ASEAN Renewable Energy Long-term Roadmap

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ASEAN Centre for Energy

One Community for Sustainable Energy

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About ACE

Established in 1999, the ASEAN Centre for Energy (ACE) is an intergovernmental organisation within the ASEAN structure that independently represents the interests of the 10 ASEAN countries in the energy sector. The Centre accelerates the integration of energy strategies within ASEAN by providing relevant information and expertise to ensure the necessary energy policies and programs are in harmony with economic growth and the region's environmental sustainability. It is guided by a Governing Council composed of Senior Officials on Energy leaders from each ASEAN Member State and a representative from the ASEAN Secretariat. Hosted by Indonesia's Ministry of Energy and Mineral Resources (MEMR), the ACE's office is located in Jakarta, Indonesia.

Acknowledgement

The development of the ASEAN Renewable Energy Long-Term Roadmap has been a significant and collaborative undertaking. This publication would not have been possible without the dedicated effort and support of numerous individuals and organisations, to whom we extend our sincere gratitude.

We extend our deepest appreciation to the entire team at the ASEAN Centre for Energy (ACE). This roadmap is a testament to their collective expertise and tireless commitment. Special recognition is owed to Dr Tharinya Supasa, Monika Merdekawati and Zahrah Zafira as the lead analysts and authors, including Veronica Ayu Pangestika and Gadiz Liberty Namira as the researchers from the Sustainable and Renewable Energy (SRE) Department. We are grateful for the invaluable contributions on the modelling and data processing work by Rizki Kresnawan, Ilham Rizaldi, Lazuwardi Imani and Silvira Ayu Rosalia from Modelling, Policy, and Planning (MPP), and Jason Veysey, the Energy Modelling Programme Director at Stockholm Environment Institute (SEI). Additionally, we appreciate the guidance of the ASEAN Plan of Action for Energy Cooperation (APAEC) team throughout the roadmap development, including the expert review and opinion from colleagues across ACE whose analytical rigour and dedication formed the backbone of this work, particularly Fossil Fuels, Hydrocarbon and Minerals (FOM), Power Generation and Interconnection (PIN), and Energy Efficiency and Conservation (EE&C) technical teams.

We are profoundly grateful for the consistent guidance and strategic direction provided by the Renewable Energy Sub-Sector Network (RE-SSN). Their regular feedback, deep country-specific knowledge, and unwavering support throughout the development process were instrumental in shaping the roadmap's relevance and ensuring its alignment with the priorities of all ASEAN Member States.

This endeavour was also significantly strengthened by the generous and steadfast support of our international partners. We wish to extend our special thanks to the governments of New Zealand, Australia, and Norway. Their numerous contributions and collaborative engagement have been critical in enabling the modelling and stakeholder consultations required for a study of this scale and importance.

The spirit of collaboration that defined the creation of this roadmap is the same spirit that will be required to turn its vision into a reality. We look forward to continuing this journey together with all our partners towards a more sustainable and prosperous energy future for ASEAN.

Foreword

As the ASEAN Ministers on Energy convene to launch the next phase of our regional energy cooperation, we stand at a critical and opportune moment. The unveiling of the new ASEAN Plan of Action for Energy Cooperation (APAEC) for 2026-2030, alongside this landmark ASEAN Renewable Energy Long-Term Roadmap, marks a united commitment to transforming the challenges of energy security and climate change into an unprecedented opportunity for regional growth and prosperity

This roadmap is not merely a technical study; it is a strategic blueprint for securing ASEAN's long-term economic competitiveness. Through a rigorous, science-based analysis of three distinct pathways—the ASEAN Policy-Aligned Scenario (APAS), the ASEAN Renewable Electricity Coupling (AREC) Scenario and the ASEAN Shared Energy Resources (ASER) Scenario—it provides an evidence-based framework for making the policy and investment decisions that will position our region as a leader in the global clean energy economy

The central message is compelling: deep regional cooperation is the key to unlocking our collective competitive advantage. By working together to build an integrated ASEAN Power Grid and create unified regional markets for clean energy, we can achieve economies of scale, drive costs down and foster an innovation ecosystem that no single Member State could achieve alone. This roadmap details the specific infrastructure, market mechanisms and levels of cooperation required to make this vision a reality.

This document is, therefore, more than an energy plan. It is a core pillar of the ASEAN Community Vision 2045, outlining how the energy transition can be leveraged to build a more resilient and economically competitive ASEAN, powered by secure, affordable and sustainable energy. Equally, it reflects ASEAN's people-centred vision, placing citizens at the heart of regional progress and ensuring that the benefits of the clean energy transition are shared across all communities.

The pathways laid out in this study are invitations to action—to innovate, to invest and to lead. I call upon all our Member States, Dialogue Partners, and stakeholders to embrace the collaborative spirit of this roadmap. Let us work together to seize this opportunity, building a more competitive, resilient and prosperous ASEAN for generations to come.

**Dato Ir. Ts.
Abdul Razib Dawood**

Executive Director,
ASEAN Centre for Energy (ACE)

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Abbreviations

ACE	ASEAN Centre for Energy
AEC	ASEAN Economic Community
AEO	ASEAN Energy Outlook
AERN	ASEAN Energy Regulators Network
AMS	ASEAN Member States
APAEC	ASEAN Plan of Action for Energy Cooperation
APAS	ASEAN Policy-Aligned Scenario
APG	ASEAN Power Grid
APGCC	ASEAN Power Grid Consultative Committee
AREC	ASEAN Renewable Electricity Coupling
ASER	ASEAN Shared Energy Resources
ATS	Country Targets Scenario (from AEO8)
BAU	Business as Usual
BOF	Blast Oxygen Furnace
CNS	Carbon Neutrality Scenario (from AEO8)
CO_2e	Carbon Dioxide Equivalent
COD	Commercial Operation Date
DPs/IOs	Dialogue Partners and International Organisations
EAF	Electric Arc Furnace
EE&C	Energy Efficiency & Conservation
EI	Energy Intensity
EV	Electric Vehicle

FOM	Fossil Fuels, Hydrocarbon and Minerals
G-to-G	Government-to-Government
GEDSI	Gender Equality, Disability, and Social Inclusion
GW	Gigawatt
GWh	Gigawatt-hour
HAPUA	Heads of ASEAN Power Utilities/Authorities
HVDC	High Voltage Direct Current
ICEV	Internal Combustion Engine Vehicle
IEA	International Energy Agency
JIET	Just and Inclusive Energy Transition
LCOE	Levelised Cost of Electricity
LTRM	Long-Term Roadmap
MEPS	Minimum Energy Performance Standards
MoU	Memorandum of Understanding
MPP	Modelling, Policy, and Planning
Mtoe	Million Tonnes of Oil Equivalent
MW	Megawatt
Mtoe	Million Tonnes of Oil Equivalent
NDCs	Nationally Determined Contributions
OBS	Outcome Based Strategy
PA	Programme Area
PDP	Power Development Plan

PHES	Pumped Hydro Energy Storage
PIN	Power Generation and Interconnection
PPA	Power Purchase Agreement
RAS	Regional Aspiration Scenario (from AEO8)
RE	Renewable Energy
REC	Renewable Energy Certificate
REPP	Regional Energy Policy and Planning
RE-SSN	Renewable Energy Sub-Sector Network
RSO	Regional System Operator
SAF	Sustainable Aviation Fuel
SRE	Sustainable and Renewable Energy
TFEC	Total Final Energy Consumption
TPES	Total Primary Energy Supply
VPP	Virtual Power Plant
vRE	Variable Renewable Energy

Executive Summary

This ASEAN Renewable Energy Long-Term Roadmap (RE LTRM) serves as a strategic blueprint to transform the region's energy transition vision into concrete action, aligning ASEAN's economic outlook with its climate mitigation goals. It serves as a conceptual framework to guide the activity planning for the forthcoming ASEAN Plan of Action for Energy Cooperation (APAEC) 2026-2030 by offering a science-based analysis of the policy choices needed to enhance regional competitiveness and achieve a sustainable energy future.

Building on the 8th ASEAN Energy Outlook (AEO8), this roadmap sharpens the focus for decision-makers. While AEO8 presented broad potential futures, this roadmap narrows the options by defining and analysing three distinct pathways (the ASEAN Policy-Aligned Scenario (APAS), the ASEAN Renewable Electricity Coupling (AREC) Scenario and the ASEAN Shared Energy Resources (ASER) Scenario). These scenarios are specifically designed to chart an actionable course for bridging the critical gap between the AEO8's Regional Aspiration Scenario (RAS) and its high-ambition Carbon Neutrality Scenario (CNS), providing precise insights on the policy choices needed to advance the region's decarbonisation ambitions.

From National-led Deployment to Regional Integration. The next decade's transition will be driven by a rapid increase in renewable capacity in the power sector, led by strong national plans. However, the analysis shows a distinct flattening of the capacity growth curve post-2035, indicating that sustaining the momentum requires a strategic redesign, as well as a stronger energy efficiency ambition for the end-use sector. Despite their continued growth, renewable energy (RE) and variable renewable energy (vRE) face resource constraints. Without more stringent electricity demand reduction, there is a real risk that the region's power sector could once again become locked into reliance on fossil fuel-fired plants for several more decades, even if carbon pricing is applied.

Renewables Will Overtake Fossil Fuels by 2030. A critical tipping point is projected to occur around 2030, where total renewable capacity will surpass the total fossil fuel capacity. This transition is so rapid that vRE capacity alone is set to overtake coal as the single largest source on the grid during this period. This marks the beginning of a long-term structural shift where coal and oil decline, while natural gas peaks in the medium term before handing over of its flexibility role to storage.

A High-vRE Grid is a Universal and Non-Negotiable Future. Across all scenarios, the share of generation from vRE converges at a very high level of 42–47% by 2045. This indicates that the entire region is destined for a future where the grid is operationally dominated by intermittent renewables, making investment in flexibility an urgent priority. This challenge will require tailored national strategies, as vRE leaders like Viet Nam will face the advanced challenges of a 60–70% vRE share while others will focus on managing daily energy surpluses.

Decarbonising Industry and Transport is the Core Long-Term Challenge. The industry and transport sectors account for the majority of demand growth. The decarbonisation of these sectors requires a diverse policy and strategy spectrum with fuel switching options including electrification, bioenergy, and low-carbon fuels such as green hydrogen. Also, further analysis and evidence pertaining to technology readiness, local supply chain, cross-border trade potential, financial returns and incentives, and availability of supply to meet the needs are needed to facilitate dialogue among stakeholders and explore the deeper practical and feasible pathways that best fit the ASEAN context.

Only a Multi-Sector Approach Can Bend the Emissions Curve. A coordinated power-sector focus (the AREC pathway) is essential but is shown to be insufficient, as regional emissions plateau and begin to rise again post-2035. Only the deep, multi-sector, market-driven policies of the ASER pathway—which address industry and transport through clean fuel markets and carbon pricing—can put the region on a firm path to an absolute reduction in emissions.

The Ambitious ASER Pathway is an Achievable Future. The analysis shows the transformative ASER pathway is not a radical leap, but a logical enhancement of existing national plans. This is demonstrated by the model's outcomes for Viet Nam and Indonesia’s power sector, for instance, which are highly aligned with its own ambitious national Power Development Plan (PDP).

The ASEAN Power Grid is Critical but Requires Continuous Expansion. The APG is essential for a capital-efficient transition, enabling resource sharing that reduces the need for redundant domestic capacity. However, the analysis indicates that key trade corridors, such as Thailand-Lao PDR, will operate near maximum utilisation by 2030, highlighting an urgent need to begin planning for future capacity reinforcements to avoid long-term bottlenecks.

Intra-Regional Biofuel Trade is Key to Energy Security. The region faces a structural deficit in bioethanol. It is able to meet only 10-20% of its demand with domestic production under current policy, leaving it reliant on imports. The ASER scenario demonstrates that enabling intra-regional trade is the key to unlocking new production capacity across more member states, potentially increasing capacity by more than three times by 2045 and significantly strengthening ASEAN’s collective energy resilience.

Chapter 1

The Role of the Roadmap in Supporting ASEAN Community Vision 2045

This roadmap serves as a strategic blueprint, reflecting and aligning the ASEAN economic outlook with the energy transition and climate mitigation strategies. It also provides a conceptual framework for shaping activities throughout the next APAEC cycle.

Framework for Turning Vision into Action

Achieving ASEAN's vision to become the world's fourth-largest economy by 2045 requires a fundamental transformation of the energy systems in each of the ten ASEAN Member States (AMS) and of the energy system of the region as a whole. This long-term roadmap for renewable energy (RE) offers insights into how each energy sector will transition over the timeline, outlining the different actions and supportive measures necessary to advance sustainable growth and enhance regional competitiveness. Furthermore, it identifies gaps that require deepening cooperation.

Grounded in science-based analysis, this roadmap guides the complex interplay of national transition priorities, the political will for advancing resource integration, and the urgent demands of RE to support economic development in three distinct, plausible pathways. These pathways consider various interventions that simulate magnitude actions, including the development of higher ambitions and quicker responses, while also analysing how broader policy perspectives interact with different energy sectors, such as the impact of the industry's decarbonisation roadmap on transport decarbonisation decisions. It offers evidence-based direction for shaping the future of cooperation—both among the AMS, and with international partners—across the seven programme areas of the ASEAN Plan of Action for Energy Cooperation (APAEC).

The roadmap's long-term pathways offer a concrete conceptual framework that delineates the steps needed to advance RE at both the national and regional cooperation level. It also serves as the guiding document for linking the APAEC programme areas workplan and fostering coordinated actions towards achieving the region's shared energy transition ambitions.

The Function of the Roadmap in Bridging the Gaps

The ASEAN RE Long-Term Roadmap is not a standalone exercise but a continuation and deepening of the strategic groundwork established by the 8th ASEAN Energy Outlook (AEO8). While the AEO8 provided a helicopter view of potential futures, this roadmap aims to define specific policy routes, identify promising technologies along with their readiness for adoption, assess renewable supply chain outlooks, and advance integration of regional cooperation. These elements are drawn from collective discussions intended to address the critical gap between the AEO8's Regional Aspiration Scenario (RAS) and its high-ambition Carbon Neutrality Scenario (CNS).

In line with APAEC 2026-2030, which integrates Just and Inclusive Energy Transition (JIET) principles, future implementation of this roadmap can further ensure that regional cooperation and policy actions translate into equitable and broadly shared benefits for all ASEAN citizens.

The Roadmap Narrows Down Energy Transition Options to Facilitate Energy Planning

The options for energy transition are numerous and dynamic; each poses different trade-offs and requirements. However, not all options will be prioritised uniformly at the same time; it depends on the ASEAN context. This roadmap acts as a “policy funnel”, gradually narrowing the broad possibilities to a set of detailed and practical actions to support the discussion and decision-making of member states. It fosters a clearer focus and more efficient resource allocation. It also identifies the relevant platforms and stakeholders necessary for enhancing the deployment of RE and timely redesigning of its enablers.

Catching the Energy Transition Momentum in ASEAN

The ASEAN Policy-Aligned Scenario (APAS) in this roadmap projects a higher RE share than the AEO8's equivalent Country Targets Scenario (ATS).

APAS incorporates the latest national plans (such as the updated power development plans (PDPs) of Viet Nam and Indonesia released through 2025). Additionally, APAS includes the updated cost projections for power plant technology in 2025, which were collected from the country and subsequently optimised. This indicates that the pathway is shifting towards a higher share of RE, particularly after 2030.

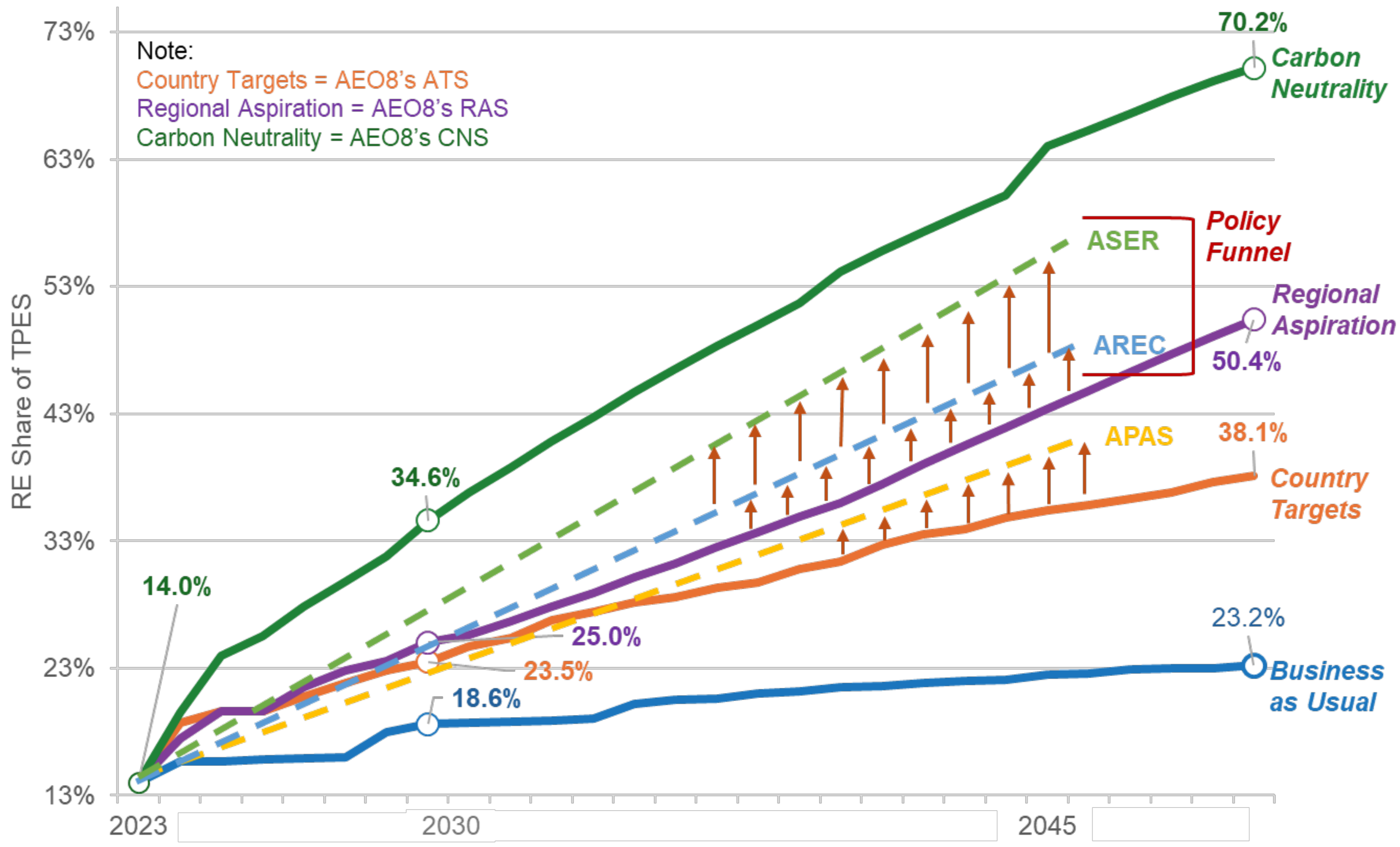
Charting the Path to Carbon Neutrality

The regional platforms to facilitate cross-border trade in various RE equipment and supplies must be strengthened to leverage ASEAN’s low carbon vision, leaning toward carbon neutrality.

As a means to advance regional integration and enable the sharing of electricity and RE resources, the ASEAN Renewable Electricity Coupling Scenario (AREC) and ASEAN Shared Energy Resources Scenario (ASER) offer important gap-filling potential. (More details about these scenarios are given in the next chapter.)

This roadmap has been developed continually from AEO8 by narrowing the gaps of country visions under the AEO8's Country Targets Scenario (ATS) and the Carbon Neutrality Scenario (CNS). It captures the feasible and practical options that were brought forward nationally and on the ASEAN agenda.

ASEAN RE Long-term Roadmap Role in Regional Energy Planning

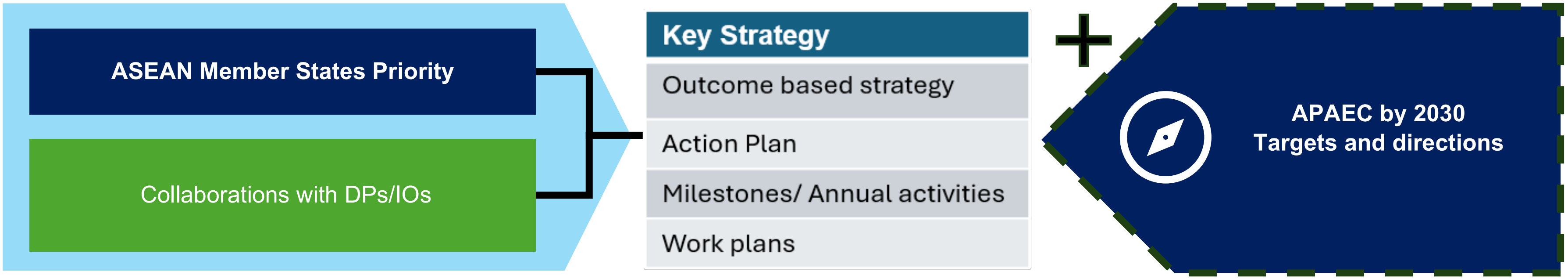


The Roadmap Offers Guidance and Direction Beyond RE Programme, Covering the Alignment and Coordination of the Cross-Sectoral Workplan for Seven Programme Areas in APAEC

Beyond guiding APAEC's internal structure, the roadmap serves a crucial dual strategic purpose: it empowers individual Member States to enhance their national planning while simultaneously strengthening ASEAN's collective position in guiding international energy partnerships.

Framework for Applying Roadmap Insights to the APAEC 2026-2030 Programme Areas

Programme Areas of APAEC 2026 - 2030						
PA 1 ASEAN Power Grid	PA 2 Oil & Gas Connectivity, Security, and Sustainability	PA 3 Clean Coal Transformation	PA 4 Energy Efficiency & Conservation	PA 5 Renewable Energy	PA 6 Regional Energy Policy and Planning	PA 7 Civilian Nuclear Energy



The ASEAN RE Long-Term Roadmap integrates policy horizontally beyond RE, for example, electrification, carbon pricing and decarbonisation of hard-to-abate sectors. APAEC has adopted the roadmap's results as renewable targets for a new cycle. The sectoral transformation insights navigate how each programme area could contribute to overarching targets. The roadmap outlines the necessary direction, speed and magnitude for the actions set over the next five years. The document presents a unified view for stronger partnerships, which can be used as the basis of a framework to design ASEAN's cooperation with dialogue partners and international organisations.

While the short term is crucial, mid- and long-term perspectives extend well beyond a five-year planning cycle, offering an essential overview for preparing the complete journey. This allows policymakers to initiate the necessary strategic planning in the next APAEC, addressing the challenges that will emerge beyond 2030. As each energy choice requires significant investment and involves a long-term payback period, short-term decisions will affect the lock-in position of long-term operations which must be ensured through a no-regret approach.

The RE programme acts as the RE deployment accelerator across supply and end-use sectors. Through the development of this roadmap, it provides the central strategy that breaks down silos between the power, industry and transport sectors, accelerating a cohesive, cross-cutting approach to decarbonisation among all relevant stakeholders.

The ASEAN Power Grid (APG) programme functions as the enabler of regional (cross-border) integration of power trading and build the integrated infrastructure that is essential for a high-RE system.

The Energy Efficiency & Conservation (EE&C) programme leads the demand-side efforts by advancing energy management in key sectors and strengthening efficiency standards for equipment and vehicles.

The Clean Coal Transformation programme contributes to the RE target by creating space in the energy system for renewables to grow through the development of strategies to facilitate a just and inclusive phase-down of coal.

The Oil and Gas Security and Sustainability programme plays a dual role. It supports higher RE integration by ensuring the availability of natural gas for grid flexibility, while simultaneously contributing to overall emission reduction efforts by promoting initiatives to abate methane emissions in oil and gas activities.

The Civilian Nuclear Energy programme contributes to the supply-side transformation by promoting nuclear energy as a stable, high-density and low-carbon power source to support long-term energy diversification and security.

The Regional Energy Policy and Planning (REPP) programme ensures that long-term energy planning remains responsive to both national contexts and regional integration goals through monitoring and evaluation mechanisms. It also provides a cross-cutting platform to integrate Gender Equality, Disability and Social Inclusion (GEDSI) and JIET principles into regional policy framework.

The Roadmap as a Strategic Foundation for APAEC

The direction provided by the roadmap informs the high-level Outcome Based Strategy (OBS) for each Programme Area. *The magnitude* of the required build-out directly shapes the Action Plan, defining the scale of the initiatives that must be undertaken. *The pace* of the transition informs the Milestones and Annual Activities, setting a clear timeline and sequence for the detailed work plans.

Enhancing National Planning and International Engagement

The roadmap provides a clear framework that helps Member States leverage the benefits of regional initiatives for their own national planning and priorities. This creates a mutually reinforcing dynamic where strong national plans support a successful regional vision, and vice-versa. Furthermore, this clear strategic direction empowers ASEAN in its engagement with international partners. It allows the region to proactively guide the collaborations to ensure that technical assistance and investment programmes are precisely tailored to support ASEAN's strategic goals.

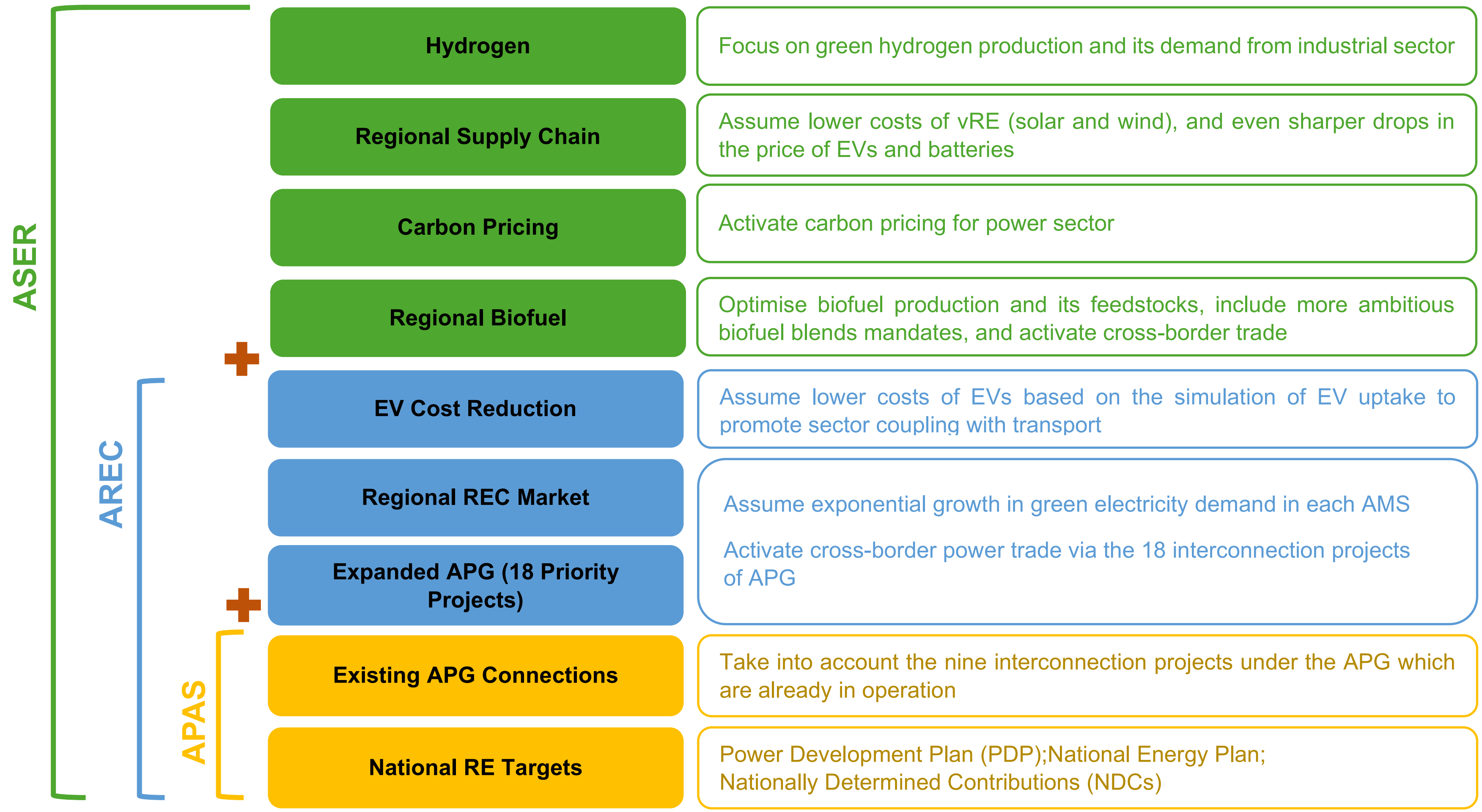
Chapter 2

Strategic Implications of ASEAN's Long-term Energy Pathways

2.1. Introduction of Long-term Pathways

The policy choices and core philosophy of each scenario are defined, in logical progression, in national ambition and in regional cooperation. They define distinct pathways for transforming the energy sector into a cornerstone of the region's future economic competitiveness.

Building Blocks of Energy Transition Policy Ambition



This roadmap explores a range of plausible futures for ASEAN's energy system by defining and analysing three distinct scenarios. These are not merely forecasts; they are designed as a strategic toolkit to guide decision-making, each answering a fundamental question about the region's future. Each one is structured within an analytical framework defined by two critical drivers: the level of regional integration (from limited to advanced) and the primary growth driver (from policy-driven to market-driven). These scenarios represent a logical progression of increasing policy ambition, with each building upon the last.

Scenario 1: APAS – ASEAN Policy-Aligned Scenario

The APAS scenario serves as the essential baseline, answering the question: *What is the aggregated future for ASEAN if the transition is driven only by each national commitment?* It is positioned in the "Limited Regional Integration" and "Policy-Driven" quadrant of the framework and models the outcomes based on existing national RE targets set out in PDPs and Nationally Determined Contributions (NDCs), with regional cooperation limited to existing APG connections. The strategic implication of this pathway is one of capped ambition. While progress is made, it is limited by uncoordinated national efforts, leading to potential economic inefficiency and continued vulnerability to global fuel price shocks.

Scenario 2: AREC – ASEAN Renewable Electricity Coupling

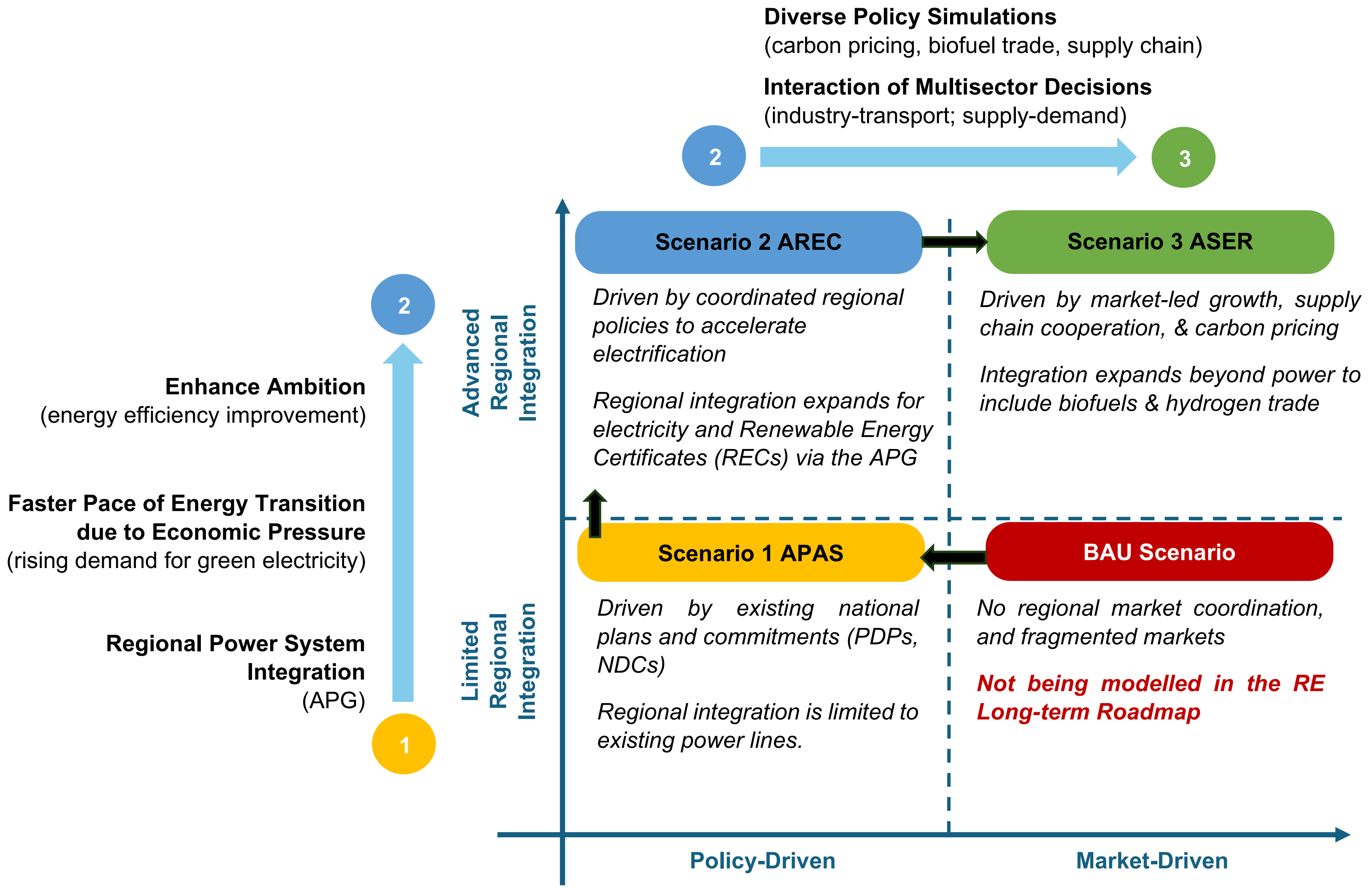
The AREC scenario represents a significant, coordinated step-up in regional cooperation, answering the question: *What can be achieved if ASEAN deepens regional cooperation through coordinated policies, but focuses these efforts on the power sector?* It moves into the "Advanced Regional Integration" quadrant while remaining "Policy-Driven". This is achieved by adding two key policy levers on top of the APAS foundation: the activation of 18 Priority Projects to expand the APG and the creation of a regional REC market. The AREC pathway is therefore a pragmatic, lowest-cost approach for a clean power system, but its policy tools are strategically aimed at the power sector only.

