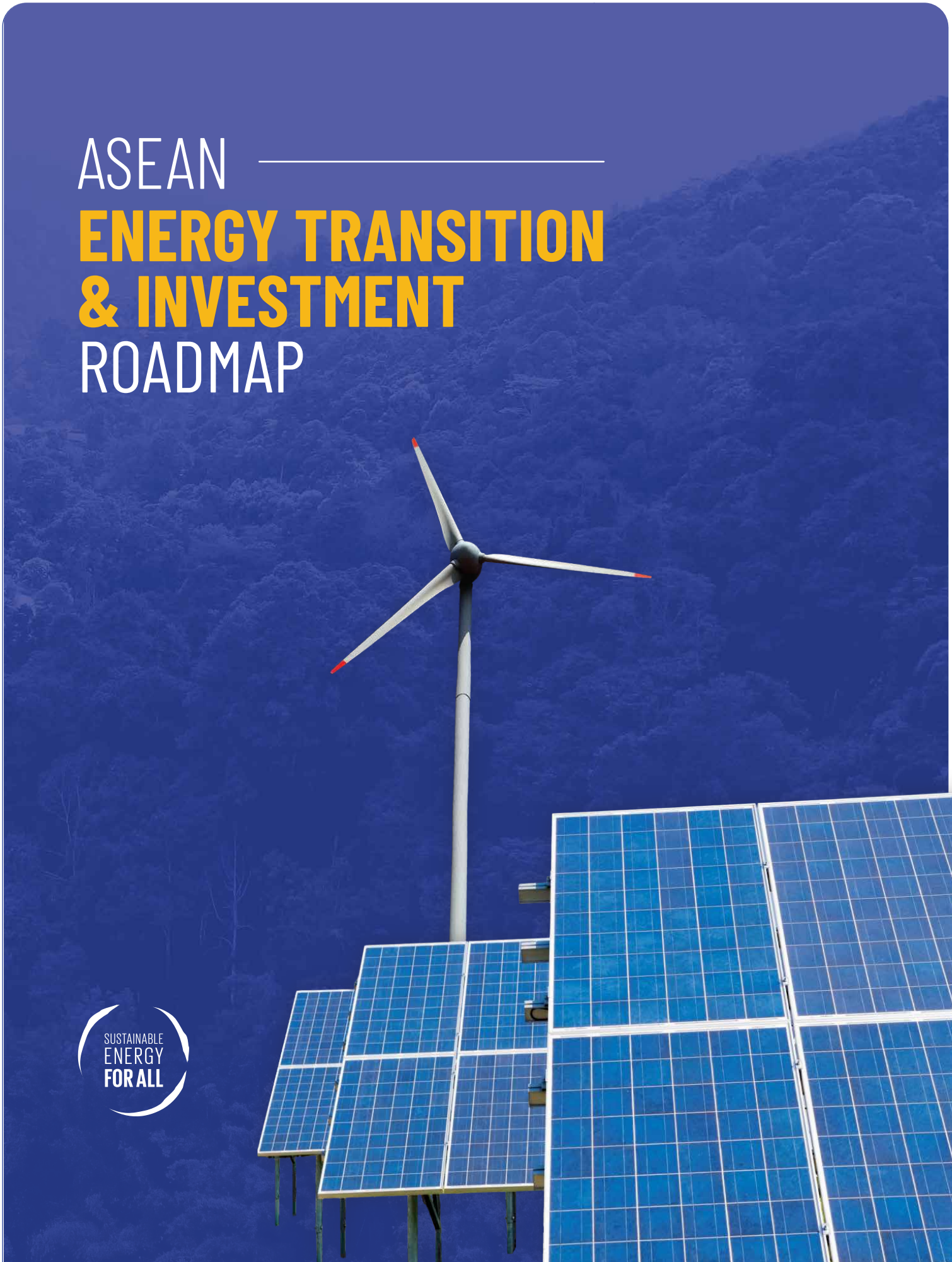
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ASEAN
ENERGY TRANSITION & INVESTMENT ROADMAP



SUSTAINABLE ENERGY FOR ALL





Foreword

ASEAN's energy transition represents one of the most significant opportunities for the region in the years ahead. As economies continue to grow and energy demand rises, the challenge is clear: how to meet these needs while advancing climate ambitions and strengthening long-term energy security. This Energy Transition and Investment Roadmap demonstrates that these objectives can go hand in hand. It shows that ASEAN can pursue a pathway towards carbon neutrality while continuing to foster economic growth and support industrial development.

The Roadmap sets out the key enablers of a successful energy transition. It highlights the critical role of expanding renewable energy, strengthening power grids and regional interconnections, improving energy efficiency, accelerating electrification, and mobilising the investment needed to translate ambition into implementation. Taken together, these measures can help ensure that ASEAN's growing energy needs are met in a way that is secure, affordable, and sustainable.

The Roadmap also underscores the value of long-term planning and regional cooperation. Collaboration across borders will be essential to unlocking the opportunities of interconnection, enhancing energy security, and building a more resilient and sustainable energy future for the region.

The UK commends the Regional Energy Policy and Planning Sub-Sector Network and the ASEAN Centre for Energy for their leadership, expertise, and close collaboration in delivering this important milestone. I would also like to thank Sustainable Energy for All and Palladium for their technical expertise and support throughout the development of this Roadmap. Their collective efforts have produced an important resource that can help guide ASEAN's energy transition.

The UK is proud to be a partner in ASEAN's energy transition journey. We remain committed to working alongside ASEAN and its institutions through knowledge sharing, technical cooperation, and continued collaboration to support a secure, affordable, and sustainable energy future. I look forward to seeing the Roadmap's vision translated into tangible progress across the region and to deepening our partnership in the years ahead.



Helen Fazey
UK Ambassador to the
Association of Southeast
Asian Nations (ASEAN)

ASEAN's energy transition is integral to sustaining regional economic growth, strengthening energy security, and advancing towards a secure, resilient, and low-carbon energy future. With diverse energy systems, national circumstances, and development priorities, the region requires coordinated efforts, evidence-based planning, and sustained investment to achieve an affordable, reliable, and inclusive energy transition.

Guided by the ASEAN Plan of Action for Energy Cooperation (APAEC) 2026-2030, ASEAN continues to strengthen regional energy cooperation and translate its shared aspirations into concrete actions. In supporting these efforts, the ASEAN Centre for Energy (ACE) remains committed to providing analytical insights and policy-relevant research through its flagship publications, particularly the ASEAN Energy Outlook (AEO), alongside other regional studies and initiatives that inform ASEAN's energy planning, policy development, and investment priorities.

In this context, the ASEAN Energy Transition and Investment Roadmap (ETIR), developed by Sustainable Energy for All (SEforALL) in collaboration with ACE and ASEAN Member States, offers additional perspectives on potential energy transition pathways and their implications for regional energy systems, infrastructure development, investment requirements, and socioeconomic considerations. The study contributes to the broader body of regional knowledge and provides complementary analysis to support discussions on ASEAN's energy transition and investment needs.

ACE welcomes this collaboration with SEforALL, supported by the ASEAN-UK Green Transition Fund under the UK Mission to ASEAN. We also extend our appreciation to ASEAN Member States and relevant stakeholders for their valuable contributions and insights throughout the development of this study.

Moving forward, ACE looks forward to continued collaboration with ASEAN Member States, dialogue and development partners, and other stakeholders in advancing the implementation of APAEC 2026-2030, strengthening evidence-based policymaking, and mobilising investment to support a secure, resilient, and sustainable energy future for ASEAN.



Dato' Ir. Ts. Razib Dawood
Executive Director
ASEAN Centre for Energy

ASEAN's continued economic growth is driving a rapid expansion in energy demand across the region. How that demand is met will have lasting implications for ASEAN's competitiveness, energy security and sustainable development. The task now is to ensure that the region's ambition is matched by the investment and implementation needed to deliver a more secure, affordable and sustainable energy future.

The ASEAN Energy Transition and Investment Roadmap (ETIR) provides a practical, evidence-based foundation to inform those decisions. Developed by Sustainable Energy for All (SEforALL) in collaboration with the ASEAN Centre for Energy (ACE) and the ASEAN Secretariat, it brings together national priorities and regional ambition to identify pathways for accelerating ASEAN's energy transition and the investments needed to deliver them.

Importantly, this Roadmap has been shaped with ASEAN. The contributions of Member States, energy planners and regional institutions throughout its development have helped ensure that it reflects the region's diverse realities and aspirations.

I acknowledge the support of the UK Mission to ASEAN, through the ASEAN–UK Green Transition Fund, and the leadership and collaboration of ACE throughout the development of this roadmap.

The next step is to turn the evidence presented in this Roadmap into action: mobilising capital, strengthening regional cooperation and converting transition priorities into investable opportunities that deliver for people, economies and the planet. SEforALL remains committed to working alongside ASEAN and its partners to support implementation of the roadmap.



Damilola Ogunbiyi
Chief Executive Officer and Special Representative of the UN Secretary-General for Sustainable Energy for All (SEforALL)





Acknowledgements

SEforALL gratefully acknowledges the financial support of the UK Mission to ASEAN through the ASEAN–UK Green Transition Fund (GTF), which made the development of the ASEAN Energy Transition and Investment Roadmap (ETIR) possible. The UK's continued commitment to supporting ASEAN's clean, inclusive and resilient energy transition has been instrumental in advancing this work.

SEforALL extends its sincere appreciation to the ASEAN Centre for Energy (ACE) for its close collaboration, technical guidance and coordination throughout the development of the ETIR, including its support in aligning the roadmap with ASEAN energy priorities and processes.

We are particularly grateful to the ASEAN Member States, including representatives and focal points from the Regional Energy Policy and Planning Sub-Sector Network (REPP-SSN) and relevant national energy-planning agencies, for generously contributing their time, national data, policy insights and technical expertise. Their active participation in the regional workshops, country consultations and validation process was essential in ensuring that the ETIR reflects the diverse circumstances, ambitions and priorities of the region.

SEforALL also acknowledges the guidance of the ASEAN Secretariat and the contributions of regional and international partners, technical experts and stakeholders who shared their knowledge and perspectives throughout the process. The ETIR is the result of this collective effort and reflects a shared commitment to advancing a secure, affordable, just and net-zero-aligned energy future for ASEAN.

This report was prepared by a team comprising Mr Divyam Nagpal; Mr Alvin Jose, formerly of SEforALL; Ms Jacqueline Lam, formerly of SEforALL; Dr Anindya Bhattacharya; Ms Iqlima Fuqoha; Dr Ioannis Pappis; Mr Tamojit Chatterjee; Ms Yogitha Miriyala; Mr Anant Wadhwa; Ms Amanda Castolina; Dr Naomi Tan; Mr Giulio Franci; Ms Alice Uwamaliya, formerly of SEforALL; Ms Wei Li; Ms Rosemary Idem; and Ms Ava Jean Strasser. The team conducted the research, analysis, and report preparation, drawing on its collective expertise in energy transition planning, energy systems analysis, policy, and investment.

ASEAN ENERGY TRANSITION & INVESTMENT ROADMAP

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EXECUTIVE SUMMARY



ASEAN is one of the largest and fastest-growing economic regions in the world. At around **GBP 2.9 trillion,** it was the world's **fifth-largest economy in 2024,** accounting for about 3.5% of global output. Services now contribute about 55% of regional GDP, while industry has held steady at around 30%. Growth is expected to remain robust, at around 4.2% in 2025 – 2026 and 4.5 – 4.8% over the longer term.

This growth will reshape the region's energy needs. Across the modelled economies, real GDP is projected to increase almost **fourfold between 2020 and 2050,** while population grows only modestly, from about 594 million to 653 million. Energy demand will therefore be driven overwhelmingly by rising incomes, industrialisation and urbanisation rather than by population growth. By 2050, passenger and freight transport activity each increase more than fourfold, cement production nearly quadruples, steel production nearly triples, chemicals demand more than triples and cooling demand grows about eightfold. How this demand is met will shape ASEAN's competitiveness, energy security, affordability and development prospects for decades to come.

Energy, climate and the role of the ETIR

ASEAN's energy sector emitted around **1.6 $GtCO_2$ in 2020,** about 5% of global energy-related CO_2 emissions, and this share would grow without accelerated decarbonisation. At the same time, ASEAN is among the regions most exposed to climate change: five of the world's 20 most at-risk countries are ASEAN Member States (AMS), and unchecked climate impacts could reduce regional GDP by 11% by 2100 and displace 87 million people in flood-prone areas. The transition is also an economic opportunity. The ASEAN Strategy for Carbon Neutrality (CNS) estimates that a green transformation could add GBP 2.2–3.9 trillion to **GDP and create 49–66 million jobs by 2050.**

The region has set a clear policy direction. The CNS, launched in 2023, sets out a pathway towards regional carbon neutrality. The ASEAN Plan of Action for Energy Cooperation (APAEC) 2026–2030, endorsed by ASEAN energy ministers in October 2025, raises ambition to a **30% share of renewables in total primary energy supply (TPES), a 45% share in installed power capacity and a 40% reduction in energy intensity** (from 2005 levels) by 2030. Progress against earlier targets has been mixed: renewables reached 15.6% of TPES in 2022, against a 2025 target of 23%. The challenge now is to match ambition with investment and implementation.

The ASEAN Energy Transition and Investment Roadmap (ETIR) is designed to support that task. Developed by Sustainable Energy for All (SEforALL) in collaboration with the ASEAN Centre for Energy (ACE) and the ASEAN Secretariat, with support from the UK Mission to ASEAN through the ASEAN–UK Green Transition Fund, it supports implementation of the CNS and is aligned with the ninth ASEAN Energy Outlook (AEO9) and APAEC 2026–2030. It links regional ambition with sector-level technology choices, investment needs and socio-economic outcomes.

Scope of the ETIR and the scenarios assessed

The ETIR identifies a least-cost trajectory for ASEAN's energy sector to meet growing demand across power, transport, buildings, industry and agriculture while reaching carbon neutrality by 2050. It combines an energy systems model covering more than 200 technologies, and an economic model linking energy demand to each country's development. Importantly, the regional model is built from **10 interconnected national energy system models,** preserving each AMS's resources, economic structure and transition priorities while linking national systems through cross-border electricity trade to represent the ASEAN Power Grid (APG). Beyond energy and emissions, the ETIR assesses investment requirements, employment, gender and youth dimensions, electricity access and land-use emissions.

The report compares two principal scenarios: **Business as usual (BAU)** represents a least-cost pathway based on current technology trends and costs, including committed power projects and APG initiatives to 2030, without additional climate ambition. **Net-zero emissions (NZE)** accelerate the deployment of clean technologies so that the energy sector is fully decarbonised and turns net-negative by 2050, supported by a further expansion of regional power interconnection.

Both scenarios are designed to meet the same underlying demand for energy services, such as tonnes of steel and cement, passenger- and freight-kilometres, and cooling. How that demand is met differs, however. Under NZE, final energy use is much lower because electric technologies are more efficient, while electricity demand is much higher. Comparing the two scenarios therefore isolates the changes in technology, fuels, investment and jobs that the transition requires. A current policies scenario is retained as a reference.

Key findings

Without a change of course, emissions more than triple; the NZE pathway instead turns the energy sector net-negative by 2050. Under BAU, energy-sector emissions rise from around 1.6 $GtCO_2$ in 2020 to 5.3 $GtCO_2$ by 2050. Under NZE, emissions peak in the 2030s, fall to about 1.5 $GtCO_2$ by 2045 and reach net-negative emissions of – 2.2 $GtCO_2$ by 2050, through deep decarbonisation across all sectors combined with bioenergy with carbon capture and storage (BECCS). Industry becomes the largest source of negative emissions, followed by power, while direct emissions from buildings and agriculture are eliminated. A third Current Policies scenario is maintained as a reference case. It shows that existing national policies and committed projects to 2035 would reduce 2050 emissions to about 3.6 $GtCO_2$, roughly a third below BAU, but would fall well short of carbon neutrality. Land use emissions, which add about 55% to the region's sequestration burden, are also integrated into the wider net-zero strategy.

The shape of this pathway makes action in the 2020s and 2030s essential. Because emissions only peak in the 2030s and still stand at about 1.5 $GtCO_2$ in 2045, the NZE pathway depends on a rapid scale-up of low- and negative-emissions technologies. A reduction that steep is only achievable if the coming two decades are used to build the infrastructure, supply chains, institutions and investment pipelines that are required. These decades also determine whether long-lived assets are locked in, including power plants, industrial facilities, vehicles and air conditioners, many of which will still be operating in 2050. Every year of delay makes the required pace of decarbonisation steeper and the transition more costly and increases the risk of stranded assets.

Behind the NZE pathway lies a fundamental change in how ASEAN uses energy, with electricity at its centre. Under BAU, final fuel use triples to 64,655 PJ by 2050 and fossil fuels still supply 85% of primary energy. Under NZE, the same energy services are delivered with 43% less final energy due to electrification-driven efficiency gains. Electricity rises from 17% of final fuel use in 2020 to 63% in 2050, followed by improved biomass, hydrogen and biofuels. In primary energy supply, coal and oil fall from 42% and 37% in 2020 to 14% and 3% respectively, while modern biomass, natural gas, nuclear and other renewables make up the 2050 mix.

This places the power system at the heart of the transition, and it must become both much larger and much cleaner. Under NZE, electricity generation reaches 7,962 TWh in 2050, about 77% more than under BAU, and installed capacity reaches over 2.1 TW, twice the BAU level. Utility-scale solar PV expands from 20 GW to 830 GW, alongside 160 GW of large hydropower and 279 GW of wind. Firm low-carbon capacity, including nuclear, underpins reliability. Coal falls to 3% of generation, compared to 55% under BAU. Regional integration deepens, with cross-border interconnection capacity rising from about 20 GW under BAU to 35.5 GW under NZE. Hydrogen emerges as a major new energy carrier, with production rising to more than 10,000 PJ in 2050.

Clean electricity and hydrogen in turn enable industry to decarbonise while continuing to grow. Steel and cement output under NZE is identical to BAU, yet industrial energy use is 32% lower. Whereas BAU industry becomes roughly two-thirds coal-based, under NZE electricity supplies close to half of industrial energy, biomass around 28% and hydrogen around 18%. Low-temperature heat and mechanical power, the largest industrial energy block, is almost entirely electrified using commercially available electric boilers and efficient motors. Where direct electrification is harder, new production routes take over: hydrogen-based direct reduced iron with electric arc furnaces supplies around 60% of steel output by 2050, while hydrogen-fired kilns provide 55–60% of cement output and CCS-equipped routes around a third, with clinker substitution a cheaper complementary lever.

The same pattern holds in buildings, where the transition expands rather than constrains access to comfort and modern energy. Space cooling is the fastest-growing end use: the residential cooling stock roughly doubles to 629 million units, and commercial cooling systems grow more than sevenfold by 2050. Under NZE, efficient air conditioners and fans reduce the energy needed to meet this demand, and electricity supplies more than 95% of residential energy. Electric stoves account for more than 90% of cooking by 2050. LED lighting becomes near-universal in both scenarios by the mid-2030s, and data-centre capacity more than triples to 5.1 GW.

Transport undergoes the most visible transformation, delivering the largest energy savings of any sector. Transport fuel use in 2050 is 62% lower in NZE than under BAU, driven largely by electric vehicles, with electricity supplying about 61% of transport energy and biofuels 26%. By 2050, the fleets of two- and three-wheelers and cars are almost entirely electric, as are around 90% of buses and 97% of heavy trucks, with hydrogen covering the remainder. Ammonia replaces oil in shipping, while aviation shifts progressively towards sustainable aviation fuels. Agriculture follows a similar path, becoming fully electrified and using 39% less energy than under BAU.

Implications for energy security and employment

The transition strengthens ASEAN's energy security by reducing overall fossil fuel use and imports. Under BAU, ASEAN grows more dependent on imported energy, with the domestic share of oil supply falling from 84% to 52% by 2050. The NZE pathway reverses this: fossil-fuel requirements in 2050 are **57% lower than under BAU,** and energy import dependence falls. Recurrent spending on imported fuel is replaced by investment in domestic, long-lived assets. The nature of energy security also changes. It increasingly depends on reliable and resilient power systems, adequate flexibility and well-governed interconnections, and on managing new dependencies on batteries, electrolysers and critical minerals. Energy security strategies should therefore evolve from fuel security towards technology, mineral and supply-chain resilience.

The transition is also a net creator of jobs. By 2050, the NZE pathway supports around 24.4 million direct energy-sector jobs, 8.6 million more than under BAU, including 5.4 million additional jobs in power and 3.4 million in transport. Oil and gas employment is around 73% lower than under BAU, requiring reskilling, social protection and economic diversification in fossil-fuel-dependent communities. The employment advantage widens sharply from the 2040s, so skills systems must be built now. Inclusion is central: women make up only around 8% of ASEAN's energy workforce, while people aged 15–34 make up about a third of the population. Closing the last-mile energy access gap remains a key part of a just transition.

Investment needs

Delivering the NZE pathway requires a step change in annual investment. Capital investment across all sectors averages around GBP 520 billion a year between 2020 and 2050, compared with about GBP 350 billion a year under BAU. The additional capital and operating investment needed to move from BAU to NZE averages about GBP 210 billion a year, with transport and power accounting for around 80% of it. This is not a net increase in the cost of the energy system: higher investment is largely offset by lower spending on fuel, which falls by around a quarter relative to BAU. The transition therefore shifts spending away from recurrent fuel purchases, much of them imported, towards long-lived domestic assets. This investment will not come from public budgets alone. It will come from a broad mix of governments, utilities, private investors, businesses and households. Vehicles account for around half of annual capital investment under NZE, most of it spent by households and firms buying electric two- and three-wheelers, cars, buses and trucks.

Annual needs are backloaded. They remain close to BAU levels through the 2020s and early 2030s, then rise to almost GBP 870 billion a year in the late 2040s as vehicle electrification, industrial fuel switching and hydrogen production reach scale. The central challenge is mobilising this capital rather than affordability. This decade should be used to build the institutions, bankable project pipelines, regulatory reforms and financing instruments, including targeted blended finance and deeper local-currency markets, that can absorb much larger volumes later. Existing initiatives such as the Just Energy Transition Partnerships with Indonesia and Viet Nam and the APG Financing Initiative provide a foundation.

Priorities for the region and the path forward

The ETIR shows that ASEAN can pursue carbon neutrality while continuing to expand energy services, industrial output and employment. Timing is critical: early action in the 2020s and 2030s keeps the pace of change manageable, whereas delay would leave an ever steeper and more costly path to carbon neutrality by mid-century. Key priorities include:

Electrify end uses and expand the power system ahead of demand. With electricity generation needing to reach almost 8,000 TWh by 2050, about six times the 2020 level, generation, networks and flexibility (storage, demand response and dispatchable low-carbon capacity) must be planned and financed with sufficient lead time.

Accelerate the ASEAN Power Grid. Cross-border capacity rises to 35.5 GW under NZE, almost double the BAU level, and regional power exchange could save an estimated USD 2–3 billion a year in investment and system costs. Delivering this means building on the ASEAN Interconnection Masterplan Study and the Lao PDR–Thailand–Malaysia–Singapore Power Integration Project, harmonising technical and regulatory frameworks and enabling multilateral power trade.

Put efficiency first. Even under NZE, roughly two-thirds of the cooling stock remains inefficient in 2050, so there is considerable scope for further savings. Priorities include regionally harmonised minimum energy performance standards for cooling and key appliances, efficient data centres and targeted industrial efficiency programmes, especially for small and medium-sized enterprises.

Build hydrogen and carbon-capture ecosystems through industrial clusters. By 2050, hydrogen supplies around 18% of industrial energy and CCS-equipped routes around a third of cement output under NZE. Demand aggregation, interoperable certification and shared infrastructure can make these investments viable and sustain industrial competitiveness.

Mobilise finance and put people at the centre. Additional investment of around GBP 210 billion a year calls for bankable pipelines, de-risking instruments and new sources of climate financing. Realising the 8.6 million additional jobs requires skills, just-transition and inclusion programmes, given that women hold only around 8% of energy jobs today.

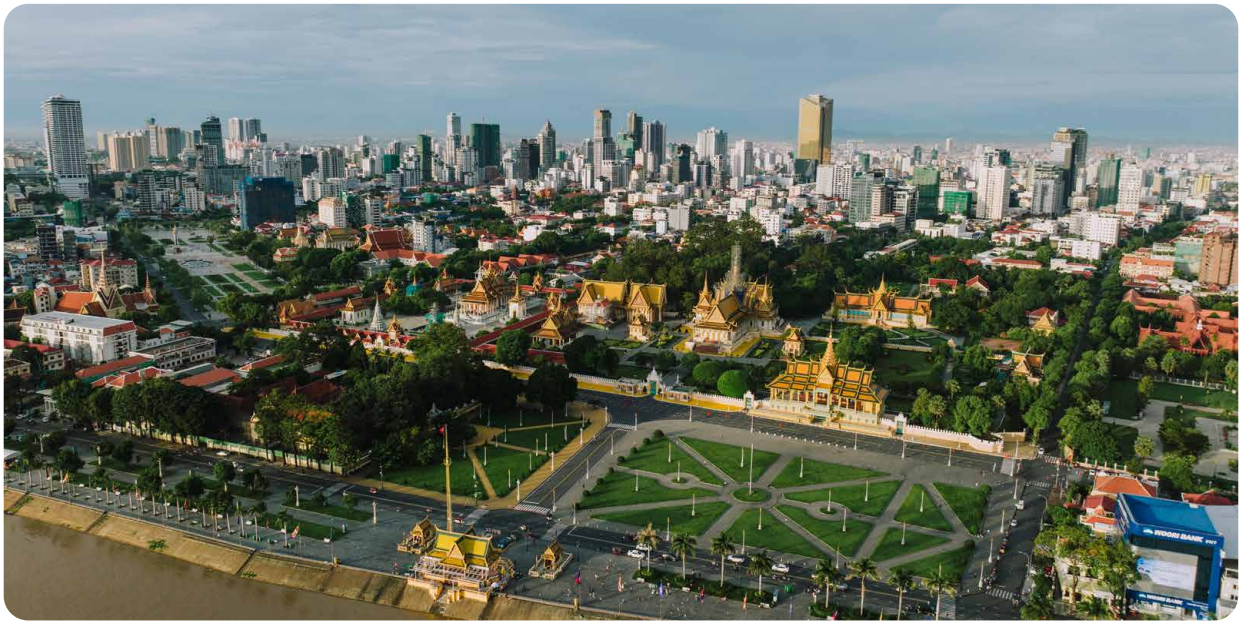
These priorities should be taken forward through established regional processes, informing REPP-SSN, the Senior Officials Meeting on Energy and the ASEAN Ministers on Energy Meeting, the implementation of APAEC 2026–2030 and the CNS, continued APG development and future editions of the ASEAN Energy Outlook.

Regional coordination cannot, however, substitute for national action. AMS begin from very different starting points in resources, energy systems, industrial structures and levels of development, so the pace and shape of the transition will vary. Because the ETIR is built on individual country models, it can generate national net-zero trajectories for each AMS. A key next step is to translate the regional roadmap into tailored, nationally owned country roadmaps and investment plans, aligned with national energy plans, power development plans and climate commitments, and converted into pipelines of investable projects. Anchoring regional ambition in national priorities will allow ASEAN to deliver an energy transition that is secure, affordable, just and aligned with its shared goal of carbon neutrality.



Chapter 1

INTRODUCTION



1.1 Context

The Association of Southeast Asian Nations (ASEAN)[1] launched its Carbon Neutrality Strategy (CNS) in 2023 setting out a regional pathway toward carbon neutrality while unlocking substantial socio-economic benefits from the green transformation. The energy sector will play a fundamental role in achieving regional carbon neutrality. It accounted for approximately 1.6 Gt of CO_2 emissions in 2020 or about 5% of global energy-related CO_2 emissions. Without accelerated decarbonisation, the region's energy sector is expected to remain a major contributor to future emissions due to rising consumption and expanding supply.

This ASEAN Energy Transition and Investment Roadmap (ETIR), developed with the support from the UK Mission to ASEAN through the ASEAN–UK Green Transition Fund (GTF), provides an evidence-based analysis outlining a trajectory for the energy sector that achieves carbon neutrality by 2050 while meeting energy demand necessary for socio-economic development. The ETIR builds on established regional energy outlooks (e.g., the ASEAN Energy Outlook series) and is guided by regional and national policy frameworks and strategies, including the ASEAN Plan of Action for Energy Cooperation (APAEC) and ASEAN Economic Community (AEC) Blueprint.

[1] A regional group of states in Southeast Asia: Brunei Darussalam, Cambodia, Indonesia, Lao PDR, Malaysia, Myanmar, Philippines, Singapore, Thailand, Timor-Leste and Viet Nam.

1.2 Background

ASEAN represents one of the largest and fastest growing economic regions of the world. At GBP 2.9 trillion,[2] ASEAN was the world's fifth-largest economy globally in 2024 accounting for about 3.5% of total global output (ASEAN Secretariat, 2025a). ASEAN's economic structure continues to gradually shift towards services contributing to about 55 % of total GDP in 2024, while the share of the secondary sector (industry) has remained largely constant over the past decade at around 30% and signalling the sustained position of the region as a manufacturing hub. Since 2005, ASEAN has also consistently maintained a trade surplus (ASEAN Secretariat, 2025a).

The region is also one of the most vulnerable to climate change, with five of the 20 most at-risk nations. Without immediate intervention, the effects of climate change will have a significant impact on ASEAN, including an 11% GDP loss by 2100 and 87 million people displaced in areas at risk of flooding across Indonesia, Malaysia, Myanmar, Thailand, and Viet Nam.

Initial assessments have projected that a transition to carbon neutrality could not only be a regional solution for climate change but also contribute to socio-economic development objectives. It is estimated that a green future could contribute GBP 2.2 – 3.9 trillion to GDP by 2050, increase investments to GBP 2.7 – 4.9 trillion by 2050, and create 49 – 66 million additional jobs by 2050 (ASEAN Secretariat, 2023).

The ASEAN CNS was developed to support this green transition. This regional Strategy describes an inclusive green economy transition that fosters sustainable growth while complementing national efforts. The Strategy envisions four core programs to sustain ASEAN's global competitiveness while preparing for the transition: (1) development of green industries; (2) interoperability within ASEAN; (3) globally credible standards; and (4) green talent. Building on ASEAN's strengths and existing national efforts, the collaborative strategy presents a detailed roadmap of initiatives to empower ASEAN's journey toward carbon neutrality.

ASEAN's climate ambitions are underpinned by a well-established regional energy policy architecture. Under the APAEC 2016–2025 (Phase II), ASEAN Member States (AMS) committed to raising the share of renewable energy to 23% of total primary energy supply (TPES) and 35% of installed power capacity by 2025, alongside a 32% reduction in energy intensity from 2005 levels. Progress has been mixed: by 2022, the renewable energy share of TPES stood at 15.6%, leaving a significant gap to the 23% target, while its share of installed capacity was on track to exceed the 35% goal, with projections reaching 39.6% by 2025.

Building on these foundations, the 43rd ASEAN Ministers on Energy Meeting endorsed APAEC 2026–2030 in October 2025, raising regional ambition to a 30% share of renewables in TPES and a 45% share in installed power capacity by 2030, alongside a 40% reduction in energy intensity from 2005 levels. These sequential APAEC targets sit alongside, and directly reinforce, the broader decarbonisation agenda set out in the ASEAN CNS, reflecting a shared recognition that the region's energy sector must be central to any credible pathway towards a green economy.

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[2] GBP is used as the default currency in this report with the following conversion rate adopted where original values are reported in USD: 1 USD = 0.73 GBP

1.3 Scope and Objectives

The ASEAN ETIR supports the implementation of the ASEAN CNS through a regional multi-sectoral energy systems modelling approach incorporating all major sectors, including power, transport, residential, commercial, industrial, and agriculture. Specifically, the ETIR analyses the least-cost trajectory for the region's energy sector to meet demand growth across sectors while reaching carbon neutrality by 2050. Chapter 2 provides an overview of the Methodology followed, including the open-source tools utilised for the analysis.

The ETIR develops and applies two scenarios for the ASEAN energy sector: a business-as-usual (BAU) scenario and a net-zero emissions (NZE) scenario. Each scenario considers demand growth based on the region's macro-economic context (discussed in Chapter 3), end-use energy requirements by sector, fuel mix, existing project pipelines across sectors and investment requirements. The NZE scenario is designed to achieve regional net-zero emissions by 2050, while the BAU scenario reflects the continuation of current policies and trends without this net-zero constraint.

Comparing the results across scenarios enables assessment of the changes required across the energy system, including renewable energy and energy efficiency deployment, fossil-fuel use, energy-system costs and investment needs. Chapters 4 and 5 provide an overview of the results across the two scenarios. The analysis also considers selected environmental, social and economic indicators, including macroeconomic and employment impacts.

Drawing on the modelling results and stakeholder engagement, the ETIR, in Chapter 7, sets out evidence-based regional overarching and sector-specific recommendations aligned with ASEAN's development, green-growth and carbon-neutrality ambitions. These recommendations are intended to inform regional cooperation and provide the context for country-specific energy transition pathways. Because the ETIR is built on individual country-level energy system models, it can also produce national NZE trajectories for each AMS. While not within the scope of this regional report, such national trajectories, together with sectoral insights, could support net-zero roadmapping and investment facilitation efforts by practitioners at the country level.



Chapter 2

METHODOLOGY



2.1 Integrated Modelling Framework

The primary objective of the ASEAN ETIR is to assess the overall energy sector and sectoral least-cost pathways to achieve net zero by 2050 and provide insights on technology mix and the investment required to support mitigation actions across the ASEAN region. The study examines all major sectors in which energy is consumed, including power, transport, buildings, industry, and agriculture. The scope focuses on energy-related CO_2 emissions.

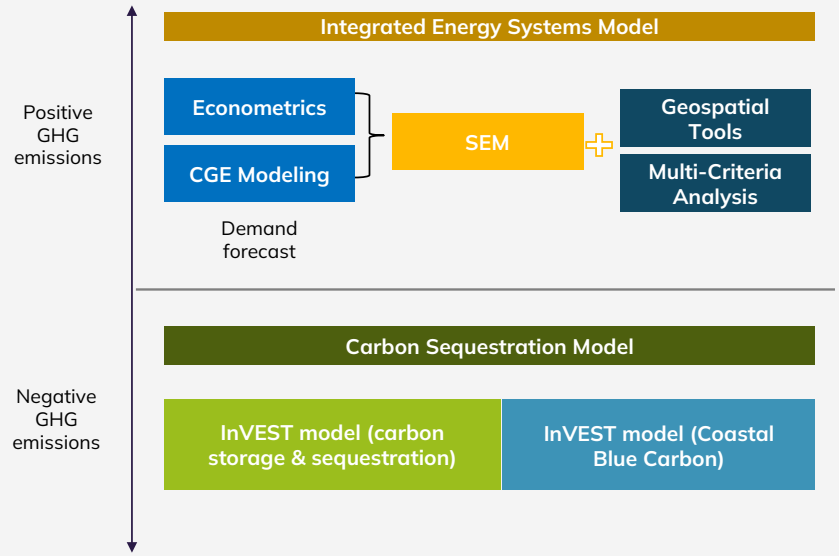
An integrated assessment modelling framework is applied, using a computable general equilibrium (CGE) linked with a least-cost energy systems optimisation model to assess technology pathways for each ASEAN Member State and for the region as a whole. The mitigation assessment examines the role of emissions-abatement technologies and negative emissions options, including technological solutions and natural carbon sequestration. The cost of achieving the emissions-reduction pathway is assessed primarily through the capital expenditure (CAPEX) of technologies, together with their lifetime fuel and maintenance costs.

The study also evaluates the macroeconomic impacts, jobs created, and costs and benefits associated with the mitigation actions. A complementary analysis further looks at the requirements for minerals associated with the energy transition under the various scenarios to 2050.

The ETIR is developed in close collaboration with the ASEAN Secretariat and the ASEAN Centre for Energy (ACE), building on the ASEAN Energy Outlook (AEO). Its overarching goal is to position clean energy technologies and nature-based carbon sinks as strategic options for ASEAN Member States, consistent with their development priorities and green growth ambitions. The study uses a combination of models and analytical tools to address the different components of the assessment (Figure 1). All models and tools used in the study are open access and license-free, facilitating adoption and knowledge transfer.

FIGURE 1

Illustration of models and tools used for the study



Note: SEM = SEforALL Energy Systems Model; CGE = Computable General Equilibrium

2.1.1 SEforALL Energy Systems Model (SEM)

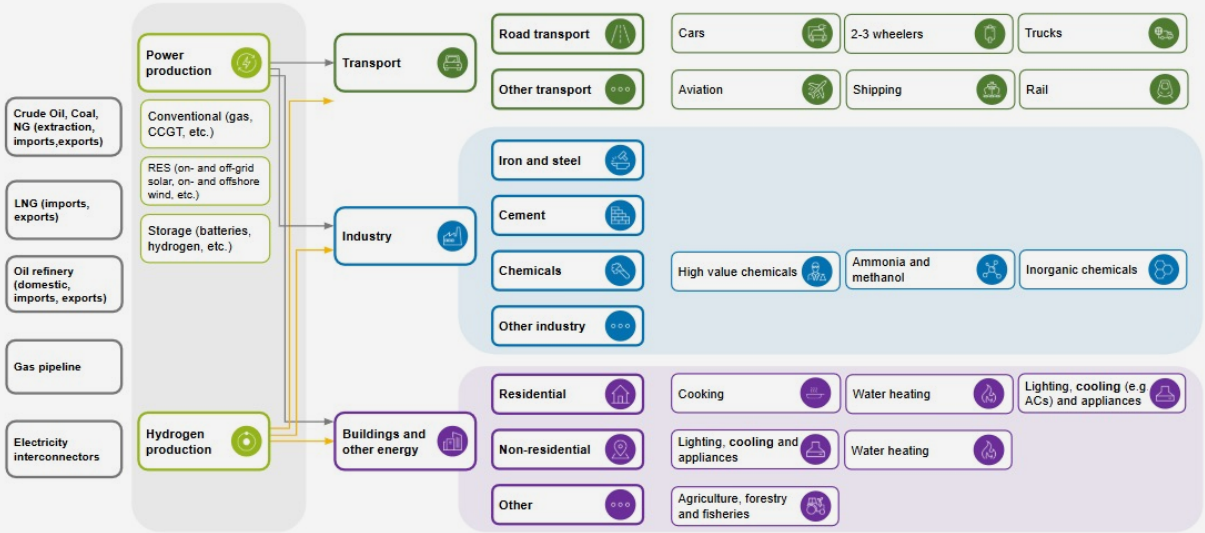
The Sustainable Energy for All (SEforALL) Energy Systems Model (SEM) is a long-term energy systems model designed to identify least-cost pathways for energy systems to achieve net-zero, low-carbon or energy security objectives for an economy, country, or region. It has been developed based on the OSeMOSYS (Open Source Energy Modelling System) framework and expanded to provide detailed sectoral analysis. In addition to a comprehensive power sector representation, including mini-grids and distributed renewable energy (DRE), SEM covers transport (road, rail, aviation, and shipping); industry (cement, iron and steel, chemicals, and other industries to be profiled as needed); agriculture (agro-food processing and agricultural motive power); and buildings (lighting, cooling, cooking, and other appliances).

SEM also incorporates key energy transition technologies, including battery energy storage systems (BESS), hydrogen, carbon capture, utilisation and storage (CCUS), and bioenergy with carbon capture and storage (BECCS). At present, SEM does not explicitly model land use, land-use change and forestry (LULUCF) or its contribution to achieving NZE. Instead, it focuses on decarbonisation pathways across energy demand segments and on balancing negative-emissions technologies where feasible. LULUCF carbon-sink potential is assessed separately using the InVEST model. SEM also does not undertake power system load flow analysis.

One of SEM's key advantages is its broad technology coverage with more than 200 technologies and its high level of granularity in the industrial sector (Figure 2). The model includes detailed technology options and associated investment requirements for sectors such as cement, steel and chemicals, including coal carbon capture and storage (CCS), hydrogen-based direct reduced iron (DRI), gas carbon capture, utilisation and storage (CCUS), electric arc furnaces (EAFs), and heat pumps. It can also estimate the number of technologies required under different decarbonisation pathways, such as electric cookstoves and electric buses. The transport sector includes freight trucking as well as two- and three-wheelers. SEM can also represent cooling demand and the associated energy consumption and emissions through its cooling module. The sub-sector and technology-level granularity of CAPEX, OPEX and fuel costs provides a detailed basis for understanding investment requirements and informing national financing strategies.

FIGURE 2

Overview of the technology options across sectors in the SEM



2.1.2 Global Trade Analysis Project (GTAP) Model

Energy demand forecasting is undertaken using two complementary approaches. A CGE model is applied in countries where input-output tables are available, while an econometric approach is used for the remaining countries. A key consideration in both approaches is the comparison of growth rates with those of similar economies and the historical GDP-per-capita trajectories of developed economies.

The CGE model used in the study is the Global Trade Analysis Project (GTAP), which captures the inter-economic indirect and induced effects associated with the level of economic output required to achieve the target GDP per capita and the corresponding energy demand. The base-year economy derived from the model is subsequently projected using a recursive-dynamic approach. Key exogenous drivers of the projections include population growth, total factor productivity and labour productivity growth.

2.1.3 InVEST Model

InVEST is a suite of free, open-source software models used to map and value ecosystem services that sustain and enhance human well-being. These services include the production of goods such as food; life-support processes such as water purification; life-fulfilling services such as recreation; and the conservation of options such as genetic diversity for future use. Despite their importance, natural capital and ecosystem services are often poorly understood and insufficiently monitored and, in many cases, subject to rapid degradation and depletion. InVEST enables decision-makers to quantify trade-offs associated with alternative management choices and identify areas where investment in natural capital can support human development and conservation.

