatives such as cascading power sources, solar and other emerging technologies. Additionally, to better manage peak demand fluctuations and ensure a stable power supply for both domestic use and export, we are assessing the potential integration of energy storage solutions like PHES.'

— Datuk Haji Sharbini Suhaili, Group Chief Executive Officer, Sarawak Energy, Malaysia

[1] International Energy Agency, *Southeast Asia Energy Outlook 2022*, May 2022.

[2] Malaysian Ministry of Economy, *National Energy Transition Roadmap: Part 1: Flagship catalyst projects and initiatives*, July 2023, p 17.

[3] Kuungana Advisory, *Diagnostic for Competitive Arrangements for Energy Transition: Final report*, May 2024, p 25.

[4] International Energy Agency, *Grid-scale storage*, IEA website, n.d., accessed 17 March 2025.

Understanding the potential and benefits of PHES in the region

With Australian Government support through Partnerships for Infrastructure (P4I), government agencies, utilities and key energy research institutions, such as the ASEAN Centre for Energy, are now better equipped to understand the critical role of storage, particularly PHES, in enabling a transition to renewable electricity in Southeast Asia. This support is also assisting regional partners to identify potential sites for implementing PHES technology. Partners are also gaining insights into the key parameters needed to align PHES with their specific electricity objectives. Box 1 explains how PHES technology works.

