ASEAN Green Future Project Phase 2.3 Report

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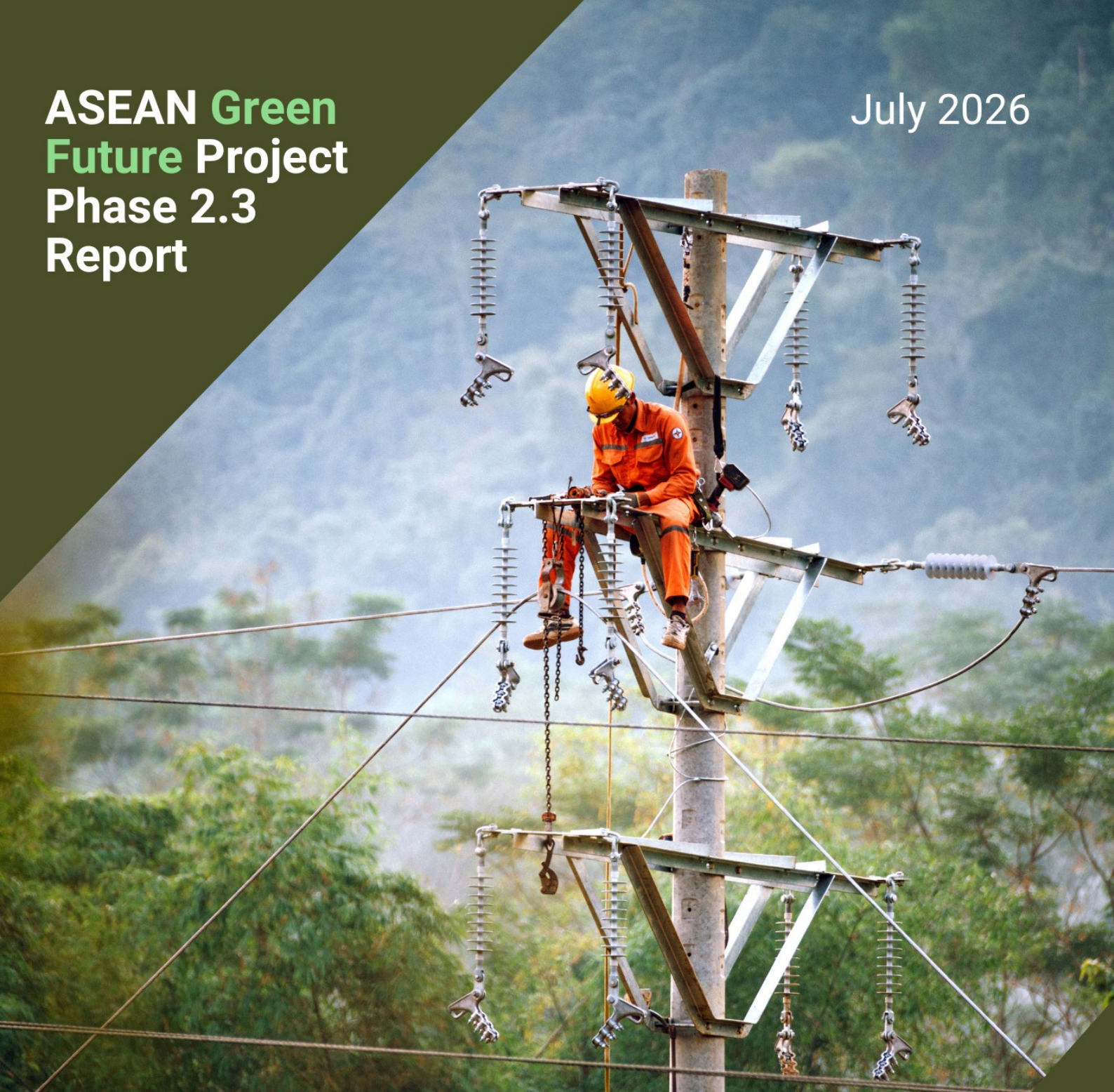

EXECUTIVE SUMMARY

Integrated Resilience: A First-of-its-Kind Transition Framework for a Decarbonised ASEAN Power Grid

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About ASEAN Green Future

ASEAN Green Future is a multi-year regional research project that involves the UN Sustainable Development Solutions Network (SDSN), Climateworks Centre and nine country teams from leading universities and think tanks, each focussed on an ASEAN Member State (Cambodia, Indonesia, Lao PDR, Malaysia, Myanmar, Philippines, Singapore, Thailand and Vietnam). The researchers undertake quantitative and qualitative climate policy analysis and develop net zero pathways to inform policy recommendations and support the strategic foresight of policy makers.

