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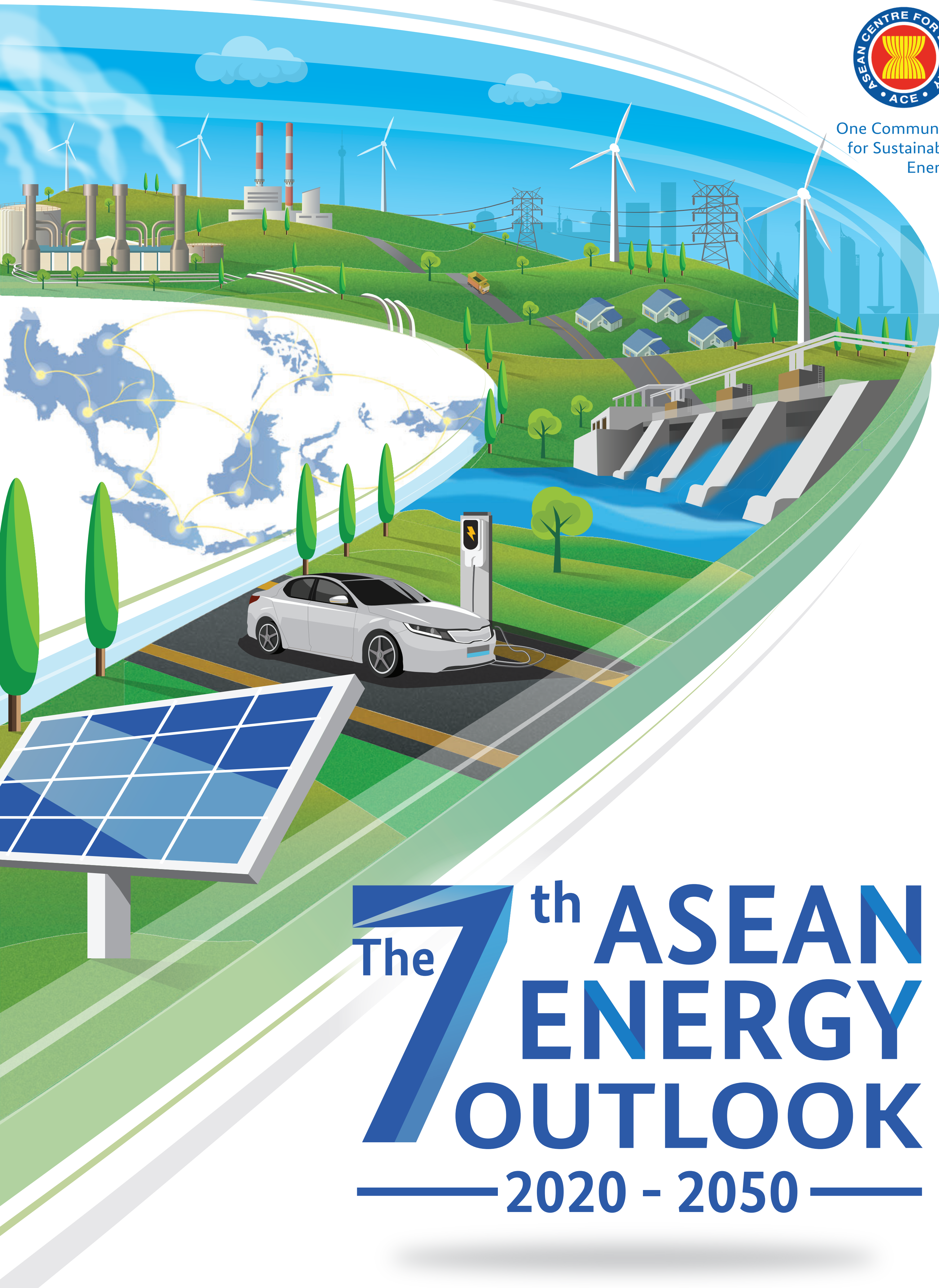

# The 7th ASEAN ENERGY OUTLOOK

## 2020 - 2050

[The 7th ASEAN Energy Outlook 2020 - 2050]



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# About ACE

Established in January 1999, the ASEAN Centre for Energy (ACE) is an intergovernmental organisation that independently represents the 10 ASEAN Member States' (AMS) interests in the energy sector. The Centre serves as a catalyst for the economic growth and integration of the ASEAN region by initiating and facilitating multilateral collaborations as well as joint and collective activities on energy. It is guided by a Governing Council composed of Senior Officials on Energy from each AMS and a representative from the ASEAN Secretariat as an ex-officio member. Hosted by the Ministry of Energy and Mineral Resources of Indonesia, ACE's office is located in Jakarta.

Among others, ACE cooperates with GIZ, on behalf of the German Federal Ministry for Economic Cooperation and Development (BMZ). The ASEAN-German Energy Programme (AGEP) is a jointly implemented project by ACE and GIZ. AGEP seeks to strengthen ACE in its role as a regional centre of excellence for sustainable energy. One key activity is to support the development of AEO, beginning with AEO4. AGEP's continuous support of AEO7, along with the Ministry of Economy, Trade and Industry (METI) of Japan, and the ASEAN Climate Change and Energy Project (ACCEPT), is well recognised.


*Photo source : ACE*

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Overall guidance was provided by Dr Nuki Agya Utama, Executive Director of ACE, and Mr Sergey Makarov, Principal Advisor for AGEP, GIZ.

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# Forewords

The ASEAN Member States (AMS), through the ASEAN Centre for Energy (ACE), presented the 7th ASEAN Energy Outlook (AEO7), launched at the 40th ASEAN Ministers Energy Meeting (AMEM) in September 2022, hosted by Cambodia. This flagship publication is supported by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH through the ASEAN-German Energy Programme (AGEP), the Ministry of Economy, Trade and Industry (METI) of Japan, and the ASEAN Climate Change and Energy Project (ACCEPT).

The unprecedented Covid-19 pandemic and its recovery, coupled with the volatility of global energy prices due to ongoing war and a carbon-constrained world, forced the energy sector to adapt to these rapid changes, including in Southeast Asia. Given our unique circumstances, the situation is also exacerbated by interminable energy security issues, both in energy resources and supporting materials, such as copper, lithium, nickel, and rare earth elements.

Against this backdrop, AEO7 reports the latest status of ASEAN's energy landscape and projects multiple realistic futures to gather insights for exploring a more challenging time ahead. As with its predecessors, AEO7 complements the ASEAN Plan of Action for Energy Cooperation (APAEC) 2016–2025 Phase II: 2021–2025, creating pathways toward achieving regional energy targets. Three central scenarios are continued: the Baseline Scenario, AMS (National) Targets Scenario (ATS), and the APAEC (Regional) Targets Scenario (APS).

As ASEAN's official energy think tank, ACE achieved a new milestone by performing 100  of the modelling work for AEO7 in-house, further embodying the spirit of "from ASEAN by ASEAN to ASEAN." Compared to the 6th ASEAN Energy Outlook, additional ten years of future scenarios were explored in AEO7. In the demand sector, disaggregation in the commercial and industrial sectors was conducted. This exercise clearly demonstrates the importance of data in energy modelling and policy planning.

Beginning in AEO7, a new scenario based on optimisation is introduced. The Least-Cost Optimisation (LCO) Scenario is a technology-neutral optimisation scenario applied to the power sector, reflecting all potentially viable technologies in emerging economies, such as ASEAN. This scenario considers the cost-effectiveness, affordability, and maturity of technology to fulfil growing electricity demand, including the deployment of energy storage and interconnection.

In 2020, an energy intensity reduction of 23.8% was achieved amidst the pandemic. Continuing the progress with national targets, though, does not result in achieving the regional target of 32% by 2025. Similarly, renewable energy in TPES has a projected 5.5% gap in achieving the target by 2025. Conversely, the installed-capacity target is on the way to reaching 37.9% by 2025, according to ATS, exceeding the target. AEO7 provides insight on ways to fill the gap through adopting stringent energy efficiency measures, increased electrification, and optimisation of renewable energy resources.

The LCO Scenario sheds light on a cost-effective alternate future, post-2025. An electricity generation system that costs USD 174.7 billion less than the APS can be realised during the projection period of 2021-2050. The cost-effective system of the LCO Scenario, though, will reduce the share of RE in TPES by 5.3% in 2050, compared to APS. Interestingly, it results in a more energy-efficient system, since the energy intensity reduction is projected to be 3.5% higher than the APS by 2050.

I deeply appreciate the tireless efforts of our in-house team, the active collaboration with the AMS Working Group members, and the strong support from our partners. We trust this report will be a valuable key reference for the ASEAN energy sector. I hope this report might also generate opportunities for more collaborative partnerships to advance the ASEAN energy sector.

**Dr Nuki Agya Utama**
**Executive Director, ACE**

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

The Association of Southeast Asian Nations (ASEAN) continues to become a global growth driver and an important economic force, with a population of 667 million people in 2020, accounting for about 8.7% of the total global population. In 2022, the real combined GDP of the ASEAN Member States (AMS) is estimated to reach USD 8.5 trillion (2017 constant, PPP) and is expected to continue expanding as much as 3.6 times by 2050.

The region's energy sector was hit by the Covid-19 pandemic in many ways. Declining energy consumption was most evident and severe in the transportation and industrial sectors due to lockdown policies and significant mobility restrictions. Half of the ASEAN countries also experienced a downturn in electricity consumption. In spite of this, the ASEAN region has experienced one of the strongest post-pandemic recoveries, thriving on the potential of renewable energy sources. Regional resilience was demonstrated over the past two years by the increasing share of installed capacity from RE-based power plants, including biomass, solar, wind, and geothermal.

Since 2014, the ASEAN-German Energy Programme (AGEP) – a cooperation between the ASEAN Centre for Energy (ACE) and the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH on behalf of the German Federal Ministry of Economic Cooperation and Development (BMZ) – has supported ACE in the development of its Energy Outlook. By providing technical and policy advice, and capacity building, we are delighted to support ACE and AMS in pursuing their sustainable energy ambitions.

The 7$^{th}$ ASEAN Energy Outlook (AEO7) maintains the strong involvement of Member States, providing a better understanding of energy trends and challenges the region faces in the coming decades. In this edition, the Outlook continues the projections within the Baseline, AMS Targets, and APAEC Targets Scenarios, with the addition of the Least-Cost Optimisation Scenario. The latter scenario allows the region to consider cost-effectiveness as a means to ensure an inclusive and just energy transition whilst achieving energy security, accessibility, affordability, and sustainability for all.

We believe that the AEO7 will become one of the key references for policymakers and all stakeholders in ASEAN in developing a policy framework to ensure secure, accessible, affordable, and sustainable energy in each country and across the region. We look forward to stronger cooperation between ACE and GIZ in advocating energy transition.

**Sergey Makarov**

**Principal Advisor for AGEP, GIZ**

# Contents






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## CHAPTER 4 : ASSESSING MEASURES FOR ENERGY RESILIENCE

## CHAPTER 5 : RECOMMENDATIONS AND IMPROVEMENTS



## APPENDICES




ISSN 2963-539X Volume 7, 2022

# List of Figures

# List of Tables

*Photo source : APC 2021 Winner - Philippines*

# EXECUTIVE SUMMARY

Since 2006, the ASEAN Energy Outlook (AEO) has become the primary source of energy information, analysis and projection for the ASEAN region. It has created regularly updated regional energy outlooks and strategic reports on important thematic issues. In particular, the AEO reports show whether and how national and regional targets for the energy sector - on topics like energy accessibility and affordability, energy efficiency, energy security, and environmental sustainability - can be achieved, and what policies, measures, and technologies are needed to help meet those targets.

What distinguishes the AEO from other energy outlooks is that it is built upon a strong foundation of data and modeling insights from the deep and durable cooperation, coordination, interaction and integration between the ASEAN Centre for Energy (ACE) and the ten ASEAN Member States (AMS). The AMS have provided much of the data upon which the AEO is based and all modeling results are carefully vetted by the AMS to ensure they are realistic representations of local contexts and regional development plans. The resulting projections thus reflect the countries' official expectations for future energy development. This approach creates a sense of ownership and understanding, and helps increase the usefulness of the results for the region at large.

Recent editions of the AEO have adopted a new, bottom-up modeling approach, better suited for examining the implications of national and regional policies and providing a technology-rich picture of how ASEAN's energy systems will grow and change in the coming decades. This edition, the 7th ASEAN Energy Outlook (AEO7), expands on that bottom-up modeling approach, with improved and more detailed modeling conducted for the commercial and industrial sectors, allowing for more insights into how national and regional targets can be achieved, factoring in each Member State's particular characteristics.

**Baseline Trends**

AEO7's Baseline Scenario examines trends in the absence of new policies. Key findings from the Baseline Scenario modelling include:

- In line with rapid economic growth, energy demand in the region is expected to triple by 2050 from the 2020 level under the Baseline Scenario. Total final energy consumption (TFEC) is expected to reach 473.1 Mtoe by 2025 and 1,281.7 Mtoe by 2050.
- Fossil fuels are projected to continue to supply most of the regional energy demand, with oil accounting for 47.4% of TFEC, followed by electricity (20.3%), coal (14.5%), and bioenergy (9.2%) in 2050.
- Cooking and cooling will remain the primary energy use in the residential sector, making up about 82% of the sector's demand in 2050.
- Petroleum remains the primary energy source in the transportation sector (accounting for 91% of sectoral energy consumption in 2050), and transportation remains one of the highest energy-consuming sectors in the region.
- The Total Primary Energy Supply (TPES) is expected to grow by a factor of about 4, from 654 Mtoe in 2020 to 2,647 Mtoe in 2050.
- Oil, natural gas, and coal dominate the region's energy supply, accounting for about 88% of TPES in 2050, leaving renewables at 11.9%. In the medium term, without policy interventions, the region is projected to reach a renewable energy (RE) share of only 14.4% of TPES by 2025, little changed from the 2020 value of 14.2% and falling short of the target set in the ASEAN Plan of Action for Energy Cooperation (APAEC) 2016-2025 Phase II: 2021-2025 (i.e., 23% in TPES by 2025).

- Without significant discoveries or additions to existing production infrastructure and with the expected rate of utilisation of fossil fuels, ASEAN is projected to become a net importer of natural gas by 2025 and coal by 2039.
- ASEAN electricity generation is expected to increase threefold by 2050 from the 2020 level, reaching 3,388 TWh in that year. Installed power capacity reaches 959 GW in 2050 and consists primarily of coal (33.8%), natural gas (26.1%), and hydropower (21.6%), following the region's historical dispatch.

The modelling of policies designed to help attain national and regional targets showed that it is possible to mitigate many of the aforementioned adverse trends.

**Energy Demand**

National efficiency measures and fuel shifting could significantly slow the growth in TFEC. By incorporating national policies, the AMS Target Scenario (ATS) projects to achieve a 9.9% demand reduction versus the Baseline Scenario by 2025, with regional policies in the APAEC Target Scenario (APS) further boosting this to a 14.1% saving. By 2050, the savings will reach 39.6% for national policies and 53.7% once additional regionally focused measures are included. These savings are achieved through a range of measures, including promoting energy efficiency in electric technologies in the residential and commercial sectors (e.g., efficient lighting, cooling, and appliances), improvements in industrial processes, fuel economy, and electric vehicle (EV) in the transportation sector.

To reach regional targets, a range of policy interventions are required.

In the household sector, a 5% annual increase in clean cooking coupled with increased electrification is needed. This could be achieved by using cleaner wood stoves in rural areas and electric induction stoves in 70% of urban households. In addition, an increase in the penetration of efficient air conditioning and refrigeration units by 60% to 100% is required by 2050.

In the transportation sector, alignment with the ASEAN Fuel Economy Roadmap will require a 5.2% annual improvement in the fuel economy of private vehicles up to 2030, and at least a 3% yearly improvement thereafter. In addition, a 2% annual increase in the share of buses in the transportation fleet is necessary.

Attainment of EV deployment targets will also be crucial. Although several Member States have set promising targets and strategies for increasing EV uptake, national policies are projected to lead to an EV share of 2.5% of the passenger road transportation fleet by 2025 and 9.6% by 2050 in ATS. Thus, higher targets and additional policies are required to help meet these targets, coupled with establishing targets in some AMS that have not yet set EV deployment objectives. Significant fuel saving potential can be expected through attaining EV targets, biofuel mandates, and fuel economy improvement strategies to meet the regional target. Deploying more efficient electric and hybrid vehicles reduces gasoline and diesel usage in passenger road transportation by about 72% and 59%, respectively, on average by 2050 versus the Baseline Scenario.

Given the importance of the transportation sector and with petroleum projected to remain the primary energy source in that sector in the Baseline Scenario, energy efficiency and conservation policies will be important in helping to reduce the region's dependency on oil. Implementing the measures in the AMS scenario reduces the share of oil consumption in transportation sector to 82.5% by 2050, and with the additional measures included in the APS, consumption further decreases to 72.5%. By that time, electricity accounts for 8.2% of transportation energy demand, biofuels for 17% and compressed natural gas for 2.4%.

Industry is another major energy-consuming sector that remains highly reliant on coal, oil, and natural gas in the Baseline Scenario. A doubling of energy-saving efforts is required in this sector to achieve ASEAN's goals. Although Member States have started to set energy intensity reduction targets in this sector, achieving those targets will be difficult due to the current paucity and often proprietary nature of data. This makes it challenging to conduct proper accounting, and thus to implement and then monitor suitable energy savings programmes. Efforts need to be stepped up to improve the data quality and ensure that energy savings can be properly overseen in the sector.

The AEO7 modelling shows the huge benefits of taking action in the industrial sector. With energy efficiency policies implemented in ATS and APS, electricity demand can be reduced tremendously. With the implementation of measures, the dramatic electricity growth in industrial sector can be kept to a more reasonable level by a factor of just 2.3 with national policies and of just 1.7 with the addition of regional polices by 2050, as compared to the 2020 level.

**Primary Energy Supply and Import Dependence**

The AEO7 modelling finds that national and regional policies, especially those focused on energy efficiency, can reduce the overall growth in TPES in 2050 from 2,647 Mtoe in the Baseline Scenario to 2,034 Mtoe with the implementation of national policies and 1,766 Mtoe with additional regional policies. With all national policies implemented, fossil fuel supply requirements are projected to be reduced by 11% in 2050 relative to the Baseline Scenario.

AEO7 modelling shows that ASEAN will not be able to meet its energy intensity (TPES/GDP) reduction targets without policies to promote energy efficiency. ATS indicates that AMS could achieve a 29.2% reduction by 2025, but this still would not be enough to meet the 32% goals set by the APAEC. Hence, the implementation of stronger energy efficiency policies is deemed crucial. By 2050 the AEO7 modelling indicates that ASEAN can potentially achieve an energy intensity reduction of 38.6% with national policies and 46.7% with the addition of regional policies.

ASEAN is expected to become net importer of natural gas by the mid-2020s and coal by the late 2030s, according to the Baseline Scenario. Implemented national and regional policies only serve to delay the date when the region becomes a net importer of natural gas by one year.

In terms of oil, ASEAN has been a net importer since before 2005. The shift to renewables expected in the policy scenarios manifests in a reduced need for oil imports. National policies are expected to reduce oil imports by up to 26% by 2050 versus the Baseline Scenario. This figure is projected to reach a 34% reduction with the addition of regional policies.

**Electricity Generation**

AEO7 modelling highlights the importance of energy efficiency measures in helping to keep the growth in demand for electricity within reasonable limits. Without new policies, the Baseline Scenario projects electricity generation requirements to grow at an average rate of 4.3%/year. With national energy efficiency policies in place, this growth comes down to a more achievable factor of 2.3, or 3.7%/year. With regional policies in place, it further declines to a factor of 1.9, or 3.2%/year. These relative declines are particularly notable because they happen even as the region pursues policies to encourage the electrification of the transportation sector.

The modelled national and regional policies also result in changes to the mix of power plants built and dispatched in the coming three decades. Under ATS, 787.2 GW of power plant capacity is required in 2050, compared to 958.8 GW in the Baseline Scenario. By 2050, the mix of power plants in ATS is projected to be dominated by hydropower (27.9% of capacity), natural gas (25.3%), coal (20.5%) and solar (9.7%). With additional regional policies in place, an even lower 719.4 GW of capacity is required. This reduction allows hydropower to increase its share to 35.4% of capacity, while other policies lead to a more prominent role for solar power, which increases its share of capacity to 13%. Natural gas remains important, accounting for 23.6% of capacity, while coal decreases to just 10.6%.

AEO7 explores the implications of promoting least cost planning in the electric sector through the LCO Scenario to achieve regional RE generation targets. This scenario foresees achieving a higher share of coal in total generating capacity in 2050 (23.9%), whilst the percentage for natural gas declines to 16.5%, compared to ATS and APS. There is significant bioenergy growth, reaching a share of 11.5% in 2050, as compared to the 2020 value of 3.4%. Nuclear energy is also introduced in the region, with 5.2 GW deployed by 2050 (<1% of the power mix). It should be noted that the LCO Scenario does not consider any pollution externality costs in its optimisation approach. When these are included, the LCO Scenario will produce different outcomes, with a clear preference for cleaner-generating technologies like solar, wind, hydro, and geothermal.

Modelling of the ASEAN power grid and battery and energy storage systems were also explored as a part of the LCO Scenario. The results show a high preference for building transmission lines to interconnect the following regions: Thailand – Peninsular Malaysia (additions), Peninsular Malaysia – Sumatra (new), Sarawak – Brunei Darussalam (additions), Lao PDR – Vietnam (additions), Thailand – Myanmar (new), Thailand – Cambodia (new). The modelling suggests that constructing these lines to be operational as early as 2025 would be cost-effective. Furthermore, additional new lines from the Philippines to Sabah are suggested by 2030.

Batteries can be used to provide stored power during mid-day peak hours, overnight periods, and other times when solar and wind generation are reduced. Thus, they are projected to be crucial in enabling higher penetration of RE and maintaining the power grid's stability. In the LCO Scenario, the region is expected to require 26.6 GW of battery capacity to store about 1,100 GWh of electricity by 2050.

In terms of overall RE shares, as previously noted, existing policies are projected to be unable to meet the regional target of 23% RE in the TPES by 2025. Aside from the above-mentioned policies for electric generation, the AEO7 modelling finds that additional and/or more stringent biofuel mandates at the national level will be required to meet the RE target.

The challenges in achieving and maintaining RE targets underline the need for fuel-shifting strategies in the industrial, transportation, and other demand-side sectors.

| 2025 | Renewable Share in Total Primary Energy Supply | Renewable Share in Intalled Power Capacity | Energy Intensity Reduction based on 2005 level |
|---|---|---|---|
| APAEC Target | 23% | 35% | 32% |
| Status in ATS | 17.5% | 37.9% | 29.2% |

**Investment Requirements**

Supporting power expansion and target achievement throughout 2021-2025 requires an investment of USD 184 billion in the Baseline Scenario, USD 154 billion in ATS, and USD 109 billion in APS. In the earlier years (2021-2030), the annual power investment requirement varied from USD 17 billion to USD 34 billion. In the mid-term (2031-2040), half of the scenarios follow a declining trend reaching the highest value of USD 31 billion for the Baseline Scenario and the lowest value of USD 17 billion for the LCO Scenario. In the long-term (2041-2050), as the region expands new builds to meet the higher energy demand, annual power investment ranges from USD 25 billion to USD 42 billion.

Overall power investment needed throughout the entire period is USD 1,070 billion for the Baseline Scenario. With the expected capital requirement reduction resulting from demand-side management, it may only require USD 879 billion in ATS and USD 726 billion in APS. The LCO Scenario requires just USD 582 billion, or about 80% of the APS.

RE investments account for about 59% in ATS and 77% in APS of the total investment required in total for the power sector. In the LCO Scenario, a notable addition to the investment cost is nuclear energy which may account for up to 2.9% of the power investments.

**Greenhouse Gas Emissions, Job Creation, and Land Use**

Without new policies, ASEAN's GHG emissions, excluding from international transportation, are projected to reach 6,704 Mt $CO_2$-eq in 2050, a 3.7-fold increase compared to 1,815 Mt $CO_2$-eq in 2020. The expected population growth rate to 2050 corresponds to an annual rate of 8.5 $tCO_2$-eq per capita for ASEAN as a whole, although with large variations among the Member States. This level is broadly comparable to current per capita rates of GHG emissions in the European Union region today. GHG emissions in the Baseline Scenario in 2050 are projected to come primarily from the power (58%), transportation (21%), and industrial (18%) sectors. Hence, improvements in these sectors would considerably reduce ASEAN's overall emissions.

AEO7's modelled policy measures are projected to slow the rate of increase in emissions significantly. Implementing national measures results in 2050 emissions being kept to 4,030 Mt $CO_2$-eq in 2050 (about 5.1 $tCO_2$-eq per capita). Enacting additional regional policies would result in a further decline to 2,966 Mt $CO_2$-eq in 2050 (about 3.8 $tCO_2$-eq per capita). However, the LCO Scenario, which tends to favour coal-fired generation (albeit coupled with strong demand-side energy efficiency and fuel switching measures), results in overall GHG emissions of 3,117 Mt $CO_2$-eq in 2050 (about 3.94 $tCO_2$-eq per capita).[1]

The social cost of these polluting emissions was evaluated using a set of externalities. In the Baseline Scenario, the cost of maintaining historical trends towards 2050 is calculated as USD 4,569 billion. Emission reductions in the ATS and APS bring the cost down to USD 2,481 billion and USD 1,804 billion, respectively, in 2050. The LCO Scenario is estimated to have a higher social cost of emissions at USD 1,849 billion.

Strong renewable deployment in the APS is projected to provide up to 5.5 million new jobs by 2050. About 77% of these would be involved in the construction, operation and maintenance of baseload RE plants, including hydropower (67%) and geothermal (10%). Meanwhile, solar power plants will be accounted for 19% of these new jobs. Job creation in other scenarios are significantly lower: 3.9 million for the Baseline Scenario, 4.6 million for ATS, and 3.2 million for the LCO Scenario.

[1] As noted earlier, however, the LCO Scenario does not seek to minimise emission externality costs.

AEO7 also analyses the land requirement to produce these biofuels. Biofuel is expected to be widely used as a blending fuel in the transportation sector. Analysis of the land area required to supply the increasing demand due to biofuel mandates indicates that up to 5.6 million Ha of land for growing palm oil is required, with 3.2 million Ha for sugar cane in the regional policies scenario. This value corresponds to about 2% of the total land area of Southeast Asia. The Baseline Scenario requires even greater land areas for biofuel production (11.2 million Ha or 2.5% of the AMS land mass), whilst the amount is slightly lower for the national policies scenario (6.9 million Ha or 1.5% of the AMS land area).

Sustainable biofuel production is crucial, especially in the water-energy-food nexus and land use context. It should also be noted that AEO7 does not explicitly model the agriculture and land use, nor the water system, which can be a useful improvement in understanding these intersectoral relations. Bioenergy with carbon capture storage, which is more commonly applied to bioenergy utilisation for power or heat generation, can be an option to offset the emissions caused by land use change due to biofuel.