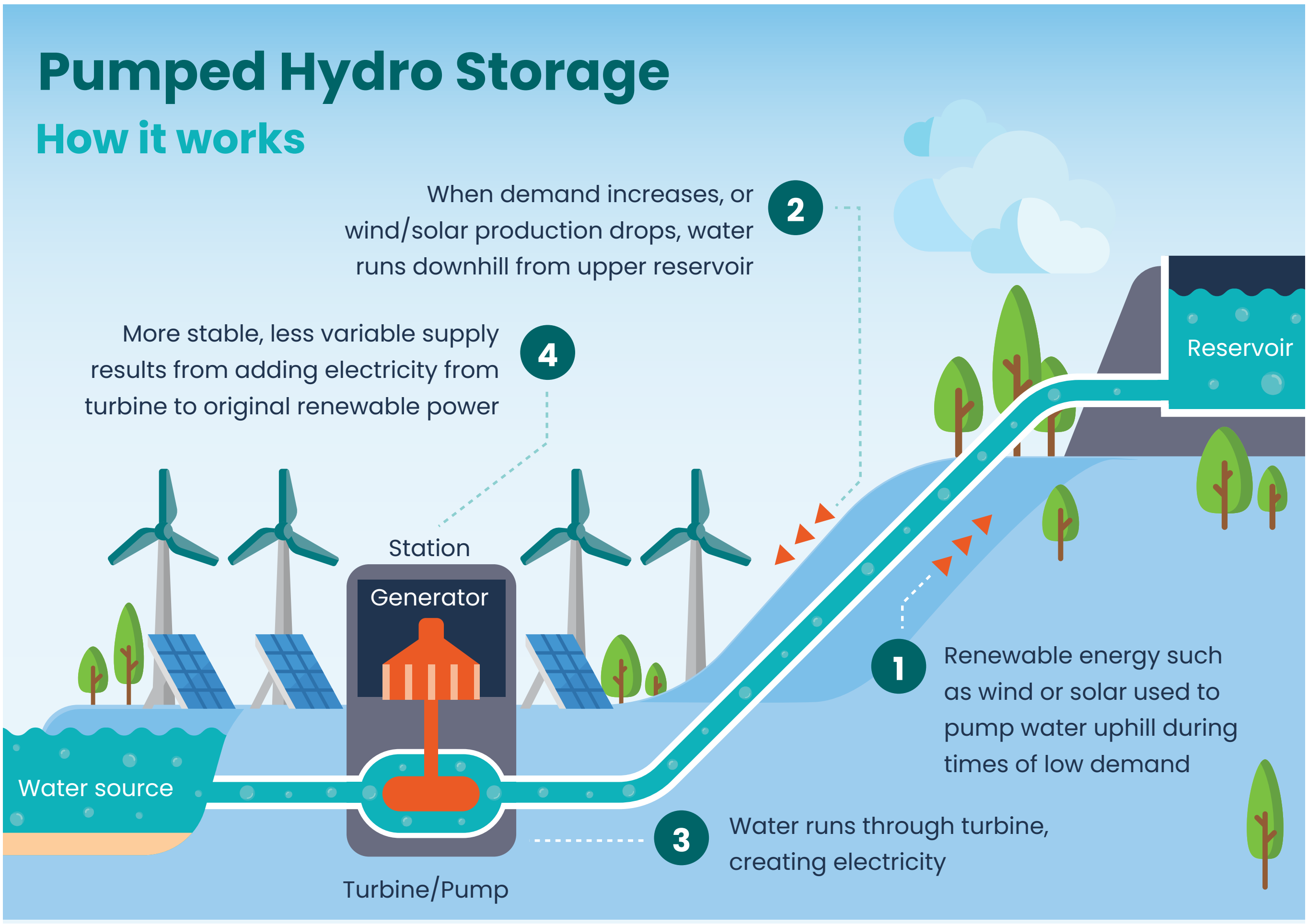
Box 1

How PHES works

Pumped hydroelectric energy storage (PHES) is a well-established technology for large-scale energy storage. It operates by using surplus electricity to pump water from a lower reservoir to a higher one, storing energy in the form of gravitational potential energy. When demand for electricity increases, the stored water is released to generate power through turbines (Figure 1). In 2020, PHES accounted for over 90% of global energy storage capacity.[1]

[1] International Energy Agency, *Grid-scale storage*, IEA website, n.d., accessed 17 March 2025.

Figure 1: Pumped hydroelectric energy storage – how it works



Source: Australian Renewable Energy Agency, '*What is pumped hydro and how does it work?*', ARENAWIRE, 20 August 2017, accessed 17 March 2025.

The critical services that PHES can provide in evolving power systems

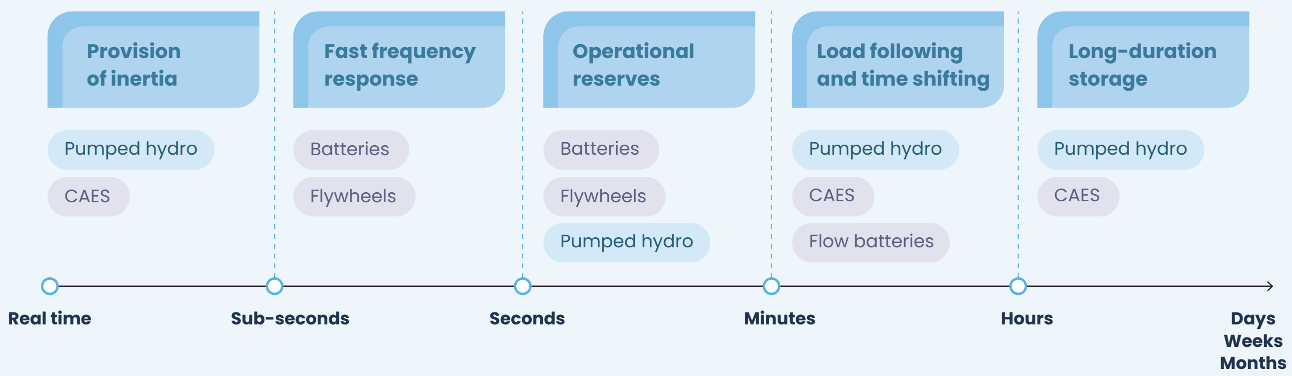
In general, electricity storage systems can absorb, store and reinject electricity into the grid. Electricity storage, particularly through PHES, can:

- **provide reserve capacity:** Grid-scale energy storage helps address challenges posed by the variability and uncertainty of solar photovoltaic and wind energy, ensuring a reliable power supply by managing fluctuations in supply and demand, such as during periods without sunlight.
- **maintain grid stability:** Grid-scale energy storage is crucial as the energy transition accelerates. Inverter-based resources, such as solar and wind, do not inherently provide key grid stability services – such as system strength, inertia, network support and ancillary control – traditionally supplied by synchronous generating units like gas, coal and hydropower plants. As energy systems face growing vulnerabilities from extreme weather and the physical impacts of climate change, finding new sources for these services becomes increasingly urgent. Power system operators will need to identify and procure alternative solutions, including energy storage, synchronous condensers, advanced inverters and virtual power plants.[5]

In addition to these 2 main functions, grid-scale energy storage like PHES can absorb excess electricity, significantly reducing the need for curtailment of renewable energy generation during peak generation times and ensuring that more renewable electricity is utilised effectively.