The Phase 1 country reports present priorities and actions to date, and key technology and policy opportunities to further advance domestic climate action. The Phase 1 regional report positions Southeast Asia's low carbon transition pathways within a global context using the country reports and other studies. This series of reports, produced through a synthesis of existing research and knowledge, builds the case for advancing the region’s climate agenda. Phase 2 of the ASEAN Green Future project employs quantitative modelling to assess decarbonisation pathways for the power sectors of ASEAN Member States.

Foreword

The world has been experiencing extreme weather events (e.g. high heat, big floods, and powerful typhoons) at a greater frequency than suggested by historic data. This worrying increase in frequency reflects, in large part, human-induced climate change caused by the rise in the concentration of atmospheric CO2. The large growth in CO2 concentration in the air from a stable value of 280 parts per million (ppm) in the pre-1750 era to an average 427.5 ppm in 2025, with heavy concentrations in May and June 2025 that exceeded 430 ppm.

The 430 ppm level was what the Intergovernmental Panel on Climate Change (IPCC) had identified in 2014 to be the threshold greenhouse gas concentration for limiting global warming to 1.5°C. IPCC had warned that a temperature rise that exceeded 1.5°C would lower productivity in food production significantly, and reduce biodiversity greatly. In mid-2026, it seems that the most probable outcome would be a temperature rise that would exceed 2.0°C, thereby increasing the likelihood that the tipping points on a number of environmental fronts would be exceeded, e.g. the thawing of the permafrost that would release the huge amount of CO2 stored there, and the melting of the icesheets at the two poles could raise the sea level by 5 feet by 2300.

The two chief causes of the large rise in CO2 concentration are the use of fossil fuel and the deforestation of land. The transition to net zero emissions would therefore require the decarbonization of engineering systems which enable the physical comfort of modern life, and the recarbonization of the natural systems of the Earth that enable life.

To contribute to the analytical framework that would guide government programs and private investments to accomplish these two objectives, the Asia Headquarters of the UN Sustainable Development Solutions Network (SDSN-Asia) started in 2021 (amidst the Covid-19 crisis) two projects:

- the **ASEAN Green Future** project to mobilize country teams to identify options in pathways to net zero emissions in Cambodia, Indonesia, Laos, Malaysia, Myanmar, Philippines, Singapore, Thailand and Vietnam; and
- the **Science Panel for Borneo** project to mobilize scientists in Brunei, Indonesia, and Malaysia to identify options in the green transformation of Borneo Island that are economically dynamic, socially inclusive, and environmentally friendly.

The ASEAN Green Future project is much relieved and proud to issue this progress report to support the ASEAN Power Grid (APG) objective that was strongly reconfirmed by the ASEAN Summit in 2025. The APG objective is the correct target because isolated national efforts to achieve net zero emissions are highly inefficient. The cost of producing green energy varies greatly across countries and the individual national demand for green energy does not equal the individual national potential in green energy production. An integrated APG to create a common market in green energy is the lowest-cost way to meet the demand for green energy in ASEAN. Furthermore, an integrated APG will also result in greater individual energy security. A cloudy day in one country and/or an engineering malfunction in energy generation in another country would see an import of green energy by both countries from the other ASEAN members.

This report is the first computational application of the LEAP-NEMO (Low Emissions Analysis Platform - Next Energy Modelling system for Optimization) framework to integrate nine national power sector models to analyse options for optimising green energy generation, storage and transmission across an ASEAN-wide setting. This integrated modelling effort—simulating ASEAN-wide policy scenarios—was undertaken by a core team led by Professor Leong Yuen Yoong. This task could not have been successfully completed if not for constant active support from the Cambodia team led by Professor San Vibol; the Indonesia team led by Professor Alin Halimatussadiah; the Lao team led by Professor Phouphet Kyophilavong; the Myanmar team lead by Mr. Hang Za Dal, Dr. Kensuke Yamaguchi and Professor Noah Kittner; the Philippines team led by Professor Maria Joy Abrenica; the Singapore team led by Professor Euston Quah; and the Thailand team led by Professor Bundit Limmeechokchai. Equally importantly, valuable conceptual feedback and helpful technical guidance were given by the Stockholm Environment Institute team (Dr. Charlie Heaps, Silvia Ulloa, and Jason Veysey), Climateworks Centre (Professor John Thwaites, Trang Nguyen, Tim Graham, Jannata (Egi) Giwangkara, Muhammad Rizki Kresnawan, Dr. Ceren Ayaz Yilmaz, and Phat Pumchawsaun), RE-CONNECT (Dr. Panagiotis Fragkos, Anna Flessa, and Dr. Alexandros Tsimpoukis), and the ASEAN Centre for Energy (Dr. Zulfikar Yurnaidi and Muhammad Rizki Kresnawan). This report truly embodies the spirit of SDG 17 (global partnership), and is analytically much stronger because of it.