The InVEST Carbon Storage and Sequestration model estimates the amount of carbon currently stored in a landscape and the amount of carbon sequestered over time. It aggregates the biophysical carbon stored in four pools: aboveground living biomass, belowground living biomass, soil, and dead organic matter, based on land-use and land-cover (LULC) maps provided by users. Where future LULC maps are available, the model estimates changes in carbon stocks over time. The model can also value carbon sequestration as an ecosystem service using additional information such as the market value or social cost of carbon, its annual rate of change, and a discount rate.

The InVEST Coastal Blue Carbon module quantifies the value of carbon storage and sequestration services provided by coastal ecosystems. The module allows users to incorporate spatially explicit disturbances to coastal vegetation caused by climate change, such as sea-level rise, and human activities, such as wetland drainage or shoreline hardening. It can also estimate avoided emissions and identify areas where carbon stocks experience net gains or losses over time.

Coastal vegetation and wetland ecosystems can remove substantial amounts of carbon dioxide from the atmosphere, helping regulate the climate. Mangroves, seagrasses and salt marshes store carbon and continuously accumulate additional carbon in their biomass and sediments, creating long-term carbon reservoirs. The model can therefore be used to assess changes in carbon storage over time and compare outcomes across alternative management scenarios. The study will use two InVEST modules: the Carbon Storage and Sequestration module and the Coastal Blue Carbon module.

2.2 Value added by the ETIR

The ASEAN ETIR provides a comprehensive assessment of the energy transition by integrating energy supply and demand across key sectors. It goes beyond energy system and emissions analysis by quantifying investment requirements and energy system costs, as well as the broader socioeconomic impacts of the transition, including macroeconomic (GDP) impacts and net job creation.

A key value added of the ETIR is its integrated approach to energy demand and economic development. Energy demand projections are linked to the broader macroeconomic outlook through the CGE framework, where energy system transformation can be assessed in terms of its implications for economic activity, sectoral output, and GDP. This provides a more dynamic interaction between energy transition and economic development than a conventional energy-system assessment based solely on exogenous demand assumptions. The ETIR also captures new and emerging sources of energy demand, including data centres, alongside evolving electrification and hydrogen in industrial processes, helping to reflect the changing structure of ASEAN economies.

The ETIR also incorporates a broad range of emerging and enabling technologies relevant to long-term decarbonisation, including hydrogen, renewable energy technologies, energy storage, electrification and other low-carbon technologies. This enables the assessment to consider not only currently established technologies, but also the potential evolution of the energy system as new technologies become increasingly competitive and are deployed at scale. The regional ETIR model is built as an integrated aggregation of 10 country-level energy system models,[3] rather than viewing ASEAN as a single homogenous energy system. This approach preserves the distinct resources availability, economic structures, energy demand profiles, technology pathways, and transition priorities of each AMS, while enabling these national systems to be assessed collectively. Integration allows national transition pathways to be connected through regional electricity trade with shared resources, thereby identifying opportunities that may not be visible from a purely national assessment. ETIR assesses the least-cost development of ASEAN power interconnections, examining how cross-border electricity trade and expanded regional interconnection capacity can optimise the use of renewable energy resources across Member States; enhance energy security and system flexibility; and support the achievement of the ASEAN carbon neutrality strategy by 2050.

The ETIR therefore considers not only the expansion of individual national power systems but also how regional power integration and progressively expanded interconnections can facilitate a cost-effective and coordinated pathway towards carbon neutrality. The ETIR also incorporates negative-emissions pathways, including BECCS and carbon sequestration opportunities through LULUCF and coastal ecosystems. Its longer-term modelling horizon and emphasis on country-level outputs allow the analysis to capture national transition priorities and their implications within the broader ASEAN regional context.

In summary the major uniqueness of the ETIR is as follows:

- Ten interconnected national models: the Roadmap links country-level energy systems through electricity trade to represent the APG network and assess the benefits of regional integration.
- Common but differentiated pathways: the Roadmap preserves each Member State's resources, economic structure, demand profile and transition priorities, while generating consistent regional insights.
- Development-led energy demand: the Roadmap derives future energy needs from country development plans and regional economic growth, rather than relying solely on externally fixed demand assumptions, as well as captures new and emerging sources of energy demand, including data centres.
- Integrated sector-coupling analysis: the Roadmap connects power, transport, industry, buildings and agriculture to capture country-specific technology choices across more than 200 technology options, system interactions (e.g. electrification of end-uses) and policy implications.
- Energy and natural carbon systems: the Roadmap combines technological decarbonisation and BECCS with terrestrial and blue-carbon stock and sequestration assessments.
- Critical minerals and value chains: the Roadmap links renewable-energy expansion with regional mineral requirements, supply availability and opportunities for supply chain development.

[3] The ETIR covers ten AMS reflecting Members at the time of the start of the analysis. Timor-Leste, which joined ASEAN in 2025, is not yet modelled.

2.3 Scenarios

The ASEAN ETIR considers three scenarios as outlined in Table 1. Business as usual (BAU) represents a least-cost development pathway based primarily on current technology trends without explicitly enforcing national energy policies or additional climate ambitions. The current policies scenario (CPS) incorporates existing national energy policies and targets, resulting in greater deployment of renewable energy and cleaner technologies. Net-zero emissions 2050 (NZE) represents an accelerated transition pathway requiring the energy sector to achieve full decarbonisation by 2050; it is supported by increased regional power interconnection.

TABLE 1
Scenarios designed for analysis

Business as Usual (BAU)	Current Policies Scenario (CPS)	Net-Zero Emissions 2050 Scenario (NZE)
The BAU scenario assumes that ASEAN Member States continue to grow at approximately 4.2% in 2025–2026, increasing to around 4.5 - 4.8% in the long run, reflecting resilient domestic demand, export performance and investment. Energy demand and activity levels are driven by projected GDP-per-capita growth and population. The energy demand required to support this economic growth is met through technologies that are available at current costs and levels of market maturity, with investments determined by least-cost deployment. Energy efficiency is not prioritised because of the absence of a robust action plan. National energy policies and targets are not explicitly imposed; consequently, the technology mix broadly follows current trends. On the supply side, committed power projects between 2025 until 2035 are considered, including the ASEAN Power Grid initiatives.	The CPS assumes the same development objectives as the BAU scenario. Technology deployment is aligned with current national energy policies and targets across ASEAN Member States, including policies supporting a higher share of renewable energy and the deployment of cleaner technologies across sectors.	The NZE 2050 scenario assumes the same development objectives as BAU and CPS, while accelerating the deployment of clean technologies to achieve the ASEAN carbon neutrality strategy by 2050. Under this scenario, the energy sector is fully decarbonised by 2050. ASEAN power interconnections are assumed to expand further to support regional energy security and the energy transition.

For the remainder of the report, results are presented primarily for BAU and NZE scenarios as these provide a clear contrast between a continuation of current development trends and an accelerated pathway towards ASEAN carbon neutrality. It allows the analysis to highlight the incremental changes, technology shifts, investment requirements, emissions reductions and socio-economic impacts associated with the energy transition. CPS is retained as an important policy reference case but is not reported extensively, as it represents an intermediate policy pathway.

2.4 Data and Assumptions

Key data points and assumptions used in the modelling exercises for each sector are summarised in Table 2. Key data points and national energy policies were compiled and subsequently validated with representatives of AMS during validation workshops. Data from national statistics documents were complemented by inputs from ACE.

TABLE 2
Data and assumptions for the ETIR model development

Sector	Input variable	Data source
Socioeconomic indicators	GDP – current and projected	IIASA SSP2 (Myanmar and Lao PDR) and GTAP; validated by AMS during the second workshop
	Population – current and projected	IIASA SSP 2 (Myanmar and Lao PDR) and GTAP
	Number of households	ACE (2025)
	Energy Balance Table	ACE and national sources (2025)
	Energy policies and targets	ACE's AEO8; validated by AMS during the second workshop
Power	Power generation assets – existing & future (capacity, generation, efficiency, capacity factor)	ACE and national sources; discussed during the first workshop with AMS
	Transmission and distribution (T&D) losses	ACE and national sources (2025)
	Power interconnection plans	ACE and national sources (2025)
	Hourly load profile	ACE (2025)
	Capacity factor for solar and wind	Renewable Ninja (2025)
	Technology costs (capital, operational, and fixed costs)	Transition Zero ASEAN Power Grid v1 (2024)
	Fuel costs	Transition Zero ASEAN Power Grid v1 (2024)
Transport	Number of vehicles by transport mode and fuel type	ACE (2025)
	Annual distance travelled	ACE (2025)
	Fuel economy	ACE (2025)
	Technology costs	Global database
Buildings/cooking	Number of stoves per fuel type per households	ACE, WHO Global Health Observatory
	Thermal efficiency	Multiple external sources for each AMS (e.g., IEA and The World Bank)
	Technology costs	Global database

TABLE 2 (continued)
Data and assumptions for the ETIR model development

Sector	Input variable	Data source
Buildings/cooling	Number of cooling appliances or % of cooling appliance per household & services	ACE (2025)
	Annual energy intensity for each cooling appliance	ACE, multiple external sources for each AMS (e.g., BCA Singapore, DEDE Thailand, IEA Southeast Asia Cooling)
	Share of floor area requiring cooling	ACE, ASEAN SHINE, national benchmarking studies
	Technology costs	Global database
Buildings/data centre	Historical trend in data-centre establishment	ACE (2025)
	Split between colocation and hyperscale data centres per country	ACE (2025)
Buildings/lighting	Number of lighting appliances or % of lighting appliance per household and services	ACE (2025)
	Annual energy intensity for each appliance	ACE (2025)

2.5 Stakeholder Engagement

The ETIR has been developed in close collaboration with ACE and regional and national stakeholders throughout the data-collection and analysis process. The ETIR has benefited from data, policy inputs and technical feedback provided by AMS through focal points from the Renewable Energy and Power Policy Sub-Sector Network (REPP-SSN), alongside relevant national energy-planning agencies.

The work has also been aligned with the ASEAN Energy Outlook 9 (AEO9), APAEC 2026–2030, and the work of the ASEAN Secretariat task force supporting the ASEAN Strategy for Carbon Neutrality. This coordination is intended to ensure that the ETIR complements existing ASEAN processes and provides decision-makers with consistent evidence on least-cost transition pathways, investment needs, enabling infrastructure and socioeconomic implications.

Two regional capacity building and consultation workshops were conducted during the development of the ETIR. Beyond strengthening technical capacity, the workshops provided a structured mechanism for AMS to review the underlying data, assumptions and preliminary findings, helping to ensure that the ETIR reflects national circumstances and regional priorities.

- The first regional capacity building workshop was held in July 2025 in Bangkok and brought together REPP-SSN focal points, national energy planners, ACE, and regional and international partners. The workshop focused on deepening participants' understanding of energy system analysis and scenario modelling. Participants gained hands-on modelling experience, applying energy sector analysis to national contexts, addressing real-world challenges, validating data, and exploring tailored energy transition pathways through in-depth country consultation sessions. The workshop also strengthened a growing regional network of energy modellers and planners to support the further development of the ETIR.
- The second workshop, held in February 2026 in Manila, marked a critical milestone in strengthening and validating the ETIR's analytical foundation. REPP-SSN focal points and representatives of relevant national agencies reviewed the initial ETIR findings, modelling inputs and policy assumptions to assess whether the proposed transition pathways adequately reflected national and regional realities. One-on-one country consultations enabled more detailed examination of national data landscapes, energy policies and planning priorities. Participants also strengthened their practical understanding of the SEforALL SEM and the CGE model. Feedback received during the workshop and subsequent bilateral consultations has been incorporated into the refinement of national inputs, modelling assumptions and scenario results.

Collectively, these engagements have helped build regional and national ownership of the analytical process, strengthen regional modelling capacity, and ensure that the ETIR is technically robust, policy relevant and grounded in ASEAN Member States' priorities. The resulting analysis is expected to support continued consideration through REPP-SSN and the Senior Officials Meeting on Energy, while informing wider ASEAN discussions on investment planning, power system development, energy security, green jobs and a just and equitable transition.

2.6 Limitations and Future Areas of Refinement

The outcomes of this study should be interpreted in the context of the model structure, temporal resolution, input data and underlying assumptions. This section discusses limitations and areas for further improvement in future versions of the ETIR and deep-dive analyses. The SEforALL SEM is designed to identify least-cost medium- to long-term energy transition pathways rather than reproduce detailed short-term power system operation. In this study, the model year is represented through monthly time slices, without intra-day or day-to-day resolution. Also, due to the size of the model, which contains the energy supply system of 10 ASEAN countries across all sectors, the analysis is in five-year intervals rather than annual.

Furthermore, hydropower availability is further represented through four seasonal periods: the wet season (November–March) and three dry-season periods (April–May, June–September and October), rather than through monthly hydrological profiles. As a result, variations in hydropower availability within these periods, including short-term changes in water availability, are not explicitly captured, which may affect the representation of hydropower operation and its interaction with other generation and storage technologies. In addition, a national electricity load profile is applied to residential and commercial electricity demand, while limited data means that electricity consumption in other sectors is not represented using sector-specific load profiles. The model therefore does not fully capture differences in the timing and coincidence of electricity demand across sectors, which become increasingly relevant under the NZE pathway as transport, industry and other end uses become progressively electrified. Battery storage is represented through a single generic battery storage technology, rather than through multiple battery technologies with different storage durations, efficiencies, costs and operational characteristics. Consequently, the results do not capture the potential differentiation in the roles of short- and longer-duration battery storage technologies within the future power system. Taken together, these temporal and technological simplifications may influence the representation of peak demand, variable renewable energy integration, storage operation and overall system flexibility requirements.

The analysis is also subject to limitations associated with the availability, consistency and reference year of the underlying input data. The model was developed using the most recent data available during the study period, with many of the core energy system inputs sourced from ACE and national sources up to 2025, complemented by international and sector-specific datasets. The modelling therefore reflects the technology characteristics, costs, fuel prices, energy system conditions and policy information available at the time of model development. Differences in data availability and granularity across AMS also required the use of regional or international datasets where country-specific information was unavailable. Furthermore, given the modelling horizon to 2070, projections of future energy demand, technology costs and performance, fuel prices, resource availability and deployment conditions are inherently uncertain and may evolve differently from the assumptions adopted in this study. Consequently, the results should be interpreted as indicative least-cost pathways under the assumptions considered, rather than as forecasts of the precise technology mix, investment requirements or power system operation.

The transport sector modelling holds transport activity and modal shares constant across the BAU and NZE scenarios. Decarbonisation under NZE is therefore achieved primarily through changes in vehicle technologies and fuels, rather than shifts between transport modes. The pathway does not capture the potential contribution of shifts from private vehicles to public transport or rail, or from road freight to rail and other lower-emission modes. Such shifts could reduce transport energy demand and emissions, potentially lessening the scale of technology deployment and fuel switching required to achieve net zero.

The ETIR also draws on complementary analyses covering macroeconomic impacts, power system flexibility, investment requirements, land-use change and carbon sequestration, employment, gender equality, and energy access. Each of these components is subject to its own methodological and data limitations. The macroeconomic and employment results reflect modelled relationships between sectors and should not be interpreted as precise forecasts of GDP or job creation. Investment estimates represent indicative capital requirements based on modelled technology deployment and assumed unit costs; they do not constitute project-level financial assessments and do not fully capture financing costs, transaction costs, project development constraints or differences in country risk.

The land-use and carbon-sequestration analysis is influenced by the spatial resolution, land-cover classifications and assumptions used to project future land-use change. It does not fully capture local ecological conditions, competing land uses, implementation feasibility or the permanence of carbon sequestration. Similarly, the gender, youth and energy access assessments are constrained by the availability and comparability of disaggregated data across AMS. These components are therefore intended to identify regional trends, distributional considerations and priority areas for further analysis, rather than provide comprehensive country-level assessments.

The different analytical components also operate at varying spatial and temporal resolutions and are not fully integrated through a single iterative modelling framework. Results across chapters should therefore be interpreted as complementary perspectives on ASEAN's transition, rather than as outputs with identical boundaries, assumptions or levels of precision.

Taken together, these limitations do not diminish the value of the ETIR as a regional strategic planning tool. Rather they define its appropriate use: to compare alternative pathways; identify the direction and approximate scale of change; highlight investment and policy priorities; and support further national and sector-specific analysis. The results are not intended to be used as substitutes for national energy planning, detailed power-system studies, project feasibility assessments or country-level policy design.

Chapter 3

ENERGY DEMAND OUTLOOK



This chapter sets out projected energy service demand for the region over the period 2020–2070, disaggregated by country and by end-use sector. The projections are the demand-side output of a Global Trade Analysis Project (GTAP)-based computable general equilibrium (CGE) framework, in which country-level macroeconomic and demographic trajectories drive sectoral activity, which in turn drives demand for energy services.

The demand set is expressed in service and activity terms rather than as final energy consumption. Residential and commercial demands are given in petajoules of delivered or useful energy; transport demand is expressed as passenger-kilometres and tonne-kilometres; and the material-producing industries are expressed as physical output in million tonnes per year. This structure is deliberate: it allows the supply-side model to determine the fuel and technology mix that meets each service demand. The demand sector covers industry, buildings, agriculture, data centres, aviation and shipping. It excludes road transport, which enters the model as activity rather than energy, and it expresses cooling demand as useful thermal energy.

3.1 Demographic and Macroeconomic Drivers

The macroeconomic drivers underlying the demand projections are summarised in Table 3. Real GDP is reported in constant 2014 US dollars, consistent with the GTAP 10A base year, and population is drawn from the Shared Socioeconomic Pathways.

TABLE 3

Population, real GDP and GDP per capita, selected years

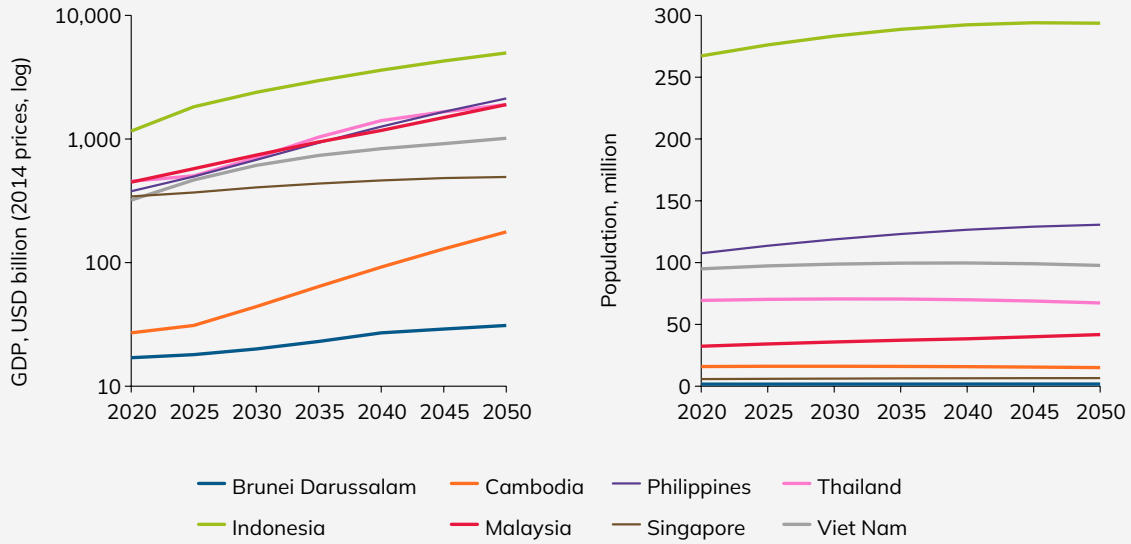
Country	Population 2020	Population 2030	Population 2050	GDP 2020	GDP 2030	GDP 2050	GDP/capita 2020	GDP/capita 2050
Brunei Darussalam	0.5	0.5	0.5	17	20	31	38,006	58,253
Cambodia	15.9	16.1	15.1	27	44	177	1,674	11,730
Indonesia	267.2	283.3	293.6	1,159	2,386	4,968	4,337	16,917
Malaysia	32.3	35.8	41.1	448	741	1,576	13,860	38,345
Philippines	107.5	118.8	130.6	378	678	2,129	3,514	16,295
Singapore	5.8	6.1	6.6	343	406	530	59,579	80,303
Thailand	69.4	70.6	67.3	455	705	1,898	6,564	28,187
Viet Nam	94.9	98.8	97.7	320	612	1,014	3,369	10,382
Total	593.5	629.9	652.6	3,147	5,592	12,322	–	–

Note: Population in millions; real GDP in USD billion at constant 2014 prices; GDP per capita in USD at constant 2014 prices. Totals cover the eight economies for which macroeconomic output is reported.

Three features of the driver set shape everything that follows. First, the region is demographically mature by the standards of a developing region: the reported population of the eight modelled economies rises from roughly 594 million in 2020 to about 630 million by 2030 and 653 million by 2050, with the rate of increase falling sharply after 2030 (Figure 3). Cambodia, Thailand and Viet Nam all show declining populations before 2050, and Indonesia peaks around 2045. Demand growth in ASEAN is therefore driven overwhelmingly by rising income and structural change, not by population expansion as such.

FIGURE 3

Real GDP and population trajectories by country, 2020–2050



Second, income convergence is rapid but highly uneven. Cambodia's real GDP per capita rises roughly sevenfold between 2020 and 2050, and that of the Philippines' more than fourfold, while Brunei and Singapore grow from an already high base. The absolute spread nonetheless remains wide throughout: Singapore's per-capita income in 2050 is still of the order of five times that of the Philippines.

Third, the economic weight of the region remains concentrated. Indonesia alone accounts for roughly 37% of the reported real GDP of the eight modelled economies in 2020 and around 40% by 2050 (Table 4).

TABLE 4

GDP at current (nominal) model prices (USD billion)

Country	2020	2030	2040	2050	Expected GDP growth rates 2020–50 (%)
Brunei Darussalam	18	22	29	36	2.0
Cambodia	25	40	82	147	6.5
Indonesia	1,147	2,195	3,209	4,074	5.0
Malaysia	453	749	1,185	1,864	4.3
Philippines	370	651	1,197	1,980	5.9
Singapore	354	454	540	642	1.5
Thailand	451	663	1,155	1,348	4.9
Viet Nam	297	532	718	862	3.9

Note: Nominal GDP is derived as real GDP multiplied by the model's endogenous GDP price index. It reflects relative price movements within the CGE numéraire and should not be read as a market exchange-rate forecast.

3.2 Sectoral Demand Projections

3.2.1 Industry

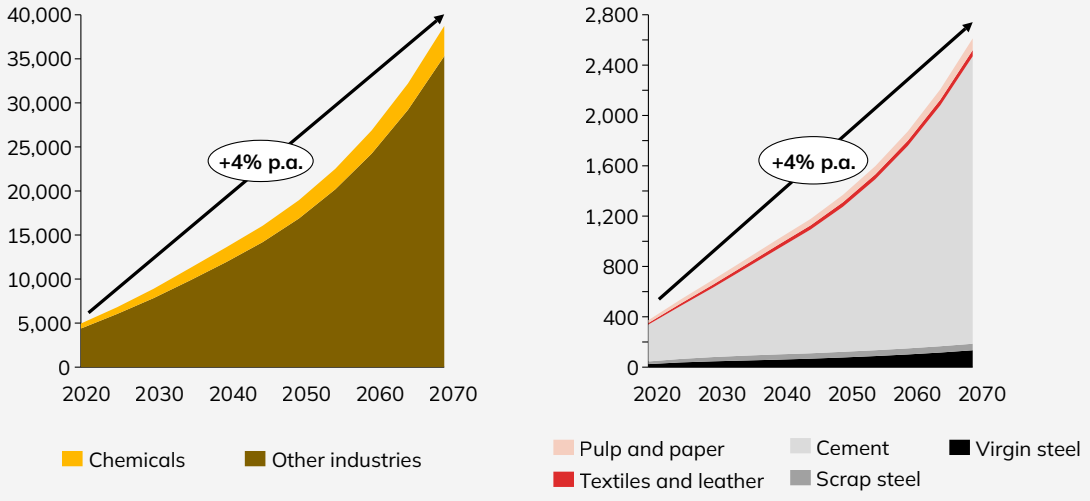
There is strong growth across most industrial sectors, driven by regional economic expansion and infrastructure development. Chemicals demand is set to more than triple, rising from 566 PJ in 2020 to 2,076 PJ by 2050 (Figure 4). Indonesia and Thailand are the largest contributors throughout the period, with the Philippines and Viet Nam also showing significant growth as their chemical industries expand.

Cement production grows rapidly, nearly quadrupling from 293 Mt to 1,153 Mt by 2050. Viet Nam leads production today, but Indonesia and Thailand also emerge as major players by 2050, reflecting their strong infrastructure build-out. The overall increase is driven by ongoing urbanisation and construction activity across the region.

Steel production more than doubles, rising from 45 Mt in 2020 to 122 Mt by 2050. Viet Nam is the largest producer today, though Indonesia and Thailand show strong catch-up growth over the period. Malaysia and the Philippines also contribute steadily.

Paper and textiles production grows from 34 Mt to 94 Mt over the period. Indonesia dominates this sector, accounting for the bulk of output, with Thailand and Viet Nam also playing notable roles. Other industries show the most expansion, more than tripling from 4,381 PJ to over 16,868 PJ by 2050. Indonesia is the largest market by a wide margin, followed by Malaysia, Thailand and Viet Nam.

FIGURE 4
Demand projection for the industry sector in PJ (left) and Mt (right)

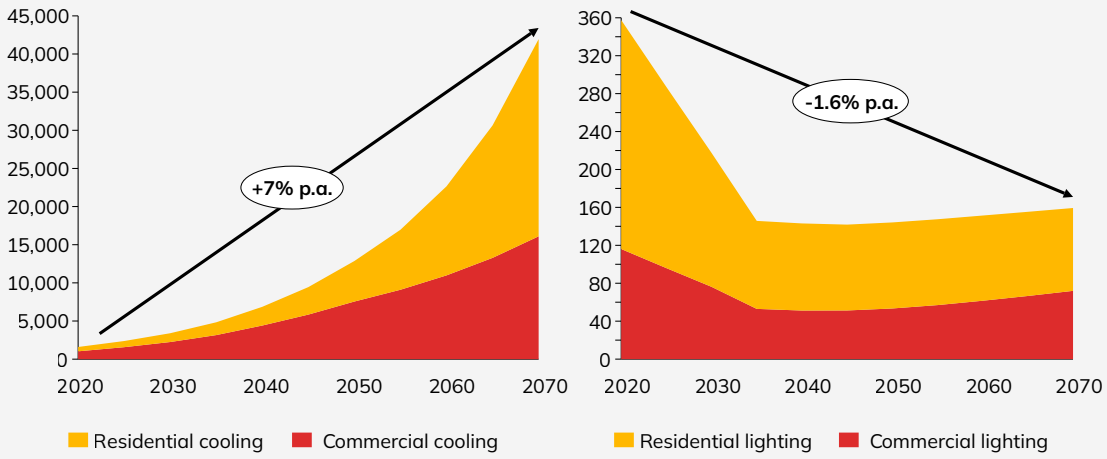


3.2.2 Buildings: Residential and Commercial

Cooling demand is set to rise sharply. Total cooling thermal demand is expected to grow from around 1,595 PJ in 2020 to nearly 12,864 PJ by 2050 (Figure 5), the highest growth rate in the buildings sector. This upward trend reflects growing thermal comfort needs across both residential and commercial buildings, supported by rising temperatures and wider use of air conditioning equipment. This rapid growth highlights the importance of deploying highly efficient air conditioners, as the projected demand can be met more efficiently and sustainably with better technology, while also avoiding the long-term lock-in of inefficient cooling systems that would strain energy systems for decades.

Lighting demand moves in the opposite direction. Total lighting use falls from about 356 PJ in 2020 to roughly 143 PJ by 2040 and then stays flat through 2050 (Figure 5). The main reason is the switch to LED bulbs, which are far more efficient than older incandescent ones. This transition is mostly complete by 2035. Both residential and commercial lighting decline, with the residential sector seeing the steepest drop.

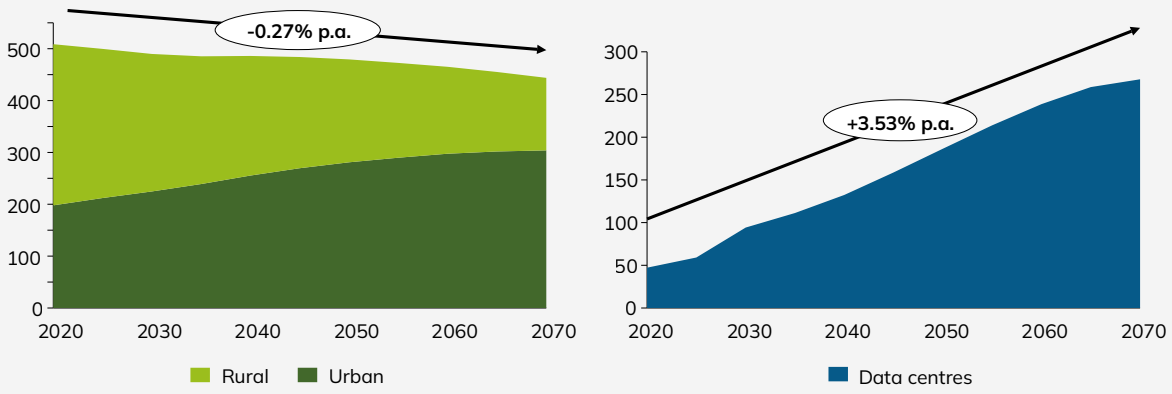
FIGURE 5
Demand projection for cooling and lighting in buildings (PJ)



Cooking demand is expected to decline over the projection period (Figure 6). Rural cooking decreases steadily as populations move to urban areas. At the same time, urban cooking rises, driven by this ongoing urbanisation trend. Despite the rise in urban cooking, overall demand still drops. This is because urban households use more efficient cooking appliances and fuels compared to rural areas, leading to a net reduction in total energy use for cooking, similar to the efficiency-driven decline seen in lighting.

Data centre demand shows a different regional story (Figure 6). Today, Singapore is the largest contributor to data centre energy use in the region. Looking ahead to 2050, the landscape shifts, with Indonesia, Malaysia and Singapore emerging as the top three markets. This reflects the rapid digitalisation and cloud infrastructure expansion taking place across these economies, with Malaysia and Indonesia catching up significantly over the projection period.

FIGURE 6
Demand projection for residential cooking and data centres (PJ)

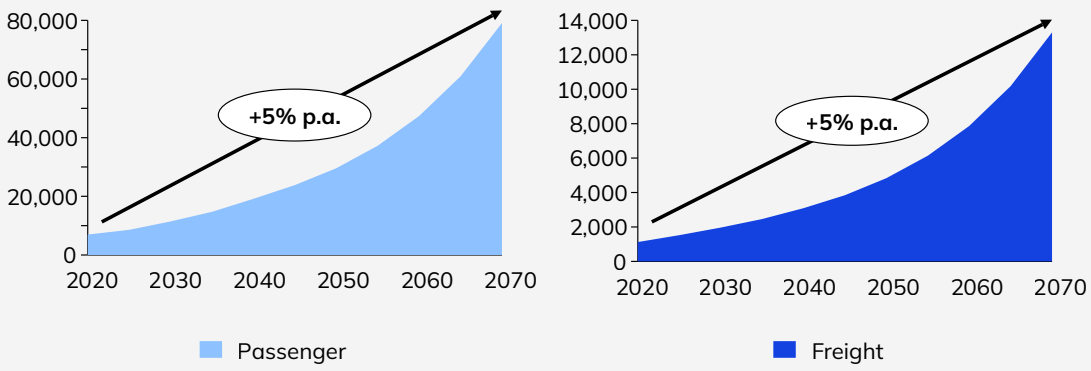


3.2.3 Transport

Passenger transport demand is projected to grow at approximately 5% per year, increasing from 6,964 billion passenger-km in 2020 to an estimated 29,555 billion passenger-km by 2050 (Figure 7). Currently, Indonesia, Malaysia and Thailand are the largest contributors, with these countries also accounting for the largest shares of demand in 2050.

Freight transport demand also has a similar growth rate to that of passenger transport, increasing from 1,125 billion tonne-km in 2020 to an estimated 4,832 billion tonne-km by 2050. Indonesia, Malaysia, and Thailand are currently the largest contributors, while freight demand in the Philippines grows at around 8% per year, making it the third-largest contributor by 2050.

FIGURE 7
Demand projections for passenger (billion passenger-km) and freight transport (billion tonne-km)

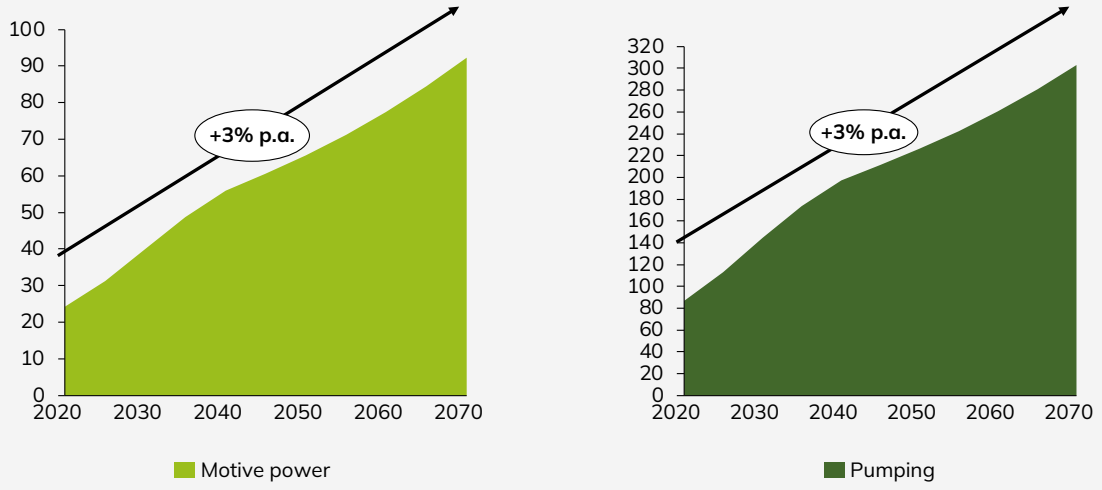


3.2.4 Agriculture

Agricultural motive power demand is projected to grow at a steady 3% per year, more than doubling from around 24 billion vehicle-km in 2020 to around 66 billion by 2050 (Figure 8), with Indonesia, Thailand and Viet Nam remaining the highest-contributing markets throughout the period.

For agricultural pumping, energy demand follows a similar 3% annual growth trajectory, rising from around 87 PJ in 2020 to nearly 226 PJ by 2050 (Figure 8), with Thailand and Viet Nam leading total consumption while Malaysia and the Philippines also emerge as significant contributors.

FIGURE 8
Demand projection for agricultural motive power (billion vehicle-km) and agricultural pumping (PJ)



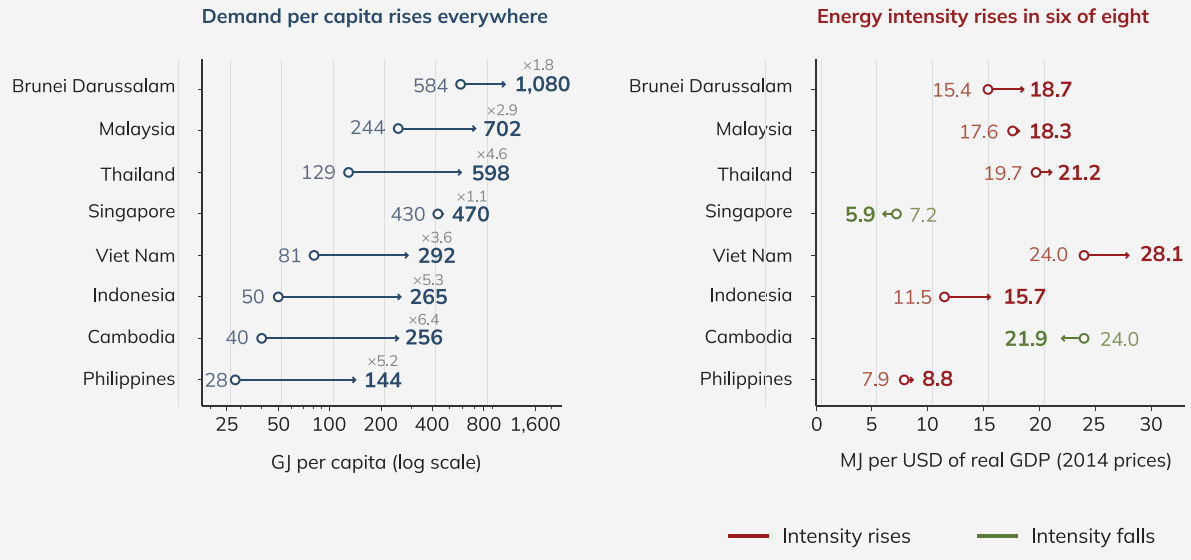
3.3 Demand Intensity and Per-Capita Convergence

Per-capita energy-denominated demand across the modelled economies rises from roughly 75 GJ in 2020 to 132 GJ by 2030 and 309 GJ by 2050 (Figure 9). Convergence is substantial but incomplete: Cambodia moves from 40 to 257 GJ per capita between 2020 and 2050 and the Philippines from 28 to 144 GJ, yet the Philippines remains at roughly a quarter of Thailand's level at the end of the period.

The intensity result deserves particular attention. Energy demand per unit of real GDP rises rather than falls in six of the eight modelled economies – Indonesia from 11.5 to 15.7 MJ per dollar, Thailand from 19.7 to 21.2 and Viet Nam from 24.0 to 28.1. Only Cambodia and Singapore show declining intensity. Figure 9 below shows the energy demand intensity to GDP and per capita to demonstrate the diversity of the energy-economy linkage of the region.

FIGURE 9

Diversity of energy demand intensity in the region between 2020 and 2050



3.4 Implications for Supply-Side Planning

Demand growth to 2050 is heavily concentrated: Indonesia, Malaysia, the Philippines, Thailand and Viet Nam together account for around 96% of the increase in regional demand, and regional supply-side and interconnection planning should be weighted accordingly. Within that growth, cooling stands out as the defining end use of the transition – residential and commercial cooling together grow faster than any other demand category and are overwhelmingly electric. Because their peak coincides with peak temperature, cooling is as much a peak-capacity problem as an energy problem, with direct implications for reserve margins, storage and demand response.

On the industrial side, cement is the binding constraint. A near-quadrupling of clinker output by 2050 implies process emissions that fuel switching or grid decarbonisation alone cannot address, pointing instead to clinker substitution, alternative binders and carbon capture as the relevant policy levers.

The residential re-acceleration after 2050 is worth interrogating. Residential demand grows at 5% to 2050, but its share then rises sharply to 31% by 2070, driven almost entirely by cooling. Whether this reflects a genuine saturation dynamic or an artefact of the model's elasticity structure should be checked before the post-2050 results are relied upon. The rising energy-intensity trajectory limits how the baseline can be used for policy purposes. The projections embed little structural efficiency improvement, so while they remain usable as a reference point against which policy scenarios are compared, they should not be presented as a business-as-usual (BAU) expectation.

Chapter 4

ENERGY TRANSITION ROADMAP FOR NET-ZERO EMISSIONS BY 2050



4.1 Overview

Under business as usual (BAU), annual CO_2 emissions from the energy sector increase from around 1.6 Gt in 2020 to 5.3 Gt by 2050, as growing demand leads to the continued use and expansion of fossil fuels (Figure 10). Under the current policies scenario (CPS), national policies across ASEAN Member States drive a transition towards lower-carbon energy systems across sectors, reducing total CO_2 emissions to 3.6 Gt in 2050.

The current policies scenario (CPS) illustrates the evolution of ASEAN's energy system under existing national policies (e.g. renewable technology targets and clean cooking policies), strategies and power development plans, including committed and planned capacity additions through approximately 2035. Under CPS, total primary energy supply increases from approximately 46,840 PJ in 2020 to 82,130 PJ in 2050, 8% below BAU in 2050, mainly because of lower coal (-36%) and oil (-25%) supply and higher uranium (7%) and renewable energy supply. Final energy consumption reaches 55,151 PJ in 2050, 15% below BAU in the same year. Clean-transition policies and energy-efficiency measures reduce coal use by 40%, biofuel use by 32% and oil use by 5%, while gas and electricity use increase by 38% and 15%, respectively. Although energy demand continues to grow with population and economic activity, the energy mix becomes less carbon-intensive than under BAU as existing national policies accelerate the deployment of renewable energy and other lower-carbon technologies, improve energy efficiency and increase total installed power-sector capacity by 450 GW in 2050. More specifically, national power development plans result in greater deployment of solar (+325 GW), wind (+97 GW), hydropower (+5 GW) and other low-carbon capacity, such as nuclear (+82 GW), by 2050, while constraining the longer-term expansion of coal (-166 GW) compared with BAU. Consequently, fossil-fuel requirements and associated conversion losses are lower than under a continuation of historical trends in BAU.