The summary table below provides a quick reference to some of AEO7's key assumptions and modelling results, enabling easy comparison amongst the four scenarios.

| | Historical 2020 | Baseline Scenario | | AMS Target Scenario (ATS) | | APAEC Target Scenario (APS) | | Least-Cost Optimisation (LCO) Scenario | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2025 | 2050 | 2025 | 2050 | 2025 | 2050 | 2025 | 2050 |
| Population (million persons) - constant across scenarios | 667.1 | 698.2 | 791.7 | 698.2 | 791.7 | 698.2 | 791.7 | 698.2 | 791.7 |
| GDP (billion 2017 USD PPP) - constant across scenarios | 7,839 | 9,811 | 30,254 | 9,811 | 30,254 | 9,811 | 30,254 | 9,811 | 30,254 |
| Total final energy consumption (TFEC, in Mtoe) | 385 | 473 | 1,282 | 426 | 774 | 406 | 593 | 406 | 593 |
| % Electricity in TFEC | 22.7% | 21.9% | 20.3% | 23.1% | 25.5% | 23.3% | 27.3% | 23.3% | 27.3% |
| Total primary energy supply (TPES, in Mtoe) | 654 | 818 | 2,647 | 759 | 2,034 | 731 | 1,766 | 710 | 1,649 |
| % Coal in TPES | 26.9% | 25.9% | 22.1% | 25.0% | 12.8% | 21.6% | 7.5% | 29.7% | 13.4% |
| % Oil in TPES | 34.9% | 37.5% | 43.1% | 35.7% | 39.3% | 33.6% | 39.6% | 34.0% | 42.3% |
| % Gas in TPES | 20.9% | 20.2% | 22.6% | 20.0% | 24.6% | 20.0% | 24.0% | 11.4% | 20.0% |
| % RE in TPES | 14.2% | 14.4% | 11.9% | 17.5% | 23.0% | 23.0% | 28.7% | 23.4% | 24.3% |
| EI reduction from 2005 level | -23.8% | -23.7% | -20.0% | -29.2% | -38.6% | -32.0% | -46.7% | -33.8% | -50.2% |
| Installed power capacity (GW) | 293 | 378 | 959 | 380 | 787 | 376 | 719 | 399 | 620 |
| % RE in installed power capacity | 33.3% | 34.5% | 35.0% | 37.9% | 49.3% | 41.5% | 63.2% | 38.0% | 52.5% |
| Electricity generation (TWh) | 1,126 | 1,345 | 3,388 | 1,278 | 2,566 | 1,229 | 2,108 | 1,231 | 2,114 |
| Energy-related GHG emissions (Mt $CO_2$-eq) | 1,815 | 2,253 | 6,704 | 2,016 | 4,030 | 1,790 | 2,966 | 1,848 | 3,117 |

# REPORT OUTLINE

- **CHAPTER 1 : Introduction**

Establishes contextual setting of the ASEAN energy landscape, challenges, efforts, ambitions, and the role of regional cooperation and outlook in addressing energy dynamics within the region.

The population and economic growth activities linked to global energy dynamics and implications for the energy sector

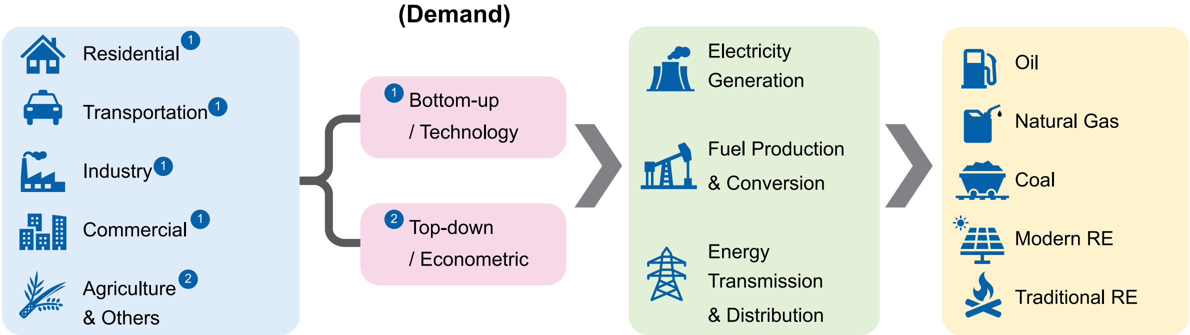
The elements of energy security, accessibility, affordability, inclusivity, and sustainability challenges for ASEAN

The role of energy cooperation under the ASEAN Plan of Action for Energy Cooperation (APAEC) and AEO7 supports in creation of pathways to address the challenges

- **CHAPTER 2 : Methodology**

Provides the reasoning behind the AEO7 modelling arrangement of continuing the historical patterns, or achieving national or regional targets, as well as a technology-neutral scenario.

**Modelling Process of AEO7**




Historical data from 2005 - 2020 are projected to 2021 - 2050 on four scenarios.

**The Four Scenarios of AEO7**


**Baseline Scenario**
The energy growth pattern kept at constant level as of last historical year

**AMS Targets Scenario (ATS)**
Achievement of ASEAN official national energy targets

**APAEC Targets Scenario (APS)**
Achievement of APAEC's aspirational regional targets on RE and EI

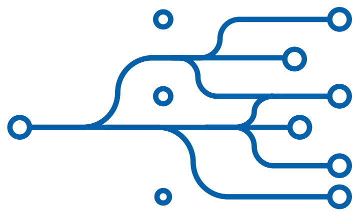
**Least-Cost Optimisation (LCO)**
Least-cost power sector dispatch to attain APAEC's regional targets

**Increase ambitions of RE and EE/EI standards** → Least-cost option in power sector

The degree of ambition escalates from the Baseline Scenario to APS, whilst the LCO Scenario serves an alternative scenario that considers all the viable technologies in the region in determining the power generation mix that would best meet the region's electricity demand whilst satisfying the APAEC's regional targets.

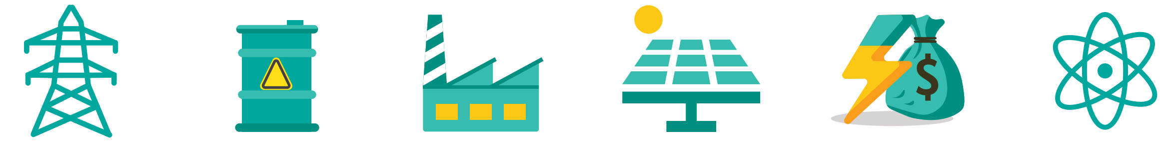
- **CHAPTER 3 : Exploring Multiple Futures**

  Explains the analysis of the modelling results based on the AEO7 scenarios and the implications for energy demand and supply, emissions, and socio-economic impacts in the ASEAN region, including social cost of energy, renewable job creation, and land use of biofuel.



- **CHAPTER 4 : Assessing Measures for Energy Resilience**

  Elaborates on six emphasised energy sectors considered essential to attaining secure and reliable energy amidst transition.



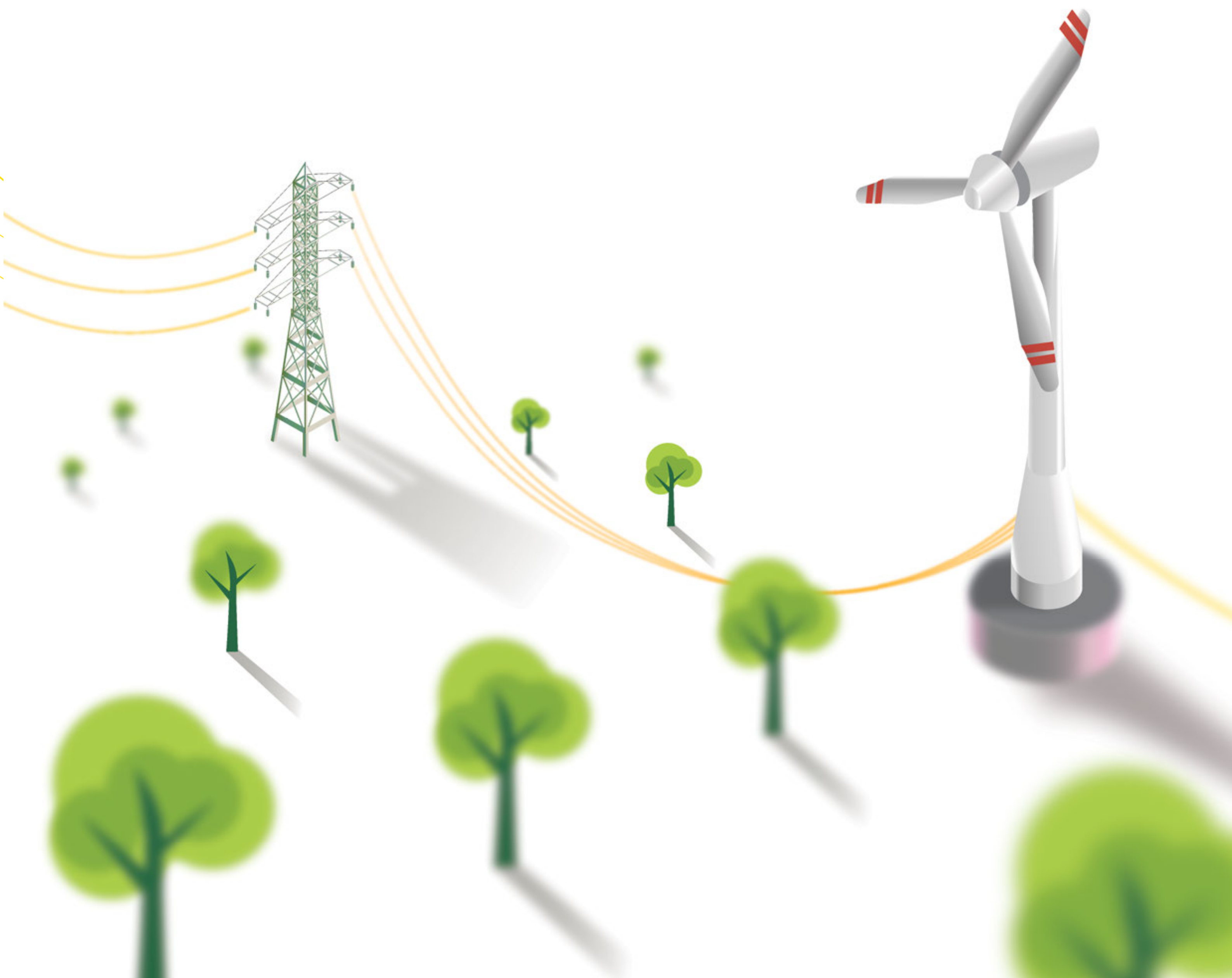
Grid Integration | Fossil Fuels | Industrial Efficiency | Renewable Energy | Financing Energy Transition | Nuclear Power

- **CHAPTER 5 : Recommendations and Improvements**

Offers key energy policy proposals and strategic steps to address barriers in utilising resources to meet the demand of the ASEAN Member States from end-use and power sectors and aligning them with the regional targets, in conjunction with institutional, data, and model improvement prospects for the subsequent editions of the ASEAN Energy Outlook.

# CHAPTER 1

# INTRODUCTION

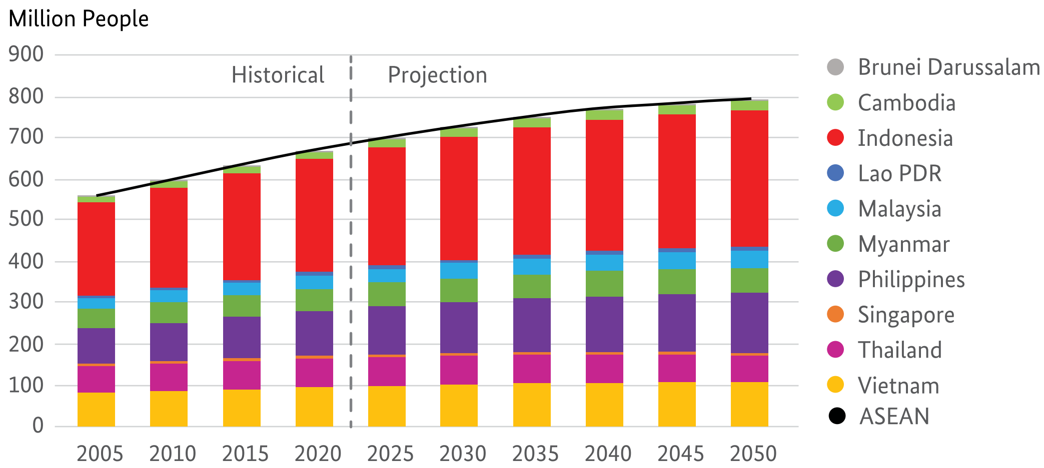


# CHAPTER 1
# INTRODUCTION

## 1.1 ASEAN Socio-Economic and Energy Demand Status

ASEAN Member States (AMS) make an important contribution to the overall global social development and economic dynamism due to their population size and increasing economic growth. The total population of AMS consistently accounted for about 8.7% of the total world population from 2005 to 2022[2] . In 2020, it was about 667 million people (Figure 1.1), of the 7.8 billion of the global population. Although the population is projected to continue increasing, the trend shows a decreasing annual growth rate, from 1% in 2021 to 0.2% in 2050. In 2050, the total population of AMS is predicted to be about 792 million people out of roughly 9.7 billion global population.

**Figure 1.1 Population of AMS, 2005 - 2050**




*Source: Population estimates and projections of World Bank DataBank.*

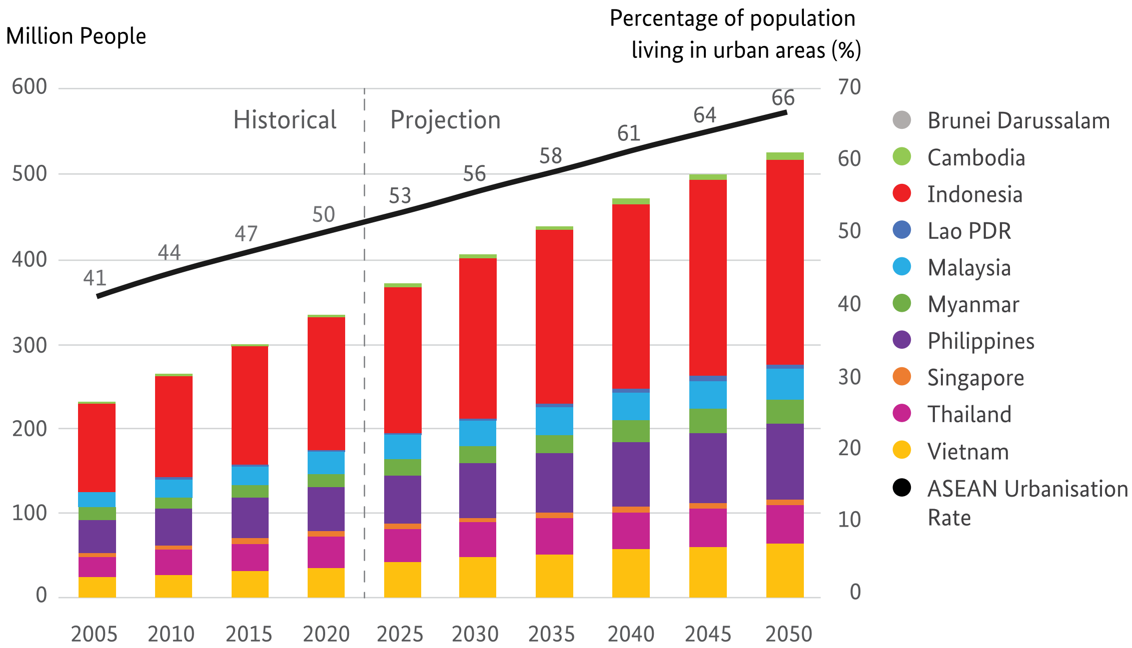
The ASEAN population growth rate is similar to the global population growth rate. From 2006 to 2021, ASEAN maintained a stable annual population growth rate of between 1% and 1.3%, which was slightly higher than the global population growth rate of 1% to 1.2%. A similar situation is also observed in the projected population of AMS for the period 2022-2050[3].

Each AMS experienced different trends in population growth rates. Amongst the AMS, four countries (Cambodia, Lao PDR, Malaysia, the Philippines) are found to have slightly higher population growth rates than the whole ASEAN or the world at large. In 2021, Cambodia and Lao PDR had a population growth rate of about 1.4%, while Malaysia and the Philippines reported 1.3%. In comparison, the global population growth rate in the same year was about 1%. As population growth is one of the critical drivers for future economic growth and energy demand, without a proper strategy implemented by AMS and each key country, such as strengthening energy efficiency (EE) measures to control energy demand, the national and regional energy targets will be affected.

[2] Data retrieved from World Bank DataBank, Population estimates and projections
https://databank.worldbank.org/source/population-estimates-and-projections
[3] Projection retrieved from World Bank DataBank, Population estimates and projections

The growth of ASEAN urbanisation rate follows a similar trend to the population growth rate, though slightly higher. From 2005 to 2020, this rate has risen in the range of 1.1% to 1.6%. Urbanisation rate growth is projected to decrease from 1.1% in 2021 to 0.8% in 2050. About 66% of the population in ASEAN is expected to live in urban areas by 2050 (Figure 1.2).

**Figure 1.2 ASEAN Urban Population, 2005 - 2050**




*Source: Population estimates and projections of World Bank DataBank.*

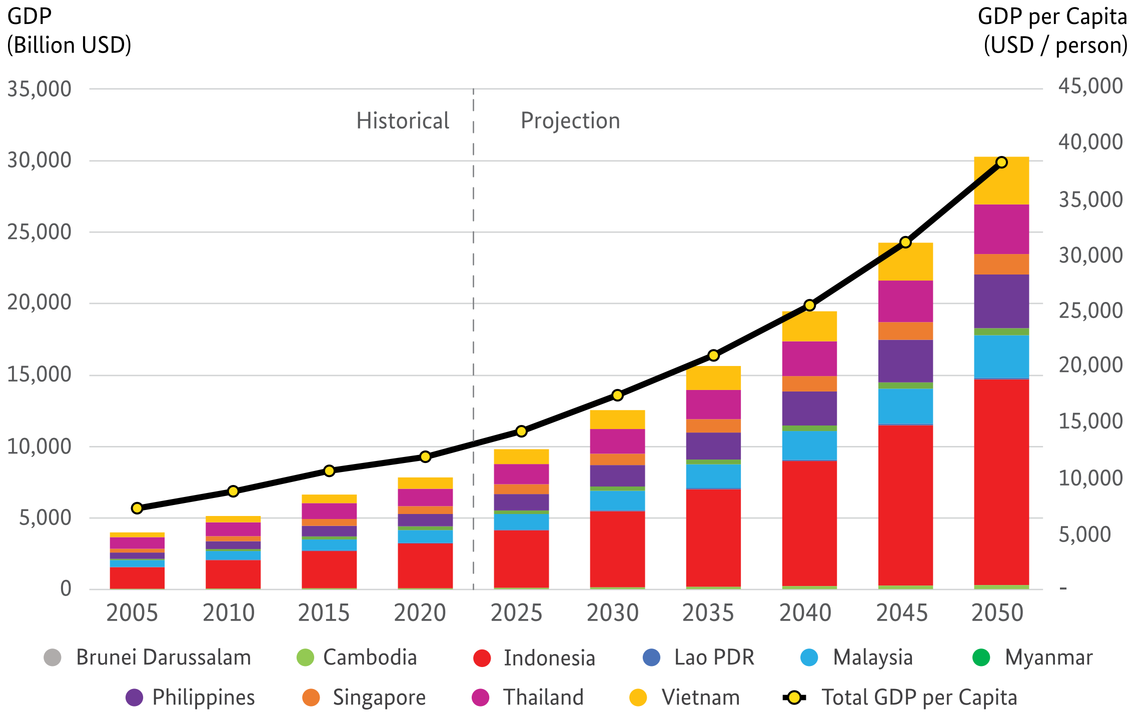
Regarding economic growth, AMS shows a combined real GDP growth rate from 3% to 7% during 2005-2050[4]. Except in 2020, when AMS experienced economic recession due to the Covid-19 pandemic, the total economic growth rate for AMS was -4%. The pandemic affected most AMS, with the exceptions of Myanmar (3.2%), Vietnam (2.9%), Brunei Darussalam (1.2%), and Lao PDR (0.5%). Positive signs of economic recovery in the AMS began in 2021, with total economic growth of about 3%. However, positive recovery was not found in all AMS. In 2021, the growth rate of Myanmar's real GDP fell -18.4% year over year (YoY), as compared to the GDP value in 2020 due to a combination of the political environment and Covid-19. Brunei Darussalam also experienced a slight decrease in GDP in 2021, falling -1.5%.

From 2022 to 2050, the growth of combined AMS real GDP shows a positive trend with an average of 4.7%. In 2022, the real GDP of AMS is predicted to reach USD 8.5 trillion (2017 constant, PPP). GDP is expected to continuously expand by 3.6 times into 2050. Note that it is important to observe the real GDP trend in each AMS due to the diversity of socio-economic conditions across the region. Indonesia contributes the largest share of the total AMS GDP. In 2020, Indonesia's GDP accounted for about 40% of the combined AMS economies. Indonesia's GDP is expected to continue increasing to 48% of the combined AMS GDP by 2050. The projected annual GDP growth for Indonesia is 5.1% by 2050, in constant metrics.

[4] Internal calculation based on data provided by several sources (WDI, ADB, APERC, and SSP)

The second-largest AMS economy by 2050 is projected to be the Philippines, with an approximate 12% share of total AMS real GDP consistently from 2017 to 2050. Thailand and Vietnam are two additional countries that have accounted for significant percentages of overall AMS real GDP. In 2020, Thailand's and Vietnam's GDPs accounted for approximately 15% and 10%, respectively, of the combined AMS GDP. They will still rank as the third and fourth largest of the AMS total economy, with an 11% share each in 2050 (Figure 1.3).

**Figure 1.3 AMS GDP and ASEAN GDP per Capita, 2005-2050**

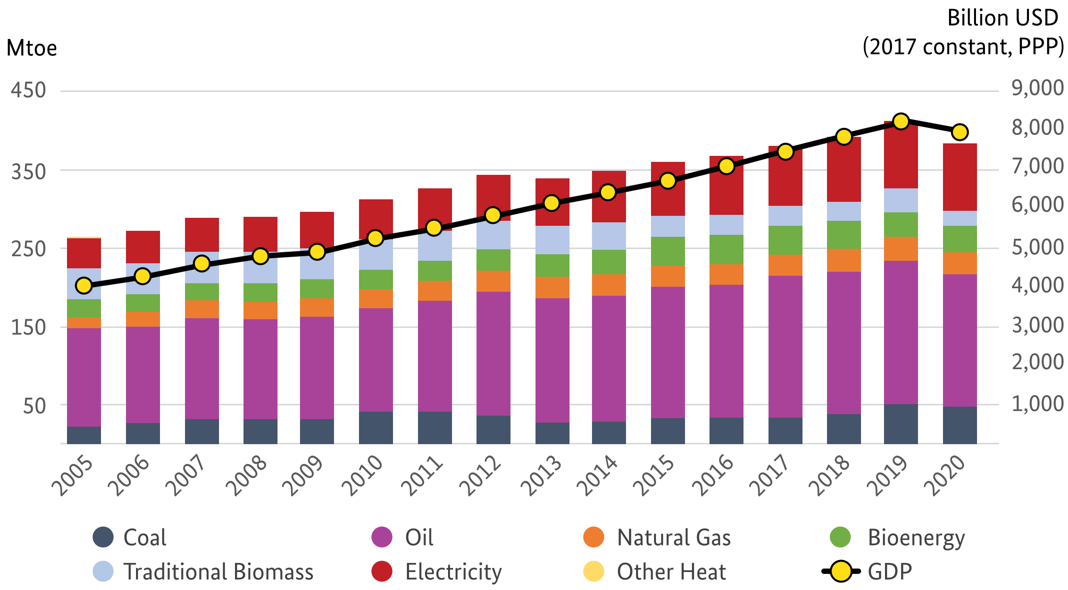



*Source: Internal calculation based on data provided by multiple sources (WDI, ADB, APERC, SSP). Note: GDP PPP at 2017 constant price.*

Socio-economic conditions represented by population and GDP are amongst the factors that affect energy consumption. ASEAN's total final energy consumption (TFEC) – the annual amount of energy consumed across all end-use sectors of the economy – had grown by 1.6 times in 2019, from 2005 levels. In 2020, consumption declined to 385 million tonnes of oil equivalent (Mtoe), or approximately 1.5 times higher than in 2005, due to the Covid-19 pandemic.

EE improvements in the last decade have somewhat restrained the overall growth in demand. Whilst the average annual growth of GDP from 2005 through 2020 is 4.6%, TFEC's average yearly growth is lower at 2.7% in the same period (Figure 1.4). AMS have implemented several energy-saving measures, such as increasing the share of efficient cooking and lighting, and raising minimum energy performance standards (MEPS) for cooling appliances.

**Figure 1.4 Energy Demand by Fuel and GDP in ASEAN, 2005-2020**



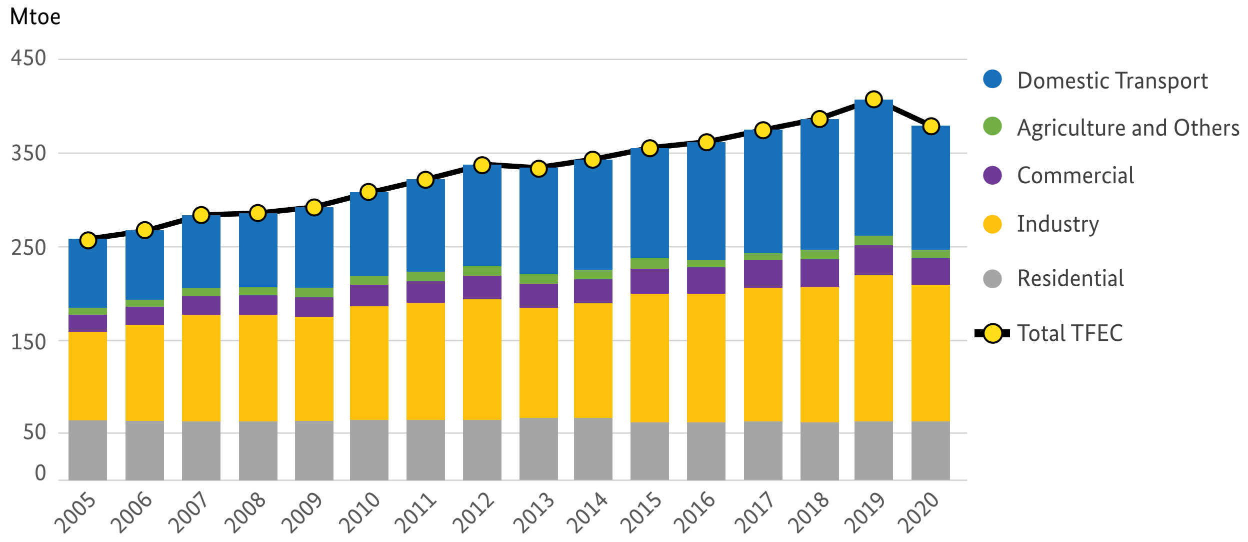

*Source: ACE. All rights reserved. Other Heat includes solar thermal.*

The ASEAN region has historically relied on fossil fuels to secure energy demand. Although the percentage of oil in 2020 was reduced to 43.8% from 47.8% in 2005, it still constituted the largest share of ASEAN TFEC. The second most significant percentage is electricity, which accounted for 14.6% and 22.7% in 2005 and 2020, respectively. The increased demand for electricity was driven by the AMS' target of universal access to electrification. Biofuel also experienced a surge since AMS have leveraged their potential for replacing oil and gas, with four mandated biofuel policies and another four in planning [1]. On the other hand, traditional biomass demand used by households was substantially reduced following the AMS' commitment to accelerating access to clean cooking technology.

Industry remained the largest energy-intensive sector, followed by transportation. These sectors accounted for approximately 39.1% and 34.8%, respectively, of ASEAN TFEC in 2020 (Figure 1.5). Industrial demand in 2020 grew by 1.6 times the 2005 level. Although energy consumption in transportation was the second highest with 133.9 Mtoe in 2020, it increased by 1.8 times, the highest when compared to 2005. Before the Covid-19 pandemic, the transportation sector consumed almost twice its energy level in 2005.

All AMS have already set national energy efficiency and conservation (EE&C) targets in their countries, with several nations having started declaring detailed sectoral policies in industry and transportation. For example, Singapore will increase effort toward achieving a 1%-2% annual improvement in industrial EE [2], whilst Vietnam is aiming for a 5% reduction in fuel and oil consumption for transportation relative to Baseline [1]. In addition, most AMS have initiated fuel switching policies to reduce internal combustion engine vehicles and increase the share of electric transportation [3].