We invite you to join us in the ASEAN Green Future project moving forward. Please do not hesitate to contact Professor Leong Yuen Yoong and myself (wtwoo@ucdavis.edu).

Woo Wing Thye
Vice President for Asia
UN Sustainable Development Solutions Network
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Acknowledgments

The ASEAN Green Future (AGF) country teams extend our heartfelt gratitude to the Jeffrey Cheah Foundation, Climateworks Centre (CWC), and the late Harold Mitchell. Their shared vision and generosity provided the fertile soil in which this research took root, and upon which regional capacity could flourish.

Our deepest respect flows quietly to John Thwaites, who walked steadfast alongside the AGF country teams to the very end—always focusing his heart on nurturing the people, fostering the freedom of spirit and intellect, and upholding fair processes.

We are also deeply grateful to the late Michael James Platts for his boundless love (大愛無疆) for Southeast Asia, and for his enduring gift of spiritual and philosophical grounding that elevated the vision and ethos of AGF. "*Nowhere is too far away from Cambridge*," he would say—a reminder that love and the Spirit know no bounds.

With reverence, we honour the Stockholm Environment Institute (SEI) for sustaining the AGF country teams in developing the LEAP-NEMO framework, with heartfelt thanks to Dimas Fauzi, Pimolporn Jintarith, Niall O'Connor, Charlie Heaps, Silvia Ulloa, Kuntum Melati, Uttam Ghimire, Jason Veysey, and Guillaume Bouchard. Our gratitude embraces Panagiotis Fragkos, Anna Flessa, and Alexandros Tsimpoukis of RE-CONNECT (Horizon 2020 / European Commission), together with Zulfikar Yurnaidi and Muhammad Rizki Kresnawan of the ASEAN Centre for Energy (ACE), whose technical insights and modelling craft illuminated our path.

We place on record our profound gratitude to Feng Limin, Wang Xiaofei, and the broader intellectual community at the Global Energy Interconnection Development and Cooperation Organisation (GEIDCO), whose wisdom, global vision, technical mastery, and entrepreneurial spirit deeply enriched our systemic framework and regional capacity. Findings of this work were first shared across three keynote lectures to engineering scholars and energy industry practitioners at Tianjin University and GEIDCO in Beijing in May 2026, where their engagement and feedback helped sharpen our synthesis. Our deep appreciation flows to Zhang Pei at Tianjin University, whose vision through the ASEAN–China Scholar Programme opened a vital space for intellectual *pushing hands* at that defining moment.

Our warm thanks extend to Eddie Widiono, Ha Yejin, Dimas Fauzi, Hazland bin Haji Abang Hipni, and Ceren Ayaz Yilmaz for their thoughtful reflections on this work, alongside our peer reviewers across the wider energy ecosystem who are now engaging with the findings. Their insights will continue to nourish and enrich our ongoing path.

Finally, our quiet appreciation rests with the administrative, finance, and operational teams across all partner institutions—anchored steadfastly by Lee Chooi Yee, and by Trang Nguyen, whose vital leadership at CWC held up half the sky.

The trials and tribulations along this journey served as a crucible for transformation and purification. The grace and peace that come after are a testament to the quiet power of containment and yielding.

Cultivating Shared Foundations for Regional Energy Governance

"Collaborative Model Development for ASEAN Green Future" workshop, hosted through the generous institutional support and core funding of the Stockholm Environment Institute (SEI) at the SEI Asia Centre in Bangkok, Thailand.

We honour SEI's steadfast dedication to nurturing regional intellectual capacity, empowering local scientific leadership, and bridging environmental policy with technical rigour across Southeast Asia. This work stands as a beautiful harvest born of goodwill and intellect.