Changes in end-use sectors further contribute to the lower energy and emissions trajectory. In transport, existing policies support the deployment of 269 million more electric vehicles by 2050 and the adoption of more efficient vehicle technologies, reducing the number of oil and biofuel vehicles by 149 million and 73 million, respectively, relative to BAU. In buildings, appliance-efficiency measures and the transition towards modern, cleaner cooking technologies increase the number of electric stoves by 65 million in 2050, reducing energy requirements and the use of traditional and fossil-based fuels. Existing industrial energy-efficiency and fuel-switching measures also moderate growth in industrial fossil-fuel consumption. Together, these changes substantially reduce energy-sector CO_2 emissions compared with BAU. Emissions under CPS reach approximately 3,593 $MtCO_2$ in 2050, 1,732 $MtCO_2$ below BAU. CPS therefore demonstrates that policies already adopted or planned across ASEAN can substantially moderate emissions growth. However, additional and accelerated action across all sectors is required to achieve the deeper structural transformation represented by the NZE pathway.

By contrast, the net-zero emissions (NZE) pathway achieves net-negative emissions from 2050 through more ambitious mitigation measures across all sectors. ASEAN reaches net-negative emissions of -2.2 $GtCO_2$ by 2050. This outcome is largely driven by deep sectoral decarbonisation and the deployment of bioenergy with carbon capture and storage (BECCS).

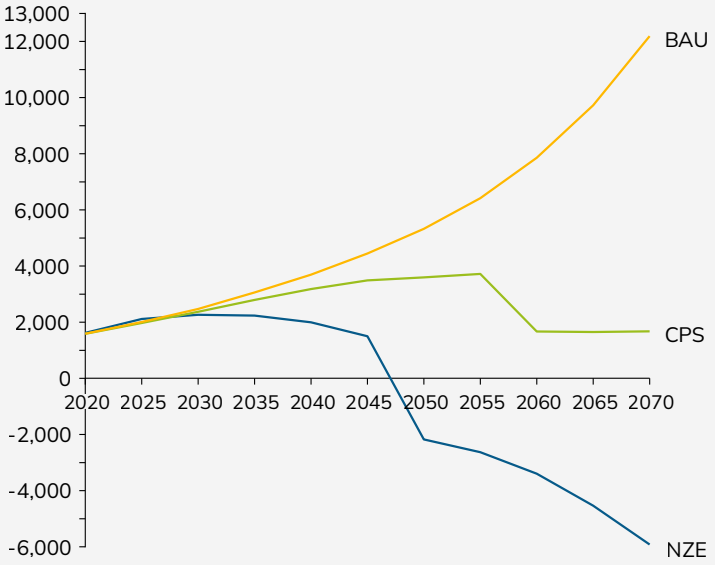
The energy-sector transition in the NZE scenario is characterised by expanded electrification across all sectors, greater use of hydrogen and other low-carbon fuels, and substantial improvements in energy efficiency. Consequently, total final fuel consumption under NZE is around 43% lower than under BAU in 2050, despite meeting the same underlying energy-service demands. Transport and industry drive most of the reduction in energy use. Electricity becomes the dominant fuel under NZE, accounting for around 63% of fuel use by 2050, owing to the higher efficiency of electric vehicles, electric boilers and heat pumps compared with conventional internal combustion engine (ICE) vehicles and combustion-based technologies. Transport accounts for most of this change. Electricity rises from almost zero to 61% of final transport energy by 2050, displacing demand for refined products. Industry electrifies more slowly, from 22% to 47%, because high-temperature heat is more difficult to electrify directly. The primary energy mix also shifts substantially from coal, oil and gas under BAU towards biomass, nuclear and renewable energy under NZE. This transformation reduces ASEAN's exposure to imported fossil fuels and strengthens regional energy security. Import dependence, measured as imports divided by total primary energy supply, falls from 21% in 2030 to 2% in 2050. Coal and gas use in final energy also falls sharply, with coal declining from 3,528 PJ in 2045 to 1,006 PJ in 2050.

The NZE pathway does not remain entirely flat until 2040 followed by a single decarbonisation step. As shown in Figure 10, energy-sector emissions peak during the 2030s and subsequently decline, reaching approximately 1.5 $GtCO_2$ by 2045. The relatively gradual reduction in the earlier periods partly reflects the remaining lifetime and turnover of the existing fossil-fuel-based technology stock across the power, transport and industry sectors.

The more pronounced decline occurs between 2045 and 2050, as the pathway reaches the net-zero target year and low-carbon and negative-emissions technologies reach greater deployment. In particular, the transition to net-negative emissions in 2050 is influenced substantially by BECCS in the power and industrial sectors, rather than solely by an abrupt retirement of the existing fossil-fuel fleet. Results are also presented at five-year intervals, meaning that the figure represents changes occurring progressively within each model period rather than a single discrete transition in 2050. Nevertheless, the results indicate that achieving NZE by 2050 requires a significant acceleration in the deployment of low- and negative-emissions technologies during the 2040s.

FIGURE 10

Total annual energy sector emissions for BAU, CPS, and NZE ($MtCO_2$)



4.1.1 Emissions by Sector

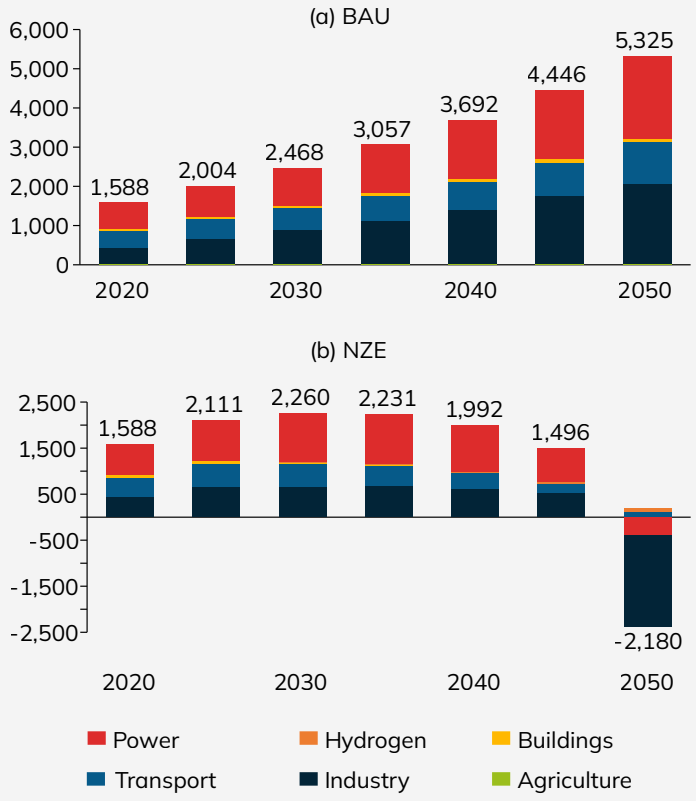
In 2020, the power sector was the largest source of emissions, accounting for approximately 42% of the total, followed by industry (27%) and transport (26%) (Figure 11). Although power-sector emissions increase 3.1-fold in absolute terms by 2050 under BAU, their share of total emissions declines to around 40%, reflecting the increasing penetration of renewable and nuclear technologies in the power mix. By contrast, industry's share of emissions increases to approximately 39% in 2050. Transport's share declines to 20%, primarily because of the increasing penetration of biofuels and other lower-carbon transport technologies. Emissions from the buildings and agriculture sectors increase moderately over time but continue to account for only a small share of total emissions.

By contrast, in the NZE scenario, the deployment of low-carbon technologies across all sectors, combined with BECCS in the power and industry sectors, enables ASEAN to achieve net-negative CO_2 emissions from 2050 onwards.

Net emissions from the power sector decline to approximately -387 $MtCO_2$ in 2050, reflecting extensive decarbonisation through renewable energy and negative emissions from BECCS. Industry becomes the largest source of negative emissions, reaching approximately -2 $GtCO_2$ in 2050, largely because of the deployment of energy-efficient industrial technologies, electrification, hydrogen and BECCS. In buildings, the increasing adoption of electric cooking technologies and improved biomass stoves eliminates direct CO_2 emissions from 2050 onwards. Similarly, the electrification of agricultural energy uses reduces direct energy-related CO_2 emissions from agriculture to zero from 2050 onwards. Hydrogen production introduces a comparatively small source of residual emissions, increasing from zero in the base year to approximately 70 $MtCO_2$ in 2050.

FIGURE 11

Total annual emissions by sector for BAU and NZE scenarios, 2020-2050 ($MtCO_2$)



4.1.2 Fuel Mix under BAU and NZE to 2050

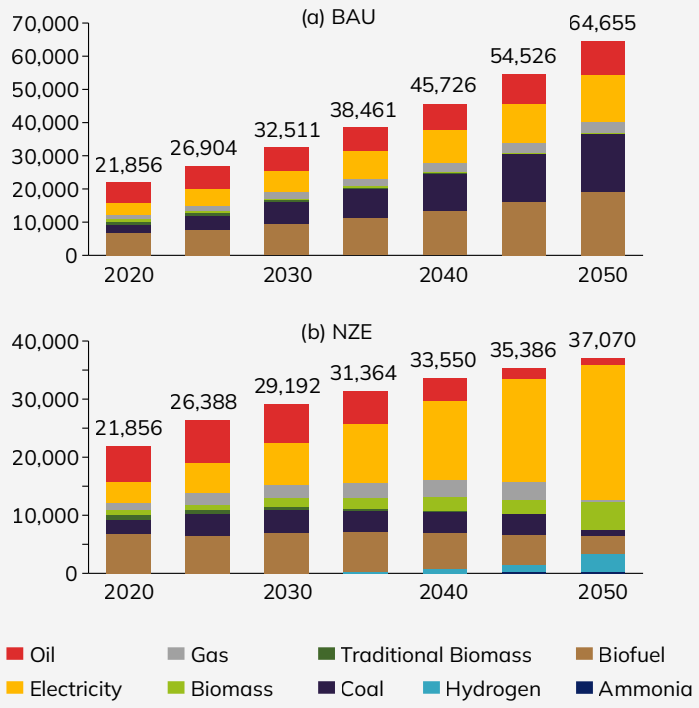
Under BAU, total fuel use increases substantially, from 21,856 PJ in 2020 to 64,655 PJ in 2050 (Figure 12). Liquid hydrocarbons account for the largest share of total fuel use in 2020, at approximately 48%, followed by electricity (17%), coal (11%) and biofuels (around 10%). The remaining fuels - improved biomass, gas and traditional biomass - account for smaller shares of around 4%, 5% and 4%, respectively. High oil and biofuel consumption is driven primarily by transport, while electricity is used largely in buildings and coal in industry. Improved biomass is consumed mainly in industry and buildings, gas predominantly in the power sector, and traditional biomass in cooking. Coal records the largest increase by 2050, with consumption rising sevenfold, largely because of its expansion in the power sector. Gas and electricity consumption also increase substantially, by approximately ninefold each. These trends reflect strong growth in energy demand associated with economic activity and demographic change. Under BAU, this demand is met through both increased electricity supply and the continued expansion of fossil-fuel use.

In the NZE scenario, total fuel use increases to 37,070 PJ in 2050. Electricity accounts for the largest share of total fuel use in 2050, at approximately 63%, followed by improved biomass (13%), hydrogen (9%) and biofuels (8%). The substantial increase in electricity consumption is primarily driven by the widespread electrification and decarbonisation of all end-use sectors. At the same time, the consumption of low-carbon fuels increases considerably, while the role of fossil fuels declines, with coal and gas accounting for only around 3% and 1% of total fuel use, respectively, by 2050. Improved biomass is predominantly consumed in industries, while biofuels are primarily used in transport. Overall, this transition highlights the increasingly important roles of electricity and hydrogen in achieving net zero. As electricity demand expands substantially and electricity generation becomes increasingly dominated by renewable energy, the development of a reliable, resilient and low-carbon power system will be essential to support the decarbonisation of the wider energy system.

Despite the same underlying energy-service demands in the BAU and NZE scenarios, total fuel use is substantially lower under NZE. By 2050, total fuel consumption is approximately 43% lower than under BAU. This reduction is driven primarily by transport and industry. Transport fuel consumption decreases from approximately 30,323 PJ under BAU to 11,533 PJ under NZE by 2050, a reduction of around 62%, while industrial fuel consumption declines from 25,063 PJ to 17,063 PJ, or approximately 32%. Efficiency improvements also reduce energy use in buildings, including through the replacement of conventional air-conditioning technologies with more efficient alternatives. The results therefore indicate that the NZE transition is driven not only by fuel switching towards electricity, hydrogen and other low-carbon fuels, but also by substantial improvements in energy efficiency.

FIGURE 12

Total fuel use by type for BAU and NZE scenarios, 2020-2050 (PJ)



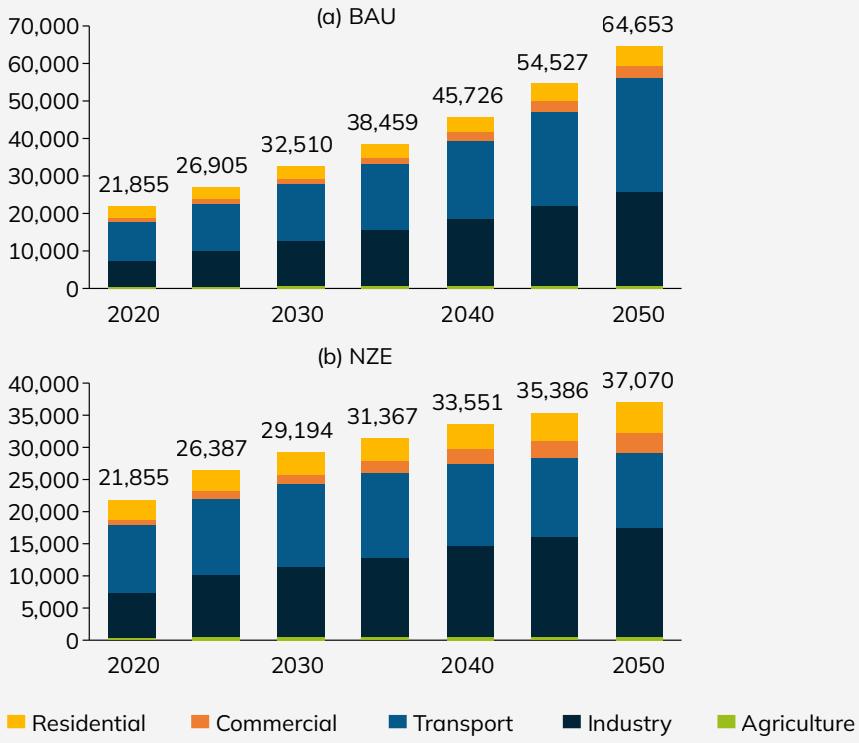
4.1.3 Fuel Use by Sector under BAU and NZE to 2050

In the BAU scenario, the sectoral distribution of total fuel use remains relatively stable over the projection period, despite a substantial increase in overall energy consumption. This is because energy demand grows across most sectors, resulting in broadly proportional increases in fuel consumption. Transport is the largest fuel-consuming sector in 2020, accounting for approximately 48% of total fuel use, followed by industry (32%), residential buildings (14%), commercial buildings (4%), and agriculture (2%). The penetration of more energy-efficient technologies, particularly in buildings, results in the residential sector's share declining to approximately 8% in 2050 (Figure 13). In contrast, the industrial sector increases its share to around 38% in 2050. Transport remains the largest fuel-consuming sector throughout the projection period, despite efficiency improvements across different vehicle types. The share of agriculture also gradually declines, falling below 1% by 2050, partly reflecting the penetration of more efficient technologies.

In the NZE scenario, the sectoral distribution of fuel use changes considerably more than in BAU, reflecting differences in the pace and extent of technological transformation across sectors. Transport remains a major energy-consuming sector but its share of total fuel use declines substantially over the projection period, primarily due to the increasing penetration of more efficient vehicle technologies, particularly electrified transport. By contrast, the relative shares of industry and commercial buildings increase, as their fuel consumption declines less rapidly, or grows relative to the substantial reduction observed in transport. In the buildings sector, efficiency improvements, including the increasing penetration of efficient air-conditioning technologies, reduce the energy required to meet the same cooling demand. Nevertheless, the increasing share of commercial buildings reflects their contribution relative to a substantially smaller overall energy requirement rather than necessarily an increase in energy intensity. Industry similarly accounts for an increasing share of total fuel use as industrial energy requirements remain significant under the NZE transition, despite the increasing penetration of low-carbon technologies.

FIGURE 13

Total fuel use by sector for BAU and NZE scenarios, 2020-2050 (PJ)



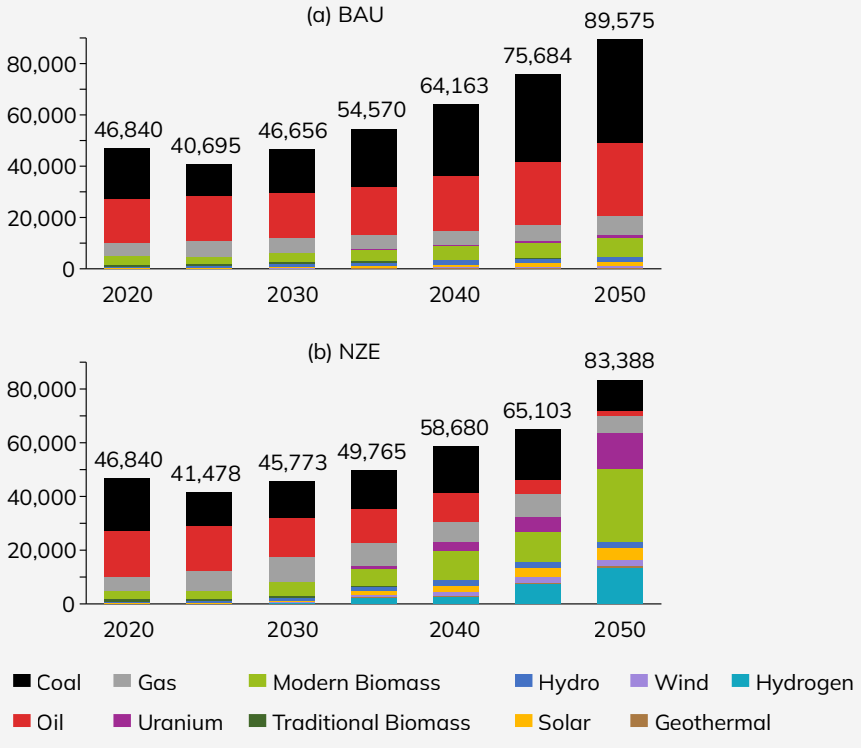
4.1.4 Total Primary Energy Supply

In the BAU scenario, total primary energy supply increases substantially in response to growing energy demand, from 46,840 PJ in 2020 to 89,575 PJ in 2050 (Figure 14). Coal is the dominant primary energy source in 2020, accounting for approximately 42% of total supply, followed by oil (37%), natural gas (11%), modern biomass (7%) and traditional biomass (2%), while other renewable energy sources, including hydro, solar, wind and geothermal, account for a relatively small share. The overall primary energy mix remains dominated by fossil fuels throughout the projection period, although its composition changes over time. Coal increases its share to approximately 45% in 2050, while the share of oil decreases to 32%. Natural gas accounts for around 9% of primary energy supply in 2050. Nuclear energy also enters the primary energy mix from 2035 onwards accounting for around 1% of total primary energy supply in 2050. Renewable energy sources also expand in absolute terms, although their contribution remains relatively limited compared with fossil fuels under BAU. Consequently, despite the increasing penetration of renewable and nuclear technologies, fossil fuels continue to account for approximately 85% of ASEAN's primary energy supply in 2050, compared with around 89% in 2020.

The results also highlight changes in ASEAN's dependence on domestic fossil-fuel resources and imports. Domestic production meets approximately 84% of coal supply in 2020, increasing to around 91% in 2050. In contrast, the domestic share of oil supply decreases considerably, from around 84% in 2020 to 52% in 2050, indicating increasing reliance on imported oil as demand grows. Although natural gas demand increases, its share of fossil-fuel supply remains similar in 2050 to its 2020 level of 12%. Overall, domestic production accounts for approximately 84% of ASEAN's fossil-fuel supply in 2020, declining to around 77% in 2050. Although ASEAN retains substantial domestic fossil-energy resources, increasing reliance on imports - particularly for oil and, in some Member States, coal and natural gas - could increase exposure to international fuel-price volatility and external supply risks.

FIGURE 14

Total primary energy supply for BAU and NZE scenarios, 2020-2050 (PJ)



In the NZE scenario, total primary energy supply increases to 83,388 PJ in 2050 as illustrated in Figure 14. However, the primary energy mix changes significantly compared with BAU as low-carbon energy sources increase their contribution and the role of coal and oil decreases substantially. Coal, which represents around 42% of total primary energy supply in 2020, decreases to 14% in 2050, while oil decreases even more significantly from 37% in 2020 to only around 3% in 2050. By contrast, improved biomass increases from 7% in 2020 to 33% in 2050, mainly due to its increased use in the power, cooking and industry sectors, including biomass technologies combined with carbon capture and storage (CCS). Nuclear energy also plays an important role in the transition, increasing to around 16% of primary energy supply in 2050. Several ASEAN Member States are currently considering or planning the introduction of nuclear power following their Power Development Plans (PDP), including Indonesia, Malaysia, the Philippines and Viet Nam. Nevertheless, achieving the scale of nuclear deployment that the NZE pathway indicates would require preparatory action and sustainable policy support.

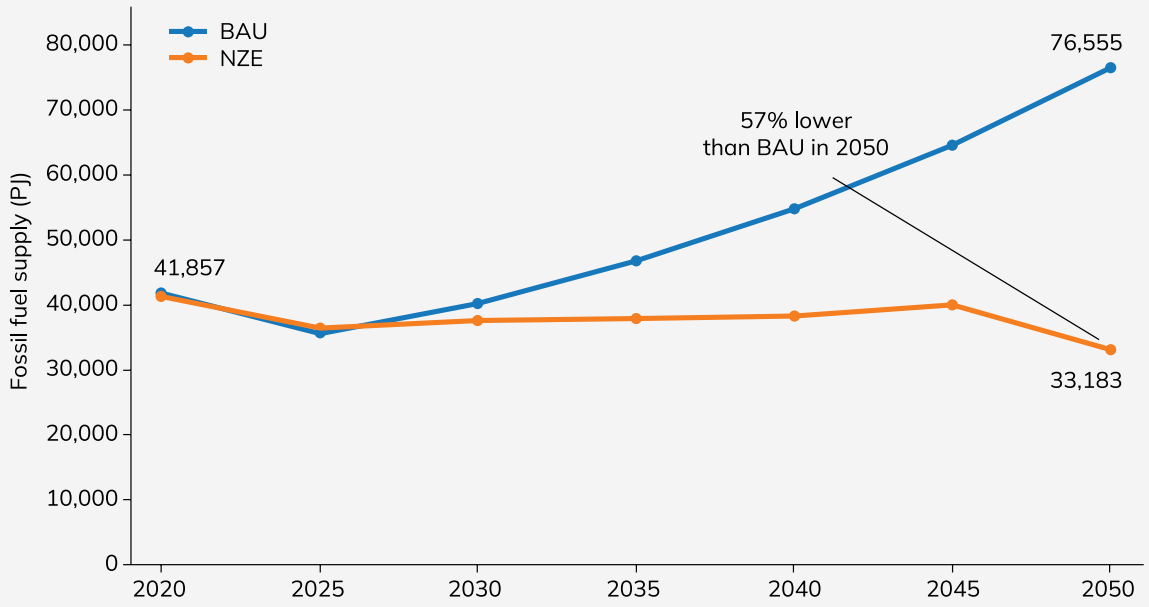
As ASEAN countries are mainly newcomers to commercial nuclear power, deployment will depend not only on plant construction lead times but also on the establishment and strengthening of independent regulatory institutions, legal and nuclear-safety frameworks, qualified human resources, appropriate sites and supporting grid infrastructure, as well as arrangements for radioactive waste management, security and safeguards. Nuclear projects are also capital intensive and require access to long-term financing and mechanisms capable of managing high upfront investment costs and project risks. These institutional and financing requirements can add considerably to the time required before a first plant can be commissioned.

Solar, wind, hydro and geothermal together increase their contribution to approximately 12% in 2050. Natural gas also continues to play an important role in the energy system, increasing from around 11% in 2020 to 24% in 2050. This significant increase is primarily driven by the growing use of natural gas as a feedstock for hydrogen production. However, the selection of gas-based hydrogen with CCS over electrolysis in the NZE scenario is an endogenous least-cost modelling result rather than an exogenous preference for blue hydrogen.

The optimisation considers the capital and operating costs, efficiencies, fuel requirements and technology constraints associated with the alternative hydrogen production routes. Although substantial renewable and nuclear capacity is deployed under NZE, this low-carbon electricity also serves rapidly increasing electricity demand associated with direct electrification across transport, buildings and industry. In addition, the expansion of renewable and nuclear generation is subject to technology-specific capacity investment constraints that reflect countries' PDPs, limiting the uptake of green hydrogen as a result. Producing additional hydrogen through electrolysis would therefore require not only investment in electrolyser capacity but also additional low-carbon electricity generation and associated system capacity. However, continued improvements in renewable energy and electrolyser technologies, declining technology costs, and opportunities for technological leapfrogging across ASEAN could enable greater deployment of renewable generation and increase the role of green hydrogen. Therefore, the use of fossil fuels is substantially reduced across several sectors as the energy systems become decarbonised and electrified.

Changes in the primary energy mix also reduce ASEAN's dependence on fossil-fuel supply compared with BAU. The divergence becomes particularly pronounced after 2030, with total fossil-fuel requirements reaching approximately 33,183 PJ in 2050 under NZE, compared with almost 76,555 PJ under BAU, a reduction of around 57% (Figure 15). Under NZE, coal supply decreases by 72% by 2050, mainly because of industrial electrification, while transport electrification reduces oil supply by 92% in the same year. In contrast, natural gas supply increases by around two and a half times because of its use in power and industry. The reduction in fossil-fuel supply under the NZE pathway therefore provides an important additional energy-security benefit by reducing ASEAN's exposure to international fuel markets.

FIGURE 15
ASEAN fossil fuel supply projection under BAU and NZE Scenarios (PJ)



This shift also changes the nature of the region's energy security challenge. As electricity becomes the dominant final energy carrier—accounting for approximately 63% of total fuel use by 2050 under NZE—the reliability and resilience of the power system become increasingly important. The transition therefore requires not only greater deployment of renewable generation, but also sufficient dispatchable low-carbon generation and storage, and stronger electricity networks and cross-border interconnections. Hydrogen also emerges as an important energy carrier, particularly for applications where direct electrification is more challenging, further increasing the importance of coordinated infrastructure development.

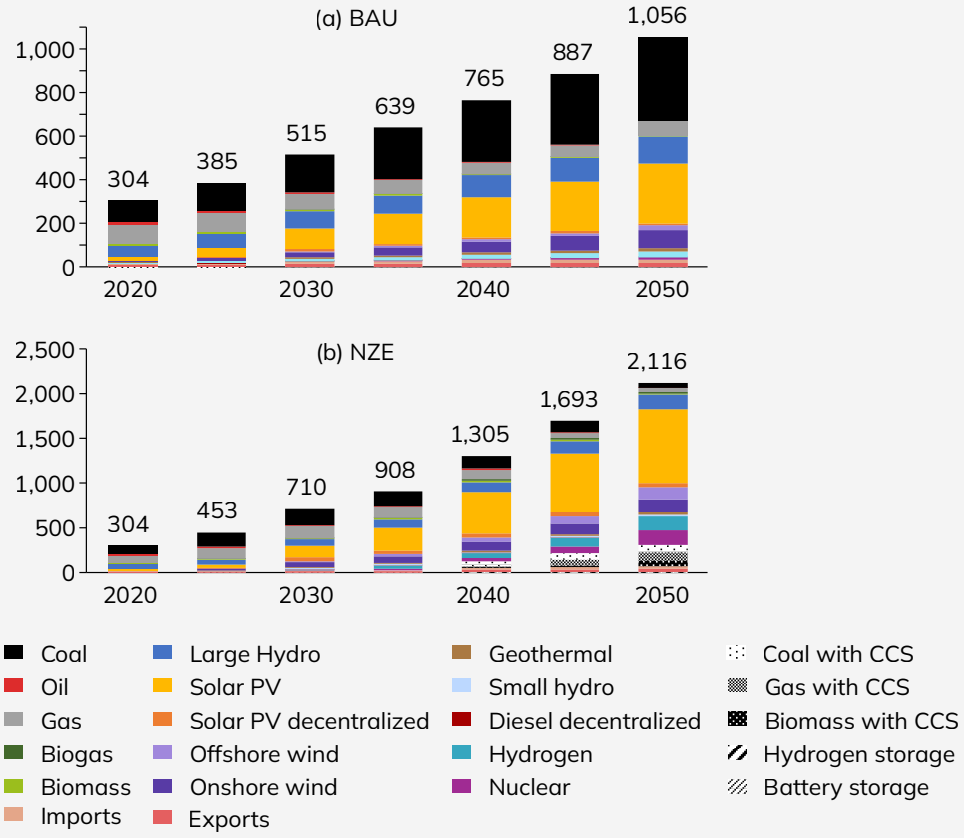
4.2 Power Sector

4.2.1 Installed Capacity

Under the BAU scenario, the total installed capacity in the ASEAN region increases substantially from 304 GW in 2020 to 1,056 GW in 2050, including imports and exports of 8 GW in 2020 and 19.8 GW in 2050, driven by continued growth in electricity demand across the region (Figure 16). In 2020, fossil-fuel technologies dominated the capacity mix, led by coal (98 GW) and natural gas (88 GW), while oil accounted for 12.6 GW. Renewable energy technologies represented approximately 32% of total installed capacity, with large hydropower constituting the largest renewable technology at over 52 GW, followed by utility-scale solar PV (20 GW), small hydropower (4.4 GW), geothermal (4.2 GW) and onshore wind (2.9 GW).

FIGURE 16

Installed total annual capacity in the power sector for BAU and NZE scenarios (including imports and exports), by technology, 2020-2050 (GW)



In line with selected national targets, nuclear capacity enters the regional mix from 2035 and reaches 12.3 GW in 2050. As electricity demand increases, renewable capacity expands considerably, reaching approximately 54% of total installed capacity by 2050, driven primarily by solar PV, large hydropower and wind. Utility-scale solar PV increases more than thirteenfold, from 20 GW in 2020 to 274 GW in 2050, while large hydropower increases approximately 2.4-fold to nearly 127 GW. Onshore wind records the fastest relative expansion, increasing approximately twenty-ninefold to 83 GW. Offshore wind also enters the capacity mix, reaching 21.8 GW by 2050, while geothermal capacity increases to 16.4 GW.

Despite this substantial renewable expansion, coal capacity continues to increase under BAU, reaching 382 GW in 2050. Natural gas capacity declines from 88.0 GW in 2020 to 71.4 GW in 2050, while renewable energy's share of total capacity rises from 32% to 54% over the same period.

Under the BAU scenario, the regional capacity expansion is characterised by markedly different country-level pathways. Indonesia maintains a large coal fleet while simultaneously expanding gas, hydropower, solar PV, wind and nuclear capacity. Coal expansion is particularly pronounced in the Philippines, Thailand and Viet Nam by 2050, while Malaysia combines a substantial coal fleet with a particularly strong expansion of natural gas capacity.

At the same time, renewable resources expand across the region: Lao PDR, Myanmar and Viet Nam continue to develop their large hydropower potential, Indonesia develops a more diversified renewable portfolio encompassing hydropower, solar and both onshore and offshore wind, while Thailand and Viet Nam experience particularly strong solar PV expansion by 2050. Battery storage also reaches 120 MW in 2050 as more renewables penetrate the power mix. Overall, the BAU capacity pathway therefore reflects substantial renewable energy deployment but does not result in a structural phase-out of fossil fuel capacity; instead, growing electricity demand is met through the simultaneous expansion of renewable resources and fossil fuel capacity.

Under the NZE scenario, the ASEAN power system requires substantial expansion and restructuring to accommodate rapidly increasing electricity demand resulting from the electrification of end-use sectors. Total installed capacity increases to 2,116 GW in 2050, including 35.5 GW of imports and exports, almost twice the capacity deployed under the BAU scenario by the end of the modelling period. While fossil-fuels account for a large proportion of installed capacity in the early years, their role declines substantially towards 2050, with coal and natural gas capacity falling to approximately 50 GW and 43 GW, respectively, compared with 382 GW and 71 GW, respectively under BAU.

Renewable energy becomes the backbone of capacity expansion, particularly through the rapid deployment of solar and wind technologies. Utility-scale solar PV records the largest absolute increase, expanding from 20 GW in 2020 to 830 GW by 2050. Large hydropower capacity more than triples, from 52 GW in 2020 to 160 GW in 2050. Wind power also grows significantly, with onshore wind reaching 145 GW in 2050 and offshore wind emerging as an important component of the regional power system, at 134 GW.

In parallel with renewable energy deployment, the NZE pathway requires substantial investment in low-carbon dispatchable technologies. Hydrogen-based generation capacity increases from 12.4 GW in 2030 to 159 GW in 2050, while nuclear capacity expands to 163 GW in 2050. CCS-equipped generation also plays an important role, with combined coal, gas and biomass CCS capacity reaching approximately 244 GW by 2050.

The transition is characterised by differentiated country pathways reflecting variations in resource availability and system requirements. Indonesia develops one of the most diversified low-carbon capacity portfolios, combining solar PV, wind, nuclear, hydrogen and substantial coal and gas CCS capacity by 2050. Viet Nam experiences particularly strong solar and wind deployment by 2050, while Lao PDR continues to rely predominantly on its hydropower resources. The Philippines also develops a highly diversified system, combining solar PV with wind, nuclear and hydrogen-based capacity by 2050. Hydrogen and CCS play particularly important roles in Malaysia and Thailand by 2050, while Malaysia develops considerable capacity of coal and gas CCS. Overall, the NZE pathway illustrates that achieving economy-wide NZE requires not only a substantially larger ASEAN power system than under BAU, but also a fundamental shift in its capacity structure towards large-scale solar and wind deployment, expanded hydropower, hydrogen-based generation, nuclear power and CCS-equipped dispatchable capacity, supported by storage and stronger regional interconnections.

4.2.2 Electricity Generation

Under the BAU scenario, total electricity generation in the ASEAN region increases from 1,319 TWh in 2020 to 4,509 TWh in 2050, including 56 TWh in 2020 and 192 TWh in 2050 of traded electricity, reflecting the rapid growth in electricity demand across the region (Figure 17). In 2020, coal dominates the fuel mix, accounting for 44% of total generation, followed by natural gas (32%) and large hydropower (14%), while the remaining generation is supplied by biomass (3%), geothermal (2.4%), solar PV (1.6%), oil (1%), small hydropower (1%), with biogas and onshore wind contributing less than 1% each.

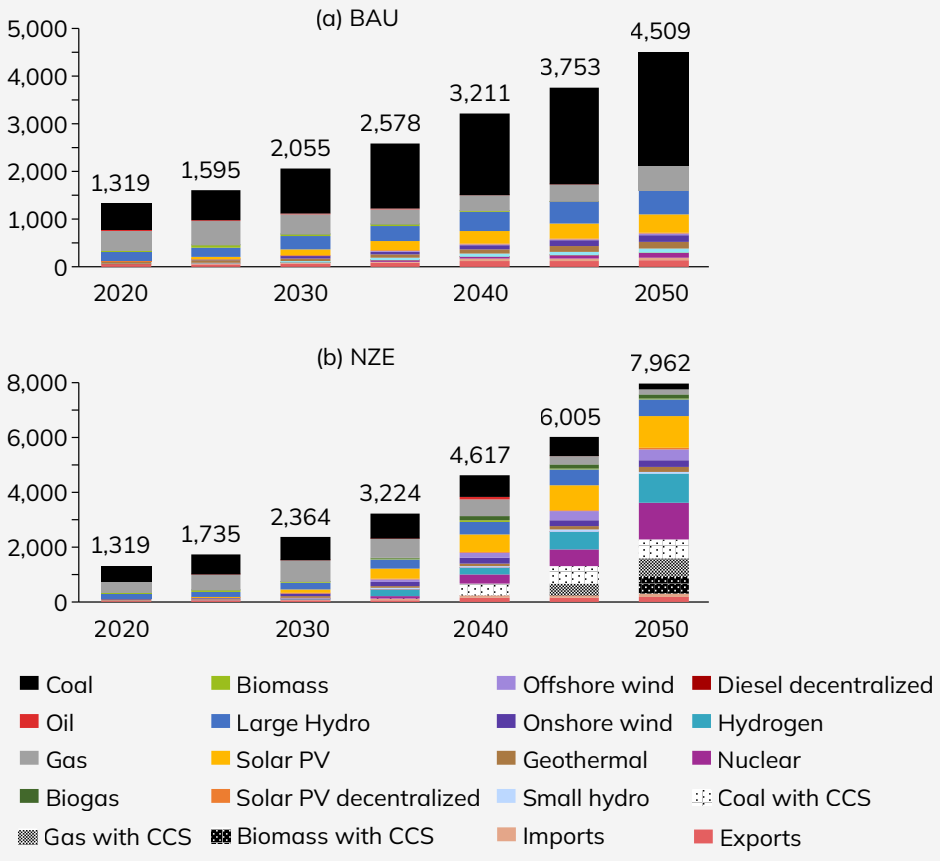
By 2050, the electricity mix remains dominated by coal, whose share increases to approximately 55%, while natural gas declines to around 12%. Large hydropower maintains a relatively stable share of approximately 12%, although its generation almost triples in absolute terms, while solar PV expands significantly to account for around 9% of total generation. Onshore and offshore wind increase to approximately 3% and 1%, respectively, geothermal reaches around 3%, and small hydropower contributes approximately 2% of total generation.

Hydrogen enters the electricity mix from 2030 onwards but remains below 1% throughout the modelling period, while nuclear generation is introduced from 2035, increasing to around 2% by 2050. The increasing penetration of variable renewable energy is accompanied by the deployment of electricity storage technologies, with electricity supplied through battery storage increasing from less than 0.01 TWh in 2025 to 0.13 TWh in 2050, while hydrogen storage increases to 0.01 TWh during 2030-2050.

At the country level, the continued expansion of coal-fired generation in Indonesia, together with additional coal development in Malaysia, the Philippines, Thailand and Viet Nam, and associated plant lifetimes drives the growth in regional coal generation, while increasing natural gas generation in Indonesia, Malaysia and the Philippines contributes to the continued role of gas in the regional electricity mix. Large hydropower expansion occurs predominantly in Lao PDR, Myanmar and the Philippines, enabling these countries to provide increasing amounts of low-cost electricity to the regional power system.

FIGURE 17

Total electricity generation annual activity for BAU and NZE scenarios, by technology, 2020-2050 (TWh)



Compared with the BAU scenario, the NZE pathway fundamentally transforms the ASEAN power sector by requiring substantially higher electricity generation to support the widespread electrification of transport, industry and cooking, while simultaneously replacing fossil fuels with low-carbon generation technologies. Consequently, total electricity generation increases to 7,962 TWh by 2050, including 299 TWh of traded electricity, with the additional demand being predominantly met through renewable energy, hydrogen, nuclear power and carbon capture technologies, supported by electricity storage and expanded regional interconnections.

Despite the significant increase in electricity demand, coal generation declines dramatically, accounting for only 3% of total electricity generation in 2050 in the NZE scenario compared with 55% under the BAU scenario, while the share of unabated natural gas decreases from 12% to only 2%. Renewable energy excluding hydrogen and nuclear expands rapidly to contribute approximately 38% of total electricity generation in 2050, led by large hydropower, which increases by around 3.4 times compared with 2020, and utility-scale solar PV, which experiences the largest expansion, increasing almost 60-fold to 1,176 TWh and becoming one of the dominant sources of electricity generation. Additional contributions are provided by offshore wind (5%), onshore wind (3%), geothermal energy (2%), and biomass and biogas, each contributing less than 1% of total generation. Alongside renewable energy, hydrogen-based power generation (1,258 TWh) and nuclear energy (1,355 TWh) emerge as key pillars of the decarbonised electricity system by 2050.

Carbon capture, utilisation and storage (CCUS) technologies also play a critical role in achieving NZE, with coal CCS, gas CCS and biomass CCS being deployed from 2040 onwards and accounting for approximately 9%, 9% and 8% of total electricity generation, respectively, by 2050.

The transition is characterised by differentiated country pathways, whereby countries with significant hydropower resources, such as Lao PDR and Viet Nam, further expand hydropower generation to support regional electricity trade, while countries with high electricity demand accelerate the deployment of solar PV across most ASEAN Member States, hydrogen-based generation particularly in Indonesia, Malaysia, the Philippines and Thailand, nuclear power in Indonesia, Thailand and the Philippines, and CCUS technologies primarily in Indonesia, Malaysia and Thailand. Rather than each country meeting future electricity demand independently, the NZE pathway increasingly relies on regional resource sharing, allowing countries with abundant renewable resources to export low-carbon electricity while reducing investment requirements in neighbouring systems. The expansion of cross-border interconnections enables greater utilisation of least-cost renewable resources across ASEAN, supporting regional electricity trade, improving system flexibility and reducing reliance on fossil-fuel generation.

4.2.3 Regional Interconnection

Greater regional power integration provides an important opportunity to support this transition. ASEAN Member States have different renewable energy resources, electricity demand profiles and technology opportunities. Expanded interconnections allow these complementary resources to be shared across borders rather than requiring each country to meet its future electricity requirements independently.

The study is aligned with the ASEAN Power Grid (APG), a flagship regional initiative aimed at strengthening electricity connectivity and facilitating cross-border power trade and cooperation among ASEAN Member States. The ASEAN Interconnection Masterplan Study (AIMS) III identified 18 priority interconnection projects to support the APG, improve system resilience and enable greater integration of renewable energy across the region. The model incorporates APG interconnection projects scheduled for commissioning in the ASEAN Energy Outlook 8 material shared by ACE in August 2025; projects remaining in the broader pipeline are excluded.