**Figure 1.5 ASEAN Total Final Energy Consumption by Sector, 2005 - 2020**

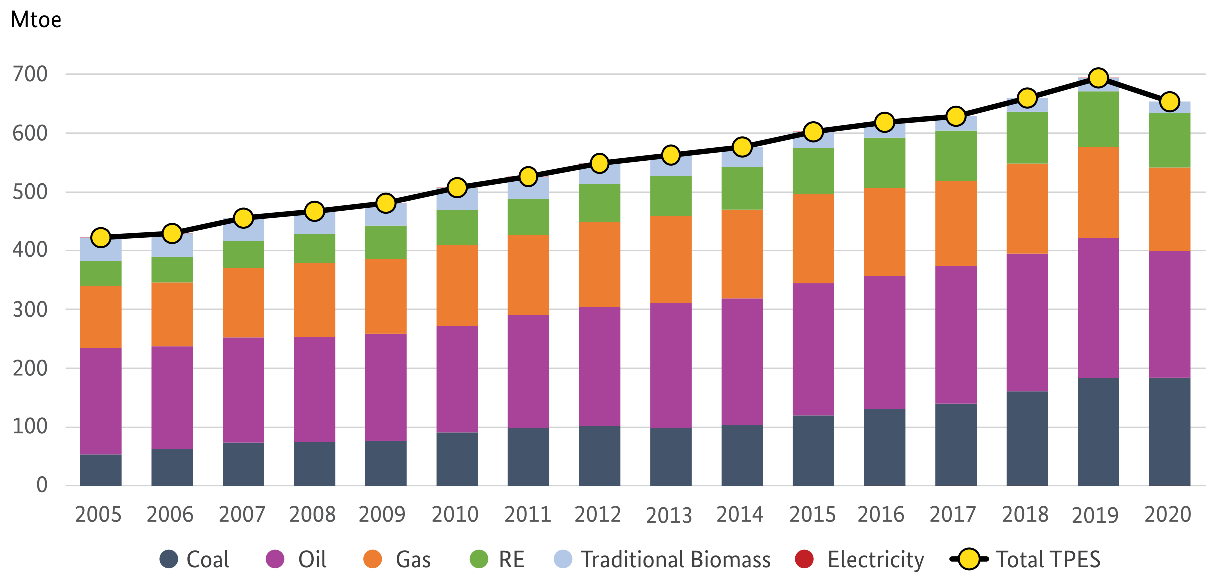



*Source: ACE. All rights reserved.*

## 1.2 Ensuring Energy Security

Responding to growing demand, ASEAN total primary energy supply (TPES) has sharply increased. The TPES in 2020 reached 654 Mtoe, approximately 1.5 times the 2005 level (Figure 1.6), almost similar to TFEC growth. Fossil fuels dominated the region's energy mix, which accounted for about 83% in 2020, as compared to 14.2% renewables (excluding traditional biomass). With an increasing reliance on fossil fuel imports, the ASEAN region could face serious energy security challenges, as the availability of energy sources at an affordable price could be jeopardised. Fuel markets have proven to be highly volatile and sensitive to crises, such as global pandemics and geopolitical conflicts.

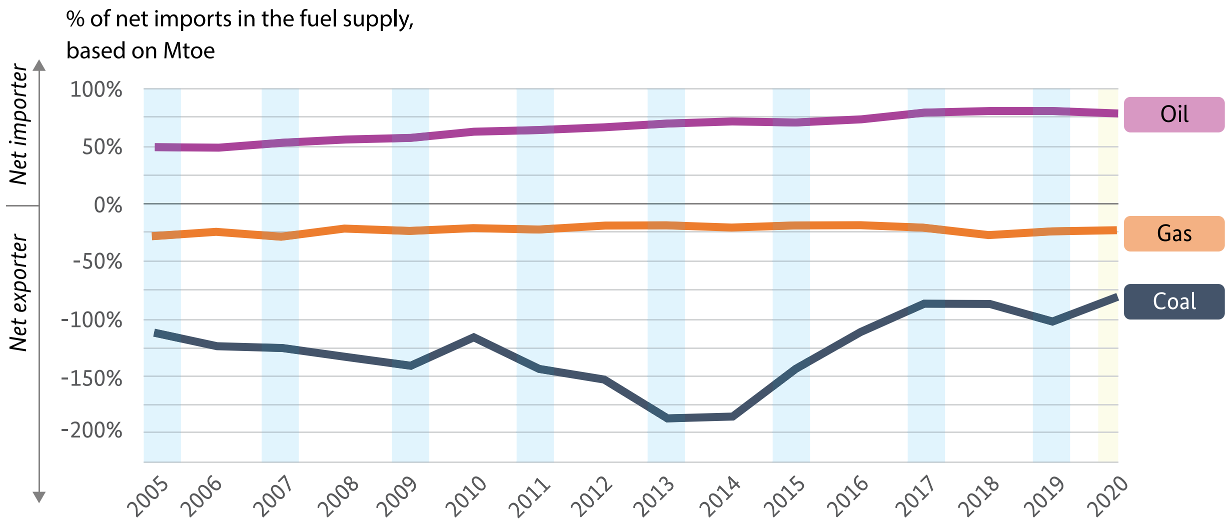
**Figure 1.6 ASEAN Total Primary Energy Supply by Fuel, 2005-2020**




*Source: ACE. All rights reserved. Note: RE excludes traditional biomass used in households.*

ASEAN has been a net oil importer since before 2005 but a net exporter of gas and coal. Total net imports (imports minus exports) of oil, including petroleum products, as a share of primary oil supply, rose from 48% in 2005, to 79% in 2020 (Figure 1.7). A higher percentage means more regional reliance on oil imports. The increased use of gas, primarily replacing domestic oil, has had a positive environmental benefit within the ASEAN region but has also raised some risks associated with energy supply security. Although ASEAN was still a net gas exporter in 2020, the trend shows the region is slowly moving toward becoming a net gas importer. Natural gas imports accounted for 21.6% of the total ASEAN gas-based primary supply in 2020, up from 13.8% in 2005. Too much dependence on energy imports might harm the region's energy security, especially during crises like pandemics, geopolitical war, and global financial crises.

**Figure 1.7 ASEAN Dependency on Coal, Gas, and Oil 2005-2020**



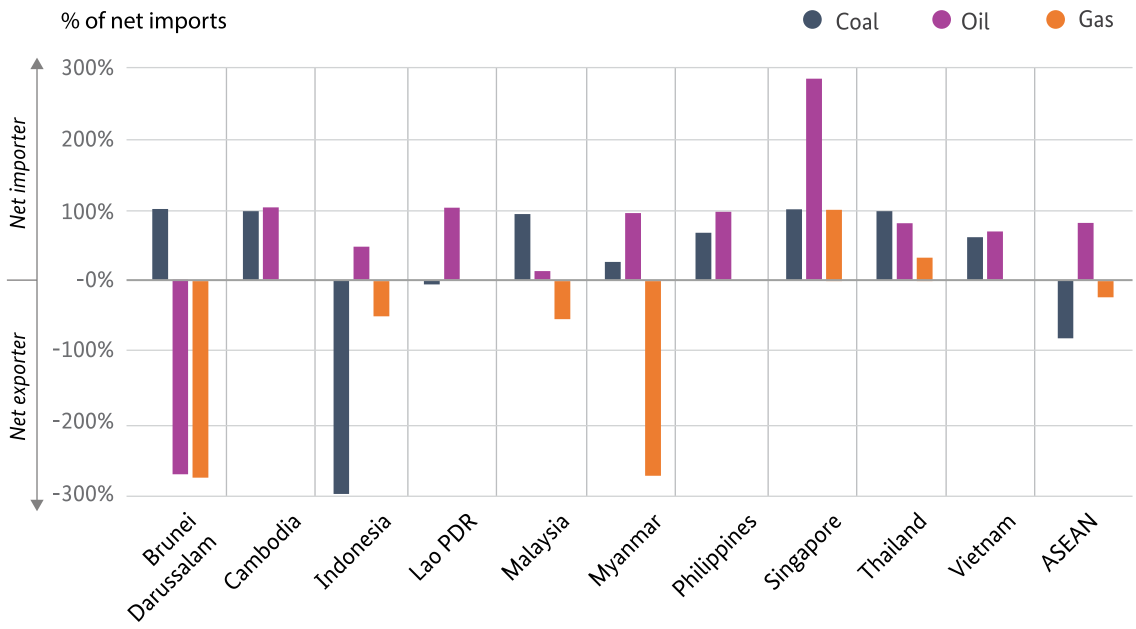

*Source: ACE. All rights reserved. Note: A negative dependency rate indicates a net exporter of energy. Values exceeding 100% indicate an accumulation of stocks. The balance is for the region as a whole; the resources and imports/exports of individual AMS vary significantly.*

The net dependence on fossil fuel imports varies significantly amongst the AMS, as illustrated by Figure 1.8. Brunei Darussalam, which has been heavily exporting oil and gas, was still an exporter of both fuels in 2020, but a net importer of coal. However, the trend from 2005 to 2020 shows the country is moving toward becoming an oil importer. On the other hand, Myanmar is an oil importer and gas exporter, showing a trend toward becoming both an oil and gas importer.

The summary of the fossil fuels import status for each AMS is shown in Figure 1.8. Most AMS are net oil importer, but details might differ between one country to and another. Indonesia, for instance, has a positive value in oil import dependency. However, but, it has a substantial negative value in coal import dependency. This indicates that Indonesia is a net oil importer, whilst but exports exporting a significant amount of coal—one of the largest coal exporters. Meanwhile, Singapore has a positive value in coal and gas import dependency and a significantly positive rate in oil import dependency. This rate indicates that in fuel import activity, Singapore heavily depends on oil, coal, and gas imports. Other than for domestic use, Singapore also consumes crude oil and produces petroleum products through its refinery.

Collectively, the ASEAN region is moving toward more oil importers and gas exporters. Noting this and accentuated by recent trends of increasing oil and gas relative scarcity, it is important for AMS to improve its energy security. Measures such as improving stock reserves should be considered in insolating countries from price shocks or import disruptions.

**Figure 1.8 Fossil Fuels Dependency Rate for Each AMS in 2020**



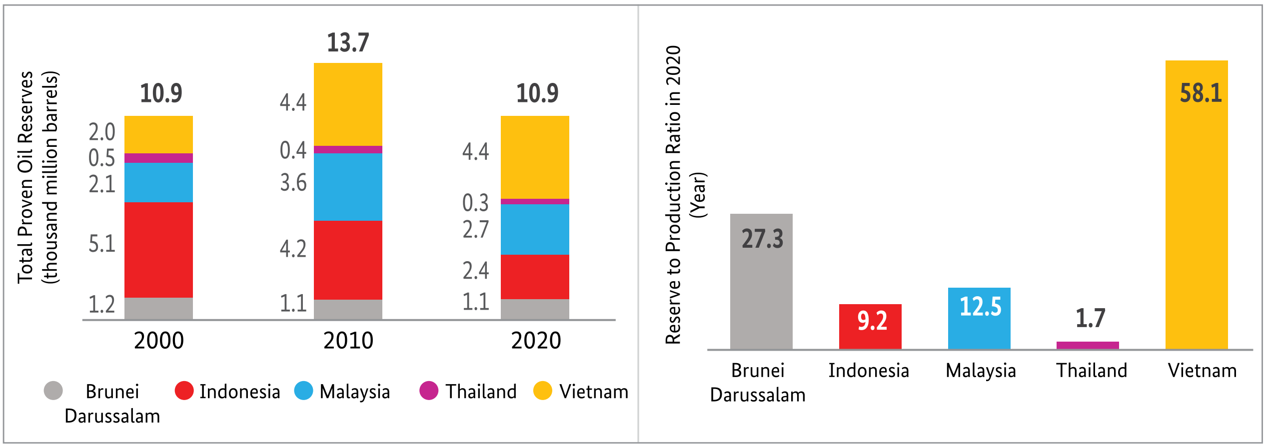

*Source: ACE. All rights reserved. Note: Dependency rate is net energy imports divided by gross available energy, expressed as a percentage. A negative dependency rate indicates a net exporter of energy. Values exceeding 100% indicate an accumulation of stocks.*

Oil reserves in ASEAN had a structural decline of 20% from the 2010 level to 10.9 billion barrels of oil in 2020 (Figure 1.9). No significant additional reserves were identified in that decade due to exploration challenges, especially in deep-water areas. Low oil prices hindered investment in more challenging fields, and unstable political landscapes led to complex business environments.

Vietnam dominated oil reserves in 2020, with an overall stake of 40%, followed by Malaysia with 25% and Indonesia with 22%. However, Vietnam's reservoirs are challenging to exploit as many are located in deep-water areas, so that its reserves have not significantly decreased from 2010 to 2020. As a result, the extensive reserves in Vietnam, coupled with a low oil production rate, results in a longer Reserves-to-Production (R/P) ratio of up to 58.1 years, signalling more investment is required to optimise the exploitation. On the other hand, Malaysia's and Indonesia's reservoirs, with greater production rates, would only last up to 12.5 and 9.2 years, respectively.

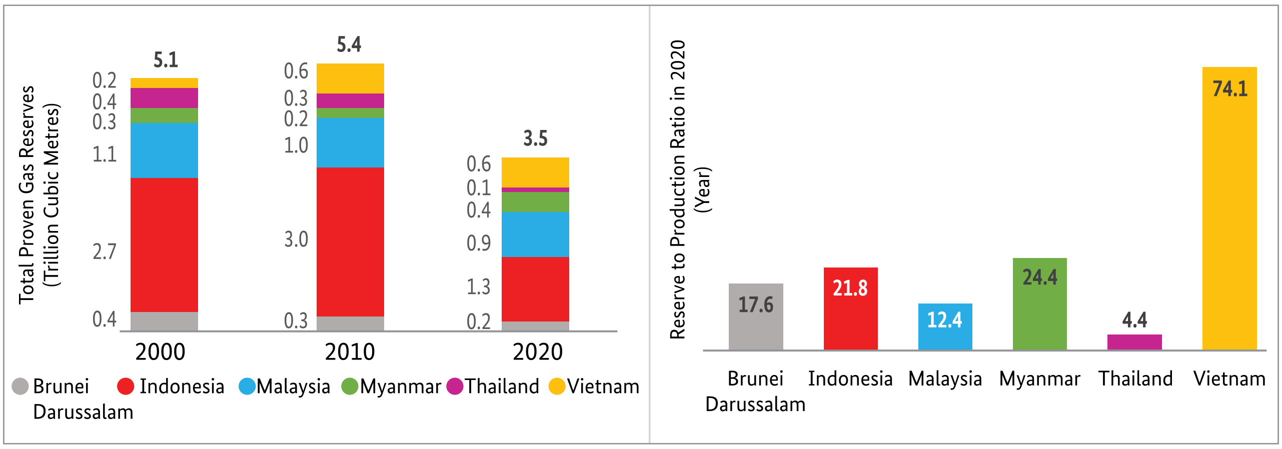
In terms of gas, the ASEAN gas reserves in the period of 2010-2020 have shown a significant decrease of up to 35% (Figure 1.10). The decline is attributed to small new gas field discoveries, low gas prices, lack of gas infrastructure that hinders upstream investment and higher operating costs in high $CO_2$ content gas fields. Indonesia, as one of the prominent gas producers, is the primary contributor to the significant regional reserve decrease. The country's reserves have dropped by 1.7 tcm or 57% in the last ten years. Considering the R/P ratio, even though Vietnam did not have the largest reservoirs, the lower production rate compared to Indonesia and Malaysia means the country's reservoirs could last the longest, up to 74.1 years. Meanwhile, Myanmar, Indonesia, and Brunei Darussalam, as the primary ASEAN gas exporters, are predicted to maintain their gas production for up to 24.4, 21.8, and 17.6 years respectively, assuming output remains at the 2020 level. However, newly discovered oil and gas reserves, such as in Andaman, Indonesia, could attract investment and increase production in the upstream oil and gas industry [4].

**Figure 1.9 AMS' Oil Reserves**




*Source: ACE, 2021* [5].

**Figure 1.10 AMS' Gas Reserves**




*Source: ACE, 2021* [5].

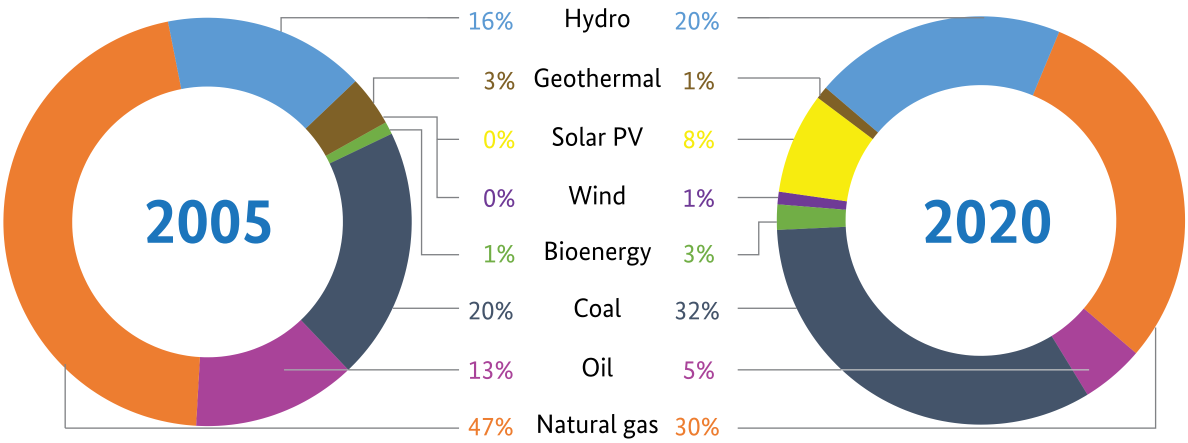
Promoting fuel-switching to bioenergy in the transportation sector would reduce demand for imported oil, thus ensuring energy security. Biofuel achieved its most significant increase in 2020, with 222 times the level in 2005. Several AMS have adopted policies to substitute oil products with biofuels, especially palm oil, including Indonesia, Malaysia, and Thailand. Accelerating biofuel blending mandates up to B30[5] and E30[6] for more potential countries could be a key measure for achieving the regional RE target. Bioenergy could also be utilised in power plants, for instance, using 5% biomass feedstock in the existing coal co-fired plants. However, the production of biofuel feedstocks can harm ecologies, as well as affect environments and food supplies. Thus, extensive research and development (R&D) is needed to leverage the production of high-quality biofuel and reduce its negative effects.

The AMS have implemented policies related to biofuel, in addition to other targets in past years, which have driven a large uptake of renewable energy (RE) and clean technologies. The RE policies include increasing the share of renewables in TFEC, TPES, installed capacity, and power generation. Each AMS has its untapped potential resources. Solar photovoltaic (PV) is the most viable option in Brunei Darussalam and Singapore. Cambodia is just beginning to include solar and wind in its energy mix after the recent development of large hydropower projects. Indonesia, the region's largest energy consumer, also looks to diversify its hydro-based renewable electricity mix.

[5] 30% palm-oil based Methyl-Ester and 70% diesel fuel
[6] 30% Ethanol and 70% Gasoline

Electricity generation facilities in ASEAN are varied and include coal, oil, natural gas, hydro, geothermal, solar PV, wind, and bioenergy (biomass, biogas, waste). The total installed capacity grew by 166.9% during 2005-2020. Solar PV had the most significant increase, gaining from 1 MW in 2005 to 23,058 MW in 15 years, reaching 8% of ASEAN's total installed capacity (Figure 1.11). Until 2018, natural gas was the fuel with the largest share, but coal began to lead. In 2020, installed coal capacity increased more than four times from the 2005 level. At the same time, the declining trend in oil and gas was due to the dwindling reserves in the last few decades. Meanwhile, the total RE share of the ASEAN installed capacity grew from 19.1% in 2005 to 33.3% in 2020.

**Figure 1.11 ASEAN Installed Capacity by Fuel 2005 vs 2020**



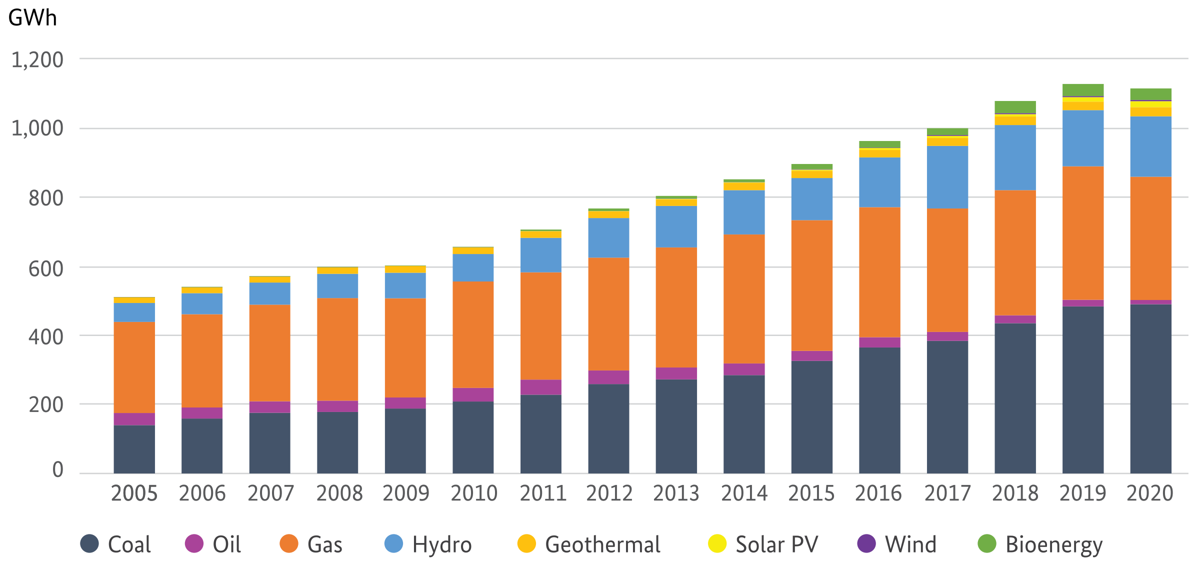

*Source: ACE. All rights reserved. Note: Bioenergy includes biomass, biogas, and waste.*

To support ASEAN's growing electricity demand, the total power generation of AMS steadily increased from approximately 510.4 TWh in 2005 (Figure 1.12). It reached a production record at 1,126.4 TWh in 2019, an era of generation expansion in ASEAN. The contribution of bioenergy significantly accumulated from 19.6 TWh in 2017 to around 41.4 TWh in 2018.

Although the combined fossil fuels share shows a declining trend, they were still the primary energy source in ASEAN. Fossil fuels accounted for about 85.8% and 78.4% of total power generation in 2005 and 2019, respectively. Specifically, coal contributed 42.9% to the generation mix in 2019, followed by natural gas with 33.8%. On the other hand, approximately 21.6% of power was generated by renewable sources in 2019, including hydro (14.4%), bioenergy (3.6%), geothermal (2.2%), solar PV (1.1%), and wind (0.3%) at the same year.

In 2020, ASEAN electricity production declined by 0.1% YoY due to a marked decrease in oil, gas, and bioenergy generation during the Covid-19 pandemic. In contrast, the share of coal expanded, reaching almost 44% of total power generation in 2020. Generation from RE sources also increased to 23.3% in the same year. Solar PV was the primary contributor, displaying the most rapid growth and increasing its stake in the generation mix from 6.9 TWh in 2018 to 17.9 TWh in 2020, a more than two-fold development. These encouraging figures indicate that RE sources have a role to play in ensuring energy security, and can bring about positive impacts on energy generation.

**Figure 1.12 ASEAN Power Generation 2005-2020**

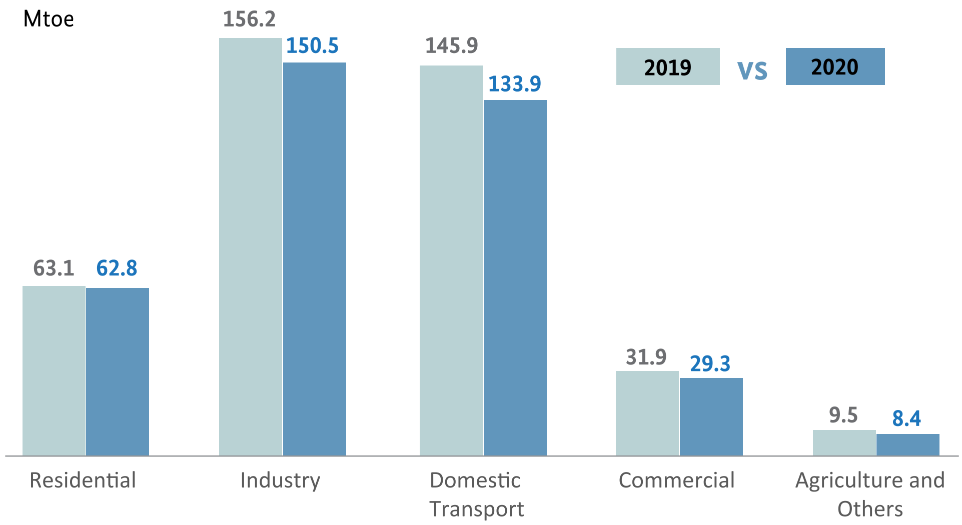



*Note: Bioenergy includes biomass, biogas, and waste. Source: ACE. All rights reserved.*

## 1.3 Energy and the Covid-19 Crisis

The Covid-19 pandemic has profoundly impacted the ASEAN energy sector in many ways. Due to mobility restrictions imposed on AMS during the pandemic, energy consumption in key sectors declined significantly. The lockdown decisions taken by AMS authorities to curb virus transmission disrupted many economic activities, especially in contact-intensive sectors, such as transportation. In addition, lower demand for manufactured goods and the limited supply of labour in factories contributed to sluggish activity in the industrial sector. These sectors are amongst the worst hit during the pandemic (Figure 1.13). Conversely, the residential sector was not greatly impacted by the health crisis.

**Figure 1.13 ASEAN Energy Consumption by Sector in 2019 and 2020**




*Source: ACE. All rights reserved.*

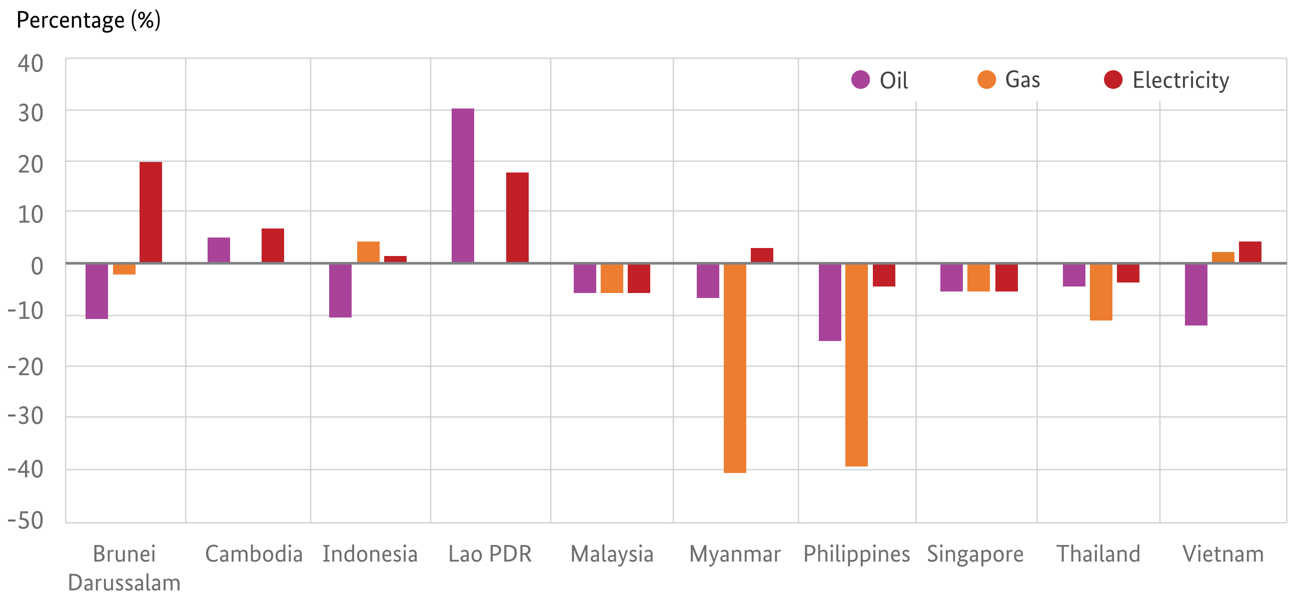
The oil market disruptions were more severe than other energy sources. Mobility restrictions imposed by authorities in AMS countries contributed to this. The transportation sector output in ASEAN dropped by 8.2% in 2020 YoY. Given that the transportation sector contributed approximately 60% to oil demand, lower transportation demand reduced oil consumption significantly, with the Philippines and Vietnam experiencing the largest declines at 15% and 12%, respectively [6]. Due to this reduction, oil demand in ASEAN was the lowest since 2016.