In Quiet Partnership for the Region's Energy Future

Technical calibration and troubleshooting of the ASEAN Green Future–ASEAN Power Grid (AGF-APG) LEAP-NEMO model with the ASEAN Centre for Energy (ACE) in Jakarta on 4 December 2025. Left: Low Wai Sern (AGF); Right (ACE): Muhammad Rizki Kresnawan (front) and Dr. Zulfikar Yurnaidi (back).

We honour ACE's steadfast commitment to nurturing the intellectual base and collaborative spirit of the wider energy ecosystem.

Harmonising Ambition with Systemic Insight

True global energy transition requires both grand technical mastery and the quiet resilience of pioneers. Through knowledge exchange and collaboration with the Global Energy Interconnection Development and Cooperation Organization (GEIDCO), ASEAN Green Future's diagnostic and prescriptive frameworks for cross-border integration were born.

We honour GEIDCO's enduring idealism and world-class technical dedication—translating a bold, decadal vision of global interconnectivity into grounded, practical pathways for regional grid homeostasis and shared sustainability across ASEAN.

EXECUTIVE SUMMARY

Integrated Resilience:
A First-of-its-Kind Transition Framework for a Decarbonised ASEAN Power Grid

Executive Overview

As the Association of Southeast Asian Nations (ASEAN) faces accelerating power demand and intensifying climate imperatives, remaining static in national energy isolation (Scenario S1) is no longer economically or environmentally viable. This report presents the first generation-storage-transmission co-optimised LEAP-NEMO[1] modelling assessment of the ASEAN Power Grid (APG), establishing a strategic blueprint to transition from fragmented bilateral trade to a deeply coupled, multilateral clean energy market by 2040.

Grounded in calibrated regional data, the baseline projections for installed capacity (GW) and total generation (TWh) closely align with the 8th ASEAN Energy Outlook (AEO8) published by the ASEAN Centre for Energy. Moving beyond static modelling paradigms, this analysis introduces cross-decadal temporal variance and fuel price trajectories through 2050, capturing the evolving economic pressure that volatile global fossil fuel markets exert on traditional strategies of isolated national sovereignty.

Crucially, as national expansion plans and APAEC 2026–2030 priorities continue to position natural gas as a primary transition fuel, an unconstrained regional grid naturally defaults to gas as its primary flexibility mechanism. The central finding is therefore definitive: **physical interconnector deployment alone cannot break the structural inertia of legacy thermal assets. To prevent regional coupling from merely re-entrenching fossil baseload, grid integration must be explicitly paired with robust carbon pricing or targeted fossil phase-out policies.**

To evaluate these dynamics, this study models three distinct regional development pathways alongside one sensitivity analysis (summarised in Table ES-1).

Table ES-1: ASEAN Power Grid Scenario Design Architecture

Scenario	Interconnection Capacity	Dispatch Logic	Optimisation Goal
S1 (Isolation)	Isolated (no transboundary lines)	National isolation	National self-sufficiency
S2 (Policy Baseline)	Policy-specified (AIMS III baseline)	Coordinated cross-border trade	Policy-guided expansion
S3 (Market Integration)	Endogenous (fully co-optimised)	Frictionless regional trade	System-wide least-cost optimum
S3+ (Deep Decarbonisation)	Endogenous (fully co-optimised)	Near zero carbon integration	Near-zero emissions power benchmark

[1] Calculations are powered by the Stockholm Environment Institute (SEI) Low Emissions Analysis Platform (LEAP) integrated with the Next Energy Modelling system for Optimisation (NEMO), solving long-term capacity expansion and operational dispatch simultaneously across 2026–2050.

Core Working Hypotheses & Strategic Realities

1. **The Isolation Penalty vs. the Integration Dividend (Scenarios S1 versus S3):** Without cross-border co-optimisation of generation, storage and transmission, ASEAN Member States are forced to maintain massive redundant capacity for local self-sufficiency—leaving **102 GW of coal and 172 GW of natural gas** operating in 2050 while **discarding 27.3% of potential clean energy (932.8 TWh/year**). The isolation penalty is not merely higher cost, but the systematic spillage of decarbonisation capital.

2. Conversely, under full regional integration (S3), the efficiency dividend is extraordinary: the region meets demand with **966 GW of installed capacity versus 1,473 GW under isolation**—delivering **7% more usable energy (3,547 TWh versus 3,318 TWh) with nearly 35% less physical infrastructure (507 GW less hardware)**. Simultaneously, required grid storage capacity plummets by **65% (from 128 GW down to 45 GW)**, proving that cross-border interconnectors dramatically reduce the need for capital-intensive batteries.