Recent developments demonstrate progress towards deeper regional electricity integration. In particular, the Lao PDR-Thailand-Malaysia-Singapore Power Integration Project (LTMS-PIP), which is also considered in this analysis, has become ASEAN's first multilateral cross-border electricity-trading project. Following an initial phase that allowed up to 100 MW of electricity trade, the second phase increased the maximum trading capacity to 200 MW and introduced multidirectional electricity flows. In parallel, ASEAN continues to develop the technical, regulatory and institutional arrangements required to expand multilateral power trade and create a more integrated regional electricity system.

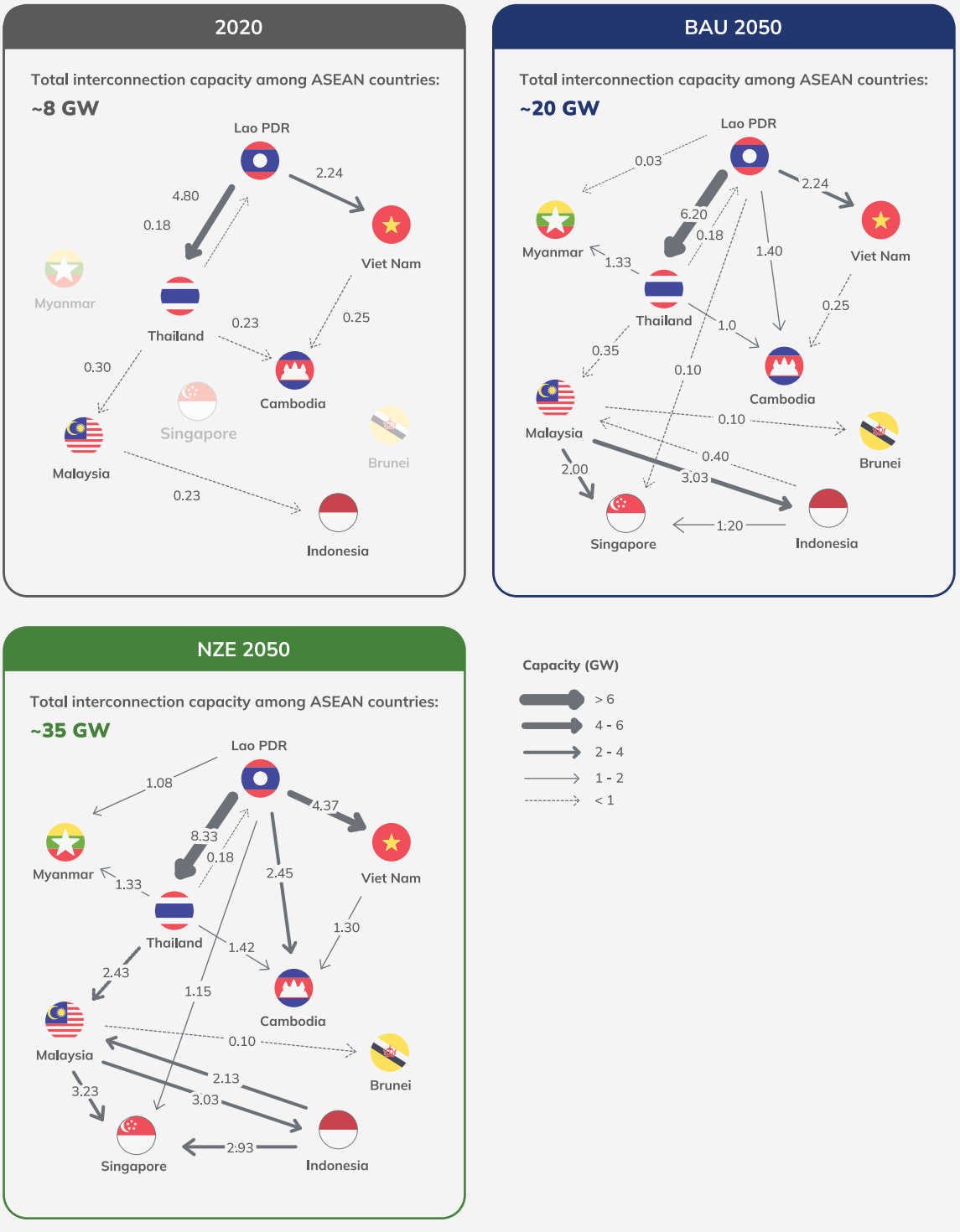
The modelling therefore allows cross-border electricity interconnection between Member States, reflecting the broader objectives of the APG and enabling an assessment of how regional power trade and interconnection requirements could evolve under the BAU and NZE pathways (Figure 18). Under NZE, traded capacity increases further, enabling greater use of least-cost resources, supporting system flexibility and reducing reliance on unabated fossil-fuel generation.

Interconnection capacity expands substantially under the NZE pathway, reinforcing the strategic role of the APG in balancing variable renewable generation and enabling cross-border access to low-carbon electricity. By 2050, some of the largest interconnections include Lao PDR–Thailand (8.33 GW), Lao PDR–Viet Nam (4.37 GW), Indonesia–Singapore (2.93 GW), Malaysia–Singapore (3.23 GW) and Thailand–Malaysia (2.43 GW), while capacity also increases across links supplying Cambodia, Myanmar and other ASEAN markets. These modelled corridors are consistent with the broader direction of the APG, which seeks to strengthen cross-border electricity connectivity.

For example, AIMS III identifies Lao PDR-Thailand and Lao PDR-Viet Nam as major regional interconnections, with around 5.4 GW and 5 GW, respectively, envisaged under its 2040 renewable energy scenario. The same corridors emerge in the NZE results, reaching 8.33 GW and 4.37 GW, respectively, by 2050. This analysis also identifies substantial expansion of the Indonesia-Singapore, Malaysia-Singapore and Thailand-Malaysia corridors, all of which are reflected in APG planning. Compared with BAU, the stronger expansion of cross-border capacity under NZE indicates that deeper regional integration will be important for sharing renewable resources, improving system flexibility and reliability, and reducing the need for countries to balance increasingly renewable-based power systems solely through domestic resources.

Future cross-border interconnection capacities are differentiated by scenario. BAU assumes a more conservative expansion based primarily on existing and committed/planned interconnections, while NZE allows additional capacity expansion along identified APG corridors to represent deeper regional electricity-system integration. Corridor-specific expansion assumptions were applied, with higher capacity ranges for major regional interconnections and more moderate expansion for smaller links. Under the NZE scenario, total cross-border interconnection capacity reaches approximately 35.5 GW by 2050. This is broadly comparable in magnitude to the level of regional interconnection identified in AIMS III Phase 1 and 2, which estimates approximately 33.5 GW of total interconnection capacity by 2040 under the ASEAN Renewable Energy Target Scenario. While the scenarios and time horizons are not directly equivalent, the comparison indicates that the scale of regional interconnection expansion represented under the NZE pathway is broadly consistent with ASEAN's regional power-system planning studies.

FIGURE 18
ASEAN power interconnection capacities by links (GW)



Note: Arrows indicate the direction of the interconnection; faded flags mark countries with no cross-border link in that year. Only links among ASEAN Member States are shown. Values in GW (interconnection capacity).

The results show a substantial increase in regional electricity exchange under NZE. Lao PDR in particular strengthens its role as a major regional electricity exporter, building on its significant hydropower resources. By 2050, electricity exports from Lao PDR to Thailand increase from approximately 54 TWh under BAU to 73 TWh under NZE, while exports to Viet Nam decrease from approximately 19 TWh to 11 TWh (Figure 19). Electricity exports from Lao PDR to Cambodia also increase from around 12 TWh to 21 TWh, while new or expanded flows towards Myanmar and Singapore further strengthen Lao PDR's role within the regional power system.

Regional integration also expands elsewhere. Electricity trade between Indonesia and Malaysia increases considerably under NZE, while Malaysia and Singapore continue to exchange significant volumes of electricity. Thailand maintains an important position in the interconnected system, importing substantial electricity from Lao PDR while also supplying neighbouring Cambodia and Myanmar. These flows illustrate how stronger regional interconnections can enable countries with abundant low-carbon resources to support growing electricity demand elsewhere in ASEAN.

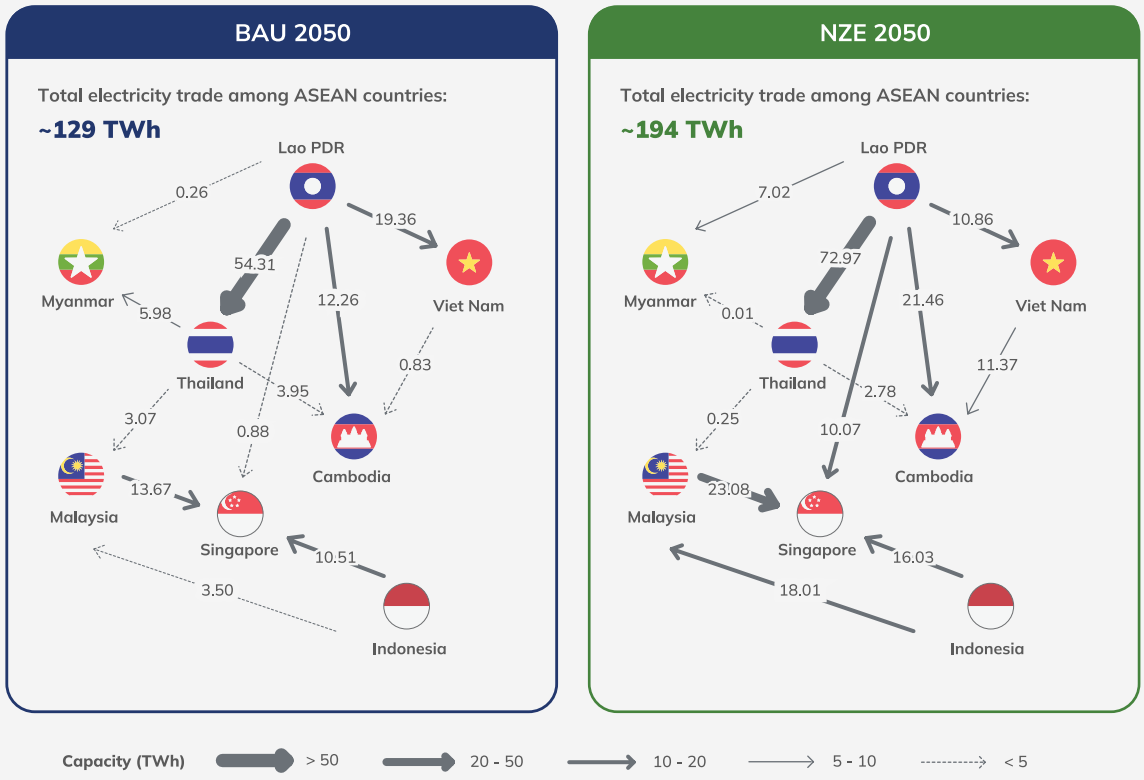
TABLE 5
ASEAN cross-border electricity trade by 2050

From	To	BAU (GW)	NZE -exporter (GW)	NZE in use (GW)	Change (GW)	Multiple
Lao PDR	Thailand	6.20	8.33	8.33	2.13	1.3×
Malaysia	Singapore	2.00	3.23	3.23	1.23	1.6×
Indonesia	Singapore	1.20	2.93	2.93	1.73	2.4×
Lao PDR	Viet Nam	2.24	4.37	4.37	2.13	2.0×
Indonesia	Malaysia	0.40	2.13	2.13	1.73	5.3×
Malaysia	Indonesia	3.03	3.03	3.03	0.00	1.0×
Lao PDR	Cambodia	1.40	2.45	2.45	1.05	1.8×
Thailand	Malaysia	0.35	2.43	2.43	2.08	6.9×
Viet Nam	Cambodia	0.25	1.3	1.3	1.05	5.2×
Thailand	Cambodia	1.00	1.42	1.42	0.42	1.4×
Thailand	Myanmar	1.33	1.33	1.33	0.00	1.0×
Lao PDR	Singapore	0.10	1.15	1.15	1.05	11.5×
Lao PDR	Myanmar	0.03	1.08	1.08	1.05	36.0×
Thailand	Lao PDR	0.18	0.18	0.18	0.00	1.0×
Malaysia	Brunei	0.10	0.10	0.10	0.00	1.0×
Total		19.81	35.46	35.46	15.65	

Traded capacity increases from 19.81 GW under BAU to 35.5 GW under NZE in 2050. Lao PDR is the hub of the regional system, with 17.38 GW, or 43% of all NZE trade, compared with 0.18 GW of imports; its net position nearly doubles. Indonesia is the only country to shift from a net importer to a net exporter, moving from net imports of 0.23 GW to net exports of 2.03 GW, entirely through new flows to Malaysia and Singapore. Conversely, Singapore's net import requirement more than doubles to 7.31 GW, or 18% of all regional trade, sourced from three partners rather than one. Malaysia's exports rise from 5.13 GW under BAU to 6.36 GW under NZE in 2050, yet its net position falls from +4.48 GW to +2.95 GW because imports rise almost sixfold. It shifts from a straightforward net exporter to a transit and balancing hub.

FIGURE 19

Projected ASEAN power exchange under BAU and NZE scenarios by 2050



Note: Arrows indicate the direction of electricity trade. Only trade among ASEAN Member States is shown. Values in TWh, 2050 projection.

The expansion of electricity trade nevertheless creates new requirements for energy security. Greater interdependence means that cross-border transmission infrastructure must be sufficiently reliable and resilient, while system planning and operation increasingly need to consider regional rather than exclusively national conditions. Coordinated development of interconnections, harmonisation of technical and regulatory frameworks, and mechanisms supporting multilateral electricity trade will therefore become increasingly important as ASEAN Member States progress towards a more integrated power system.

Overall, the results indicate that the NZE pathway can strengthen regional energy security by reducing exposure to imported fossil fuels, diversifying energy supply and enabling greater utilisation of ASEAN's domestic low-carbon resources. At the same time, energy security increasingly shifts from securing fossil fuel supplies towards ensuring reliable electricity infrastructure, sufficient system flexibility and effective regional coordination. The development of the ASEAN Power Grid can therefore become an important enabler of both decarbonisation and energy security, allowing Member States to leverage complementary resources while strengthening the resilience of the regional energy system.

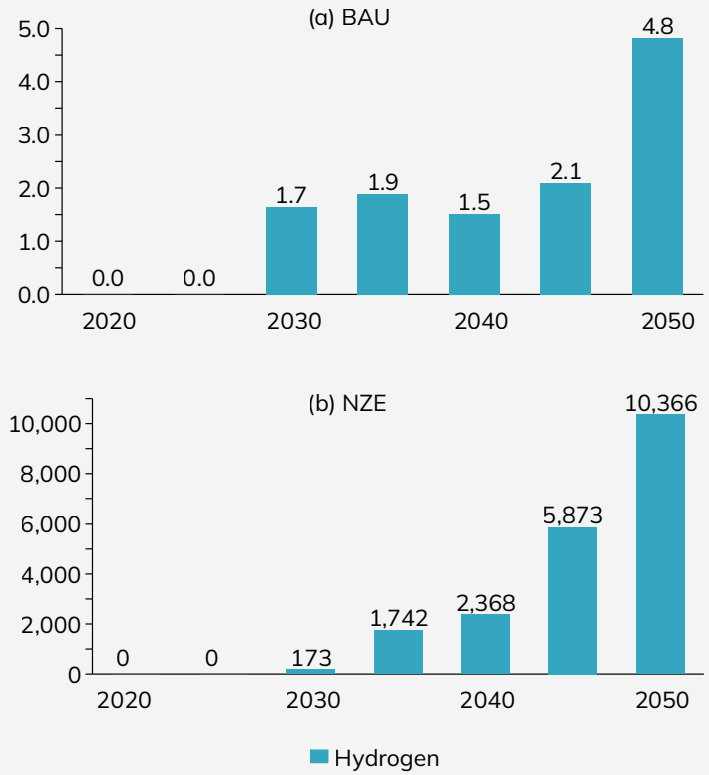
4.2.4 Hydrogen

Hydrogen plays a limited role in the ASEAN energy system under the BAU scenario but becomes a key energy carrier under the NZE pathway, supporting the decarbonisation of hard-to-abate sectors where direct electrification is more challenging. Under BAU, total hydrogen production remains negligible throughout the modelling period, increasing from approximately 1.7 PJ in 2030 to only 4.8 PJ in 2050 (Figure 20). Production is also geographically concentrated, with the Philippines accounting for most hydrogen production during the earlier years of the projection period, while Lao PDR becomes the main producer from 2050 onwards.

By contrast, the NZE scenario results in a rapid and substantial scale-up of hydrogen production across ASEAN. Total production increases from approximately 173 PJ in 2030 to 10,366 PJ by 2050 (Figure 20). The expansion is initially driven largely by Indonesia, Malaysia and Thailand, while hydrogen production becomes increasingly diversified across ASEAN over time. By 2050, Malaysia emerges as the largest hydrogen producer. Smaller but increasing contributions are also observed in Brunei Darussalam, Cambodia, Lao PDR, Myanmar and Singapore. Overall, the results demonstrate that achieving NZE requires the development of a large-scale regional hydrogen economy that becomes increasingly distributed across ASEAN as hydrogen demand expands across the power sector and other end-use sectors.

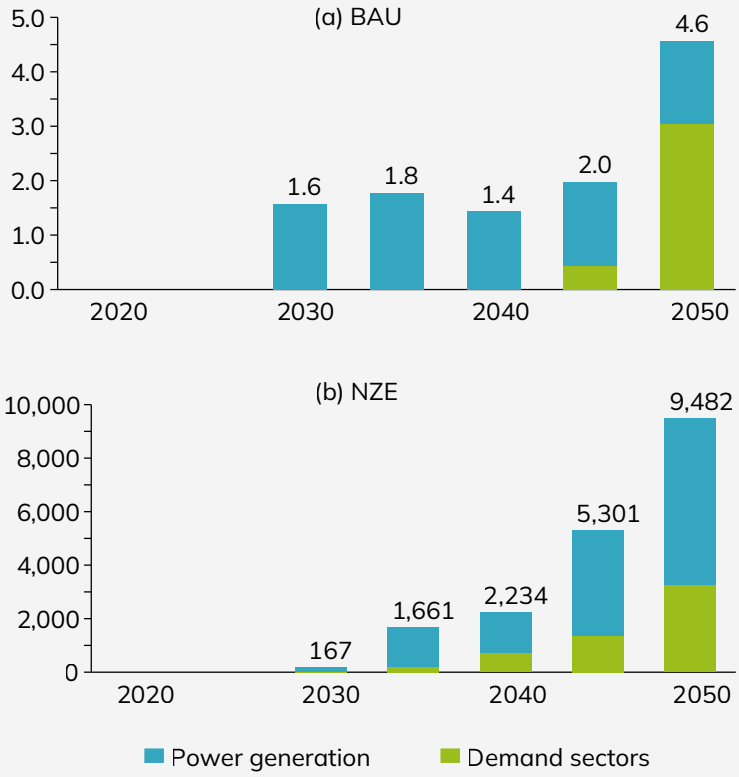
FIGURE 20

Total annual hydrogen production for BAU and NZE scenarios, 2020-2050 (PJ)



Based on the annual hydrogen production shown above, Figure 21 presents the split in hydrogen use between supply-side power generation and end-use sectors. Achieving NZE requires rapid growth of 14% per year from 2030 onwards. Hydrogen-fired power plants account for 66% of NZE hydrogen demand in 2050, while demand from end-use sectors, such as transport and industry, increases more gradually after 2040 to account for the remaining 34%.

FIGURE 21
Total annual hydrogen usage for power generation and demand sectors for BAU and NZE scenarios, 2020-2050 (PJ)



4.3 Transport Sector

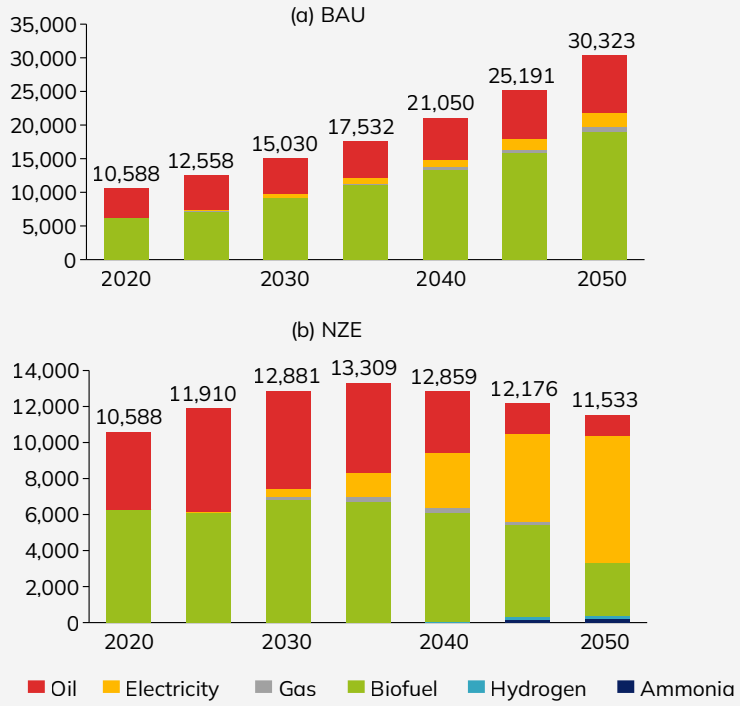
In the BAU scenario, total fuel consumption in the transport sector increases from 10,588 PJ in 2020 to 30,323 PJ in 2050 (Figure 22). Biofuels represent the largest share of transport fuel consumption in 2020, accounting for approximately 59%, followed by oil (41%), while electricity and gas account for a negligible proportion. Nevertheless, as transport demand increases and consequently the vehicle fleet expands, the share of oil decreases to 28% in 2050, mainly due to the increasing penetration of biofuel and electric vehicles. Biofuels increase their share to approximately 63% in 2050, while electricity increases from negligible levels in 2020 to 7% in 2050. Gas also increases in absolute terms but continues to represent only around 2% of total transport fuel consumption. At the same time, efficiency improvements in transport technologies reduce the amount of fuel required to meet a given level of transport demand, particularly through the increasing penetration of electric vehicles, which are more energy-efficient than conventional internal combustion engine vehicles. As a result, even under the BAU scenario, the transport sector gradually shifts towards a less carbon-intensive fuel mix, with increasing penetration of biofuels and electricity.

In the NZE scenario, the transport sector experiences a significant transition towards electrification and low-carbon fuels. Total fuel consumption reaches 11,533 PJ in 2050 as transport demand continues to grow. Electricity becomes the dominant energy carrier, accounting for approximately 61% of total transport fuel consumption in 2050. By contrast, the share of oil decreases significantly to around 10% in 2050, while gas is completely phased out from 2050 onwards. Biofuels continue to play an important role, accounting for approximately 26% of transport fuel consumption in 2050. The continued consumption of oil in the longer term is partly associated with its use in biofuel blends and therefore increases in absolute terms towards 2050 as biofuel consumption and overall transport demand increase. Hydrogen also gradually penetrates the transport sector, reaching around 1% of total fuel consumption by 2050, while ammonia plays a smaller role.

The significant penetration of electric vehicles and other more efficient transport technologies also reduces the amount of energy required to meet the same transport demand. This can be clearly seen when comparing the NZE and BAU scenarios, as total transport fuel consumption reaches only 11,533 PJ in NZE compared with 30,323 PJ in BAU by 2050, representing a reduction of approximately 62%. Therefore, the transition of the transport sector under NZE is driven not only by the replacement of fossil fuels with electricity, biofuels, hydrogen and ammonia, but also by improvements in energy efficiency, particularly through the large-scale penetration of electric vehicles.

FIGURE 22

Total annual transport fuel use for BAU and NZE scenarios, 2020-2050 (PJ)



4.3.1 Two- and Three-Wheeler Fleet

Under the BAU scenario, the ASEAN two- and three-wheeler fleet expands substantially over the modelling period, increasing from around 248 million vehicles in 2020 to 646 million in 2050 (Figure 23). Conventional liquid-fuel vehicles remain dominant throughout most of the period, accounting for around 81% of the fleet in 2020 and increasing in absolute terms from approximately 200 million vehicles to 400 million in 2050. The number of electric two- and three-wheelers increases from 470 in 2020 to around 101 million in 2050. The number of biofuel E10 vehicles also expands considerably, from approximately 48 million in 2020 to 145 million in 2050, accounting for around 22% of the fleet in 2050. At the country level, Indonesia remains the largest market for conventional two- and three-wheelers, with conventional liquid-fuel vehicles representing 71% of the ASEAN liquid fleet by 2050, while Malaysia shows a stronger shift towards electric two- and three-wheelers. The Philippines, by contrast, experiences substantial growth in bioethanol E10 vehicles in the future.

Under the NZE scenario, the two- and three-wheeler fleet undergoes a significant transformation towards full electrification. The total fleet increases from approximately 248 million vehicles in 2020 to 713 million in 2050. The increase, despite total passenger demand remaining unchanged across the modelling period, is driven by a modal shift within road passenger transport among cars, two- and three-wheelers and buses. While conventional liquid-fuel vehicles initially dominate, their share falls rapidly from around 81% in 2020 to 31% in 2035, before declining to around 1% by 2045 and being completely phased out by 2050. Biofuel E10 follows a similar trajectory, declining from approximately 48 million vehicles in 2020 to around 33 million in 2040 and being fully phased out by 2050. Electric two- and three-wheelers consequently become the dominant technology from 2035, increasing from less than one million vehicles in 2020 to 253 million in 2035, and subsequently reaching around 713 million by 2050. The transition towards electric two- and three-wheelers is evident across all countries in the region, reflecting a region-wide shift away from internal combustion engine (ICE) technologies. These results highlight the central role of rapid electrification of two- and three-wheelers in decarbonising ASEAN road passenger transport under the NZE pathway.

FIGURE 23

Annual two- and three-wheeler stock for BAU and NZE, 2020-2050 (million units)

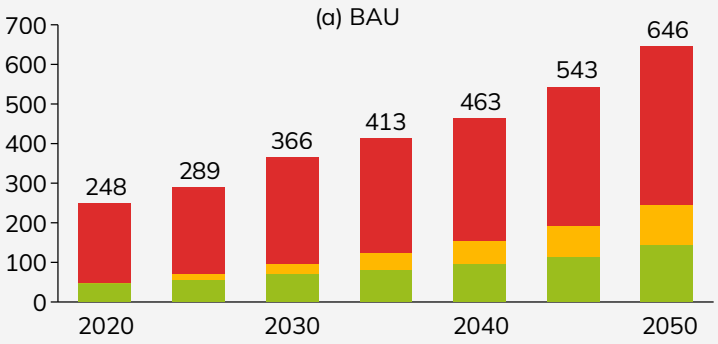
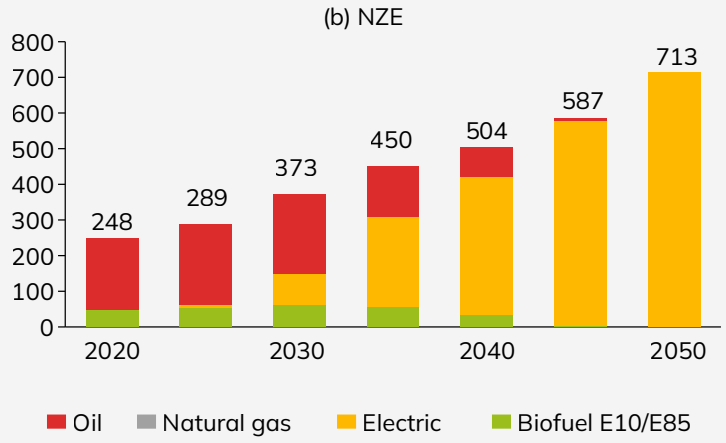


FIGURE 23 (continued)
Annual two- and three-wheeler stock for BAU and NZE, 2020-2050 (million units)



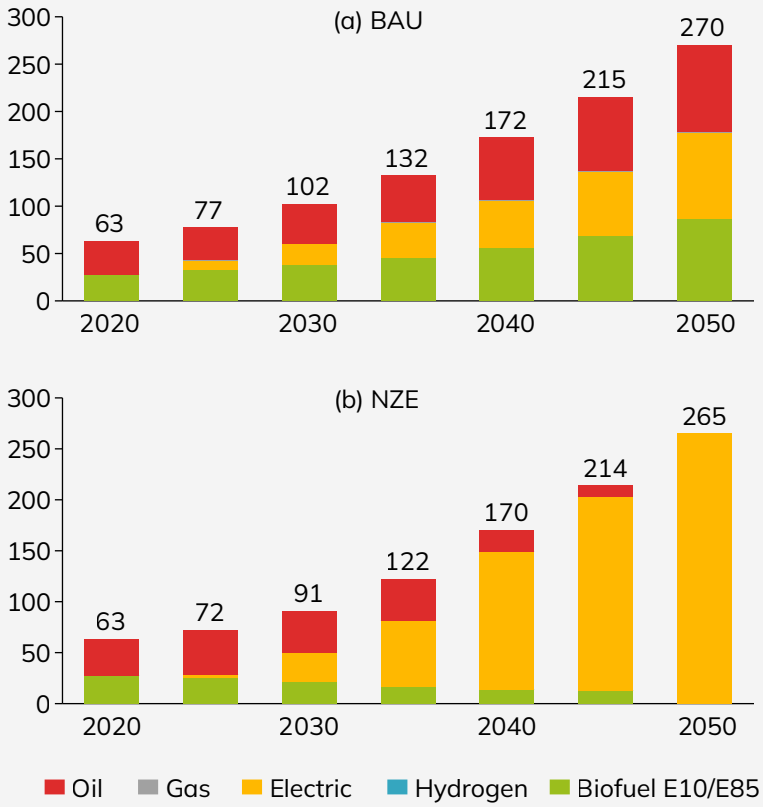
4.3.2 Passenger Car Fleet

Under the BAU scenario, the passenger car fleet expands considerably throughout the modelling period, increasing from approximately 63 million vehicles in 2020 to 270 million in 2050 (Figure 24). Conventional liquid-fuel and biofuel E10 vehicles dominate the fleet in 2020, accounting for approximately 36 million and 28 million vehicles, respectively, while the number of electric cars is negligible. Despite the continued expansion of conventional technologies, electric vehicles progressively gain importance, increasing in number to around 91 million in 2050. Nevertheless, the transition remains gradual under the BAU scenario, with conventional liquid-fuel cars also increasing to approximately 92 million in 2050. The number of biofuel E10 vehicles similarly expands, reaching around 86 million in 2050, while biofuel E85 and gas vehicles retain comparatively small shares of the total fleet. Overall, the BAU pathway results in an increasingly diversified passenger car fleet, with electrification gaining momentum but without the complete displacement of internal combustion engine technologies by the end of the modelling period.

Under the NZE scenario, the passenger car fleet undergoes a rapid transition towards electrification. The total car fleet increases from approximately 63 million vehicles in 2020 to 265 million in 2050. As with two- and three-wheelers, changes in the size of the car fleet relative to the BAU scenario, despite total passenger demand remaining unchanged, are driven by the modal shift within road passenger transport among cars, two- and three-wheelers and buses. Conventional liquid-fuel cars initially remain the dominant technology, increasing from approximately 36 million vehicles in 2020 to 43 million in 2025, before declining rapidly to around 11 million in 2045 and being completely phased out by 2050. Biofuel E10 vehicles follow a similar trajectory, declining from approximately 28 million vehicles in 2020 to 12 million in 2040 and being fully phased out by 2050. Electric cars consequently become the dominant technology from 2035, increasing from a negligible level in 2020 to approximately 65 million in 2035. By 2050, the passenger car fleet is almost fully electrified, with approximately 265 million electric vehicles. The number of hydrogen cars remains negligible throughout the modelling period. These results demonstrate that widespread electrification, combined with the phase-out of conventional liquid-fuel and biofuel vehicles, is the principal pathway for decarbonising passenger car transport under the NZE scenario.

FIGURE 24

Annual car stock for BAU and NZE scenarios, 2020-2050 (million units)



4.3.3 Bus Fleet

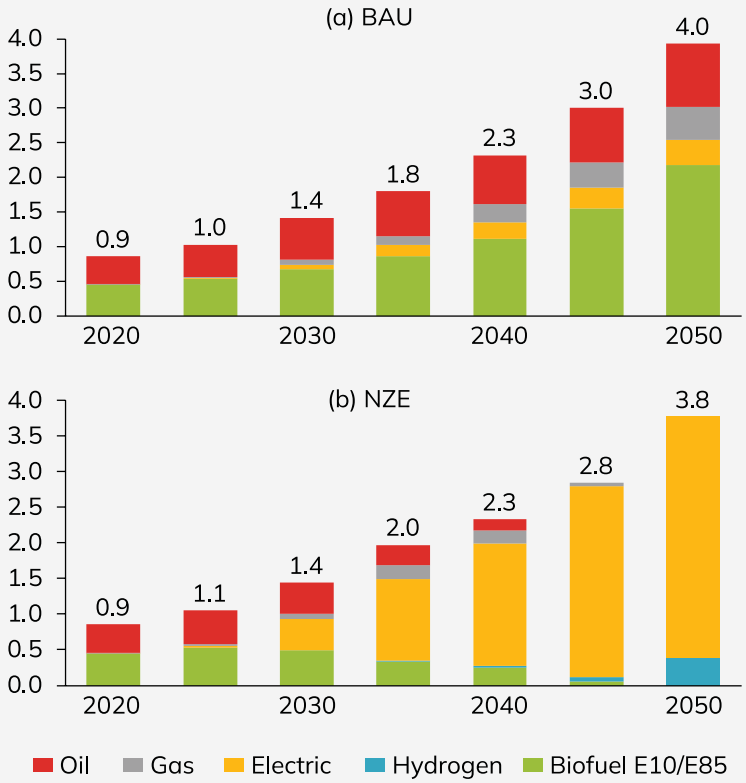
Under the BAU scenario, the ASEAN bus fleet expands steadily throughout the modelling period, increasing from approximately 0.86 million vehicles in 2020 to 3.93 million in 2050 (Figure 25). Liquid fuel and biofuel E10 buses dominate the fleet in 2020, accounting for approximately 0.40 million and 0.44 million vehicles, respectively. Although conventional liquid-fuel buses continue to increase in absolute terms, reaching around 0.91 million in 2050, their share of the total fleet gradually declines as alternative technologies expand. Biofuel E10 becomes increasingly important, reaching approximately 1.58 million buses in 2050, while biofuel E85 also expands considerably after 2030, reaching around 0.6 million vehicles by 2050. Electric and gas buses experience more moderate growth, reaching approximately 0.36 million and 0.48 million vehicles, respectively, by 2050, while hydrogen buses do not enter the fleet under the BAU scenario. Overall, the BAU pathway results in an increasingly diversified bus fleet, although combustion-based technologies continue to account for the majority of vehicles throughout the modelling period.

Under the NZE scenario, the ASEAN bus fleet undergoes a substantial transition away from conventional fuels towards electric and hydrogen technologies. The total fleet increases from approximately 0.86 million vehicles in 2020 to 3.77 million in 2050. By 2050, the model shows a modal shift towards cars and two- and three-wheelers and away from buses. This shift is primarily driven by the relative cost competitiveness of the different passenger transport modes under the model assumptions, with cars and two- and three-wheelers providing lower-cost options for meeting passenger transport demand compared with buses. As the model minimises total system costs while satisfying the same overall passenger transport demand, it increasingly favours these more cost-competitive modes over time.

The number of conventional liquid-fuel buses declines from approximately 0.40 million vehicles in 2020 to 0.16 million in 2040 and they are completely phased out by 2045, while biofuel E10 buses follow a similar trajectory and are fully phased out by 2050. Electric buses consequently expand rapidly, from a negligible level in 2020 to approximately 3.38 million in 2050. In contrast to cars and two- and three-wheelers, hydrogen also emerges as an important decarbonisation option for buses, increasing from a negligible presence in the 2030s to approximately 0.39 million vehicles in 2050. By 2050, the regional bus fleet is therefore fully composed of zero-emission technologies, with electric buses accounting for approximately 90% of the fleet and hydrogen buses for the remaining 10%. These results indicate that the decarbonisation of ASEAN bus transport relies on a combination of widespread electrification and the longer-term deployment of hydrogen buses.

FIGURE 25

Annual bus stock for BAU and NZE scenarios, 2020-2050 (million units)



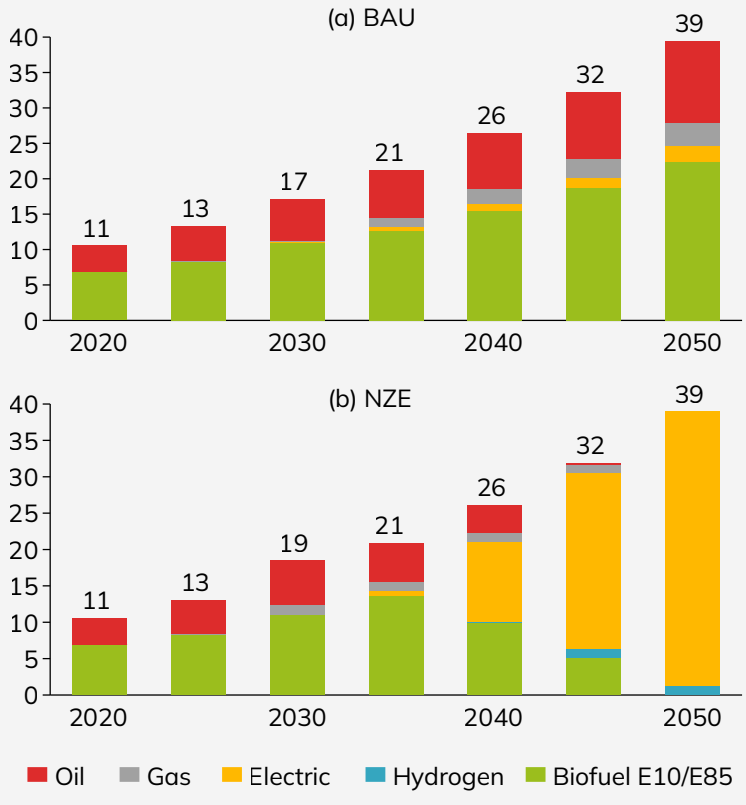
4.3.4 Heavy Truck Fleet

Under the BAU scenario, the ASEAN heavy truck fleet expands substantially in response to growing freight transport demand, increasing from approximately 10.6 million vehicles in 2020 to 39.4 million in 2050 (Figure 26). The fleet remains largely dependent on combustion-based technologies throughout the modelling period. The number of conventional liquid-fuel trucks increases from approximately 3.7 million vehicles in 2020 to 11.5 million in 2050, while biofuel E10 trucks remain a major component of the fleet, increasing from around 6.9 million to 15.5 million over the same period. Biofuel E85 and natural gas trucks also progressively gain importance, reaching approximately 6.9 million and 3.2 million vehicles, respectively, by 2050. Electric trucks gradually enter the fleet from 2030 onwards but remain comparatively limited, increasing to around 2.2 million vehicles in 2050, while hydrogen trucks do not emerge under the BAU scenario. Overall, the BAU pathway is characterised by continued reliance on oil and biofuels, with only a gradual penetration of electric trucks.

Under the NZE scenario, the heavy truck fleet undergoes a fundamental transition towards zero-emission technologies. The total fleet increases from approximately 10.6 million vehicles in 2020 to 39.4 million in 2050 (Figure 26). Conventional liquid-fuel trucks initially increase but subsequently decline rapidly, falling from approximately 6.2 million vehicles in 2030 to only 0.2 million in 2045, before being completely phased out by 2050. Natural gas and biofuel trucks follow a similar trajectory and are also fully phased out by 2050. Electric trucks emerge as the principal decarbonisation option, increasing from approximately 0.1 million vehicles in 2030 to 11.1 million in 2040 and 37.8 million in 2050. Hydrogen trucks complement electrification in the longer term, reaching approximately 1.2 million vehicles in 2050. Consequently, by 2050 approximately 97% of the heavy-truck fleet is electric and 3% is hydrogen-powered. These results indicate that the decarbonisation of heavy-duty road freight under the NZE scenario is primarily driven by electrification, complemented by an increasing role for hydrogen in the longer term.

FIGURE 26

Annual truck stock for BAU and NZE scenarios, 2020-2050 (million units)

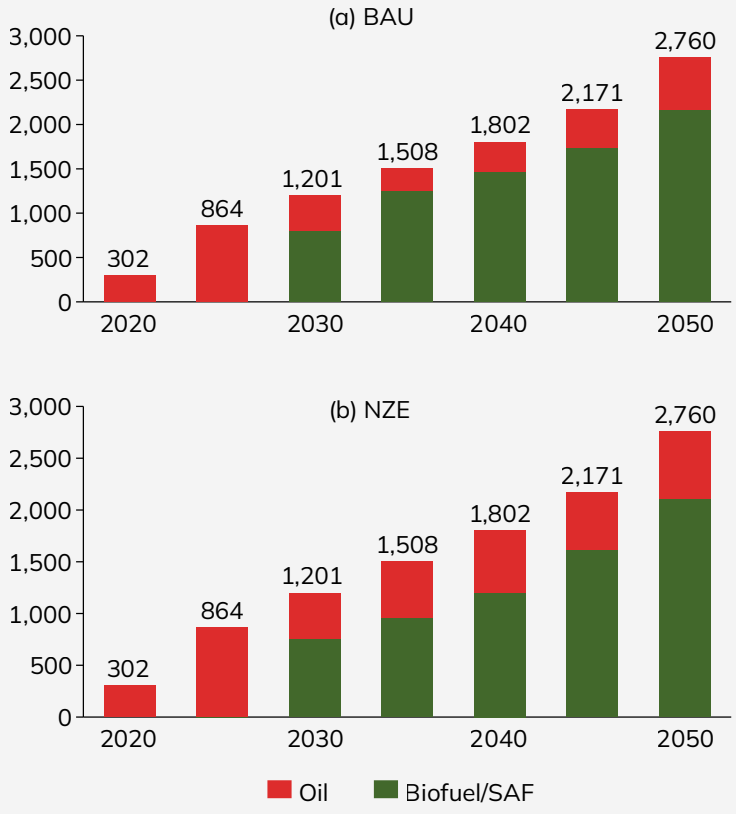


4.3.5 Aviation

Aviation activity across ASEAN increases significantly over the modelling period, from around 302 PJ in 2020 to 2,760 PJ in 2050, reflecting the continued growth in aviation demand across the region (Figure 27). Under the BAU scenario, this increasing demand continues to be met by conventional oil-based aviation fuels throughout the modelling period.