The key system services provided by PHES and other electricity storage solutions are illustrated in Figure 2. To maximise their potential, PHES systems should be designed to align with existing regulatory and market frameworks, enabling them to capitalise on the services they can provide. These services are essential for ensuring commercial feasibility.[6]

Figure 2: Overview of system services provided by PHES compared to other technologies



CAES = compressed air energy storage

Source: International Renewable Energy Agency, *Electricity Storage Valuation Framework: Assessing system value and ensuring project viability*, March 2020, p 22.

[5] International Renewable Energy Agency, *Electricity Storage Valuation Framework: Assessing system value and ensuring project viability*, March 2020.

[6] D Gilfillan and J Pittock, *APEC Workshop on the Use of Pumped Storage Hydropower to Enable Greater Renewable Energy Use and Reliable Electricity Supply*, [APEC Energy Working Group technical paper], Asia-Pacific Economic Cooperation (APEC) Secretariat, January 2022.

Representatives from the Ministry of Energy and Mines, Laos, explore ANU's global PHES atlas to identify high-potential sites during a 2-day workshop in Vientiane. Source: P4I

The role of PHES and complementary technologies in electricity markets

PHES is particularly effective for longer-term energy storage, such as overnight and seasonal storage. This contrasts with a battery energy storage system, which is typically designed for short-term storage lasting from minutes to hours. By storing surplus energy generated during low-demand periods, PHES makes energy available during times of high demand or low generation.[7] These technologies are complementary. The strategic and coordinated use of PHES and battery energy storage systems could provide greater flexibility, supporting cross-border electricity trading – a shared goal among many countries in the region.[8]

> **'We have mapped out priority grid interconnection projects to expand multilateral power trading in the region, identifying 18 existing or planned connections crucial to achieving the ASEAN Power Grid objectives.[9] While further research is needed, it would be fascinating to explore the overlap between these potential interconnection zones and areas with high PHES potential. We, at the ASEAN Centre for Energy, see PHES as an important solution to optimising renewable energy integration while enhancing flexibility in regional electricity markets.'**
>
> — Monika Merdekawati, Senior Research Analyst, Sustainable and Renewable Energy Department, ASEAN Centre for Energy

[7] A Blakers, T Weber and D Silalahi, '*Pumped hydro energy storage to support 100% renewable energy*', Progress in Energy, 2025, 7(2):022004, doi:10.1088/2516-1083/adaabd.

[8] ASEAN Centre for Energy, *8th ASEAN Energy Outlook: 2023–2050*, November 2024.

[9] ASEAN Centre for Energy, *ASEAN Power Grid Interconnections Project Profiles*, November 2024.

The status of PHES in the region and its potential

Thailand currently leads in existing PHES capacity, but the Philippines is set to surpass it soon, with around 5.7 gigawatts of PHES projects in the pipeline.[10] Indonesia is developing its first PHES facility in West Java,[11] and Vietnam has announced plans to pursue similar developments. Despite these advancements, the region's PHES capacity remains far below the technology's full potential.

Modelling by the Australian National University (ANU) indicates that Southeast Asia has substantial PHES potential. The university's global PHES atlas records over 66,330 potential development sites in the region (Figure 3).[12] ANU classifies the sites according to the following criteria:

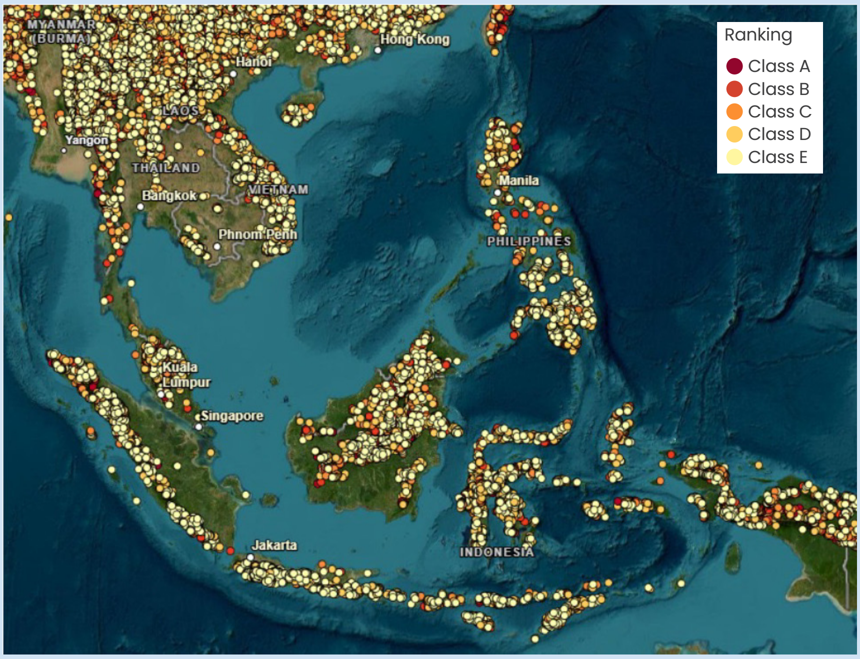
- off-river and on-river
- greenfield, bluefield, brownfield, ocean, seasonal and 'turkey's nest'.