The Covid-19 pandemic negatively impacted the gas market in the region. Gas consumption declined, though not as much as oil consumption. On average, in 2020, gas consumption of ASEAN countries fell by roughly 9.8%, with Myanmar having the greatest decline in gas consumption by -40.8% (Figure 1.14). The pandemic also worsened the region's declining trend in gas production. Gas production in 2020 was lower than in 2010 [6]. The reduction was driven by decreased demand and halted projects in several fields.

Unlike oil and gas, coal consumption in some ASEAN countries recorded positive growth in 2020. Half of the AMS experienced an increase in coal consumption in 2020, as compared to the previous year. Coal consumption annual growth in Lao PDR in 2020 reached around 220%. Whilst coal consumption was relatively resilient during the pandemic, its production experienced disruptions. As one of the world's biggest coal-producing countries, Indonesia experienced a 9% reduction in coal production [6]. This decline exceeded Indonesia's ten-year average growth rate, reaching 9.2%. The disparity between coal consumption and production during the pandemic significantly contributed to a global coal price boom.

Concurrently, electricity demand in Southeast Asia on average increased by 3.5% in 2020. Almost similar to coal, four of ASEAN countries experienced a drop in electricity consumption. In particular, the Philippines and Thailand, representing the larger economies in ASEAN, experienced a downturn in electricity consumption in 2020, with decreases of 4.5% and 3.4%, respectively. In contrast, Brunei Darussalam, Lao PDR, and Vietnam saw increased demand for electricity in 2020, with electricity consumption rising by 19.9%, 17.9%, and 4.2%, respectively.

**Figure 1.14 Fuel Consumption Annual Growth of AMS in 2020**




*Source: ACE. All rights reserved.*

The RE sector showed resilience amidst the pandemic. It is reflected in the contribution of RE sources to the installed capacity of electricity in AMS. Whilst the installed capacity from other sources mostly declined or was stagnant in 2020, RE-based power plants, such as biomass, solar, wind, and geothermal, increased. Several factors contributed to the resilience of RE, such as long-term contracts and the continued installation of new plants. Virtually all countries, except Myanmar, managed to increase the installed capacity from RE sources. Vietnam and Cambodia performed substantially better over the pandemic as RE-sourced growth in installed capacity reached 42.5% and 13.1%, respectively (Table 1.1). The additional installed capacity of RE in Vietnam contributed to the overall installed capacity of the country's electricity sector, which increased by 22.3%. Singapore also recorded high growth in installed capacity of renewables, with 21.2% for solar PV only.

**Table 1.1 Installed Capacity Growth by Energy Sources in 2020 (% Change, YoY)**

| Country | Coal | Oil | Natural Gas | Renewables | Total |
|---|---|---|---|---|---|
| Brunei Darussalam | N/A | 25.0 | 22.1 | 1.3 | 22.1 |
| Cambodia | -4.8 | 144.1 | N/A | 13.1 | 22.4 |
| Indonesia | 5.1 | 1.8 | 7.2 | 3.4 | 5.2 |
| Lao PDR | 0.0 | N/A | N/A | 8.0 | 6.5 |
| Malaysia | 0.0 | -81.8 | 4.5 | 9.8 | 1.9 |
| Myanmar | 0.0 | -0.02 | 32.9 | 0.0 | 13.6 |
| Philippines | 5.1 | -0.6 | 0.0 | 3.4 | 3.0 |
| Singapore | N/A | -44.0 | 0.0 | 10.9 | -4.3 |
| Thailand | 0.0 | 0.0 | 1.5 | 0.7 | 1.1 |
| Vietnam | 6.4 | 8.0 | -4.4 | 42.5 | 22.3 |

*Source: ACE. All rights reserved. Renewables includes Hydro, Geothermal, Solar PV, Wind, Bioenergy.*

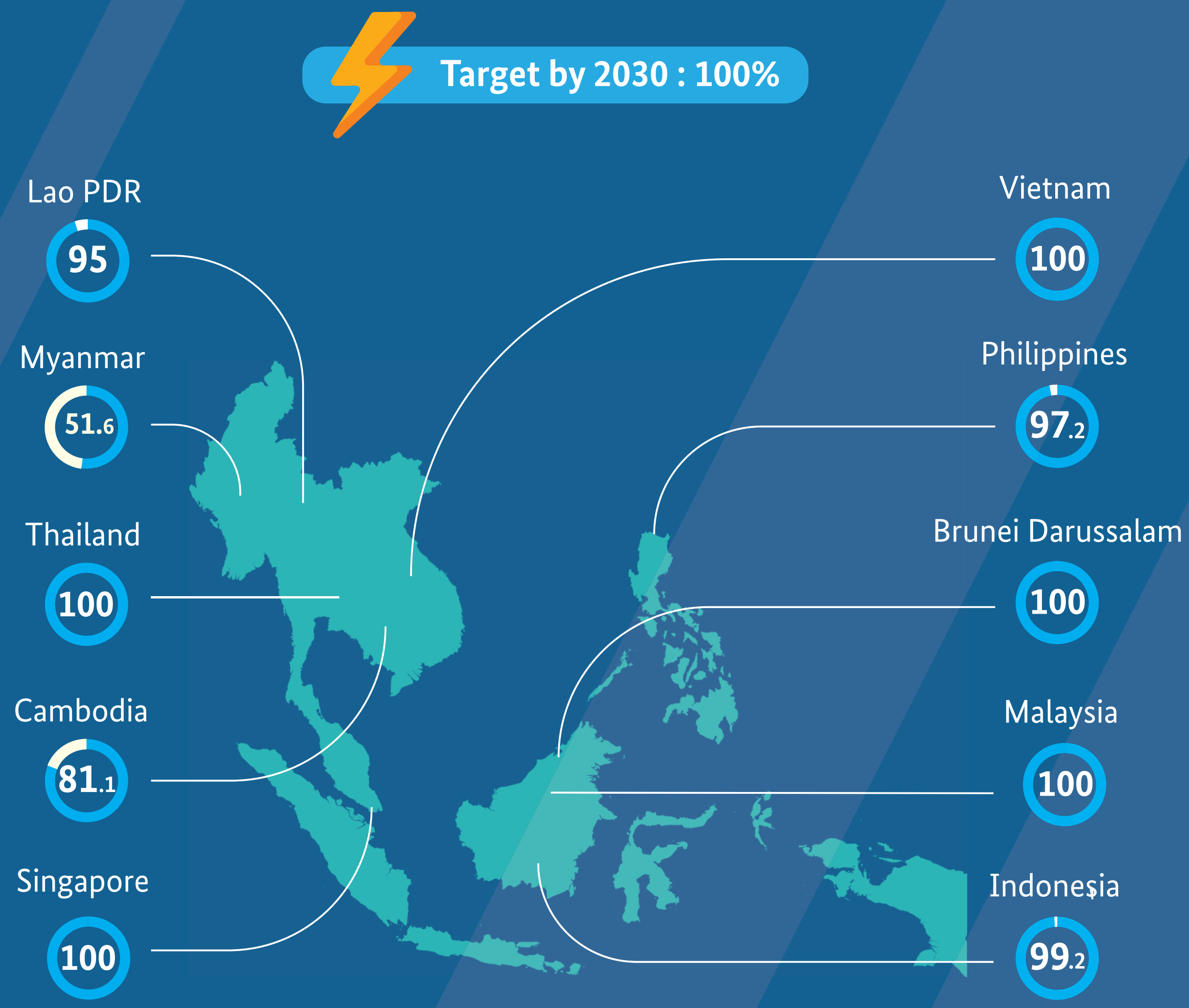
## 1.4 Providing Inclusive Energy for All

ASEAN requires significant effort to fulfil inclusive energy accessibility. The political will has been expressed at the 39th ASEAN Ministers of Energy Meeting (AMEM) by means of its Joint Ministerial Statement to encourage and initiate more programmes and projects for inclusive energy for all [7].

*"The Joint Declaration, which serves as Brunei Darussalam's 2021 Priority Economic Deliverable (PED) on energy, called for concrete actions to develop robust policies and measures, and to strengthen national, bilateral and multilateral energy programmes and projects that enhance energy resilience and improve energy security, in all of its aspects in the region, which form the foundation of an inclusive and just energy transition, in achieving access to affordable, reliable, sustainable, and modern energy for all."*

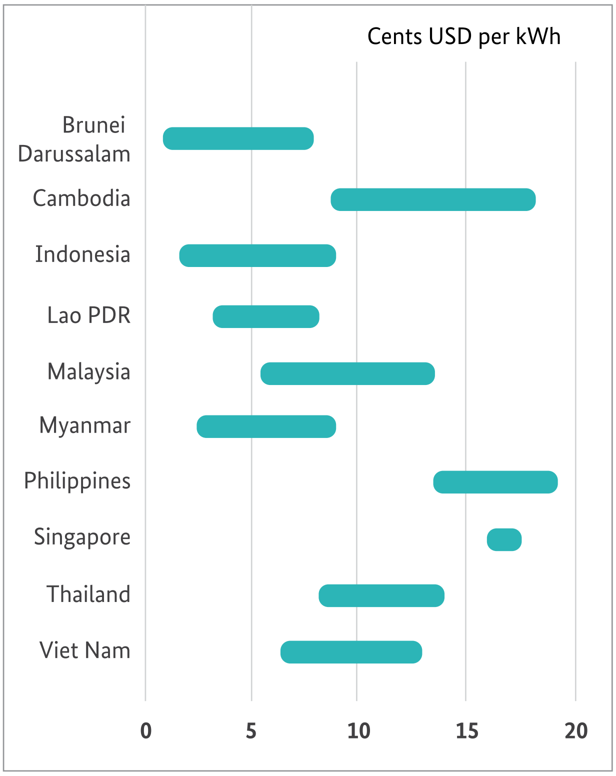
Despite ASEAN's ambition, the targets for universal access to modern energy under the Sustainable Development Goal (SDG) 7, entitled "Affordable and Clean Energy", are yet to be achieved for several AMS. The accessibility target is derived from two indicators: the proportion of the population with access to electricity and the proportion relying primarily on clean fuels and technology for cooking. As of 2020, an estimated 8 million ASEAN households still lacked electricity, and 200 million people did not use clean cooking methods.

**Figure 1.15 Electrification Rate of AMS (% of Households)**



In terms of electricity, Cambodia, Indonesia, Lao PDR, Myanmar, and the Philippines were the five economies yet to provide 100% electrification (Figure 1.15). Indonesia, which previously targeted a full penetration by 2020, narrowly missed the target at 99.2% (of households) and readjusted its plan to reach the 100% rate in 2022 [8]. The remaining numbers are comprised of last-mile communities that are not connected to the electrical supply, whether to the grid or off-grid. Meanwhile, Myanmar has achieved roughly half of the population. Closing these vast gaps between Myanmar and the rest of the AMS is the priority to achieve this target together. In addition, the parameters for access to energy should not only account for physical connection but should also address quality, affordability, and sustainability.

**Figure 1.16 Comparison of Electricity Tariffs for Households Pre-Covid-19 in ASEAN**




*Source: ACE, 2020* [9].

Electricity tariff rates varied across the AMS, based on production cost, tariff components and variables, and available subsidies. Figure 1.16 summarises the range of tariffs applied in each AMS prior to Covid-19 [9], [10]. The Philippines and Cambodia have the highest rates amongst the ten AMS, though many households have not fully been electrified. During the pandemic, disrupted power generation led to increasing electricity tariffs. Respective AMS authorities instituted various short-term supports for end-users, primarily residential, in the form of exemptions, deductions, adjustments, extensions, and refunds. In addition, there are possible price hikes globally due to the war in Ukraine. In addressing affordability issues, collective efforts could provide opportunities to control the current energy price. Continuously declining renewable costs may promote electrification in off-grid areas at an affordable price [10].

Compared to the electrification rate, clean cooking access target gaps are considerable. As of 2020, approximately 30% of the total ASEAN population still relied on traditional biomass (e.g., wood, tree leaves, crop wastes, charcoal) or kerosene as primary cooking fuel. It will require more effort to achieve 100% penetration by 2030.

Clean cooking accessibility is unevenly distributed across the ASEAN region. There is a significant gap between the country with the lowest rate (Lao PDR)[7] and countries with 100% clean cooking access, such as Brunei Darussalam and Singapore. In addition to Lao PDR, several other AMS still have access levels below 50%, including Myanmar, Cambodia, and the Philippines. Clean cooking is not yet a priority for some governments, as limited national targets exist. In some cases, clean cooking does not fall under the purview of a specific ministry.

Clean cooking access across ASEAN has progressed over the preceding decade, with significant improvements made by several AMS. For example, Indonesia increased its clean cooking access rate by 43% in 2020, up from the 2010 level by means of an extensive kerosene-to-LPG switching programme. Over the same period, Cambodia and Myanmar have doubled their clean cooking accessibility, but the proportions remained low.

[7] Data retrieved from WHO Household air pollution data https://www.who.int/data/gho/data/themes/air-pollution/household-air-pollution

In terms of gender inclusivity, meaningful participation of women in energy generally remains underexplored. The ASEAN Gender Outlook found that women reap little benefit from their underemployment in the energy sector, but they tend to be hit harder by fossil fuel pollution [11]. Energy transition efforts offer an advantageous momentum to realise women's potential in its development. Optimisation of women's roles and opportunities in the renewable energy sector would be beneficial to the just and inclusive energy transition. Yet, the regional efforts are constrained, as shown by the limited number of renewable energy policies that are directly tied to gender mainstreaming efforts.

Overall, inclusive energy is not just a matter of "leaving no one behind" but necessitates plans to provide a non-disruptive transition to all impacted sector. Carefully designed energy policies should consider the energy transition impacts on cross-cutting issues, such as land-use changes and eliminating local livelihoods caused by renewable-based power plant installations. Thus, having stakeholder engagement is the key to avoid unjust circumstances arising when the economies of energy shift to a more conscientious sustainability. By having this engagement, government may also avoid abrupt policy transformations in their regulatory frameworks by formulating a holistic approach, that may cause economic dislocations. Impetuous transitions may have a domino effect on energy and commodity prices, thus amplifying regional social issues.

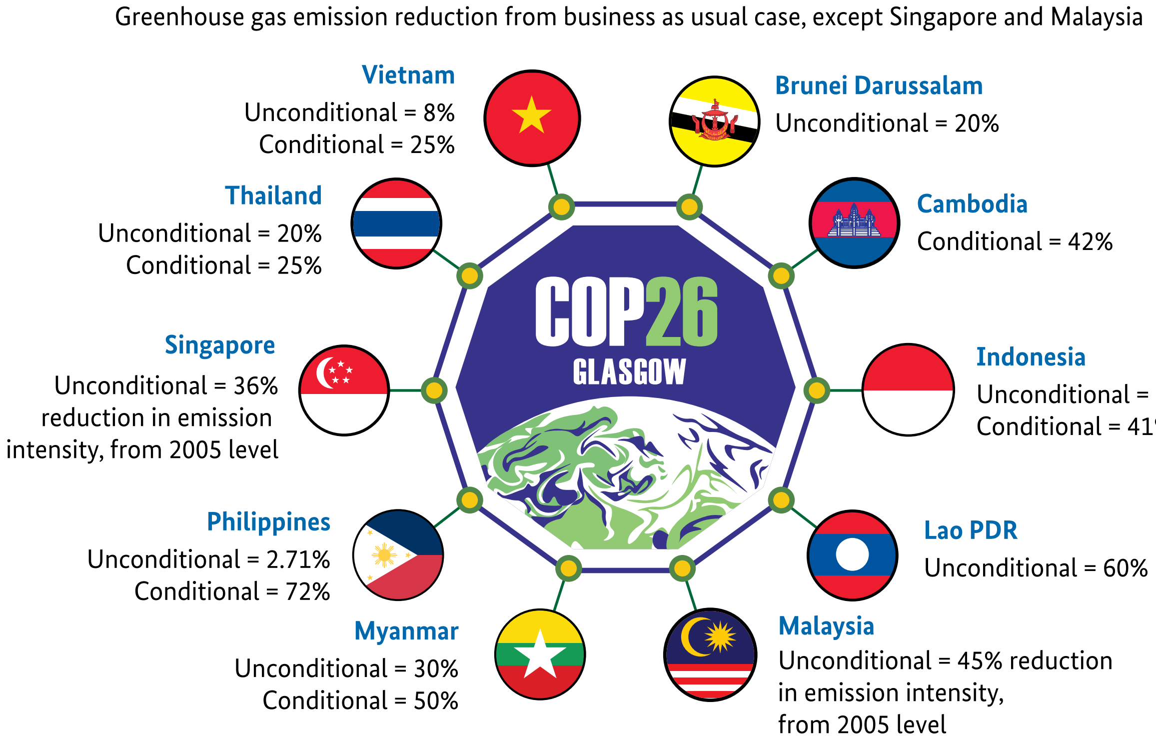
## 1.5 Achieving Environmental Sustainability

ASEAN's rapid population growth and emerging economies come with a trade-off on the environmental element of the energy trilemma. Amongst them are air pollution and greenhouse gas (GHG) emission levels. The combustion of fossil fuels drives worsening air pollution in the region [12]. Amongst many key pollutant indicators, particulate matters, measuring 2.5 microns or less in diameter (PM2.5), present the greatest health threat as they may be absorbed into the bloodstream through inhalation. The source of PM2.5 pollutants are derived from, amongst other sources, combustion in power plants, on-road transportation, industrial processes, and stoves, which makes this indicator relevant to energy development.

Noting that the new guideline level were cut by half from 10 $\mu g/m^3$ to 5 $\mu g/m^3$, AMS cities with PM2.5 levels are ranging from 5.7 $\mu g/m^3$ in Bengawan, Malaysia (least polluted city), to 52.2 $\mu g/m^3$ in Lampang, Thailand (the most polluted city). The Covid-19 pandemic and large-scale mobility restrictions have reduced the regional PM2.5 levels by 5% between 2020 and 2021 led by Malaysia (24%), the Philippines (22%), and Singapore (17%). However, sustaining the decrease will be a major challenge during and after the economic recovery.

Transitioning to cleaner energy remains a priority, as all AMS are signatories to the Paris Agreement and have updated their Nationally Determined Contributions (NDCs) during 2020 and 2021, to emphasise fairness and common but differentiated responsibilities. Figure 1.17 summarises the latest AMS' commitment to reducing GHG emissions as stated in their updated NDCs. In the updated NDCs, all of the AMS addressed $CO_2$ emissions, and only Myanmar did not include methane. Malaysia removed the conditional element, whilst both Myanmar and the Philippines upgraded their NDCs to add unconditional targets.

**Figure 1.17 AMS Emission Reduction Commitment**




*Source: AMS NDC. Note: "Unconditional" refers to implementation targets set by countries based on their own resources and capabilities, whilst "conditional" refers to targets that countries would undertake if international means of support are provided. Conditional targets are higher than unconditional.*

Despite most of the AMS naming the energy sector as the key target to curb GHG emissions, the commitment remains below the necessary levels to address the global 2-degree trajectory. ASEAN will likely fall short of targets, even if the conditional reduction commitments are met [13]. Being a region with high economic growth and low contribution to global emissions, ASEAN faces challenges in setting up more ambitious actions to mitigate the climate threat. However, almost all Member States have pledged net-zero or carbon neutrality (Table 1.2), strengthening the importance of energy transition orientation beyond low-carbon technology and offsetting the current business-as-usual (BAU) bias. The two terms represent similar concepts with different scope of commitment embodying the interests of each AMS. Net-zero embodies a commitment to reducing GHG emissions with the goal of balancing between emissions produced and removed in the overall emission balance, whilste carbon neutral refers to a more concentrated concept of emissions being equally offset [14].

In addition, half of the Member States have pledged to phase out coal, the most emissions-intensive fuel, through the global coal-to-clean power transition statement in the 2021 United Nations Climate Change Conference of Parties (COP26) [15]. The pledge was endorsed by several AMS, including Brunei Darussalam, Indonesia, the Philippines, Singapore, and Vietnam, accounting for roughly 76% of the ASEAN installed coal capacity in 2020. Indonesia and the Philippines did not adopt all clauses of the coal pledge. Nevertheless, the phase-out-coal pledge by the five noted AMS is evidence of their strong commitment, given the region is not a major emitter of GHGs, yet bears the worsening impacts of climate change despite the increased supply of coal in the last decade.

**Table 1.2 Official Emission Targets Within the AMS**

| Country | Official Emissions Target |
|---|---|
| Brunei Darusalam | • Reduce GHG emissions by at least 10% through better supply and demand management of electricity consumption by 2035<br>• Reach net zero emissions by 2050 |
| Cambodia | • Reduce GHG emissions by 42% or 64.5 Mt $CO_2$-eq by 2030 from the BAU level<br>• Reach carbon neutral by 2050 |
| Indonesia | • Reduce GHG emissions by 29% by 2030 from the BAU level<br>• Reach net zero emissions by 2060 or sooner |
| Lao PDR | • 60% GHG emission reductions compared to the Baseline Scenario, or around 62,000 kt $CO_2$-eq in absolute terms<br>• Reach net zero emissions by 2050 conditionally |
| Malaysia | • Reduce economy-wide carbon intensity (against GDP) by 45% in 2030 compared to the 2005 level<br>• Reach carbon neutral by 2050 |
| Myanmar | • Reduce emissions by 244.52 Mt $CO_2$-eq<br>• Reach carbon neutral by 2050 |
| Philippines | • Reduce and avoid GHG emissions by 75% (or 3,340.3 Mt $CO_2$-eq) from BAU, of which 2.71% is unconditional and 72.29% is conditional |
| Singapore | • Achieve peak emissions at 65 Mt $CO_2$-eq around 2030<br>• Reach net zero emissions by or around mid-century |
| Thailand | • Reduce GHG emissions by 20% by 2030 from BAU, of which 117.6 Mt $CO_2$-eq from the energy sector<br>• Target carbon neutrality by 2050 and net zero emissions by 2065 |
| Vietnam | • Reduce GHG emissions by 8% unconditional by 2030, compared to the BAU scenario<br>• Reach net zero emissions by 2050 |

*Source: Multiple official documents.*

## 1.6 The Role of Regional Cooperation and the Outlook in Addressing Energy Challenges

Amidst the challenges, the AMS continue to push forward with regional cooperation by means of its ASEAN Plan of Action for Energy Cooperation (APAEC). Serving as the regional energy cooperation blueprint and in line with the goals of the ASEAN Economic Community, the latest iteration of the plan is the APAEC 2016-2025 Phase II 2021-2025. Endorsed by the 38th AMEM in 2020, it retains the theme of "Enhancing Energy Connectivity and Market Integration in ASEAN to Achieve Energy Security, Accessibility, Affordability and Sustainability for All". It adds a sub-theme of "Accelerating Energy Transition and Strengthening Energy Resilience through Greater Innovation and Cooperation" [16].

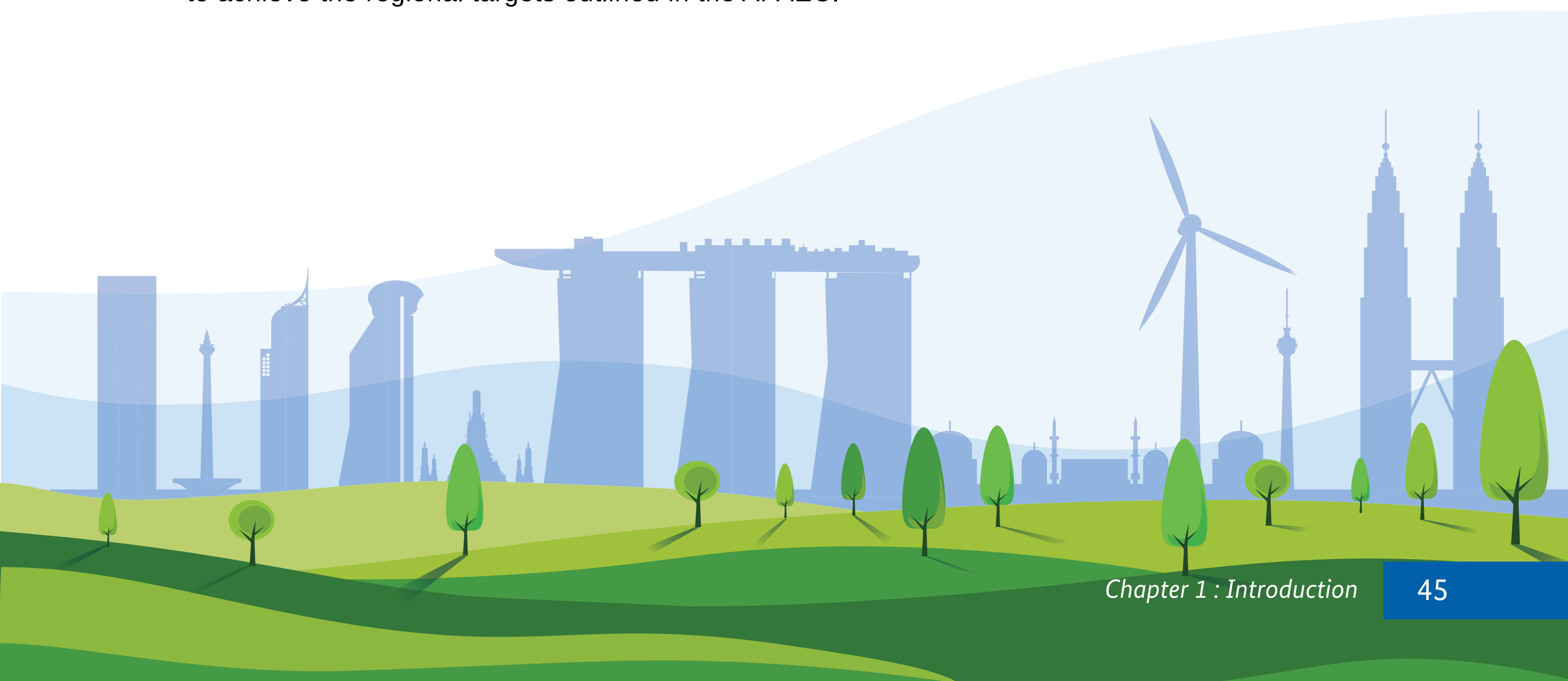
As stated in the APAEC theme, the AMS recognise the importance of regional cooperation in ensuring energy security, accessibility, affordability and sustainability at both the national and regional levels. It becomes even more crucial with the global trend of energy transition and the need to ensure energy resiliency, especially amidst the various shocks due to the Covid-19 pandemic, the subsequent recovery, and other geopolitical events. Realising this, Cambodia set the theme of "ASEAN A.C.T.: Addressing Challenges Together" for its ASEAN Chairmanship in 2022 [17]. In the energy sector, the 7th ASEAN Energy Outlook (AEO7) publication is one of Cambodia's priority deliverables in 2022.