In the NZE scenario, aviation activity follows a similar growth trajectory while the growing demand is met by biofuels and sustainable aviation fuels (SAF) which account for a substantial share of aviation fuel consumption by 2050. Nevertheless, conventional oil remains part of the aviation fuel mix and its consumption is not fully eliminated by 2050. The continued use of oil reflects the more limited availability of technically and economically viable decarbonisation alternatives for long-haul aviation compared with other transport modes. Consequently, the transition in aviation is characterised primarily by progressive diversification from conventional jet fuel towards lower-carbon fuels, rather than a complete replacement within the modelling period.

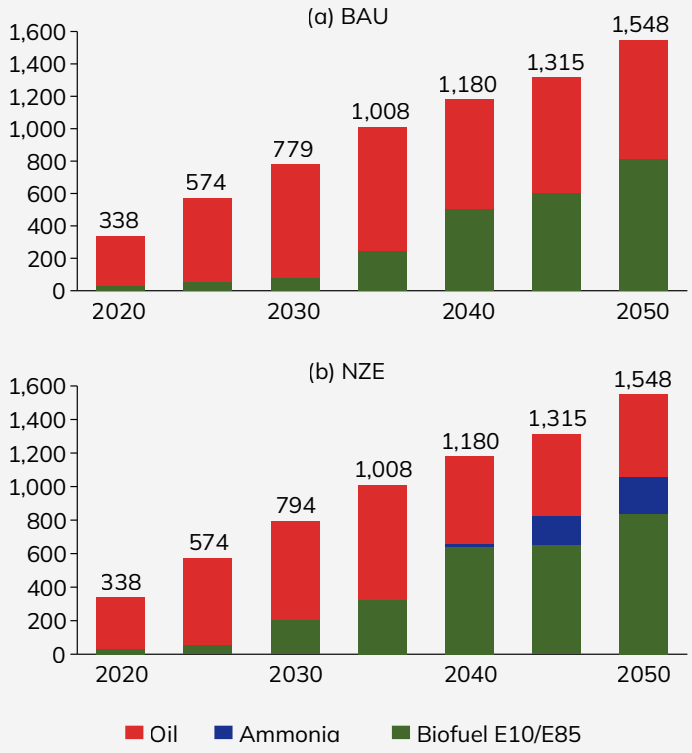
FIGURE 27
Annual aviation activity for BAU and NZE scenarios, 2020-2050 (PJ)



4.3.6 Shipping

Shipping activity across ASEAN increases significantly over the modelling period, from approximately 338 PJ in 2020 to 1,548 PJ in 2050, reflecting continued growth in maritime transport demand across the region (Figure 28). Under the BAU scenario, this growing demand continues to be met entirely by conventional oil-based fuels throughout the modelling horizon. By contrast, the NZE scenario results in a major shift in the shipping fuel mix. Among the low-carbon shipping options represented in the model, ammonia and biofuels provide alternatives to conventional oil-based fuels, with ammonia emerging as the preferred option under the model's least-cost optimisation. Ammonia begins to penetrate the sector from 2040 and expands rapidly thereafter, accounting for the majority of shipping activity by 2045 and fully replacing oil by 2050. From 2050 onwards, ammonia supplies all shipping activity, thus eliminating its reliance on oil. The results highlight fuel switching, particularly towards low-carbon ammonia, as the main pathway for decarbonising ASEAN's shipping sector.

FIGURE 28
Annual shipping activity for BAU and NZE scenarios, 2020-2050 (PJ)



4.4 Residential and Commercial (Buildings) Sector

The buildings results show rising demand for modern energy services alongside a rapid change in the technologies and fuels used to provide them. Household formation, higher incomes, commercial floor space growth, cooling ownership, appliance use and digital infrastructure all expand over the modelling period. The NZE 2050 pathway does not depend on restricting access or economic activity; it changes the efficiency and carbon intensity of service delivery, with electricity becoming the principal energy carrier across residential and commercial uses. The common feature is continued growth in useful services, while the divergence between scenarios is expressed mainly through equipment efficiency, the pace of stock replacement and the emissions intensity of electricity supply.

The difference between BAU and NZE is strongest where the model has clear alternatives to inefficient or directly emitting technologies. Residential final energy falls relative to BAU through efficiency improvements, modern energy access and fuel switching. Lighting converges because LEDs are already the least-cost option in both pathways. Commercial fuel use, commercial cooling and data centre capacity remain close across the scenarios, which means their emissions outcome is determined mainly by equipment performance, operating practice and the carbon intensity of electricity rather than by a reduction in the underlying service demand. Where both pathways select similar technologies, the result indicates that cost and performance improvements are already sufficient to drive adoption without an additional net-zero constraint, although implementation quality still affects realised savings.

This creates a direct dependency between buildings and the power sector. Electrification reduces direct fossil-fuel use but transfers more demand to the electricity system and can intensify peak loads, especially from cooling and data centres. Under NZE, electricity use for cooling appliances in the residential and commercial sectors increases from 546 PJ in 2020 to 2,781 PJ in 2050, while electricity use for data-centre cooling rises from 6 PJ to 57 PJ. The regional energy transition therefore requires investment in clean electricity generation, transmission and distribution, efficient appliances, building envelopes, energy codes, demand response and affordable access to modern services.

Residential final energy demand increases from 3,062 PJ in 2020 to 5,203 PJ in 2050. Under NZE, it increases from 3,062 PJ in 2020 to 4,728 PJ in 2050 (Figure 29). Residential final energy demand increases in both pathways as population, incomes, household formation, appliance ownership, and access to modern energy services expand. The increase is sustained through 2050 and beyond, showing that the buildings sector transition occurs alongside higher levels of comfort and energy access. Electricity becomes the largest component in both scenarios. Under BAU, however, oil and modern biomass remain in the mix for longer, and the decline in traditional biomass is more gradual. Under NZE, the total is lower from the 2040s onward even as the same broad service categories continue to grow. The growing separation after the middle of the century is best understood as the cumulative effect of many equipment replacement decisions rather than a single reduction in household service demand.

In 2020, electricity and oil each account for roughly 33% of residential demand, with traditional and modern biomass supplying most of the balance. By 2050, electricity provides approximately 75% of BAU demand and more than 95% of NZE demand. The difference is driven by the way services are delivered rather than by lower household activity. Efficient appliances and electric technologies require less final energy to provide the same lighting, cooling, cooking, and other household services than many combustion-based alternatives. The faster reduction of traditional biomass also reflects wider access to modern energy services, while the decline in oil is enabled by electrification. Once the transition is largely completed, electricity accounts for almost the entire residential energy mix, leaving a smaller residual demand for biomass and other fuels. In a least-cost framework, these gains compound as inefficient devices retire and replacement technologies provide the same useful output with lower fuel input, particularly for cooking, cooling, lighting, and other appliance-based services.

Commercial final energy demand rises from 830 PJ in 2020 to 3,259 PJ in 2050. The NZE pathway follows almost the same trajectory, reaching 3,256 PJ in 2050 (Figure 30). This represents an almost fourfold increase by 2050 in both pathways. Commercial energy demand expands strongly in both BAU and NZE as offices, retail, hospitality, public services, digital activity, and other commercial floor space grow. The trajectories remain very close throughout the model horizon, indicating that the same broad level of commercial activity and energy services is maintained in both pathways. Electricity supplies almost all final energy, while oil, gas, coal, and biomass make only a very small contribution. The principal result is therefore the sustained expansion of an already highly electrified sector. The close trajectories show that economic and service-sector expansion is preserved under NZE, while the emissions outcome is determined mainly by how efficiently the additional electricity demand is supplied and used.

FIGURE 29

Total annual residential fuel use for BAU and NZE scenarios, 2020-2050 (PJ)

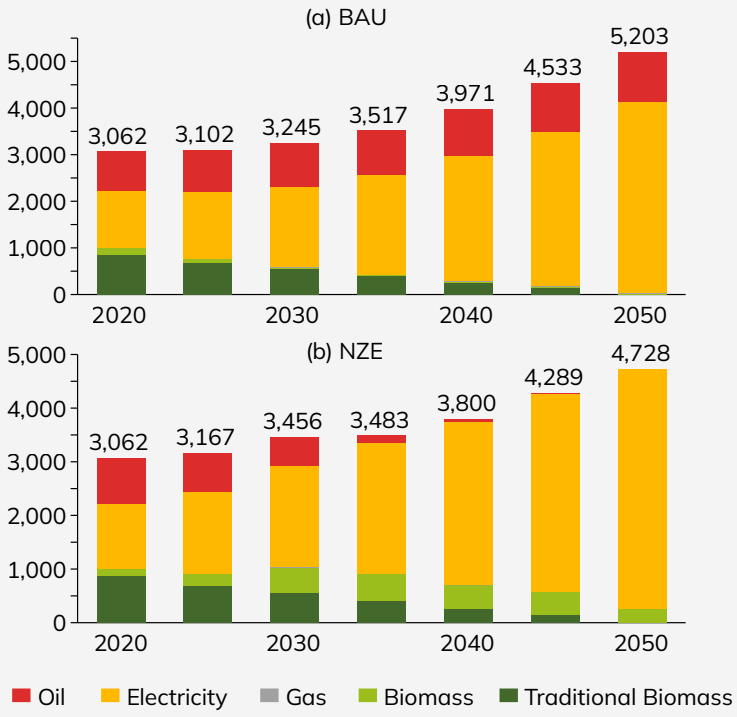
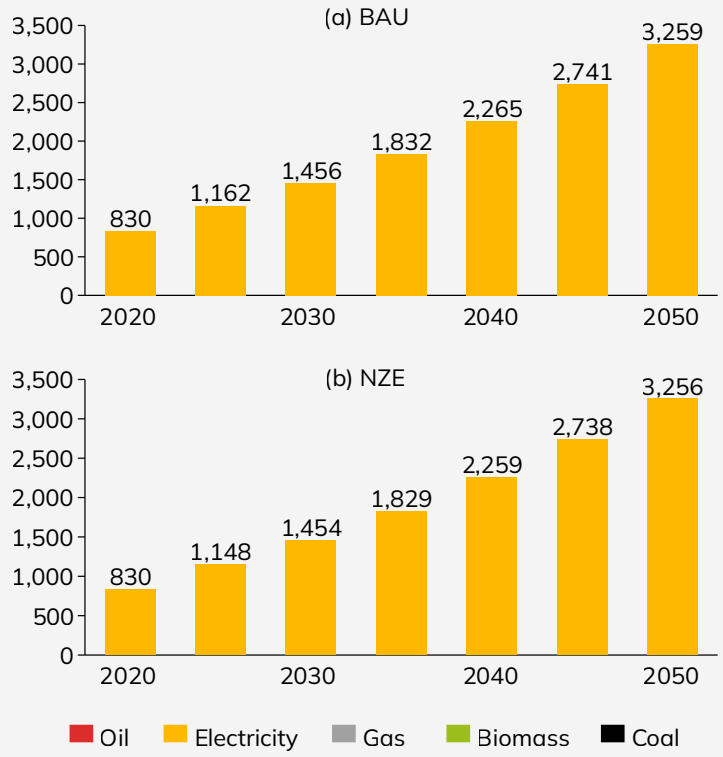


FIGURE 30
Total annual commercial fuel use for BAU and NZE scenarios, 2020-2050 (PJ)



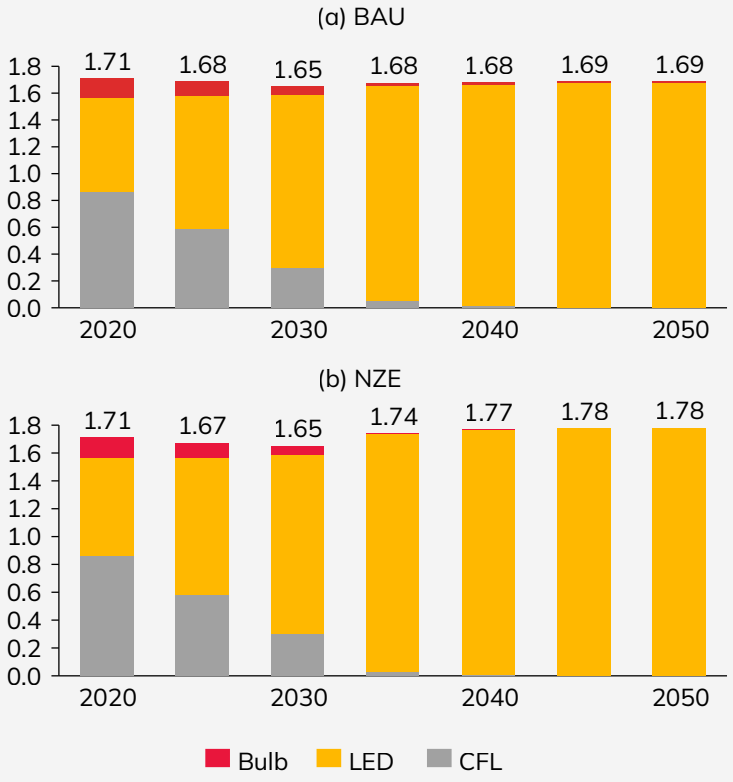
4.4.1 Lighting

The residential lighting stock remains broadly stable over the modelling period (Figure 31). The important result is the near-complete change in composition. Compact fluorescent lamps account for a large share of the 2020 stock, conventional bulbs retain a small role, and LEDs expand rapidly during the 2020s and early 2030s. By the mid-2030s, almost the entire stock is served by LEDs in both scenarios, and this structure is maintained through 2050. This means that the principal transition is a near-complete change in lamp composition, while the quantity of lighting service remains stable and continues to reflect household access and occupancy patterns.

At the starting point of 2020, compact fluorescent lamps represent about half of the residential stock, LEDs roughly 40%, and conventional bulbs less than 10%. By 2050, LEDs account for almost the entire stock in both scenarios. The convergence occurs because LED lighting is already economically attractive without requiring a scenario-specific net-zero constraint. LEDs provide the same lighting service with substantially less electricity and longer operating lifetimes than conventional bulbs or compact fluorescent lamps. Normal stock turnover and replacement therefore drive the transition in BAU as well as NZE. Rapid turnover is feasible because lamps have relatively short replacement cycles, LEDs are widely available, and their lower operating cost can recover a higher purchase price over the product lifetime, although policy intervention may be required (e.g. buyback programmes, demand aggregation) to overcome the upfront costs.

FIGURE 31

Annual residential lighting stock for BAU and NZE scenarios, 2020-2050 (billion units)

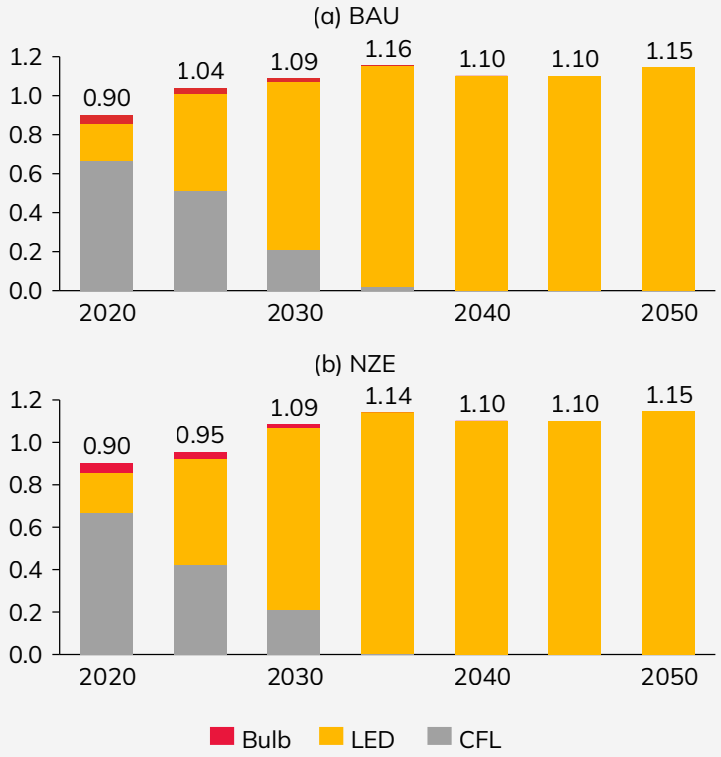


Commercial lighting stock increases from approximately 0.9 billion units in 2020 to 1.15 billion units in 2050 (Figure 32). BAU and NZE converge on the same 2050 totals, indicating that the scenarios preserve the same expansion in commercial floor space and lighting services. Commercial lighting grows with the expansion of offices, retail, hospitality, public facilities, and other service-sector buildings. The stock increases steadily after the initial replacement period and continues rising through 2050, reflecting the long-term increase in commercial floor space and lighting services. As in the residential sector, the main transformation is in technology composition rather than the total number of lighting points. The increasing stock therefore represents additional lighting points associated with expanding commercial activity, rather than a reversal of the efficiency gains achieved through the technology transition.

In 2020, compact fluorescent lamps accounted for approximately 70% of the commercial lighting stock, LEDs for around 20%, and conventional bulbs for less than 10%. LEDs rise to virtually 100% of the 1.15-billion-unit stock in 2050. Compact fluorescent lamps make up most of the initial commercial stock but are replaced quickly, while conventional bulbs disappear during the 2020s. LEDs supply nearly all lighting services from the mid-2030s onward in both pathways. This result shows that efficient lighting is a no-regret investment whose cost and performance advantages are sufficient to drive adoption under BAU. The NZE pathway does not need a fundamentally different lamp technology; its additional gains must come from how lighting systems are designed, controlled, maintained and integrated into buildings. Because this shift occurs in both pathways, the NZE result should be interpreted as consolidation of an already cost-effective market trend, supported by clean electricity and improved system operation rather than a separate technology substitution.

FIGURE 32

Annual commercial lighting stock for BAU and NZE scenarios, 2020-2050 (billion units)



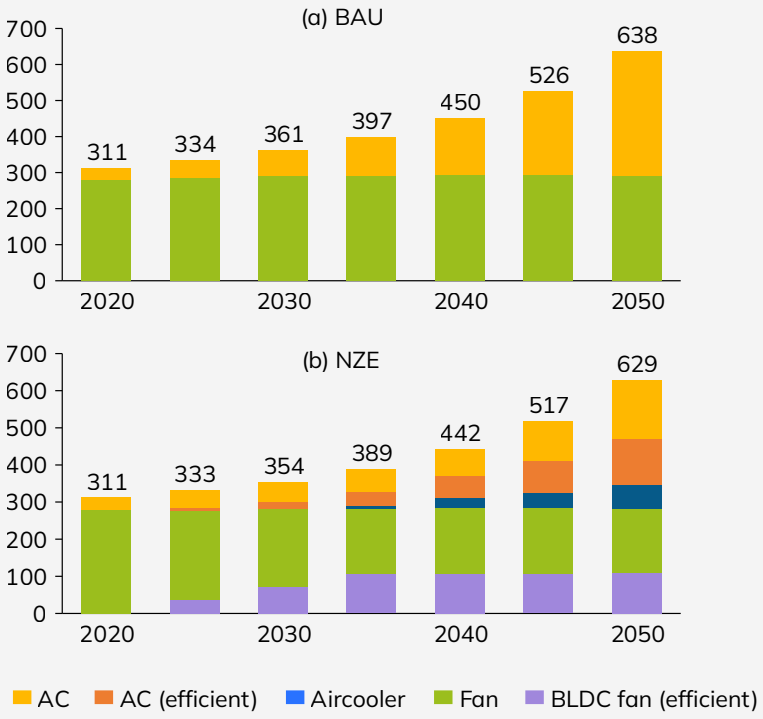
4.4.2 Cooling

Residential cooling is one of the fastest-growing energy services in the analysis. The BAU equipment stock increases from approximately 311 million units in 2020 to 638 million in 2050 (Figure 33). NZE follows nearly the same service-demand trajectory, increasing from approximately 311 million units in 2020 to 629 million in 2050. This close alignment indicates that decarbonisation does not depend on constraining access to thermal comfort. Instead, the pathway accommodates the substantial expansion in the regional cooling stock while changing the efficiency and composition of the equipment used to deliver that service.

In BAU, fans account for roughly 90% of the 2020 stock, but conventional air conditioners become the largest component by 2050 and represent more than 50% of the stock. Under NZE, efficient air conditioners and efficient brushless direct current (BLDC) fans together provide approximately one-third of the stock in 2050, with air coolers and conventional fans retaining additional roles. The main difference is the technology mix. BAU growth is led largely by conventional air conditioners, with the fan stock changing more gradually. NZE introduces efficient air conditioners at scale and expands efficient BLDC fans, which can cool using much less electricity than conventional equipment. The shift becomes more pronounced as the stock grows, showing why standards introduced during the 2020s and 2030s have a long-lived effect. Because appliances remain in service for many years, delaying efficiency improvements would lock in higher demand through 2050. The growing efficient share in NZE illustrates the importance of early standards, since each inefficient unit purchased during rapid market expansion can remain in use for many years and lock in higher electricity demand.

FIGURE 33

Annual residential cooling technology mix for BAU and NZE scenarios, 2020-2050 (million units)

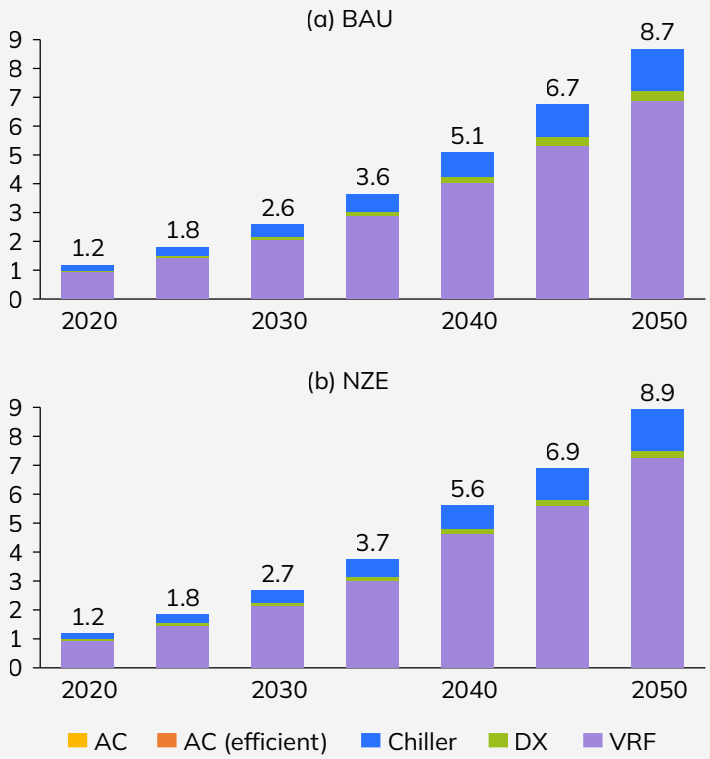


Commercial cooling stock expands from approximately 1.2 million systems in 2020 to 8.7 million in 2050 under BAU. Under NZE, it increases from the same 1.2 million systems in 2020 to 8.9 million in 2050 (Figure 34). The result indicates that the pathway preserves growth in offices, retail, hospitality, healthcare and public services, and that the emissions outcome depends primarily on equipment performance, refrigerant management, building design and the carbon intensity of electricity rather than on restricting commercial cooling access.

Variable refrigerant flow systems represent approximately 75-80% of commercial cooling stock in 2020 and retain a similar dominant share in 2050. Chillers provide most of the remaining capacity, while direct-expansion systems and individual air conditioners remain comparatively small in both pathways. Variable refrigerant flow systems dominate in both scenarios, while chillers and direct-expansion systems provide the remaining capacity. The overall technology structure is similar because commercial cooling is already highly electrified and because the stock categories do not fully reveal improvements in seasonal efficiency, controls, sizing and operating practice. NZE consequently relies on better-performing equipment and cleaner electricity rather than a wholesale change in the number or broad type of systems. Long asset lifetimes mean that performance requirements adopted before 2035 influence energy use well beyond 2050. The limited difference in the displayed stock categories does not imply identical performance, because seasonal efficiency, control strategies, part-load operation, system sizing and maintenance can materially change electricity consumption within the same technology class.

FIGURE 34

Annual commercial cooling technology mix for BAU and NZE scenarios, 2020-2050 (million units)

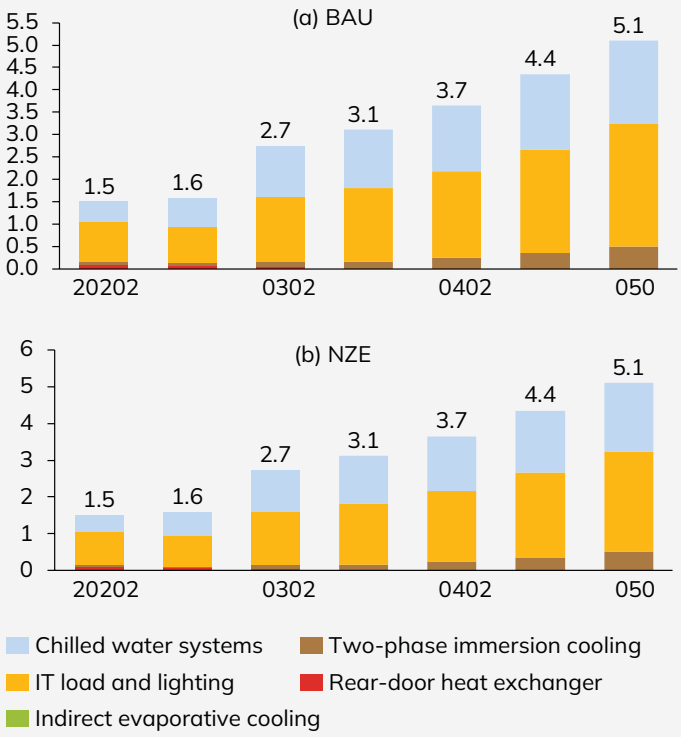


4.4.3 Data Centres

Data centre capacity increases from 1.5 GW in 2020 to 5.1 GW in 2050 in both BAU and NZE (Figure 35). Capacity therefore more than triples by 2050. The identical trajectory shows that the model preserves the expansion of cloud services, digitalisation, data storage, and computing activity under the net-zero constraint. The strongest absolute increase occurs before 2050, when capacity grows by 3.6 GW. Decarbonisation must therefore be delivered through the efficiency and electricity supply of these facilities, not through lower digital service demand.

IT load and lighting account for approximately 60% of the 1.5 GW total in 2020 and just over half of capacity in 2050. Chilled-water systems provide roughly one-third of the total throughout, while two-phase immersion cooling grows from a marginal role in 2020 to about 10% in 2050. The absence of a scenario difference means that decarbonisation is achieved without constraining digital-service demand. Instead, emissions are reduced through efficient servers and cooling, higher utilisation and a progressively cleaner electricity supply. The increasing role of immersion cooling reflects the need to manage higher heat densities, while chilled-water systems continue to provide the largest cooling contribution. Additional gains can come from improved power usage effectiveness, workload management, virtualisation, and heat reuse even though these measures are not shown as separate capacity categories.

FIGURE 35
Annual data centre capacity for BAU and NZE scenarios, 2020-2050 (GW)



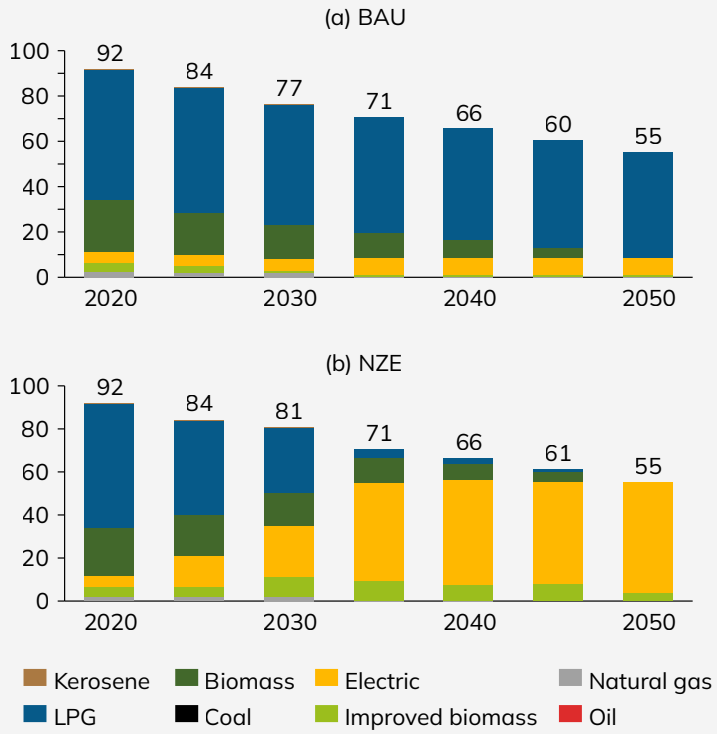
4.4.4 Cooking

In the BAU scenario, the total number of cookstoves in rural areas decreases from 92 million in 2020 to over 55 million in 2050, mainly as a result of continued urbanisation and the associated decline in rural cooking demand (Figure 36). In the base year, LPG stoves account for the largest share of rural cookstoves (62%), followed by traditional biomass (25%), electric (5%), improved biomass (5%), and natural gas stoves (around 2%). Over time, LPG further strengthens its dominant position, accounting for 84% of rural cookstoves in 2050. Electric cooking also gains importance, with its share increasing to 14% in 2050, while traditional biomass is gradually phased out by 2050. These trends reflect existing national policies and assumed technology transitions in the cooking sector across ASEAN Member States. The most significant transformation occurs in Indonesia, where electric stoves become the dominant cooking technology in the long term, with increasing electrification also observed in Malaysia, the Philippines, Thailand, and Viet Nam. In contrast, LPG remains or becomes the dominant cooking technology in countries such as Cambodia and Singapore.

In contrast, under the NZE scenario, the total number of cookstoves is expected to follow a trajectory similar to that of the BAU scenario; however, the technology mix changes substantially. Electric cookstoves almost completely replace LPG and become the dominant cooking technology by 2050, reaching 51 million units and accounting for approximately 93% of the total cookstove stock. Improved biomass cookstoves account for the remaining 7%, at approximately 4.1 million units. Consequently, almost all ASEAN Member States are expected to transition predominantly to electric cooking in the long term, resulting in the near-complete elimination of direct emissions from the cooking sector.

FIGURE 36

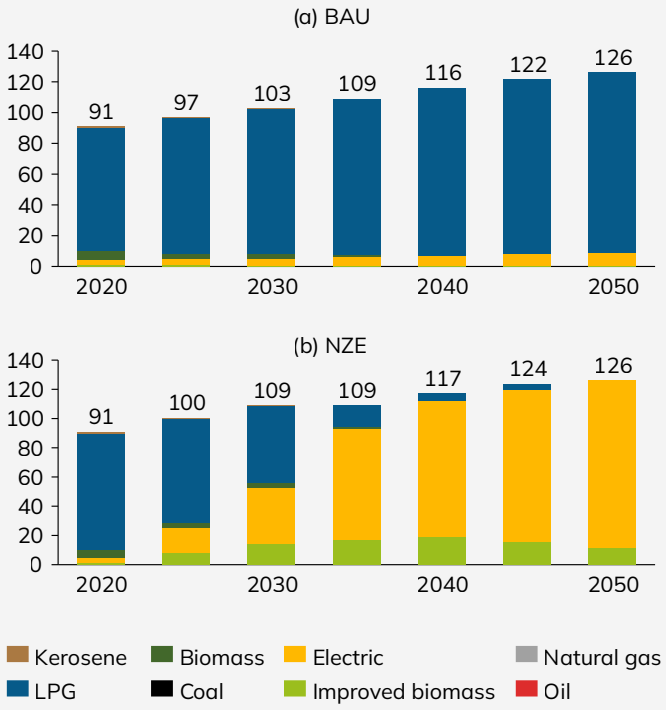
Annual rural cooking stock for BAU and NZE scenarios, by fuel, 2020-2050 (million units)



In the BAU scenario, the total number of cookstoves in urban areas increases from approximately 91 million in 2020 to 126 million in 2050, mainly as a result of population growth and continued urbanisation (Figure 37). In the base year, LPG stoves account for the largest share of urban cookstoves (88%), followed by traditional biomass (6%), electric (4%), and improved biomass stoves (1%). LPG remains the dominant cooking technology throughout the projection period, with its share increasing to approximately 93% in 2050. Electric cooking gradually gains importance, with its share increasing to 7% in 2050. By contrast, traditional biomass is gradually phased out by 2040, while improved biomass represents only a marginal share of the urban cookstove stock in the long term. These trends reflect existing national clean cooking policies and assumed technology transitions across ASEAN Member States. Most countries broadly maintain their base-year technology trajectories, while Cambodia, Lao PDR, Myanmar and the Philippines experience a more pronounced transition away from traditional biomass cooking.

By contrast, under the NZE scenario, while the total number of urban cookstoves follows the same trajectory as in the BAU scenario, the technology mix changes substantially over time. Electric cookstoves fully replace LPG by 2050, reaching 114.5 million units and accounting for approximately 91% of the total urban cookstove stock. Improved biomass accounts for the remaining 9%, at approximately 11.6 million units. The transition towards electrification continues thereafter. Consequently, almost all ASEAN Member States are expected to transition predominantly to electric cooking in the long term, resulting in the near-complete elimination of direct emissions from the cooking sector.

FIGURE 37
Annual urban cooking stock for BAU and NZE scenarios, by fuel, 2020-2050 (million units)



4.5 Industry Sector

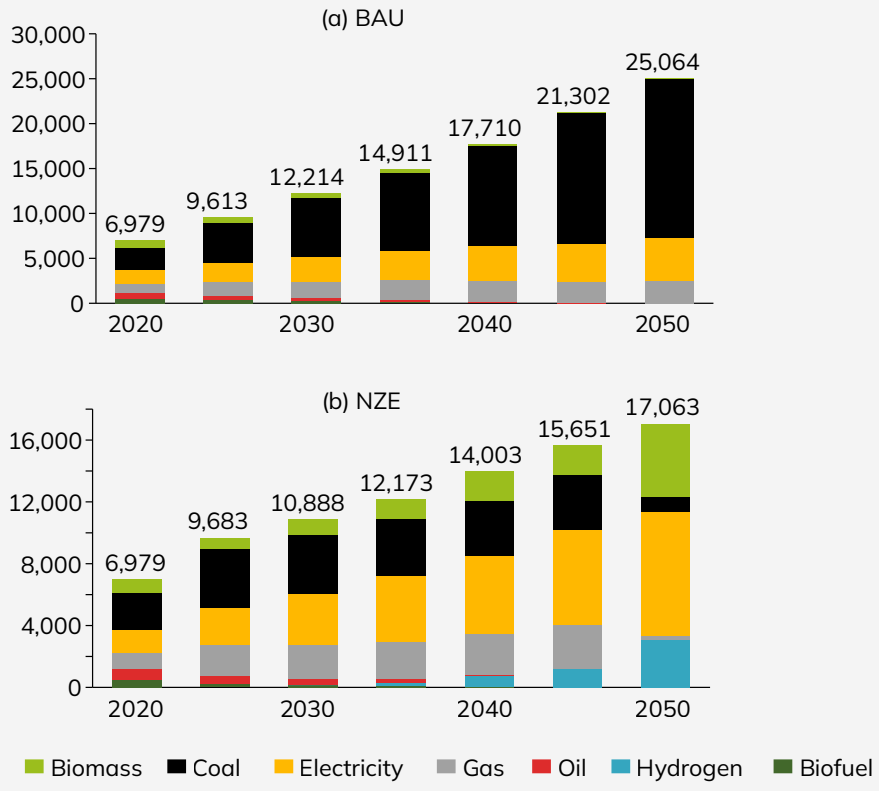
Industry presents a more differentiated transition than buildings because industrial demand combines electricity, low-temperature heat (LTH), high-temperature heat (HTH), feedstocks, and process emissions. The aggregate results show that industrial output continues to expand under NZE, while fuels and production routes change substantially. The pathway does not apply a single solution across all subsectors. It uses direct electrification where technically suitable, hydrogen for selected high-temperature and reductive processes, sustainable biomass where appropriate, and carbon capture for residual emissions that are difficult to eliminate through fuel switching alone. The pathway therefore differentiates between applications that can electrify directly, processes that require new fuels, and residual emissions that need capture, rather than imposing one uniform solution on all industrial demand.

Total industrial final energy use rises from 6,979 PJ in 2020 to 25,064 PJ in 2050 under BAU. Under NZE, it rises from 6,979 PJ in 2020 to 17,063 PJ in 2050 (Figure 38). The NZE pathway therefore uses approximately 32% less final energy than BAU in 2050, while still supporting continued growth in industrial output. Industrial energy use grows strongly in both pathways as manufacturing and material production expand. BAU rises rapidly through 2050 and continues accelerating thereafter, while the NZE trajectory grows more slowly and remains substantially below BAU. The widening separation shows that the net-zero transition decouples industrial growth from an equivalent increase in final energy demand. This does not indicate lower industrial ambition; rather, it reflects more efficient equipment, electrified processes, and alternative production routes that deliver the required output with less final energy.

Coal supplies roughly one-third of industrial energy in 2020 and rises to around two-thirds of BAU demand in 2050. In NZE, electricity provides close to half of industrial final energy in 2050, while hydrogen rises to around 18% and biomass to approximately 28% by 2050; coal, gas, oil, and biofuel make up the smaller residual share. The fuel mix changes as significantly as the total. BAU becomes increasingly dependent on coal, with electricity and gas also growing. Under NZE, coal declines after the transition period, electricity becomes the largest component, and hydrogen and sustainable biomass expand for processes that cannot be served efficiently by direct electricity. Residual oil and gas become comparatively small. Electric motors, furnaces and heat technologies reduce conversion losses, while hydrogen and biomass provide options for high-temperature heat, reduction and feedstock applications. This diversified mix reflects the technical heterogeneity of industry, with electricity serving efficient motors and lower-temperature processes, while hydrogen and sustainable biomass address selected high-temperature, reductive or feedstock-related requirements.

FIGURE 38

Total annual industry fuel use by type for BAU and NZE scenarios, 2020-2050 (PJ)



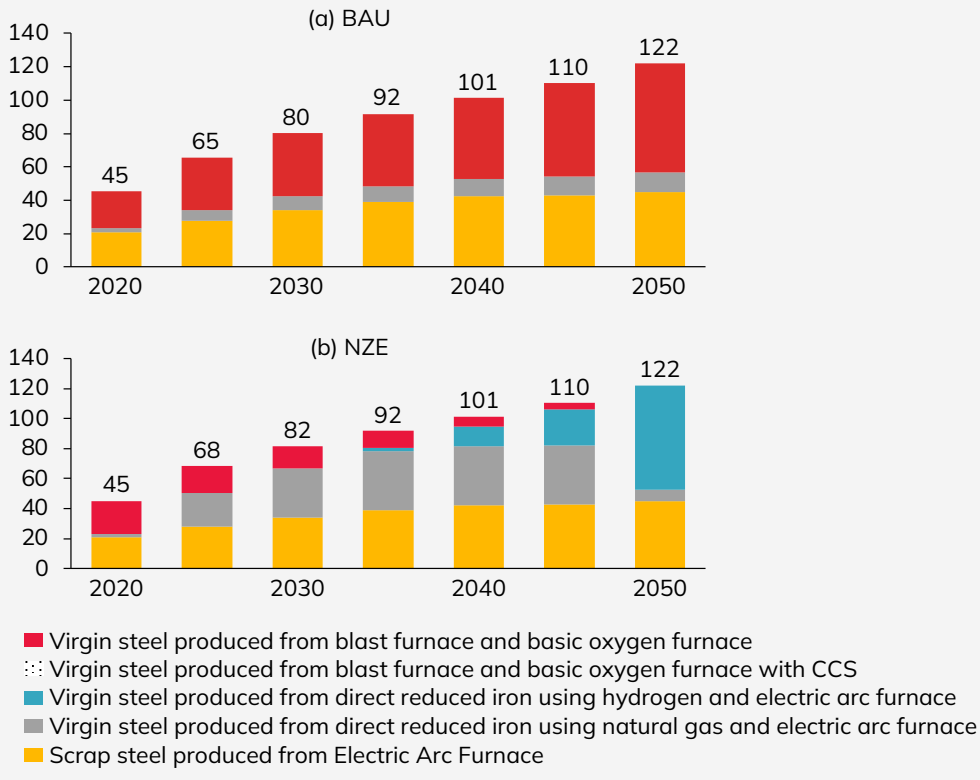
4.5.1 Iron and Steel

Iron and steel output increases from 45 Mtpa in 2020 to 122 Mtpa in both pathways in 2050 (Figure 39). By 2050, regional steel production is therefore around three times its 2020 BAU level, while the long-term activity trajectory converges fully across the scenarios. The model consequently achieves deep decarbonisation without reducing the supply of steel needed for buildings, transport systems, energy infrastructure and industrial equipment. The distinguishing feature is the production route: the NZE pathway changes how primary and secondary steel are produced while maintaining the same 2050 output.