3. **The Phased Co-Optimisation Pathway (Scenarios S2 & S3/S3+):** Regional coordination slashes both capital expenditures and carbon emissions progressively. Transitioning from isolated national grids (S1) to immediate, policy-driven interconnectors (S2) cuts the regional renewable curtailment rate nearly in half (from **27.3% to 13.8%)** and recovering **439.7 TWh** of clean energy annually. Advancing further from S2 to deep multilateral market coupling (S3/S3+) pushes curtailment rates down towards technical minimums, unlocking regional resource efficiency.

4. **The Infrastructure Imperative & Sovereign Realities: As subsea maritime links carry a significant capital premium over overland lines,** model findings indicate that to build an economically optimal grid, regional planning bodies must **focus immediate capital on reinforcing overland "Middle Corridors"** through Thailand, Malaysia, and Cambodia, alongside the **targeted opening of the Sabah—Philippines subsea gateway** to unlock Borneo's clean energy surplus. Rather than prioritising prestige long-distance subsea links, this phased terrestrial-first strategy breaks localised "sovereignty traps" by diversifying regional load profiles and anchoring transboundary grid stability.

5. **The Decarbonisation Cost Narrative & the "Valley of Vulnerability":** Achieving a near-zero emissions regional grid must be re-framed from a net cost burden to a long-term operational stabiliser. Deep decarbonisation under the S3+ pathway requires an aggressive structural shift firm renewables (hydro and geothermal) alongside a hydrogen-ready thermal fleet. While this scales cumulative capital expenditure (2026-2050) to **USD 4.45 trillion for S3+ compared to USD 3.64 trillion for S3**, this upfront CAPEX fundamentally alters grid economics—replacing volatile, recurring fossil fuel OPEX with zero-marginal-cost generation that insulates the regional economy from global commodity price shocks.

   However, as demonstrated by severe fuel price shocks and supply chain constraints in a companion national study on Malaysia[2], energy sovereignty during this transition is non-linear. The state must actively navigate a **"Valley of Vulnerability"**—a perilous mid-transition phase where legacy thermal assets are retired before renewables, storage, and cross-border corridors achieve critical mass. Managing this Valley requires proactive policy levers: maintaining strategic gas reserves, expanding demand-response, and deploying regional interconnection as vital bridge infrastructure.

[2] W. T. Woo, Y. Y. Leong, W. S. Low, C. C. Lee, C. M. Goh, A. Flessa, A. Tsimpoukis and A.-N. Kouvarda, "Sovereign Energy Resilience: Orchestrating Malaysia's Power Sector Transformation through Market-Based Decarbonisation," in ASEAN Green Future, 2026.

The Dual-Engine Framework: Uniting Physics & Governance

A central insight of this work is that **physical interconnection alone is not a climate strategy.** While grid integration optimises capital and physics (x-axis), pure market integration without policy alignment risks simply optimising natural gas dispatch. Deep regional decarbonisation requires a **Dual-Engine Green Market Framework** along the governance (y-axis):

- **Multilateral green power trading:** Dedicated regional market segments for certified clean electrons, offering renewable generation a clear economic premium over fossil fuels.
- **Cross-border consumption guarantees:** Harmonised national renewable consumption quotas across ASEAN Member States, legally obligating transit corridors to carry clean power and forcing the market to optimise for carbon reduction rather than chasing cheap, fossil-backed electrons.

Furthermore, to safeguard system stability, the APG must be nested within a **Multi-Layered Defence Architecture**: embedding rapid protection and storage at the level of *physics* (x-axis), polycentric dispatch and safety-veto rules within *governance* (y-axis), and pre-engineered grid-splitting capabilities anchored in *regional diplomacy* (z-axis) to prevent localised shocks from triggering cascading regional blackouts.