ASEAN is pursuing energy cooperation through the seven programme areas of APAEC, with the 2025 aspirational targets of reaching 23% of renewable energy in the primary energy supply and 35% in installed capacity, as well as 32% energy intensity reduction based on 2005 level. Cooperation is promoted through knowledge sharing and capacity building, regional policy development, and joint activities. These include roadmaps on lighting standards and sustainable buildings [18] and cooling [19], RE-Gender [20], and long-term RE. In addition, it is also essential to develop the ASEAN Power Grid (APG) and regional common gas market, as well as key studies such as the ASEAN Interconnection Masterplan Study (AIMS) III.

Energy connectivity in the region recently received a boost from the successful multilateral power trade between Lao PDR and Singapore, via Thailand and Malaysia.  An expansion of the Lao PDR-Malaysia power trade, the Lao PDR-Thailand-Malaysia-Singapore Power Integration Project (LTMS-PIP) is the flagship project of the APG, an aspirational vision of an interconnected regional power grid. LTMS-PIP, the first multilateral cross-border electric trade involving four AMS, is transmitting up to 100 MW of hydropower-based electricity from Lao PDR to Singapore via Thailand and Malaysia. With LTMS-PIP as a pathfinder project, the APG could optimise the region's renewable energy sources and improve energy security and stability.

Multilateral energy cooperation and integration is a complex issue. It is essential to have unified goals and pursue them through unified actions. When successfully completed, the project will expand trade amongst AMS and improve the region's energy security, access and affordability. Together, the AMS can accelerate the transition to clean energy to ensure a more sustainable future. These considerations have already led the ten member nations to work together, putting forward commitments for cleaner energy development, and translating many national-level targets (including NDCs) into common regional goals.

Since 2006, the AEO has become one of the most important documents to support ASEAN energy policy and planning. It is guided by APAEC Phase II 2021-2025, under the Regional Energy Policy and Planning (REPP) programme area. Action Plan 1.2 stated, "Publish regular regional energy outlooks and strategic reports on the thematic issue". Over the past several years, the primary objective has remained the same: to support the creation of pathways for achieving regional targets. Concurrently, the roles of ACE and AMS as drivers of the AEO continue to be strengthened. In both the 5th ASEAN Energy Outlook (AEO5) and the 6th ASEAN Energy Outlook (AEO6), published in 2017 and 2020, respectively, the energy policies and targets of the ten Member States were used to drive the AMS National Target Scenario (ATS). Durable collaboration within the AMS is the key factor. Such collaboration is extended to the development of the APAEC Regional Target Scenario (APS), noting the inputs from the Member States on strategies to achieve the regional targets outlined in the APAEC.

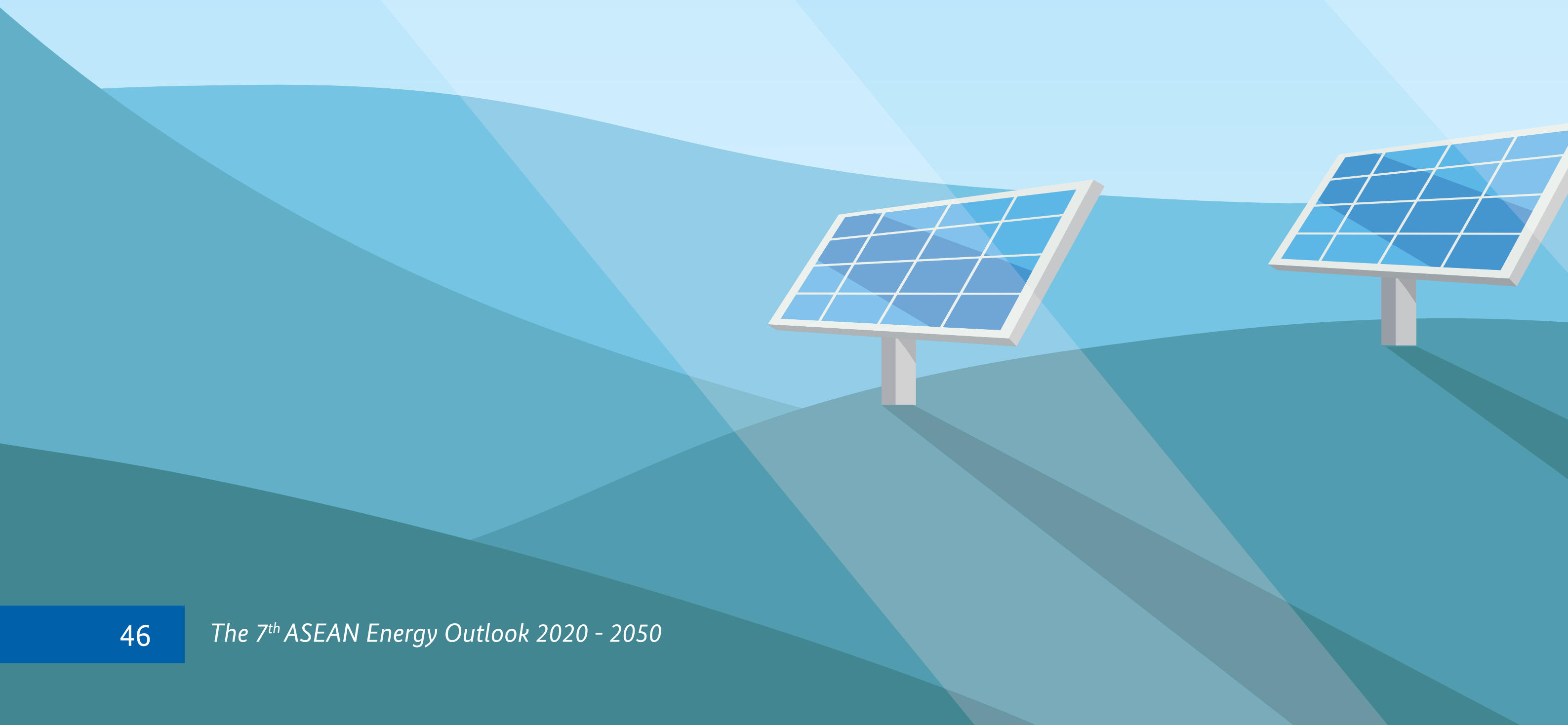


This edition, AEO7, expands the bottom-up approach to energy demand in all sectors. Previously, in AEO6, the bottom-up approach was used in the transportation and residential sectors. In spite of data limitations, AEO7 disaggregates the commercial and industrial sectors for a better understanding of demand, including projections and target-achieving strategies. This approach allows each national model within AEO7 to be adjusted based on the country's characteristics. The strong involvement of Member States in developing AEO7 provides a better understanding of the energy trends and challenges the region faces in the coming decades.

The model distinguishes AEO7 from other energy outlooks. It is developed based on solid cooperation, coordination, interaction and integration between ACE and the officially appointed experts (statisticians, outlook experts, and policymakers) from the ten Member States. Thus, the projections reflect the countries' official expectations for future energy development, creating a greater sense of ownership and understanding. Coupled with the strong involvement of experts from the Member States, this increases the likelihood of further utilisation of both the processes and results for the future needs of the countries and the overall region.

AEO is expected to be the primary source of energy information, analyses and projections in the region, providing profound and cohesive insights into the trends in energy supply and consumption at both the regional and national levels, nothing impacts on socio-economic development and the environment; and efforts to enhance energy connectivity and market integration in the region to achieve energy security, accessibility, affordability and sustainability for all.

The Outlook is divided into four broad chapters that follow this introduction. Chapter 2 presents the scenarios under alternative targets and techno-economic assumptions. Chapter 3 examines the modelling results of all scenarios, especially in achieving the regional targets, showing side-by-side comparisons amongst scenarios. Chapter 4 provides specific thematic insights on relevant topics to ASEAN. Finally, Chapter 5 highlights policy recommendations.



# CHAPTER 2
# METHODOLOGY

# CHAPTER 2
# METHODOLOGY

## 2.1 Scenario Overview

AEO7 lays out ASEAN energy prospects by examining four scenarios from 2021 to 2050, using historical data from 2005 to 2020. Similar to the previous AEOs, AEO7 explores the Baseline Scenario, the AMS Target Scenario (ATS) for national targets, and the APAEC Target Scenario (APS) for regional targets. New to this edition is the Least-Cost Optimisation (LCO) scenario, which is introduced as the fourth scenario.

Each scenario assumes different sets of energy targets and policies, with a gradual increase in the level of effort put forth, to predict the impacts on energy consumption, supply, electricity generation, access, $CO_2$ emissions, and other cross-cutting issues.

**Baseline Scenario**

This scenario follows the historical trend of AMS energy systems. It assumes a BAU level of effort put forth by each AMS, without any modelling interventions to meet existing national RE/EE targets. Hence, it also excludes firm plant capacity additions from power development plans (PDP).

**AMS Targets Scenario (ATS)**

This scenario ensures attainment of official national policies, especially for energy efficiency (EE) and renewable energy (RE) targets. Includes PDP installation targets and firmed capacity additions, and provides modelling interventions to meet energy-related targets under the various countries' Nationally Determined Contributions (NDCs).

**APAEC Targets Scenario (APS)**

This scenario seeks to bridge the gap between national and regional targets outlined in APAEC 2016-2025 by escalating national energy intensity reduction and RE targets, and/or setting new target for Members States that could potentially adopt specific policies.

**Least-Cost Optimisation (LCO) Scenario**

This scenario explores the least-cost dispatch in the power sector to meet the regional target throughout the entire modelling period with a technology-neutral approach that considers all viable technologies in the region.

**Table 2.1 Summary of AEO7 Energy Scenarios and Key Assumptions**

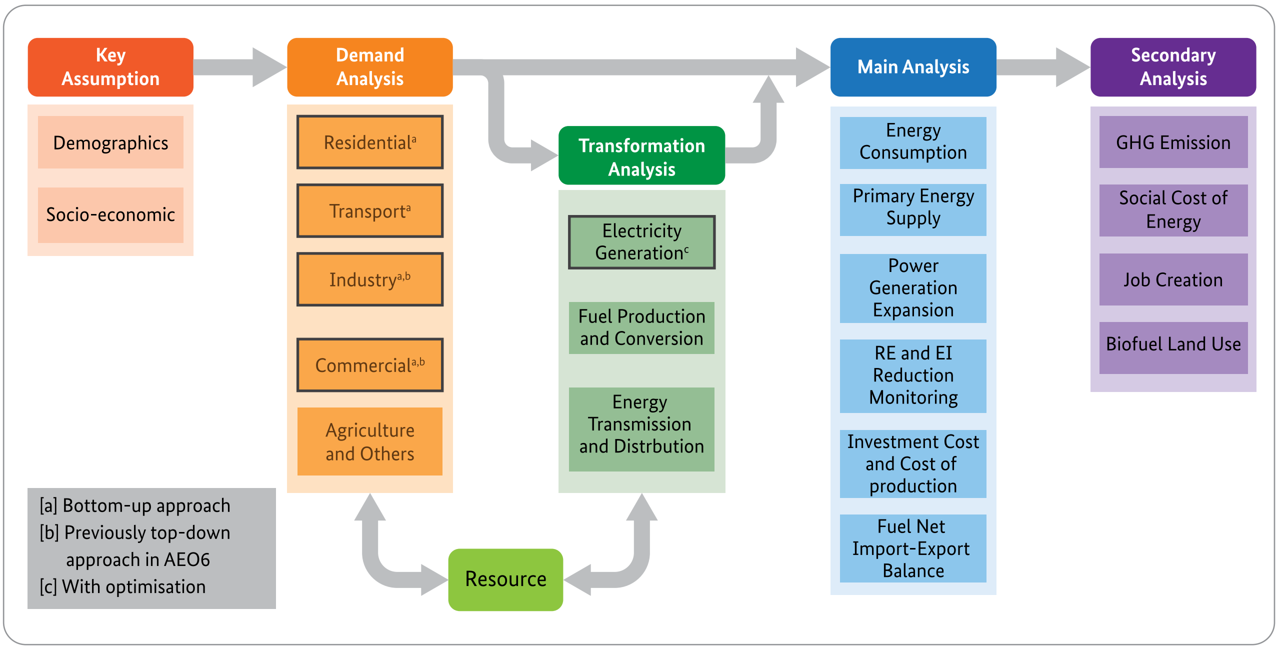
| Scenario | Energy Efficiency | Renewable Energy | Power Generation Capacity | Energy Targets and Measures in NDCs |
|---|---|---|---|---|
| Baseline | Keep constant at the level of last historical year | The growth rate kept based on the last historical year | No installed capacities from ASEAN Power Development Plan (PDP) | Not considered in the modelling |
| AMS Targets Scenario (ATS) | Based on individual Member States' targets | Based on individual Member States' targets | Consistent with PDP, prioritising renewable energy when adding new capacity | Energy-related items in NDCs, including EE, RE and energy access targets |
| APAEC Targets Scenario (APS) | Raise individual Member States' targets to meet the regional target | Raise individual Member States' targets to meet the regional target | Included PDP at minimum but accelerated deployment of RE capacity based on each country's potential | Energy-related items in NDCs, including EE, RE and energy access targets, but scaled up where possible |
| LCO | Same deployments of EE&C strategies with APS to meet the regional target | The power system was optimised to determine the least cost dispatch that allows attainment of national and regional RE targets | The PDP capacity additions are included but model is allowed to build additional plants, and select the dispatch that constitutes the least-cost | Limited to APS demand-side interventions which may include scaled-up NDC, EE, and energy access targets |

## 2.2 Modelling Technique and Data Standardisation

### 2.2.1 Modelling Technique

The AEO model is structured to consider resource use and conversion flow in the Energy Balance Table (EBT), since most of the historical input from previous years is derived from the EBT. Figure 2.1 summarises the AEO model structure. AEO7 used Low Emissions Analysis Platform (LEAP) software, a scenario-based demand-driven modelling tool that can track energy consumption, production and resource extraction in all sectors of an economy.

**Figure 2.1 AEO7 Modelling Structure and Analysis**




### *Demand side*

Demand-side modelling explores five foundational sectors – Residential, Transportation, Industrial, Commercial, and Others (including agriculture and non-energy use). Transformation or supply-side modelling explores both electricity generation and non-power processes such as oil and gas production, refining, distribution, coal mining, biofuel production, and charcoal production. Overall fuel requirements are estimated in the resource module, which considers fuel reserves (coal, oil, and gas) and annual RE potential (hydropower, geothermal, solar, wind, and biomass).

AOE6 relied on a hybrid methodology that combined “top-down” and “bottom-up” approaches to estimate changes in energy demand from different end-use sectors in ASEAN economies. However, in AEO7, the bottom-up approach is extended not only to the residential and transportation but also to the industrial and commercial sectors

The top-down approach projects energy demand using historical growth and econometric projections of each demand sector. In contrast, the bottom-up approach calculates energy demand by disaggregating it according to activity level or technology transition, including energy intensity/efficiency and fuel share.

The bottom-up approach is preferred on the demand side, as it can model energy policies, such as the shift to clean-cooking technologies and efficient appliances, energy savings in specific sub-sectors, deployment of electric vehicles (EVs), and biofuel mandates. This allows changes in electricity demand to be determined as an input to electricity sector modelling and fossil fuel demand as an input to non-power process modelling. Detailed discussion on the sectoral bottom-up approach is presented in D.2 Demand Sector Modelling.

***Transformation side***

In terms of power modelling, the sum of the resulting electricity demand and import/export targets are fed to the electricity module to determine capacity expansion and generation per power plant type. The results are constrained by technical parameters, including process efficiency, planning reserve margin, maximum availability, and capacity credit, to model the actual utilisation and historical builds of power plants in the region.

The **maximum availability** of a process is the ratio of the maximum energy produced to what would have been produced if the process ran at full capacity for a given period, expressed as a percentage. Maximum availability is normally defined by planned and forced outages. All scenarios considered the maximum value reached based on historical data to limit the dispatch of available technologies. However, an improved approach was made in AEO7 to account for the intermittency of solar and wind resources. This outlook considered some geographical parameters, such as irradiance (for solar) and wind speed (for wind power), to determine the variation of its resource availability throughout each hour in a year. This specific behaviour is deemed necessary in the modelling process, particularly in assessing battery requirements and operation in the region.

In the AEO7 model, the **capacity credit** used for countries has been estimated to reach the planning reserve margin indicated in their PDP. In case it was not available in any submitted reports and policy documents, the value was taken from the AIMS III.

In addition, **cost constraints** are incorporated, including capital cost, fixed and variable operational and maintenance cost, and fuel cost, to determine the investment and expense of deployment for specific plants.

Electricity generation modelling follows two approaches: Simulation and Optimisation. Baseline Scenario, ATS and APS use the **simulation approach** that forecast the power sector capacity expansion and dispatch based on historical behaviour of consumers. As it meets the electricity demand based on past trends, the resulting plant additions and utilisation, it does not necessarily result to least-cost options for the power system. However, the advantage of this approach is that it could possibly capture real-life considerations for electricity dispatch that is beyond costs, yielding a more realistic power mix.

**The optimisation approach**, used in the LCO Scenario, meets the electricity demand ensuring a minimized overall cost. Unlike the simulation approach, the advantage of this approach includes responsiveness to cost trends. It could therefore better evaluate uptake of some technologies, especially in the long-term forecasting where cost reduction due to technology deployment is possible. None of the two approaches is better than the other, hence both are explored in this current AEO edition to have a better view of ASEAN's multiple energy futures. Cost parameters and optimization approach are discussed in more detail in Section 2.3.4 Least-Cost Optimisation Scenario.

The Fuel Production and Conversion determines energy balance around extraction of primary fuel (e.g., coal, crude oil, natural gas, biomass) to its conversion into secondary fuels (e.g., gasoline, diesel, biofuel) considering import/export targets. This is done via modelling transformation by specifying feedstock and process efficiency of product conversion (e.g., petroleum products, LNG, biodiesel). Transformation processes includes oil refining, charcoal production, gas production, processing and distribution, coal mining, and biofuel production.

### 2.2.2 Data Standardisation

Several essential components need to be acknowledged in the energy data processing. The official data source has different sets of formats and definitions. It is a dynamic database, meaning it is continually revised with updated policies, reference sources and methodologies. In AEO7, energy data submissions are standardised. Bottom-up modelling presents a challenge as it requires a sophisticated and extensive dataset. This approach necessarily has limited sources that provide detailed disaggregation data and relies on the assumption of data standardisation.

Data processing and data standardisation are inseparable in energy modelling. Data collection is also one of the crucial aspects of the modelling flow. Some aspects of **data collection** for AEO are:

- Response from the data owner, which can be related to political issues, or difficulties related to ministries providing the data;
- Confidentiality, given that not all data is open to the public, or requires strict controls;
- Data is generally received at the aggregate level, and thus intensive consultation is required to retrieve detailed data;
- Data validity and reliability, the importance of checking for data transparency and consistency based on the eclectic sources providing the information;
- Maintaining incomplete or outlier data, since annual data collection may have gaps that can be filled using certain assumptions about the missing information.

The EBT format for all AMS is standardised within LEAP, which is most closely aligned with the contained energy method. The work is performed using one model containing ten national datasets. The primary process of data standardisation is to balance data output calculations in the EBT standard version for all AMS. The validation steps should be clearly defined for each energy process. The process of data checking based on findings from AMS EBT are:

- Total supply (TPES) should not be higher than total demand (TFEC);
- Total transformation should have a negative value;
- Check for significant gaps in power output between EBT and power statistics;
- Check the average efficiency of non-combustible RE power (solar, wind, hydro, geothermal), where primary energy input must equal the electricity output;
- Standardise primary energy supply using the average efficiency.

With regard to outlier data, intensive checks and cleaning are crucial to maintaining quality. Developing models and analysing results necessitate that countries decide which energy data sources they wish to include. This presents a significant challenge, but having comprehensive, comparable, and timely energy data will significantly improve insights into the energy outlook and contribute to achieving evidence-based energy policy decisions.

## 2.3 Projection Modelling

### 2.3.1 Baseline Scenario

The Baseline Scenario considers historical trends and excludes any policy interventions, such as RE and EI/EE policies, as well as PDP. Population and economic growth have been the primary drivers of the increase in sectoral energy demand.

In the residential sector, the efficiency of technologies (cooking, lighting, appliances) is taken as a constant with the latest available data, assuming negligible improvements in efficiency technologies in the absence of EE&C policies. However, access to clean cooking and electrification is assumed to increase following the average annual growth from 2005-2020 for each country.

The share and energy intensity of sub-sectors within the industrial sector is held constant with the latest available data. However, production growth (iron steel, pulp paper, chemicals, non-metallic minerals, textiles and leather) and value-added products (food, beverages, tobacco, mining and construction) follow the expected growth in industrial GDP for each country.

Similarly, the share and energy intensity of commercial spaces are held constant with the latest available data in the commercial sector. Growth in energy use is projected from the increase in Gross Floor Area, which is a function of Service GDP per capita.

In the transportation sector, fuel economy, vehicle loading, and vehicle mileage are held constant with the latest available data. The number of vehicles is projected, taking into account growth in population, urbanisation, and per capita income. The share of vehicle types running with a specific fuel remains the same throughout the years, and biofuel usage follows actual consumption rather than the stated blending mandates. Rail, domestic air, and inland waterway consumption are held constant with the latest historical data, since more information would be required to model the growth of these transportation modes.

The power sector is projected using the simulation approach wherein power sector capacity expansion and dispatch are determined to meet the electricity demand based on historical behaviour of consumers. Own-use and losses, as a percentage of electricity, are held constant with the latest available data. In other transformation processes (e.g., biofuel and coal production, oil refining, gas processing, etc.), the import and export targets are held constant with the latest historical data, but the production, import and export projections are estimated based on the demand and availability of indigenously produced resources. The resources considered are only those “proven reserves” from the latest available data, and does not consider additional exploration or new construction in coal mining, nor oil and gas extraction infrastructure.

### 2.3.2 AMS Targets Scenario

ASEAN will keep producing and consuming affordable energy, fuelling dynamic economic growth. However, the Member States realised that continuing the historical energy trend in the Baseline Scenario is not sustainable. If there are no significant changes in priorities and policies, it will harm their energy security and contribute to more GHG emissions. Hence, each AMS has set its own policies for EE/EI and RE, and submitted its NDCs to reduce emissions, in support of the Paris Agreement.

The AMS Targets Scenario (ATS) models the impact of these existing national policies and measures that will lead the AMS to reach their targets. It incorporates more recent information on energy-saving goals, action plans on renewables, and PDPs. All AMS have EE targets in their national energy policies, but not all of them set out the targets for specific sectors. The ATS includes more ambitious energy-saving targets, in addition to rapid advances in low-carbon energy technologies, especially RE. Table 2.2 summarises the AMS official energy targets for access, efficiency/intensity, and renewables.

**Table 2.2 Official Energy Targets and Policies of ASEAN Member States**

| Country | Sector | Official Target |
|---|---|---|
| Brunei Darussalam | Efficiency / Intensity | • Reduce electricity consumption by 30% by 2035 as compared to the base year 2011 in all sectors (residential, commercial, industrial, and governmental)<br>• Increase the total share of EVs to 60% of the total annual vehicle sales by 2035 |
| | Renewables | • Achieve a 30% share of RE in the power generation mix by 2035 |
| Cambodia | Access | • At least 90% of households will have access to the electricity grid by 2030 |
| | Efficiency / Intensity | • 15% reduction in energy demand by 2030 relative to baseline[8] |
| | Renewables | • 25% increase in renewable energy in the power mix (generation capacity) by 2030 (solar, wind, hydro, biomass) |
| Indonesia | Access | • Reach 100% electrification rate by 2022 |
| | Efficiency / Intensity | • Reduce energy intensity (TPES per GDP) by 1%/year through 2025<br>• Achieve ~19,000 4-wheeled EVs and ~750,000 2-wheeled EVs by 2025<br>• Achieve 2 million units of electric cars and 13 million units of electric motorbikes by 2030 |
| | Renewables | • Increase RE share to 23% in primary energy supply by 2025 and 31% by 2050<br>• Biodiesel blending ratio target 30% by 2025; Bioethanol blending ratio 20% by 2025 and 50% by 2050<br>• Achieve a 19.6% share of RE in electricity production in 2030 |
| Lao PDR | Access | • Increase the electricity access rate to 98% of total households by 2025 |
| | Efficiency / Intensity | • Reduce TFEC by 10% by 2030 and 20% by 2040 as compared to the baseline[9] |
| | Renewables | • 30% share of RE in total energy consumption by 2025, including 20% renewable electricity share (excluding large-scale hydro) and 10% biofuel share (blending ratio 5%-10%)<br>• 13 GW total hydropower capacity (domestic and export use) in the country by 2030 |

[8] Refer to its national energy outlook BAU scenario
[9] Refer to its national energy outlook BAU scenario

| Country | Sector | Official Target |
|---|---|---|
| Malaysia | Efficiency / Intensity | • 52,233 GWh of electricity savings over a 10-year period from 2016 to 2025 against BAU, corresponding to an electricity demand growth reduction of 8% at the end of the plan |
| | Renewables | • Increase the RE share to 31% in the power capacity mix by 2025 and 40% by 2035 |
| Myanmar | Access | • Increase electricity access rate to 60% by 2025-2026 and 100% by 2030 |
| | Efficiency / Intensity | • Achieve energy savings from the 2012 baseline by 16% by 2025 and 20% by 2030<br>• 5% reduction by 2025 and 7% by 2030 in traditional biomass use, relative to 2012 levels, via the promotion of energy-efficient cooking stoves |
| | Renewables | • Increase the share of RE to 39% in electricity generation by 2030 (28% hydro or 5156 MW, and 11% other RE or 2000 MW) |
| Philippines | Access | • Achieve a 100% household electrification rate by 2022 |
| | Efficiency / Intensity | • Save 5% energy from oil products and electricity by 2040 as compared to BAU<br>• Reach 10% penetration rate for EVs for road transportation (motorcycles, cars, jeepneys) by 2040 |
| | Renewables | • Increase the RE share to 35% in the power generation mix by 2030 and 50% share by 2040<br>• Implement 5% blending for biodiesel starting in 2022 |
| Singapore | Efficiency / Intensity | • Improve energy intensity by 35% in 2030, compared to the 2005 level<br>• Achieve 1%–2% annual improvement in industrial EE<br>• Achieve 100% cleaner-energy public bus fleet and taxis by 2040 (electric or hybrid vehicles)<br>• Reduce total energy consumption by more than 8 million MWh per year |
| | Renewables | • Increase solar energy deployment to at least 1.5 GWp by 2025 and 2 GWp in 2030 |
| Thailand | Efficiency / Intensity | • Reduce 30% energy intensity (TFEC/GDP) by 30% by 2037 relative to the 2010 level<br>• Achieve 30% electric vehicles manufactured by 2030 |
| | Renewables | • Increase the RE share to 30% in TFEC by 2037, including 15%–20% renewable electricity in total generation; 30%–35% of consumed heat from renewables; and a 20%–25% biofuel share in TFEC |
| Vietnam | Efficiency / Intensity | • By 2025, reduce energy intensity in TFEC by 5%-7% and keep power losses under 6.5%<br>• By 2030, reduce energy intensity in TFEC by 8%-10%, keep power losses under 6%, and reduce fuel and oil consumption by 5% in transportation |
| | Renewables | • Increase the RE share in TFEC to 32.3% by 2030 and 44% by 2050<br>• Increase the RE share in power generation to 32% by 2030 and 43% by 2050 |

*Source: Multiple official documents.*

**Table 2.3 Translation of National Targets into the Model**

| Residential | Transportation | Industrial and Commercial | Power Plants |
|---|---|---|---|
| • **Cooking:** Increasing the share of households utilising modern cook stove with LPG, natural gas, biogas, and electricity as fuel. Overall reduction of households using traditional fuels (kerosene, wood, biomass, charcoal) as per centage of cooking access is improved throughout the modelling period.<br><br>• **Efficiency:** Increasing the share of households that utilises efficient air conditioners, refrigeration and lighting through replacement of existing appliances after their lifetime with efficient counterparts | • **Biofuel:** Reflecting the share of biodiesel and ethanol consumption in transportation fleet as a function of nationall ystated biofuel mandates and diesel and gasoline usage, respectively.<br><br>• **Efficiency:** Improvements in fuel economy following the global historical trends reduce the fuel required to travel a given distance.<br><br>• **EVs:** Increasing the share of hybrid/EV in the transportation fleet and/or the targeted number of EVs per type as indicated in national policies. | • **Efficiency:** Implementing annual energy intensity reduction to attain the nationally-stated total or annual energy saving targets for the whole sector and/or particular sub-sector. | • **Renewable energy:** Firm additions of renewable installation capacity targets and/or prioritisation of addition of renewable capacity until the country-specific targets are met.<br><br>• **Fossil fuels:** Implementation of coal-phase down and/or shift to cleaner coal technology for countries with an indicated target. |

### 2.3.3 APAEC Target Scenario

APAEC Target Scenario (APS) includes RE and EE measures to meet the 2025 regional target under APAEC 2016-2025 Phase II: 2021-2025 [16]. It explores the efforts required to reach the EI and RE targets of APAEC. This scenario explores a higher level of ambition beyond the national targets. It focuses on analysing the additional energy savings that might be achieved by the individual countries and beyond the Baseline Scenario and ATS.