In BAU, conventional blast-furnace and basic-oxygen-furnace steel supplies about half of output in 2050, while scrap-based electric-arc furnaces (EAFs) provide most of the balance. In NZE, hydrogen-based direct-reduced iron (DRI) and EAFs supply approximately 60% of the 122 Mtpa produced in 2050; scrap-based EAFs supply the remainder. BAU relies increasingly on conventional blast-furnace-basic-oxygen-furnace (BF-BOF) production alongside scrap-based EAFs. NZE first expands scrap-based production and gas-based DRI with EAFs, then shifts strongly toward hydrogen-based DRI after the mid-2040s. Hydrogen-based DRI becomes the dominant source of virgin steel by 2050, while conventional BF-BOF production is largely phased out. The sequencing reflects the maturity and infrastructure needs of the technologies, with gas-based DRI providing a potential transitional route before renewable hydrogen is available at scale. The staged transition reflects asset turnover and technology readiness, since gas-based DRI can support early deployment of EAFs while renewable hydrogen production and delivery infrastructure scale toward 2050.

FIGURE 39

Annual iron and steel production for BAU and NZE scenarios, 2020-2050 (Mtpa)



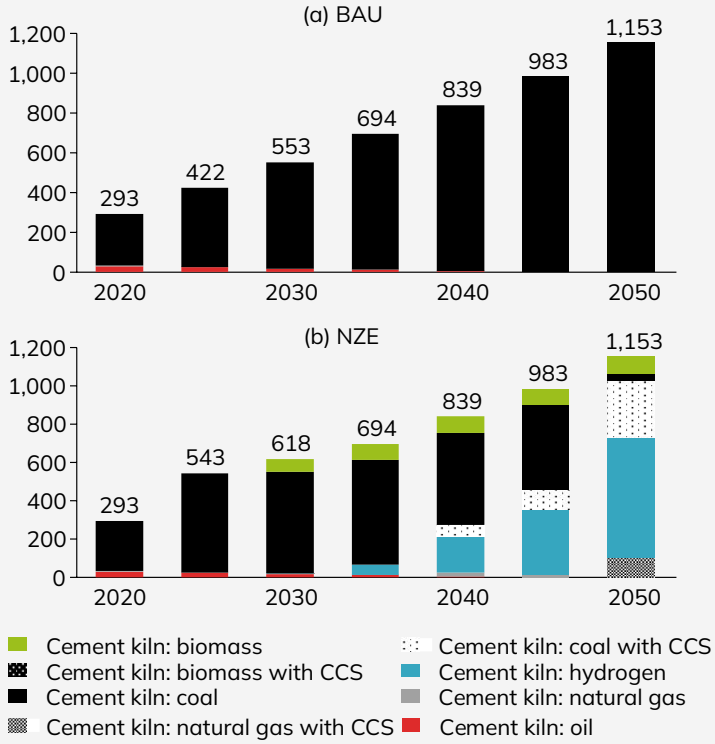
4.5.2 Cement

Cement production rises from 293 Mtpa in 2020 to 1,153 Mtpa in 2050 in both pathways (Figure 40), reaching almost four times its 2020 level. The identical activity totals show that NZE is achieved by changing kiln fuels, production routes and emissions controls rather than by reducing the volume of cement available to meet construction and infrastructure demand. Production continues to rise thereafter, demonstrating that the transition does not constrain cement supply for regional development. Instead, the pathway shifts from heavy reliance on fossil fuels towards a more diversified portfolio of low-carbon fuels and carbon capture and storage (CCS) to provide kiln heat and manage process emissions.

BAU is almost entirely coal-based in 2050. Under NZE, hydrogen-fired kilns provide roughly 55-60% of output, while capture-equipped coal, gas and biomass routes collectively provide around one-third and unabated fuels decline to a small residual share. Sustainable biomass contributes during the transition, hydrogen supplies high-temperature kiln heat, and capture-equipped routes expand after 2050. Hydrogen reduces combustion-related emissions, while carbon capture addresses remaining fuel emissions and the process emissions released during clinker production. This combination is necessary because fuel switching alone cannot eliminate the CO_2 released through calcination; clinker substitution, process changes or capture are also required.

FIGURE 40

Annual cement production for BAU and NZE scenarios, 2020-2050 (Mtpa)



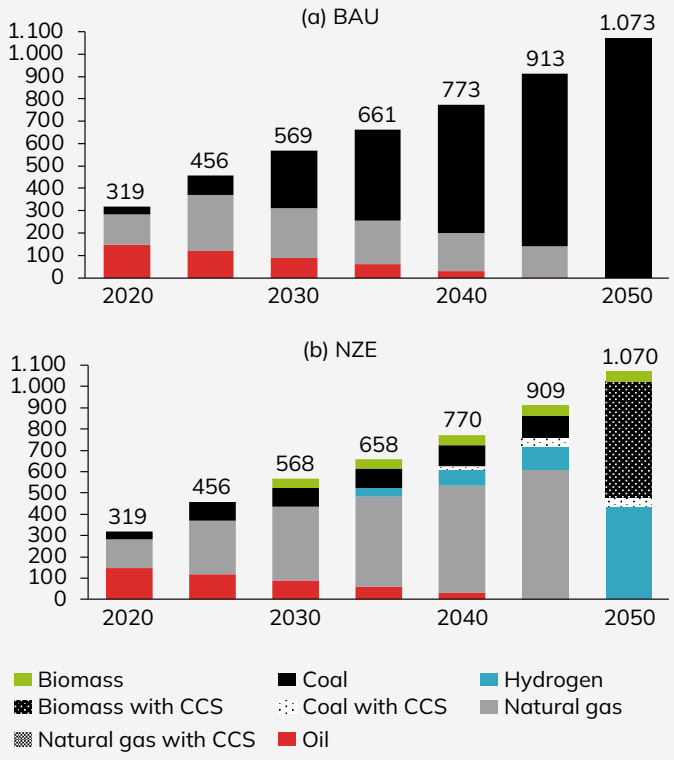
4.5.3 High-temperature Process Heat

HTH process-energy demand in oil-based chemicals rises from 319 PJ in 2020 to 1,073 PJ in 2050 under BAU. Under NZE, it rises from 319 PJ in 2020 to 1,070 PJ in 2050 (Figure 41). The totals are therefore almost identical at the three decision points, which confirms that the principal scenario effect lies in the technology and fuel mix rather than in the level of chemical activity or useful process heat. Energy demand for HTH processes in oil-based chemicals rises steadily in both pathways, reflecting continued growth in chemical production and associated heat requirements. The broad activity trajectory is maintained under NZE, and any temporary divergence between model years reflects the timing of technology deployment rather than a sustained reduction in output. This result is important because chemical HTH is a hard-to-abate demand that cannot be addressed solely through conventional efficiency measures.

The BAU mix shifts from a combination of oil, gas, and coal in 2020 to almost complete reliance on coal by 2050. Under BAU, coal becomes the dominant source of HTH as demand expands, with gas and oil playing smaller roles. NZE first reduces oil and coal through greater use of gas and efficiency improvements, then introduces hydrogen and capture-equipped gas at scale around 2050. Hydrogen becomes a major source of direct process heat, while natural gas with carbon capture supplies a complementary route. The transition reflects the limited availability of direct electrification options for some HTH processes and the need to manage residual emissions from continued fuel use. The continued role for capture-equipped gas reflects the limited availability of direct electrification for the highest-temperature duties and the value of retaining a dispatchable heat source where hydrogen supply may be constrained.

FIGURE 41

Annual oil-based chemicals HTH processes for BAU and NZE scenarios, 2020-2050 (PJ)



Process-energy use in other chemicals increases from 243 PJ in 2020 to 792 PJ in 2050 under BAU. Under NZE, it rises from the same 243 PJ in 2020 to approximately 851 PJ in 2050 (Figure 42). The temporary difference around 2050 reflects the energy requirements and conversion characteristics of the alternative technology mix. Energy use in other chemical processes grows substantially in both pathways.

BAU increases gradually and becomes increasingly dependent on coal, gas and electricity. NZE expands electricity and natural gas earlier, then shifts toward a combination of electricity and natural gas with carbon capture from around 2050. Total energy can be temporarily higher in individual NZE model years because technology conversion and capture systems introduce auxiliary energy requirements, but the pathway maintains the same long-term expansion of chemical production and process services. The temporary increase in some NZE years should therefore be read as a change in conversion route and auxiliary energy requirements, not as an increase in chemical output beyond the pathway assumption.

In 2020, electricity supplies approximately half of process energy, natural gas around one-third, and oil and other fuels the remainder. By 2050, BAU obtains roughly 70% from coal, whereas NZE obtains around 60% from electricity and 40% from capture-equipped gas. The technology sequence reflects the diversity of the subsector. Low- and medium-temperature heat, motors, pumps and mechanical processes can be electrified relatively early, explaining the rapid growth of electricity under NZE. Higher-temperature or process-specific applications retain gaseous fuels for longer and adopt carbon capture where direct electrification is less suitable. This produces a staged transition rather than an immediate replacement of every fuel. The additional energy used by capture equipment is offset by the reduction in unabated emissions from the remaining gas-based processes. Capture-equipped gas becomes more important only after direct electrification opportunities have been used, which is consistent with reserving carbon-management infrastructure for process duties that remain difficult to abate.

FIGURE 42

Annual chemicals HTH and LTH processes for BAU and NZE scenarios, 2020-2050 (PJ)

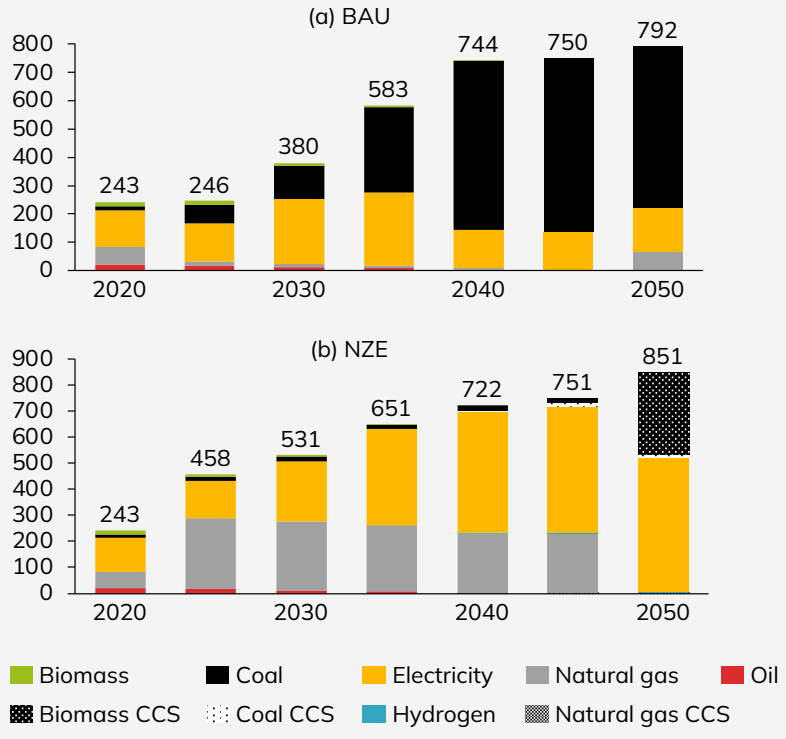
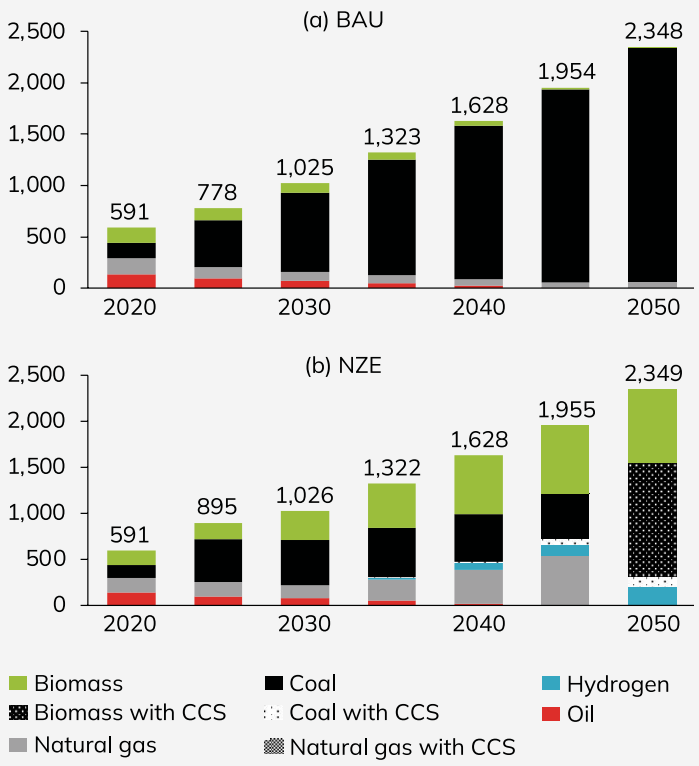


FIGURE 43

Annual other industries HTH processes for BAU and NZE scenarios, 2020-2050 (PJ)



HTH process energy demand in other industries increases from 591 PJ in 2020 to 2,348 PJ in 2050 under BAU and NZE (Figure 43). The similar totals indicate that the pathway preserves industrial activity and the quantity of high-temperature heat required. The transformation under NZE occurs in how that heat is produced. BAU becomes increasingly coal intensive, while NZE keeps unabated fossil fuel use comparatively limited and introduces a more diverse set of lower-carbon energy carriers and carbon-management options. The central result is thus a change in the carbon intensity and diversity of HTH supply, rather than a reduction in the quantity of industrial service delivered.

In BAU, coal rises from about half of the 2020 mix to more than 90% in 2050. Under NZE, sustainable biomass and capture-equipped biomass or other capture-equipped fuels together provide the large majority of process energy in 2050, with hydrogen supplying a smaller but growing share. NZE expands sustainable biomass during the transition, introduces hydrogen for selected duties, and relies increasingly on capture-equipped fuels after 2050. The pathway reflects the technical difficulty of directly electrifying some HTH processes and the value of retaining multiple low-carbon options. Biomass can replace coal where feedstock supply and process performance allow; hydrogen can serve applications requiring clean high-grade heat; and carbon capture can manage residual emissions from fuels that remain technically or economically difficult to replace.

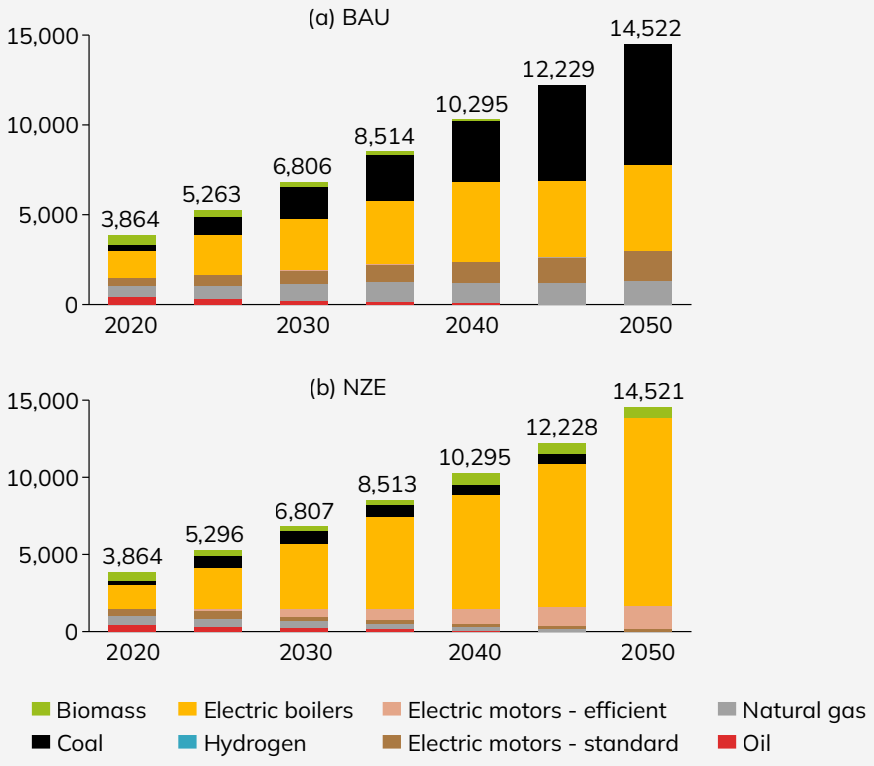
Total energy use for LTH processes in other industries increases substantially as industrial production and associated heat and mechanical-energy requirements expand. Under BAU and NZE, demand rises from approximately 3,864 PJ in 2020 to around 14,522 PJ in 2050 (Figure 44). The close alignment between the scenario totals indicates that the net-zero transition does not reduce the underlying level of industrial activity or the useful energy services required. Instead, the main transformation occurs in the technologies and energy carriers used to provide LTH and mechanical power.

The technology mix diverges substantially between the pathways. In 2020, electric boilers already provide approximately 40% of process energy in both scenarios, while biomass and natural gas each contribute around 14%, oil approximately 12%, standard electric motors about 11%, and coal around 8%. Under BAU, coal expands rapidly and supplies approximately 6,700 PJ, or 46% of total demand, in 2050. Electric boilers provide around 4,802 PJ, or 33%, while standard motors and natural gas contribute approximately 11% and 9%, respectively. Under NZE, coal, oil and natural gas are phased out by 2050. Electric boilers provide approximately 12,200 PJ, or 84% of total process energy, in 2050, followed by efficient motors at around 1,488 PJ, or 10%, and biomass at approximately 686 PJ, or 5%.

The NZE result reflects the technical suitability of LTH industrial processes for direct electrification. Electric boilers can replace combustion-based heat without requiring major changes to the underlying industrial service, while efficient motors reduce electricity requirements for pumping, ventilation, compression, material handling and other mechanical processes. Biomass provides a limited transitional contribution but is phased out as clean electricity and electric technologies become available at scale. Hydrogen is not selected for these applications because direct electricity provides a more efficient and generally lower-cost option for LTH, allowing hydrogen to be reserved for industrial processes that are more difficult to electrify. The transition therefore creates a major dependency on low-carbon electricity generation, grid reinforcement and reliable industrial connections.

FIGURE 44

Annual other industries LTH processes for BAU and NZE scenarios, 2020-2050 (PJ)



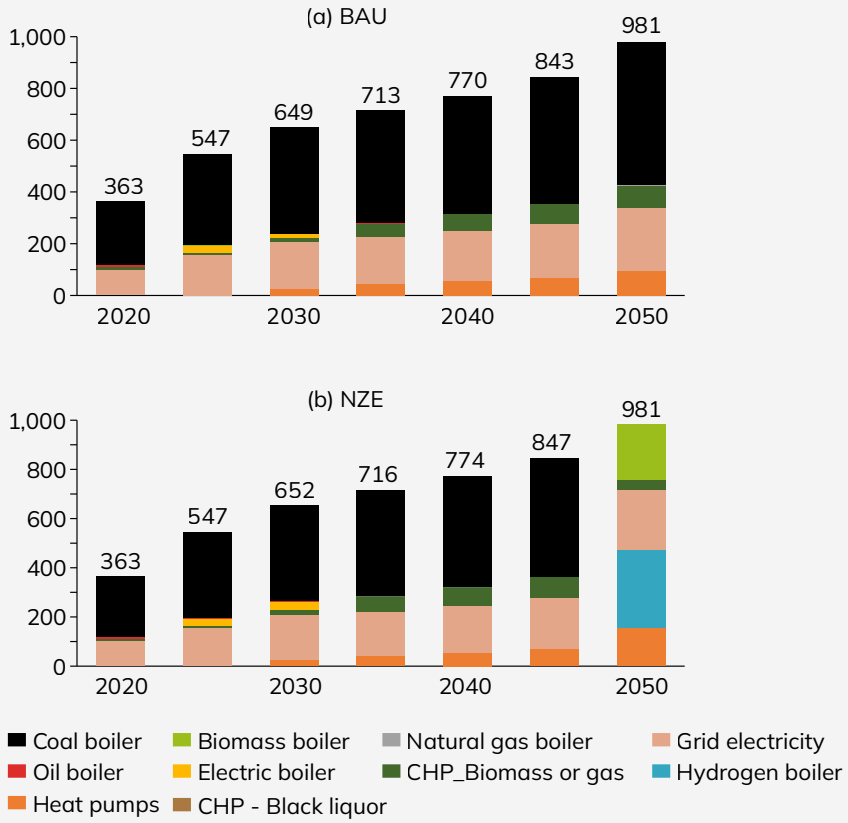
4.5.4 Pulp and Paper

Pulp and paper process-energy use increases from 363 PJ in 2020 to 981 PJ in 2050 in both pathways (Figure 45), reaching approximately 2.7 times its 2020 level. The closely aligned totals indicate that NZE maintains the same broad level of output and useful energy services. Decarbonisation is therefore driven mainly by process efficiency, fuel substitution and the replacement of coal-dominated steam and heat production with technologies suited to the sector's different temperature requirements, rather than by a reduction in productive activity.

Coal supplies approximately two-thirds of BAU pulp and paper process energy in 2020 and more than half in 2050. Under NZE, the 2050 mix is distributed broadly among hydrogen, grid electricity, sustainable biomass and heat pumps. Some coal remains during the asset-turnover period but is rapidly displaced after the mid-2040s by these technologies and combined heat and power. This diversified portfolio reflects the sector's combination of low- and high-temperature processes, steam demand and access to process residues that can support firm on-site renewable energy when managed within sustainable supply limits.

FIGURE 45

Annual pulp and paper production for BAU and NZE scenarios, 2020-2050 (PJ)



4.5.5 Textiles and Leather

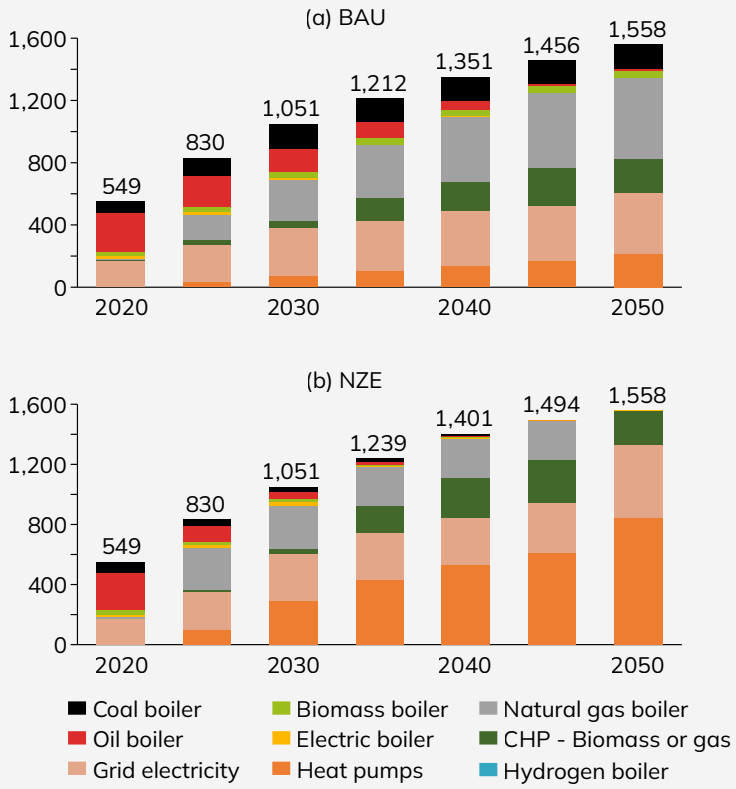
Textiles and leather process-energy use increases from 549 PJ in 2020 to 1,558 PJ in 2050 under both pathways (Figure 46). The totals indicate that output and energy-service demand remain robust, while the principal transition occurs through the substitution of low-carbon technologies for direct fossil-fuel boilers and through modest efficiency gains after 2050. Energy use in textiles and leather grows with production in both pathways and remains closely aligned through 2050.

The result shows that the transition maintains the growth of manufacturing activity and the supply of textiles and leather products. The main change is the technology used for washing, dyeing, drying, finishing, motors, and other heat and mechanical services. The convergence through 2050 indicates that the pathway protects manufacturing activity, while the later divergence reflects higher equipment efficiency and a different balance between heat, electricity and combined production.

At the 2020 starting point, oil boilers are the largest single component, at roughly 45% of process energy. Under NZE, heat pumps supply approximately half of the 1,558 PJ total in 2050, with grid electricity and combined heat and power supplying most of the balance (Figure 46). The technology mix reflects the suitability of many textile processes for electrification, while combined heat and power continue to serve larger or HTH processes. This sequencing matches the diversity of sector processes, because washing, drying, motors, and LTH can electrify earlier, while higher-temperature or continuous duties may continue to use combined heat and power during the transition.

FIGURE 46

Annual textiles and leather production for BAU and NZE scenarios, 2020-2050 (PJ)



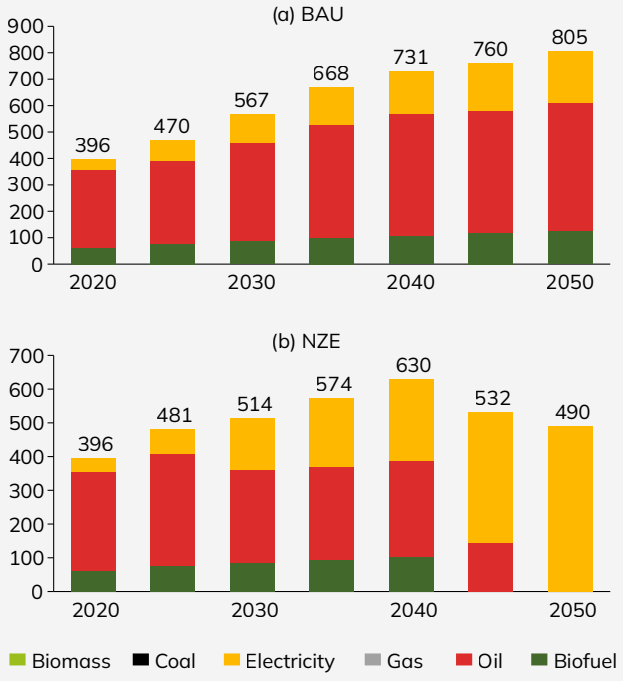
4.6 Agriculture Sector

Agriculture differs from the preceding sectors because the modelled transition is highly concentrated in machinery, irrigation, processing and other productive uses that are supplied mainly by oil in the starting years. Under BAU, growth in agricultural activity is met principally through greater oil use, with electricity providing a smaller but increasing contribution. Under NZE, oil remains important through the 2040s and is then displaced by electricity, producing a pronounced reduction in final energy demand while the underlying requirement for agricultural services continues to expand (Figure 47). The result therefore represents both fuel switching and a substantial improvement in end-use efficiency, rather than a contraction in farming activity, food production or rural economic development. Agricultural final energy use increases from 396 PJ in 2020 to 805 PJ in 2050 under BAU. Under NZE, energy use decreases to 490 PJ in 2050. The total energy use in NZE is therefore approximately 39% below BAU in 2050, even as irrigation, mechanisation, processing and other productive services continue to expand. The reduction reflects both fuel switching and the higher end-use efficiency of electric motors and drivetrains, which require less final energy than internal combustion equipment to deliver a comparable amount of useful work.

In BAU, oil supplies approximately 80% of agricultural final energy in 2020 and around 60% in 2050; electricity increases from less than 10% to roughly 25% over the same period. In NZE, electricity fully replaces oil and biofuel by 2050 and supplies essentially 100% of the 490 PJ total in 2050. The fuel composition explains the change in the total. BAU remains dominated by oil throughout the modelling period, with electricity increasing steadily but not replacing oil at scale. In NZE, oil remains significant through 2045, after which the displayed mix becomes almost entirely electric. Electric motors and drivetrains use final energy more efficiently than internal combustion machinery, so the same pumping, processing or mechanical service can be delivered with a smaller energy input. The visible step between 2045 and 2050 should be interpreted as a modelled technology replacement period, representing the aggregation of many equipment purchases and retirements rather than a simultaneous physical conversion in a single year. Practical implementation would therefore be phased, beginning with mature stationary loads and extending to mobile and heavy machinery as suitable technologies, charging systems and service networks become available.

FIGURE 47

Total annual agriculture fuel use for BAU and NZE scenarios, 2020-2050 (PJ)



Chapter 5

INVESTMENT OUTLOOK FOR NET-ZERO EMISSIONS BY 2050

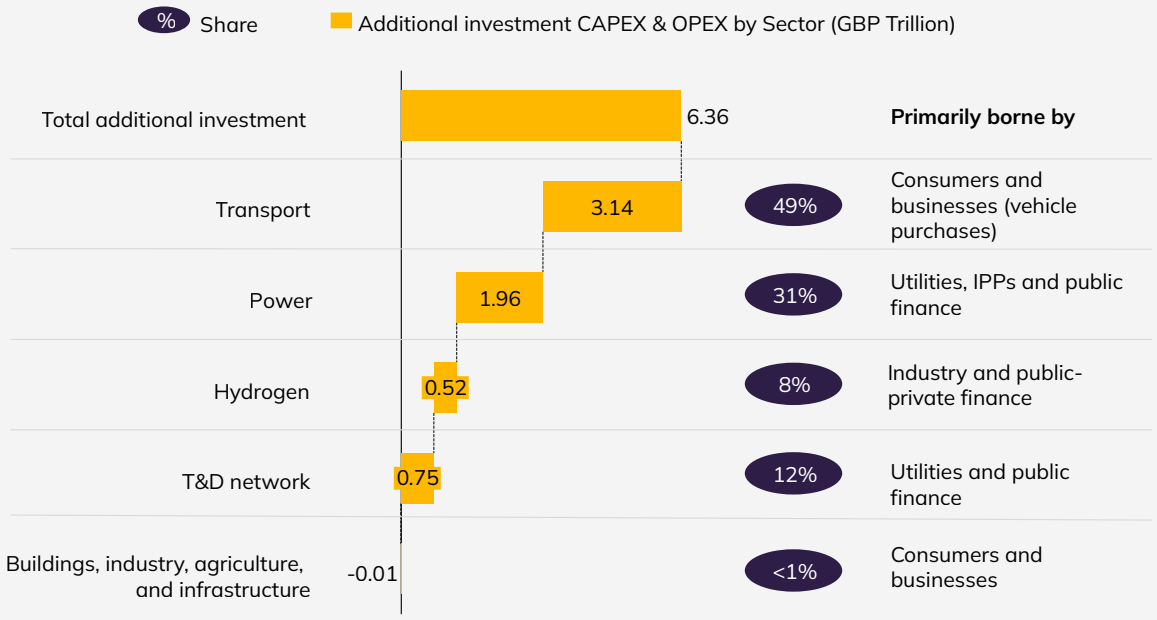


5.1 Overview

The net-zero pathway entails a pronounced change in the structure of energy-sector expenditure rather than a commensurate increase in its overall magnitude. **In aggregate, cumulative total energy spending up to 2050 is estimated to be marginally lower under the net-zero (NZE) pathway than under the business-as-usual (BAU) pathway, at approximately GBP 43 trillion compared with GBP 44 trillion, a reduction of 2.7%** (Figure 50). Beneath this broadly stable aggregate, the composition of expenditure alters markedly: capital investment in NZE rises by approximately one half, from an estimated GBP 10.6 trillion to GBP 15.7 trillion, and operating and maintenance expenditure increases modestly in NZE too. However, **fuel expenditure falls by roughly one quarter under NZE compared to BAU as fossil fuels are progressively displaced by low-carbon technologies.** The NZE pathway therefore substitutes investment in long-lived domestic assets for recurrent expenditure on imported and combusted fuel, with associated benefits for energy security and the retention of value within regional economies.

This distinction is material to the interpretation of the overall investment outlay that follows, which is reported on a gross, whole-system basis. It encompasses not only supply-side investment in generation, networks, storage and fuel production, but also end-use capital, most significantly the cost of renewing and electrifying the vehicle and appliance stock. Realising the pathway requires additional capital and operating investment across all sectors of approximately GBP 6.4 trillion cumulatively to 2050, equivalent to an average of some GBP 210 billion per year (Figure 48). This sum represents the gross investment to be mobilised rather than a net burden upon the economy. As noted above, the higher capital outlays required under NZE are substantially offset by lower fuel expenditure over the period to 2050.

FIGURE 48
Sectoral split of incremental investment CAPEX & OPEX (GBP trillion)



Two features of this requirement have direct policy implications, as detailed later in this chapter. First, incremental investment is concentrated by sector: transport and power account for the majority, with networks, buildings, industry, agriculture and hydrogen comprising the remainder. Second, investment needs are concentrated in time. They remain close to BAU throughout the 2020s and early 2030s before rising severalfold towards 2050, as fleet electrification, industrial fuel switching and hydrogen production reach commercial scale.

The distribution of these costs is correspondingly uneven. Households and firms bear a substantial share of transport investment directly through vehicle purchases, whereas power, network and hydrogen investment falls principally to utilities, independent power producers and public finance.

This back-loaded investment profile has a clear implication for sequencing. The principal task for the current decade is not to deploy the largest capital tranches, but to establish the institutions, project pipelines and financing instruments capable of absorbing substantially larger volumes in subsequent periods. The remainder of this chapter examines the scale, composition and timing of investment in each major sector and the enabling measures required, before setting out an overall approach to financing.

5.2 Overall Capital Investment

Across all sectors, the net-zero pathway requires cumulative capital investment of approximately GBP 15.7 trillion between 2020 and 2050, compared with GBP 10.6 trillion under the BAU pathway (Figure 49). This represents an increase of roughly half, or around GBP 5.1 trillion, and corresponds to average annual investment of about GBP 520 billion under NZE compared with GBP 350 billion under BAU. The requirement is not distributed evenly over the period: annual investment remains close to BAU levels through the 2020s and early 2030s before rising markedly to almost GBP 870 billion per year in the second half of the 2040s, as transport electrification, industrial decarbonisation and the expansion of hydrogen production reach their most capital-intensive phase.

Demand sectors dominate the composition of this investment. Transport represents the largest component throughout the period, reflecting the capital cost of renewing and electrifying the vehicle fleet. The power sector is the second largest and rises steadily as generation, storage and network capacity are added. Industry, buildings, hydrogen, transmission and distribution networks, and agriculture account for a smaller but growing share. Network and hydrogen investment expands particularly in the later periods as the system integrates larger volumes of variable renewable generation.

The contrast between the two pathways widens over time: whereas under BAU investment continues to flow substantially towards conventional supply and vehicles, under NZE it is progressively redirected towards low-carbon generation, electrified end-uses and enabling infrastructure.

Two measures of the investment requirement recur throughout this chapter and should be distinguished. The first is the gross capital investment described above, which captures total expenditure on physical assets under each pathway. The second, which provides the basis for the financing analysis, is the additional capital and operating investment required to move from BAU to NZE. This is estimated at approximately GBP 6.4 trillion cumulatively to 2050 (Figure 48) and **is defined more broadly to reflect differences in operating expenditure, with results disaggregated by sector.** Neither measure should be interpreted as a net increase in the cost of the energy system, which remains broadly unchanged once the associated reduction in fuel expenditure is considered (Figure 50).

FIGURE 49

5-year cumulative capital investment by sector, BAU and NZE scenarios (GBP trillion)

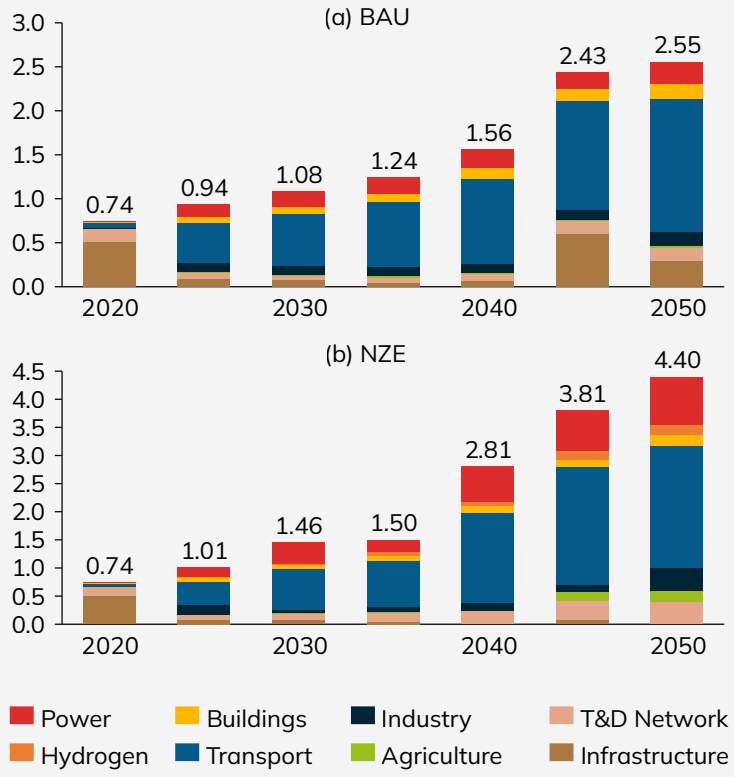
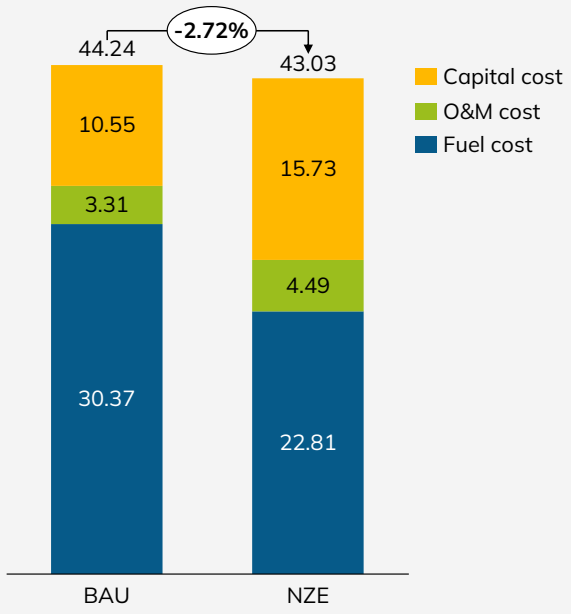


FIGURE 50

Total cumulative spending of BAU and NZE scenarios (GBP trillion)



5.3 Power Sector

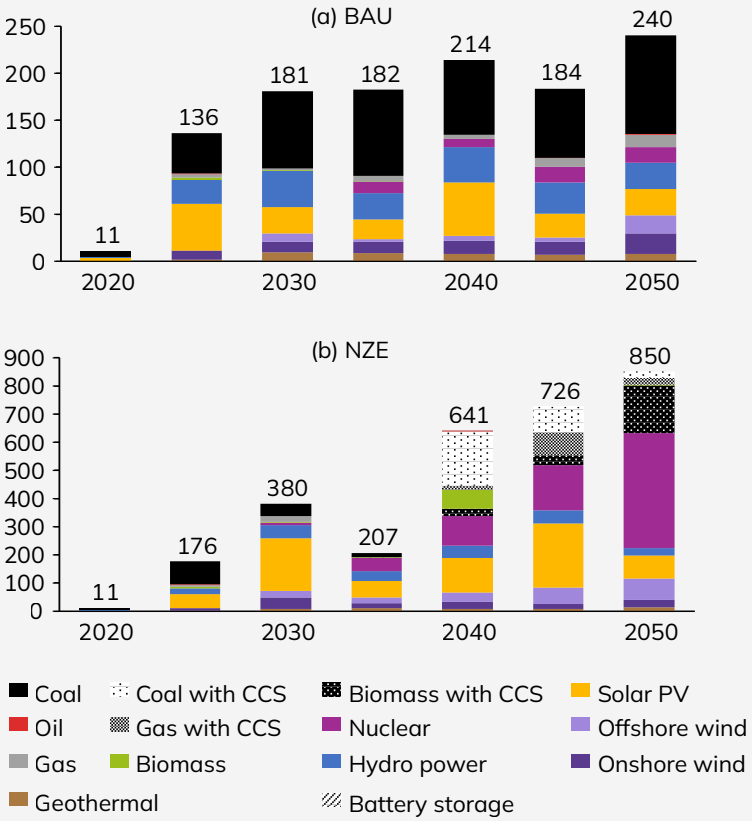
By 2050, cumulative capital investment in the power sector will reach GBP 3 trillion under NZE, equivalent to an average of around GBP 100 billion per year and close to three times the requirement under BAU (Figure 51). Investment scales up early and remains high throughout the period, while its composition will shift decisively from coal and gas toward solar PV, onshore and offshore wind, nuclear and battery storage.

Figure 51 further shows the significant shift in investment from conventional generation towards renewable energy and nuclear power, which are key technologies for the region's transition to net-negative emissions. Together, nuclear and renewable energy account for 94% of total power-sector investment in 2050 under NZE. Given the volume of coal that remains in the system during the transition, a managed phase-down is central to the power sector pathway. This requires mechanisms to accelerate the retirement of coal-fired capacity while managing stranded-asset risks and social consequences, supported by dedicated financing. Just Energy Transition Partnerships (JETPs) provide one such mechanism. Indonesia (USD 20 billion or approximately GBP 15 billion) and Viet Nam (USD 15.5 billion or approximately GBP 11.5 billion)[4] have already secured international commitments, complemented by the de-risking instruments identified in regional assessments (ACE, 2026a).