Scenario 3: ASER – ASEAN Shared Energy Resources

The ASER scenario is the most transformative, answering the question: *How can ASEAN leverage deep regional integration and competitive markets to achieve economy-wide decarbonisation?* It moves into the "Market-Driven" quadrant, building upon the AREC framework by adding three final, game-changing policy layers. It introduces regional biofuel and hydrogen trade, implements market mechanisms like carbon pricing and fosters regional supply chain cooperation on solar PV, wind turbine, battery and electric storage, including EV batteries. While this creates a highly economically competitive region, it also requires the highest level of investment and political will to achieve the harmonisation of regulations and enable deep, cross-sector market integration. This is the only pathway designed to achieve a full, economy-wide energy transformation.

The choice for ASEAN is not "what if" we transition, but "how": as individual nations (APAS), as a coordinated power bloc (AREC), or as a single, transformative clean energy economy (ASER).

Key Policy Levers of ASEAN Renewable Energy Long-term Scenarios



2.2. Impacts of Policy Ambition on Regional Renewable Energy Share

Coordinated electrification is the indispensable engine for achieving ASEAN's near-term (next APAEC) RE targets, but a strategic leap to multi-sector market integration is required in the long term to overcome the inherent limits of a power-sector-only approach and fully decarbonise the economy

The strategic impact of each policy pathway is best measured by its effect on key regional indicators. The RE share in TPES is a crucial metric, as it provides a true, economy-wide view of progress by including the transport and industry sectors, revealing the direct consequences of each scenario's policy ambition.

APAEC (2026–2030): Tackling the Implementation Gap

The renewable growth of both AREC and ASER presents a similar trend. This phenomenon is because the energy transition will be driven by renewables in the power sector during the next APAEC cycle. There are several factors that influence this trend, such as the surge in the demand for renewable electricity, mature RE technology and market readiness, cost-competitive and emerging technology to support grid stability with higher variable renewable energy (vRE) and stakeholders having access to more skills and knowledge. The demand for electricity is clearly increasing due to the shift towards greater electrification on the demand side, which is further stimulated by the EV policy.

In contrast, decarbonising the end-use industry remains a topic of limited discussion. While the plans to replace coal with domestic biomass for high-heat applications are mentioned, widespread adoption faces hurdles. Furthermore, scalable solutions like green hydrogen and its derivatives are not yet at market price parity.

Mid-Term (2031–2040): The Divergence of Ambition

This is the decade where the strategic limitations of a power-sector-only approach become apparent, and the full potential of the ASER pathway is revealed. After 2035, the renewable growth curve presented in AREC begins to flatten as its policy tools, focused on the power sector, reach their natural limit. The most cost-effective solar and wind projects have been built, and the grid faces increasing challenges integrating higher shares of variable renewables. At the same time, the region's largest sources of emissions—heavy industry, shipping and aviation—remain largely unaddressed.

In contrast, the ASER curve continues its steep ascent, driven by its ability to decarbonise end-use sectors through new regional markets for clean fuels. This reality presents a critical strategic choice. The region cannot rely on power sector policies alone to continue making rapid progress on decarbonisation post-2035. It must begin laying the groundwork for deeper market integration and the new clean fuel value chains envisioned in the ASER scenario, such as developing the infrastructure and trade policies for green hydrogen, ammonia and advanced biofuels.

Long-Term (2041–2045): Securing a Competitive Future

In the final phase, the ASER pathway solidifies its lead, on track to achieve a regional RE share of nearly 60%. This is the period during which the full benefits of shifting from project-by-project cooperation (AREC) to embrace a truly integrated, regional energy market appear.

This new market-driven paradigm fundamentally differs from the old project-by-project model, which was confined to isolated, often bilateral agreements for specific power plants or transmission lines. However, the successful proliferation of these bilateral cooperation arrangements in the power sector in the preceding decades was the pivotal enabler for this integrated future. Far more than just establishing the physical grid interconnections, each project served as a practical learning ground. They built the institutional know-how required to manage cross-border tariffs and harmonise technical standards, which in turn fostered the political trust necessary to evolve from simple transactions to deeper, multilateral commitments.

This groundwork is what allows the region to leap from simple energy sales to a truly dynamic, region-wide marketplace. The deep integration allows for the most efficient allocation of capital and resources across the entire economy, directing investment to where it is most effective—from large-scale offshore wind farms in the most viable locations to fostering a thriving regional trade in biofuels and green hydrogen.

Ultimately, the leap to the ASER pathway, while requiring greater investment and political will in the preceding decades, reveals itself as a necessary strategic move. The ultimate prize is not just a higher climate target, but the creation of a more competitive region, built upon the foundations of greater energy security, lower and more stable long-term energy costs and new opportunities for leadership in green industries.

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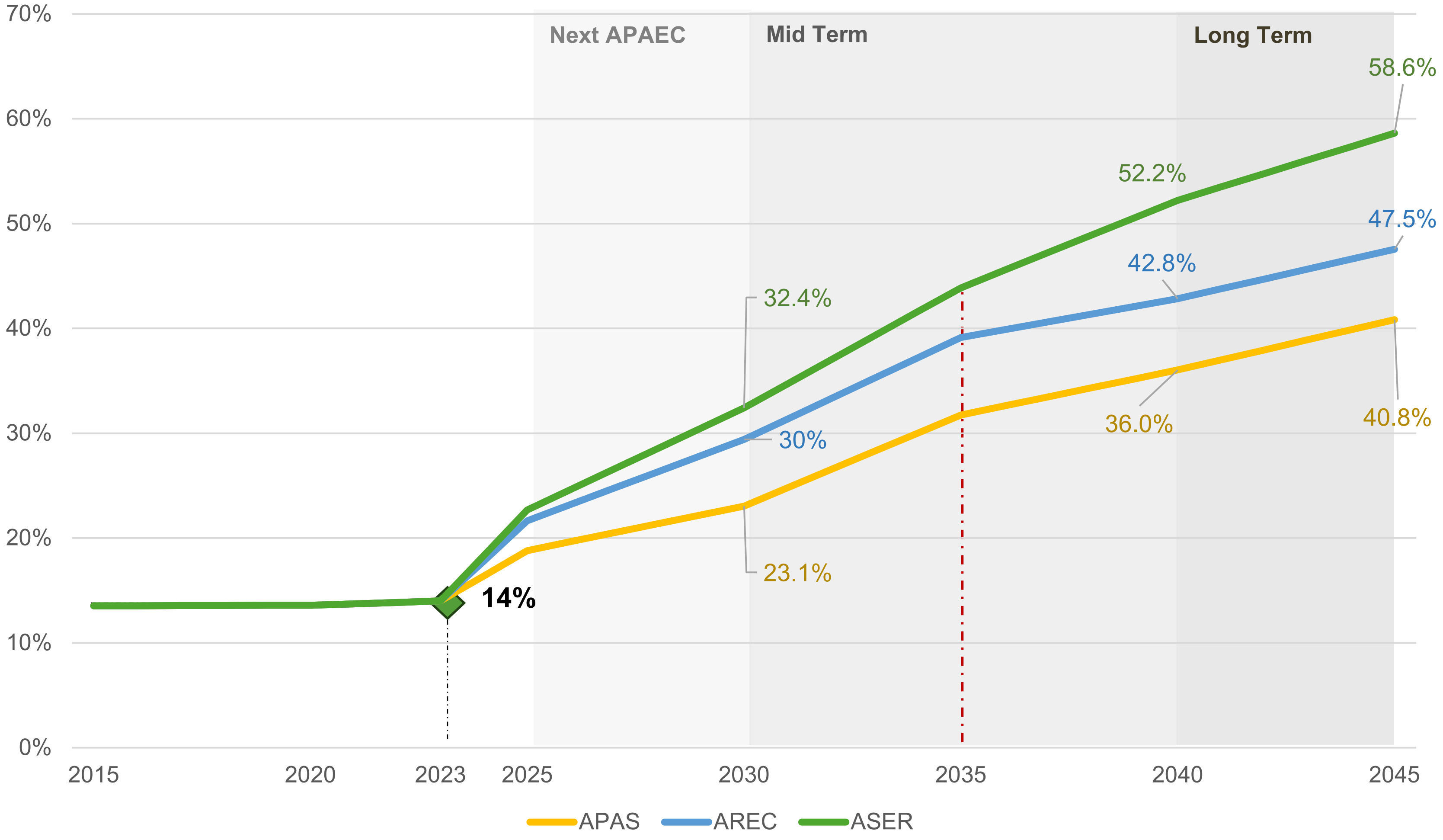
The pathways define a strategic decision: AREC offers the pragmatic path to a clean power sector, while ASER represents the transformational leap to a deeper decarbonised and competitive regional economy.

Renewable Energy Share of TPES in ASEAN



Strong national plans will drive a rapid increase in the renewable capacity share through the next decade, but sustaining this momentum post-2035 will require a strategic shift towards the advanced regional policies needed to master deep system integration.

Having seen the economy-wide progress in the share of RE in the TPES, we now focus on the primary engine driving this transition: the power sector. A critical indicator for this is the RE share of installed capacity. This metric measures the physical build-out of renewable generation facilities relative to the total system size, and its trajectory portrays strong near-term momentum followed by long-term integration challenges.

APAEC 2026–2030: Securing the Near-Term Leap

The upcoming APAEC cycle presents a significant challenge, requiring the region to close a gap of more than 10% from its current RE share of 33.5%. While this represents a major undertaking, the analysis shows a powerful underlying momentum in growth across all three scenarios. This strong trajectory, driven by ambitious national PDPs and the compelling economics of new renewables, indicates that this steep increase is achievable. The key implication for policymakers is therefore twofold: the immediate strategic discussion must focus on implementing the policies needed to secure this challenging but achievable near-term growth, while also using this momentum as a confident foundation to begin planning for even higher long-term ambitions.

Mid-Term (2031–2040): From Rapid Deployment to Deep Integration

The first half of this period continues the rapid deployment of renewables that occurred before 2030, building on strong national momentum. However, after 2035, a distinct flattening of the curve begins across all three scenarios. This slowdown is not caused by a lack of RE resources, nor is it a deliberate pivot back to fossil fuels. Instead, it reflects the convergence of two major challenges.

Firstly, the slowdown is influenced by the natural planning horizons of many national PDPs. These plans are the key drivers of the impressive growth pre-2035, but many are scheduled to conclude during this period, creating a potential policy gap.

More fundamentally, the flattening signals the arrival of the deep integration challenge. As the share of renewables in the grid pushes towards 60%, the easy wins from straightforward deployment are exhausted. The primary barrier to growth shifts from the cost of building new generation to the complexity and cost of managing the entire system. Adding further capacity is no longer a simple matter of installation; it demands significant investment in grid flexibility, energy storage and sophisticated management systems to maintain stability.

It is during this decade that the strategic divergence between the pathways becomes most critical. While all scenarios must confront this new reality, the advanced regional market mechanisms and cooperative planning frameworks of the ASER scenario are specifically designed to overcome these integration barriers. This is why, despite the fact that growth also slows, the ASER pathway is able to maintain greater momentum, laying the imperative groundwork for realising the high-penetration grid of the next decade.

Long-Term (2041-2045): Mastering the High-Penetration Grid

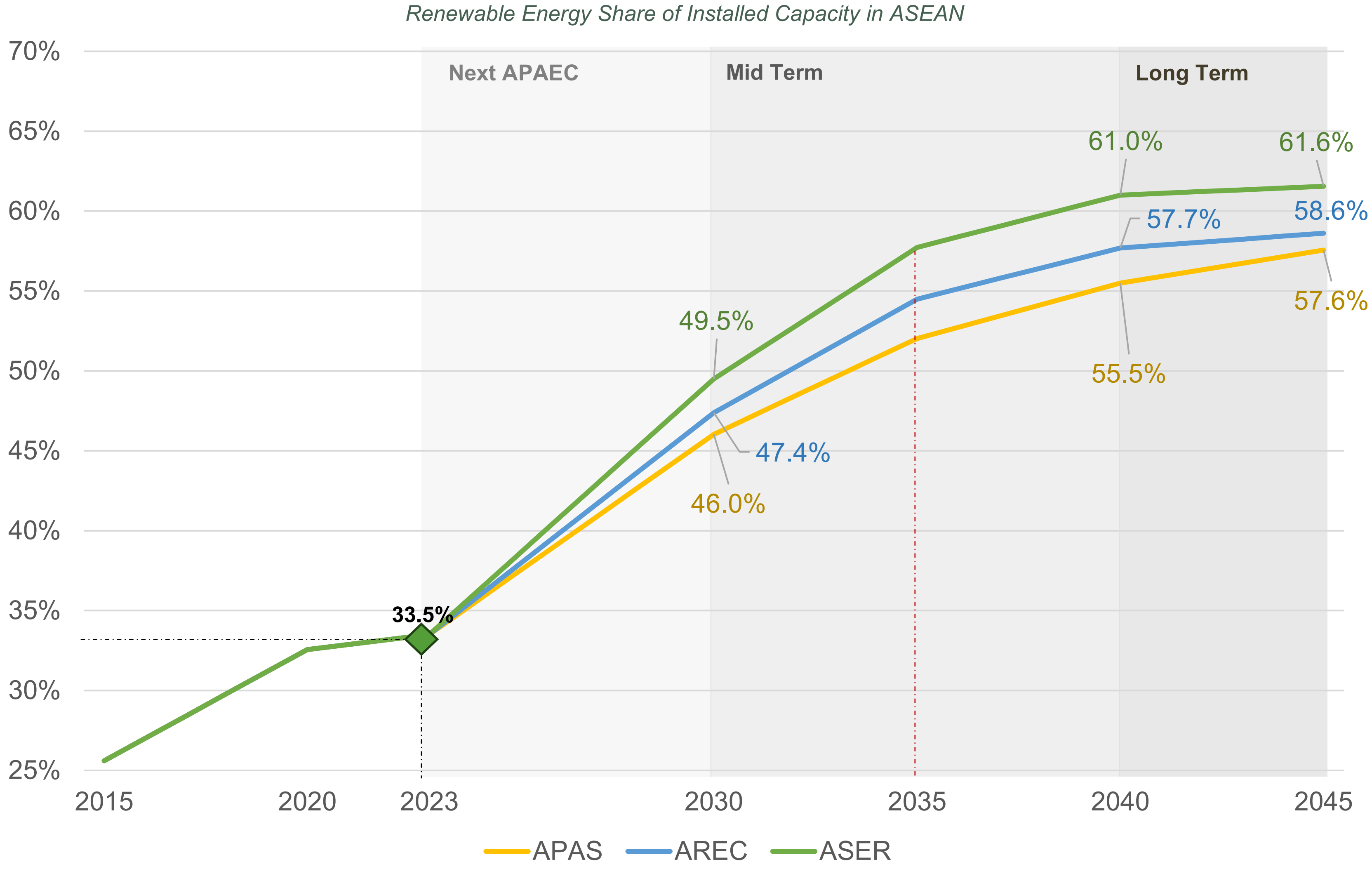
In this phase, the system is mature, and the flattening of the curve is pronounced across all scenarios. The growth in the RE share is now a slow, hard-won battle of incremental gains. The main focus for system planners is no longer deployment, but on mastering the operation of a highly complex, high penetration RE grid.

The ASER pathway's ability to achieve a higher final share of RE in this period stems directly from the introduction of carbon pricing, which acts as a powerful market signal to hamper any potential bounce-back to coal and gas. Carbon pricing renders continued investment in fossil fuels economically unviable. At the same time, it pushes the system to favour non-fossil, dispatchable substitutes to ensure reliability. The higher installed capacity of biomass and hydropower in the ASER scenario is a direct result of this, as they provide essential baseload and firm capacity without emissions.

Furthermore, the deeper regional market and supply chain integration inherent in ASER results in lower technology costs for vRE like solar and wind, as well as for energy storage. This creates a virtuous cycle: as vRE becomes cheaper, its deployment accelerates, which in turn creates a clear market-driven need for flexibility. Consequently, the modelling results show a significantly higher build-out of storage capacity in ASER—not as an external assumption, but as a crucial, emergent investment to ensure the stability of a grid dominated by renewables.

This demonstrates that the final, most difficult steps in decarbonising the power sector are entirely dependent on having the right market structures in place.

The near-term challenge for ASEAN's renewable capacity is a race for quantity; and the long-term challenge is the system complexity and integration.



2.3. Different Pathways to a More Energy-Efficient ASEAN

Coordinated electrification delivers the region's foundational energy efficiency gains, but the deeper, market-driven incentives of the ASER pathway are necessary to offset the energy cost of a full, multi-sector decarbonisation.

Analysis of energy intensity reveals a striking trend: the ambitious AREC and ASER pathways deliver a dramatic and remarkably similar improvement, consistently outperforming the baseline scenarios (APAS). This similarity comes from minor changes in assumptions due to restricted perspectives on how to decide on a stringent energy efficiency plan, particularly within the industrial sector.

The Shared Foundation of Efficiency

Both the AREC and ASER pathways offer a massive and immediate improvement in energy intensity by 2025. This is driven by the same core mechanism: the efficiency multiplier effect of coordinated electrification. By replacing less efficient direct combustion of fuels in vehicles, and by introducing electric motors with higher efficiencies, improved waste heat recovery, and electrification of low-heat supply, both scenarios fundamentally reduce the amount of primary energy required to power the economy. This shared strategy is the reason their performance is so closely aligned from the very beginning.

The Subtle Differences

While their overall trajectories are similar, small variations reveal the unique character of each pathway, showcasing a clear example of the multi-policy choices available in the region. The key differences emerge in how each scenario tackles transport decarbonisation and the long-term challenge of heavy industry.

In the mid-term (2031-2040), the two pathways achieve a very similar reduction in final energy consumption, but through fundamentally different strategies.

The AREC pathway, which assumes the use of only domestic biofuel resources, finds that the most efficient policy is to promote a direct technology switch from internal combustion engine vehicles (ICEV) to EV. This is also driven by the assumption of falling EV costs which permits cost parity with ICEV. In contrast, the ASER pathway assumes cross-border biofuel trade. This market integration makes blended biofuels more widely available and cost-effective. As a result, continuing to use efficient ICEV powered by this cleaner fuel blend remains a highly competitive decarbonisation option, even when compared to the falling cost of EVs.

The further enhancement in ASER is due to a more advanced optimisation; its assumption of deep regional supply chain cooperation drives battery costs even lower, which in turn reduces the costs of EVs and the overall renewable technology costs, accelerating both the adoption of RE generation in the power sector and the associated efficiency gains.

However, in the long-term, a surprising reversal occurs, with AREC projected to be marginally more efficient than ASER. This is not a flaw in the ASER model, but a reflection of its greater ambition. The transition from AREC to ASER is less about efficiency assumptions and more about the underlying drivers: AREC remains policy-driven, focusing on power decarbonisation, while ASER shifts to a market-driven, economy-wide transition. To decarbonise the entire economy, ASER assumes that green hydrogen will be introduced to tackle hard-to-abate sectors like heavy industry. ASER's mission requires building new clean fuel industries, and these processes of creating green hydrogen and advanced biofuels involve inherent energy transformation losses. These energy conversion costs are the primary reason for ASER's slightly higher total primary energy supply in the final years.

The Strategic Implication of Choosing Between Efficiency and Effectiveness

This brings us to the most important insight:

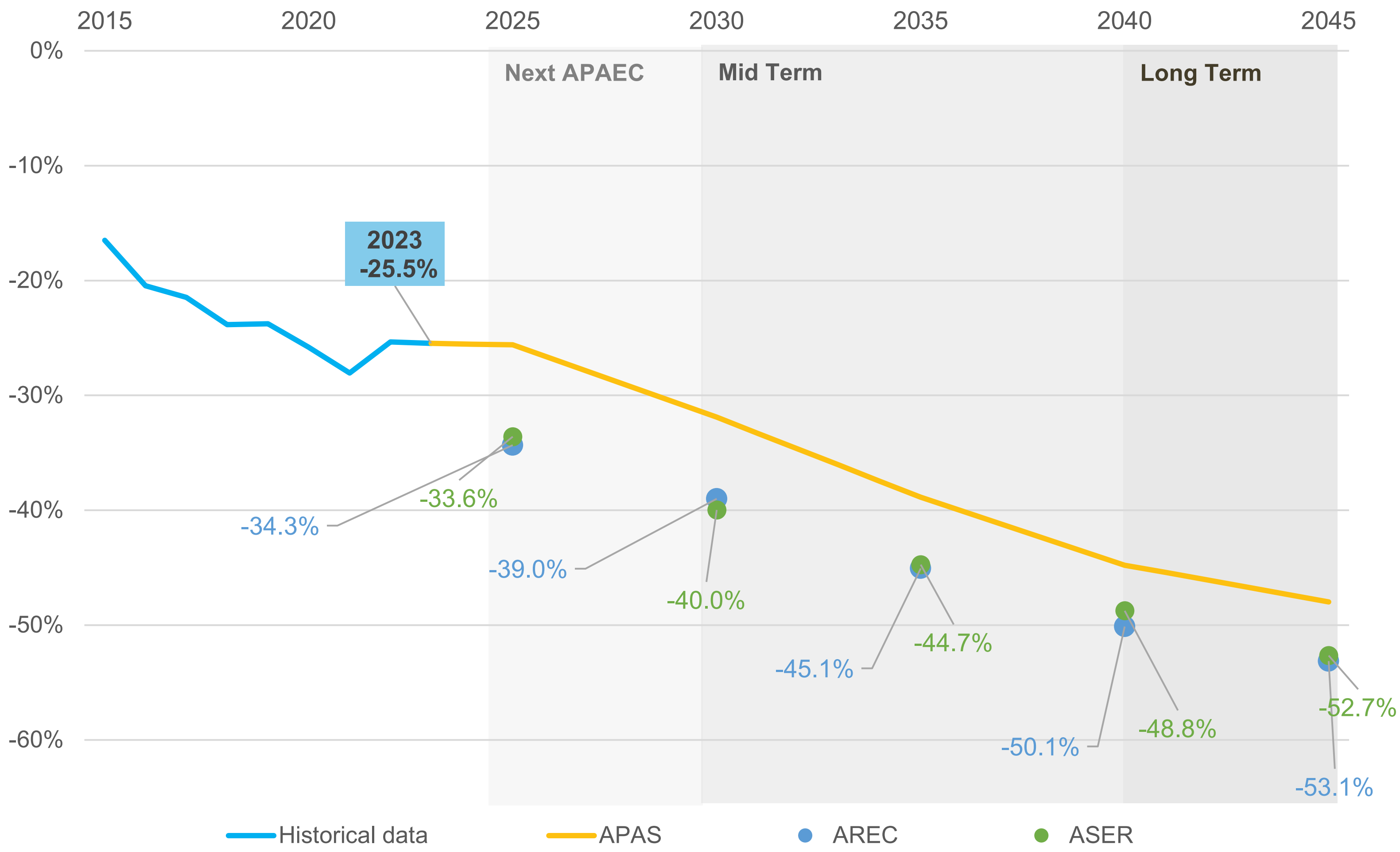
The small, long-term gap in energy intensity is not the main story; the different missions of the scenarios are the main story.

AREC is a model of maximum efficiency. It showcases the decarbonisation of the power sector with the absolute minimum primary energy input and electrification on the demand side.

ASER is a model of maximum effectiveness. It is the only pathway that attempts to decarbonises the entire economy by building new clean fuel industries to tackle the hard-to-abate sectors. While this makes ASER slightly less “efficient” in the energy intensity metric, it reflects the calculated trade-off of expanding the scope of decarbonisation from the power sector to the whole economy. The crucial takeaway is that this minor efficiency trade-off is the price of achieving a fully decarbonised, multi-sector clean energy system.

AREC is the pathway of system efficiency for coupling a decarbonised grid with electrified transport and industry, while ASER is the pathway of decarbonisation effectiveness for the entire economy.

Energy Intensity Reduction in ASEAN



2.4. Defining the Pathways for Bending ASEAN's Emissions Curve

A coordinated focus on the power sector is sufficient to halt the growth of emissions, but only a deeper, multi-sector approach that addresses industry and transport with new clean fuels can put the region on a firm path to absolute emissions reduction.

Building on the economic benefits of reducing energy intensity and increasing RE, the ultimate test of each pathway is its direct impact on total greenhouse gas emissions. This indicator serves as the bottom-line scorecard for regional climate action, and the analysis of the three long-term pathways reveals three fundamentally different climate futures for ASEAN.

APAS Trajectory Warns of Continually Rising Emissions

The APAS pathway, representing the sum of current national commitments, shows a clear upward trend in emissions. This is a critical reality check, demonstrating that the region's unconditional NDCs and national plans focused on energy security are being outpaced by the powerful momentum of economic growth. Continuing to build new fossil fuel capacity alongside renewables and leaving emissions from industry and transport largely unaddressed leads to emissions growing by over 900 million tonnes from 2020 to reach a high of nearly 3.2 gigatonnes of CO_2e by 2045.

AREC Offers Plateauing, But Not Decreasing Emissions

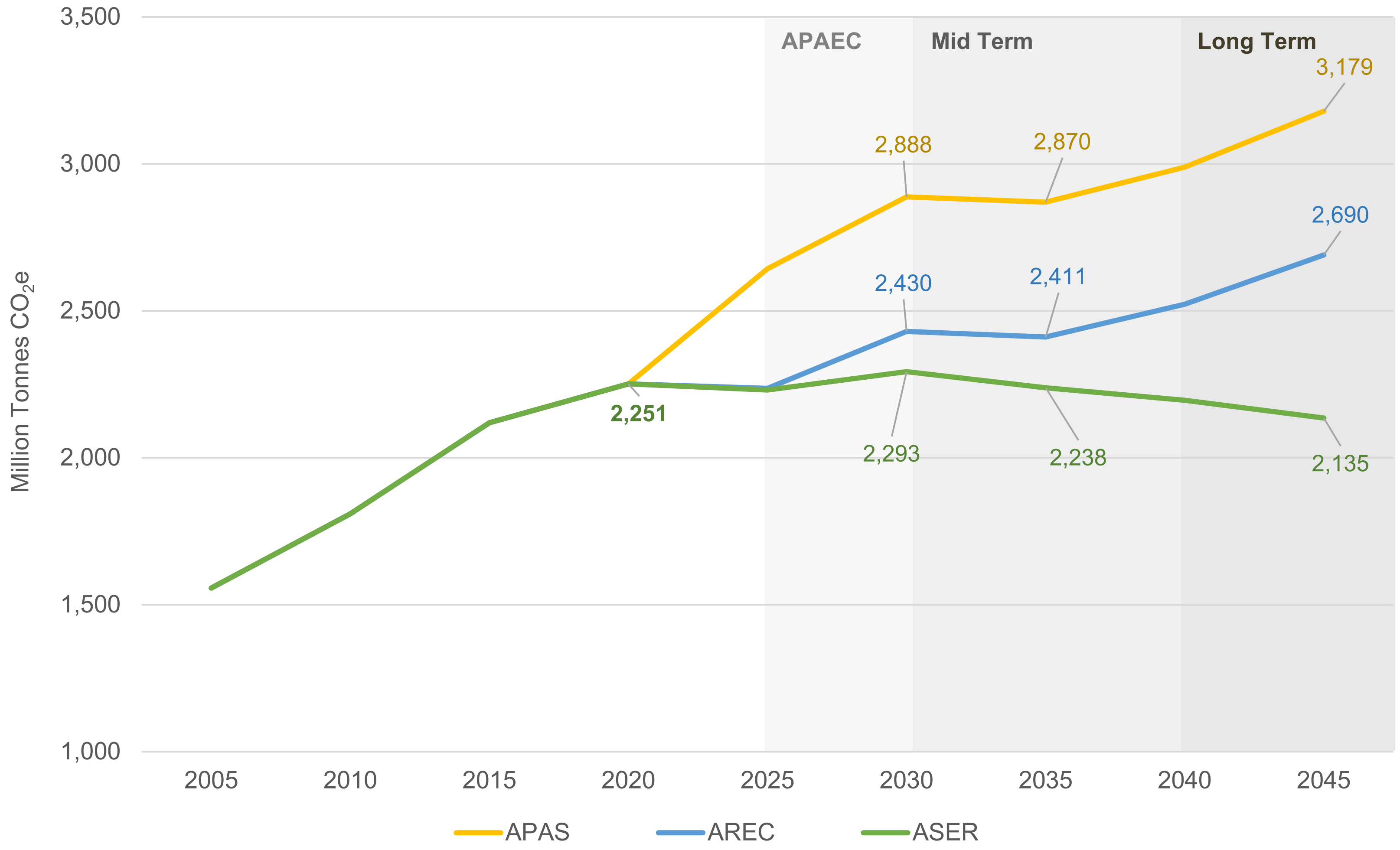
The AREC pathway demonstrates the significant impact of coordinated regional action in the power sector. It successfully flattens the curve, keeping long-term emissions far below the APAS level. However, the chart shows that after an initial peak in 2030, emissions plateau and then begin to slowly rise again, reaching ~2.7 gigatonnes by 2045. This provides a crucial insight: decarbonising the power sector is essential for slowing emissions growth, but is not sufficient on its own to put the region on a downward trajectory, as emissions from other sectors continue to grow.

ASER is the Only Pathway to Absolute Reduction

The ASER pathway is the only scenario that achieves the ultimate goal of bending the curve on regional emissions. It is the only one that shows a definitive peak in emissions around 2025, followed by a sustained and steady decline. By 2045, emissions fall to ~2.1 gigatonnes—below where they were in 2020. This proves that achieving an absolute reduction in regional emissions is possible, but it requires the deep, multi-sector and market-driven policies that are unique to the ASER scenario. The ability to tackle emissions across the entire economy—through regional clean fuel markets (biofuels & hydrogen) and carbon pricing—is what makes this downward trajectory possible. This creates a profound divergence: by 2045, the difference between the APAS and ASER pathways is over one gigatonne of CO_2e per year, representing the quantifiable climate benefit of choosing a path of deep, ambitious and comprehensive regional cooperation.

Only the deep, multi-sector market integration of the ASER scenario can bend the region's emissions curve downwards and align the region closer with global climate commitment.

ASEAN Energy Sectors' Emissions Level



Chapter 3

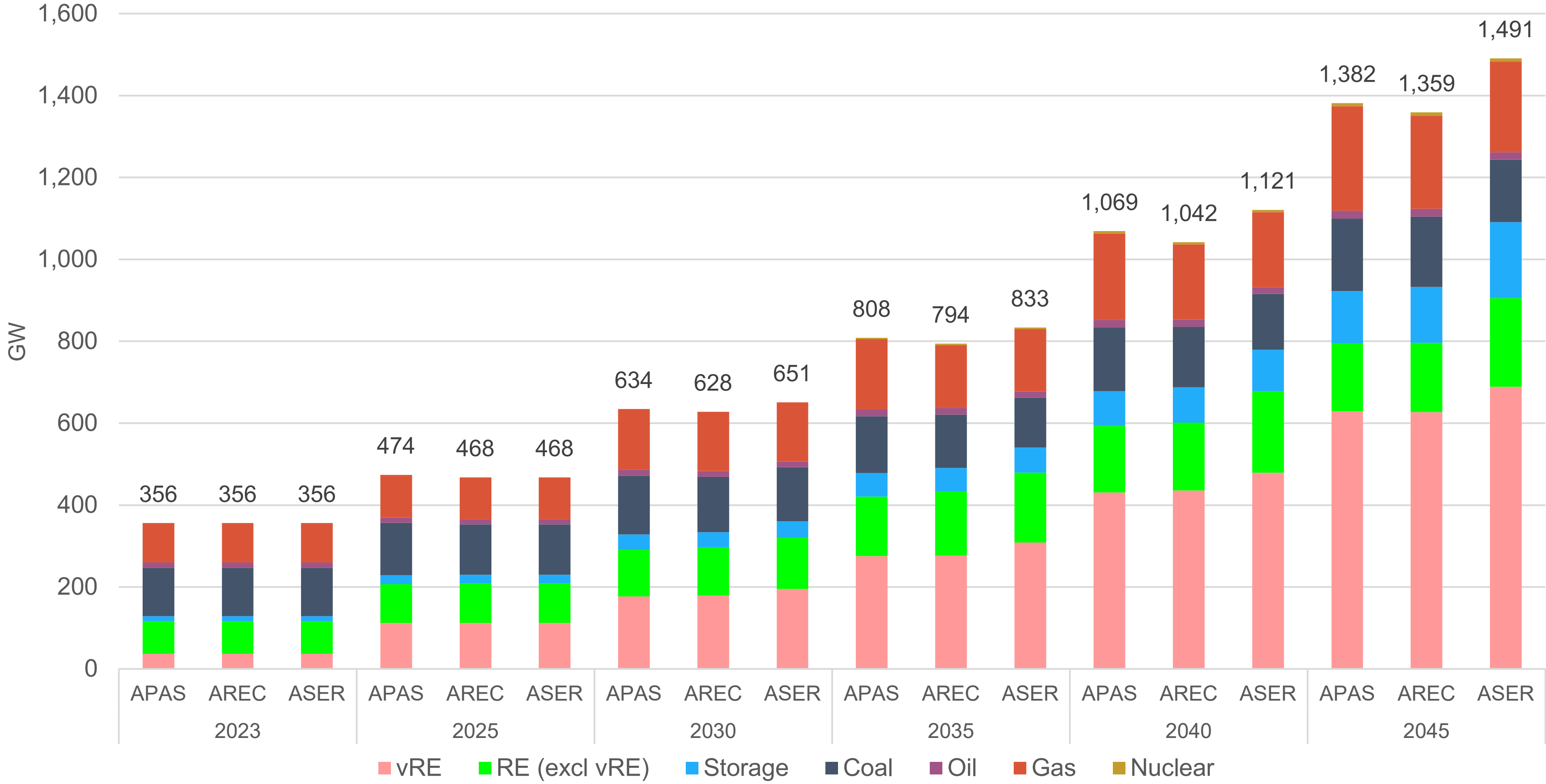
Sectoral Transformation

3.1. Power Sector Transformation

3.1.1. Generation Capacity Needs

ASEAN's power infrastructure future lies in the options of uncoordinated expansion (APAS), optimised fossil fuel replacement (AREC) and a transformational, economy-wide scale-up (ASER).