**Energy Efficiency and Conservation**

To reduce energy intensity by 32% by 2025 and encourage EE&C efforts, especially in transport and Industry

**Renewable Energy**

To increase the share of RE to 23% in TPES and 35% in Installed power capacity by 2025

**Table 2.4 Translation of the Regional Targets into the Model**

| Residential | Transportation | Industrial and Commercial | Power Plants |
|---|---|---|---|
| • **Cooking:** Higher share of clean and more efficient cooking technology, especially electric stoves and biogas.<br><br>• **Efficiency:** Higher penetration of more efficient air conditioning and refrigeration units. | • **Biofuel:** Higher biofuel mandates for countries with existing biofuel mandates, and setting reasonable blending mandates for countries without existing biofuel policies.<br><br>• **Efficiency:** Alignment with the ASEAN fuel economy roadmap by taking the annual average fuel economy improvement rate for the entire region.<br><br>• **EVs:** Higher share of hybrid/EV in the transportation fleet.<br><br>• **Mass Transportation:** Increasing the share of passenger-km served by buses. | • **Efficiency:** Higher annual energy intensity reduction relative to nationally-stated total or annual energy saving targets for the whole sector and/or particular sub-sector. | • **Renewable energy:** Higher prioritisation of addition of renewable capacity relative to fossil-based plants in meeting demand.<br><br>• **Fossil fuel:** Reduced utilisation of existing coal, oil and gas plants in power generation. |

### 2.3.4 Least-Cost Optimisation Scenario

A new analysis is introduced into the AEO7, with the Least-Cost Optimisation (LCO) Scenario using a technology-neutral approach by applying the least-cost optimisation of all viable technologies in the power sector. As there are developing countries in the ASEAN region, AMS should consider cost-effectiveness, affordability, safety, and sustainability to fulfil the growing energy supply and demand. The scenario currently runs independently within the power system, but future AEOs intend to extend the optimisation approach to all sectors.

An optimal system is defined as a configuration with the lowest total net present value of production cost over the entire planning period. Cost parameters accounted for in this scenario include capital cost, fixed and variable operating and maintenance cost, and fuel cost.

Capital cost was benchmarked against the overnight capital expenditure cost per technology based on available data from existing power plants in ASEAN and considered Asia-Pacific and global data if not available, especially for emerging technologies. The top five technologies with the highest average capital costs in ASEAN are Pumped Hydropower Storage, waste, geothermal, nuclear, and biomass (Figure D.2).

Capital cost reductions in renewable and emerging technologies are projected due to increased deployment and thus, incorporated in the scenario. The percentage of annual reductions per fuel type on a 5-year basis is presented in Figure D.3.

Fixed and variable operating and maintenance (O&M) costs are benchmarked on the available data from existing power plants in ASEAN and considered Asia-Pacific and global data if not available, especially for emerging technologies. Unlike capital costs, O&M costs are held constant throughout the projection years, assuming that changes will remain insignificant (Figure D.4 and Figure D.5) [18].

Photo source : GIZ


# CHAPTER 3

# EXPLORING MULTIPLE FUTURES

# CHAPTER 3
# EXPLORING MULTIPLE FUTURES

## 3.1 Energy Demand

Under the Baseline Scenario, wherein the growth in energy demand is expected to follow historical trends, TFEC in ASEAN is projected to increase approximately 23% by 2025 from the 2020 level, rising to 473.1 Mtoe from 385 Mtoe (Figure 3.1).

In line with rapid economic growth, regional **energy demand is expected to triple that of 2020 levels by 2050**. With no policy intervention, fossil fuels are projected to continue to dominate the energy sector until 2050. Oil will still make up the largest share of TFEC, dominating through 2050, at 47.4% of TFEC, followed by electricity (20.3%), coal (14.5%), and bioenergy (9.2%).

Despite the fact that the bioenergy share in TFEC is much lower than oil, it exhibits the same compound annual growth rate (CAGR) as oil and gas, at 4.4%, throughout the projection period (2021-2050). The rapid growth of bioenergy consumption and demand follows the recent extensive development of biofuels in several AMS. It is being heavily utilised to replace fossil fuels in two energy-intensive sectors (transportation, industrial).

Under the ATS, fuel switching policies set by AMS will not significantly change future trajectories. Although the **national efficiency measures will help to greatly reduce total demand** by 39.6**%** in 2050, as compared to the Baseline Scenario (Figure 3.1), oil still contributes the largest share of 40.3% of TFEC. Fuel shifting policies will help to slightly raise the share of electricity, natural gas, and biofuel to 25.5%, 9.2% and 9.8%, respectively.

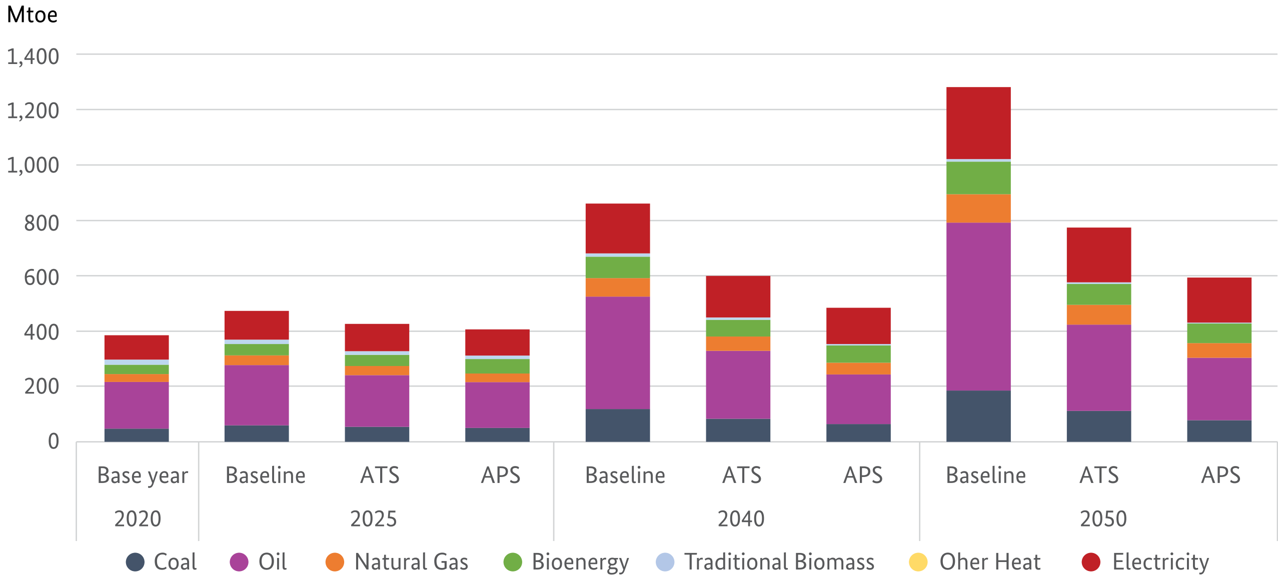
In the residential sector, improved electrification and clean cooking access allow the reduced use of traditional biomass and increased use of modern cookstoves that utilises biogas and electricity. Remarkable policies on clean cooking includes Myanmar's target of a 5% reduction in traditional biomass use and Lao PDR's target of having 50,000 households utilising biogas, by 2025.

In transportation, EV deployment targets allow a shift from the use of conventional fuel to electricity. Several Member States have promising targets in EV penetration including Singapore's plan for a 100% cleaner-energy public bus and taxi fleet by 2040 and Cambodia's target of 40% of all cars and urban buses and 70% of motorbikes to be electric-fuelled by 2050.

Biofuel mandates contribute to the increased utilisation of biodiesel and biofuel. Biofuel is blended into widely-used transportation fuels – gasoline and diesel – and serves as an alternative fuel that yield around the same performance as non-blended ones. Remarkable policies on biofuel deployment include the Philippines' 5% biodiesel and 10% bioethanol blending targets by 2040. Indonesia is pursuing biodiesel and bioethanol blending ratio of 30% and 20%, respectively, by 2025, and an even higher target of 50% bioethanol blending ratio by 2050.

Additional **sectoral policy improvements are still required to meet the APAEC target** which will be outlined in succeeding paragraphs. APS, where the APAEC EI reduction target is met in 2025 and maintained beyond that, projects energy demand at 593 Mtoe in 2050, roughly half of the Baseline Scenario in the same year.

**Figure 3.1 ASEAN Total Final Energy Consumption Projections by Fuel Across Scenarios**

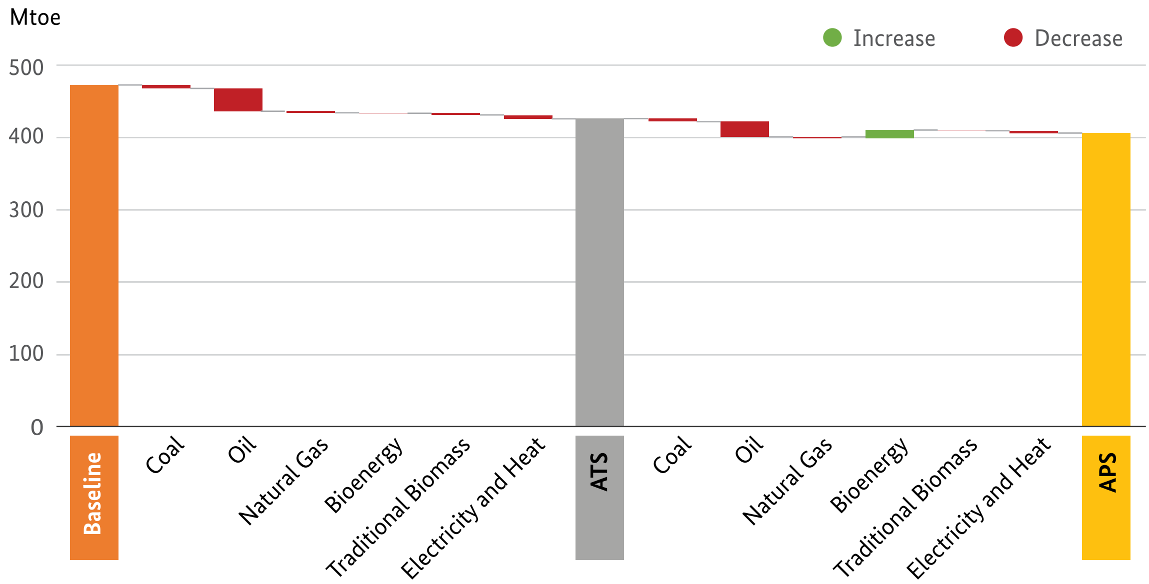



*Note: The LCO Scenario and APS have the same value.*

Compared to ATS, the shares of electricity and bioenergy in ASEAN energy demand will rise by two percentage points by 2050, resulting from electrification of cooking, and more stringent EV deployment and biofuel mandates in several AMS.

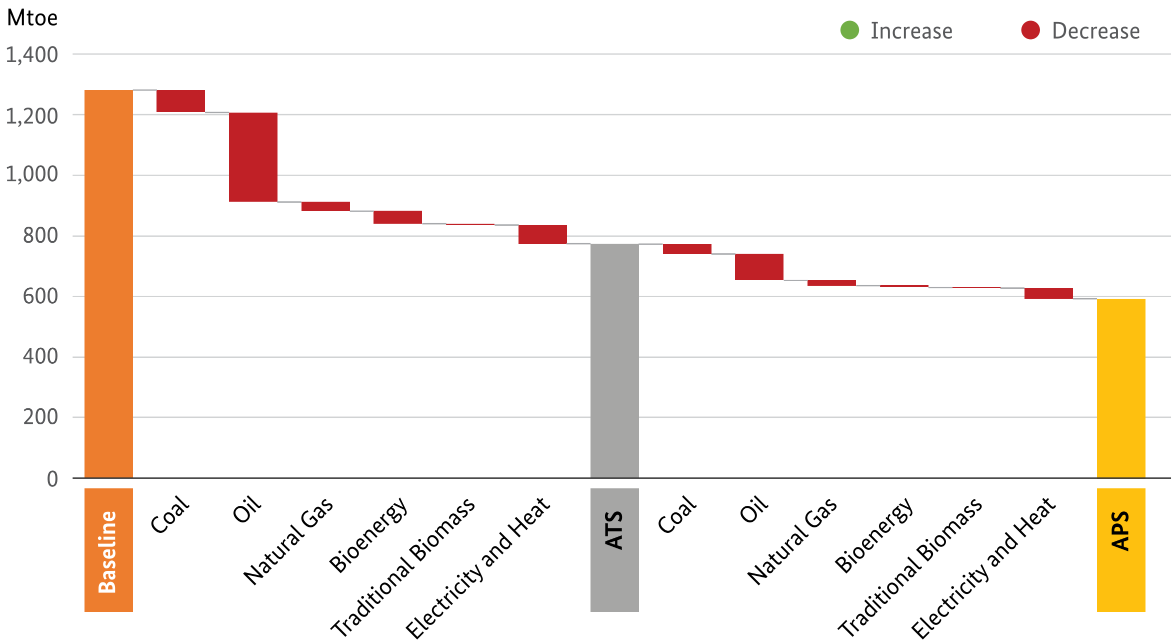
This shift to electricity and biofuel coupled with the use of more efficient technologies throughout all end-user sectors, will significantly reduce the fossil fuel portion, especially for oil. With stronger regional efforts, avoided energy consumption could reach 14.2% in 2025 and 53.7% in 2050, as compared to the Baseline Scenario (Figure 3.2 and Figure 3.3).

**Figure 3.2 TFEC Fuel Shifting in 2025 Across Scenarios**




*Note: The LCO Scenario and APS have the same value.*

**Figure 3.3 TFEC Fuel Shifting in 2050 Across Scenarios**




*Note: The LCO Scenario and APS have the same value.*

Sectoral analysis shows that all end-use sectors see an increase in energy consumption under the Baseline Scenario, ATS, and APS driven by population and economic growth (Figure 3.4). In the Baseline Scenario, industry and transportation shares are projected to remain the largest energy-consuming sectors. By 2050, their shares in TFEC will grow by 3.8% and 3.6%, respectively, whilst residential and commercial proportions will decrease by 10.1% and 0.5%, as compared to 2020.

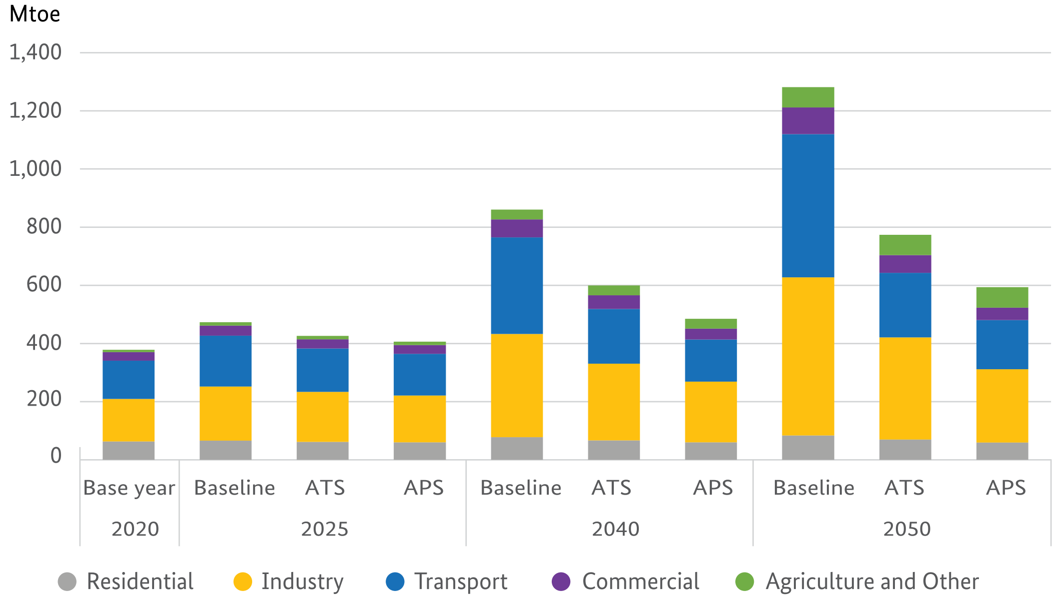
The decrease in residential shares follows historical trends, where its proportion significantly declined from 24.9% in 2005 to 16.6% in 2020. The commercial share increased between 2005 to 2020, but only marginally at 0.6%. As this growth was less significant than that of the industrial and transportation sectors within the same period, it is projected that the commercial percentage will be slightly reduced by 2050.

Compared to the Baseline Scenario, the avoided energy consumption under ATS will be the greatest in the transportation and industrial sectors in the near term (2025), with 25.7 Mtoe and 13.7 Mtoe, respectively (Figure 3.4). This is expected due to various EE&C policies looking to be set by the AMS, especially in areas applying fuel economy for vehicles, as well as MEPS and electrical equipment labelling for industry and buildings. In the long term, AMS have set more ambitious EE policies in the transportation and industrial sectors (Table 2.2), with further reductions of 269.9 Mtoe and 193.1 Mtoe by 2050, respectively, as compared to the Baseline Scenario.

Stronger EE measures are required across the final energy sectors to reach the regional targets in APS. In the residential sector, **access to clean cooking should increase by 5% annually**. This can be achieved by transitioning to cleaner cooking technologies, such as using cleaner wood stoves in rural areas and induction stoves in 70% of households in urban areas. AMS must also **increase the penetration of efficient air conditioning and refrigeration units** in residential use by 60% to 100% by 2050.

**Higher fuel economy needs to be more urgently implemented** in the transportation sector, in addition to the fuel shift to electricity and biofuel usage. Following the ASEAN Fuel Economy Roadmap [21], there should be a **5.2% annual improvement in fuel economy by 2030** and a further 3% beyond that. ASEAN should also press for **mass transportation**, with a 2% annual increase in the share of public buses in the transportation fleets seen as greatly contributing to the attainment of the regional target.

**Figure 3.4 Energy Consumption by Sector Across Scenarios**




*Note: The LCO Scenario and APS have the same value.*

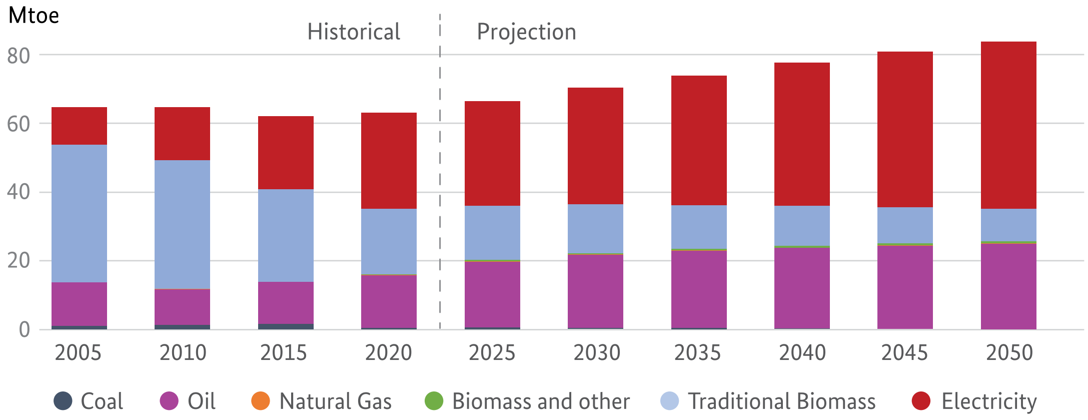
**Biofuel is viewed as an essential tool that can diversify the energy mix within ASEAN.** AMS with existing bioenergy policies should further enforce and uphold their biofuel blending mandates. At the same time, nations without them, such as Myanmar and Vietnam, should actively encourage such mandates to be introduced. Furthermore, AMS should consider **doubling current energy-saving efforts in all national policies** concerning the industrial and commercial sectors, in order to achieve the regional targets under APS. Energy intensity could be reduced in a cost-effective manner by applying strategies centred around improving awareness, financial incentives, and EE standards.

### 3.1.1 Residential

In 2020, total end-use energy in the residential sector amounted to 63.2 Mtoe, which is a 1.9% decrease as compared to 2005. Traditional biomass, oil, and electricity have been the primary energy sources since 2005, representing 61.9%, 19.7%, and 16.9% of the 2005 TFEC in the residential sector. Although the primary sources remained the same, in 2020, electricity had the largest share, followed by traditional biomass. The share of electricity and oil consumption significantly increased to 44.2% and 24.3% of the ASEAN total residential energy demand, whilst the use of traditional biomass dropped to 30.3%. Coal and natural gas consumption in the residential sector was insignificant, with approximate respective end-use shares of just 0.5% and 0.2% in 2020.

The projected TFEC in the Baseline Scenario for the residential sector is expected to climb gradually from 2020 to 2050 (Figure 3.5). Electricity consumption is forecast to rise significantly with an Average Annual Growth Rate (AAGR) of 1.9% over the period 2021-2050. At the same time, the use of coal resources in the residential sector will be eliminated beginning in 2049. Annual marginal growth rates of 0.9% for natural gas at 0.9% and 3.9% for biogas and solar energy are expected for the period 2021 to 2050. In contrast, traditional biomass consumption is projected to fall with an expected AAGR of -2.3% over the same period. Without any policy intervention, the TFEC for ASEAN's residential sector will reach 83.5 Mtoe in 2050. Of this estimated amount, electricity will account for 58.1%, oil 29.6%, traditional biomass 11.3%, biogas and solar 0.8%, and natural gas consumption 0.2%.

**Figure 3.5 TFEC by Fuel in the Residential Sector, Baseline Scenario**

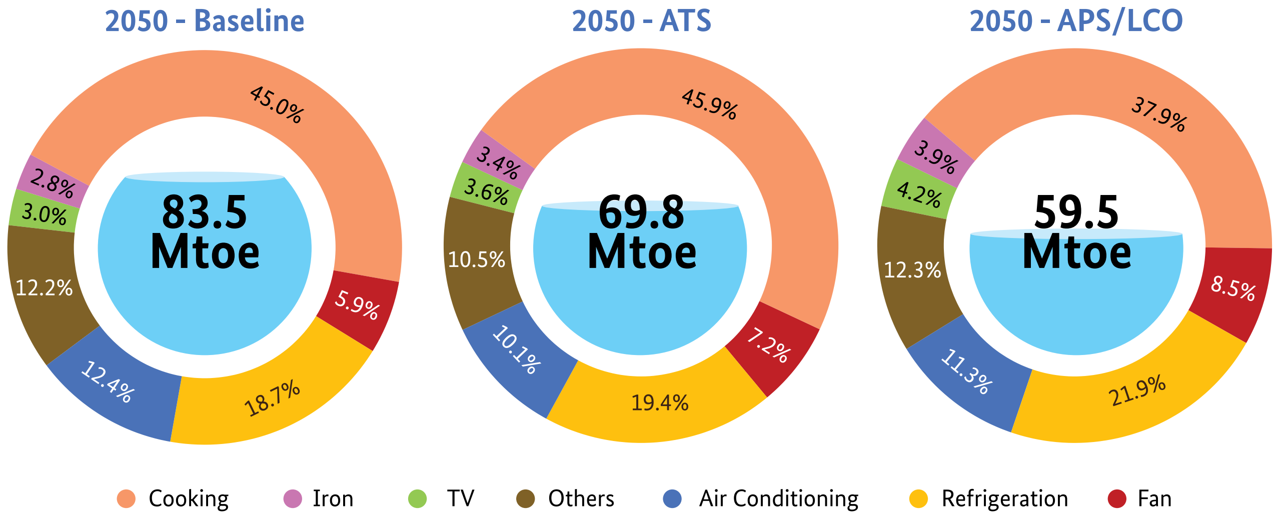



Analysing the household electrical appliance consumption, for 2050, total end-use energy is expected to increase to 83.5 Mtoe, without any policy intervention. Cooking, refrigeration, and air-conditioning are responsible for the largest energy consumption in the residential TFEC, accounting for 45%, 18.7% and 12.4%, respectively (Figure 3.6). Total cooking consumption in 2050 in the ATS (32 Mtoe) is lower than the Baseline Scenario (37.5 Mtoe), but the share in the residential TFEC is slightly higher (45.9%). The reason for that is the reduction in cooking consumption is not as significant as that of air conditioning and other appliances due to the higher implementation of more efficient standards for these devices. On the other hand, APS sees a lower percentage of cooking consumption and a higher share for other appliances in the residential TFEC than in ATS.

Through enhanced policies promoting clean cooking and electrification, the region can significantly reduce the use of LPG, biomass, and charcoal for cooking, as shown in Figure 3.7. Whilst a shift from traditional biomass to LPG use is seen in rural households, the increase shift from LPG-fired stove to electric stove is seen as a major trend in urban areas.

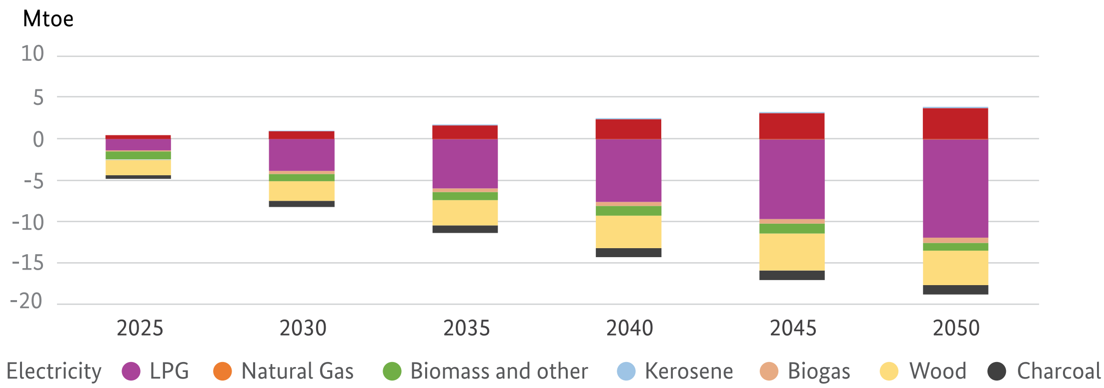
Using more efficient electric stoves may consume about 16% less of the energy required by stoves that combust fossil-based fuel to supply the same number of households. Average annual savings over LPG, wood, and charcoal are estimated to be 29%, 40%, and 58%, respectively, as compared to the Baseline Scenario. This entails less dependence on imported fuel but, more importantly, enhanced residential welfare due to less indoor pollution from burning fuels for cooking.