[4] All USD to GBP conversions in this chapter have been done at the current exchange rate 1 USD = 0.73 GBP

FIGURE 51

5-year cumulative capital investment required in the power sector for BAU and NZE scenarios (GBP billion)



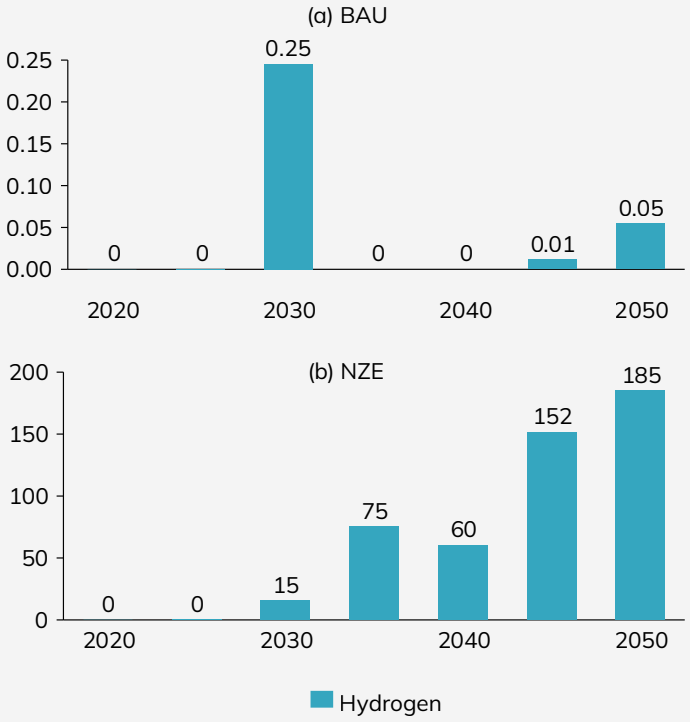
Regional power sector interconnection is an important aspect of transition. Greater cross-border electricity trade through interconnectors can accelerate the transition and reduce system costs (see chapter 4 for further details). Under NZE, the region may require cumulative investment of GBP 1.3 trillion between 2025 and 2050, equivalent to an annual average of around GBP 52 billion, to develop the power infrastructure, including cross-border transmission, and support a combined electricity generation and trade volume of 7,962 TWh by 2050. This is equivalent to approximately 1% of the regional GDP[5] invested in power infrastructure, including the ASEAN Power Grid (APG).

[5] ASEAN regional GDP is expected to be around USD 30T by 2050 (ACE, The 7th ASEAN Energy Outlook)

Hydrogen

Hydrogen is a new investment category with no meaningful BAU baseline. Cumulative NZE investment reaches GBP 487 billion by 2050, compared with negligible expenditure under BAU (Figure 52). The expansion is strongly back-loaded, with investment remaining minimal through the 2020s before accelerating to GBP 337 billion between 2040 and 2050 as electrolysis and associated infrastructure reach commercial scale. Because almost all hydrogen investment is additional under the transition, its realisation will depend heavily on early policy signals and financing.

FIGURE 52
5-year cumulative capital investment required for hydrogen for BAU and NZE scenarios (GBP billion)

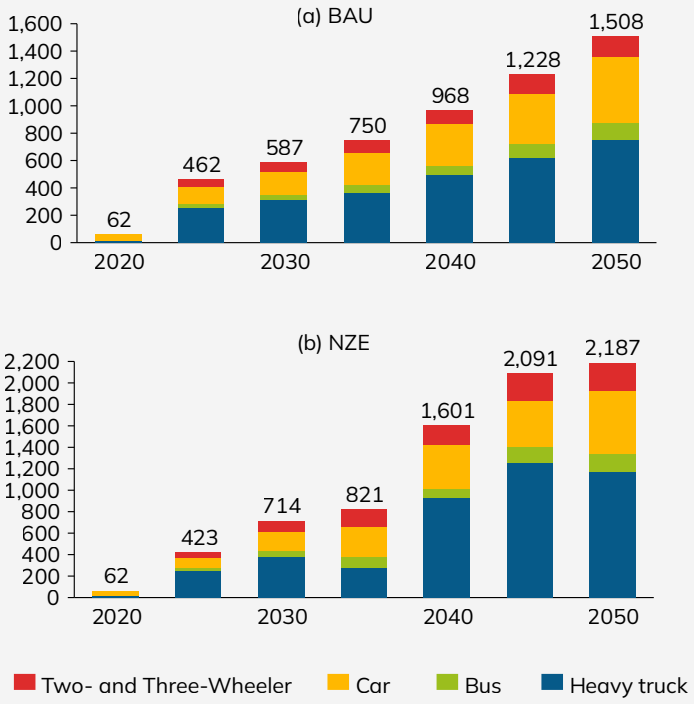


5.4 Transport Sector

Cumulative capital investment in transport reaches GBP 7.9 trillion under NZE by 2050, around 42% above the GBP 5.6 trillion required under BAU by 2050 and equivalent to an annual average of approximately GBP 265 billion, compared with GBP 185 billion under BAU (Figure 53). This estimate covers vehicle costs only and excludes other infrastructure costs. It represents economy-wide capital investment by both the public sector, including governments, and private consumers and firms. The pathways diverge from the late 2030s as fleet electrification accelerates across two- and three-wheelers, cars, buses and heavy trucks. Cars and two- and three-wheeled vehicles dominate near-term volumes, while heavy trucks and buses account for a growing share of investment in later periods as the harder-to-electrify modes are addressed.

FIGURE 53

5-year cumulative capital investment required in the transport sector for BAU and NZE scenarios (GBP billion)



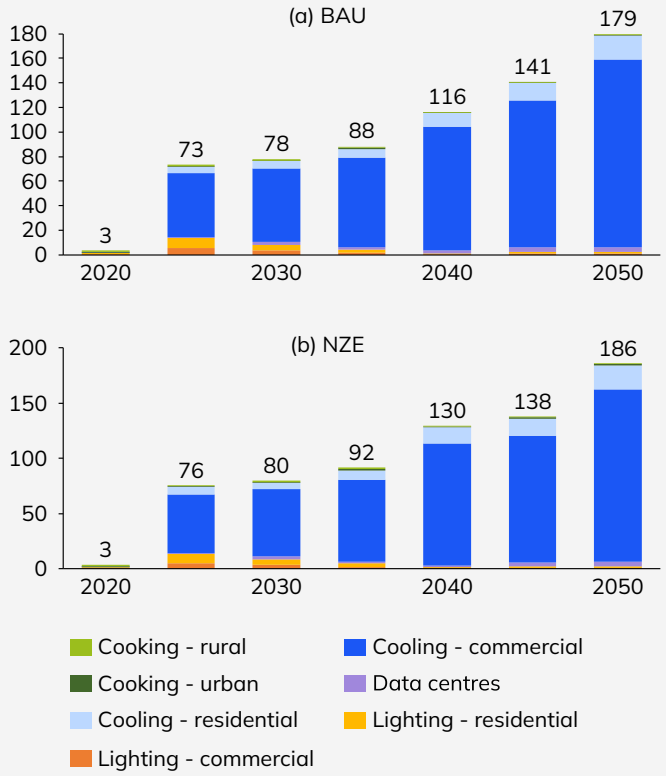
5.5 Residential and Commercial (Buildings) Sector

Urbanisation and growth in residential and non-residential floor space are increasing demand for energy services across ASEAN. More than half of the region's population is projected to live in cities by 2030 (ASEAN Secretariat, 2025b). Under NZE, cumulative building sector investment is estimated at GBP 705 billion between 2020 and 2050, approximately 4% above the BAU level (Figure 54).

Space cooling is the fastest-growing energy use in ASEAN's buildings, increasing the need for investment in cooling appliances (IEA and ASEAN, 2022). Efficient commercial and residential cooling accounts for 87% of additional investment in the buildings sector under NZE relative to BAU between 2020 and 2050, followed by electrified and clean cooking (9%) and modern lighting (4%) (Figure 54).

FIGURE 54

5-year cumulative capital investment required in the buildings sector for BAU and NZE scenarios (GBP billion)



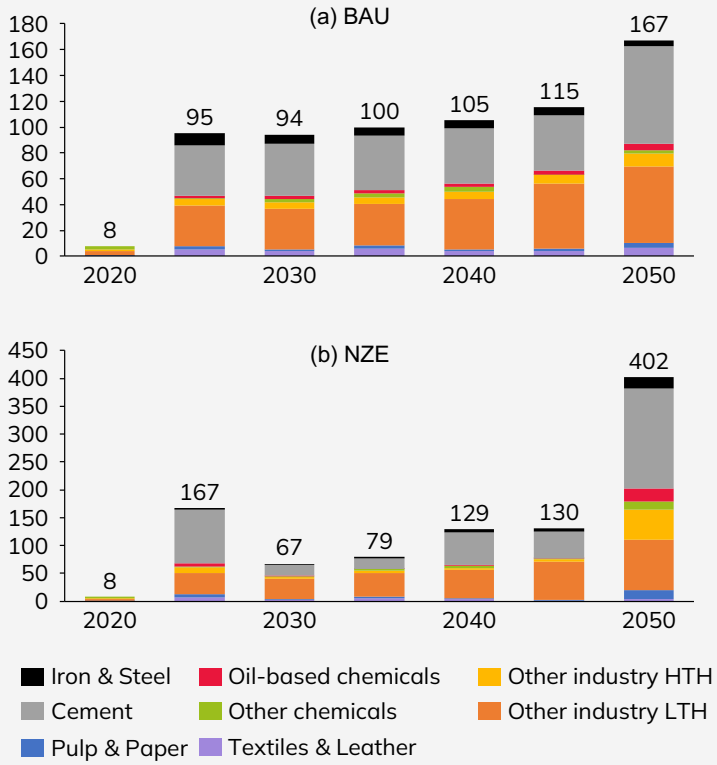
5.6 Industry Sector

Under NZE, ASEAN industries undergo significant improvements in terms of process efficiency, fuel switching and technology. Cumulative capital investment in industry is estimated to reach GBP 983 billion, around 43% above the GBP 686 billion required under BAU (Figure 55).

Investment remains close to BAU through the 2030s before rising sharply to GBP 402 billion during 2045–2050, as heavy industry adopts hydrogen-based, electrified and carbon-capture routes. Iron and steel, cement and the chemical sub-sectors drive the incremental cost, reflecting the capital intensity of switching high-temperature heat and feedstock processes to low-carbon alternatives.

FIGURE 55

5-year cumulative capital investment required in the industry sector for BAU and NZE scenarios (GBP billion)



5.7 Financing the Transition: Ways and means

As noted at the beginning of this chapter, the additional capital and operating investment required to move from BAU to NZE amounts to approximately GBP 6.4 trillion cumulatively to 2050, or an average of around GBP 210 billion per year (Figure 48). Transport and power account for the largest share, at GBP 5.1 trillion (80%), principally for electrification. Transmission and distribution networks, buildings, agriculture, industry and hydrogen account for a further GBP 1.3 trillion (20%) above BAU. This requirement represents gross investment to be mobilised rather than a net addition to overall system costs, as substantial fuel savings offset the additional investment and expenditure.

These figures should be considered alongside prevailing investment levels and independent estimates for the region. Energy investment in Southeast Asia has averaged approximately USD 72 billion (GBP 53 billion) per year in recent years, less than half of which has been directed towards clean energy (IEA, 2024); the International Energy Agency (IEA) estimates that alignment with the region's announced climate goals would require total investment to exceed USD 130 billion (GBP 96 billion) per year by 2030, and clean-energy investment specifically to exceed USD 190 billion (GBP 140 billion) per year by 2035 (IEA, 2024). **These benchmarks capture supply-side and efficiency investment but exclude most vehicle purchase costs; the whole system totals reported are therefore larger and not directly comparable.** On a comparable supply-side basis, however, the requirements identified in this analysis are of a consistent order of magnitude. The central challenge is therefore one of mobilisation rather than aggregate affordability.

Because the requirement increases severalfold towards 2050, governments and financing partners should use the current decade to establish the institutions, instruments and pipelines capable of absorbing substantially larger volumes in later periods. Priority actions include formulating long-term sectoral investment plans aligned with the net-zero pathway, bringing forward policy and regulatory reforms that reduce risk for private capital, and developing the project-preparation capacity required to convert investment needs into a bankable pipeline. Sequencing these enabling measures ahead of the largest capital tranches is essential for delivering the later and more capital-intensive stages of the transition. It is also consistent with regional assessments of ASEAN's investment gap and the instruments available to close it (ACE, 2026a; IEA, 2024).

Sectoral investment in the region therefore requires structural, regulatory and legal reforms to create an investment-ready environment. The following sections summarise the required changes by sector to support policymaking in the coming years.



POWER SECTOR

Delivering the sectoral investment will require an integrated resource plan and a competitive procurement framework that gives investors a clear project pipeline and revenue certainty. The integrated resource plan would need to be prepared by national governments and system operators and coordinated regionally through ASEAN, while competitive procurement applies mainly to mature utility-scale renewables and storage, with early-stage technologies such as hydrogen and offshore wind supported through complementary instruments such as risk guarantees until they become bankable.

Power-market reforms should reduce investor risk while rewarding the system flexibility required by a renewables-based grid. Permitting should also be streamlined so that projects can be built at the required pace. These reforms include cost-reflective tariffs, standardised and bankable power purchase agreements, transparent grid-access and dispatch rules, and capacity or ancillary-services markets that reward flexibility. They are intended to address the risks of greatest concern to investors, including off-taker and utility creditworthiness, curtailment, currency and interest-rate exposure, permitting and land acquisition, and policy and regulatory uncertainty



NETWORKS AND INTERCONNECTION

Grid infrastructure, especially the APG, should be developed proactively and in step with generation, so that network capacity does not become a binding constraint on renewable deployment or on the later scale-up of storage and offshore wind. The scale of this task is reflected in recent regional financing initiatives: in October 2025 the Asian Development Bank (ADB) and the World Bank launched the APG Financing Initiative, including an ADB regional fund intended to unlock around USD 10 billion (~GBP 7 billion) to de-risk interconnection projects for private investors (ADB, 2025). These sums are modest against the far larger cumulative investment the grid will ultimately require, underscoring the need to mobilise private capital at scale.



HYDROGEN

Governments should prioritise production support and offtake guarantees to underwrite initial demand, coordinate the planning of production, transport and storage infrastructure, and establish clear standards and certification to give investors confidence. Concessional and first-loss capital will be needed to absorb demand and technology risks that private investors will not initially bear and to establish the first commercial-scale projects on which the sector's later expansion depends.



TRANSPORT

Achieving the NZE target will require careful sequencing because the region's vehicle stock shapes both the scale and timing of investment. Two- and three-wheelers, ownership of which in Southeast Asia is almost four times the global average, together with passenger cars, dominate the earlier phase. Their electrification is comparatively inexpensive where suitable models and charging infrastructure are available. The electrification of buses and heavy freight is more capital-intensive and technologically demanding, and accounts for a growing share of investment during the 2040s.

Realising this investment will depend as much on enabling policy as on the vehicles themselves. Governments should set clear zero-emission vehicle targets and timelines to give manufacturers and investors a predictable trajectory, and introduce fiscal incentives to reduce the upfront cost of electric vehicles while their purchase prices remain above parity. Public co-funding and streamlined permitting should accelerate the deployment of charging infrastructure. Investment in grid reinforcement, local assembly and workforce reskilling will also help ensure that supporting capacity does not constrain the pace of electrification.



BUILDINGS

Cooling is the central driver in the buildings sector. Rising incomes, rapid urbanisation and warming temperatures are increasing demand for air conditioning. The efficiency of cooling equipment, improvements in the thermal performance of building envelopes and the deployment of district cooling where feasible are therefore major determinants of the sector's energy and investment trajectory. Alongside cooling, the transition involves a shift from biomass and fossil fuels towards electric and other clean cooking technologies. This has a pronounced equity dimension for lower-income and rural households. The sector must also accommodate rapid growth in electricity demand from data centres. Because much of the required change can be achieved through routine equipment replacement, the effectiveness of standards, codes and labelling will depend on appropriate incentives and policy measures that address the needs of both homeowners and businesses.

The buildings sector is best addressed through regulation supported by targeted finance. Priority actions include introducing and progressively tightening minimum energy-performance standards, building codes and appliance labelling, so that rapidly growing demand for cooling and appliances is met by efficient, clean technologies rather than conventional equipment. These measures should be complemented by accessible finance and targeted subsidies for lower-income households, as well as workforce capacity to deliver retrofits and efficient installations at scale. This would help make low-carbon technologies the default choice for routine replacements at little additional cost.



INDUSTRY

Because industrial assets are long lived, near-term reinvestment and retrofit decisions will determine both the scale of the later requirement and the risk of locking in emissions or stranding capital. Policy would therefore need to aim to align major reinvestment cycles with low-carbon options, and to develop industrial clusters that allow hydrogen, clean power and carbon-capture infrastructure to be shared and their costs reduced. Carbon pricing, standards and targeted support for first-of-a-kind facilities will be needed to make low-carbon production competitive with incumbent processes, and to give industry the confidence to commit capital ahead of the pathway's later and larger investment phase.



WAYS & MEANS

The closure of that gap depends less upon securing the total investment requirement than upon reducing the cost of capital and allocating risk to the parties best placed to bear it. Three priorities are central.

First, concessional and blended finance should be deployed selectively. Rather than functioning as a general subsidy, such finance should be directed at the specific risks that private capital is unwilling to price, including partial credit and payment guarantees, first-loss and subordinated tranches, and currency-hedging facilities. Multilateral development banks have a central role in this regard, furnishing both risk-sharing capacity and institutional credibility (ACE, 2026a).

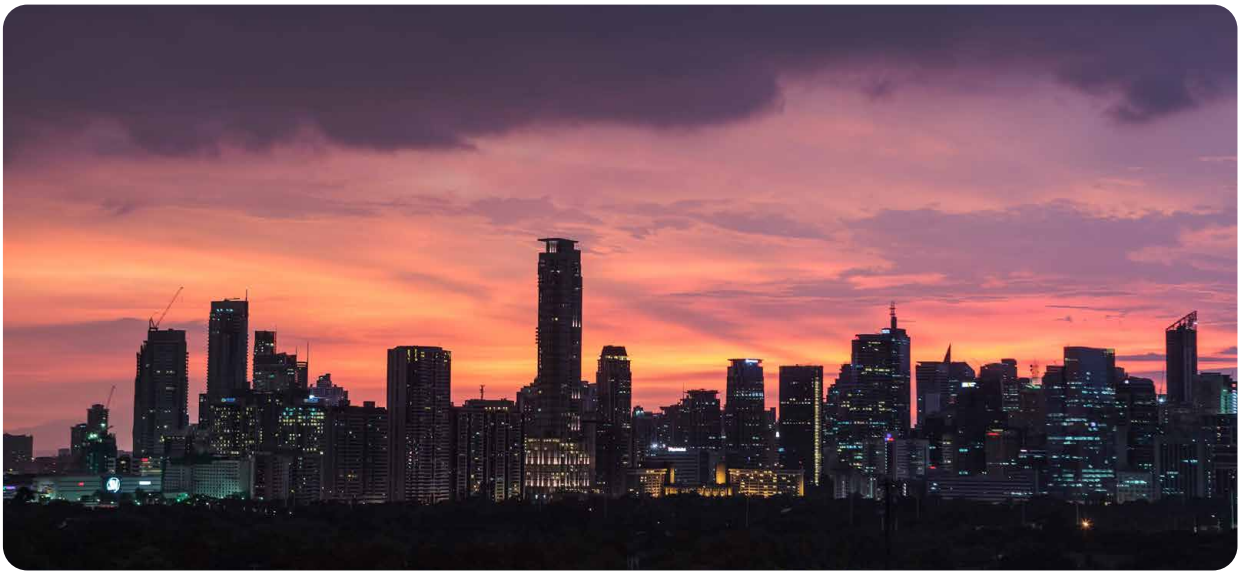
Second, dedicated financing vehicles are required for those segments least amenable to conventional finance. The managed phase-down and early retirement of coal-fired capacity cannot be financed through ordinary project finance and necessitate purpose-built structures such as JETPs. Energy efficiency, being constrained by financing rather than by technology, requires energy service companies, on-bill repayment mechanisms and dedicated credit lines administered through local banks.

Third, the development of domestic capital markets and local currency finance underpins both preceding objectives. A transition financed predominantly in foreign currency transfers exchange-rate risk to national balance sheets. Deeper local green-bond markets can strengthen domestic banking capacity, while a pipeline of investment-ready projects would enable international capital to be channelled through local institutions at manageable risk.

Finally, financing arrangements should reflect the incidence of costs. The substantial consumer-borne share of transport investment is best supported through vehicle finance, targeted incentives and charging infrastructure. Public and concessional finance may then be concentrated on generation, networks, storage and hydrogen, where the public return is greatest.

Chapter 6

SOCIO-ECONOMIC DIMENSION OF NET ZERO BY 2050



ASEAN's transition to net zero emissions entails a structural transformation that extends well beyond the energy system. Changes in how energy is produced, traded and consumed will have far-reaching implications for employment, livelihoods, gender equality, and access to modern energy services.

The transition is unfolding against a backdrop of sustained economic expansion. Regional economic growth is projected at around 4.5–4.6% in 2025–26, accompanied by rising energy and electricity demand, particularly in economies undergoing rapid industrialisation. The relationship between economic growth and energy demand varies considerably across Member States. In some fast-growing economies, electricity demand is still rising faster than GDP, while in more mature economies growth is becoming increasingly decoupled from energy consumption. The socio-economic implications of the transition are therefore expected to vary considerably, both across and within Member States.

A growing body of evidence suggests that a well-managed energy transition can strengthen rather than constrain economic development. Action towards a pathway aligned with 1.5°C is estimated to boost the region's GDP to 2050, with additional economy-wide employment (IRENA, 2025). The ASEAN Strategy for Carbon Neutrality similarly estimates that a coordinated regional approach could generate between USD 3.0 and 5.3 trillion in additional GDP and between 49 and 66 million additional jobs by 2050 across the economy (ASEAN Secretariat, 2023). What is also increasingly evident is that the gains are not automatic. They depend on supporting policies for industrial development, skills, social protection and a fair distribution of costs and benefits.

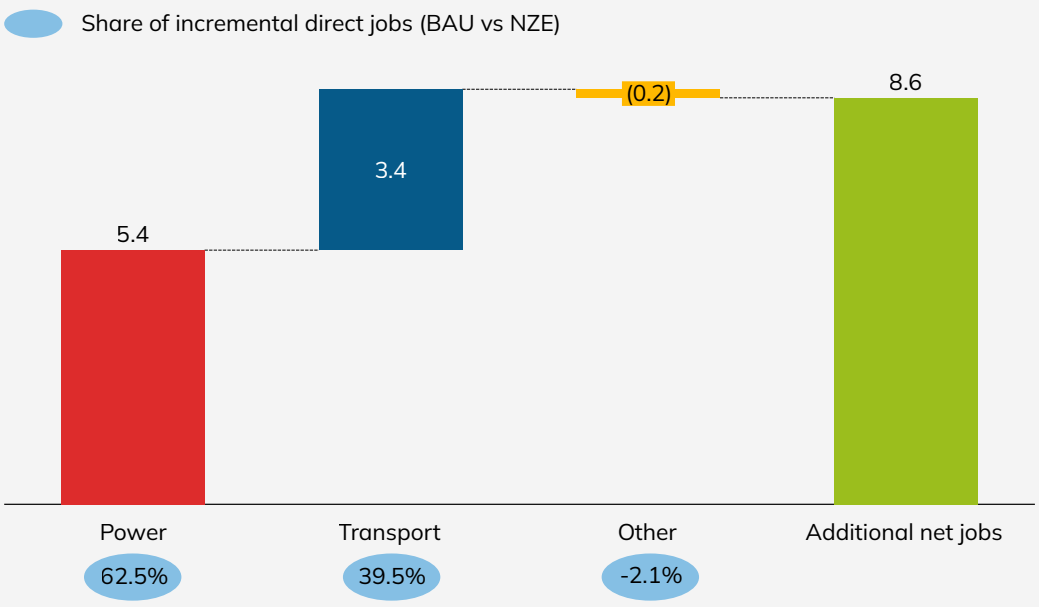
This chapter examines these issues through three lenses: employment impacts across the power, transport and other energy sectors; gender equality and youth inclusion; and electricity access. The common thread is a just and inclusive transition, one that turns the investment needed for net zero into decent jobs, wider opportunity and affordable energy for all ASEAN citizens.

6.1 Employment Impacts

Job creation remains an important priority for the region with a young, fast-growing workforce. The assessment uses a bottom-up, technology-specific employment-factor approach to assess direct job creation potential under BAU and NZE scenarios. The analysis estimates direct employment across five segments of the energy value chain: production and transformation; manufacturing; construction and installation; operation and maintenance; and retail and distribution. It captures both temporary jobs, which arise during the construction and installation of energy assets, and ongoing jobs, which are sustained throughout their operating life.

By 2050, NZE supports approximately 24.4 million direct jobs in the energy sector, compared with 15.8 million under BAU, resulting in 8.6 million additional jobs. These comprise approximately 5.4 million additional jobs in the power sector and 3.4 million additional jobs in the transport sector, partly offset by 0.2 million fewer jobs in other sectors, including employment in oil and gas and the cooking sector (Figure 56).

FIGURE 56
Net additional direct jobs in energy sector in NZE vs. BAU in 2050, by sector (million jobs)



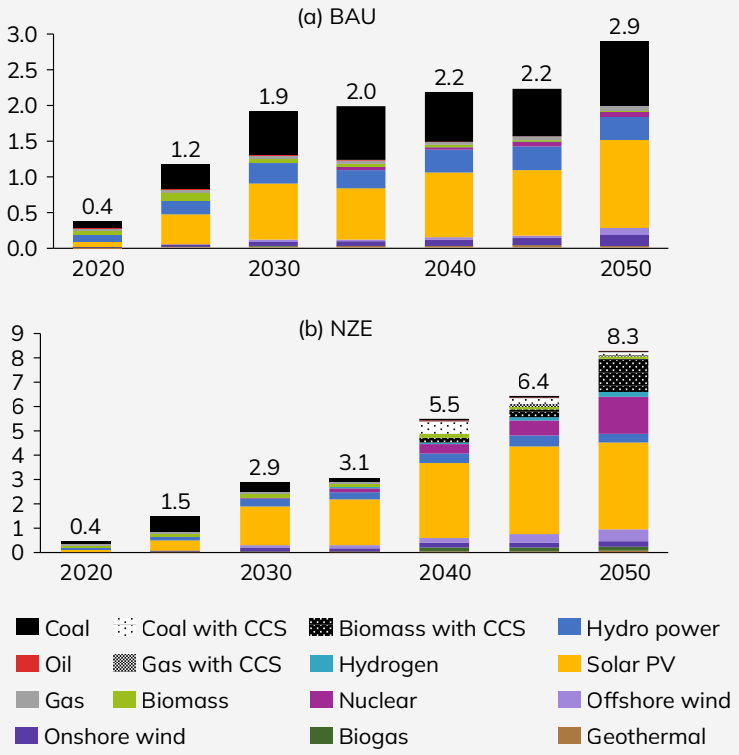
Note: Direct jobs include temporary positions associated with new investment, such as construction and installation, and ongoing jobs in operations and maintenance. Other sectors include employment in oil and gas extraction and the cooking sector.

Employment in the power sector reaches approximately 2.9 million jobs under BAU and 8.3 million under NZE in 2050 (Figure 57). It accounts for approximately 18% of total BAU employment and 34% of total NZE employment. The additional 5.4 million jobs under NZE are driven by the accelerated deployment of solar PV, biomass-fired generation with CCS and nuclear power. Realising these employment gains will require concerted efforts at both regional and national levels on skills needs assessments, investment in training infrastructure and regional harmonisation of occupational standards across technical and non-technical roles.

As employment in fossil-fuel-based activities declines, reskilling and workforce transition programmes will also be essential to help workers move from fossil-intensive activities into new and emerging sectors. Governments should identify transferable skills, align vocational training with future project pipelines, provide recognised certification and placement support, and prioritise fossil-fuel-dependent regions for new clean-energy investment through, for instance, site repurposing. This would help ensure that the transition is just and inclusive and does not leave communities behind.

FIGURE 57

Jobs in the power sector under BAU and NZE scenarios, 2020-2050 (million jobs)



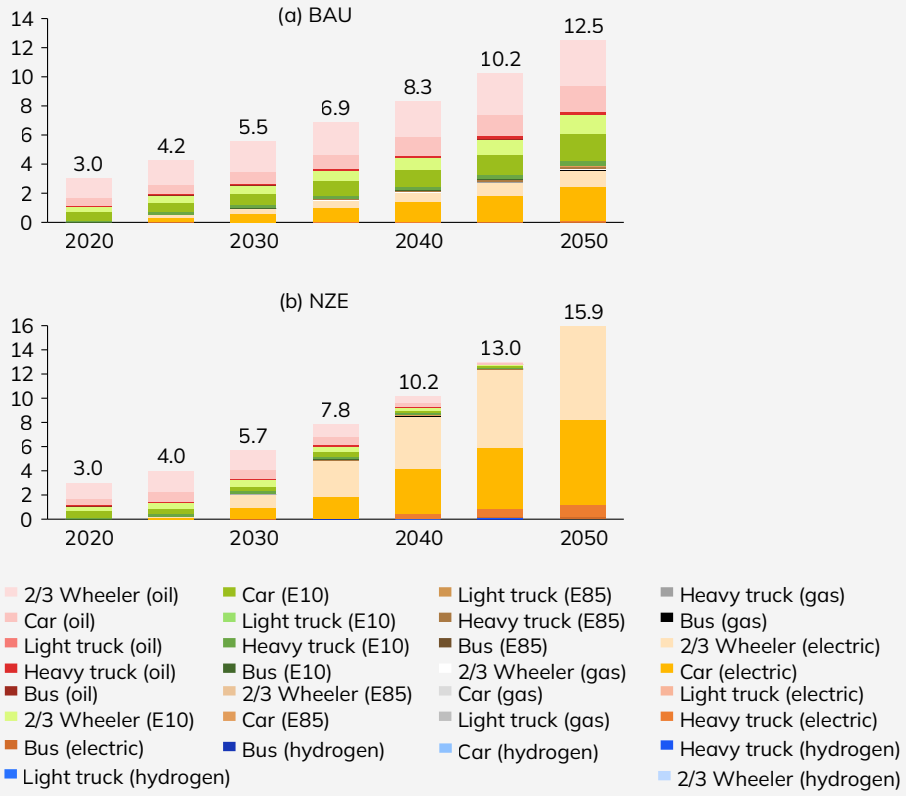
Transport remains the largest employment sector under both scenarios, reaching approximately 12.5 million jobs under BAU and 15.9 million under NZE in 2050 (Figure 58). This represents approximately 79% and 65% of total employment, respectively. Under BAU, employment remains distributed across conventional, biofuel, gas, and electric vehicles. Under NZE, it increasingly shifts towards electric mobility, charging infrastructure, and hydrogen-based transport. The transition therefore reallocates rather than eliminates transport employment, creating approximately 3.4 million additional jobs by 2050.

Realising these gains will require targeted reskilling programmes for workers currently employed in conventional internal combustion engine (ICE) vehicle manufacturing, operations and maintenance, and fuel distribution. The shift to electric mobility changes the skills profile of the sector significantly. ICE vehicle manufacturing and servicing rely mainly on mechanical skills, while EVs require competencies in high-voltage electrical systems, battery technology and management systems, power electronics, electric motors, vehicle software, among other areas. New opportunities will emerge in battery manufacturing, charging infrastructure installation and maintenance, and battery repurposing and recycling. Skills related to vehicle assembly, body and chassis work, braking and suspension systems, and quality control remain largely transferable, providing a foundation on which targeted upskilling can build.

Governments should align vocational training and certification with projected technology uptake, while supporting affected workers and regions through redeployment assistance, social protection and investment in emerging transport value chains. This would help ASEAN shift away from fossil-intensive transport employment while retaining industrial capabilities and creating higher value domestic jobs.

FIGURE 58

Jobs in the transport sector under BAU and NZE scenarios, 2020-2050 (million jobs)



The other sector combines employment in cooking and oil and gas extraction. Employment reaches approximately 0.40 million jobs under BAU and 0.22 million under NZE in 2050, representing a net reduction of approximately 0.18 million jobs. This is driven mainly by reduced fossil-fuel production under NZE resulting in substantially lower oil and gas extraction employment than under BAU. This highlights the need for worker reskilling, redeployment, and targeted support for communities dependent on fossil fuel economies.

The employment gains under NZE represent both net job creation and a structural reallocation of employment across sectors and technologies. However, workers displaced from fossil-intensive activities may not automatically have the skills, qualifications, or geographical mobility required for emerging clean-energy jobs. A just transition strategy will therefore be needed to combine reskilling and redeployment with income support, social protection, regional economic diversification and targeted clean energy investment in fossil-dependent communities. These measures will be essential to ensure that the shift away from fossil-heavy employment delivers sustained and inclusive benefits across ASEAN.

6.2 Gender and Youth

ASEAN's energy transition will reshape employment, household energy use, mobility and industrial value chains. These shifts may affect women and young people differently due to inequality in access to education, employment, finance and decision-making. Gender and youth inclusion are therefore essential issues for the energy transition. This section applies a gender- and youth-responsive lens to the ETIR scenario results, combining (i) quantitative findings generated by the ETIR on jobs, technology deployment, investment and energy access; (ii) the policy and institutional baseline set out in the Gender Equality in ASEAN Energy Booklet; and (iii) a qualitative analysis of barriers, opportunities and enabling measures. Youth is defined as people aged 15–35, consistent with the ASEAN Youth Development Index, while recognising that national definitions differ.

Regional policy foundation

The analysis is aligned with ASEAN's emerging just and inclusive energy transition architecture. APAEC 2026-2030 explicitly places a just and inclusive energy transition at the centre of regional energy cooperation and, under Regional Energy Policy and Planning, promotes the integration of gender equality, disability and social inclusion (GEDSI) into energy policy and planning. ASEAN Centre for Energy (ACE) identifies five connected areas for implementation: energy access and affordability; education and capacity; energy employment; gender and social inclusion; and inclusive governance.

24.4m	+8.6m	8%	34%
ETIR jobs under NZE by 2050	**additional jobs versus BAU in 2050**	**reported female share of ASEAN's energy workforce**	**share of ASEAN population aged 15-34**

Sources: ETIR; ASEAN Centre for Energy. Gender Equality in ASEAN Energy Booklet Volume III (2026); ASEAN Secretariat. Priority Areas of Cooperation on Youth, including the estimate that people aged 15-34 account for 34% of ASEAN's population; ASEAN Centre for Energy. Toward a Gender-Inclusive Energy Future: Mainstreaming Gender in ASEAN Energy Policy under APAEC 2026-2030 (2025), including the indicative estimate that women account for 8% of ASEAN's energy workforce.

Gender equality

Women are critical to ASEAN's energy transition as consumers, household energy managers, workers, business owners, community leaders and policymakers. However, women account for only around 8% of the ASEAN energy workforce, showing that a technology-led expansion of the sector will not by itself close the participation gap.

Barrier	Why it matters for the ETIR pathway
Occupational segregation	Power engineering, construction, transport operations and heavy industry remain male-dominated. These are also the sectors where ETIR identifies the largest employment expansion.
Unequal access to STEM and work experience	Women may have educational attainment but remain less represented in technical specialisations, apprenticeships, field assignments and employer networks that lead to energy careers.
Care and mobility constraints	Unpaid care work, safety concerns, remote project sites and inflexible work arrangements can limit entry and retention, particularly during construction and operations.
Finance and procurement gaps	Women-led SMEs may be excluded from clean-energy value chains by collateral requirements, limited track records and weak access to procurement information.
Limited voice in decisions	Underrepresentation in utilities, companies and planning institutions increases the risk that affordability, safety, access and livelihood impacts are insufficiently reflected in programme design.

Opportunities under NZE

Under the NZE pathway, the opportunity is not only confined to engineering roles, but also expands to a much wider ecosystem of jobs. The type of roles cut across project development, manufacturing, construction, grid services, operations and maintenance, digital systems, finance, community engagement, appliance distribution and recycling.

- Power: ETIR projects an additional 5.4 million jobs by 2050 under NZE compared to under BAU. Inclusive recruitment, apprenticeships and supplier-development programmes could open technical and professional pathways for women at scale.
- Electric mobility: transport employment reaches 15.9 million jobs by 2050 under NZE, with activity shifting toward EVs, charging infrastructure and hydrogen mobility. Opportunities extend from engineering and assembly to sales, financing, fleet management, software, maintenance and battery circularity.
- Buildings and clean cooking: efficient cooling, electric cooking and appliance replacement can support local distribution, installation and maintenance enterprises. These activities can create accessible entry points for women-led SMEs, including outside major industrial centres.
- Distributed energy: mini-grids, rooftop solar and productive-use applications can strengthen livelihoods and enterprise opportunities where women are already active in agriculture, food processing, retail and services.

Youth inclusion

Young people represent approximately one-third of ASEAN's population, creating a large potential workforce for the transition. However, the challenge is ensuring that education and training systems keep pace with technology deployment. Without action, ASEAN could face simultaneous youth underemployment and shortages of transition-critical skills. Several key barriers remain, particularly the mismatch between young people's skills and the needs of emerging clean-energy sectors:

- Mismatch between curricula and employer demand, particularly in renewable power, grids, energy efficiency, electric vehicle maintenance, batteries, hydrogen, and digital energy systems.
- Limited access to practical experience, apprenticeships and formal certification, leaving fresh graduates without the work history required for formal energy-sector jobs.
- Concentration of training institutions and new investment in major urban or industrial centres, creating unequal access for rural, low-income and remote youth.
- High rates of informal or insecure employment in parts of the region, which can leave young workers without adequate wages, occupational safety, social protection or progression pathways.
- Limited access to startup finance, networks, laboratories and procurement opportunities for youth-led clean-energy enterprises.

The transition requires more than short courses. Governments, education providers and employers should jointly forecast occupational demand, update curricula, provide paid work-based learning, recognise portable qualifications and publish placement outcomes. Programmes should explicitly include young women, rural youth, low-income groups and persons with disabilities, with practical support where participation costs would otherwise be prohibitive. ETIR shows the employment advantage of NZE widening sharply from the 2040s. Skills and institutional capacity must therefore be built in the 2020s and 2030s, before deployment reaches its highest volumes. Examples of potential youth pathways include:

ETIR transition area	Potential youth pathways	Priority preparation
Renewable power, grids and storage	Installation, electrical work, system operation, forecasting, cybersecurity, maintenance and project development	Regional competency standards; apprenticeships with utilities and developers; technician certification
Electric and hydrogen mobility	Vehicle assembly and servicing, charging, fleet operations, battery diagnostics, software and recycling	Modernised automotive TVET; employer-linked training; safe battery-handling and circularity skills
Efficient buildings and cooling	Energy auditing, retrofits, controls, refrigerant management, appliance servicing and energy-service companies	Cooling technician certification; digital building skills; pathways for micro- and small enterprises
Low-carbon industry	Energy management, electrification, hydrogen, carbon management, material efficiency and industrial digitalisation	Industry-led curricula; reskilling for incumbent workers; advanced technical and safety training
Distributed and rural energy	Mini-grids, solar home systems, productive-use equipment, local maintenance and agri-energy services	Decentralised delivery; toolkits and finance for local entrepreneurs; recognition of prior learning

Worker transition and place-based impacts

NZE creates more jobs overall but reduces oil and gas employment relative to BAU by approximately 73% in 2050. Workers cannot be assumed to move automatically into renewable power, grids, EVs or hydrogen: new jobs may require different skills, be created in different locations, or offer different working conditions. Women employed indirectly in fossil-fuel-dependent local economies and young people entering these labour markets may also be affected even when they are not counted as direct energy workers.

Just-transition planning should therefore be place-based. Fossil-fuel-dependent regions need early labour-market mapping, social dialogue, income and social-protection measures, recognition of transferable skills, funded reskilling, local economic diversification and transparent timelines. Gender analysis should cover both formal workers and the wider local economy, including informal and care work that is often invisible in sector employment statistics.

Energy affordability, access and household welfare

The buildings energy transition pathway expands access to modern energy services while electrifying household demand. Under NZE, electricity supplies more than 95% of residential final energy by 2050, and the regional cooling stock grows from about 311 million units in 2020 to about 629 million in 2050. The transition therefore cannot be delivered solely through technology standards; it must also ensure that connections, appliances, cooling and clean cooking are affordable and reliable.

These issues have gender and youth dimensions. Women often manage household energy and may bear disproportionate health and time burdens from polluting cooking fuels. Female-headed and low-income households may face greater financing constraints for efficient appliances. Students and young workers benefit from reliable electricity, cooling and digital connectivity, while poor service or high tariffs can restrict education and livelihood opportunities. Targeted subsidies, concessional consumer finance, social tariffs where appropriate, efficient-appliance programmes and strong consumer protection can help prevent electrification from widening existing inequalities.

Land, infrastructure and participation

Large-scale renewable generation, grids, hydropower, biomass supply and industrial infrastructure can create local benefits but may also affect land, livelihoods and community resources. Women, youth, indigenous peoples and informal land users may have limited formal representation even where they experience material impacts. Inclusive planning should provide accessible information, meaningful participation at times and in formats that different groups can use, transparent grievance mechanisms, and community-benefit arrangements. Participation should influence project design and benefit sharing, rather than function only as consultation after key decisions have been taken.

Considerations for a gender- and youth-responsive NZE Pathway

Achieving a gender- and youth-responsive NZE pathway will require priority actions across skills development, inclusive employment, enterprise support, access to finance, and meaningful participation in decision-making.