ASEAN Installed Capacity Options Across Scenarios, 2023–2045



Understanding the Long-term Trade-offs of Different Pathways for Power Capacity Expansion

Regional cooperation is the key to reshaping the region's installed capacity, enabling a far more aggressive replacement of the fossil fuel fleet with a combination of renewable generation and storage infrastructure as reflected by AREC and ASER's pathways.

The total installed capacity of each pathway reveals a telling, counter-intuitive trend. The regionally coordinated AREC scenario results in the leanest, most efficient power system, requiring less total capacity than the baseline scenario, APAS. In contrast, the highly ambitious ASER scenario requires the largest system of all. This dynamic between APAS and AREC illustrates the advantages of promoting energy efficiency in industry and activating cross-border power trade which can lead to a reduction in the need for additional capacity. The trade-off between AREC and ASER emphasises the effect of carbon pricing on reductions in coal and gas power plants. In the absence of stringent energy efficiency regulations – similar efforts with respect to energy efficiency in both scenarios – a greater capacity of vRE and storage will be necessary to replace the phase-down of fossil fuels.

The APAS Reflects Uncoordinated Expansion

The APAS pathway leads to a future of uncoordinated expansion, resulting in a massive system of 1,374 GW by 2045. Critically, this growth is inefficient, as the scenario concludes with the largest fossil fuel fleet (451 GW) of the three. This represents a path of energy sprawl, where new renewable capacity is layered on top of an expanding fossil fuel system without a clear strategy for replacement, leading to a bloated, carbon-intensive grid with a high risk of stranded assets.

The AREC is an Alternative of Optimised Fossil Fuel Replacement

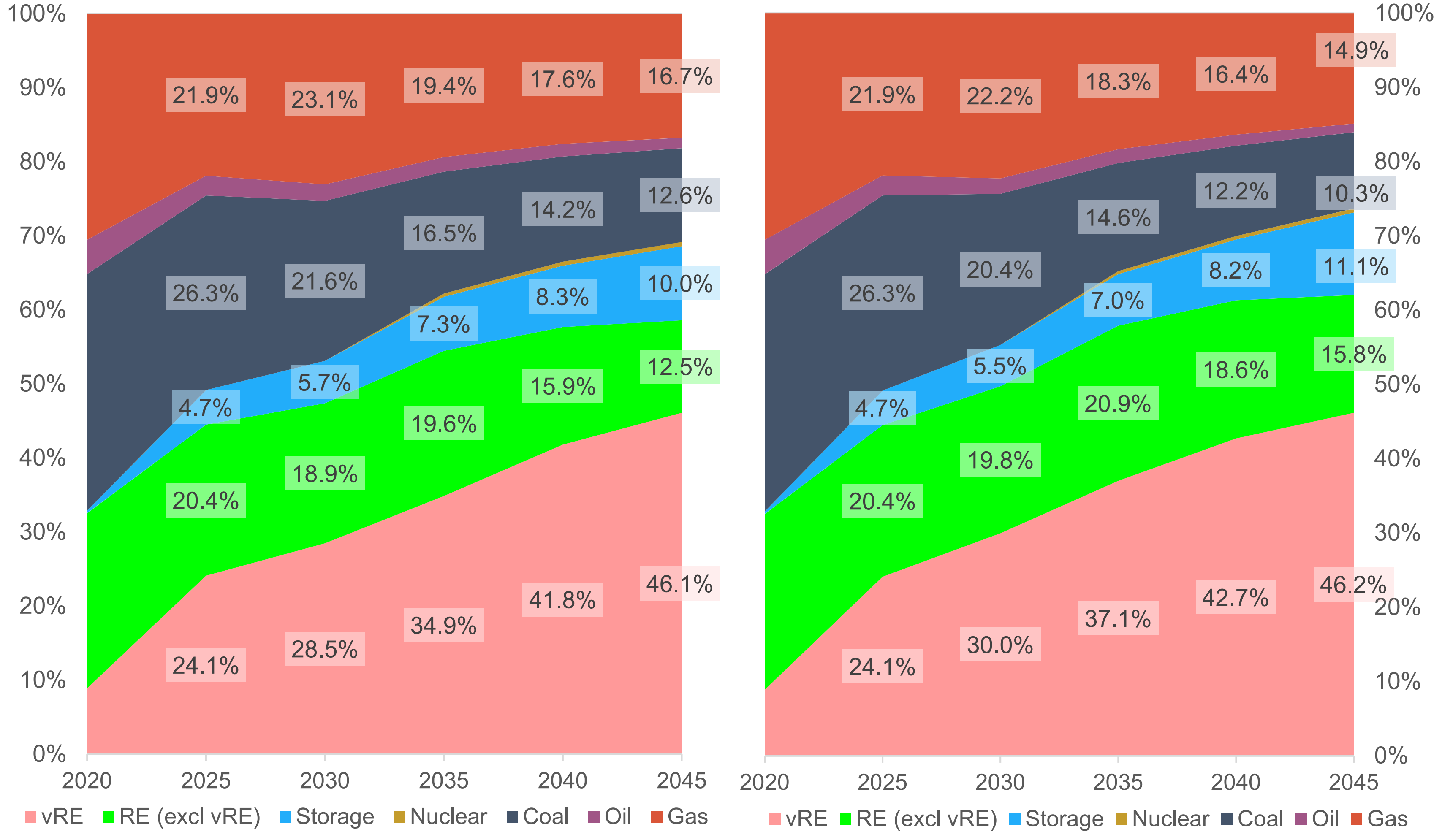
The AREC pathway demonstrates the power of strategic optimisation, delivering the leanest and most capital-efficient system throughout timelines. By leveraging regional cooperation to share resources and build renewables in the best locations, AREC achieves a renewable build-out similar to APAS but with a significantly smaller fossil fuel fleet. This illustrates that regional cooperation is a powerful tool for capital efficiency, allowing the system to actively replace the need for some fossil fuel plants and efficiently support the electrification of transport and industry.

The ASER is A Future of Transformational Scale-up

The ASER pathway requires a build-out on a transformational scale, resulting in the largest total system at 1,483 GW by 2045. This monumental scale is not a sign of inefficiency but of a vastly expanded mission. ASER builds upon the electrification efforts of AREC and adds the capacity needed to build a new clean fuels economy, using its massive renewable fleet (906 GW) and a significant addition of storage fleet (185 GW) to power the production of regional supply chain of RE technology, biofuels and green hydrogen. This represents a major industrial and infrastructure project designed to achieve a more complete decarbonisation of the economy, especially in hard-to-abate sectors.

ASEAN will achieve a re-ordering of the power system hierarchy within the next APAEC period (2026-2030) that establishes vRE as the new core of the grid.

ASEAN Installed Capacity Mix based on AREC (left) vs ASER (right), 2020-2045



Charting the Tipping Points of the AREC Pathway

The AREC transition is driven by a dual RE strategy—with vRE providing the massive scale and conventional RE providing the firm foundation—which is enabled by a tactical flexibility hand-off from natural gas in the near term to storage fleets in the long term.

Having assessed the long-term trade-offs of the three pathways, a deeper analysis of the AREC scenario is essential. As the most capital-efficient pathway and the foundation for the upcoming APAEC 2026-2030 regional targets, examining its internal dynamics provides the most direct insights into the policy priorities and strategic challenges facing ASEAN in the near to medium term. The evolution of its installed capacity mix reveals a clear, phased strategy for transforming the region's power sector.

APAEC (2026–2030): Critical Tipping Points

This initial period is the most formative phase of the entire transition, where the hierarchy of the power system is fundamentally re-ordered. Very early in this period, vRE capacity surpasses conventional RE for the first time. Also, vRE overtakes coal to become the single largest source of installed capacity on the grid. By 2030, the system crosses a historic milestone as total renewable capacity surpasses the total fossil fuel capacity. This period is therefore defined by a rapid and decisive substitution, establishing a new order where renewables, led by vRE, are the primary source of new capacity. In the first half of APAEC, it is highly important to provide regulatory frameworks for energy storage systems in grid-scale and isolated systems and to strengthen technical knowledge to ensure that the growth of vRE is not hampered.

Mid-Term (2031–2040): vRE Takeover and Shift of the Flexibility Role from Gas to Storage

This decade is about cementing the gains of the previous phase and accelerating the displacement of coal. The relentless growth of vRE continues, with its share climbing from 28.5% to 41.8%, marking the grid as officially a renewable-majority system. The first half of this decade (2031-2035) witnesses the single most significant five-year reduction in coal's share of the power system, as it falls by over 5 percentage points. This period also witnesses the beginning of the strategic flexibility hand-off. The share of natural gas begins its steady decline, whilst the share of energy storage continues its consistent rise, nearly doubling from 5.7% to 8.3%. This signifies a deliberate, planned transition from relying on fossil-based flexibility to clean, technology-based flexibility.

Long-Term (2041–2045): A Mature, vRE-Dominant System

In the final phase, the system reaches its mature, rebalanced state. vRE is the dominant source of capacity at 46.1%. The flexibility hand-off is now complete, with energy storage becoming a major pillar of the grid at 10%.

The remaining incumbents have settled into their new, long-term roles: conventional renewables and coal now have almost identical, smaller shares (~12.5%). The declining share of conventional renewables, particularly hydropower, is driven by the conclusion of most national PDPs which extend to around 2030-2035. As planned hydro capacity additions cease, total capacity stagnates. Meanwhile, natural gas provides the final, essential block of dispatchable capacity, with new capacity added in countries like Viet Nam to ensure grid stability. This directly explains why the share of conventional RE decreases more rapidly than that of natural gas; whilst the absolute capacity of the former is stagnant, that of the latter is being actively expanded to fulfil a critical grid-balancing role.

The grid is no longer a fossil-fuel system with renewables added; it is a renewable-dominant system supported by a diverse portfolio of firm and flexible assets.

The Strategic Advance of ASER Capacity Mix

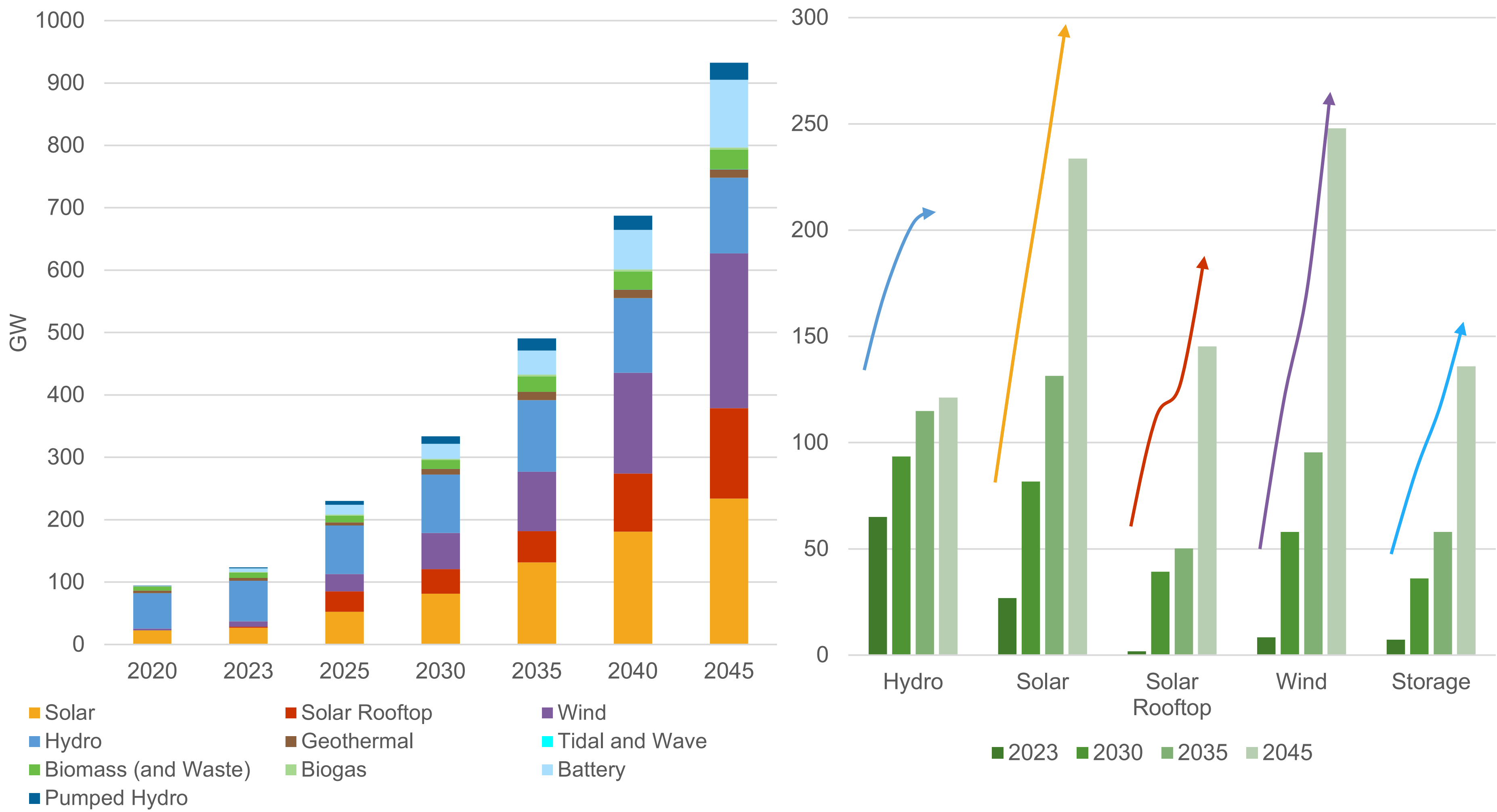
The AREC pathway represents a monumental transformation for the region's power sector. Building upon this foundation, a comparison with the ASER scenario's final capacity mix reveals the additional benefits that the region could reap by pursuing a higher level of ambition. The ASER pathway does not just increase the total renewable share; it fundamentally optimises the entire system for resilience and economic efficiency.

The ASER pathway achieves a more resilient and deeply decarbonised grid by investing more heavily in clean, flexible and firm capacity. For instance, whilst AREC builds a robust grid with 10% energy storage, the ASER pathway expands this to nearly [~14-15%] of the total capacity, creating a much larger buffer to integrate vRE. Furthermore, its reliance on natural gas for balancing is reduced. This is because ASER develops a larger share of firm, non-fossil renewables like biomass and hydropower, which total a combined [~15%] of the mix compared to just 12.5% for conventional renewables in AREC.

ASER's market-driven approach, underpinned by carbon pricing and regional supply chain integration, creates a more economically efficient system. As it drives down the costs of vRE and storage, the strong investment signals for firm renewables like biomass stimulate new regional markets. This not only optimises the power sector but also positions the region to lead in new green industries that a purely power-sector-focused approach might overlook.

A coordinated regional strategy requires more than a simple RE push; it demands a full system transformation with a massive build-out of solar, wind, hydro and storage fleets.

Long-term Evolution of Renewable Energy and Storage Capacity (left) and Key Technology Expansion (right), 2020–2045



Reconfiguring the Power and Energy Storage Systems to Supply Electricity to ASEAN Countries

The AREC infrastructure strategy evolves from an initial, all-encompassing build-out, to a mid-term focus on massive utility-scale projects, and finally to the long-term challenge of managing a highly decentralised grid.

Understanding the distinct roles of each renewable and storage technology is essential for transforming the AREC pathway from a high-level target into an actionable plan. This pathway signifies a fundamental shift towards a more decentralised, distributed and open electricity system, driven by the massive growth of variable renewables. This deeper, technology-specific analysis clarifies the sheer scale of the required capacity increase, which in turn informs the necessary investment priorities. Crucially, it highlights the urgent need not just for physical hardware, but for foundational grid and electricity market improvements.

Preparing for the Next APAEC Period (2026–2030)

The most immediate priority for the region is preparing for the unprecedented industrial and investment challenge required in the next five-year cycle. The model shows that this is not about one technology, but about rapidly scaling up multiple, distinct clean energy fleets simultaneously. In comparison to 2023, the required capacity additions by 2030 include,

- ✓ vRE: utility-scaled solar 3x increase of ~55 GW; rooftop solar 22-fold increase, adding ~37 GW; wind power 7-fold increase of ~50 GW.
- ✓ Hydropower build-out of ~29 GW (1.4x); geothermal capacity addition of ~4 GW (1.9x).
- ✓ Battery storage 4-fold increase adding ~19 GW; pumped hydro 7-fold increase adding over 10 GW.

Evolving Roles in the Mid- to Long-Term

Conventional Renewables

The steady, linear growth of hydropower and geothermal capacity, particularly in the mid-term (2031-2040), is critical. These technologies provide the firm, dispatchable and clean power that acts as the reliable anchor for an increasingly vRE-heavy system.

vRE Expansion in Two Phases

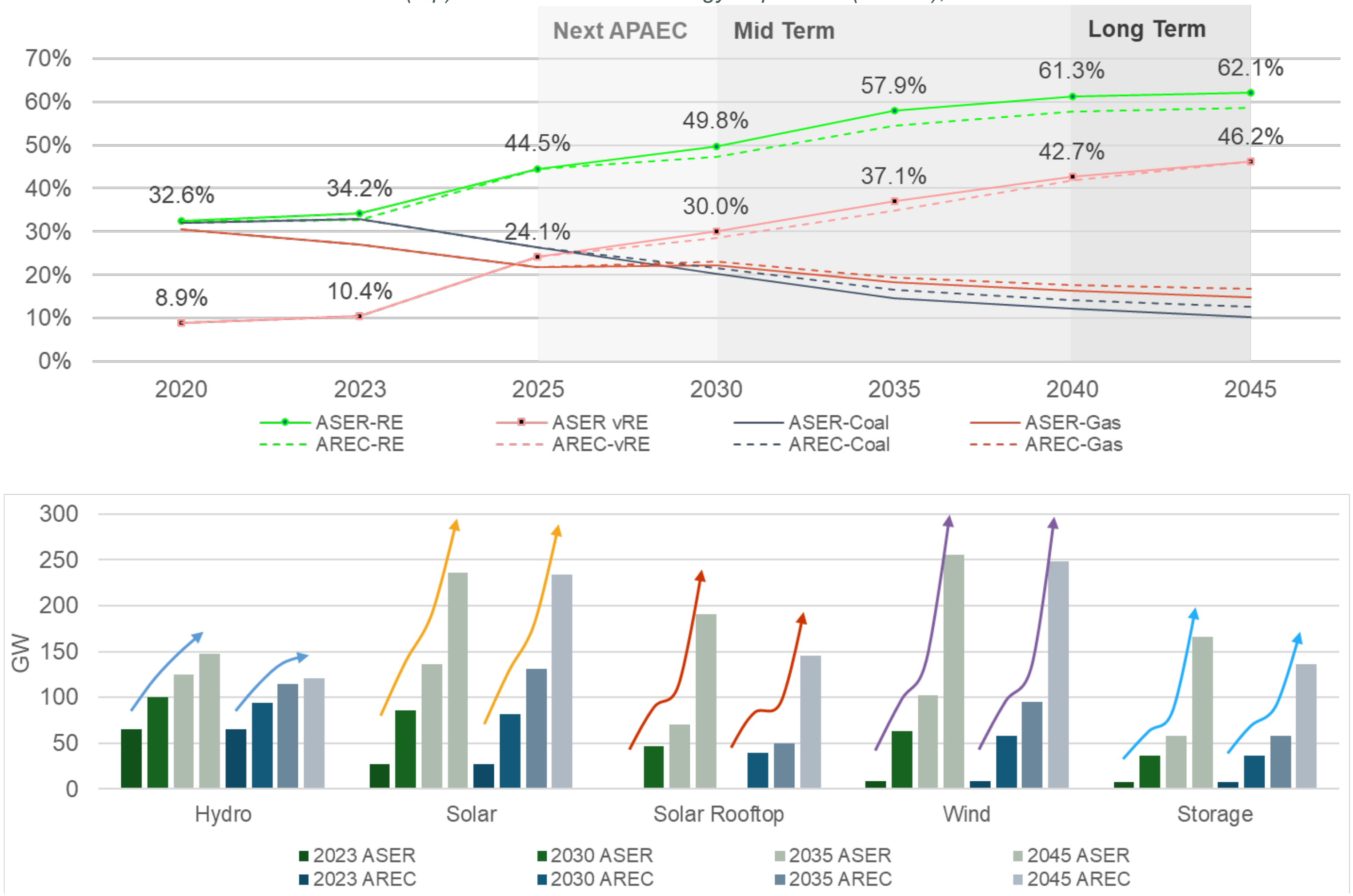
In the first phase (2031–2035), the strategy focuses on facilitating the development of massive utility-scale solar and wind projects. During this phase, the explosive initial growth of rooftop PV temporarily slows down as the system prioritises the integration of these larger projects. In the second phase (2036–2045), a second, market-driven wave of solar rooftop deployment re-accelerates. This, combined with the continued expansion of utility-scale vRE, requires a shift to a highly decentralised grid.

Energy Storage

The growth trajectories of battery and pumped hydro storage directly mirror the vRE build-out. This confirms its non-negotiable role as the essential enabler of the power system transition. The massive expansion of storage in the next APAEC cycle and in the long term, where it becomes a 100+ GW pillar of the system, is what ensures the reliability of the entire vRE-dominant grid.

Renewables will supersede fossil fuels around 2030. A key tipping point within APAEC 2026–2030 is that VRE capacity will surpass that of coal and gas, which is consistent for both ASEC and ASER.

Comparison of AREC vs ASER Installed Capacity Outlook in Fuel Mix (top) and Selected Technology Expansion (bottom), 2020–2045



Policy Options for the Optimal Energy Transition Pathway

After establishing the foundation of the AREC pathway, ASEAN can unlock the faster and deeper decarbonisation of the ASER vision through strategic policy choices that reallocate investment from coal and gas to a diverse and resilient system built on firm renewables, decentralised solar and large-scale energy storage.

Having assessed the implications of AREC, it is essential to understand the strategic options available to ASEAN for pursuing an even deeper decarbonisation. The AREC pathway is not just a theoretical model; it forms the ambitious but achievable foundation for the upcoming APAEC 2026-2030 regional targets. This analysis, therefore, explores a key strategic question: *after successfully building the AREC foundation, what policy decisions need to be made for ASEAN to unlock the full benefits of the transformational ASER vision in the mid- to long-term?*

The Immediate APAEC Mission (2026–2030)

The primary focus of the upcoming APAEC cycle is the successful execution of the AREC pathway. This period is best understood as building the essential groundwork upon which higher ambitions can be built. By activating the 18 priority ASEAN Power Grid (APG) projects and establishing a regional Renewable Energy Certificate (REC) market, the region will build the physical infrastructure, regulatory experience and institutional trust that are the absolute prerequisites for the deeper, multi-sector integration envisioned in ASER.

ASER Offers a Faster and Deeper Transition

The ASER pathway is not just more ambitious in its final outcome; it accelerates the entire transition. Key tipping points—such as vRE overtaking coal, and total renewables surpassing fossil fuels—are achieved 1-2 years earlier than in the AREC scenario. This faster pace is driven by a more decisive and immediate reduction in coal and gas capacity, creating a performance gap that widens significantly after 2035 and results in a higher ultimate RE share of 62.1%.

Beyond sheer speed, the ASER pathway builds a fundamentally more diversified and robust clean energy system. It requires a renewed, long-term commitment to hydropower post-2035 for clean regional grid balancing. It unlocks a revolution in decentralised energy, with the rooftop solar ambition far exceeding that of AREC, and its market-driven approach incentivises a more front-loaded expansion of wind power by 2030. Finally, this pathway prepares for the deep decarbonisation by building a more sophisticated and flexible grid; whilst storage needs are similar up to 2035, the post-2035 period sees ASER requiring a significantly larger storage capacity to manage the complexity of its fully integrated, multi-sector system.

Key Policy Options and Investment Needs

Once the AREC foundation is in place, the region will be at a new strategic crossroads. The model shows that continuing on the AREC path leads to a plateau in decarbonisation. The leapfrog to ASER is the opportunity to break through this ceiling, but it requires a deliberate shift in infrastructure focus and policy ambition in the post-2030 period. This entails commitment to the following:

Reinvesting from Coal to Dispatchable Renewables

This option requires strategically redirecting long-term investment from new coal power plants to clean, firm capacity. The graphs show that ASER's policy choices reduce the final share of coal in the capacity mix from 12.6% to 10.3%. This freed-up capital is instead channelled into sustained investments in hydropower and geothermal. It represents a direct substitution, replacing the traditional role of fossil-fuel baseload with clean, dispatchable assets for regional balancing.

Shifting from Centralised Generation to a Revolution in Decentralised Energy

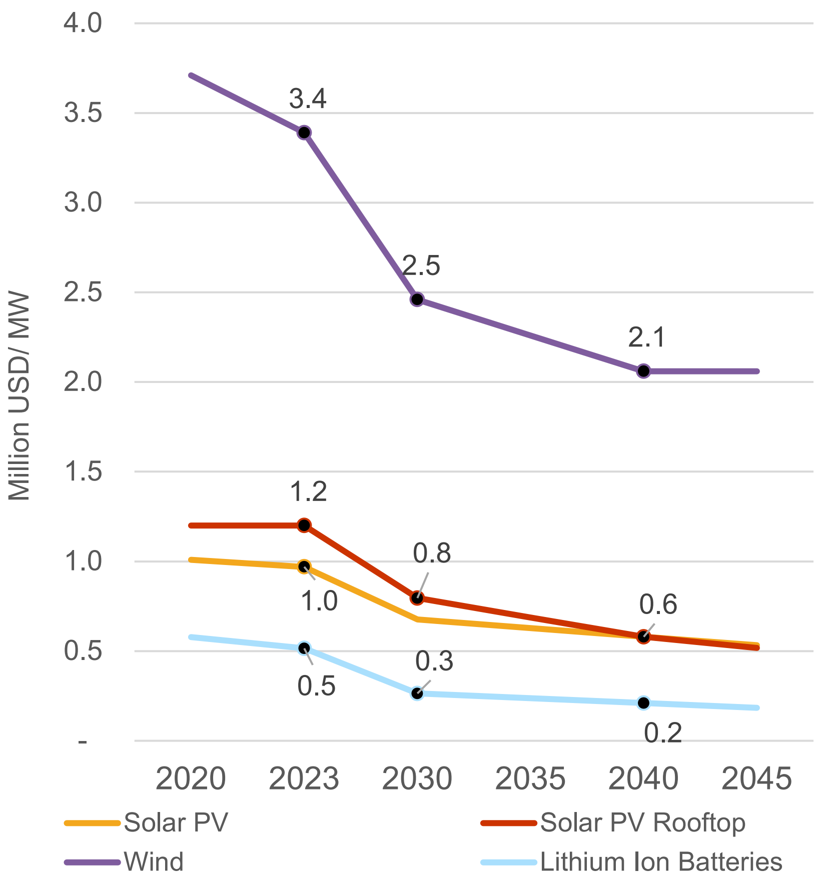
This pathway necessitates policies that unlock a massive, market-driven wave of solar rooftop deployment. As the bar chart shows, the ASER vision results in a rooftop solar fleet that is over 45 GW larger than that in AREC. This represents a fundamental reallocation of capital from large, centralised power stations to millions of distributed assets, empowering consumers and enhancing grid resilience from the ground up.

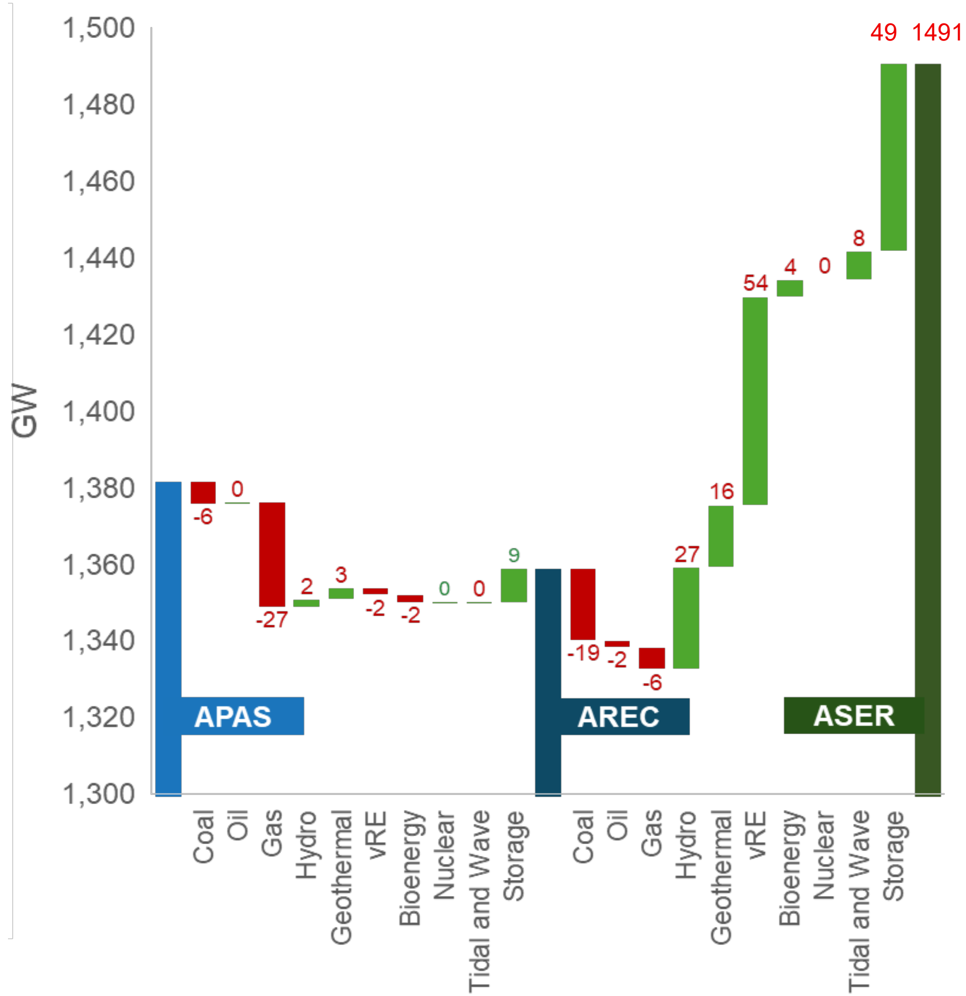
Replacing Gas Peaker Plants with a Massive Investment in Storage

Unlocking the ASER vision requires a major reallocation of investment from fossil-fuel flexibility to clean technology flexibility. The line chart clearly shows that ASER significantly curtails the long-term role of natural gas (reducing its final share from 16.7% to 14.9%). This investment is strategically redirected towards deploying a much larger storage fleet—nearly 50 GW more than in the AREC path. This is a direct substitution, replacing the need for new gas-fired peaker plants with faster, cleaner, and more versatile technology-based flexibility.

ASER's powerful “push-pull” strategy enables a massive RE build-out, which in turn reveals the critical and complementary need for a robust demand-side management strategy.

ASER’s Key Policy Interventions
on Reducing RE Technology Costs in 2020–2045 (left) and Enforcing Carbon Pricing in 2045 (right)





Deep Dive into the ASER's Core Policy Levers

The most ambitious pathway simultaneously uses regional cooperation to make clean energy cheap, and carbon pricing to make fossil fuels expensive, but this powerful strategy leads to a much larger physical grid, creating a critical trade-off where stringent energy efficiency becomes essential to manage the ultimate scale and cost of the transition.

The ASER pathway's success in delivering an accelerated transition is driven by a "push-pull" economic strategy. This approach, on one hand, uses proactive regional policies to pull down the cost of clean technologies and, on the other, implements market-based instruments to push out fossil fuels, creating a powerful feedback loop that reshapes the entire energy system.

The "Pull" Factor: Driving Down Clean Technology Costs

The ASER pathway's foundation is a proactive regional industrial strategy to drive down technology costs. The model assumes this policy has the following profound effects:

For Solar PV

To achieve the goal of halving solar costs by 2045, with rooftop solar reaching cost parity with utility-scale, the region must focus on three levers: developing upstream manufacturing for panels and cells to achieve economies of scale; creating a harmonised regulatory framework for prosumer schemes; and investing in skills training and certification for a quality installation workforce.

For Wind Power

To achieve an almost-40% cost reduction, ASEAN can leverage its considerable expertise from the offshore oil and gas sector. The low-hanging fruit is in offshore foundation work. This is supported by coordinated investment in port infrastructure to handle massive components, fostering a regional maritime and offshore service ecosystem, and collaborative development zones to de-risk investment in the best wind sites.

For Batteries

To achieve the game-changing 60% cost reduction, the strategy is to build a "mines-to-megafactories" value chain. This involves securing the region's critical mineral supply (namely nickel), using the massive, predictable demand of the ASER scenario to attract investment in gigafactories, and developing a circular economy for battery recycling and waste management.

The "Push" Factor: Levelling the Playing Field with Carbon Pricing

Complementing this powerful economic pull, the introduction of carbon pricing creates a decisive break away from fossil fuels. The 2045 waterfall chart on the right provides the clearest evidence of this, showing two distinct leaps with fundamentally different strategic objectives.

APAS → AREC

This leap from APAS to AREC is primarily a technical and regulatory transformation. The waterfall shows that the biggest change is a massive -27 GW reduction in gas capacity, with only a minor -6 GW reduction in coal. This is the result of AREC's coordinated grid planning; the expanded APG creates a more efficient regional system that can eliminate a large amount of redundant or inefficient national gas capacity. This leap represents the benefit of making the existing power system work smarter.

AREC → ASER

This second, more ambitious leap is a full economic transformation, driven by a powerful market signal which is the introduction of a carbon price. This price is set as an escalating incentive for decarbonisation, rising from USD 40 per tonne in 2030 to USD 160 per tonne by 2050.

The escalating price fundamentally changes the investment landscape. Its immediate effect makes new, long-term investments in high-emission power sources unviable, which is why the coal capacity is reduced by 19 GW. As the price continues to rise, it also drives the ultimate gas-to-storage substitution for flexibility, where 6 GW of gas storage is displaced by 49 GW of new storage.

Crucially, the market certainty created by the carbon price helps to unlock the huge, across-the-board build-out of all clean energy sources needed to replace fossil fuels, including +54 GW of vRE, +27 GW of hydro, and +16 GW of geothermal. This demonstrates the power of an escalating carbon price to not only penalise the use of fossil fuels but to create a clear financial case for investing in the entire portfolio of zero-carbon solutions.