Off-river PHES sites do not require new river dams, reducing their impact on natural waterways. They also carry a lower risk of flood-related disruptions, making them more disaster- and climate-resilient. In addition to off-river and on-river, the atlas classifies sites into 6 types:

- Greenfield sites involve creating 2 new reservoirs.
- Bluefield sites use at least one existing reservoir.
- Brownfield sites repurpose former mining areas.
- Ocean sites use the ocean as the lower reservoir.
- Seasonal sites are paired with very large rivers.
- Turkey's nest sites involve constructing a ring dam on flat land or around a natural depression to create an upper reservoir.[13]

P4I, in close collaboration with ANU and experts in social inclusion and climate and disaster resilience, supports countries, states and utilities in assessing potential PHES sites. These assessments cover technical (engineering), social, environmental, financial and market factors. Social and environmental considerations include topography, geology, flood risks, land acquisition and resettlement, water availability and usage (for example, for farming), potential biodiversity impacts, and protection of culturally significant areas. Such site assessments enable decision-makers to establish clear project parameters, which is essential for securing sustainable financing and de-risking investment.[14]

Figure 3: Potential PHES sites in Southeast Asia



Note: Map shows potential 50-gigawatt-hour, 18-hour storage sites. The best potential sites are Class A (dark red).

Source: Geoscience Australia, *Pumped hydro: 50GWh 18h - (ANU)* [overview location map], Geoscience Australia Portal, n.d., accessed 17 March 2025; and Australian National University (ANU) 100% Renewable Energy Group, *Pumped hydro energy storage atlases*, ANU website, n.d., accessed 17 March 2025.

[10] NC Winofa and K Selvaraju, '*Pump it up: Southeast Asia bets big on pumped hydro with 18 GW by 2033*', Rystad Energy, 18 June 2024.

[11] World Bank Group, *Indonesia's first pumped storage hydropower plant to support energy transition* [media release], 10 September 2021.

[12] As at 25 July 2024.

[13] Australian National University (ANU) 100% Renewable Energy Group, *Pumped hydro energy storage atlases*, ANU website, n.d., accessed 17 March 2025.

[14] International Hydropower Association, *Enabling New Pumped Storage Hydropower. A guidance note for key decision makers to de-risk pumped storage investments*, July 2024.

Nurturing collaboration between Southeast Asian and Australian stakeholders

Australia has significant domestic experience with PHES. Currently, Australia has 3 operational PHES systems,[15] with 2 additional systems under construction – Snowy 2.0 in New South Wales and Kidston in Queensland – which together will provide more energy storage capacity than all the utility-scale batteries worldwide combined. Additionally, 8 PHES projects are under serious consideration following the completion of pre-feasibility studies led by Hydro Tasmania as part of the Battery of the Nation initiative.[16] During a preliminary assessment, 14 projects were evaluated against 3 main criteria:

Scale	Sufficient size to support the Battery of the Nation objectives
Cost and value	Relatively low unit cost per megawatt installed, with expected profitability under various plausible market scenarios
Risk balance	Consideration of technical complexity, environmental and social risks, and impacts on existing system operations

Australia collaborates with Thailand, Cambodia and Vietnam through the Mekong–Australia Partnership. It also partners with Malaysia, including at the state level in Sarawak, and with Laos through P4I, working with the Ministry of Energy and Mines and Electricité du Laos (EDL).