1 **Make inclusion measurable.** Adopt a small regional results framework aligned with APAEC 2026-2030 and collect sex-, age-, occupation- and location-disaggregated data across energy employment, training, leadership, enterprise participation and programme beneficiaries. Require major publicly supported projects to report against the framework.

2 **Translate ETIR deployment into occupational demand.** Convert sector and technology pathways into periodic occupational and skills forecasts. Prioritise power systems, transmission and distribution, solar and wind, storage, EVs, charging, cooling, hydrogen, energy efficiency and low-carbon industry.

3 **Build employer-linked skills pathways.** Co-design curricula with employers; expand paid apprenticeships, internships and on-the-job training; establish portable ASEAN-aligned competency standards; and provide targeted recruitment, stipends and wraparound support for young women and underserved youth.

4 **Use public investment to change labour demand.** Include inclusive recruitment, safe-workplace requirements, apprenticeships and supplier-diversity provisions in public procurement, utility investment, concessional finance and public-private partnership agreements.

5 **Support women- and youth-led enterprises.** Provide appropriately sized grants, credit enhancement and technical assistance; unbundle contracts where feasible; improve access to procurement information; and support market linkages in distributed energy, efficiency, cooling, e-mobility and circular value chains.

6 **Protect affordability and energy access.** Pair standards and electrification with targeted consumer finance, social protection and efficient-appliance support. Monitor energy burdens and service quality for low-income, female-headed, rural and remote households.

7 **Plan early for affected workers and regions.** Map exposure to declining fossil-fuel activities, conduct social dialogue, recognise transferable skills, fund redeployment and reskilling, and support local economic diversification before closures or major demand shifts occur.

8 **Institutionalise inclusive participation.** Include women's organisations, youth representatives, workers, communities and relevant social-sector ministries in energy planning and implementation. Apply accessible consultation, grievance and benefit-sharing processes to major infrastructure.

6.3 Electricity Access

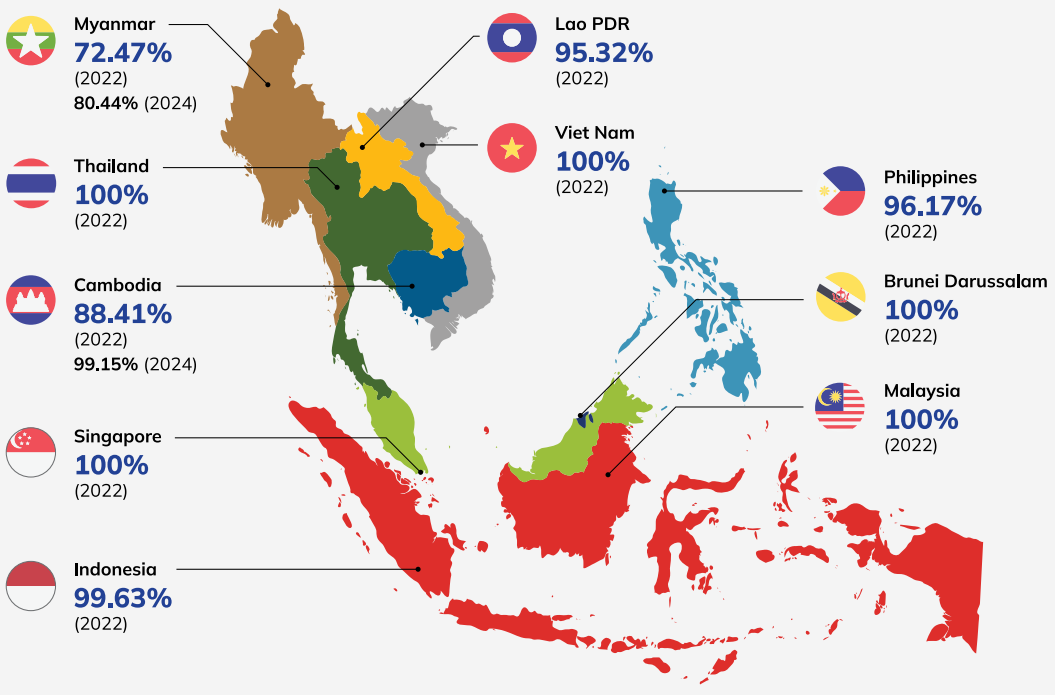
Electricity access is a fundamental driver of improved quality of life, economic growth, and sustainable development. Most ASEAN Member States have achieved high electrification rates, with Brunei Darussalam, Cambodia, Indonesia, Malaysia, Singapore, Thailand and Viet Nam reaching electricity access of 99% or above (Figure 59).

As regional electrification rates approach universal levels, the remaining challenge increasingly lies in the "last mile". The households still without access are typically located in remote, sparsely populated or hard-to-reach areas, where the cost of each new connection is highest and the ability of households to pay is often lowest. Reaching these communities requires tailored delivery models, targeted subsidies and sustained institutional commitment rather than relying on conventional grid expansion alone. Moreover, access should not be measured by connection alone. Unreliable, insufficient or unaffordable supply limits the use of electricity for education, health services and productive activities. Closing the last-mile gap, and improving the quality of existing access, is therefore essential to ensure that no community is left behind as the region pursues its net zero objectives.

ASEAN's geography makes this challenge distinctive. Indonesia comprises more than 17,000 islands and the Philippines more than 7,000. Many smaller and outer islands are not connected to main grids and have historically relied on small, isolated diesel-based systems that are costly to operate, exposed to fuel supply disruptions and price volatility, and carbon-intensive. In these settings, decentralised renewable energy (DRE) solutions, such as solar home systems, renewable-based and hybrid mini-grids, and battery storage, often provide the least-cost and fastest route to reliable access. When combined with productive-use appliances for agriculture, fisheries, cold storage and small enterprises, DRE can also support local livelihoods and income generation. Hybridising or replacing existing diesel systems on islands further offers an opportunity to reduce generation costs and fuel subsidies while contributing to decarbonisation.

FIGURE 59

Electricity access across ASEAN (%)[6]



Myanmar continues to face a significant electricity access gap, with access at 80.4% in 2024, up from 72.5% in 2022. In the development of the ETIR, the OnSSET geospatial electrification analysis tool is applied to identify the least-cost energy access technologies required to achieve universal electricity access by 2030.

The analysis indicates that achieving universal electricity access in Myanmar will require a combination of grid expansion and decentralised solutions. Grid densification of 7.4 MW is required to connect households located near the existing electricity network. A further 67 MW of hybrid solar/diesel mini-grids is identified as a suitable solution for settlements where grid connection is not economically feasible, while about 116 MW of solar home systems (SHS) would be required for more remote households.

The results indicate that grid expansion and densification represent the dominant pathway for achieving universal access, reflecting Myanmar's existing generation structure and the relatively lower generation costs associated with hydropower and natural gas. Decentralised solutions, including mini-grids and SHS, therefore play a complementary role in serving geographically dispersed and remote communities where grid extension is not the least-cost option. Overall, the OnSSET analysis demonstrates that achieving universal electricity access in Myanmar by 2030 will require a combination of grid-based and decentralised electrification solutions, supported by targeted investment in transmission and distribution infrastructure, renewable-based mini-grids, and standalone solar systems.

[6] 2022 data from 8th ASEAN Energy Outlook (ACE, 2024), 2024 data for Cambodia and Myanmar from Tracking SDG 7 Report (The World Bank, 2026)

Chapter 7

THE PATH FORWARD



ASEAN's transition to net zero warrants a structural transformation of the region's energy system, one that is both a necessity and an opportunity. It is a necessity on two fronts: first, energy security, as recent global supply chain disruptions have starkly exposed the risks of continued reliance on imported fossil fuels and materials; and second, on climate action, as global warming, rising temperature and the frequency of extreme weather events are all increasing rapidly. Sustained investment, accelerated energy efficiency and widespread electrification sit at the centre of this transformation. Together, they form the backbone of nearly every pathway to net zero identified in this report, from decarbonising power generation to reshaping how the region moves, produces and builds. The transition is also an opportunity to create jobs, catalyse new industries across clean technology supply chains and help anchor ASEAN's role as a competitive hub for new and emerging industries in the global economy.

ASEAN Member States (AMS) do not begin this transition from the same starting point. Differences in resource endowments, energy systems, industrial structures and levels of economic development mean that the pace and shape of the transition will vary considerably across the region and over different timeframes. Regional coordination and engagement therefore cannot be a substitute for national action; instead, they must be anchored in national priorities and circumstances, providing a framework within which countries can pursue shared regional goals while retaining the flexibility to chart their own pathways.

Building on the results presented in this report, this chapter reflects on the way forward, covering both cross-cutting regional implications and sector-specific policy actions.

7.1 Overarching Regional and Sector-Specific Implications

Energy demand in ASEAN will continue to expand driven by growing population, economic activity, industrialisation and urbanisation. The analysis finds that accelerating investments and policy actions over the next decade will be critical as the scale of infrastructure and technology deployment, and the associated financing requirements, increase substantially towards 2050. Delayed action would raise the risks of lock-in and higher costs. Recent supply chain disruptions provide further impetus for accelerated action, reinforcing the links between climate action and energy and economic security. This section summarises the key ways forward derived from the analysis:

Electrification represents a key decarbonisation solution. Electricity becomes the dominant fuel across AMS under NZE, accounting for around 63% of total fuel use by 2050. A significant share of this shift is concentrated in transport and industry end-use sectors, where electric vehicles, electric boilers and heat pumps displace fossil fuels at scale. These technologies are already commercially mature and widely deployed, so sectoral strategies should integrate electrification as a primary decarbonisation pathway wherever technically feasible. In several AMS, this electrification in transport and industry will also provide energy security and other macroeconomic benefits, including balance-of-payments benefits.

Accelerate power system expansion alongside planning for system flexibility. NZE requires around 80% more generation and double the BAU capacity in 2050. Planning, investment and enabling deployment policies need to begin well ahead of demand growth to ensure sufficient lead time for project and related infrastructure development. Where new energy sources, including nuclear, are planned for deployment in the 2030s, their long institutional and project-development lead times will require early preparatory work. Capacity expansion alone is not sufficient: the growing share of variable renewable energy (VRE) will also require parallel investment in system flexibility, including supply-side measures (e.g. battery energy storage system (BESS), pumped hydro storage and interconnections) and demand-side measures. These flexibility solutions, together with the underlying infrastructure should be planned and financed over the same lead-time horizon as generation capacity.

Boost ASEAN Power Grid (APG) development to scale up intra-regional trade. Cross-border capacity needs to roughly double from 19.8 GW to 35.5 GW, strengthening regional energy security. Cross-border exchange can optimise national-level capacity expansion requirements and generate subsequent savings in investment and system costs of USD 2-3 billion per year (Ember, 2026). Alongside energy trade, interconnection assets can leverage the region's seasonal and monsoon asynchrony, hydro-VRE complementarity and diversity in demand profiles to support renewable energy utilisation, avoid curtailment and enable reserve sharing.

Pursue energy efficiency across end-use sectors in tandem with supply-side interventions. Efficiency improvements, alongside modern energy access and fuel switching, help reduce residential electricity use for cooling and lighting under NZE, for instance, to around 17% below BAU levels by 2050. Lighting converges on LEDs across both scenarios, but roughly two-thirds of the cooling stock remains inefficient in 2050. Regional harmonisation of minimum energy performance standards (MEPS) for key appliances strengthens regional supply chains and contributes to lower costs. As data centre capacity triples to 5.1 GW, its contribution to the regional net-zero trajectory will depend on energy-efficient infrastructure development, utilisation, cooling technology, waste heat recovery and renewable supply matching. Across industry, targeted energy efficiency programmes backed by dedicated financing facilities should focus on energy management systems, periodic energy audits, sector-specific benchmarking, waste heat recovery and MEPS for industrial motors, drives, pumps, fans and compressors. Motor systems account for the majority of industrial electricity use and variable-speed drives on variable loads are among the measures offering the highest returns. Dedicated programmes are needed for small and medium-sized enterprises, which dominate textiles, leather, food processing and light manufacturing. Equipment leasing, energy service contracts, aggregated procurement and shared technical services can address the transaction costs that keep audits and retrofits out of reach for smaller firms.

Explore hydrogen fuel as a strategic priority. Hydrogen increases from negligible levels under BAU to more than 10,000 PJ by 2050 under NZE, creating a new strategic fuel for ASEAN, particularly in industry, where it reaches around 18% of final energy use. Early policy frameworks focusing on demand- and supply-side, standards, infrastructure specifications and planning, and market development will be important in establishing a regional hydrogen supply chain. Demand aggregation is the first-order requirement because hydrogen production at scale needs anchor offtake: industrial clusters that combine steel, chemicals and refining demand can underwrite production investment that no single plant could. Certification and guarantees of origin should be harmonised regionally and made interoperable with the schemes for importing markets.

Evaluate a broader definition of regional energy security. The NZE pathway strengthens regional resource adequacy and energy security by reducing dependence on imported fossil fuels, by 57% in 2050 compared to BAU, and increasing the contribution of domestically available renewable resources. Complemented by storage, flexible low-carbon generation and stronger regional interconnections, this more diversified supply mix reduces ASEAN's exposure to international fossil-fuel price volatility, geopolitical disruptions and supply constraints, while improving the long-term stability and predictability of regional energy costs. However, the transition could introduce new dependencies on batteries, electrolysers, electric mobility and associated minerals. Energy security strategies therefore need to evolve from fuel security towards a broader framework for technology, mineral and supply-chain resilience.

Advance a tailored industrial decarbonisation strategy. While industrial output continues to expand, industry final energy is 32% lower in NZE at over 17,000 PJ in 2050 compared to BAU, resulting from a transforming fuel mix. BAU mix is roughly two-thirds coal by 2050. Under NZE, electricity accounts for about half, hydrogen for around 18% and modern biomass for approximately 28%. Climate-related trade measures, including the EU's Carbon Border Adjustment Mechanism (CBAM), are already shaping market access for carbon-intensive exports such as cement, steel, aluminium, fertiliser and hydrogen. ASEAN exporters therefore face measurement and disclosure requirements regardless of domestic policy, making harmonised regional product carbon accounting a competitiveness measure as well as a climate measure. Low-temperature heat and mechanical power represent the single largest energy block in industry. Under NZE, electric boilers supply around 84% of this demand and efficient motors a further 10%, with coal, oil and gas phased out entirely. As the technology is already commercially available, this represents one of the most readily achievable decarbonisation opportunities in the sector, contingent on reliable and affordable industrial power supply. Production routes also shift: hydrogen-based direct reduced iron (DRI) paired with electric arc furnaces (EAF) displaces the blast furnace–basic oxygen furnace (BF-BOF) route for steelmaking. Gas-based DRI serves as a transitional pathway and must be built hydrogen-ready at the investment decision stage to avoid technology lock-in. For cement, hydrogen-fired kilns are expected to supply 55–60% of output and carbon capture-equipped routes around a third. However, clinker substitution offers a cheaper, immediately available complementary lever because it reduces process emissions directly rather than capturing them afterwards. As EAF and DRI processes require large, continuous, high-load-factor electricity supplies, grid expansion planning must account for this new industrial load profile ahead of deployment.

Develop cooling as a demand-response opportunity. Space cooling is the fastest-growing end use in the region. By mid-century, it accounts for well over half of combined buildings demand, with the residential cooling stock roughly doubling and commercial cooling systems growing more than sevenfold. When coupled with chilled-water or ice storage, cooling can also decouple the time of production from the time of demand. This could turn the region's largest and most peak-coincident load into a flexibility resource for the power system. A regional cooling demand-response programme will require policies on performance standards, demand-response-ready requirements for new air-conditioning systems, thermal storage in district cooling and time-varying tariffs.

Pursue a holistic approach to transport sector decarbonisation. Total transport fuel use falls from an estimated 30,323 PJ in 2050 under BAU to 11,533 PJ under NZE, a reduction of 62%. Electricity becomes the dominant energy carrier in transport, accounting for around 61% of fuel consumption by 2050, as conventional liquid-fuel cars and two- and three-wheelers are phased out entirely and 97% of the heavy truck fleet becomes electric. Fuel switching should be pursued in tandem with fuel efficiency standards and multimodal policies integrated with urban and land-use planning as the key pillars of transport sector decarbonisation.

Strengthen complementary infrastructure for transport electrification. The roll-out of charging infrastructure for two- and three-wheelers, passenger vehicles and fleets will require diverse delivery models, from battery swapping systems to shared public charging ecosystem and individual network connections. Standards and regulations, public-private-partnerships and harmonisation of charging components will be crucial for timely roll-out, alongside coordinated planning with grid development and reinforcement, urban planning and industry. As the electrified fleet grows, it also represents a grid flexibility resource.

Bring material efficiency and circular economy measures together. Scrap steel, circular industrial feedstocks and battery recycling can simultaneously reduce emissions and import dependence. In the steel sector, the NZE pathway relies on scrap-based EAF for a substantial share of output in 2050, requiring sorting and collection systems to be established in the 2020s and 2030s. Material efficiency programmes can also play a key role in reducing absolute demand for key commodities (e.g. cement and steel) and the associated process emissions. Circularity measures, including urban mining and technologies that enable the recovery of key materials, could further reduce demand for virgin minerals, mitigate the associated environmental impacts and unlock a secondary stream of minerals.

Support bankable project pipelines and mobilise dedicated financing. The NZE pathway requires an average annual investment of GBP 520 billion up to 2050. Investment needs vary by technology, ticket size, investor risk perception and end user, requiring a combination of public and private capital. Project pipeline volumes and bankability can be strengthened through government procurement programmes, de-risking instruments and demand-side mandates, among other measures. Targeted funding facilities will be needed for project preparation and debt and equity instruments across project and enterprise funding cycles, tailored to thematic end-use sectors such as energy efficiency, rooftop solar and industrial electrification. Article 6 and other carbon finance mechanisms can also play an important role in mobilising climate funding.

Invest in workforce skills and just transition planning. By 2050, the NZE scenario supports approximately 24.4 million direct jobs, compared with 15.8 million under BAU, resulting in 8.6 million additional jobs compared to BAU. Realising this net gain requires early investment in reskilling and redeployment programmes, domestic clean energy value chains, and support for fossil-fuel-dependent communities and regions, so that workforce capacity keeps pace with the sectors driving job creation.

Integrate land-use emissions into a broader net-zero strategy. ASEAN's abundant natural resources provide significant mitigation potential, but emissions from land use, land-use change and forestry (LULUCF) could increase the regional sequestration requirement if not managed appropriately. Carbon sinks could become carbon emitters and jeopardise regional progress towards net zero. ASEAN regional climate action plans should therefore integrate LULUCF management as an integral part of the decarbonisation pathways.

Develop a carbon capture ecosystem. The analysis indicates that carbon capture, utilisation and storage (CCUS) is one of the main technological options for moving the industrial sector towards carbon neutrality. The region is well placed in terms of geology, and its regulatory regime is developing (e.g. Malaysia's CCUS Act 2025). A regional CCUS strategy should emphasise a capture-last, not capture-first, approach, given the prohibitively high cost of removal. The strategy would also benefit from a cluster approach (e.g. cement, chemicals), with several plants sharing infrastructure, including pipelines and storage sites, where CO_2 streams are steady and concentrated.

APPENDIX A

Natural Carbon Sinks to Support NZE by 2050



This chapter documents the methodology used to project land use and land cover (LULC) change across the 10 ASEAN Member States (AMS) from a 2023 baseline to 2050, and to convert that projected change into a carbon storage and sequestration estimate. Two coupled models are used: the Patch-generating Land Use Simulation (PLUS) model for LULC projection, and the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) Carbon Storage and Sequestration model for translating LULC change into net CO_2e flux. The output of this workflow is the country-level agriculture, forestry and other land use /land use, land-use change and forestry (AFOLU/LULUCF) cumulative net-release figures (2023–2050) used in the accompanying regional assessment and policy note.

A.1 Study Area and Spatial Resolution

The assessment covers all 10 AMS. Native processing resolution was set per country to balance computational load against country extent and data availability, rather than applying a single uniform grid across the region (Table 6).

TABLE 6
The context of 10 ASEAN Member States in the study

Countries	Native resolution	Rationale
Brunei, Singapore	10 m	High-resolution national/commercial LULC products; small land area permits fine-resolution processing
Lao PDR, Myanmar, Philippines, Thailand, Viet Nam	90 m	Coarser continuous-coverage product balancing processing load against country extent
Indonesia, Malaysia, Cambodia	100 m	Coarser resolution to manage the very large processing extent (Indonesia in particular)

Because resolution varies by country, absolute Mt CO_2e comparisons across countries should be read as directionally robust rather than strictly resolution-normalised; this is noted again under limitations.

A.2 PLUS, Model Methodology (LULC projection)

The PLUS model projects a 2050 LULC map from the 2023 baseline in three linked stages:

Land Expansion Analysis Strategy (LEAS)

The Land Expansion Analysis Strategy (LEAS) isolates the expansion portions of each land use class between two historical time points (2001–2023 was used as the training window, consistent with the Global Forest Watch comparison period used for validation) and mines the association between those expansion patches and a set of driving factors using a random forest classifier. This produces, for each candidate land-use class, a development probability surface across the study area rather than a single regression coefficient, which allows the model to capture non-linear and spatially heterogeneous drivers of land conversion.

Driving factors

Driving factor layers used to train LEAS and constrain patch allocation (CARS) (below) typically span two categories:

- Natural/biophysical: elevation, slope, aspect, distance to rivers and coastline, soil type
- Socioeconomic/accessibility: distance to roads, distance to urban centres and existing built-up area, population density, and where available, protected-area and land-use-planning designations.

Demand projection (Markov chain)

Total area demand for each LULC class in 2050 is projected using a Markov transition probability matrix calibrated on the historical (2001–2023) transition frequencies between classes. This is a business-as-usual (BAU)/trend-continuation projection: it extrapolates observed historical conversion rates forward rather than assuming a policy-adjusted trajectory. This is an important methodological point flagged again under limitations, since it means announced-but-unimplemented policy commitments (e.g. FOLU Net Sink 2030) are not embedded in the 2050 baseline used here.

Patch allocation (CARS)

The CA-based multi-type random patch seeds (CARS) module allocates the Markov-projected class-level demand spatially, cell by cell, using the LEAS development probability surfaces as allocation weights, combined with neighbourhood effects (the tendency of land-use conversion to cluster near existing patches of the same class) and a random seed mechanism that allows new patches to emerge rather than only extending existing ones. Iteration continues until the allocated area for each class converges on the Markov-projected 2050 demand, producing the final projected 2050 LULC raster.

A.3 InVEST Carbon Storage and Sequestration Model

The projected 2050 LULC raster and the 2023 baseline LULC raster are each passed independently through the InVEST Carbon Storage and Sequestration model, which computes total carbon storage as the sum of four carbon pools assigned per LULC class (Table 7).

TABLE 7

The four carbon pools considered in the study

Pool	Definition	Note
AGB	Aboveground biomass – living plant material above the soil surface (trunks, branches, foliage)	Highest-uncertainty pool; most sensitive to LULC class transition
BGB	Belowground biomass – living root systems	Typically derived as a root: shoot ratio applied to AGB
SOC	Soil organic carbon – carbon stored in soil to a standard depth (commonly 30 cm)	Dominant pool for peatland and wetland classes; drives Kalimantan/Sumatra-type high-release estimates
DOM	Dead organic matter – litter and deadwood	Generally the smallest pool by contribution, but non-negligible in forest classes

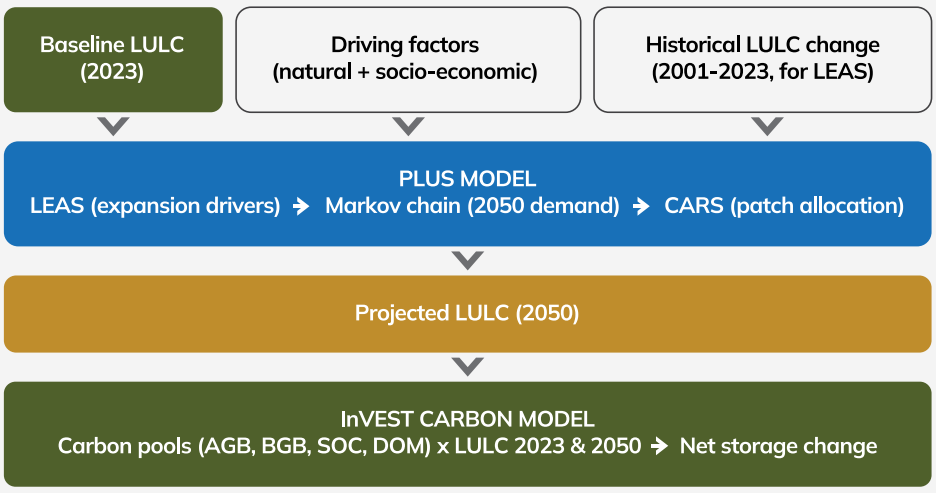
Carbon pool coefficients (tonnes C/ha by pool and LULC class) are drawn from a combination of IPCC 2019 Refinement default (Tier 1) values, national GHG inventory reports where available, and peer-reviewed regional literature, selected to reflect the dominant ecozone of each country (e.g. tropical peat swamp forest coefficients applied for relevant Kalimantan/Sumatra classes in Indonesia, rather than generic tropical forest defaults).
Net carbon storage change is computed as:

$$\Delta\text{Carbon (2023–2050)} = \text{Carbon storage(LULC 2050)} - \text{Carbon storage(LULC 2023)}$$

A positive ΔCarbon value (loss of stored carbon) is reported as net CO_2e release; a negative value would indicate a net sink. This total is then divided by the 27-year interval to derive an average annual rate ($MtCO_2e$/year), which is the figure carried into the regional and country-level combined analysis with the energy sector emissions trajectory. Figure 60 illustrates how the LULC projection is made using the PLUS model and then integrated into the InVEST model for carbon stock and flow analysis.

FIGURE 60

PLUS–InVEST coupled workflow: LULC projection feeds directly as the carbon model's 2050 scenario input



A.4 Key Assumptions and Limitations

- Single scenario: the 2050 projection is a BAU trend continuation of 2017–2023 land-use change patterns. It does not model announced policy interventions (FOLU Net Sink 2030, forest-cover moratoria, RSPO sourcing commitments) as an alternative constrained scenario.
- Static carbon pool coefficients: coefficients are held constant over the projection period per LULC class; they do not capture within-class degradation (e.g., selective logging within a forest class that is not reclassified) or age-structure effects on biomass accumulation.
- Two-point carbon accounting: carbon storage is computed only at the 2023 and 2050 endpoints, not at intermediate years; this is why the regional and country-level combined analysis treats the annual LULUCF release rate as constant across the period rather than as a modelled trajectory.
- Resolution heterogeneity: the 10 m / 90 m / 100 m split across countries (Section 2) means patch-level detail is not directly comparable between, for example, Indonesia and Singapore; aggregate $MtCO_2e$ totals are more robust than any single-pixel interpretation.
- Driving factor availability: where a data layer (e.g., protected-area boundaries, fine-grained population density) was unavailable for a given country, LEAS was trained on the reduced factor set for that country, which can affect cross-country comparability of allocation accuracy.

Model output was spot checked against Global Forest Watch (GFW) tree cover loss-derived annual carbon emissions estimates for the 2001–2024 historical period, where available at country level. For Thailand, for example, the GFW-derived historical rate (~71 $MtCO_2$/year) was compared against this model's projected annual rate (~121 $MtCO_2$/year); the model's higher rate is consistent with an accelerating, non-linear historical trend being extrapolated forward by the Markov/CARS combination, rather than a simple continuation of the recent year average that GFW's trailing rate reflects. This comparison is intended as an order-of-magnitude sense check rather than a formal accuracy validation, given the different methods, sensors and time windows underlying each estimate.

A.5 The Finding

An InVEST-based land-cover carbon assessment (2023–2050) for all 10 AMS shows every country is a net LULUCF source, not a sink, over the assessment period – driven chiefly by continued forest conversion to cropland, plantations, and built-up land, only partly offset by shrubland and cropland regrowth in some countries. This is consistent with independent global data: Southeast Asia and the developing Pacific were the single largest regional emitters from the forestry and land-use sector in 2023.

Overlaying this against the region's energy-sector decarbonisation pathway—which targets net-negative annual emissions from power and industry from 2050 onward via carbon capture and storage/carbon dioxide removal (CCS/CDR)—changes the region's true sequestration requirement.

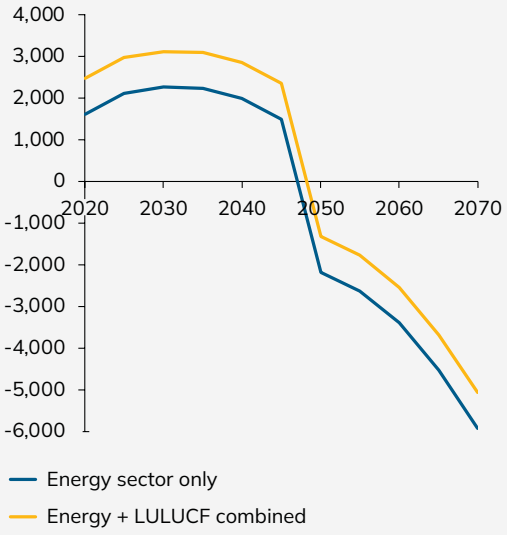
Component	Cumulative 2023-2050	Cumulative 2023-2070	Share (2050)
Energy sector (power, hydrogen, buildings, transport, industry, agriculture)	41,932 $MtCO_2e$	-31,196 $MtCO_2e$	65%
LULUCF net release (InVEST land-cover trend, 2023–2050)	23,071 $MtCO_2e$	40,161 $MtCO_2e$[7]	35%
Total regional sequestration requirement	~65,004 $MtCO_2e$	~8,965 $MtCO_2e$	100%

[7] LULUCF has no InVEST projection beyond 2050; the 2023–2070 figure extrapolates the 2023–2050 average annual release rate (~854 Mt/year) flat through 2070 and should be read as indicative, not modelled.

LULUCF adds roughly 55% to the cumulative sequestration burden implied by the energy pathway alone through 2050. Extending to 2070, the energy sector's later negative-emissions years pull its own cumulative total sharply negative but the region as a whole is still cumulatively a net emitter of ~8,965 Mt CO2e even by 2070 once LULUCF is included, meaning the debt built up through the 2020s and 2030s is not fully repaid within the modelled horizon (Figure 61). At the ASEAN aggregate level this also delays the region's annual net-zero point from ~2047 to ~2048. Figure below shows the pathway of net emissions of the region which indicates the region's emissive performance of the LULUCF sector due to various factors like rapid urbanization, infrastructure development and forest degradation including peatland drainage and shifting in agriculture pattern etc.

FIGURE 61

Regional annual net emissions: energy sector alone vs. energy + LULUCF combined, 2020–2070 ($MtCO_2e$)



A.6 Policy Options

a. FOLU / AFOLU Net Sink programs

ASEAN should consider adopting a suitable target for the forestry and land-use sector to reach net-zero, backed by a primary-forest and peatland moratorium and mandatory monitoring, reporting, and verification (MRV) down to the concession level. Malaysia's commitment to maintain at least 50% forest cover and Indonesia's FOLU Net Sink 2030 program are good starting points in this direction.

b. Peatland and mangrove restoration

Rewetting drained peatland offers disproportionately high abatement per hectare relative to upland afforestation, and mangrove/blue-carbon restoration adds a sequestration pathway for the region.

c. Governance-linked REDD+ and MRV strengthening

For countries who have large forest cover and less regulations to manage the forest, can opt for the REDD program where MRV mechanism and payment for conservation will help maintain the required level of forest.

d. Carbon markets and Article 6 cooperation

Southeast Asia supplied roughly 9% of global voluntary carbon credit volume in 2024, but the region's portfolio remains weighted toward avoidance credits rather than removals, which are increasingly preferred by buyers aligned to science-based targets. Shifting toward Article 6.2/6.4-compliant removal credits (peatland rewetting, reforestation with high-integrity MRV) would both fund the sequestration buildout and improve regional credit pricing and credibility.

APPENDIX B

LIST OF ACRONYMS



ACE	ASEAN Centre for Energy
ADB	Asian Development Bank
AEC	ASEAN Economic Community
AEO	ASEAN Energy Outlook
AFOLU	Agriculture, forestry and other land use
AGB	Aboveground biomass
AIMS	ASEAN Interconnection Masterplan Study
AMS	ASEAN Member States
APAEC	ASEAN Plan of Action for Energy Cooperation
APG	ASEAN Power Grid
ASEAN	Association of Southeast Asian Nations
BAU	Business as usual
BCA	Building and Construction Authority of Singapore
BECCS	Bioenergy with carbon capture and storage
BESS	Battery energy storage system
BF–BOF	Blast furnace–basic oxygen furnace
BGB	Belowground biomass
BLDC	Brushless direct current
CAPEX	Capital expenditure
CBAM	Carbon Border Adjustment Mechanism
CCS	Carbon capture and storage
CCUS	Carbon capture, utilisation and storage
CDR	Carbon dioxide removal
CGE	Computable general equilibrium
CNS	Carbon Neutrality Strategy
CPS	Current policies scenario
DEDE	Department of Alternative Energy Development and Efficiency of Thailand
DRE	Distributed renewable energy
DRI	Direct reduced iron
EAF	Electric arc furnace
ETIR	Energy Transition and Investment Roadmap
EU	European Union
FOLU	Forestry and other land use

GDP	Gross domestic product
GEDSI	Gender equality, disability and social inclusion
GFW	Global Forest Watch
GHG	Greenhouse gas
GTAP	Global Trade Analysis Project
GTF	Green Transition Fund
HTH	High-temperature heat
ICE	Internal combustion engine
IEA	International Energy Agency
IIASA	International Institute for Applied Systems Analysis
InVEST	Integrated Valuation of Ecosystem Services and Tradeoffs
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
JETP	Just Energy Transition Partnership
LEAS	Land Expansion Analysis Strategy
LED	Light-emitting diode
LPG	Liquefied petroleum gas
LTH	Low-temperature heat
LTMS–PIP	Lao PDR–Thailand–Malaysia–Singapore Power Integration Project
LULC	Land use and land cover
LULUCF	Land use, land-use change and forestry
MEPS	Minimum energy performance standards
MRV	Monitoring, reporting and verification
NZE	Net-zero emissions
OPEX	Operating expenditure
OSeMOSYS	Open-Source Energy Modelling System
PDP	Power Development Plan
PLUS	Patch-generating Land Use Simulation
PV	Photovoltaic
REDD+	Reducing emissions from deforestation and forest degradation, plus conservation, sustainable management of forests and enhancement of forest carbon stocks
REPP–SSN	Regional Energy Policy and Planning Sub-Sector Network
RSPO	Roundtable on Sustainable Palm Oil
SAF	Sustainable aviation fuel
SDG	Sustainable Development Goal
SEforALL	Sustainable Energy for All
SEM	SEforALL Energy Systems Model
SHINE	Standardization Harmonization Initiative for Efficiency
SHS	Solar home system
SOC	Soil organic carbon
SSP	Shared Socioeconomic Pathway
STEM	Science, technology, engineering and mathematics
T&D	Transmission and distribution
TPES	Total primary energy supply
TVET	Technical and vocational education and training
UN	United Nations
UNOPS	United Nations Office for Project Services
VRE	Variable renewable energy
WHO	World Health Organization

Unit Symbols and Fuel Blends

CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
E10	Petrol blend containing 10% bioethanol by volume
E85	Petrol blend containing up to 85% bioethanol by volume
GBP	Pound sterling
GJ	Gigajoule
Gt	Gigatonne
GW	Gigawatt
MJ	Megajoule
Mt	Million tonnes
Mtpa	Million tonnes per annum
MW	Megawatt
PJ	Petajoule
TWh	Terawatt-hour
USD	United States dollar

BIBLIOGRAPHY

ASEAN Centre for Energy (2020) ASEAN plan of action for energy cooperation 2016–2025 phase II 2021–2025. [Online]. Jakarta: ASEAN Centre for Energy. Available at: https://aebf.aseanenergy.org/publications/asean-plan-of-action-for-energy-cooperation-apaec-phase-ii-2021-2025

ASEAN Centre for Energy (2022) The 7th ASEAN energy outlook. [Online]. Jakarta: ASEAN Centre for Energy. Available at: https://aebf.aseanenergy.org/publications/the-7th-asean-energy-outlook/

ASEAN Centre for Energy (2024) The 8th ASEAN energy outlook. [Online]. Jakarta: ASEAN Centre for Energy. Available at: https://wordpress.aseanenergy.org/publications/the-8th-asean-energy-outlook/

ASEAN Centre for Energy (2025a) ASEAN plan of action for energy cooperation 2026–2030. [Online]. Jakarta: ASEAN Centre for Energy. Available at: https://aseanenergy.org/wp-content/uploads/2025/10/APAEC-2026-2030.pdf

ASEAN Centre for Energy (2025b) Toward a gender-inclusive energy future: mainstreaming gender in ASEAN energy policy under the ASEAN plan of action for energy cooperation 2026–2030. [Online]. Available at: https://aseanenergy.org/articles/toward-a-gender-inclusive-energy-future-mainstreaming-gender-in-asean-energy-policy-under-the-asean-plan-of-action-for-energy-cooperation-2026-2030

ASEAN Centre for Energy (2026a) ASEAN energy investment insights: progress and potential de-risking instruments of ASEAN energy investment. [Online]. Jakarta: ASEAN Centre for Energy. Available at: https://aseanenergy.org/publications/asean-energy-investment-insights-progress-and-potential-de-risking-instruments-of-asean-energy-investment

ASEAN Centre for Energy (2026b) Gender equality in ASEAN energy booklet. Volume III. [Online]. Jakarta: ASEAN Centre for Energy. Available at: https://aseanenergy.org/publications/gender-equality-in-asean-energy-booklet-volume-iii

ASEAN Secretariat (2023) ASEAN strategy for carbon neutrality: public summary. [Online]. Jakarta: ASEAN Secretariat. Available at: https://asean.org/wp-content/uploads/2023/08/Brochure-ASEAN-Strategy-for-Carbon-Neutrality-Public-Summary-1.pdf

ASEAN Secretariat (2025a) ASEAN key figures 2025. [Online]. Jakarta: ASEAN Secretariat. Available at: https://asean.org/wp-content/uploads/2025/12/AKF-2025_v3_202601151314.pdf

ASEAN Secretariat (2025b) Urbanisation and gentrification: addressing poverty in ASEAN cities. [Online]. Jakarta: ASEAN Secretariat; ASEAN Socio-Cultural Community Policy Brief; no. 28. Available at: https://asean.org/serial/urbanisation-and-gentrification-addressing-poverty-in-asean-cities

ASEAN Secretariat (n.d.) Priority areas of cooperation: youth. [Online]. Available at: https://asean.org/our-communities/asean-socio-cultural-community/education-youth/priority-areas-of-cooperation/

Asian Development Bank, World Bank Group, ASEAN Secretariat, ASEAN Centre for Energy (2025) ADB and World Bank Group launch the ASEAN Power Grid Financing Initiative with the ASEAN Secretariat and the ASEAN Centre for Energy. [Online]. Available at: https://asean.org/adb-and-world-bank-group-launch-the-asean-power-grid-financing-initiative-with-the-asean-secretariat-and-the-asean-centre-for-energy-ace/

Ember (2026). The ASEAN Power Grid: why every year of delay matters. [Online]. Available at: https://ember-energy.org/latest-insights/the-asean-power-grid-why-every-year-of-delay-matters/

Intergovernmental Panel on Climate Change (2019) 2019 refinement to the 2006 IPCC guidelines for national greenhouse gas inventories. [Online]. Geneva: Intergovernmental Panel on Climate Change. Available at: https://www.ipcc-nggip.iges.or.jp/public/2019rf/

International Energy Agency (2022) Roadmap towards sustainable and energy-efficient space cooling in the Association of Southeast Asian Nations. [Online]. Paris: International Energy Agency. Available at: https://www.iea.org/reports/roadmap-towards-sustainable-and-energy-efficient-space-cooling-in-the-association-of-southeast-asian-nations

International Energy Agency (2024) World energy investment 2024: Southeast Asia. [Online]. Paris: International Energy Agency. Available at: https://www.iea.org/reports/world-energy-investment-2024/southeast-asia

International Energy Agency, International Renewable Energy Agency, United Nations Statistics Division, World Bank, World Health Organization (2026) Tracking SDG 7: the energy progress report 2026. [Online]. Washington (DC): World Bank. Available at: https://trackingsdg7.esmap.org/sites/default/files/download-documents/SDG7-Report2026-0623-V4-4Web.pdf

International Institute for Applied Systems Analysis (n.d.) Shared socioeconomic pathways scenario database. [Online]. Available at: https://iiasa.ac.at/models-tools-data/ssp

International Renewable Energy Agency (2025) Socio-economic footprint of the energy transition: Southeast Asia. 2nd ed. [Online]. Abu Dhabi: International Renewable Energy Agency.
Available at: https://www.irena.org/Publications/2025/Oct/Socioeconomic-footprint-of-the-energy-transition-Southeast-Asia

Renewables.ninja (n.d.) Renewables.ninja. [Online]. Available at: https://www.renewables.ninja/

TransitionZero (2024) TZ-APG: an open access power systems model of the ASEAN Power Grid. Version 1. [Online]. Available at: https://www.transitionzero.org/products/tz-asean-power-grid-model

World Health Organization (n.d.) Proportion of population with primary reliance on fuels and technologies for cooking by fuel type. [Online]. Available at: https://www.who.int/data/gho/data/indicators/indicator-details/GHO/proportion-of-population-with-primary-reliance-on-fuels-and-technologies-for-cooking-by-fuel-type

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