The Critical Need for Demand-Side Efficiency

This massive shift towards a system dominated by vRE, however, introduces a critical new challenge. Whilst vRE is cheap to generate, its lower operational efficiency (capacity factor) means a new, large volume of installed capacity is required to produce the same level of electricity as conventional plants. This is a key reason ASER's total physical build-out is significantly larger.

This outcome strongly suggests that to make the ambitious ASER pathway more manageable and cost-effective, its powerful supply-side interventions should be complemented by an equally ambitious demand-side strategy.

The first lever aims to reduce the overall volume of electricity demand. This involves shifting from voluntary targets to mandatory policies, such as high-performance building codes for new construction, incentives for deep energy retrofits of existing buildings, and progressively tightening Minimum Energy Performance Standards (MEPS) for both industrial equipment and major appliances.

The second lever is crucial for managing a high-vRE grid by changing the times when electricity is used. This can be achieved through demand response programmes that reward industrial users for shifting consumption, implementing smart charging to encourage EV to charge when solar power is abundant, and promoting grid-interactive technologies that automatically adjust their consumption in response to grid signals.

This reality check shows that the ambitious ASER pathway is not a radical leap, but an achievable future built on the strong national ambitions of regional leaders.

Comparison of Cumulative Installed Capacity from Member State's National PDP and Model Optimisation Outcome for Solar PV, Wind and Storage, 2025–2045

The sharply rising capacity is dominated by the committed national PDP. The optimised level indicates that there is additional capacity to shift towards a cost-competitive path.

The analysis reveals two complementary roles for the region's energy powerhouses: Viet Nam's national plans serve as the ambitious anchor for the regional vision, whilst ASER's targeted enhancements for Indonesia highlight the immense, untapped potential that regional cooperation can unlock.

Grounding the ambitious ASER pathway in the context of existing national plans provides a necessary reality check. This comparison between the model's optimised outcomes and the committed PDPs of member states reveals that ASER is not a radical departure from national ambitions, but rather a logical and reasonable enhancement of them.

Study Cases: Why Indonesia and Viet Nam?

For a detailed national-level reality check, Indonesia and Viet Nam have been selected as primary case studies. This choice is driven by a critical factor: the timeliness and ambition of their national energy planning. Both nations have recently updated their PDPs in 2025, providing the most current official data with significant RE capacity expansion targets.

This contrasts with several other AMS whose energy plans are still in various stages of development. For example, Thailand's PDP is currently undergoing a revision process and is expected to be finalised and launched by the end of 2025. In other cases, national ambitions are expressed as capacity pledges rather than as fully detailed, formalised plans. This makes a direct, like-for-like comparisons challenging at this time.

In addition, these two nations also represent the diverse spectrum of challenges and opportunities across the region.

Indonesia is a major fossil fuel producer with diverse RE potential, rich in hydropower, ocean, geothermal, bioenergy, including solar and wind, facing the unique challenges of an archipelagic grid.

Viet Nam, in contrast, is a major energy importer with a renewable profile dominated by solar and wind, and a long, coastal grid topology.

This focus on Indonesia and Viet Nam provides a robust, data-driven snapshot of the transition in two of the region's key economies. Follow-up, country-by-country analysis for other member states can be conducted upon request.

Analysing the Ambition Gap

A consistent pattern emerges from the analysis across all three key technologies. Viet Nam's PDP is already highly aligned with the ambitious ASER vision, with the model's optimisation largely validating the national strategy. For Indonesia, on the other hand, the ASER pathway consistently identifies opportunities to build upon its national plans, requiring targeted additional capacity across solar, wind and storage to fulfil its potential as a regional clean energy powerhouse.

Solar Power

Viet Nam's national PDP provides a world-class foundation, with its targets being so ambitious that no additional capacity is needed in the optimisation. For Indonesia, while the PDP is a strong starting point, the model highlights the need for an additional 6 GW by 2030, a gap that widens to 14 GW by 2035 and 20 GW by 2045 to fully leverage its cost-competitive solar potential.

Wind Power

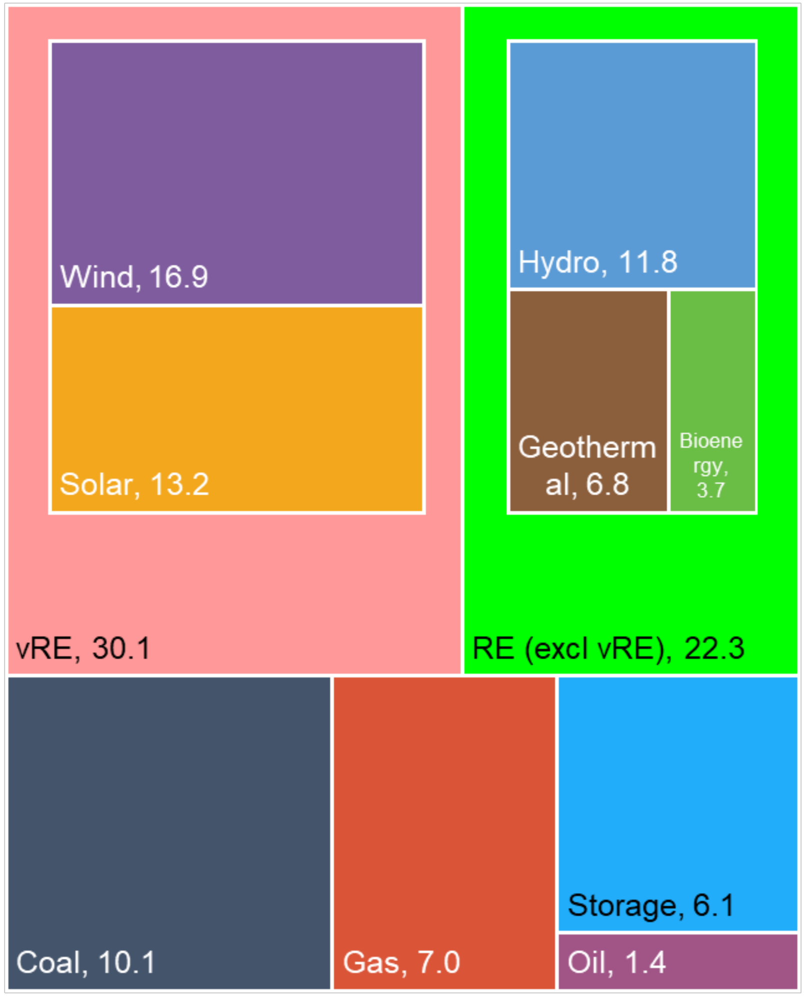
The ASER model finds that Viet Nam's ambitious national plan for wind is already aligned with the regional aspiration. In contrast, the model highlights a consistent opportunity to expand Indonesia's wind capacity to diversify its renewable portfolio, identifying the need for an additional 5 GW by 2030 and 7 GW from 2035 onwards.

Energy Storage

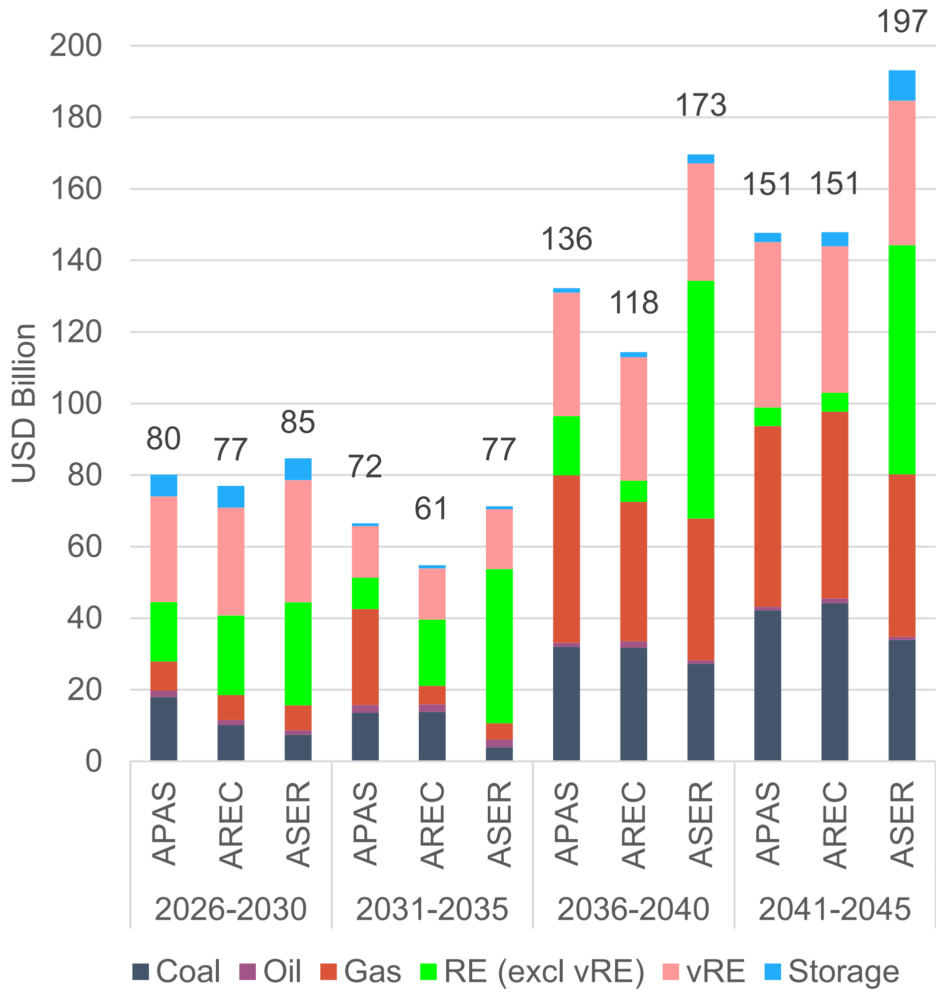
ASER confirms that Viet Nam's robust national plan for energy storage is sufficient to meet the demands of a high-vRE grid. For Indonesia, however, the model builds upon its proactive national plan by identifying the need for a significant additional 10 GW in the long-term (2045), underscoring that the most ambitious regional pathway demands the highest level of investment in enabling technologies.

AREC's capital efficiency offers a pragmatic start, but its inherent limitations in the long-term demonstrate why ASER's larger investment is essential to achieve a deeply decarbonised economy

Average Annual Investment Cost of Expanding Power Capacity
for APAEC 2026-2030 based on AREC (left) and a Comparison Across Scenarios (right), 2026-2045



Unit: USD Billion



Analysing the Investment Choices for ASEAN's Future

The AREC pathway requires an average annual investment of USD 77 billion during the APAEC cycle (2026-2030) to build a balanced clean energy portfolio. Its greatest challenge is securing finance for nearly a quarter of the capital needed for fossil fuel assets that are essential to grid stability.

Understanding the composition of the investment needs is essential for developing a pragmatic and financially sound regional strategy. This is particularly true for the AREC pathway, which not only forms the foundation for the upcoming APAEC 2026-2030, but also stands out as the most capital-efficient scenario through the crucial mid-term.

The Investment Blueprint for APAEC 2026-2030

The investment blueprint for the next APAEC cycle under a coordinated regional approach **totals USD 77 billion**. As the figure illustrates, this capital is allocated across a diverse and balanced portfolio built on three core clean energy pillars.

Nearly **40%** of the total capital, or USD 30.1 billion, is directed towards vRE. Roughly **29%** of the investment, or USD 22.3 billion, is allocated to dispatchable RE (such as hydro and geothermal) to provide the firm, reliable foundation for the grid. **8%** of the total, or USD 6.1 billion, is dedicated to storage, the essential enabling technology for flexibility.

Navigating the Fossil Fuel Financing Dilemma

The data also reveals a critical challenge. A significant portion of the required capital—USD 18.5 billion annually, or nearly a quarter (24%) of the total—is still directed towards fossil fuels, primarily coal and gas. This persistent need poses a significant dilemma for the region: *how to secure financing for these necessary assets in a global financial landscape that is rapidly shifting away from fossil fuels?*

Attracting international investment for new coal and gas projects will become increasingly competitive and costly, requiring a sophisticated and forward-looking financial strategy from ASEAN policymakers. The key is to move beyond traditional financing and embrace the principles of transition finance. One approach is to clearly differentiate between the roles of these assets: financing for essential gas peaker plants needed for grid flexibility could be prioritised, whilst establishing clear retirement schedules for coal plants.

Under a credible transition finance framework, the roles of coal and gas are assessed very differently. Natural gas is seen as a crucial bridging technology for grid stability. Transition finance frameworks, such as those advocated by Glasgow Financial Alliance for Net Zero (GFANZ), could support investment in new gas plants under strict conditions: they must be deemed essential for balancing a high penetration of vRE, they must directly enable the displacement of more carbon-intensive coal and they must be aligned with a long-term net-zero pathway (e.g., having a limited operational lifespan or being designed to be hydrogen-ready).

For coal, transition finance is squarely focused on managed phase-out. As institutions like IEEFA emphasise, there is no appetite for financing new unabated coal. However, transition finance could be mobilised to support the early retirement of existing plants or, in very specific cases, to fund essential grid stability services from the existing fleet, but only if tied to a legally binding closure date.

Given that the global standards for transition finance remain under intense debate, especially concerning the role of gas in developing economies, it is crucial for ASEAN to develop a stronger and united voice. This united position must clearly articulate the region's unique context: defining the limited, stability-focused role of these fossil fuel assets within a credible and time-bound managed phase-out plan. By proactively presenting this nuanced strategy, ASEAN can help shape the international financing conversation, sending a powerful signal that the vast majority (~76%) of its investment needs are for clean energy and positioning itself as a prime, pragmatic destination for sustainable investment.

Investment Cost Options in Long-term

The long-term investment chart reveals a clear divergence in financial strategy and priorities. In the period leading up to 2040, the AREC pathway proves to be the most capital-efficient option. This efficiency is a direct result of its core policy lever: activating cross-border resource sharing via the APG. By allowing for more efficient power generation and sharing, this approach consistently requires lower investment in fossil fuel capacity (coal and gas) and higher RE compared to the APAS baseline. In contrast, the ASER pathway requires the highest upfront investment, reflecting a conscious choice to build a more diverse and resilient portfolio of clean technologies from an earlier stage.

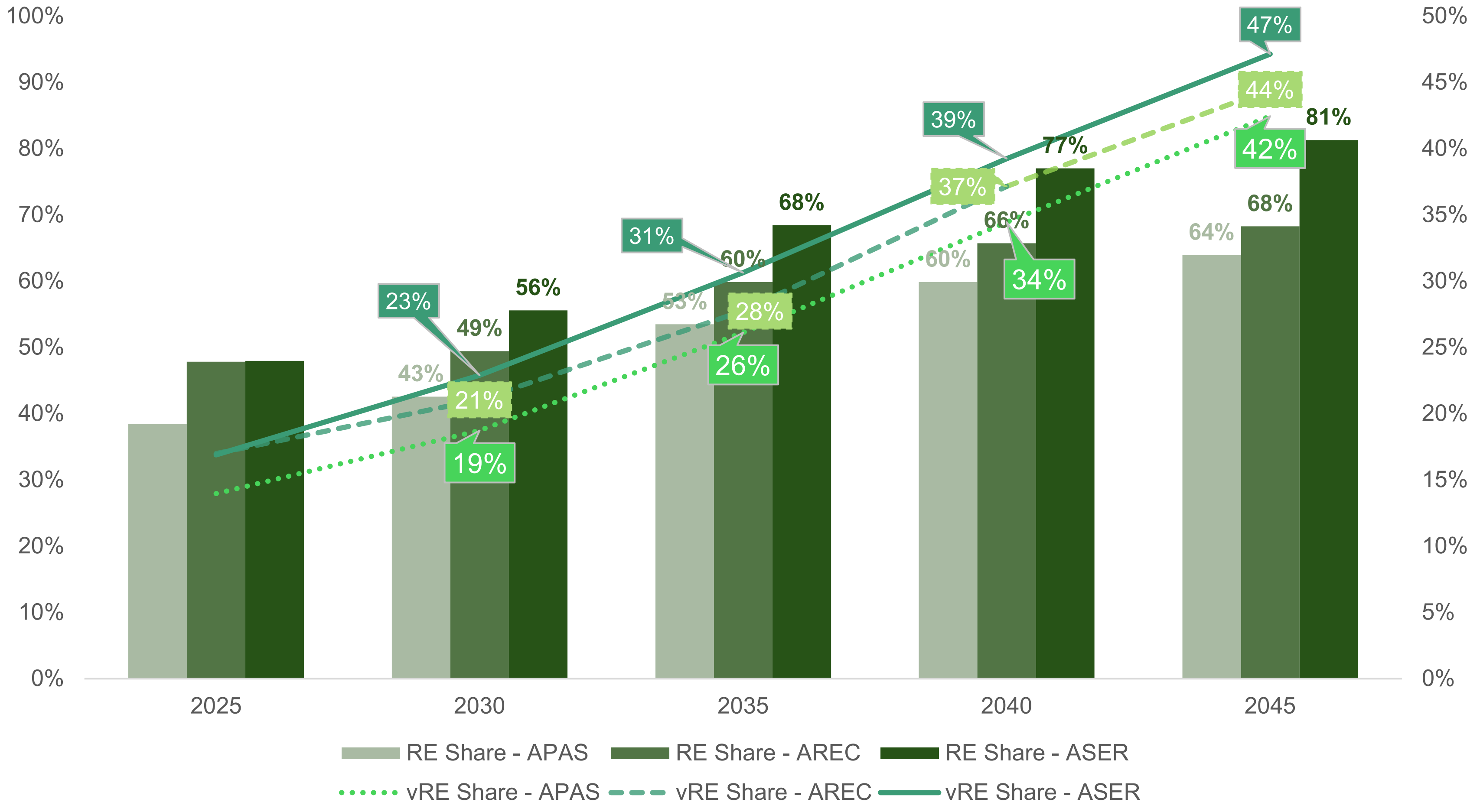
A significant shift occurs in the long term (2041-2045), where AREC's annual investment needs rise dramatically to a level comparable with the APAS baseline. This trend suggests a crucial strategic insight: the benefits of the initial 18 APG interconnection projects may be reaching their maximum capacity. Once these trade corridors are fully utilised, the ability to efficiently share resources diminishes.

Consequently, the AREC pathway is then forced to rely more heavily on building domestic capacity to meet demand and ensure grid stability, resulting in a higher level of investment in coal and gas plants and a slower expansion of RE. This causes its long-term investment profile to converge with that of the less-optimised APAS scenario, highlighting that while the APG is a powerful tool, sustaining deep decarbonisation will require continuous reinforcement of regional infrastructure.

3.1.2. Grid Improvement Needs

ASER proves that the most effective path to decarbonisation is not just maximising vRE, but also building a more balanced and resilient system that is supported with a massive fleet of dispatchable clean power.

Comparison of RE and vRE Shares in Power Generation Across Scenarios, 2025–2045



The Operational Reality of the Future Power Generation Mix

The operational implications of each pathway diverge significantly, from the high-risk volatility of APAS, to the battery-dependent flexibility of AREC, and ultimately to the enhanced resilience of ASER, which is built upon a balanced portfolio of both variable and dispatchable renewable electricity.

Moving beyond the blueprint of installed capacity (GW), the power generation mix (TWh) reveals the operational reality of each pathway. It shows how much clean energy is actually delivered to the economy and is therefore the ultimate test of decarbonisation effectiveness.

The model's projections for the power generation mix reveal two profound findings. The first is the sheer scale of the decarbonisation opportunity. The ASER pathway achieves a world-leading 81% RE share in its generation mix by 2045, far surpassing AREC (68%) and APAS (64%). This 17-percentage-point ambition gap between the baseline and the most ambitious scenario represents a massive volume of displaced fossil fuels.

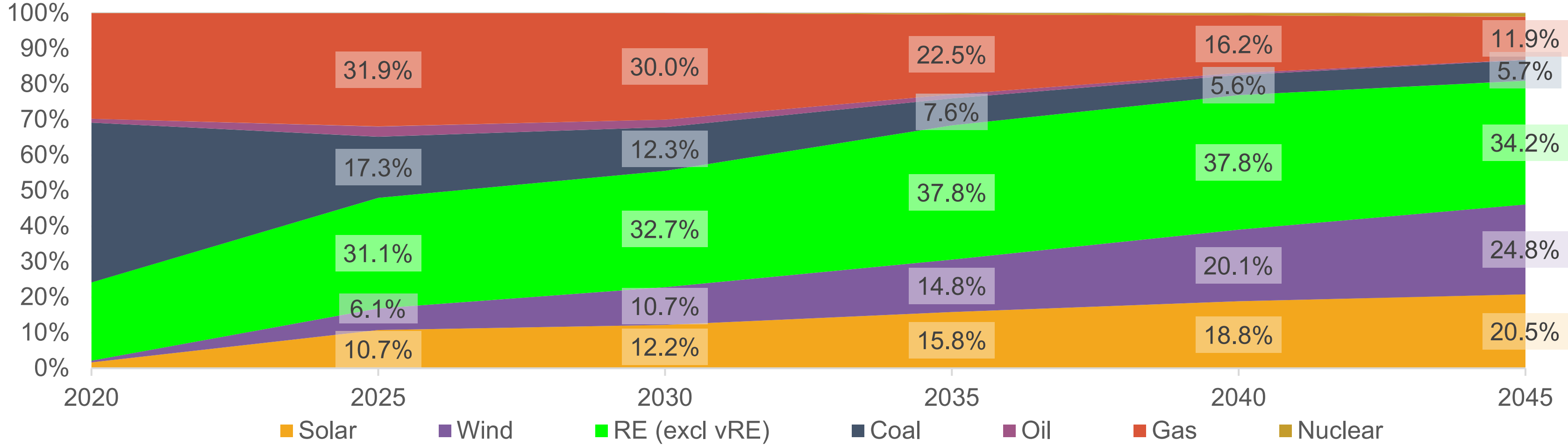
This focus on ASER is crucial for strategic reasons beyond its high RE share. The AREC pathway, while a significant improvement, leads to a plateau in decarbonisation, as its power-sector-only approach is not sufficient to create a sustained, downward trajectory for the region’s total emissions. ASER is the only pathway designed to break through this ceiling. Furthermore, it represents the most prudent long-term economic strategy, aligning the power system's evolution with an economy-wide transition to prevent future stranded assets. Therefore, **ASER serves as the primary object of this power generation assessment**, providing the clearest view of the grid planning and flexibility needs required for a truly deep and effective transition.

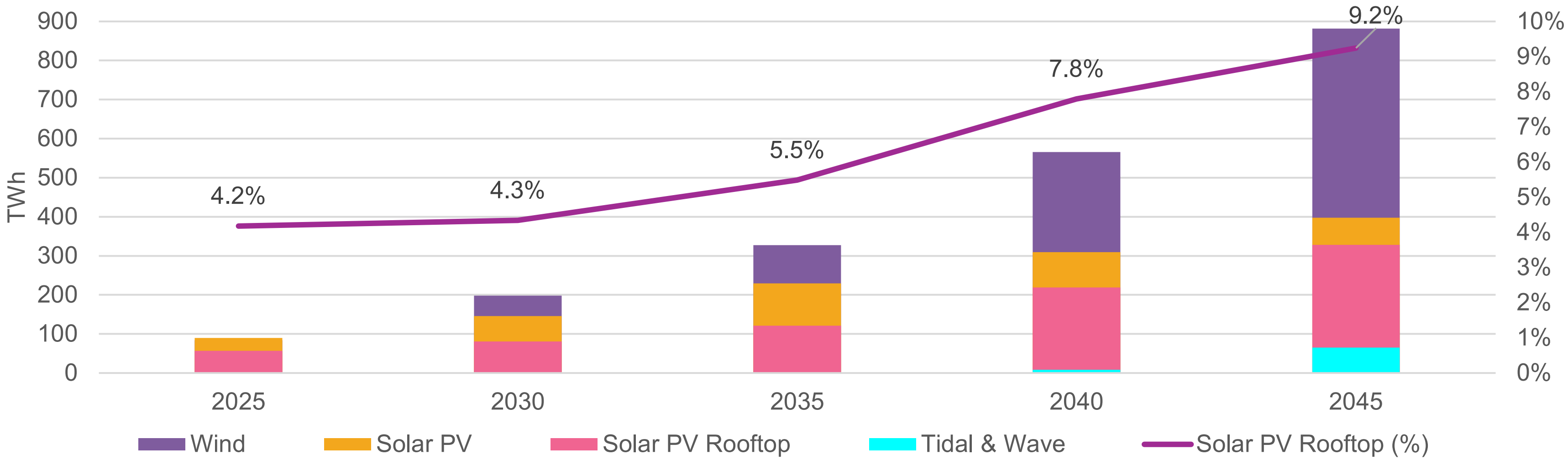
However, a second, equally important finding is the unavoidable operational challenge common to all pathways. In all three scenarios, the share of generation from vRE converges at a very high level (42% to 47%). This signals that a future where the grid is operationally dominated by intermittent solar and wind is the baseline for the entire region, making investment in flexibility a non-negotiable priority, regardless of the pathway.

Given that the operational challenge of high vRE integration is universal, the key question is what initiatives should be initiated in each phase of the transition. The power system must undergo a profound transformation, preparing for approximately 20% vRE in the short term, equipping itself for 30-40% in the medium term and ultimately aiming for nearly 50% by 2045.

The strategic decision to transform the power system in the long term will follow the decarbonisation pathway to prevent stranded assets and unnecessary reinvestment.

ASER's Power Generation Profile
In terms of Fuel Mix (top) and Rooftop PV share compared to RE generation (bottom), 2025–2045





A Deep Dive into the ASER Power Generation Profile

The ASER generation profile reveals a multi-stage transition that begins with an accelerated decarbonisation push by 2030, evolves into a mid-term challenge of managing a vRE-dominant grid, and culminates in a long-term need to manage a highly decentralised, prosumer-driven energy system.

Continuing from the high-level comparison of RE and vRE shares, it is clear that the ASER pathway offers a more balanced and diverse clean energy mix. A closer look at the ASER power generation profile is therefore necessary to understand the specific grid improvement requirements and to clarify what a leapfrog from the committed AREC pathway would mean in operational practice for the region.

Changing Structure of the ASER Fuel Mix

The top figure illustrates a complete restructuring of the power system, where the roles of the key fuel sources are fundamentally transformed between now and 2045. The expansion of vRE acts as the primary growth engine, systematically pushing out coal as the dominant fuel. Natural gas serves as a crucial transitional bridge, providing flexibility in the near term before its role is diminished. Throughout this transformation, dispatchable RE provides a large and stable foundation of clean, firm power, ensuring the system's reliability.

The bottom figure highlights the staggering absolute growth in vRE generation. This immense increase is the single biggest driver of change for system planners, creating a non-negotiable need for a grid that is profoundly more flexible and balanced.

APAEC (2026–2030): An Accelerated Transition

During this critical five-year period, the ASER pathway represents a more ambitious approach compared to the committed AREC path. Whilst both scenarios see a similar, rapid increase in the share of generation from vRE, ASER achieves a higher total RE share (55.6% vs. AREC's 49%). This performance comes from a much larger strategic investment in dispatchable renewables. This balanced approach allows ASER to displace coal far more aggressively by 2030, with the share of coal generation falling to just 12.3% compared to 17% in the AREC scenario.

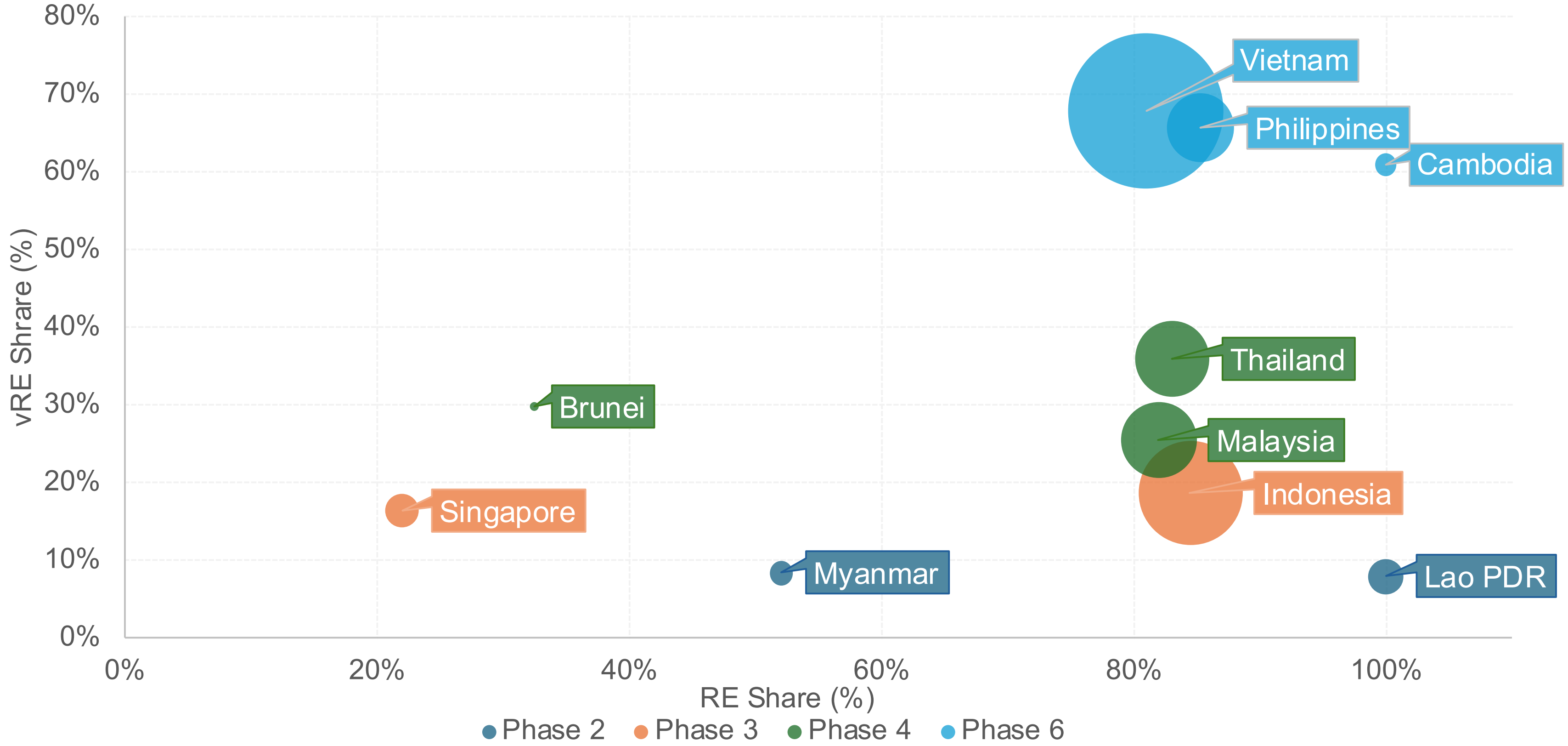
Post-2030: What the Region Must Anticipate

Mid-Term (2031–2040): The region must anticipate this decade as the vRE takeover, where vRE becomes the single largest source of electricity. The primary challenge will be managing a grid that is now operationally dominated by intermittency. This period will require the acceleration of the flexibility hand-off, where the balancing role of natural gas is systematically replaced by clean alternatives like storage and dispatchable renewables.

Long-Term (2041–2045): In the final phase, the region must anticipate the challenges of decentralisation and sector coupling. The system must be prepared for the rise of the prosumer, as a market-driven second wave of rooftop solar provides a massive share of energy (9.2% of the total).

ASEAN's energy future is a reflection of diverse national challenges, proving that the only successful strategy is a deeply integrated regional system that transforms each country's unique circumstances into a collective strength.

vRE and RE shares in each Member State's Power Generation by 2045, ASER Scenario



Notes:

- ***X-axis = Renewable energy (RE) share in power generation in 2045***
- ***Y-axis = Variable renewable energy (vRE) share in power generation in 2045***
- ***Bubble size = Total electricity generation of each country in 2045***
- ***Bubble colour = IEA phases of integrating vRE***

A National-Level Assessment of System Planning Needs

The region's future power system will be a complex ecosystem of highly specialised roles, with some nations pioneering the challenges of vRE-dominant grids, others managing massive daily energy surpluses, and specialists like Singapore and Lao PDR serving as critical hubs for energy import and balancing services, respectively.

A single ASEAN-wide vRE share masks the vastly different realities and planning challenges faced by individual member states. This diversity is clearly illustrated in the chart, where the size of each country's bubble represents its total electricity generation in 2045. From this, the region's energy systems can be broadly categorised into a few key groups: a set of major demand centres with very large energy systems (such as Indonesia and Viet Nam) whose pathways will have an outsized impact on the region; a second group of mid-size and emerging systems (such as Malaysia, Philippines and Thailand) whose primary challenge is managing their own rapid growth; and a third group of specialised systems (like import-dependent Singapore or export-focused Lao PDR) who will play unique, strategic roles.

Given this wide variance in both the scale and strategic nature of the national systems, a granular, country-level assessment is essential for deriving actionable insights. The IEA's 6 phases of vRE integration offers a consistent, globally benchmarked framework for this assessment, categorising the system planning priorities that each country will face as they move along their unique transition pathways.

Six Phases of vRE Integration Challenges

	Features	***Challenges***
Phase 6 >50%*	**Secure electricity supply almost exclusively from VRE**	**Bridge longer low vRE periods. run inverters-dominated system**
Phase 5 <50%*	**Significant volumes of surplus VRE across the year**	**Absorb large vRE surpluses, manage grid impact of peak demand**
Phase 4 <40%*	**VRE meets almost all demand at times**	**Maintain stability high vRE periods, manage grid impacts of peak supply**
Phase 3 <25%*	**VRE determines the operation pattern of the power system**	**Manage net load variability & uncertainty, and dynamic grid flows**
Phase 2 <15%*	**VRE has a minor to moderate impact on system operation**	**Manage noticeable difference load vs. net load and increased congestion**
Phase 1 <5%*	**VRE has no significant impact at the system level**	**Address potential local grid issues (e.g. voltage, congestion)**

The asterisk (*) refers to indicative share, depends strongly on the specifics of the power system in question

vRE Leaders: Viet Nam, Philippines, Cambodia

These nations are projected to become true vRE powerhouses, with variable sources providing an enormous 60-70% of all their electricity by 2045. This places them deep into IEA Phase 6, where they face the most advanced technical challenges. Their primary planning difficulties will be managing an inverter-dominated system that lacks the physical inertia of traditional power plants and ensuring energy security by bridging longer low-vRE periods. Consequently, their national system planning must prioritise procuring advanced, long-term resilience solutions, including massive investment in long-duration energy storage, maintaining a strategic fleet of dispatchable clean power, and developing markets for sophisticated grid services from inverters to maintain stability.