In Indonesia, Australia works through P4I in collaboration with the Ministry of Energy and Mineral Resources and PT PLN, with additional support from the Australian Department of Climate Change, Energy, the Environment and Water. Additionally, Australia engages with Indonesia through the Australia–Indonesia Climate and Infrastructure Partnership (KINETIK).

Through these initiatives, Australia shares valuable expertise with partners across Southeast Asia.

> **'Australia is a leader in PHES deployment and integration, successfully integrating it with solar to create a reliable, large-scale renewable energy system. Our collaboration with Sarawak Energy to study PHES systems explores how this technology can support Sarawak's electricity export strategy while meeting its ambitious renewable energy integration plans. Sarawak and Australia can mutually benefit from this growing partnership.'**
>
> — Danielle Heinecke, Australia's High Commissioner to Malaysia

[15] The 3 operational PHES systems – all river-based facilities – are Wivenhoe Power Station in Queensland, Kangaroo Valley Power Station in New South Wales (part of the Shoalhaven Scheme), and Tumut 3 Power Station in New South Wales (part of the Snowy Mountains Scheme).

[16] Hydro Tasmania, *Battery of the Nation – Pumped Hydro Energy Storage Projects: Prefeasibility studies summary report*, Australian Renewable Energy Agency, August 2019.

Lao delegates from the Ministry of Energy and Mines and Electricité du Laos (EDL) visit the Snowy Hydro Discovery Centre as part of a 5-day training in Australia on PHES and renewable energy integration. Source: P4I

Key areas of support provided by P4I include:

- **assessing the scale and potential of PHES:** Using the Australian National University's global atlas, numerous sites have been identified as suitable for PHES development, forming a foundation for stakeholder engagement.
- **analysing essential technical parameters influencing site selection:** A comprehensive evaluation of shortlisted sites includes key technical parameters such as storage capacity (for example, the volume of water that can be stored and its implications for energy output) and development costs, including capital and operational expenditures that impact project feasibility. The pre-feasibility study model used in Australia as part of the Battery of the Nation initiative is adaptable to different country contexts and an interesting case study for the region.
- **conducting power system studies to understand the role that PHES can play in specific countries' energy transition:** These system-wide studies identify the power system's needs within the local energy context and the role that storage technologies (including PHES) can play to achieve national energy goals.
- **enhancing understanding of PHES functions in providing reserve capacity and grid stability services:** Support focuses on clarifying the range of services PHES can provide, including its interaction and complementarity with other energy sources and storage technologies.
- **examining regulatory readiness and investment viability:** Critical factors for PHES deployment include existing policy settings, current regulatory frameworks and necessary legislative reforms (particularly to facilitate cross-border electricity trading), commercial viability and investment attractiveness, as well as energy market dynamics.
- **ensuring system resilience:** To address the impacts of extreme weather events and changing hydrological patterns due to climate change, measures are recommended to ensure PHES infrastructure remains resilient throughout its lifespan.
- **securing social licensing:** Integrating PHES into power systems may raise social risks and impacts. However, there are significant opportunities to embed social inclusion principles across all project phases, from planning and siting to pre-development and implementation, while ensuring meaningful community engagement.

Southeast Asia stands at a pivotal moment in its energy transition. With growing electricity demand and ambitious renewable energy targets, the region requires large-scale storage solutions, such as PHES, to ensure a resilient, sustainable and secure energy future. However, realising this vision requires sustained commitment from Southeast Asian governments. This includes streamlining regulatory frameworks and prioritising social and environmental considerations to attract sustainable financing and investment. Australia, with its expertise in solar energy, PHES, and complementary storage technologies like battery energy storage systems, is a committed partner in this journey.

Partnerships for Infrastructure

Partnerships for Infrastructure (P4I) is one of Australia's flagship infrastructure development initiatives in Southeast Asia. P4I partners with Cambodia, Indonesia, Laos, Malaysia, Philippines, Thailand, Timor-Leste, Vietnam and the Association of Southeast Asian Nations (ASEAN) to attract quality investment, address infrastructure gaps, and drive inclusion and climate-resilient development.

P4I does this by providing infrastructure advisory services, facilitating technical knowledge exchanges, building partners' technical capacity, and supporting government-to-government and other partnerships between Australian and Southeast Asian organisations.

Delivered through a single team, P4I is led by the Australian Department of Foreign Affairs and Trade in collaboration with Ernst & Young, Adam Smith International, The Asia Foundation and Ninti One.

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