Phased Strategic Roadmap (2026–2040)

Recognising that immediate transition to an open multilateral market is constrained by national energy security concerns, the report sets out a realistic, phased execution blueprint designed to build institutional trust through modular pathfinders before unlocking deep market coupling:

PHASE 1 (2026-2030): Institutional Alignment & Terrestrial Backbones

- Reinforce land-based Middle Corridors (Lao PDR-Vietnam, Thailand-Cambodia, Thailand-Peninsular Malaysia)
- Conduct surveys and concession modelling for the Sabah-Philippines gateway
- Ratify the ASEAN Submarine Power Cable Development Framework

PHASE 2 (2031-2035): Core Corridor Deployment & Multilateral Wheeling

- Commission the Sabah-Philippines (~7 GW) and Peninsular Malaysia-Sumatera links
- Implement multi-party dynamic wheeling tariffs across transit hubs
- Transition Singapore toward dynamic, multi-directional balancing

PHASE 3 (2036-2040): Deep Market Coupling & Regional Homeostasis

- Full structural transition to S3+ configuration; establish real-time ancillary services (spinning reserves, frequency response)
- Operationalise safety-veto rules and polycentric self-healing “islanded” grids

Structural Prerequisites for Implementation

To operationalise this target pathway, regional stakeholders must coordinate across three core institutional dimensions (summarised in Table ES-2):

Table ES-2: Key Institutional Prerequisites for Operationalising the Target APG Pathway

Dimension	Key Structural Prerequisites
Policy & Regulatory Frameworks	Adopt uniform legal protections via the *ASEAN Submarine Power Cable Development Framework*; institute a minimum binding regional grid code; enforce a regulatory **safety veto** prioritising security over short-term commercial dispatch.
Market Rules & Wheeling Tariffs	Transition from rigid take-or-pay bilateral contracts to multilateral dynamic wheeling tariffs; establish cross-border ancillary service markets; deploy dual-engine green market rules.
Financing & Concession Models	Mobilise multilateral development bank (MDB) blended finance and sovereign guarantees to de-risk high-CAPEX subsea corridors; adopt "symbiotic concession models" tying infrastructure returns to regional carbon credits and Renewable Energy Certificates (RECs).

Strategic and Philosophical Governance: the APG Tree of Life and the Da Yu Renewable Energy Tree of Life

While policy, tariff, and financial mechanisms provide the structural prerequisites for grid integration, translating macro-scale modelling into physical reality requires a shared conceptual language and an execution philosophy grounded in systemic wisdom. To bridge technocratic modelling with real-world deployment, this study introduces the APG Tree of Life and the Da Yu Renewable Energy Tree of Life frameworks:

- **The conceptual lens (governance & systemic alignment):** Functions as a holistic diagnostic and prescriptive model to unite transboundary stakeholders—engineers, economists, and policymakers—around a shared conceptual language. By mapping complex socio-technical dynamics onto a transparent "path of honesty," it prevents fragmented planning and fosters advanced cross-border design capabilities.
- **The governing engine (execution and ecological harmony):** Operationalises the macro-philosophy of channelisation (疏導), ensuring infrastructure deployment is tailored to local conditions (因地制宜) and respects multi-solution complementarity (多解互補). This aligns grid expansion with local ecological capacities and community endowments, converting political trust into long-term socio-economic resilience rather than mere technocratic cost minimisation.

Analytical Scope & Strategic Utility

Rather than treating engineering, policy, and systemic philosophy as disconnected dimensions, this report proposes the **APG Triple Gem Integration Architecture**, uniting these elements into three distinct operational vectors. This integrated framework allows any proposed regional grid development plan or transboundary corridor to be evaluated not just in terms of gigawatts and dollars, but also in terms of its alignment with systemic resilience and regional resource endowments.

The APG Triple Gem serves as a high-level strategic filter for regional decision-makers and investors. By establishing order-of-magnitude economic benchmarks and identifying high-leverage corridors,

it isolates the critical policy and infrastructure priorities that warrant detailed engineering and site-specific deployment. Ultimately, it delivers both the quantitative evidence and institutional architecture required to transform the ASEAN Power Grid from a patchwork of bilateral ties into a resilient, fully integrated, and decarbonised regional energy backbone.

On a physical level, the ASEAN Green Future project delivers a concrete, deep decarbonisation pathway for the APG. On a philosophical level, it opens a deeper, more holistic framework for thinking about sustainability in Southeast Asia. Specifically, grid resilience is approached through an integrated three-dimensional matrix—balancing technical system integration (x -axis), institutional governance (y -axis), and systemic philosophy and wisdom (z -axis). While decarbonisation pathways will naturally adapt as model inputs and technologies evolve, it is this capacity to evaluate sustainability in a grounded, balanced, and systemic way—while building enduring regional trust—that will steer a truly wholesome cross-border path forward.

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