The Balanced Transitioners: Thailand, Malaysia, Indonesia

This cluster of large, industrialised economies achieves a very high total RE share, but with a more balanced mix where vRE provides a significant but more modest 20-40% of generation. This places them firmly in IEA Phase 4, where the primary challenge is managing large and frequent daily surpluses of vRE. Their system planning must therefore be laser-focused on maximising all forms of flexibility to absorb this surplus energy. This requires a three-pronged strategy of investing in large-scale battery storage for daily energy shifting, creating sophisticated demand-response markets to incentivise industries to use power when it is cheap, and building strong interconnections with neighbours to create an export market.

Diverse Development Needs: Brunei Darussalam, Lao PDR, Myanmar, and Singapore

This group of countries highlights the wide spectrum of starting points and strategic roles within a deeply integrated regional system.

Brunei (IEA Phase 4): As a fossil-fuel-rich economy, its challenge is to manage the transition to a system with a significant (~30%) share of vRE generation. Like the countries in Cluster 2, its priority will be managing daily energy surpluses, where interconnection with its neighbours will be a critical tool.

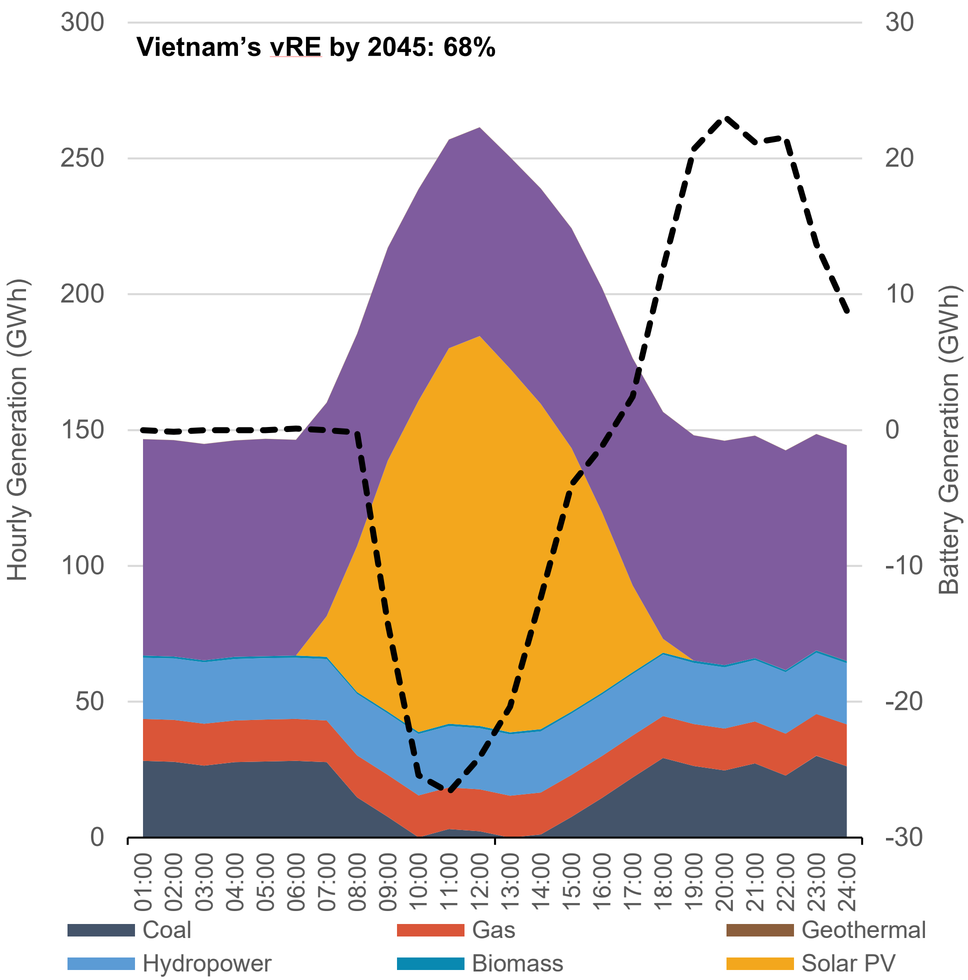
Myanmar (IEA Phase 2): Positioned at the earliest stage of vRE integration, its primary challenge is more foundational. System planning must focus on the initial grid upgrades needed to manage local congestion and accommodate the first significant wave of solar and wind projects.

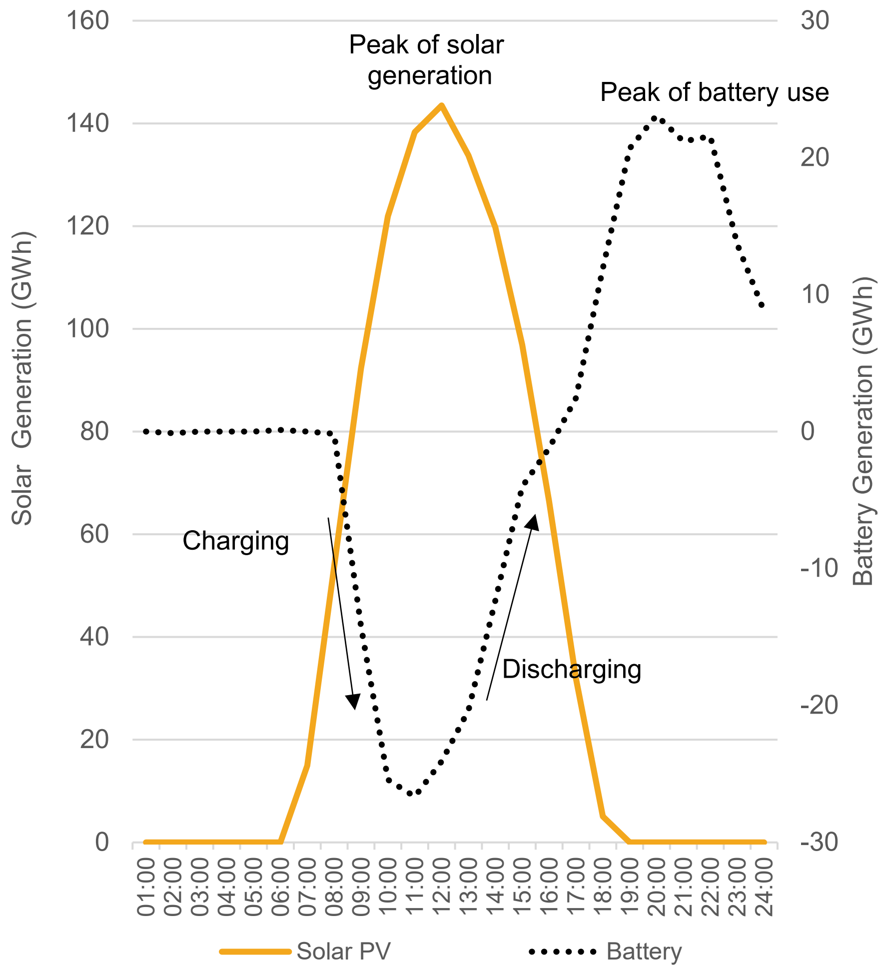
Singapore (IEA Phase 3): As a land-constrained economic hub, its primary planning priority is securing reliable, clean energy imports through the APG.

Lao PDR (Special Role): Lao PDR is a unique case. Its challenge is not managing its own vRE but leveraging its massive, dispatchable hydropower resources to act as the regional battery. Its national system planning priority is therefore building the transmission infrastructure needed to export this clean, firm and highly flexible power to balance the vRE-heavy systems of its neighbours.

Viet Nam's future grid achieves reliability through a balancing act, where the complementary roles of wind and solar are managed by the fast-acting flexibility of batteries and the dispatchable fleet.

Hourly Generation Profile of Viet Nam in 2045 based on ASER: All Fuels (left) vs Solar and Battery only (right)





An Hourly Analysis of Viet Nam's 2045 Power System

The massive influx of vRE and battery storage in Viet Nam's 2045 grid fundamentally redefines the role of the traditional power fleet, relegating coal to a minimal function and transforming gas and hydropower into flexible assets dispatched only to support the variability of solar and wind.

This country-specific deep dive continues the reality check exercise (PDP vs optimised results) by examining the hourly operational profile for Viet Nam and Indonesia. A granular, hour-by-hour analysis is essential to understand the practical flexibility requirements needed to manage the high vRE shares identified in the IEA framework. This moves beyond the theoretical challenges to show the dynamic interplay between generation sources and the specific technologies required to ensure a stable and reliable power supply.

This hourly generation profile confirms that ensuring reliability in Viet Nam's 2045 power system is not about a single solution, but about the sophisticated integration of three key components of flexibility. The first is a diverse vRE portfolio itself, where the complementary daily profiles of wind and solar provide a foundational layer of balancing. This is supported by a large fleet of fast-acting battery storage for rapid, intra-day energy shifting. Finally, the dispatchable firm capacity, primarily hydropower and gas, is essential for providing sustained energy and ensuring stability during peak demand periods.

A vRE-Dominant Generation Profile

The hourly generation profile for Viet Nam in 2045 is dominated by two vRE sources. Wind power provides a high, relatively stable baseload of generation throughout the night-time and off-peak hours. This is complemented by a massive peak of solar PV generation during daytime hours. This complementary timing between the two primary energy sources provides the foundational layer of system balancing.

The Impact on Fossil Fuel Dispatch

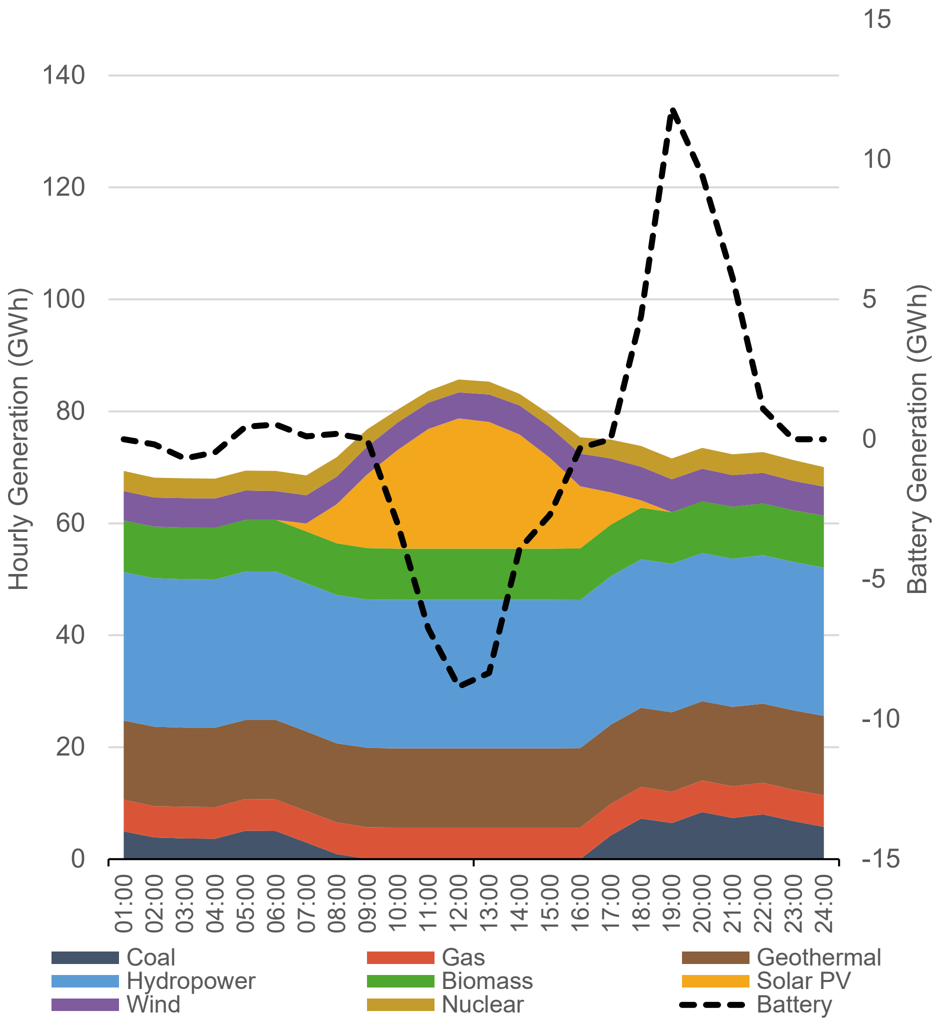
The large-scale generation from renewables and storage has a direct impact on the operational profile of the fossil fuel fleet, pushing it into two distinct and much smaller roles. Coal is reduced to a minimal, residual baseload function, likely from the few remaining plants operating at a constant low output. In contrast, gas-fired generation serves as the primary source of flexible fossil capacity, dispatched specifically to help manage the steep morning and evening ramps in net demand when clean flexibility is insufficient.

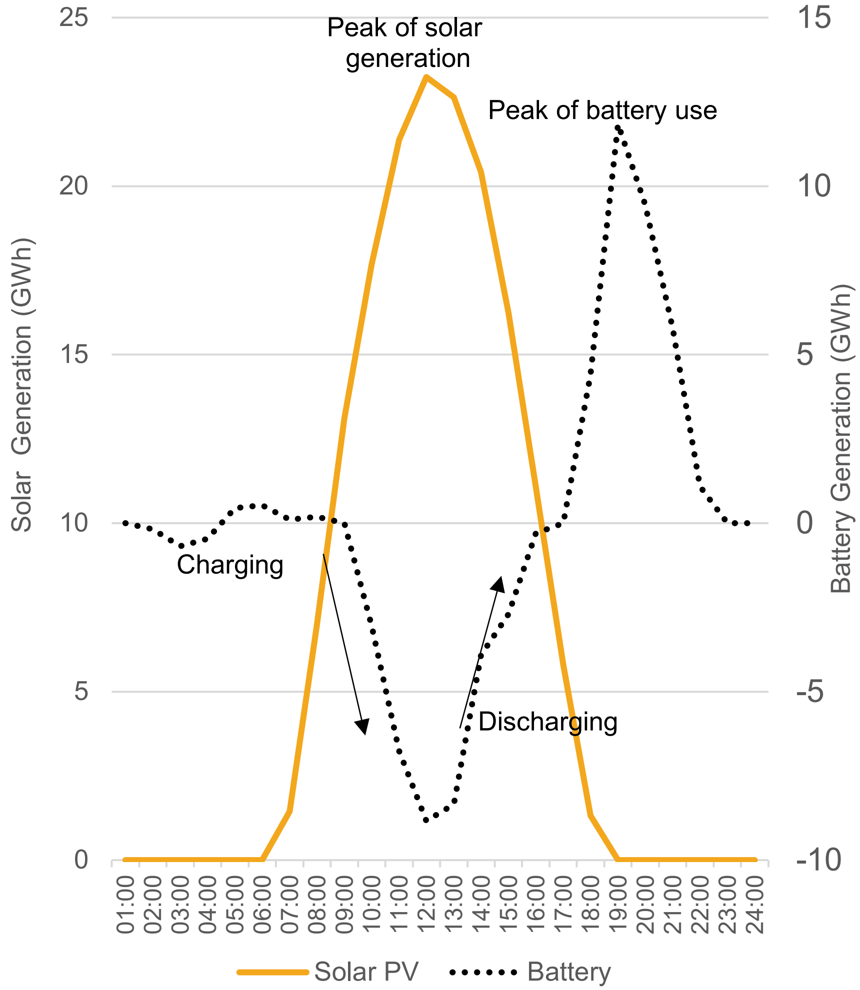
The Critical Role of Energy Storage

The battery storage fleet is the primary asset for fast-acting energy shifting and providing ancillary services. Its operational cycle is a near-perfect inverse of the solar generation curve. It absorbs surplus midday energy by charging at a high rate (up to 27 GW) and provides critical capacity during the evening peak by discharging at a similar rate (up to 25 GW). This rapid charge and discharge capability is essential for managing the steep ramps caused by solar variability and for maintaining overall grid stability.

Indonesia's "Clean Firm" strategy redefines the role of storage, using its vast hydropower fleet for the heavy lifting of energy shifting and deploying batteries for a more surgical, fast-response balancing role.

Hourly Generation Profile of Indonesia in 2045 based on ASER:
All Fuels (left) vs Solar and Battery only (right)





An Hourly Analysis of Indonesia's 2045 Power System

Indonesia's 2045 generation profile reveals a system built on a massive, stable foundation of 24/7 geothermal and flexible hydropower, which fundamentally changes the grid's dynamics by making solar a secondary contributor and reducing the overall dependency on battery storage for reliability.

Continuing the country-level analysis, Indonesia's 2045 hourly generation profile presents a fundamentally different strategy for managing a deeply decarbonised grid compared to Viet Nam. Whilst Viet Nam's system is dominated by the interplay of vRE and large-scale battery storage, Indonesia's pathway leverages its unique natural endowments to build a clean firm system. This approach is built upon a massive foundation of dispatchable RE (hydropower and geothermal), which completely changes the nature of its flexibility requirements.

The core of Indonesia's strategy relies on the powerful combination of fast-acting batteries for rapid response and the large-scale, sustained energy shifting capability of its hydropower fleet, which functions as a giant natural battery. This is all built upon a massive baseload of 24/7 geothermal power, creating a system with greater inherent stability and a reduced dependency on manufactured storage compared to a purely vRE-dominant model.

A Clean Firm Generation Portfolio

The generation profile is defined by a massive foundation of 24/7, dispatchable renewable power. Geothermal provides a significant and constant supply of baseload energy. Hydropower represents another large portion of the mix and is operated in a highly flexible manner. The portfolio is further diversified by a small but constant baseload from nuclear power, whilst wind power plays a minimal role in the overall generation mix. Solar PV contributes a significant peak during daytime hours but builds upon this existing firm foundation rather than dictating the system's overall operation.

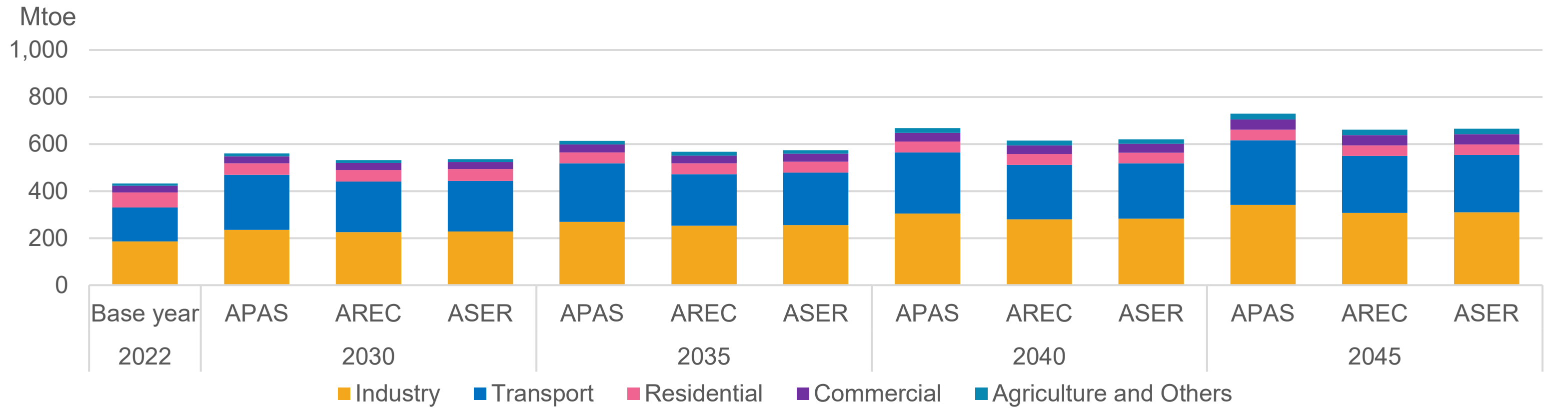
The Daily Hydro and Battery Balancing Mechanism

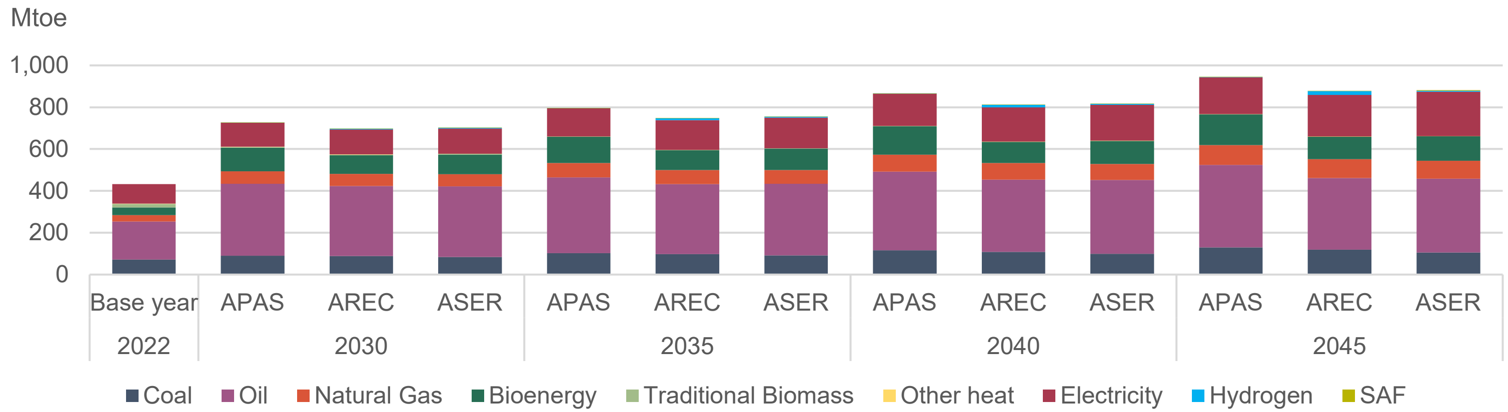
The daily challenge of integrating the midday solar peak is met by a coordinated balancing mechanism between Indonesia's hydropower and battery assets. To absorb the solar surplus, hydropower generation is significantly curtailed during the day, acting as a giant natural battery by storing water. In parallel, batteries charge at a more modest rate; the relatively shallow depth of the charging cycle (right figure) is clear visual evidence that hydropower is performing the bulk of the energy shifting. To meet the evening demand, the system uses a dual response. The battery fleet discharges in a sharp, narrow spike, a visual signature of its surgical role as a fast-response shock absorber designed to handle the steepest part of the ramp-up. Almost simultaneously, the hydropower fleet provides a sustained surge of generation by releasing the water stored during the day, doing the heavy lifting of covering the entire evening peak.

3.2. ASEAN Energy Demand

Energy demand growth curbed under decarbonisation, with AREC and ASER converging at similar TFEC levels

ASEAN's Total Final Energy Consumption by Sector (top) and by Fuel (bottom) Across Scenarios, 2022–2045





Industry and transport dominate ASEAN’s demand; fuel mix shifts under low-carbon pathways

Industry and transport dominate ASEAN’s demand; AREC and ASER reduce fossil fuel use to similar levels, though through different fuel mixes and decarbonisation strategies.

ASEAN’s TFEC is projected to increase in all scenarios, but the magnitude and structure of demand diverge significantly. From a sectoral perspective, industry and transport remain the dominant consumers of energy, together accounting for around 330 Mtoe in 2022, or more than two-thirds of total demand. In the APAS scenario, these sectors expand steadily, with industrial demand rising from 186 Mtoe in 2022 to over 235 Mtoe by 2030, while transport increases from 145 Mtoe to 234 Mtoe over the same period. By 2045, the combined consumption of industry and transport surpasses 540 Mtoe in APAS, compared with around 425-430 Mtoe in the AREC and ASER pathways, highlighting the potential scale of avoided demand under accelerated transition scenarios.

Other sectors grow more modestly and play a smaller role in shaping overall demand. Residential energy use declines slightly with efficiency improvements, from 63 Mtoe in 2022 to below 50 Mtoe by 2030 in APAS, while commercial demand stays broadly stable near 30 Mtoe. Agriculture and other uses contribute less than 15 Mtoe across scenarios, though their importance persists in rural energy access planning.

From a fuel perspective, fossil fuels continue to dominate under APAS, with oil use in transport rising sharply from 182 Mtoe in 2022 to 344 Mtoe in 2030, while coal in industry edges upward from 71 Mtoe to 91 Mtoe over the same period. In contrast, both AREC and ASER pathways show a decisive break from fossil reliance: coal demand declines steadily to around 74-84 Mtoe by 2030, while oil stabilises near 335 Mtoe, avoiding the steep growth seen in APAS. Natural gas plateaus across all scenarios, remaining close to 50-60 Mtoe by 2045.

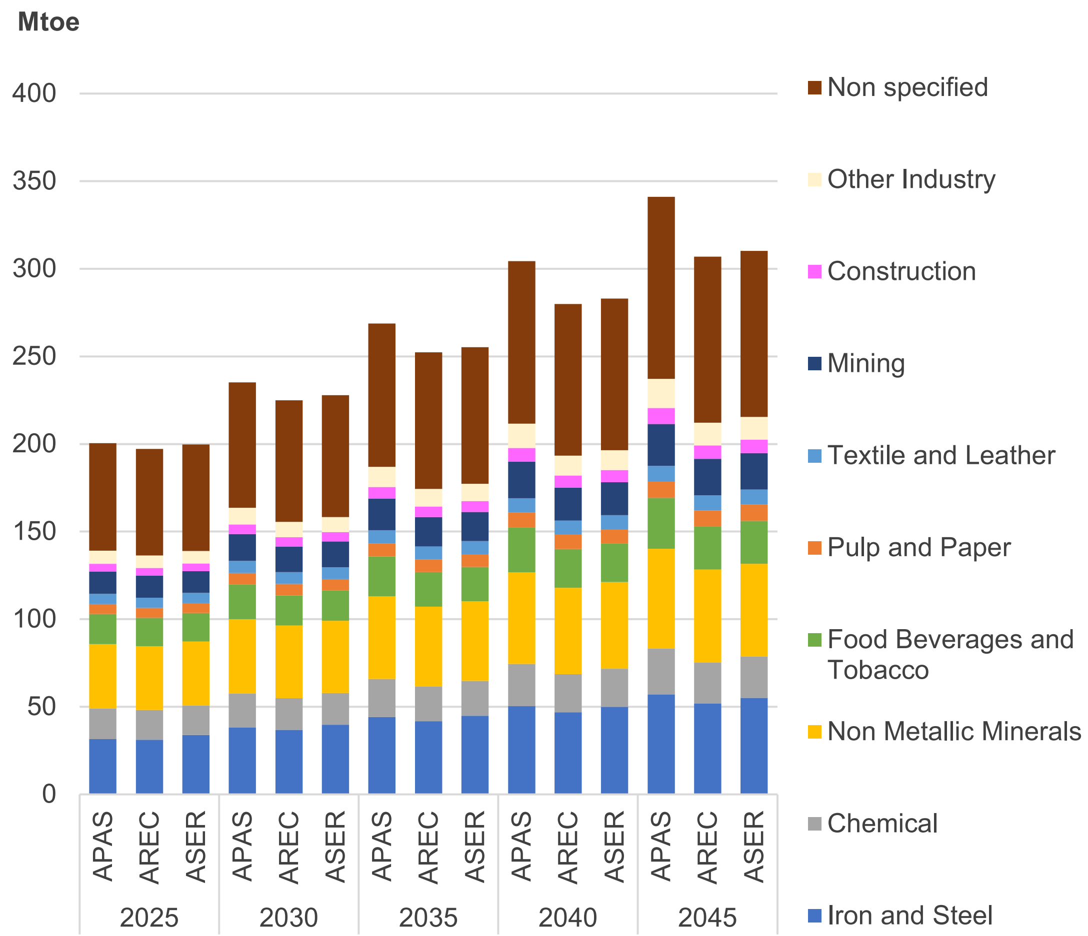
Low-carbon fuels reshape ASEAN’s demand profile in the accelerated pathways. Electricity expands from 94 Mtoe in 2022 to over 120 Mtoe by 2030, and surpasses 160 Mtoe by 2045 in ASER, reflecting widespread electrification across industry and transport. Bioenergy also grows strongly, reaching 94 Mtoe in 2030 and around 115 Mtoe in 2045, while traditional biomass declines from 17 Mtoe in 2022 to about 4 Mtoe by 2030. Hydrogen and sustainable aviation fuels (SAF), though small in scale, appear by the 2030s and expand in the long term in both transport and heavy industry.

By 2045, TFEC under AREC and ASER converges at around 660 Mtoe, compared with nearly 800 Mtoe in APAS. While the overall levels are similar, the pathways differ: AREC relies more heavily on efficiency and electrification, while ASER achieves comparable reductions with a broader mix of low-carbon fuels, including higher shares of hydrogen and bioenergy. These findings underline both the robustness of demand-side decarbonisation and the flexibility of ASEAN’s energy transition pathways.

3.2.1. Industry Sector

Industrial demand is led by high-heat sectors, with diverse decarbonisation needs

Industry Demand by Sub-Sector Across Scenarios, 2025–2045



High-heat industries dominate

Industrial demand in ASEAN is driven primarily by hard-to-abate, high-heat sectors, including iron & steel, pulp and paper, chemicals and non-metallic minerals. These subsectors account for the majority of consumption across all scenarios, reflecting their scale and reliance on fossil fuels for high-temperature processes.

Low-heat industries differ

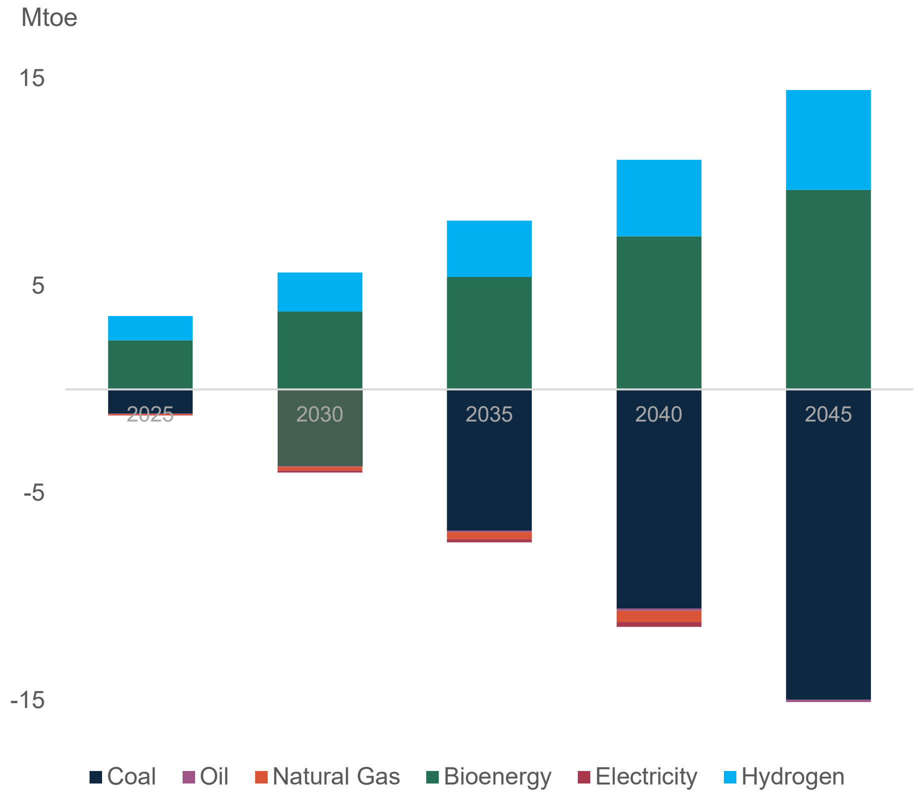
Low-heat subsectors, such as textiles and food processing, contribute a smaller share of demand but follow different pathways. Their decarbonisation relies more on efficiency improvements, electrification of low-heat processes and increased use of bioenergy.

Data gaps remain significant

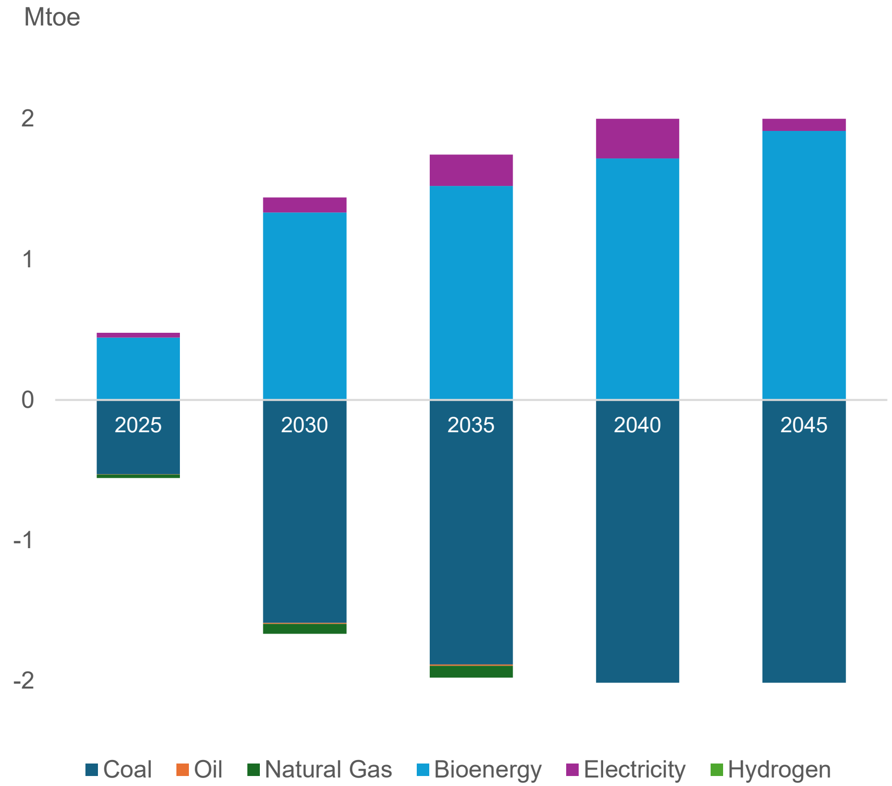
A large "non-specified" category persists in the modelling, representing a substantial portion of demand. This highlights the need for more detailed data collection and sectoral disaggregation at the national level to design effective and targeted decarbonisation strategies for ASEAN industry.