**Figure 3.6 Share of Residential Appliances in 2050 Across Scenarios**




*Note: Others include Lighting, Washing Machines, Clothes Dryers, Kettles, Water Heating, and Computer. The LCO Scenario and APS have the same value for demand.*

**Figure 3.7 Fuel Shifting due to Clean Cooking, APS vs Baseline Scenario**




### 3.1.2 Transportation

Observed historical data showed that the TFEC of ASEAN's transportation grew dramatically from 74.2 Mtoe in 2005 to 133.9 Mtoe in 2020, with an AAGR of 4.1%. Specific share contributions were road (93.8%), domestic air (3.3%), inland waterways (2.3%), rail (0.5%), and non-specified sector (0.1%) in 2020. In the Baseline Scenario, average annual consumption is forecast to increase approximately 12 Mtoe over 2021-2050. The projected TFEC in transportation will reach roughly 220 Mtoe in 2030, 332 Mtoe in 2040, and 492 Mtoe in 2050.

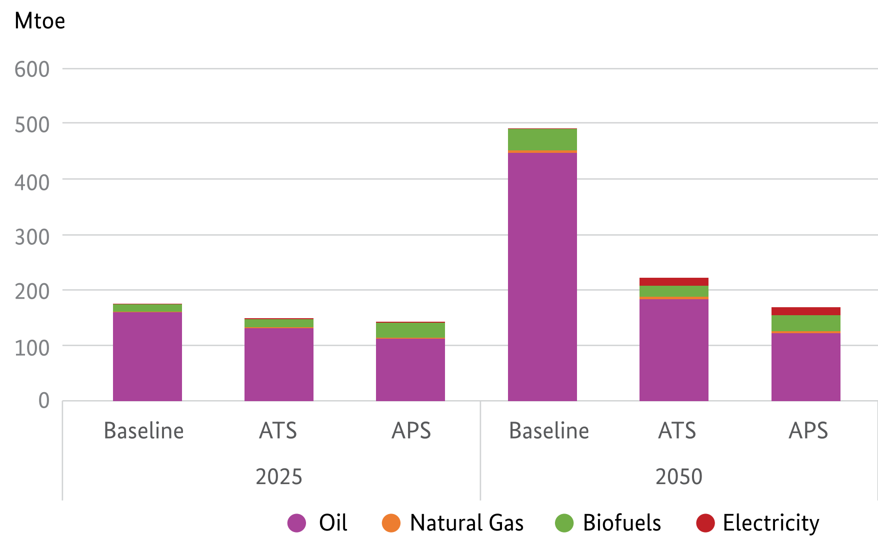
Oil is the primary fuel source, accounting for 91.4% of the TFEC in the transportation sector in 2020, followed by biofuels (7.2%), natural gas (1.2%), and electricity (0.2%). Although the oil share was the largest every year, the AAGR of oil is only 3.5% per year, the lowest fuel consumption growth rate from 2005 to 2020. Biofuel consumption increased the fastest, with an average annual rate of 51.4% during the same period. The average annual rates for natural gas and electricity consumption growth in the transportation sector was 20.4% and 7%, respectively during 2005-2020.

Based on historical trends, oil will contribute a 91.1% share of ASEAN TFEC in the transportation sector by 2050, followed by biofuels (7.8%), natural gas (1%), and electricity (0.2%). Biofuel consumption will grow the fastest over the 2021-2050 period, with an average annual rate of 4.7%, followed by oil consumption at 4.4% per year. Natural gas and electricity consumption for the ASEAN transportation sector are forecast to increase at an AAGR of 3.8% and 3.6%, respectively, during the same period.

To reach the national targets in ATS by 2025, oil and gas consumptions need to be decreased by 18% and 1%, respectively, as compared to the Baseline Scenario (Figure 3.8). On the other hand, electricity uptake must be greatly accelerated to 388.3% higher than the Baseline Scenario, followed by biofuel by 11.3%. In order to realise the regional targets by 2025 under APS, a further decrease in fossil fuels must be achieved. Oil consumption in transportation is much lower in ATS and APS. In 2050, ATS shows reduced oil demand in transportation by 59.1% to 112.3 Mtoe, with an additional reduction of 33.4% in the APS, as compared to the Baseline Scenario.

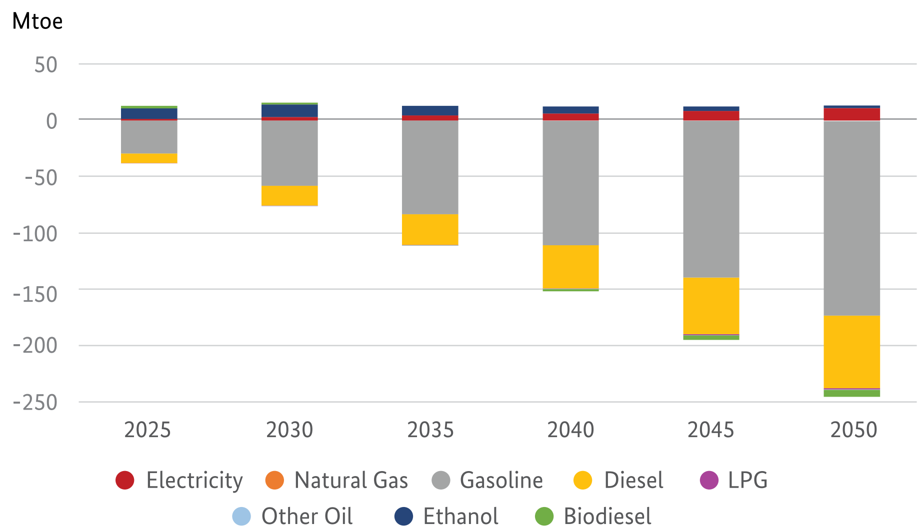
Establishing policies in the transportation sector in Member States is crucial for attaining the APAEC target. In the APS, in which EVs are favoured, biofuel mandates, and fuel economy improvement strategies are set and/or enhanced to meet the regional target, with significant fuel saving potential expected. Deploying more efficient electric and hybrid vehicles in parallel reduces gasoline and diesel usage by about 72% and 59% on average, respectively (Figure 3.9). This entails less dependence on imported fuel, but more importantly, enhances urban health and welfare due to less air pollution from fossil fuel combustion.


**Figure 3.8 Transportation Consumption by Fuel Across Scenarios**




*Note: The LCO Scenario and APS have the same value.*

**Figure 3.9 Fuel Shifting in Road Transportation, APS vs Baseline Scenario**



Road vehicles account for most of the energy consumption in transportation, with targeted annual growth averaging 10.8 Mtoe, reaching 91% of TFEC in 2050. Meanwhile, the other modes of transportation are not projected to grow significantly, with a respective annual average over 2021-2050 of 0.86 Mtoe, 0.27 Mtoe, 0.05 Mtoe, and 0.01 Mtoe for domestic air, waterways, rail, and non-specified, respectively, over 2021-2050. Amongst road transportation, private passenger vehicles will have the dominant share, with 50.3%, followed by trucks and other at 32.8% (Figure 3.10).

AMS provide promising targets and strategies for increasing the technology uptake. However, despite establishing these policies, conventional vehicles still dominate the passenger road transportation fleet into 2050. In the ATS estimation, EVs only reach up to 2.5% of the fleet by 2025 and up to 9.6% by 2050 (Figure 3.11). Higher EV targets and/or establishment of transportation electrification policies are needed to yield more energy savings in the sector.

**Figure 3.10 TFEC Projection by Road Transportation, Baseline Scenario**

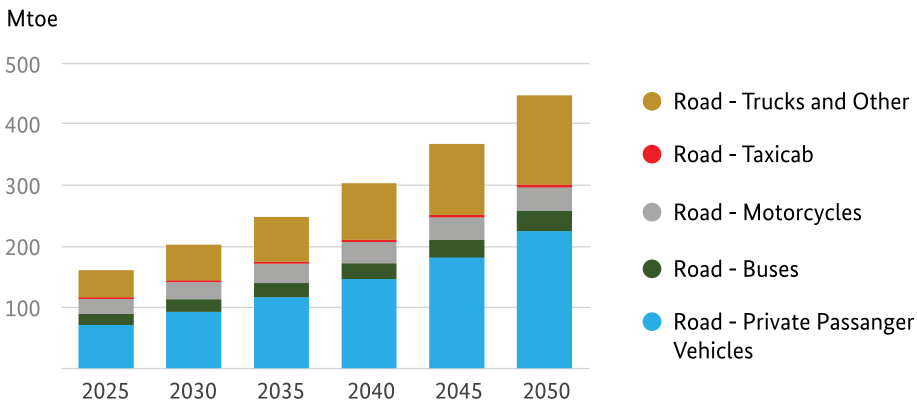



**Figure 3.11 Penetration of Electric Vehicles in Road Transportation, ATS**

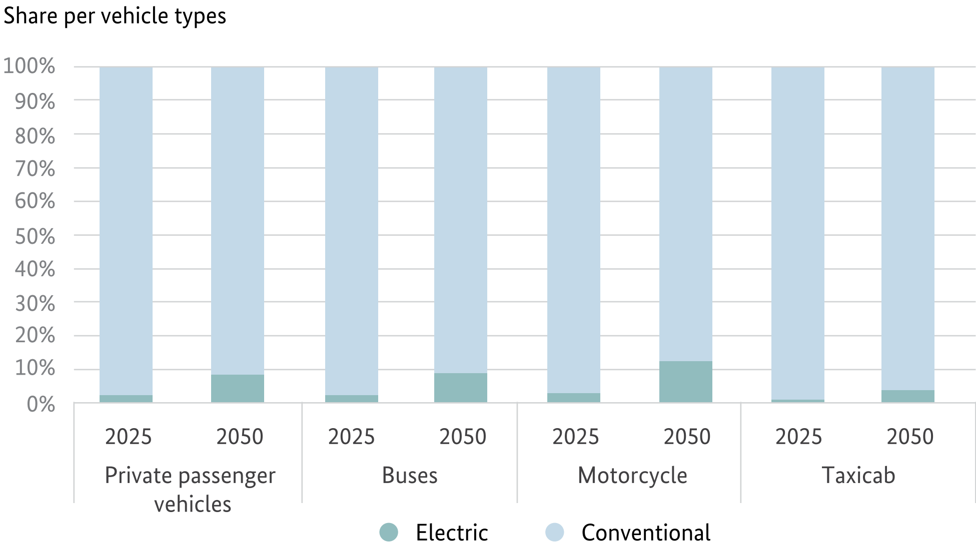



*Photo source : Freepik*

### 3.1.3 Commercial

There was a steady increase in commercial energy demand between 2005 and 2020, with an average annual growth rate of 3.3%. According to the projected data in the Baseline Scenario, the TFEC in the commercial sector will rise gradually from 29.3 Mtoe in 2020 to 42.5 Mtoe in 2030 and 92 Mtoe in 2050 (Figure 3.12). Coal is the only fuel with a decreasing growth rate over the same period. Based on projected ASEAN TFEC in the commercial sector in 2050, electricity will contribute the most, with approximately 75% share, followed by oil (17.3%), bioenergy (7.2%), natural gas (0.6%), and a small share for coal (0.03%).

**Figure 3.12 Commercial Consumption by Fuel, Baseline Scenario**

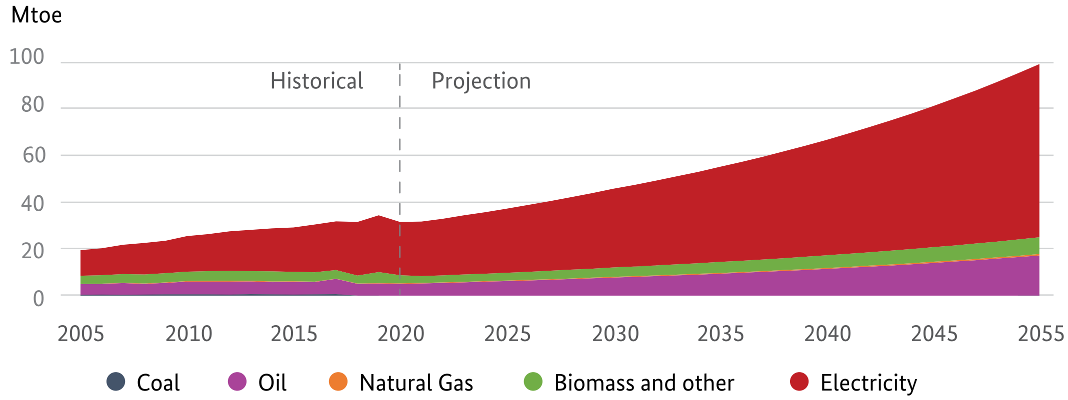
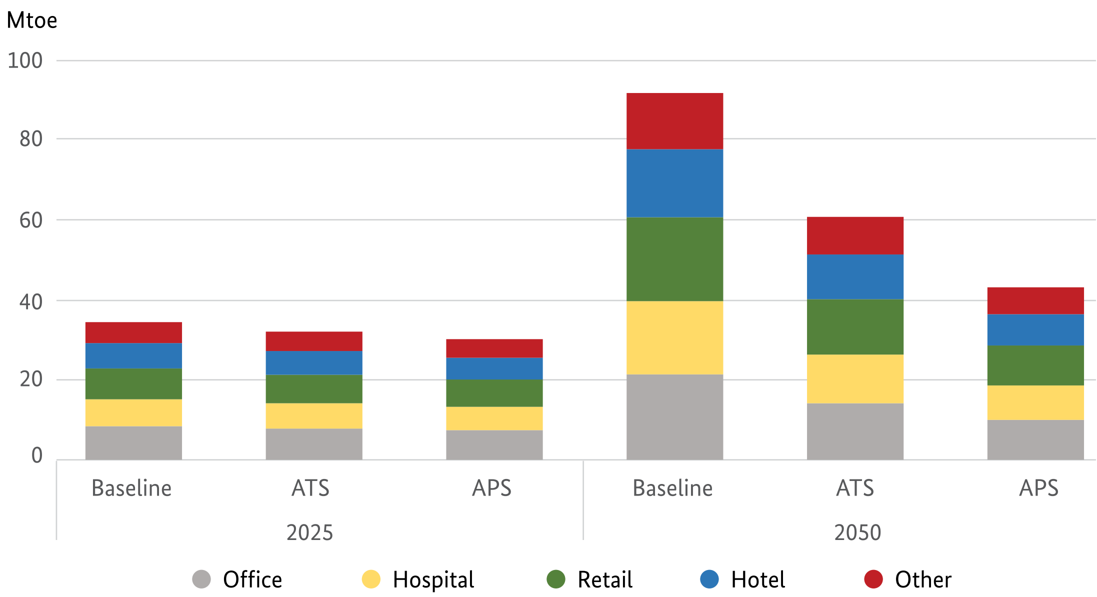




Photo source : Freepik

Total energy demand forecasts for five sub-sectors in commercial are demonstrated in Figure 3.13. ASEAN's commercial sector is comprised of office, hospital, retail, hotel, and other. In the Baseline Scenario, the share of energy demand from each commercial sub-sector is constant over the period. It is estimated that 23.4% of commercial TFEC will be from office, followed by retail (22.8%), hospital (19.9%), hotel (18.6%), and other (15.4%) by 2050. There are significant reductions in all sectors in ATS and APS, relative to the Baseline Scenario, with the largest decrease in office and retail. The energy intensity reduction is due to the attainment of nationally stated energy saving targets for the entire commercial sector and sub-sectors.

**Figure 3.13 TFEC Projection by Commercial Sub-Sector Across Scenarios**




*Note: The LCO Scenario and APS have the same value.*

The region needs to **double energy-saving efforts** in the commercial sector, as indicated in national policies. Being a highly electrified, the commercial sector may achieve a higher energy saving potential through the use of more efficient lighting, cooling and appliances, by implementing MEPS and electrical equipment labelling. A significant share of oil use, primarily diesel and LPG, dedicated to more efficient heating may also transition to electric heating. Successful implementation of these energy-saving strategies would still require enabling policies on **consumption monitoring**, **energy saving valuation** and **financial mechanisms**.

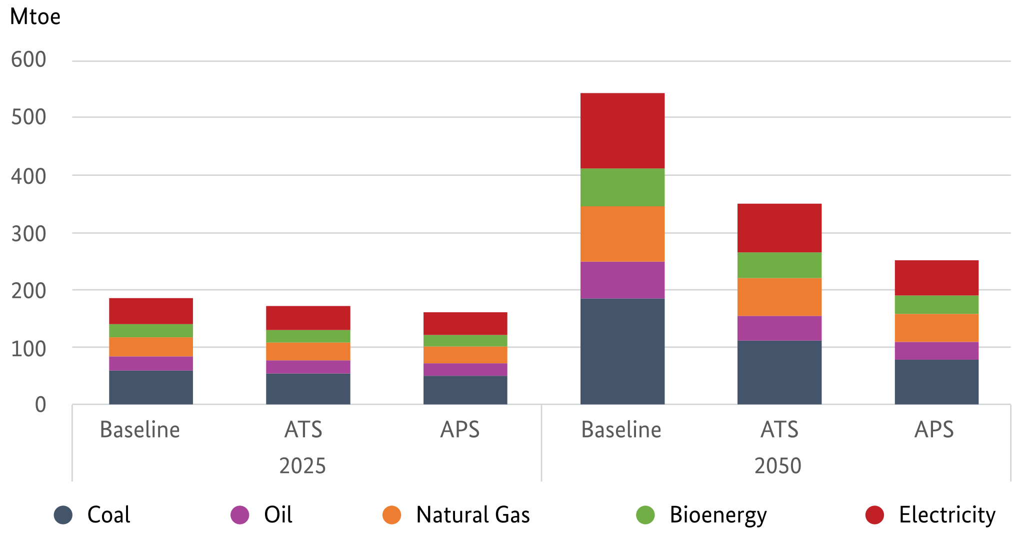
Policies on consumption monitoring would enable adoption of system enhancements such as **sector coupling** (discussed in Section 4.1.2) that could reduce or shift a portion of electricity demand over a specific period. This could potentially lead to consumer's cost savings that serve as a means of financing.

### 3.1.4 Industrial

The industrial TFEC in ASEAN has increased rapidly from 93.9 Mtoe in 2005 to 150.5 Mtoe in 2020. Oil decreased by 18%, whilst other fuel consumption grew over the same period. Coal grew the fastest at 2.3 times as compared to the 2005 level. It was the largest fuel source for industrial energy consumption in 2020, with 31.5%, followed by electricity at 24.4% and natural gas at 17.7%.

The industrial TFEC from 2021 to 2050 presented in the Figure 3.14 is forecast across all scenarios. Following historical data in the Baseline Scenario, it is estimated that the TFEC of the industrial sector will increase by 23.3% in 2025 from the 2005 level. The forecast TFEC by 2050 will increase to 544.3 Mtoe, almost quadrupling from the 2020 level, with coal seeing major growth. Coal will still dominate energy demand in the industrial sector in 2050 with 34%. Meanwhile, the ATS and APS project a significant decrease in industrial energy consumption of 35% and 54%, respectively, in 2050 as compared to the Baseline Scenario.

**Figure 3.14 Industry Consumption by Fuel Across Scenarios**




*Note: The LCO Scenario and APS have the same value.*

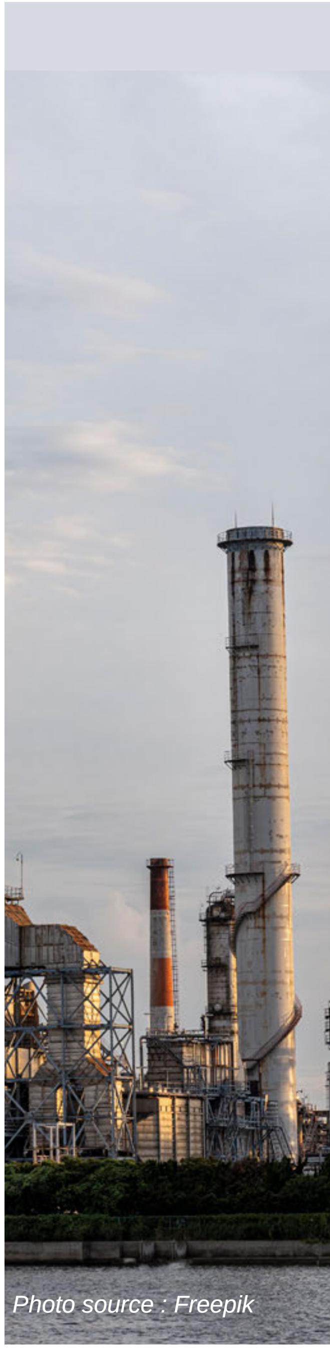
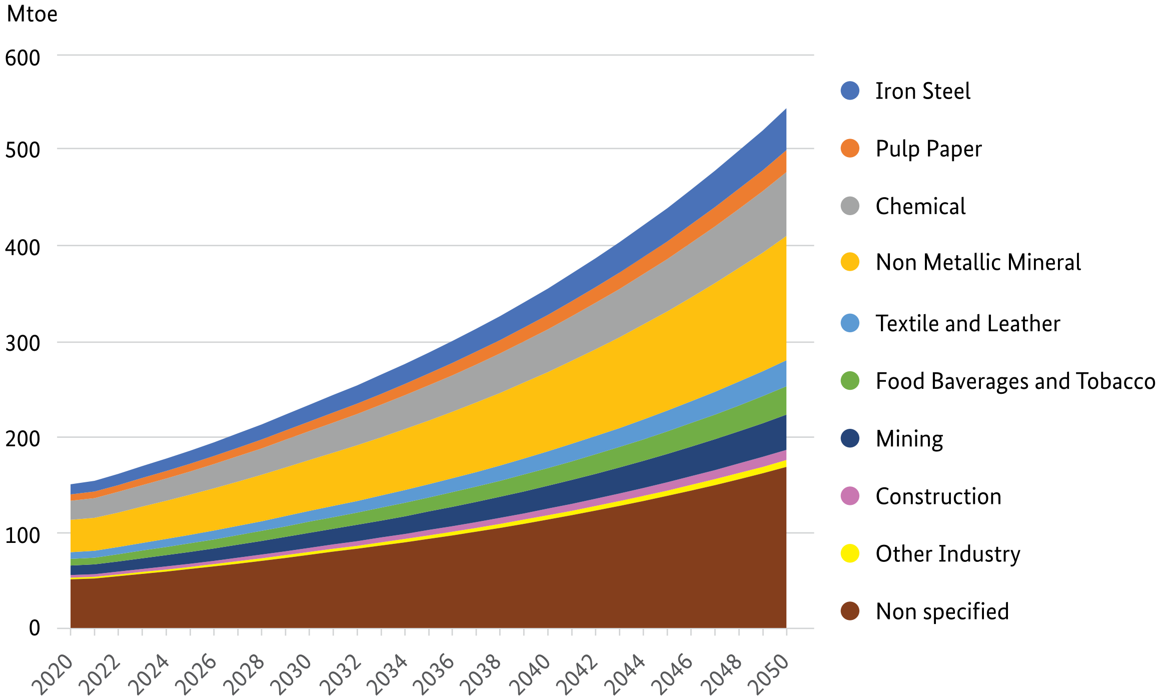


*Photo source : Freepik*

Figure 3.15 presents the energy demand in the Baseline Scenario from 2020 to 2050, by industrial sub-sectors, including iron steel, pulp paper, chemicals, non-metallic minerals, textiles and leather, 'food, beverages and tobacco' (FBT), mining, construction, other industry, and non-specified industry. Due to lack of availability, not all countries have these areas disaggregated. The fastest growth of industrial energy demand will be in FBT, which will increase by 3.3% in 2050, as compared to the 2020 level. However, this industry branch will have only the fifth largest share of industrial energy demand in 2050 with 5.4%, after non-metallic mineral (23.9%), chemical (12.3%), iron steel (8.1%), and mining (6.8%).

**Figure 3.15 TFEC Projection by Industrial Sub-Sector, Baseline Scenario**




Similar to the commercial sector, the region also needs to **double the energy-saving efforts** within the industrial sector. Being a fossil-fuel intensive sector, energy saving strategies in this sector may include raw material reductions and industrial efficiency improvements. Policies that promote efficient use of materials with improved durability, multi-use and re-use, can potentially reduce overall demand. Policies mandating specific energy saving targets, training, audits, and access to capital are all deemed effective in advancing industrial EE.

The industrial sector is difficult to decarbonise, but electrification (whenever possible) and biomass co-firing for process heating could decrease reliance on the use of coal and other thermal fuels. Switching to sustainable biogas, green hydrogen, or ammonia from solar and wind energy are also alternative heating fuels that are being explored and utilised in recent years. More details on necessary transformations for fossil fuel reductions in the industrial sector are discussed in Section 4.3.2.

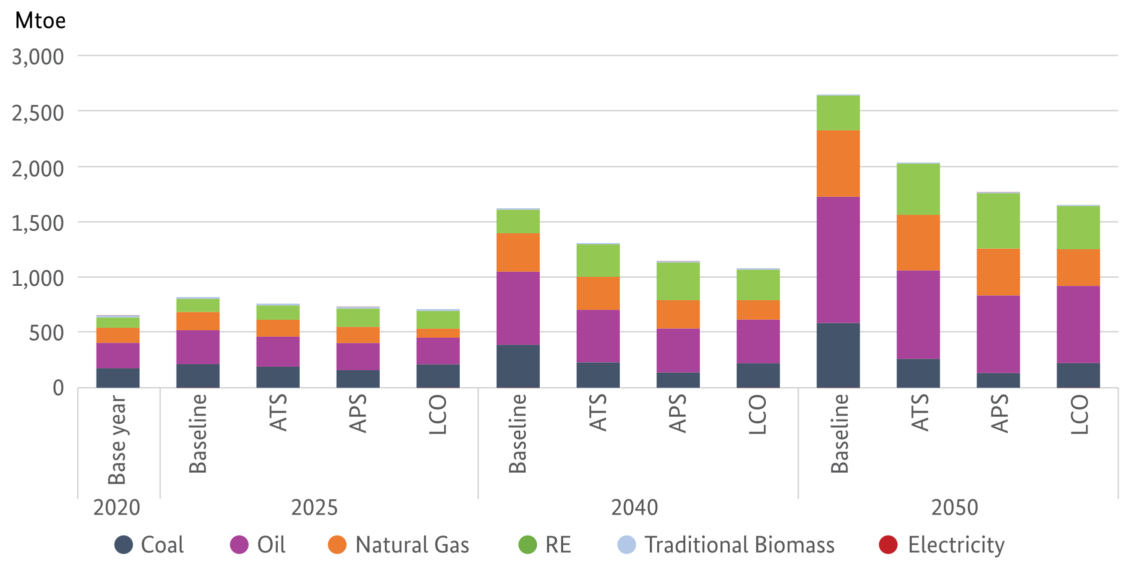
## 3.2 Energy Supply

### 3.2.1 Primary Energy Supply

TPES is a key supply-side measure derived by calculating energy production, adding energy imports, omitting energy exports and international bunkers, plus or minus changes in stock. In 2020, the primary energy mix remained dominated by oil (33%), coal (28%), and natural gas (22%), with a 14.2% share for RE. The overall projection shows AMS will supply 2.5 to 4 times more energy by mid-century, based on the 2020 level, considering the growth in fuel demand, existing and essential energy policies, and import/export targets for each AMS. With stringent EE measures in ATS and APS, reduced feedstock requirements are expected to be around 23% and 33%, respectively by mid-century (Figure 3.16). The LCO Scenario offers the least energy supply at 38%.

In the Baseline Scenario, where energy trends correspond to the BAU, fossil fuel will account for approximately 88%, equivalent to 2,324 Mtoe in 2050, leaving renewables at 11.9%. Because of the Member States' current policies, the supply of fossil fuels is forecast to be reduced by 11% for ATS, and 12.2% for the LCO Scenario in the coming three decades (2021-2050). APS shows the highest fossil fuel reduction pathway reaching 16.7% led by coal decreasing 14.5%.

**Figure 3.16 Energy Supply Projection by Fuel Across Scenarios**




Based on fuel shifting analysis, the reduction of coal is the highest amongst other fossil fuels, which may not be apparent in 2025, but appears influential by the year 2050 in APS, with only 7.5% of supply compared to the Baseline Scenario at 22%. Unlike APS, the LCO Scenario shows 8.6% growth on coal along with natural gas whilst oil and RE decline. In addition, oil share is predicted to develop in all scenarios despite the fact that it is projected to decline by 342 Mtoe in ATS, 442 Mtoe in APS, and 443 Mtoe in the LCO Scenario.