Different decarbonisation pathways across high-heat industries

Fuel Shifting in Iron & Steel Industry Demand – ASER vs. APAS, 2025–2045



Fuel Shifting in Pulp & Paper Industry Demand – ASER vs. APAS, 2025–2045



*Even among high-heat sectors, decarbonisation pathways diverge: **iron & steel** rely more on **hydrogen and biomass** to replace fossil fuels, while **pulp & paper** advance through **electrification and greater use of bioenergy**.*

Decarbonising hard-to-abate industries requires phased adoption of new technologies and fuels

Iron & steel and pulp & paper industries undergo phased transitions towards decarbonisation, with iron & steel focusing on gradual fuel substitution and technology adoption (EAF, hydrogen, biomass) to reduce reliance on coal. Pulp & paper accelerates efficiency through heat pumps and biomass cogeneration, achieving low-carbon energy integration over time.

The iron & steel and pulp & paper sectors each face unique decarbonisation challenges and pathways due to their different energy requirements and production processes. While both are energy-intensive industries, their decarbonisation strategies differ in terms of technology adoption and the types of fuel used.

Iron & Steel Industry: Phased Decarbonisation with Low-Carbon Fuel and Technologies Adoption

The iron &steel sector in ASEAN predominantly employs **Blast Oxygen Furnaces (BOFs)**, a technology that limits immediate fuel switching options. Therefore, decarbonisation in this sector necessitates a phased approach: In the **near term (2025–2030)**, the focus is on **efficiency upgrades** to reduce energy consumption and emissions, with coal demand declining modestly around 1-4 Mtoe compared with APAS. Pilot-scale substitution with biomass (+2-4 Mtoe) and hydrogen (+1-2 Mtoe) begins to emerge, but these contributions remain small. By the **medium term (2030–2040)**, structural changes become more apparent. Coal use falls by 7–11 Mtoe relative to APAS, driven by the scaling up of biomass (+5–7 Mtoe) and hydrogen (+3–4 Mtoe) in high-heat processes. The economics of hydrogen blending improve as renewable electricity costs decline, while regional biomass feedstocks become increasingly available. This transition continues to deepen in the **long term (2040–2045)** with biomass (~10 Mtoe) and hydrogen (~5 Mtoe) as core substitutes for fossil inputs.

The adoption of **Electric Arc Furnaces (EAFs)** could also be explored as a significant decarbonisation choice, offering a pathway to further reducing **coal** use in steelmaking. While **EAFs** are more commonly used globally, the ASEAN countries can integrate this technology, but will need to ensure that the right **policy** frameworks, **financial support** and **infrastructure** are in place to make **EAFs** a viable option for large-scale adoption. This transition will require significant investment in both the technology itself and the supply chains needed to support its implementation.

Pulp & Paper Industry: Transitioning to Biomass and Electrification for Decarbonisation

The pulp & paper industry, while also energy-intensive, can achieve decarbonisation through the adoption of **heat pumps** in processes like paper drying and steam condensate management to enhance energy efficiency, and reduce fossil fuel use in heat and power generation through the utilisation of **cogeneration systems using biomass**.

These technology shifts are reflected in the ASER scenario's decarbonisation pathway. In the **near term (2025–2030)**, **coal demand** is initially reduced as industries shift to **biomass** for heating, while **heat pumps** push efficiency improvements in energy use.

In the **medium term (2030–2040)**, the adoption of **combined heat and power (CHP) systems** for biomass use increases significantly. This is driven by the **economic attractiveness** of **biomass cogeneration**, as it offers a dual benefit of generating both electricity and heat, improving operational efficiency and lowering energy costs. This greater focus on **biomass cogeneration** in the medium term makes biomass a more prominent player in the energy mix, contributing to a significant reduction in **coal** and **natural gas** usage.

In the **long term (2040–2045)**, the increasing deployment of **biomass cogeneration** for high-heat industrial processes enables further decarbonisation of the pulp & paper sector. This transition, combined with continued improvements in **energy efficiency**, leads to a stable, low-carbon energy mix with **biomass** continuing to play a central role in the energy transformation of the sector.

Support for Phased Decarbonisation: Enabling Technology Adoption and Regional Coordination

To ensure the successful decarbonisation of energy-intensive sectors like **iron & steel** and **pulp & paper**, ASEAN needs to

prioritise the adoption of **advanced technologies**, support the scaling of **low-carbon fuel** options and facilitate the development of **sustainable supply chains**. Decarbonisation in these industries requires coordinated multi-sectoral efforts to create favourable conditions to overcome the financial and technological barriers, especially to enhance the deployment of technologies such as EAFs in steel production and biomass cogeneration or CHP in pulp and paper. In the regional level, member states can also enhance coordination to facilitate the development of sustainable biomass supply chains and best practices sharing on the use of energy-efficient technologies. This includes setting up financing mechanisms for early-stage adoption, investing in capacity building and ensuring policies are aligned across ASEAN to encourage the scaling of these critical technologies. By fostering collaboration and leveraging shared expertise, ASEAN can accelerate the decarbonisation of these hard-to-abate industries and achieve a more sustainable, low-carbon future for the region.

Other industries: decarbonising low-heat industries through electrification and efficiency measures

Low-heat industries can achieve decarbonisation more efficiently through electrification, supported by energy efficiency improvements. As the demand for electricity rises, ASEAN must ensure that the necessary grid improvements are carried out to enable robust demand response and that suitable market mechanisms are put in place to open more access for corporate green procurement.

Low-heat industries such as food processing, textiles and chemicals have a relatively straightforward decarbonisation pathway compared to high-heat sectors. These industries can predominantly rely on electrification—switching from fossil fuel-based heat to electric processes—which is supported by efficiency improvements across operations. In the near term (2025–2030), many industries can begin integrating electric boilers, heat pumps and other energy-efficient technologies that significantly reduce fossil fuel dependence.

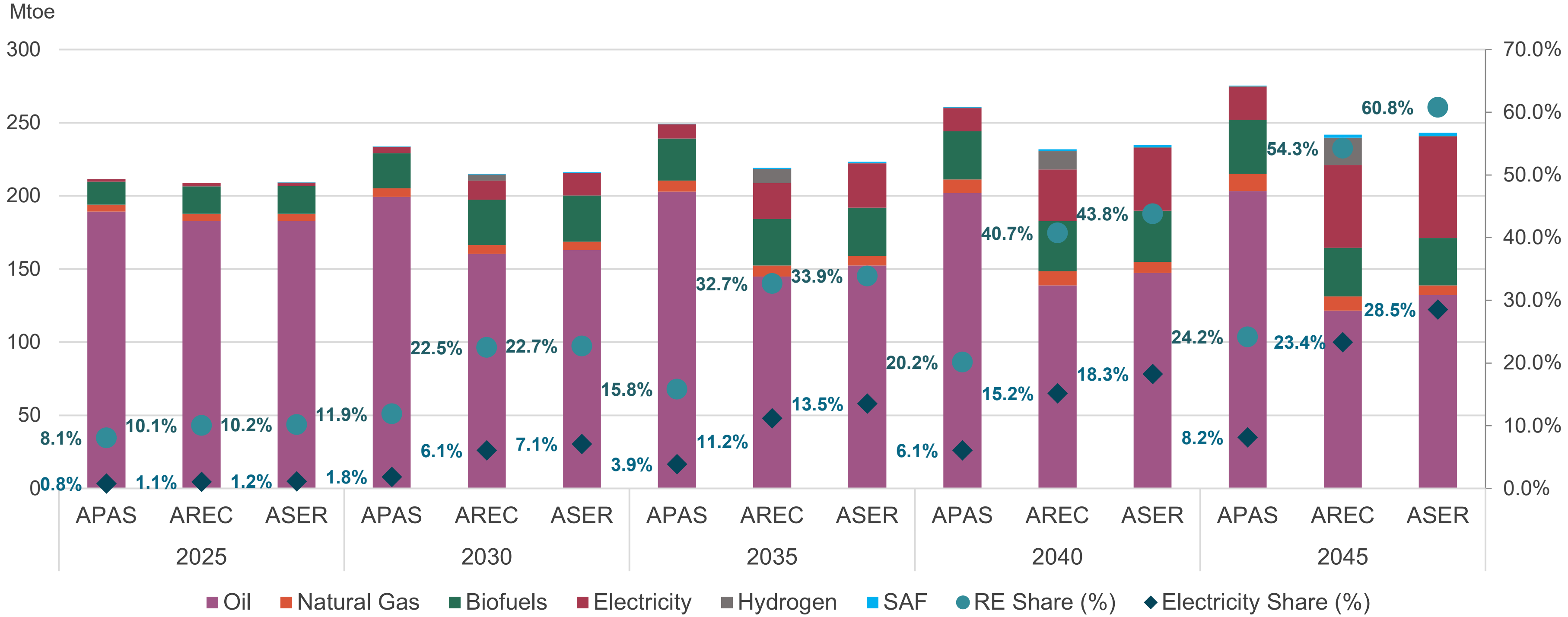
The increasing electricity demand from these industries, however, necessitates careful planning around grid stability. As electrification becomes more widespread, ASEAN must invest in enhancing grid flexibility, managing peak loads and implementing demand response mechanisms to ensure reliable power delivery. This is particularly critical as the region accelerates its energy transition to higher shares of renewable energy.

Furthermore, to facilitate corporate green electricity procurement and encourage investments in renewable energy, mechanisms like RECs and Power Purchase Agreements (PPAs) should be developed and standardised. These mechanisms not only help companies meet their sustainability targets but also stimulate the growth of the RE sector by creating a market for clean electricity. As ASEAN moves forward, these steps will be vital to ensure that low-heat industries contribute to the region's overall decarbonisation goals while maintaining a stable and resilient energy system.

3.2.2. Transport Sector

Energy demand for transport shifts from oil dominance to rising electricity and RE shares, with divergence after 2035

Transport TFEC by fuel and RE & Electricity Share Across Scenarios, 2025–2045



Diverging transport pathways show steep oil decline after 2035 in AREC and ASER, as RE shares rise to over half of demand

Near Term (2025 – 2030): Oil dominance persists

Transport remains overwhelmingly dependent on oil in the 2020s, accounting for more than 85–90% of TFEC across all scenarios. Differences between pathways are limited, as efficiency improvements and early blending of biofuels only slightly offset the growth in road freight and aviation demand. Electricity continues to play only a marginal role, contributing less than 1% of TFEC by 2030.

Medium to Long Term (2030–2045): Divergence widens

Beyond 2030, pathways diverge more sharply. Under APAS, oil demand rises from around 200 Mtoe in 2035 to more than 275 Mtoe in 2045, entrenching dependence. AREC and ASER, by contrast, achieve earlier peaks in oil use and initiate sustained declines. By 2045, the share of RE in transport reaches 54% in AREC and 61% in ASER, compared with only 23% in APAS. Electricity becomes central to this shift, growing to 23% of TFEC in AREC and 28% in ASER, while biofuels and SAF expand steadily as substitutes for oil.

Hydrogen adoption differs between the two accelerated scenarios. **AREC shows higher hydrogen use in transport**, whereas ASER directs a greater share of hydrogen towards industry. This highlights the different trade-offs in low-carbon fuel allocation that characterise the two pathways.

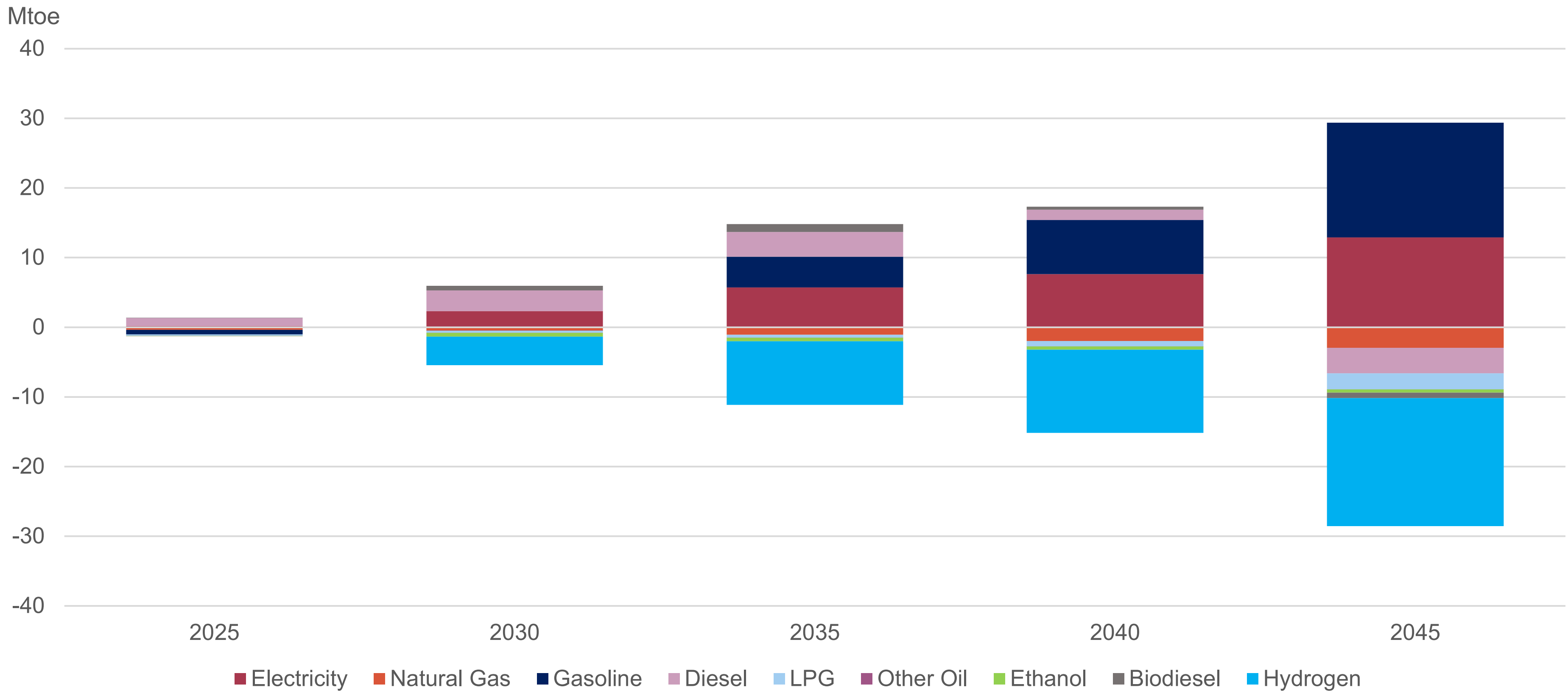
Dynamics of Decarbonisation: Fuel mix and system interactions

While both AREC and ASER achieve similar renewable penetration levels in transport, the **composition of the fuel mix diverges**. AREC leans more heavily on biofuels and hydrogen in transport, while ASER achieves higher renewable shares primarily through electrification. The higher RE share in ASER is linked not only to electrification in transport but also to the **greater share of renewables in the power sector overall**. As more transport energy demand shifts to electricity, the higher RE penetration in ASER's power system amplifies its renewable contribution to transport.

These dynamics underline the importance of viewing transport decarbonisation within the broader energy system. AREC and ASER converge on similar long-term outcomes for oil displacement, but through different balances of electrification, biofuels and hydrogen. The sector thus becomes a key testing ground for system-wide decarbonisation strategies and the allocation of low-carbon fuels across competing end uses.

Beyond total demand: contrasting fuel strategies drive transport decarbonisation

Fuel Shifting in Transport Demand: ASER vs. AREC Scenarios, 2025–2045



Hydrogen use in transport is lower in ASER than AREC as hydrogen reallocates to industry; transport compensates with more electricity and higher fossil liquid use where biofuel blending remains limited.

Different balances of electricity, hydrogen and biofuels shape transport decarbonisation in AREC and ASER

Near Term (2025–2030): Trade-offs start to surface

The earliest ASER–AREC differences are small but directional. Hydrogen use in transport is already lower in ASER (~ -4.1 Mtoe in 2025; -9.1 Mtoe by 2035), reflecting competition from industry, which draws hydrogen volumes and keeps hydrogen costs for transport to be higher. In response, electricity takes a larger role in ASER, helped by faster EV cost declines. Liquid fuels begin to react unevenly: diesel is higher in ASER early on (+3.0 Mtoe in 2030) while gasoline turns positive by 2035 (+4.4 Mtoe), signalling that some foregone hydrogen is absorbed by both EVs and internal combustion engine vehicles (ICEVs) rather than by hydrogen alone.

Mid to Long Term (2035–2045): Electrification rises; liquids rise too without wider biofuel policy

By 2040–2045 the trade-offs are pronounced. **Transport hydrogen in ASER is much lower than in AREC**, as ASER prioritises hydrogen for **hard-to-abate industry**. Electricity correspondingly climbs (+7.7 in 2040 to +12.9 Mtoe in 2045), reinforcing the EV pivot. However, liquid fuels do not fall uniformly, as gasoline increases in ASER where biofuel blending remains limited. This pattern reflects a region-wide policy gap: with **biofuel blending concentrated in several countries only** (e.g., Thailand and the Philippines), the additional demand from ICEVs in ASER (created by the hydrogen shortfall) is not offset by higher biofuel shares, so aggregate gasoline/diesel use increases relative to AREC.

System Interaction: Why ASER shows a higher RE share despite lower biofuels (and lower transport hydrogen)

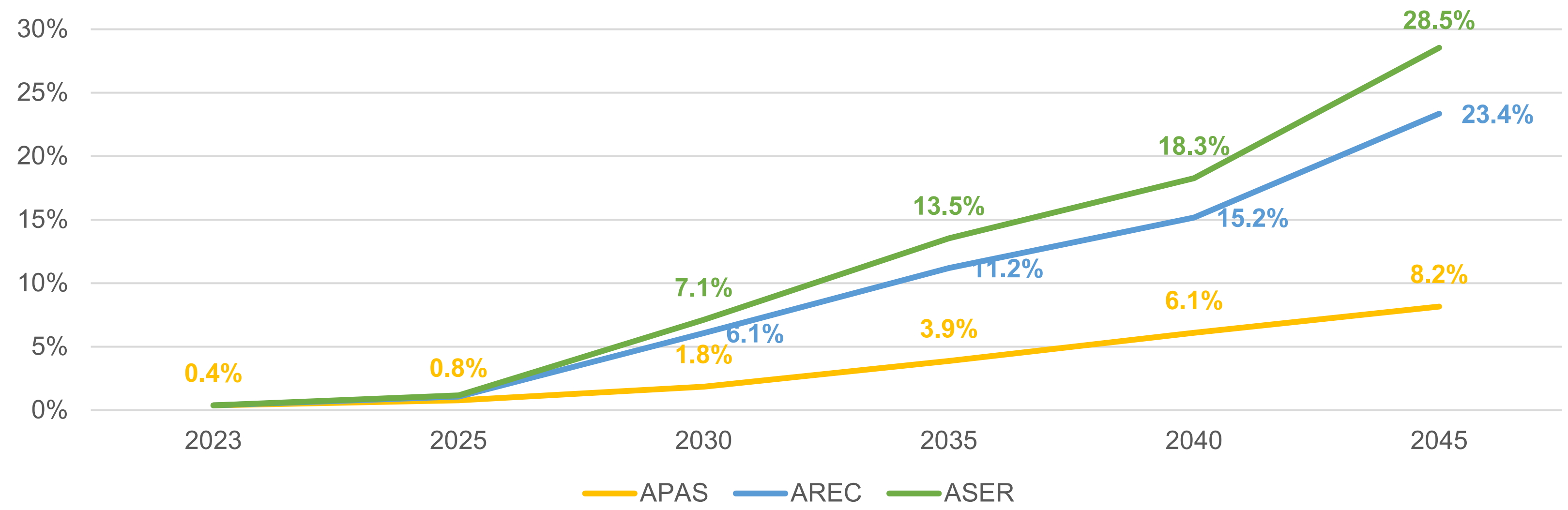
Although transport hydrogen and some biofuels are lower in ASER, the RE share in transport is higher because it includes **renewable electricity used by EVs** (definition: *transport electricity share * RE share in power generation*). ASER's power system has **higher RE penetration**, so as EV uptake grows, the **embedded renewable content of transport energy** increases more rapidly than in AREC.

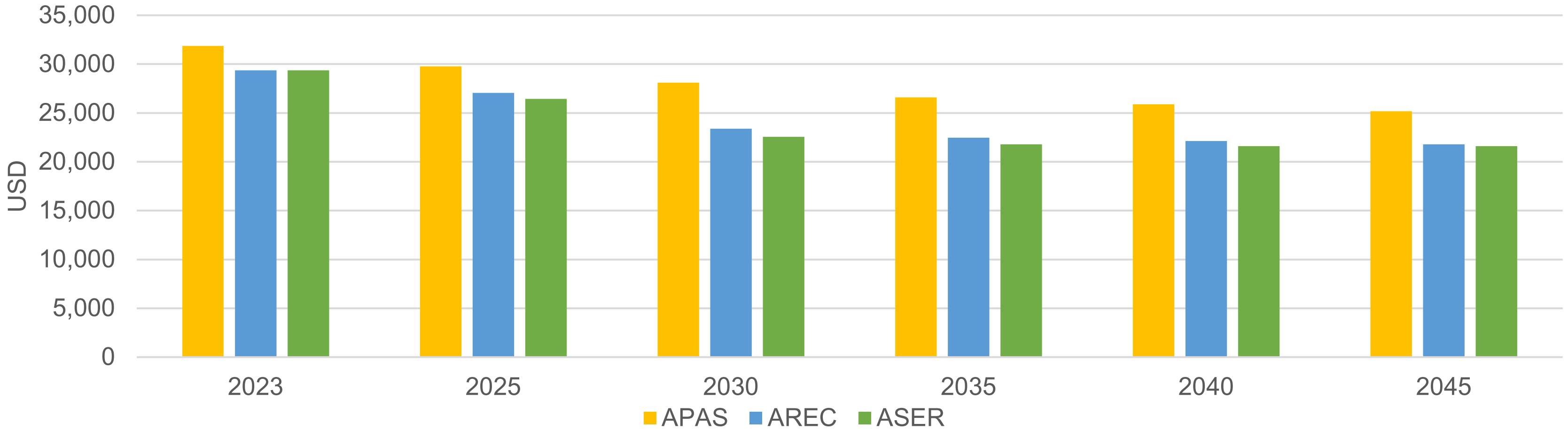
Implications: Balancing fuels to avoid fossil rebound

The fuel trade-offs highlight the need for coordinated action to ensure that transport decarbonisation stays on track. First, **accelerating EV adoption** is critical to absorb the shortfall in transport hydrogen, supported by investment in charging networks and incentives that strengthen total cost-of-ownership advantages. Second, because some ICEVs will remain, countries need to **broaden their biofuel mandates** to prevent higher gasoline and diesel use where electrification is slower. Finally, as the transport sector's decarbonisation pathway also expands to explore other low-carbon fuels such as hydrogen, **supply strategies must be coordinated across sectors**. The ASER scenario shows how simultaneous deployment in industry and transport drives competition and higher costs. Without integrated planning, this could lock in greater fossil use despite progress in electrification and renewables.

Declining cost of EVs drive diverging electrification rates across scenarios

ASEAN Transport Electrification Rate (top) and EV Cost Reduction (bottom) Across Scenarios, 2023–2045





Electrification pathways shaped by EV costs, market maturity and supply chain integration

Electrification remains slow in APAS, while faster cost reductions in AREC and especially ASER accelerate EV adoption beyond 2035.

APAS stagnates, AREC and ASER accelerate

ASEAN's transport electrification outlook diverges strongly across scenarios, driven by the pace of EV cost reductions, supply chain development and technology readiness. In the APAS pathway, electrification remains modest, with EVs accounting for only around 8% of transport demand by 2045. This outcome reflects slower EV cost reductions and a less mature market environment, which delay the competitiveness of EVs against conventional ICEVs. By contrast, both AREC and ASER pathways show a sharp acceleration after 2035, with electrification rising above 20–25% of transport demand by 2045. These gains are made possible by faster cost declines, stronger enabling conditions and more integrated regional markets.

EV costs fall before levelling off

A key driver of this divergence is the trajectory of EV cost reductions, which directly shapes adoption rates. Across all scenarios, EV costs fall steadily in the near and medium term but eventually plateau as the market matures and the maximum feasible cost reductions are reached. This pattern reflects the global experience, where steep early declines were achieved through declining battery pack costs, scale efficiencies in manufacturing and supply chain expansion, followed by a gradual levelling off once markets matured. Importantly, the assumed rate of decline differs substantially across scenarios, underpinning the spread in electrification outcomes.

Scenario assumptions drive divergence

The different electrification outcomes reflect the distinct storylines behind each scenario. In **APAS**, cost reductions are moderate because limited regional integration and weaker policy incentives constrain supply chain development, keeping ASEAN aligned with a slower, more global-average EV cost trend. In **AREC**, stronger regional cooperation and supportive policies accelerate technology uptake and supply chain efficiencies, enabling EV costs to fall more quickly. The **ASER scenario** goes further by assuming even faster progress, underpinned by earlier regional integration, deeper market coordination and rapid advances in battery technologies. These conditions result in steeper cost declines and a much sharper rise in EV adoption after 2035.

Implications for ASEAN

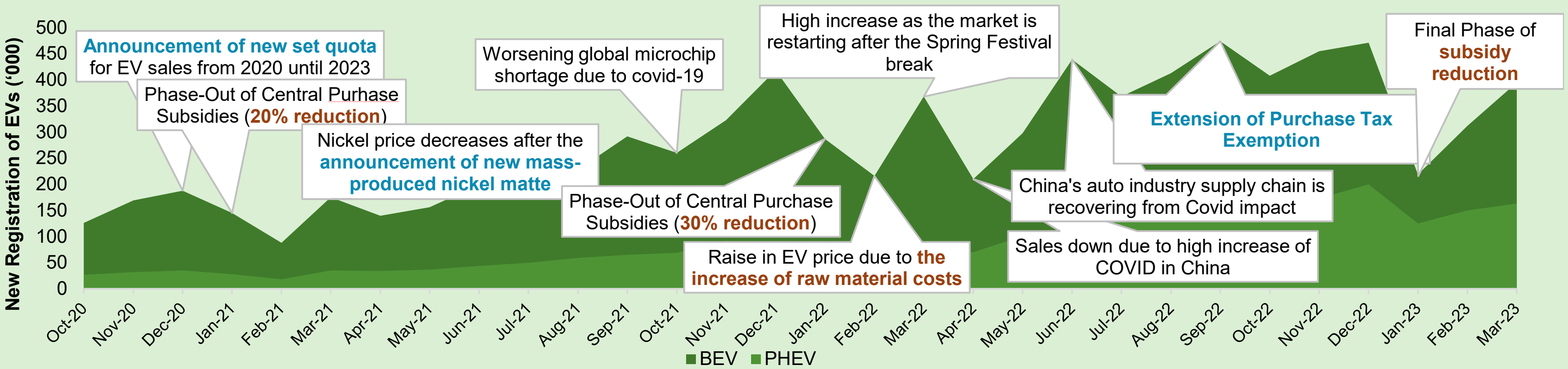
These results highlight the critical role of cost trajectories in shaping ASEAN's electrification pathway. The pace of supply chain integration and technology advancement will determine whether EVs become competitive within the next two decades or remain constrained by higher costs. Accelerating progress on these fronts is essential to unlock higher electrification rates, reduce oil dependence and enable deeper transport decarbonisation.

Case Study: How Policies and Supply Chains Shape EV Adoption

ASEAN can shorten its adoption gap by learning from the experience of leading EV markets, where targeted incentives and resilient supply chains have proved critical in sustaining growth.

China provides a valuable case study for ASEAN, having started its EV adoption more than a decade earlier through pilot subsidies launched in 2010, rapid investment in battery manufacturing and nationwide charging rollout (Reuters, 2010; BloombergNEF, 2019; ICCT, 2024). In contrast, ASEAN began its journey around 2020 with the introduction of EV roadmaps, early manufacturing ventures and initial charging deployment — reflecting an adoption lag of roughly 10 years (ASEAN, 2024; Hyundai, 2021; Laoonual, 2024).

Behaviour-Over-Time Analysis on New EV Sales in China, 2020–2023



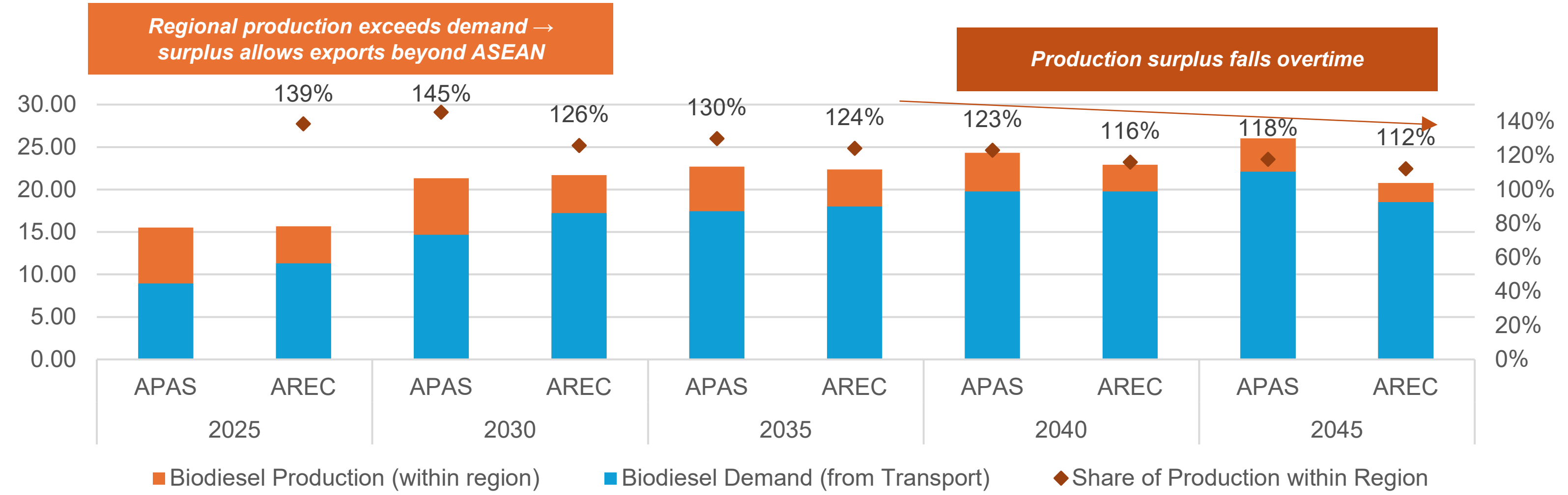
Source: IEA (2024) for EV sales/new registrations; Author's compilation for news and behaviour-over-time

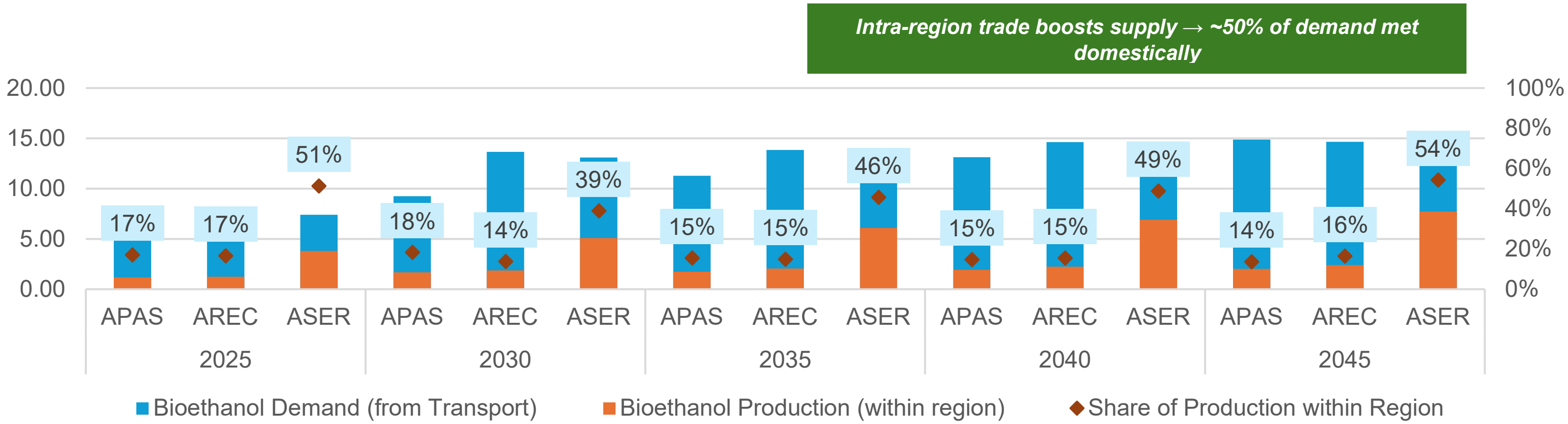
The trajectory of EV sales in China from 2020–2023 shows how **policy incentives and supply chain resilience sustained growth**. Subsidies, tax exemptions and adoption targets lowered costs and boosted confidence, while advances in battery production and raw material processing built the backbone for large-scale deployment. Even with disruptions — chip shortages, rising material costs, or subsidy phase-outs — growth continued as policies adapted and domestic supply chains absorbed shocks.

For ASEAN, the lesson is that closing the adoption gap requires more than EV roadmaps. A **holistic approach with stable incentives, strong supply chains and infrastructure planning** is essential. Regional integration can accelerate cost declines and improve resilience, enabling ASEAN to shorten its current 10-year lag and advance more quickly towards large-scale EV adoption.

Biofuel Supply and Transport Demand: Biofuel Production Trends Across Scenarios

Comparison of Biodiesel Production & Demand (top) and Bioethanol Production & Demand (bottom) Across Scenarios, 2025–2045





Balancing Biodiesel Exports and Ethanol Imports for Long-Term Energy Security

Biodiesel surpluses shrink as regional demand rises while bioethanol remains import-dependent without intra-region trade, highlighting the need for coordinated supply strategies.

Biodiesel: Current Surplus, Future Tightening

Biodiesel production in ASEAN is already higher than regional demand, enabling exports beyond ASEAN markets in the near term. This surplus reflects both established production capacity and widespread mandates for biodiesel blending across member states. However, the margin of surplus is projected to shrink steadily over time as domestic demand rises. By the 2040s, the production-demand balance becomes tighter, reducing the role of ASEAN as a net exporter and placing more pressure on continued productivity gains and the development of advanced biodiesel options.

Bioethanol: Persistent Supply Gap without Trade

In contrast, bioethanol presents a much weaker domestic supply base. Under APAS and AREC scenarios, regional production meets only 10–20% of transport demand through 2045, leaving ASEAN heavily reliant on imports from outside the region. This dependency highlights a structural vulnerability, especially given that supply chains for ethanol are concentrated in countries outside the region.

ASER: Trade Unlocks Regional Potential

The ASER scenario introduces ***intra-region biofuel trade***, which significantly improves the supply balance. By 2045, around 50% of bioethanol demand could be met through regional production once trade and optimisation mechanisms are in place. This integration not only reduces reliance on external suppliers but also improves system resilience by diversifying sourcing within ASEAN.

Implication

Taken together, these contrasting biofuel dynamics show the need for tailored strategies. For biodiesel, sustaining the role of ASEAN as a supplier requires productivity improvements and second-generation fuels. For bioethanol, the real opportunity lies in enabling intra-region trade, which can unlock untapped capacity, strengthen resilience and reduce dependence on global markets. This is explored further in the next chapter (Section 4.2), which examines the mechanisms and benefits of intra-regional biofuel trade.

Chapter 4

Building an Integrated Regional Market for Clean Energy

4.1. Cross-border Power Trade – ASEAN Power Grid Interconnection Framework

APG Interconnection Design Across Scenarios

Connection	Status	Capacity (MW)	COD	APAS	AREC	ASER
Peninsular Malaysia – Singapore (Plentong–Senoko)	Existing	1050	-	✅	✅	✅
Thailand – Peninsular Malaysia (Khlong Ngae–Grurun)	Existing	300	-	✅	✅	✅
Thailand – Peninsular Malaysia	Future	350	2035	❌	✅	✅
Peninsular Malaysia – Sumatra (Teluk Gong–Perawang)	Future	2000	2035	❌	✅	✅
Sarawak – Kalimantan (Mambong–Bengkayang)	Existing	230	-	✅	✅	✅
Sarawak – Kalimantan	Future	830	2040	❌	✅	✅
Sabah – Kalimantan (Kalabakan–Malinau)	Future	200	2035	❌	✅	✅
Philippines – Sabah (Palawan–Kudat)	Future	200	2030	❌	✅	✅
Sarawak – Brunei (Miri/Tudan–Kuala Belait)	Future	100	2025	❌	✅	✅
Thailand – Lao PDR	Existing	700	-	✅	✅	✅
Thailand – Lao PDR (Mae Chan–Ton Phueng)	Future	1300	2040	❌	✅	✅
Lao PDR – Vietnam (Nam Mo–Ban Ve)	Existing	570	-	✅	✅	✅
Lao PDR – Vietnam (Hax Tan–Pleiku)	Future	620	2040	❌	✅	✅
Thailand – Myanmar (Phitsanulok–Hutgyi)	Future	1250	2040	❌	✅	✅
Vietnam – Cambodia (Takeo–Chau Doc)	Existing	250	-	✅	✅	✅
Lao PDR – Cambodia (Don Sahong bypass)	Existing	300	-	✅	✅	✅
Lao PDR – Cambodia (Banhat–Stung Treng)	Future	500	2040	❌	✅	✅
Thailand – Cambodia (Aranyaprathet–Poi Pet)	Existing	240	-	✅	✅	✅
Thailand – Cambodia (Prachin Buri–Siem Reap)	Future	1000	2040	❌	✅	✅
Sumatra – Singapore (Paranap–Singapore)	Future	1200	2040	❌	✅	✅
Lao PDR – Myanmar	Future	350	2040	❌	✅	✅

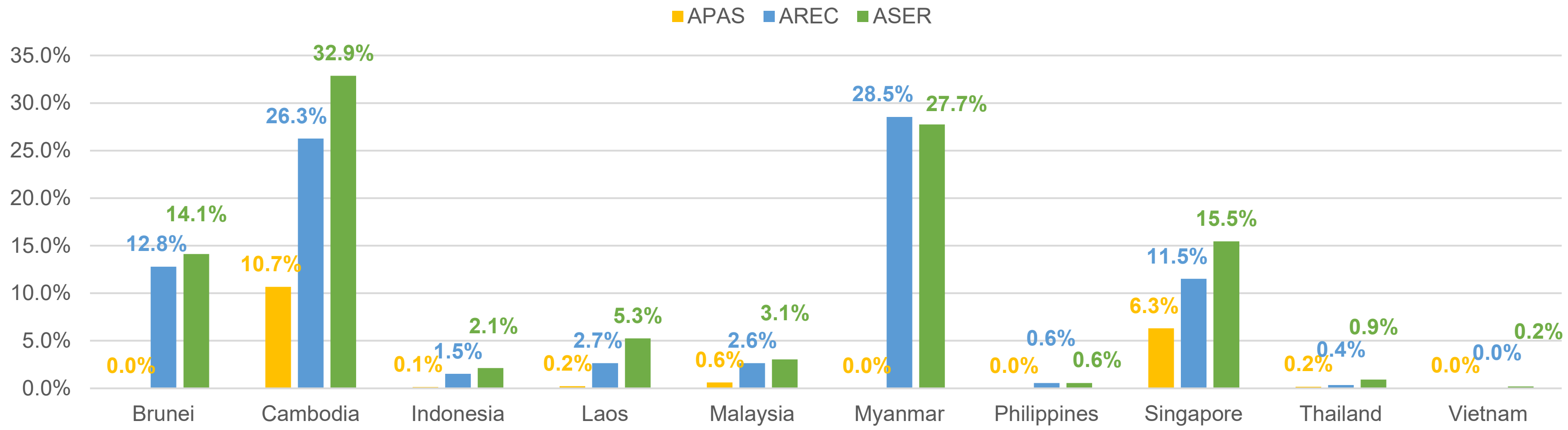
The **ASEAN Power Grid (APG)** is a flagship initiative to strengthen energy security through cross-border trade. The Roadmap's scenario design differentiates between **existing** and **future** interconnections, with future lines drawn from the **18 priority projects under ASEAN Interconnection Masterplan Studies (AIMS) III**. These interconnections are incorporated into the modelling through the following mechanisms:

- **APAS** includes only existing interconnection lines.
- **AREC** activates all 18 projects, with future lines phased in according to their expected Commercial Operation Dates (CODs).
- **ASER** mirrors the same interconnection configuration as AREC but reflects a **higher power generation ambition**, consistent with the assumptions outlined in the previous chapter.

Impact of APG Expansion on Cross-Border Trade: Future Interconnections Unlock its Key Role in Meeting ASEAN's Electricity Demand Growth

As ASEAN electricity demand and RE share in power generation rises, cross-border trade plays an increasingly critical role in balancing supply and demand across member states.

Share of Net Cross-Border Power Trade (Modelled Interconnections) from Domestic Generation Across Scenarios in 2045



Cross-border trade expands with APG development

As scenarios progress from APAS to AREC and ASER, the share of cross-border electricity relative to domestic generation increases steadily. This reflects both the addition of new interconnection lines and higher electricity demand.

By 2045, APG interconnections help countries such as Cambodia, Myanmar, Singapore, and Brunei complement their domestic generation with regional resources, ensuring demand growth can be met efficiently.

Future interconnections reshape ASEAN's power system

Beyond increasing trade, new projects like Sarawak–Brunei and Philippines–Sabah connect countries without existing cross-border links. This expands access to supply and system flexibility. In this way, the APG evolves from being just a platform for trade into a **critical enabler of renewable integration and resilience**. By pooling diverse resources across borders, it helps ASEAN manage variability, reduce curtailment and collectively meet rising electricity demand with a much higher share of renewables.

Occupancy Rate of APG Interconnections in 2045 – ASER Scenario

Comparing modelled transmission flows with theoretical maximum capacity highlights how intensively each interconnection is used.

Transmission Lines	Status	Occupancy Rate (%)
Peninsular Malaysia – Singapore (Plentong–Senoko)	Existing	42%
Thailand – Peninsular Malaysia (Khlong Ngae–Grurun)	Existing	53%
Thailand – Peninsular Malaysia	Future	52%
Peninsular Malaysia – Sumatra (Teluk Gong–Perawang)	Future	26%
Sarawak – Kalimantan (Mambong–Bengkayang)	Existing	34%
Sarawak – Kalimantan	Future	33%
Sabah – Kalimantan (Kalabakan–Malinau)	Future	35%
Philippines – Sabah (Palawan–Kudat)	Future	92%
Sarawak – Brunei (Miri/Tudan–Kuala Belait)	Future	99%
Thailand – Lao PDR	Existing	97%
Thailand – Lao PDR (Mae Chan–Ton Phueng)	Future	96%
Lao PDR – Vietnam (Nam Mo–Ban Ve)	Existing	57%
Lao PDR – Vietnam (Hax Tan–Pleiku)	Future	66%
Thailand – Myanmar (Phitsanulok–Hutgyi)	Future	89%
Vietnam – Cambodia (Chau Doc–Takeo)	Existing	49%
Lao PDR – Cambodia (Don Sahong bypass)	Existing	37%
Lao PDR – Cambodia (Banhat–Stung Treng)	Future	46%
Thailand – Cambodia (Aranyaprathet–Poi Pet)	Existing	98%
Thailand – Cambodia (Prachin Buri–Siem Reap)	Future	97%
Sumatra – Singapore (Paranap–Singapore)	Future	18%
Lao PDR – Myanmar	Future	95%

Notes – Methodology to Calculate the Occupancy Rate:

The occupancy rate measures how intensively each interconnection is used relative to its theoretical maximum. It is calculated by multiplying line capacity (MW) by annual hours (8,760) to derive the maximum possible energy (TWh) and comparing it with modelled flows. This benchmark is useful but should be read with caution:

- *Actual transfer capability is lower than nameplate values due to system security requirements.*
- *Using net annual flows may understate utilisation where bidirectional exchanges are frequent.*
- *Moderate annual occupancy can still mask hourly congestion.*
- *The metric shows utilisation trends but not the wider operational value of interconnections.*

Finally, the current model simplifies power trade by expressing results only in absolute values. This may give the impression of "full" utilisation for lines with large import–export imbalances, while not fully capturing balanced two-way trade. More detailed tools would be needed for such cases.

Several interconnections are already approaching full utilisation, highlighting APG's critical role and the need for deeper system assessment

Several lines operate near maximum utilisation

By 2045, interconnections such as **Sarawak–Brunei, Thailand–Lao PDR, and Thailand–Cambodia** are projected to operate at very high occupancy levels (95–99%). This reflects their importance as backbone corridors of regional electricity trade. Their near-saturation highlights how effectively these lines are serving ASEAN's growing demand, while also suggesting that **expanding or reinforcing capacity beyond 2045 will be important to avoid bottlenecks**.

New entrants also make strong use of future links

Future projects like **Philippines–Sabah and Thailand–Myanmar** quickly reach high utilisation once operational, with occupancy rates above 90%. This shows how transformative new interconnections can be for countries that currently lack cross-border trade. Their strong uptake illustrates pent-up demand for regional integration and suggests that **planning for potential future capacity increases will be critical to sustain these new trade corridors over the long term**.

Balanced utilisation across other lines

Several interconnections demonstrate moderate utilisation levels (30–60%), indicating their role in providing flexibility to balance flows and absorb variability from renewables. Their presence ensures resilience and optionality, and **their role may grow further as ASEAN's demand and renewable integration continue to rise**.

Strategic value beyond utilisation metrics

While some interconnections show lower utilisation rates in the model, their true system value extends well beyond what is captured in this analysis. The benefits of regional connectivity cannot be fully quantified without detailed operational studies, which would assess how these links enhance reserve sharing, balancing, and peak-load management across ASEAN's grid. These operational advantages are critical for improving system stability and integrating higher shares of variable renewable energy. **Future feasibility studies will therefore be essential** to capture the full value of these interconnections and guide the next phase of APG expansion.

Overall Implication: APG's crucial role in the future

The occupancy analysis shows that APG interconnections already play a vital role in ASEAN's power system and will become increasingly important as demand grows. However, this analysis represents only a first step in assessing the APG's benefits. The occupancy rate captures utilisation trends but not the full operational value of interconnections such as reserve sharing, balancing, and peak-shifting, which can only be quantified through **detailed feasibility studies**. These next-level assessments are crucial to fully capture the APG's system-level benefits and guide investment priorities for deeper regional integration.

Way Forward: Turning APG Plans into Realisation

Continuing APG infrastructure development and strengthening regional planning framework

ASEAN's immediate priority is to continue the **development and expansion of APG infrastructure**, building on the 18 interconnection projects identified under the **AIMS III**. Strengthening AIMS as a **regional planning framework** will ensure that future grid expansion reflects collective regional priorities and supports ASEAN's long-term vision.

To maximise its impact, ASEAN should also establish a **framework to identify interconnection projects of common regional importance,** which are interconnections that enhanced reliability, balancing and access to RE resources. At the same time, developing a **stronger regional coordination framework** is crucial to facilitate cross-border power trade using existing links and to guide new investment planning, aligning **infrastructure development with future market integration**.

Designing regional market integration to achieve optimal RE resource allocation

The primary goal of designing a regional power market in ASEAN is to achieve optimal resource allocation, thereby increasing efficiency, enhancing RE integration and lowering the overall cost of electricity supply. In other words, the aim is to maximise social welfare within ASEAN's power sector, ensuring that the power which flows through interconnectors contributes to the efficient operation of the regional system.

Moving from the nascent bilateral grid-to-grid state to Multilateral Power Trade (MPT) in a stepwise manner

The existing and ongoing APG grid transmission infrastructures are primarily bilateral in nature. To enable MPT, it is necessary to accelerate the construction and expansion of the 18 priority interconnections identified in AIMS III. These will serve as the backbone when bilateral trading evolves into a regional market. The transition should be **stepwise**, starting with enhancing bilateral exchanges, then progressing to subregional multilateral arrangements (e.g., Greater Mekong Subregion (GMS), Brunei Darussalam-Indonesia-Malaysia-Philippines (BIMP) and Lao PDR-Thailand-Malaysia-Singapore (LTMS) Power Integration Project (PIP)) and establishing a fully integrated market platform by 2045.

Building Block for moving from the current state to MPT

Infrastructure Development: Accelerate the building and expansion of the 18 AIMS III priority interconnections through joint development studies to enhance project bankability.

Market Framework Development: Standardise regulatory and commercial instruments (e.g., PPAs, wheeling charges, congestion management) and implement transparent settlement systems.

Technical Harmonisation: Align grid codes, adopt common HVDC/AC standards, and establish joint system operation protocols for secure, reliable interconnections.

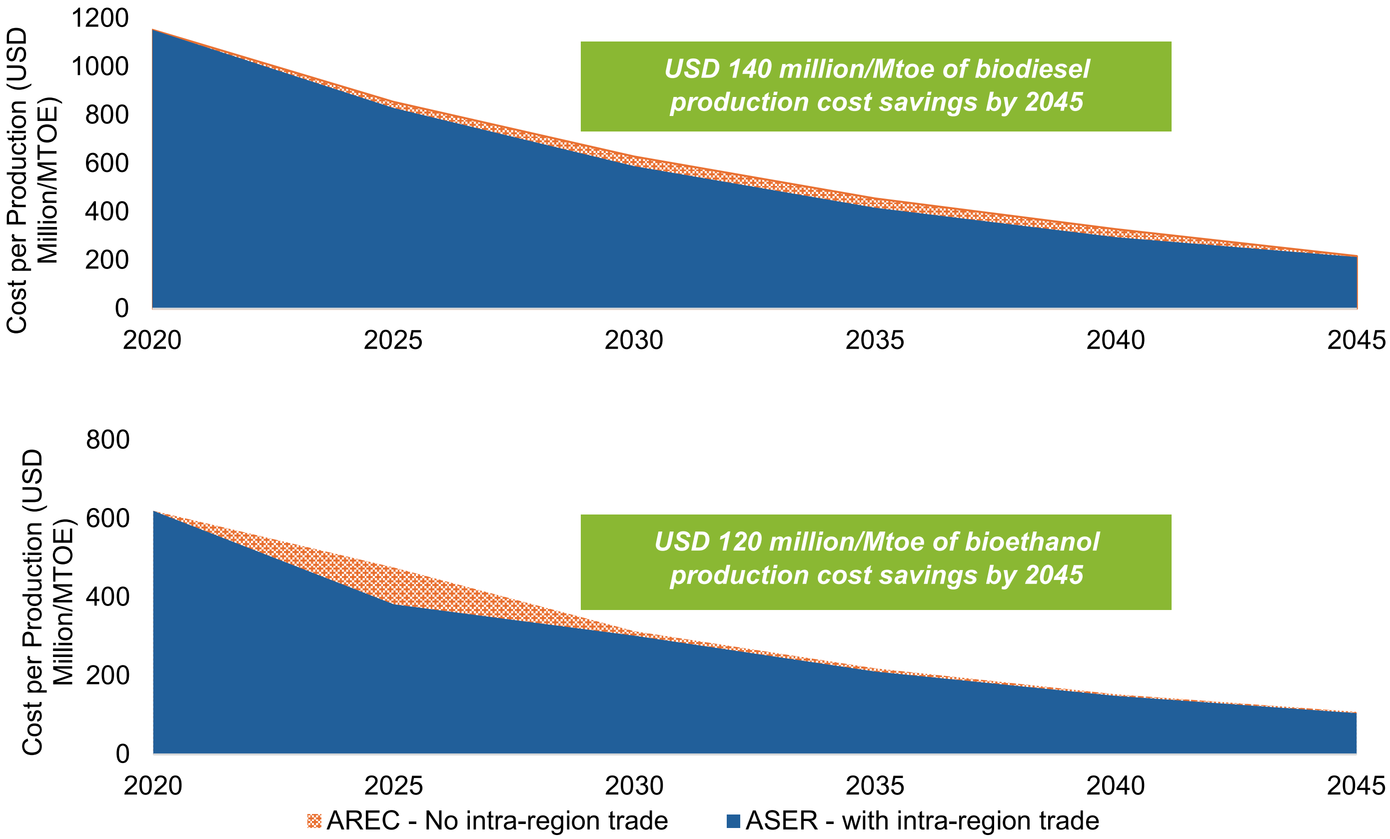
Institutional Strengthening: Operationalise the APG Enhanced Memorandum of Understanding (MoU)[1], strengthen coordination among Heads of ASEAN Power Utilities/Authorities (HAPUA), ASEAN Energy Regulators Network (AERN) and ASEAN Power Grid Consultative Committee (APGCC), and empower the APG Secretariat to guide regional planning and monitoring.

[1] APG Enhanced MoU is the successor of APG MoU that was previously in force for 15 years until 18 March 2024, comprising of ASEAN Member States' agreement to strengthen regional electricity connectivity and trade.

4.2. Intra-Region Biofuel Trade – Unlocking Potential Regional Cooperation

Why Intra-ASEAN Biofuel Trade Matters: Lower Costs, Stronger Energy Security

Comparison of Biodiesel (top) and Bioethanol (bottom) Production Cost in ASER vs. AREC, 2020–2045



Trade integration lowers total system costs by matching demand with least-cost supply, reducing import dependence and strengthening ASEAN's energy security.

Cross-border trade not only cuts costs but anchors value within ASEAN, catalysing investment, green jobs, and regional value chains

From Fragmentation to Integration

Today, ASEAN's biofuel sector remains fragmented. Indonesia and Malaysia generate persistent surpluses, while other member states continue to rely heavily on imports from outside the region. This mismatch prevents ASEAN from making the most of its agricultural strengths and results in higher overall system costs. Regional trade integration changes this picture. As highlighted in the previous chapter, introducing an intra-ASEAN trade mechanism has the potential to unlock higher supply and greater self-sufficiency across the region. Beyond this supply advantage, trade also delivers important cost-related benefits, which include reducing overall system costs, lowering import dependence and ensuring that more of the economic value from biofuels is retained within ASEAN rather than flowing overseas.

Direct Cost Savings

The optimisation results demonstrate clear financial gains when trade is enabled. By matching demand with the least-cost supply across ASEAN, overall system costs are reduced, and dependence on high-cost external imports declines. Instead of capital outflows to overseas suppliers, expenditures remain within the region, strengthening balance-of-payments positions and improving collective energy security. These savings are not marginal: they represent a structural efficiency gain, showing how coordination at the regional level can deliver benefits that national strategies alone cannot.

Anchoring Economic Value Within ASEAN

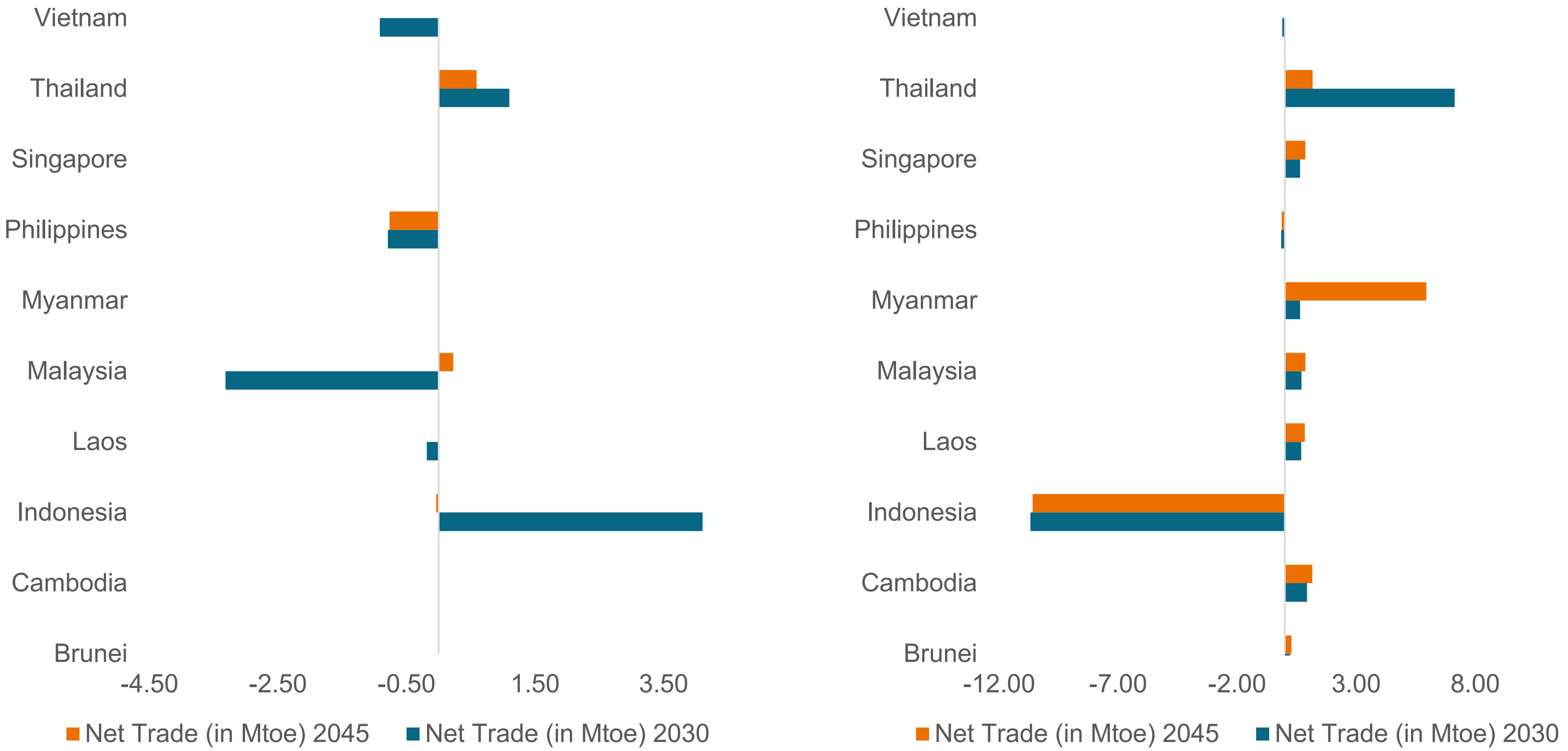
The significance of intra-regional biofuel trade goes well beyond lowering costs. By keeping economic value within ASEAN, trade creates opportunities for new investment in processing facilities, logistics infrastructure and feedstock supply chains. Stable regional demand sends a strong signal to investors, de-risking projects and encouraging expansion. These investments ripple across the economy — supporting rural incomes through stronger markets for agricultural residues, boosting industrial activity in processing hubs and creating green jobs throughout the supply chain.

Strengthening Resilience and Competitiveness

Finally, regional biofuel trade enhances resilience and competitiveness. By diversifying supply sources and anchoring them within ASEAN, member states reduce their exposure to global fuel and feedstock price volatility. At the same time, the emergence of integrated value chains positions ASEAN as a more competitive player in global biofuel markets. While imports from outside the region may still play a role, ASEAN's collective ability to meet its own demand grows significantly, shifting the region's position from being a passive importer to an active producer with stronger bargaining power.

How Intra-ASEAN Trade Reshapes Biofuel Supply and Demand

Net Trade Balance of Biodiesel (left) and Bioethanol (right) in ASER Scenario, 2030 and 2045



Biodiesel trade volumes narrow as rising domestic mandates absorb more supply, while intra-ASEAN trade enables new bioethanol exporters to emerge, diversifying production beyond Thailand and the Philippines.

From surpluses to self-sufficiency: trade balances shift with intra-ASEAN integration

Biodiesel: From Persistent Surplus to Rising Domestic Use

In the case of biodiesel, ASEAN's production capacity already exceeds regional demand, particularly due to strong output from Indonesia and Malaysia. This surplus allows the region to play an important role as a global exporter, a position ASEAN will continue to hold in the near term. However, optimisation results show that the amount of biodiesel available for trade becomes increasingly limited from 2030 to 2045. This is driven by higher domestic blending mandates in key producer countries, which steadily absorb more of the available supply. Even with these ambitious mandates, intra-ASEAN trade continues to play a balancing role. Net importers such as the Philippines, Vietnam, and eventually Indonesia itself are able to cover part of their biodiesel needs from within ASEAN, rather than relying entirely on extra-regional imports. This dynamic illustrates how trade reconfigures supply chains: surpluses narrow, but coordinated integration ensures that regional demand can still be met from ASEAN's own production base.

Bioethanol: From Deficits to Stronger Regional Supply

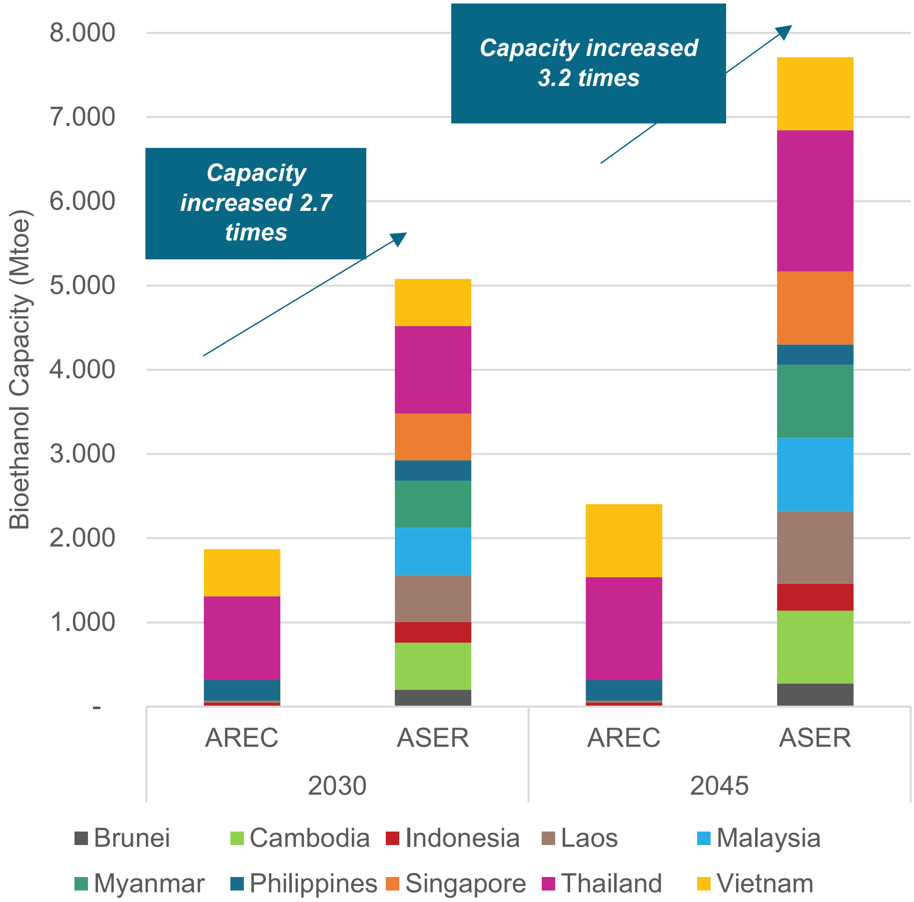
Bioethanol shows a more transformative story under intra-ASEAN trade. In a no-trade scenario, production remains concentrated in just two countries, namely Thailand and the Philippines, covering only a fraction of regional demand. With trade enabled, however, new producers emerge. Cambodia, Myanmar, and even the Philippines (expanding beyond its current base) are able to develop new capacity, supported by feedstock flows and stronger regional demand signals. This diversification allows countries that previously lacked mandates or production incentives to become active contributors to regional supply. The emergence of new exporters not only reduces dependence on Thailand and the Philippines but also spreads investment opportunities more widely across ASEAN. The optimisation results thus show how intra-ASEAN trade does more than reallocate existing output: it catalyses new investment and reshapes the geography of production. This theme is explored in greater detail in the following section, which looks at newly optimised bioethanol capacities and the role of feedstock trade in enabling their growth.

Creating Balance and Value

Taken together, these dynamics illustrate how intra-ASEAN trade reshapes the biofuel landscape from a fragmented system into a more balanced and resilient one. Biodiesel continues to provide an export opportunity for both intra- and extra-regional markets, even as domestic demand steadily increases and absorbs a larger share of supply. Meanwhile, bioethanol transforms from a deficit sector reliant on external imports into a more diversified regional market with new producers and exporters. For ASEAN as a whole, this balance ensures that surplus capacity is monetised within the region, deficit countries gain reliable access to low-carbon fuels, and reliance on volatile external markets is reduced. In short, intra-regional trade not only reduces costs but also fundamentally strengthens ASEAN's energy resilience by aligning supply and demand more efficiently across member states.

How Intra-ASEAN Trade Builds New Capacity: Unlocking Bioethanol Production Across More Countries

Comparison of Bioethanol Capacity in ASER (with Intra-ASEAN Trade) vs. AREC (without Intra-ASEAN Trade), 2030 and 2045



Expanding Capacity Through Trade

Under the ASER scenario, intra-ASEAN biofuel trade enables bioethanol production capacity to expand far beyond the no-trade AREC pathway. By 2030, regional capacity is 2.7 times higher than in AREC, and by 2045 it reaches more than 3.2 times greater. This reflects how coordinated trade mechanisms unlock cost-effective opportunities that remain untapped in a siloed, country-by-country approach.

New Producers Emerge

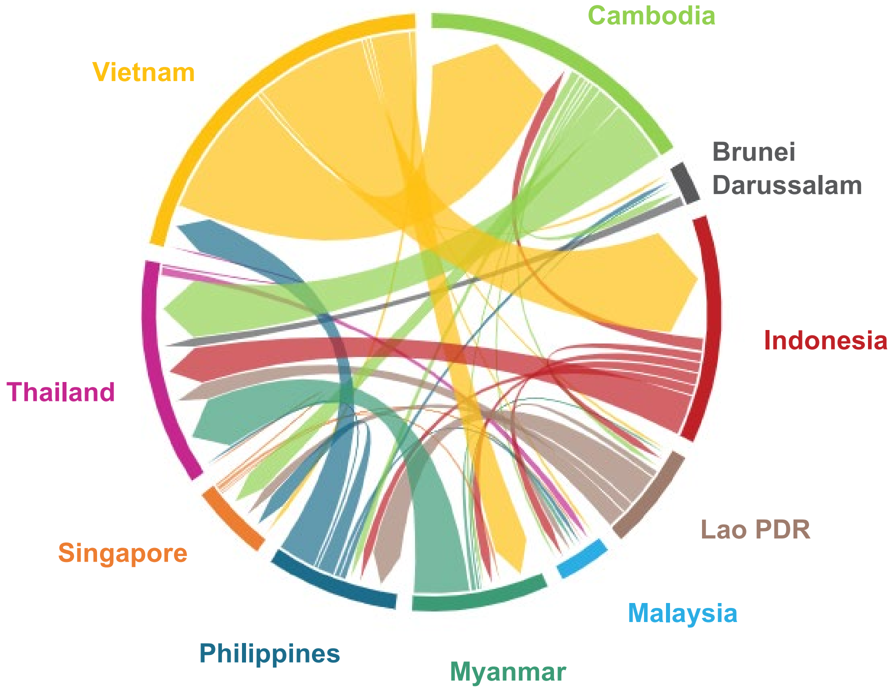
Beyond scale, the optimisation introduces entirely new producers. Countries such as Malaysia, Cambodia, and Lao PDR—previously without mandates or production capacity—become active participants in regional supply. Their emergence not only diversifies the production base but also reduces over-reliance on the traditional hubs of Thailand and the Philippines. The result is a broader and more resilient regional bioethanol ecosystem.

Linking Capacity to Feedstock Availability

This transformation is underpinned by the ability to reallocate feedstocks across borders, directing them to where new plants can operate most efficiently. The next step is to examine how feedstock trade flows enable these new producers to scale up and sustain output, providing the backbone of ASEAN's integrated bioethanol supply chain.

How Intra-ASEAN Feedstock Trade Enables Bioethanol Expansion

Chord Diagram on Bioethanol Feedstocks Trade in 2030 (ASER Scenario)



Notes:

- ***Arc size = total volume of feedstock trade from/to a country.***
- ***Chord direction = flow from exporter (origin side) to importer (destination side).***
- ***Chord thickness = volume of feedstock traded.***

Unlocking New Production through Feedstock Flows

The optimisation results show that intra-ASEAN feedstock trade, which includes cassava, sugarcane, and molasses, provides the backbone for regional bioethanol expansion. By allowing countries with surplus agricultural resources to supply others, the system creates new production hubs in places previously lacking mandates or capacity.

Emergence of Import-Export Dynamics

The chord diagram for 2030 reveals that some countries appear both as exporters and importers of feedstock. This reflects optimisation logic where costs, logistics, and plant siting drive trade decisions. In practice, such patterns are not unusual. For instance, a country may export surplus cassava from one region while importing molasses or sugarcane. Differences in processing capacity, location of feedstock surplus, and quality requirements can all lead to simultaneous inflows and outflows. This mirrors how global commodity markets function: even net exporters often import certain grades, forms, or seasonal supplies of the same commodity.

From Feedstock to Self-Sufficiency

These flows highlight how ASEAN's diverse agricultural base can be harnessed collectively, spreading opportunities beyond a few countries and reducing reliance on external markets. The model results demonstrate that feedstock mobility is the enabling mechanism behind the new production capacity shown earlier, making ASEAN more self-sufficient in transport biofuels.

Charting the Path Forward: Unlocking ASEAN's Biofuel Trade Potential

Model Results Show Potential, Not Predetermined Outcomes

The scenarios presented in this chapter are not predictions of what ASEAN will adopt, but illustrations of how intra-regional trade could work in practice. They highlight possible benefits — lower costs, expanded production capacity, and greater supply balance — to inform dialogue rather than prescribe a single pathway.

Balancing Opportunities with Trade-Offs

While regional biofuel trade can enhance resilience and competitiveness, it also requires navigating important trade-offs. Countries must weigh **domestic priorities**. Countries also need to manage **feedstock volatility**, as cross-border trade may amplify price swings and impact local farmers. Additionally, **sustainability and equity** considerations are essential, making sure that land use is responsibly managed and benefits are shared fairly across communities.

Unlocking Untapped Potential Through Collaboration

The analysis makes clear that ASEAN holds significant untapped potential in biofuel trade, which could be realised through coordinated regional collaboration. Yet, whether this potential is captured will depend on several factors: the strength of political commitment, the ability to align national policies, the development of sustainable feedstock supply chains, and the readiness of investment and infrastructure. Recognising these drivers, ASEAN can chart its own path to transform biofuels into a regional opportunity for resilience and shared growth.

Priority Actions to Enhance Regional Cooperation

Policy Dialogue

Establish a platform for ASEAN countries to discuss the opportunities and challenges of biofuel trade

Standards & Certification

Develop harmonised sustainability and quality frameworks to build trust and market integration

Infrastructure & Investment

Support logistics, storage and processing hubs that can enable efficient cross-border trade

Data & Transparency

Improve collection and sharing of feedstock, production and demand data to refine regional strategies

Chapter 5

Future Directions and Recommendations

Roadmap for ASEAN's Power Sector Transformation

Analysis of the roadmap reveals clear insights into how ASEAN's power sector can shift towards much greater dependence on variable renewable energy (vRE) and dispatchable renewable integration systems. The transition of the power system in ASEAN is divided into two distinct stages: the first stage spans from 2026 to 2035, while the second stage covers the period from 2036 to 2045. Each stage requires its own set of plans, implementation strategies, and collaborative efforts.

During the first stage, there will be massive increases in vRE deployment and storage capacity. These will drive the need to support robust changes in the power system and grid operations, the decrease in the role coal and gas power plants, and widespread expansion of the market and regulation structures. Greater accessibility to green finance will foster the efficiency and bankability of new investments. Nonetheless, transformation of the power sector alone is insufficient to keep ASEAN on track to meet its emission reduction targets. It is therefore necessary to implement economy-wide decarbonisation and unlock the full economic potential of the transition.

APAEC 2026–2030: Building the Cooperative Grid

The immediate priority for the next APAEC cycle is to execute the foundational AREC pathway. This phase is about managing the initial, massive influx of renewable energy by undertaking a simultaneous build-out of over 140 GW of vRE and nearly 30 GW of firm, dispatchable renewables to anchor the system. Success requires a focus on the following five critical areas.

Fostering RE Investment and Ensuring Financial Accessibility

The scale of the transition requires an average annual investment of USD 77 billion during this period. A sophisticated financial strategy is needed to attract green finance for the vast majority of clean energy projects (~76%) as well as specialised transition finance for the essential fossil fuel assets (primarily gas) required for grid stability. Finalising government-to-government (G to G) agreements and clear financing mechanisms for the APG will be critical to de-risking capital inflow and ensuring that projects are bankable.

Designing Markets for vRE, Batteries, and Transitional Fossil Fuels

The influx of vRE necessitates a fundamental shift in market design to value flexibility and stability, not just energy volume. The hourly analysis shows that markets must evolve to create new revenue streams for batteries that provide fast-acting energy shifting—charging during midday solar peaks and discharging during evening ramps. Simultaneously, market structures and PPAs must be reformed to incentivise natural gas and the remaining coal fleet to operate flexibly, providing stability to support renewables rather than serving as traditional baseload power.

Activating Regional Power Trade and a Regional REC Market

The activation of the 18 priority APG interconnection projects to increase the role of cross-border trade is necessary. This physical integration must be paired with market integration by establishing a regional REC market. A harmonised REC market provides a transparent mechanism for certifying green electricity across borders, expands opportunities for corporate renewable procurement, and delivers crucial financial benefits to RE producers.

Enhancing Power System Planning and Grid Operations

Managing a grid with a rapidly increasing share of vRE requires a proactive evolution in system planning and operation. For the near term, the roadmap identifies several priorities to prepare for ~25% vRE integration: harmonising regional grid codes to ensure seamless physical integration, investing in advanced weather and generation forecasting systems, and updating system planning models to better account for the variability and locational value of renewables and storage.

Developing Robust Policies for Clean Energy Supply Chains

The massive physical build-out necessitates a robust regional industrial policy to secure the supply of key technologies. This involves creating supportive frameworks to build local and regional supply chains for solar PV, wind turbines, and batteries.

Critical Policy Actions

- ✓ Accelerate the infrastructure development of the 18 priority APG projects, supported by comprehensive feasibility studies and enhanced regional planning mechanisms.
- ✓ Finalise the G-to-G agreements and financing mechanisms required for the APG expansion, derisking, and attracting the necessary capital flow.
- ✓ Develop a sophisticated regional financial strategy to attract green finance for renewables, while engaging with partners to shape and access transition finance for the gas plants essential for grid stability.
- ✓ Establish and operationalise a harmonised regional REC market to provide a transparent mechanism for cross-border green electricity procurement and create new revenue streams for RE producers.
- ✓ Focus on harmonising grid codes and technical standards to ensure the seamless physical integration of the regional grid.
- ✓ Further facilitate cross-border electricity trade by developing robust regional trading mechanisms, reforming national market structures to value flexibility, and strengthening the institutional capacity of APG's governing bodies.
- ✓ Establish a regional dialogue on building local and regional supply chains for solar PV, wind turbines, and batteries and sustainable sourcing of critical minerals essential for these technologies, incorporating Just and Inclusive Energy Transition (JIET) principles to ensure that supply chain benefits are shared equitably.

Mid-Term (2031–2040): From Coordinated Grid to Integrated Market

This stage is the critical tipping point. In the early years of this period, the addition of new vRE will continue substantively then reach a plateau in the second half.

It is during this period that the focus shifts from exclusive attention on the power sector to economy-wide transformations. Ways need to be found to accommodate around 30-40% of vRE integration and shift to stronger integrated multi-sectors to unlock RE potentials.

Fostering Investment in Grid Reinforcement and Digitalisation

With the initial wave of generation capacity underway, investment focus must pivot to critical enabling infrastructure. This requires significant capital allocation for strategic grid reinforcement and the construction of new transmission corridors to connect resource-rich areas with demand centres. This physical build-out must be supported by continued investment in grid digitalisation, including advanced real-time monitoring and control systems, which are essential for managing a more complex and decentralised power network.

Deepening Market Reforms for System Flexibility

As the grid becomes operationally dominated by vRE, market reforms must accelerate to properly value flexibility. The key action is the introduction of advanced market-based instruments, principally carbon pricing, to level the playing field and drive the gas-to-storage substitution. This creates a viable business case for large-scale battery deployment by establishing mature ancillary service markets that compensate for fast-response capabilities. Furthermore, demand response programmes must be scaled up from pilots to full commercial offerings to activate industries as a major source of grid flexibility.

Expanding the Role of the APG

The APG's role evolves from a simple trade enabler to a crucial provider of large-scale, cost-effective flexibility. With key corridors approaching maximum capacity post-2030, the focus must shift to planning for and investing in strategic reinforcements and new interconnections. An enhanced APG facilitates more dynamic cross-border trade of green electricity, allowing the region to smooth out vRE variability over a wider geographical area and enabling a stepwise transition from bilateral towards multilateral exchanges.

Mastering Grid Operations with 30-40% vRE

In order to accommodate 30-40% vRE, the region must master operating in IEA's Phase 4 of vRE integration, where the primary challenge is managing large and frequent daily surpluses of solar and wind power. The roadmap outlines a three-pronged strategy to manage this: deploying large-scale battery storage for daily energy shifting (absorbing midday solar for evening use); creating sophisticated demand-response markets to incentivise industries to use power when it is cheapest; and leveraging the APG to create an export market for surplus renewable generation.

Integrating Policy Across Energy-Consuming Sectors

With the power sector's transition accelerating, a robust and integrated policy focus on end-use sectors is imperative. This includes launching regional industrial policies to build local supply chains for EVs and batteries to drive mass-market adoption. Critically, this is the decade to begin the commercial-scale deployment of low-carbon fuels. This requires integrated planning for producing resources like green hydrogen.

Critical Policy Actions

- ✓ Introduce advanced market-based instruments, principally carbon pricing, to level the playing field and drive the most efficient decarbonisation choices.
- ✓ Launch a regional industrial policy to cooperate on building local supply chains for renewable generation (solar, wind), energy storage (batteries), grid infrastructure (cables, substations), supported by coordinated planning on critical minerals essential to these technologies.
- ✓ Accelerate grid expansion and reinforcement for the next phase of APG expansion to avoid the long-term capacity bottlenecks. This must be paired with strategic transmission reinforcement at the national level to support the massive build-out of utility-scale vRE projects.
- ✓ Enable a decentralised and integrated energy system by implementing the regulatory frameworks for a highly decentralised grid, including standardised rules for prosumers and pilot programmes for Virtual Power Plants (VPPs).

Long-Term (2041–2045): Reaching Economics-Wide Decarbonisations

In this final phase, the system matures into a fully transformed, deeply decarbonised state. The challenge is no longer about building new capacity, but about mastering the operation of this new, complex, and highly integrated energy system.

Finalising Investment in a Fully Decarbonised System

This is the most capital-intensive phase, with annual investments peaking to complete the transformation. The focus of this investment is on the most advanced and large-scale projects, such as establishing regional offshore wind hubs and financing the second, massive market-driven wave of rooftop solar. Capital is also directed towards building out the final tranches of the massive energy storage fleet (over 100 GW), which now serves as a cornerstone of the grid's reliability.

Perfecting Market Designs for an Inverter-Dominated Grid

With the grid now dominated by inverter-based resources (solar, wind, batteries), market reforms must be perfected to maintain stability. This requires the development of advanced market designs that can procure sophisticated grid services (like synthetic inertia and fast frequency response) directly from inverters. This phase also sees the full implementation of policies for a decentralised system, including establishing rules and platforms for peer-to-peer (P2P) energy trading between prosumers.

The APG as a Mature Super Grid

The APG evolves from a series of interconnections into a mature super grid—a fully integrated regional backbone. Its role expands beyond balancing vRE to enabling new clean energy economies. It facilitates a fully realised MPT market and, crucially, serves as the essential infrastructure to connect large-scale green hydrogen production centres to industrial demand hubs across the region.

Mastering the Operation of a Complex, Decentralised System

The primary operational challenge is mastering a highly complex, decentralised, and inverter-dominated grid, characteristic of IEA's Phase 6 of vRE integration. System operators must manage the rise of the prosumer from the second wave of rooftop solar and ensure energy security by bridging longer, multi-day periods of low vRE. This requires the sophisticated and coordinated dispatch of a diverse flexibility portfolio, including short-duration batteries, long-duration storage, and dispatchable renewables.

Implementing Deep Sector Coupling

This final phase is defined by the implementation of deep sector coupling. The power sector is no longer planned in isolation. Advanced regulations and market mechanisms are implemented to seamlessly integrate the operations of the electricity grid with the now-mature regional markets for green hydrogen and biofuels. This means that buildings, industrial facilities, and the EV fleet (via vehicle-to-grid technologies) are no longer passive consumers but are fully integrated, active participants that contribute to the flexibility and stability of the entire energy system.

Critical Policy Actions

- ✓ Full implementation of policies for a decentralised system, including rules for peer-to-peer energy trading, and developing advanced market designs that procure essential grid services (e.g., inertia) to ensure the stability of an inverter-dominated grid.
- ✓ Deep sector-coupling regulations that seamlessly integrate the operations of the power grid with the new industrial and transport clean fuel markets.
- ✓ Launch targeted investment frameworks and incentives to drive the final phase of generation build-out, focusing on advanced projects like regional offshore wind hubs and unlocking the second, market-driven wave of rooftop solar.

Roadmap for Transport and Industrial Sector Transformation

Decarbonising the transport and industrial sectors is as important as decarbonising the power sector. As the transport and industrial sectors are the dominant consumers of final energy, they represent one of the most difficult challenges faced in ASEAN's energy transition. Compared with the more advanced planning in the power sector, there is greater need to construct a more solid strategy for these sectors. This includes clearer choices of technologies and incentives to ensure investment returns, better integration of renewable energy supply and demand, stronger sector coupling, and accelerated energy efficiency improvements. Addressing these areas will require a phased journey, with different strategic priorities in the short-, mid-, and long-term.

Therefore, the central insight from this analysis is that the process of decarbonising the transport and industrial sectors cannot be achieved in silos. The most effective and efficient pathway is the ASER scenario, which creates a single, integrated regional market for all clean energy carriers—electricity, biofuels, and hydrogen. This allows the region to flexibly allocate these valuable resources to the sectors where they are most needed, creating the most resilient and competitive clean energy economy for the future.

APAEC 2026–2030: Laying the Groundwork

This period is about establishing the foundational policies and infrastructure that will enable an efficient and effective transition in the following decades.

Transport Sector

The main crossways for transport decarbonisation are electrification, biofuel mandates, fuel economy improvements, modal shifts, and, to some extent, the use of green hydrogen. While fuel economy and modal shift remain part of the analysis, the roadmap places greater emphasis on optimising the EV–biofuel pathway by examining the implications of promoting EV supply chains alongside blended biofuel policies. The immediate priority in this stage is to establish policy frameworks for intra-regional biofuel trade to address the bioethanol deficit and to create stable conditions for EV market development.

Industrial Sector

Prioritising energy efficiency measures for both electricity and heat processes is crucial in this period. ASEAN should explore market-ready technology solutions for fuel switching, particularly electrification in low-heat industries, while preparing for biomass utilisation as a replacement for coal in high-heat processes. At the same time, establishing frameworks and regulations for new investments is essential to prevent lock-in to polluting and low-efficiency industrial facilities.

Cross sectoral planning

Sector coupling, such as electric transport and electric heating, is important for achieving end-use decarbonisation. However, this increase in electrification raises grid stress by elevating peak electricity demand, which could potentially lead to overloads, voltage fluctuations, and power outages if not managed properly. Meanwhile, the intermittent generation from vRE is also increasing grid stress. To manage these impacts, mitigation strategies are needed, such as storage, demand-side management, smart charging, etc.

Critical Policy Actions

- ✓ Establish a regional platform for policy dialogue to create the framework for intra-regional biofuel trade.
- ✓ Implement stable, long-term incentives and harmonised standards for EV charging infrastructure.
- ✓ Launch coordinated energy efficiency programmes for industry, focusing on waste heat recovery and electrification.

Mid-Term (2031–2040): Accelerating the Transition

This is the decade when the transition accelerates and the divergence between pathways becomes most apparent.

Transport Sector

The priority is to achieve mass-market adoption of EVs by leveraging regional supply chain cooperation to reduce EV costs. Bioethanol and biodiesel will continue to play important roles, although the gradual withdrawal of subsidies will require a more cost-driven, market-based approach. In parallel, the design and implementation of vehicle retirement frameworks will influence decisions on fleet renewal and the pace of clean vehicle uptake.

Industrial Sector

Fuel switching shifts from pilot to commercial scale during this period. The priority is to drive widespread electrification in low-heat industries, supported by proven and bankable projects. In high-heat sectors, the stronger deployment of biomass to replace coal and gas boilers is expected, while electric boilers should also be explored and benchmarked against biomass options. Hard-to-abate industries such as iron & steel will begin to explore green hydrogen solutions to support the production of green steel.

Cross sectoral planning

Ensuring that the electricity consumed by transport and industry originates from renewable sources is critical for achieving genuine decarbonisation of end-use sectors. At the same time, green hydrogen production should be aligned with surplus vRE availability, particularly during peak generation periods, to maintain cost competitiveness and avoid straining the power system. Strengthening the integration of power, industry, and transport will be essential for enabling higher levels of vRE penetration and system flexibility.

Critical Policy Actions

- ✓ Launch a regional industrial policy to cooperate on building local supply chains for EVs and batteries, including coordinated planning on critical minerals for their production.
- ✓ Develop harmonised sustainability and certification standards for biofuels to facilitate a liquid regional market.
- ✓ Establish the first regional green hydrogen pilot hubs and the necessary infrastructure to begin supplying high-heat industrial sectors.

Long-Term (2041–2045): Achieving Deep Decarbonisation

This phase requires stronger energy efficiency measures to flatten demand and ensure a cost-effective pathway. Integrated and transparent decarbonisation plans across transport, industry, and the broader energy system are crucial to design no-regret applications and maximise efficiency. Yet, the Roadmap findings reveal a lack of robust strategies on the ground, highlighting the need for intensified dialogue and advanced regional cooperation to achieve deep decarbonisation.

Transport Sector

Electrification remains the primary driver, supported by cost competitiveness from local EV supply chain promotion. A regional biofuel trade market within ASEAN will also be essential to leverage abundant resources and provide resilience. In this long-term period, the focus will be on ensuring sustainable feedstock and production for biofuels to secure a resilient and responsible supply chain. Green hydrogen, meanwhile, is more likely to be directed towards hard-to-abate industrial sectors rather than transport.

Industrial Sector

In high-heat industries, the promotion of biomass is reinforced by the region’s abundant supply, while energy efficiency must be scaled up to curb demand growth. Green hydrogen becomes the central pillar for decarbonising iron and steel production. For low-heat industries, electrified technologies such as heat pumps are expected to dominate.

Critical Policy Actions

- ✓ Introduce advanced market mechanisms, such as carbon pricing or green product standards, to drive the final fuel-switching decisions.
- ✓ Implement sector-coupling regulations that seamlessly integrate the operations of the power grid with the regional hydrogen market.
- ✓ Fully operationalise a regional data and transparency platform for biofuel and feedstock trade to ensure both market efficiency and sustainability of supply chains.

Future Directions for Regional Energy Efficiency

The modelling provides deep, quantitative insights for the supply-side transformation. A successful energy transition, however, also requires a robust, parallel strategy to manage demand. Improving energy efficiency is the cornerstone of this strategy because it directly reduces overall energy demand. This is the most cost-effective way to accelerate the transition, as every unit of energy saved is a unit that does not require investment in new generation capacity, grid upgrades, and the associated capital required.

This section, therefore, outlines future directions for regional energy efficiency, presenting a phased approach that begins with the rapid implementation of proven, low-hanging fruit and evolves towards a fully integrated, smart energy system. The following measures could be explored more in the next modelling exercises to identify more precise insights for the demand-side transformation.

APAEC: 2026–2030: Capturing the Low-Hanging Fruit

The immediate priority for the upcoming APAEC cycle is to aggressively capture the most accessible and cost-effective energy savings across all key sectors. This requires a focus on well-established policies and technologies.

Buildings (Commercial & Residential)

The primary focus must be on cooling, which is a major driver of electricity demand growth. This can be achieved through three main levers:

- ✓ Developing and enforcing more stringent green building codes for new constructions to integrate efficiency from the start.
- ✓ Harmonising and progressively tightening regional minimum energy performance energy standards (MEPS) and labelling for key appliances. This includes strengthening standards for the most significant energy consumers like air conditioners and expanding the harmonisation to other high-impact appliances such as refrigerators. To speed up market transformation, this should be paired with programmes like green public procurement to stimulate demand for top-tier products.
- ✓ To unlock the major capacity expansion of rooftop solar envisioned by the roadmap's AREC and ASER, policies must promote the integration of on-site RE paired with Energy Management Systems (EMS) in both new and existing buildings. This not only reduces a building's net consumption from the grid but also serves as a foundational step towards creating the fully integrated, efficient, and smart energy system of the future.

Transport

While the uptake of small-sized electric vehicles has been steady in recent years, it is very much influenced by vehicle cost. Thus, internal combustion engine vehicles (ICEVs) still constitute the majority of passenger vehicles on the roads and the electrification of heavy-duty vehicles is expected to be slow. The immediate priority is to improve the fuel economy of the existing ICEV fleet. This can be achieved through the adoption of fuel efficiency standards for new heavy-duty vehicles and passenger vehicles and by benchmarking successful programmes implemented in other major economies.

Industry

The focus should be on promoting the adoption of energy management systems and regular energy audits.

Mid-Term (2031–2040): Deepening Sectoral Integration

As the transition matures, the focus must shift from individual measures to more integrated, systemic approaches. Benchmarking against global best practices, ASEAN can prioritise the following:

Buildings

The focus for buildings shifts from individual appliance standards to a more holistic and mandatory approach to lock in deep, long-term savings. Building energy codes should be significantly updated to cover the retrofitting of existing buildings and to mandate that new constructions are zero-energy-building-ready. For appliances, the strategy moves to higher ambition by increasing the stringency of MEPS and, crucially, adopting a Mutual Recognition Arrangement (MRA) for high-efficiency products to facilitate regional trade. Finally, this period should see a move towards mandating the integration of on-site RE and EMS for new buildings, transforming them into active, manageable assets.

Transport
The priority is to build the smart charging infrastructure necessary to manage a growing EV fleet. This involves implementing dynamic tariffs and digital controls to incentivise charging during times of high RE supply, turning the EV fleet into a flexible asset for the grid.

Industry
The focus shifts to process optimisation, driven by the restriction of inefficient technologies while promoting clean alternatives. A critical policy step is to restrict all new polluting investment, such as the installation of conventional fossil fuel-based boilers, to prevent long-term carbon lock-in. In parallel, efforts must promote the electrification of low-temperature heat processes and investing in cross-cutting technologies like high-efficiency industrial heat pumps. Encouraging the growth of energy service companies (ESCOs) will be critical to provide the necessary technical expertise and financing for these more complex projects.

Long-Term (2041–2045): Replacing Most of the Energy-intensive and Low-efficiency technology with Higher Models and Promoting Circularity

In the final phase, energy efficiency becomes fully integrated into the design of a smart, flexible, and circular energy system.

Buildings
Buildings evolve from passive consumers into active, intelligent energy hubs. This is achieved by deeply integrating on-site renewables (rooftop solar), EV charging infrastructure, and advanced demand-side management systems. The key policy action is to evolve building energy codes to mandates or strongly incentivise these integrated elements for both new constructions and major retrofits of existing buildings, effectively turning them into flexible assets for the grid.

Industry
The priority is to embrace circular economy principles, which include promoting the reuse and recycling of materials to reduce the need for energy-intensive primary production. This is a core component of a deeply decarbonised industrial sector.

Cross-Sectoral
The ultimate goal is a fully integrated, smart energy system. This requires the widespread adoption of grid-interactive technologies and advanced demand response programmes. In this future, buildings, industrial facilities, and electric vehicles will no longer be passive consumers, but active participants in the energy system, automatically adjusting their consumption in real-time to support the stability of a high-vRE grid. This is the ultimate synergy between energy efficiency and grid flexibility, and it is essential for managing the scale and complexity of the ASER pathway.

ASEAN Power Grid (APG): Enabler of Renewable Integration and Market Connectivity

The APG remains a cornerstone of the region's energy transition, serving as both infrastructure and a mechanism to enhance system flexibility, resilience, and RE integration. As outlined in Chapter 4.1, the 18 priority interconnections from AIMS III provided the foundation for modelling in this Roadmap, but ASEAN's power landscape is rapidly evolving. New grid-to-grid projects—such as Singapore–Cambodia and Singapore–Malaysia–Vietnam projects—illustrate growing momentum towards regional electricity exchange and the need to capture these developments in future planning (The Straits Times, 2025; Petronas, 2025).

Going forward, advancing APG infrastructure and strengthening AIMS as a regional planning framework will be crucial to identifying projects of common regional importance that maximise cross-border benefits. At the same time, ASEAN should work towards a stronger regional market framework to operationalise trade among member states, moving step-by-step from bilateral exchanges to multilateral power trade (MPT). This process requires not only new physical links but also harmonised technical, regulatory, and commercial mechanisms to ensure efficient and secure cross-border power flows (ACE, 2024).

Finally, the APG's value extends beyond physical connectivity when paired with Renewable Energy Certificates (RECs). The cross-border REC trading, enabled by the APG, could deliver financial benefits to RE producers, create a transparent mechanism for certifying green electricity across borders, and expand opportunities for corporate buyers seeking credible renewable procurement. Together, the APG and RECs can reinforce each other: the grid enables physical power transfer, while RECs unlock the market and financial value of those flows.

Clean Coal Transformation (CCTR): From 'Baseload' to Transitional Flexibility

The roadmap results in Chapter 3 show how coal's role will shrink over time as renewables expand, with countries like Vietnam in 2045 already experiencing sharp shifts in hourly generation due to high shares of vRE. This highlights a critical transition: coal can no longer act only as baseload: it must evolve into a **flexible resource** that supports system stability.

Experiences from countries such as Germany demonstrate that coal plants can be adapted for cycling and load-following through operational changes and targeted retrofits (GIZ, 2018). For ASEAN, this implies that in **the short to medium term**, coal will need to **provide transitional flexibility**. Policies should incentivise plants that can ramp and cycle to balance rising variable renewable energy, supported by reforms to power purchase agreements, grid codes, and market structures (Agora, 2017).

Looking further ahead, ASEAN must also prepare a **comprehensive JIET plan for coal**. This will require careful sequencing of retrofits and retirements to ensure short-term flexibility without locking in long-term reliance. Equally important will be reskilling workers and supporting affected communities, creating opportunities in emerging clean industries, and coordinating regionally to share knowledge, financing approaches, and investment in alternative economic pathways. Securing financial support for decommissioning and reinvestment will also be essential (World Bank, 2023; Agora, 2023).

Ultimately, ASEAN needs to approach clean coal technologies not as an end state but as a key pillar of **the transitional strategy**. They should be seen as a bridge that supports grid resilience today while enabling the long-term shift towards a renewable-based power system.

Oil & Gas Connectivity, Security, and Sustainability: Securing Flexibility and Preparing Low-Carbon Pathways

Oil and gas will continue to play a vital role in ASEAN's energy system through the transition period. As shown in Section 3.1, the share of gas overtakes coal after 2030, reflecting its role as a more flexible complement to vRE. Additionally, oil remains the largest component of total final energy consumption (TFEC) in end-use sectors, especially transport. These facts show the importance of ensuring security of oil and gas supply, as well as developing an integrated gas market. Having **regional market analysis**

and coordinated supply planning will be the key priorities in the **near- and mid-term** to support the transition while meeting growing demand.

At the same time, the continued reliance on oil and gas highlights the importance of reducing the sector's emissions footprint. This includes tackling methane leakage and flaring, which represent significant near-term climate impacts, as well as deploying carbon capture and storage/carbon capture, use and storage (CCS/CCUS) in upstream operations, gas processing, and refining. Such measures are essential for reducing the carbon intensity of oil and gas production and supply. However, it is important to examine the competition in technological advancement and the falling cost trend between integrating CCS/CCUS with oil and gas and renewable energy.

Looking forward, low-carbon fuels such as hydrogen will be essential for decarbonising hard-to-abate sectors like iron & steel, cement, and long-haul transport. Section 3.2 highlights the challenge of balancing deployment between industry and transport, raising concerns about cost and availability. In the near term, deploying different hydrogen pathways — including grey and blue hydrogen — can help build early demand and infrastructure, while paving the way for wider adoption of green hydrogen in the future. Building on the foundations set in the ASEAN Low-Carbon Energy Technology (ALERT) Phase I study, coordinated regional roadmaps will be needed to map supply–demand balances, infrastructure requirements, market and certification frameworks, and opportunities for cross-border cooperation.

Regional Energy Policy and Planning: Providing Timely Evidence and Effective Policy Support Amid Rapid Global Change

ASEAN's long-term decarbonisation depends on well-designed policy and market mechanisms to prevent a rebound in fossil fuel use. As shown in Section 2.4., emissions begin to rise again after 2035 in the APAS and AREC scenarios, driven by growing energy demand. Consequently, RE struggles to remain competitive when no additional policy levers are in place. By contrast, the ASER scenario, which gradually introduces carbon pricing from 2030 alongside wider decarbonisation strategies, achieves sharper reductions despite higher overall demand.

This outcome reflects a broader insight: without **carbon pricing or equivalent mechanisms**, fossil fuels risk regaining competitiveness as demand rises, creating **structural lock-in** and making later decarbonisation **more costly** (WRI, 2021; I. Mengesha, 2025). Carbon pricing also sends the necessary market signal to shift investment away from fossil-based technologies and toward renewables, efficiency, and low-carbon alternatives (ADB, 2022).

ASEAN's current landscape shows carbon pricing remains in nascent stages (ACE, 2024). Singapore has implemented a carbon tax, Indonesia has a cap-and-trade system for coal power, Vietnam is preparing its emissions trading system (ETS), and Thailand is testing voluntary carbon markets. Learning from China's ETS experience (Li et al., 2023), where weak design created rebound effects, ASEAN must ensure future mechanisms are robust, transparent, and aligned with long-term decarbonisation rather than short-term fiscal goals.

The Regional Energy Policy and Planning (REPP) programme area therefore has a **critical bridging role** in ensuring that energy planning is closely coordinated with climate and economic policies to design these instruments. Regional dialogues under REPP should track national schemes, promote best practices, and explore how carbon pricing can reinforce renewable deployment and energy security, while preventing rebound trends.

Civilian Nuclear Energy: Preparing the Ground for Future Deployment

The roadmap results indicate a modest but notable role for nuclear power from 2035 onwards, with capacity additions in countries such as Indonesia, the Philippines and Viet Nam. This reflects current national ambitions and demonstrates that nuclear, while not dominant, is part of the region's broader energy diversification strategy, seen both as a means to enhance energy security and as a decarbonisation effort. Globally, nuclear power is increasingly recognised as a complement to renewables, helping to stabilise systems with high vRE penetration by providing low-carbon baseload and flexible support (IEA, 2022).

For ASEAN, the way forward requires more than capacity ambitions. **Public awareness and acceptance** remain critical prerequisites, alongside transparent communication of safety, cost, and environmental impacts. International experiences suggest that sustained engagement, early policy clarity, and strong regulatory institutions are decisive in securing societal trust (World Nuclear Association, 2024). At the same time, member states must **accelerate policy and regulatory preparedness**, ensuring alignment with international standards and exploring new technologies such as small modular reactors (SMRs), which offer more flexible deployment models (IAEA, 2023).

Looking ahead, the member states will consider nuclear as a long-term option that complements its expansion of RE. Building regional cooperation platforms, enhancing workforce skills, and strengthening regulatory readiness are essential steps to ensure that if nuclear capacity is pursued, it contributes to resilience, self-sufficiency, and the broader decarbonisation vision of the region (SEAPP, 2023).

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Consideration of JIET Principles in ASEAN Energy Transition Strategies

This roadmap, as previously mentioned, aims to translate ASEAN's economic vision into explainable energy transition pathways and proposed actionable strategies across three distinct time bandwidths. However, this analysis has limitations in terms of capturing aspects of JIET. The discussion below draws upon insights from the ASEAN RE-Gender Roadmap (ACE, 2022) and A Guide to Just and Inclusive Energy Transition in ASEAN Report (ACE, 2025).

Workforce and Community Transition

The shift away from a fossil-fuel-based economy necessitates a comprehensive and proactive plan for the region's workforce and the communities most affected by the transition.

In the near term (APAEC 2026–2030), the focus is twofold. First, a massive upskilling effort is required to meet the immediate demand for new skills in the rapidly expanding vRE, battery, and smart grid sectors. This includes training not only energy sector professionals but also non-energy stakeholders like bankers and investors to facilitate timely investment. Second, foundational reskilling programmes must be designed and implemented for workers in industries facing disruption, particularly the coal, oil and gas, and traditional automobile sectors, to ensure a just transition from the outset.

In the mid- to long-term, this strategy must mature into a systematic plan for the entire labour force. This involves broadening the skills of workers in declining supply chains and developing a high-tech workforce for emerging technologies like green hydrogen, advanced grid management (Artificial Intelligence (AI), Internet of Things (IoT)), and cross-border energy trading. Throughout all phases, policies must ensure gender inclusion, providing equal access for women to training opportunities and actively promoting female leadership in technical and decision-making roles.

Equitable Access and Affordability

The transition's success is measured not just by the megawatts deployed, but by ensuring that its benefits reach all segments of society, particularly the most vulnerable.

While the long-term energy costs of renewables are lower, the high upfront costs of new infrastructure can create affordability barriers. A key JIET strategy is to leverage decentralised energy systems, such as solar mini-grids, to improve energy access and reliability in off-grid and remote areas. To ensure these solutions are truly inclusive, policies in the near term must prioritise financial accessibility for these communities through targeted subsidies, microfinance options, and support for community-led financing models. This ensures that low-income populations are not excluded from the benefits of clean, affordable energy.

Inclusive Infrastructure and Market Development

The development of new physical and market infrastructure must be designed to be inclusive from the ground up, ensuring all stakeholders have a voice and an opportunity to participate.

This requires establishing inclusive governance frameworks that prioritise transparency and public participation in the planning of large-scale energy projects, such as new transmission lines for the APG. This ensures that local communities have a voice in decision-making processes and that benefits are distributed equitably. Furthermore, as new markets for clean energy and flexibility emerge, they must be designed to be accessible to all, preventing a scenario where benefits are captured only by large corporations and ensuring that small and medium enterprises (SMEs) and community-led projects can also play a meaningful role.

Data-Driven Governance and Monitoring

Underpinning all JIET efforts is the need for a robust governance framework that can measure what matters.

In the short term, the immediate priority is to strengthen the ASEAN Energy Database System (AEDS) to include gender-disaggregated and social inclusion data alongside conventional technical and financial indicators. In the long term, this enhanced data will enable a mature monitoring and evaluation (M&E) system to track the real-world social outcomes of the transition by embedding JIET and GEDSI principles into data governance and policy evaluation.

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