As shown in Figure 3.17 and Figure 3.18, fuel shifting between the years 2025 and 2050 have almost identical trends, but were distinct in each scenario. Between the Baseline Scenario and ATS, oil reduction is predicted to be robust and surpassing coal, whilst the highest growth is found in geothermal, solar, and wind. In contrast, when ATS is compared to APS, coal led fossil fuel reductions with 32 Mtoe by 2025 and 127 Mtoe by 2050, which translates to the reduction in the share of coal in the power sector from 25% to 22% in 2025, and 13% to 8% in 2050.

**Figure 3.17 ASEAN TPES Fuel Shifting in 2025 Across Scenarios**

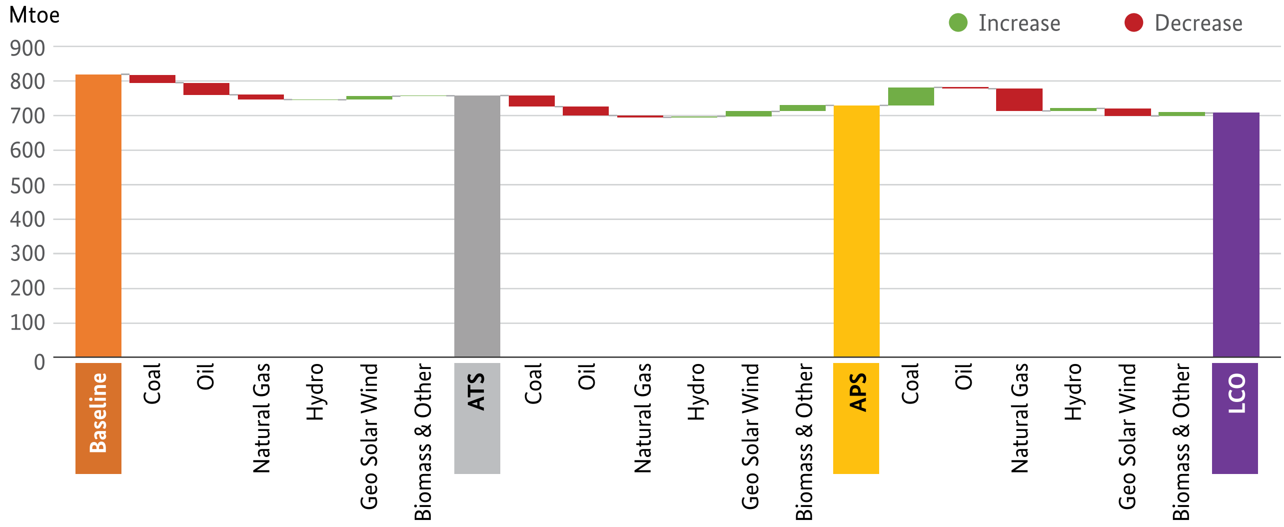
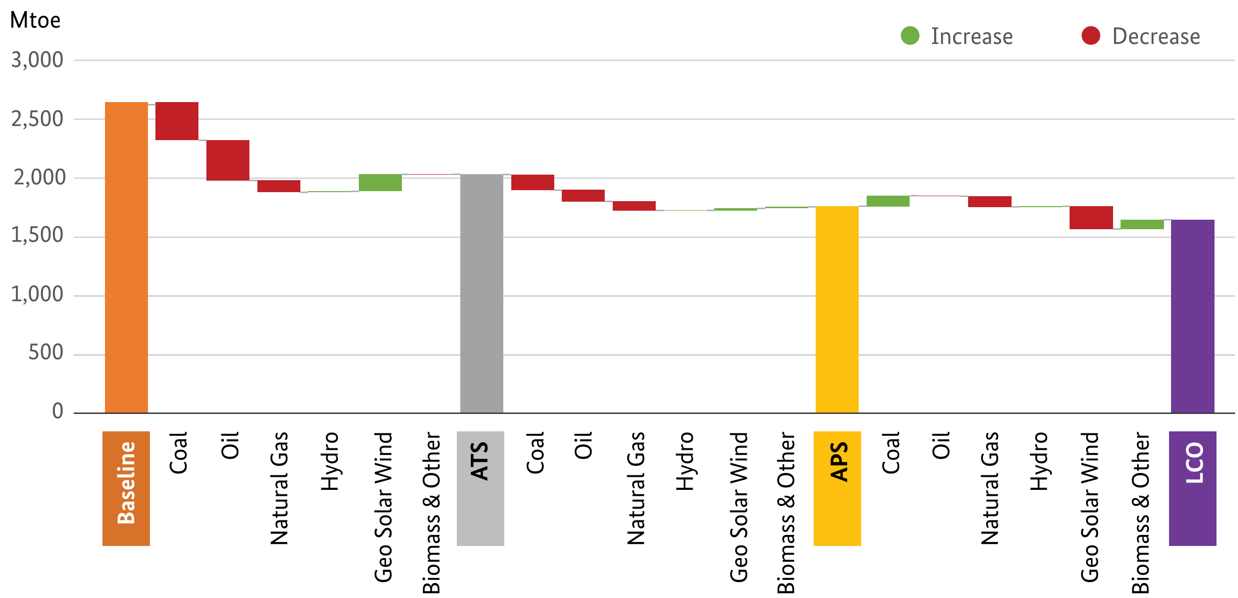



**Figure 3.18 ASEAN TPES Fuel Shifting in 2050 Across Scenarios**




Factors driving coal, oil, and gas reductions are primarily national RE policies, coal moratoria, and clean coal shifting in several AMS. In terms of supply growth, the trend shifts from primarily biomass and others in 2025, to geothermal, solar, and wind by 2050.

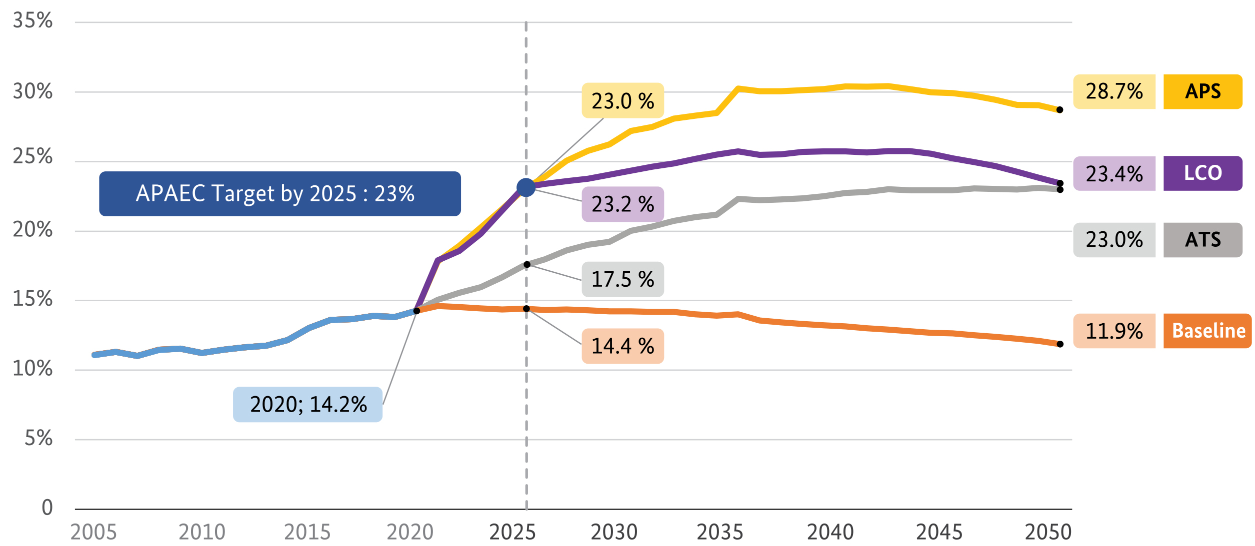
In ATS, there is a relative reduction of up to 71 Mtoe in 2025 and 764 Mtoe in 2050. The supply of renewables is projected to account for 22.8%, or doubling when compared to the Baseline Scenario of 11.9% by 2050. This scenario envisions geothermal, solar, wind, and biomass to substantially increase.

In the APS, stronger policies in end-use sectors, especially for electrification in transportation and cooking, combined with the higher dispatch of RE and EE measures are encourage, such as fuel economy improvement and energy-efficient appliances. Policies on the uptake of cleaner cooking technologies, efficient electrical equipment labelling, and MEPS are deemed necessary. These measures would decrease the share of coal (49%), natural gas (15%), and oil (13%) by 2050. Even so, fossil fuels would still constitute up 52% by 2050. RE measures, most prominent in APS, would decrease the share of coal (13%), oil (28%), and natural gas (16%) by 2050. Geothermal, solar, and wind play a crucial role in increasing the RE share in the future energy supply, for its contribution to power generation.

### 3.2.2 Renewable Energy Share

Based on APAEC targets, AMS have set out to achieve 23% of TPES from renewable sources by 2025, excluding traditional biomass (wood, charcoal, bagasse, agricultural waste) consumed by the residential sector. The RE share in TPES reached 14.2% in 2020, which was an increase of 0.4% from 2019 (Figure 3.19). It exceeded the ATS projection in AEO6 by 0.6% (13.6%). RE remains resilient despite the pandemic causing a 5.3% decline in TPES from 2019. The projection shows a drop of 0.3% in 2021 in the Baseline Scenario, and continuous growth in the other scenarios. This demonstrates that RE development is resilient in challenging times, and with concerted effort, it is possible to achieve 23% by 2025.

**Figure 3.19 Renewable Energy Share in TPES (2005-2050) Across Scenarios**




With the AEO7 update, the projection of RE share in TPES for ATS in AEO6 is slightly reduced, from 17.7% to 17.5% by 2025. It means there are improvements in RE policies pushing the current efforts closer but not necessarily outperforming other sources to achieving the 23% target, leaving a 5.8% gap in the regional target. In APS, RE share is predicted to reach 22.6%, with further coal and oil reduction by 2025. At the same time, LCO is projected to supply less RE, as compared to APS, from 2025 to 2050.

To fill the gaps between ATS and APS, Member States have the opportunity to strengthen efforts by adding a minimum RE of 35 Mtoe, whilst at the same time, reducing fossil fuels by at least 64 Mtoe. Each AMS has its strategy, depending on the availability of potential resource. For example, Singapore promotes innovative measures to increase solar rooftop and floating solar, whilst Vietnam is pushing offshore wind generation.

Each scenario has different RE share trends. In the Baseline Scenario, there is downward pressure, from 14.2% to 11.9%, despite peaking in 2025 with 14.4%. At the same time, ATS and APS share similar trends, gradually increasing until a particular year. For ATS, the peak year is 2042, becoming relatively flat beyond that; for APS, the peak is in 2035, with 29.8%, then declining to 28.3% into 2050. The decline of fossil fuel dispatch by 20% allowed RE to thrive in the power mix and energy saving efforts, resulting in a smaller denominator in RE share calculation which would increase the RE share. The cause of the RE decline lies in insufficient offset to the increase in consumption of oil, coal, and natural gas usage in the end-use sectors, particularly the industrial where fuel shifting policies were non-existent. The largest RE share increase projected in the model is 26 Mtoe in APS in 2035, followed by 23 Mtoe by 2049 in ATS. This is far greater than the maximum of 11 Mtoe in the Baseline Scenario.

Energy supply trails behind installed capacity by almost half of its value, indicating the efficient utilisation of renewables is a priority that needs to be addressed. Existing Power Purchase Agreements (PPAs) that prioritise the dispatch of the generation capacity from plants under contract, and the limited abilities of the grid network for high uptake of renewables are amongst the key barriers. Technical and regulatory aspects of dispatch management, such as smarter and more flexible grid infrastructures, are required to address higher penetration of RE in the future, with digitalisation of the energy system.

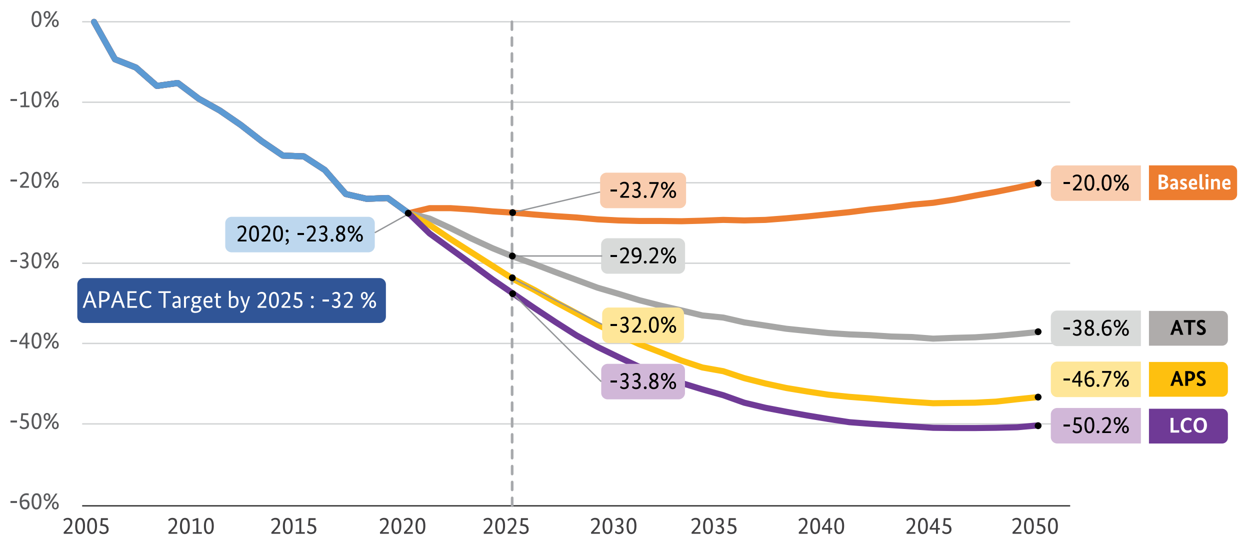
Section 4.4 discusses how the region may **enhance the dispatchability of renewable energy** which includes nascent strategies like expansion of smaller-scale hydropower to support rural electrification, coupling of floating solar plants or wind with hydropower generation. Direct use of RE in the end-user sectors may have as much impact as its deployment for electricity generation in achieving APAEC targets Use of geothermal energy for process heating would also be attractive since Member States such as Indonesia, Malaysia, the Philippines, Thailand, and Vietnam demonstrate considerable quantifiable resources. This is in addition to the established applications of biogas for clean cooking and biofuel in transportation.

Transitioning into higher RE generation requires regulatory interventions and financing. Several programmes being implemented by Member States include imposition of Feed-in Tariffs, Tendering, Net Metering, Biofuel Mandate, Renewable Portfolio Standard (RPS), Tradable Renewable Energy Certificates, and Carbon and Production Taxes. These policies aim to increase the viability of renewable energy uptake by stimulating the energy market. Public investment, loans, grants, capital subsidies, or rebates are also meaningful, wherein government or private investors finance RE and clean energy projects. More detail on **energy transition financing** is found in Section 4.5.

### 3.2.3 Energy Intensity Reduction

The second measurable regional APAEC target is to reduce energy intensity (EI) by 32% by 2025, from 2005 levels, as measured by the ratio of TPES to GDP, in constant 2017 international dollars. The Covid-19 pandemic brought Real GDP (PPP) down 3.4%, and TPES declined 5.8% from the 2019 level, yet efforts to implement the efficiency target are still on track to meet the 2025 goal. As a result, EI reduction in 2020 experienced a resilient effect of a 1.9% increase, as compared to the previous year of 23.8% (Figure 3.20).

**Figure 3.20 Energy Intensity Reduction from the 2005 Level Across Scenarios**



Both pandemic and economic recovery are seen in all AMS, thus it is important to look at how energy and GDP respond going forward via the EI indicator. The analysis shows that if the AMS achieve national targets (ATS), ASEAN will substantially progress in reducing EI by 29.2% in 2025. However, those gains are insufficient to meet the regional EI reduction target in APAEC. This indicates existing national policies do not necessarily result in achieving the APAEC target. At this pace, the 2025 target would only be reached around 2028. Another option to reach the target is by aligning to the LCO Scenario which would lead AMS to a 33.8% reduction from the 2005 level.

Closing the gap by enhancing existing national efforts is the focus of the APS. With few remaining years before 2025, it is crucial to accelerate EE efforts in line with economic recovery, along with continuous monitoring to reflect and improve EE measures. By focusing the measures targeting end-users for the most cost-efficient measures to meet these targets, transportation, cooking, and cooling would create significant energy reductions in overall energy consumption. The inclusion of fuel economy improvements, EV deployments, and mass transportation could ramp up the efforts in transport, as one of the largest demand consumers. Currently, labelling of efficient air conditioning and refrigeration units and by doubling the indicated energy-saving efforts in industrial and commercial sectors, are some of the national policies and priority measures that could be taken by AMS.

By mid-century, gaps between the Baseline Scenario and APS double, compared to 2025. The policies and measures modelled in the APS enable the region to achieve the targets, including a 32% reduction in 2025. By 2050, EI will have been reduced to 46.7% below 2005 levels. Meanwhile, the LCO Scenario offers a relatively greater reduction, as compared to APS. Reductions by as much as 3.5%, equivalent to 50.2%, are indicated for the same year.

Similar to RE deployments, improving the EE of the region would require financial drivers to fund the uptake of clean technologies. In some regions, financial incentives in a form of tax rebates, subsidies, grants, and loans are seen to be effective in encouraging technology-adopters, such as income tax holidays (IHT) and duty exemptions for EV and component manufacturers.

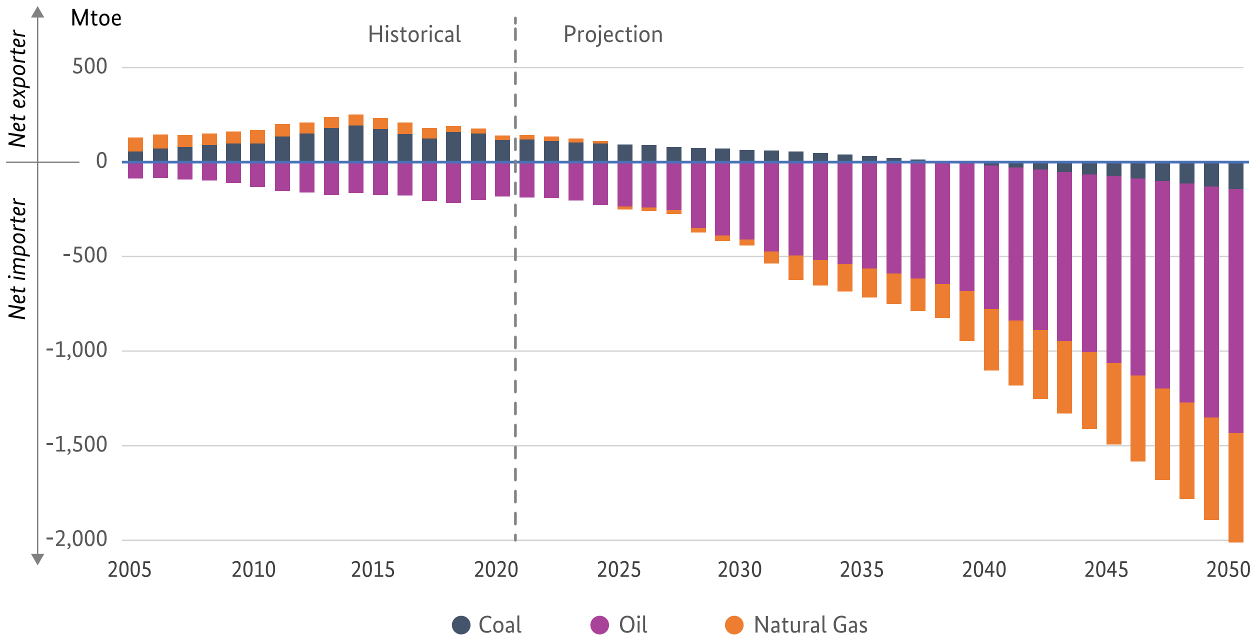
Establishment of public-private partnerships, such as an Energy Service Company (ESCO) to promote solutions to commercial and industrial facilities are gaining momentum. They reduce financial risk in EE&C projects. These policies have been proven effective in several Member States and may also be emulated in other AMS that are seeking to establish EV deployment or EE financing policies.

#### 3.2.4 Energy Imports and Exports

In 2020, natural gas and coal exports exceeded imports at almost 30 Mtoe and 153 Mtoe, respectively. Conversely, ASEAN has been a net oil importer since prior to 2005, with imports outpacing exports by 200 Mtoe. Leading up to 2050, the three sources display different projections in meeting the growing energy demand (Figure 3.21).

In the Baseline Scenario, without significant discoveries or additions to existing production infrastructures and with continuous utilisation of fossil fuels, ASEAN will become a net importer of natural gas and coal as soon as 2025 and 2039, respectively. This poses a significant energy security challenge for the region, as heavy reliance on fossil-fuel imports may affect the affordability of energy, exacerbated by price volatility.

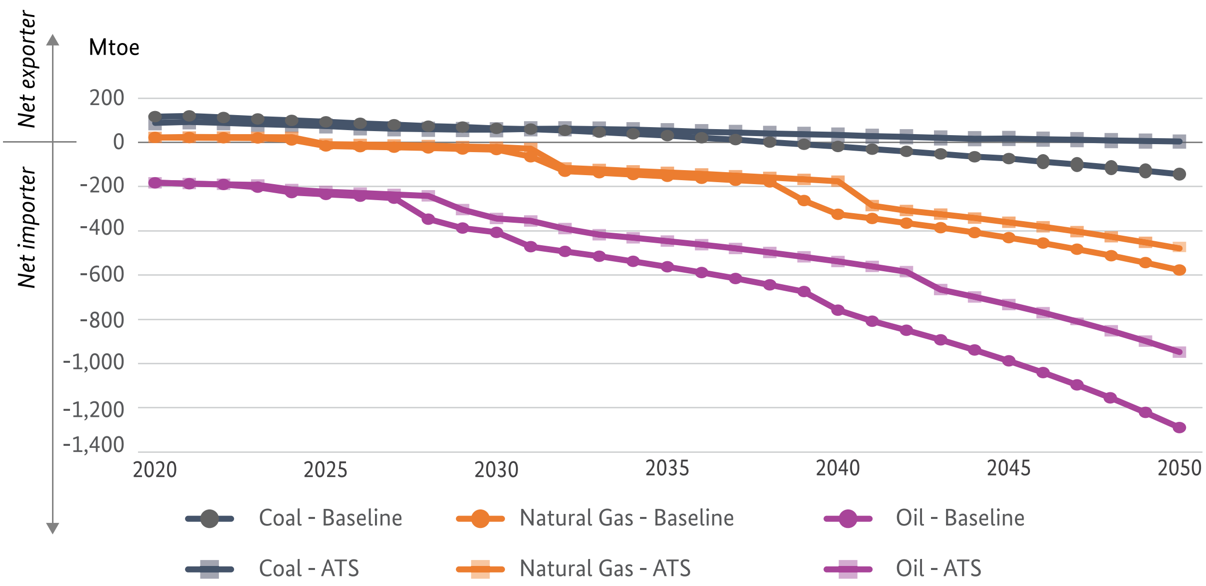
**Figure 3.21 ASEAN Energy Import-Export Balance and Projections, Baseline Scenario**




AMS' natural gas import-export projections show a one-year postponement in the APS and into 2035 in the LCO Scenario. Meanwhile, the shift from coal is pushed into post-2050 in ATS, APS, and LCO Scenario. Over the period, AMS' RE and EE policies will have the resulting effect of less utilisation for fossil fuels, with the addition of more reserves, causing a delay of four years. This condition will continue to extend fossil fuel import dependency leaving regional energy security less vulnerable.

Imports begin in the same year as in the Baseline Scenario, with gaps between exports and imports nearly halved, from -16 Mtoe to -7.5 Mtoe (Figure 3.22). This occurs due to significant supply reduction concentrated on coal, and transitional changes requiring more gas. The reliability of natural gas plays an important role during energy transition, due to RE intermittency. Having a common gas market will increase the security of natural gas supplies. Progress acceleration may be required in the Trans-ASEAN Gas Pipeline (TAGP). Advancing these measures could curb high future gas prices.

**Figure 3.22 ASEAN Energy Trade Balance by Fuel, ATS vs Baseline Scenario**



ASEAN oil imports could be reduced by 26% in ATS, and 34% in APS, in 2050 as compared to the Baseline Scenario. However, under current policies, oil imports in ASEAN are projected to reach 229 Mtoe in 2025 − only 6% less than the Baseline Scenario – and continue to triple by 2050, to an estimated 950 Mtoe. The gap between APS and ATS is only 3% in 2025, and will continue to wane until it reaches 100 Mtoe in 2050.

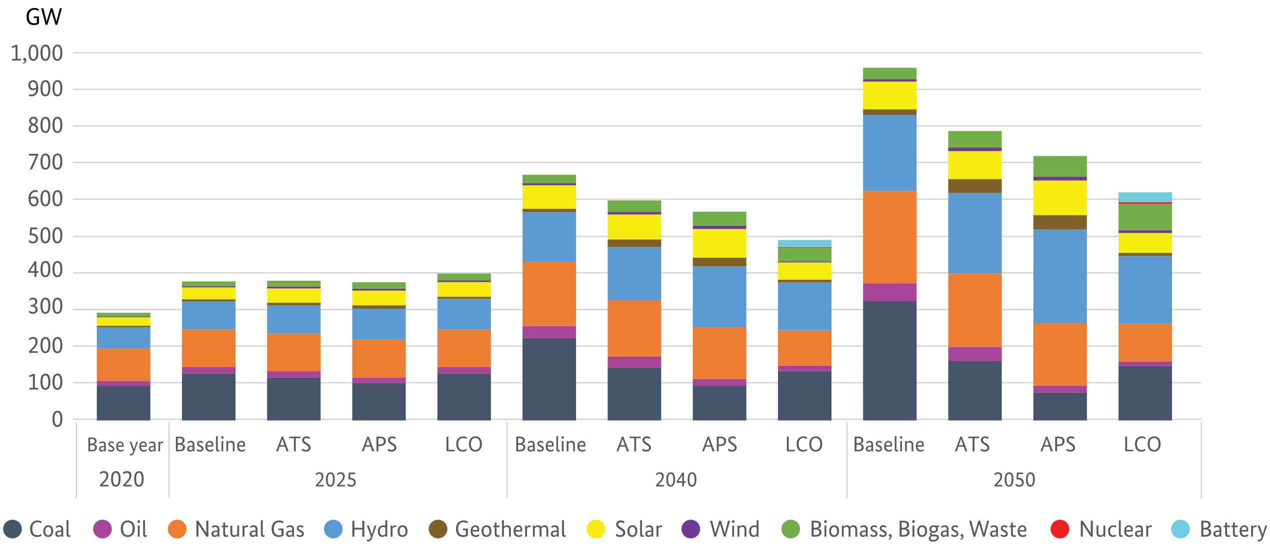
Attainment beyond APS offers the opportunity for the AMS to further delay this occurrence, and eventually detach energy security from reliance on fossil fuels. The way forward in achieving energy security requires ASEAN to focus on providing various indigenous sources of energy, such as renewable and effective use of energy, whilst also considering potential discoveries of new reserves.

## 3.3 Electricity

### 3.3.1 Installed Power Capacity

Historically, ASEAN power capacity is dependent on fossil fuels at around 67% in 2020 as the growth of added RE capacity remained low, and has even declined in the past. The high share of fossil fuels was dominant in both the Baseline Scenario and ATS up to 2050. The APS, however, predicts an equal share for renewables as early as 2033, and RE continue to grow to 63.2% (Figure 3.23).

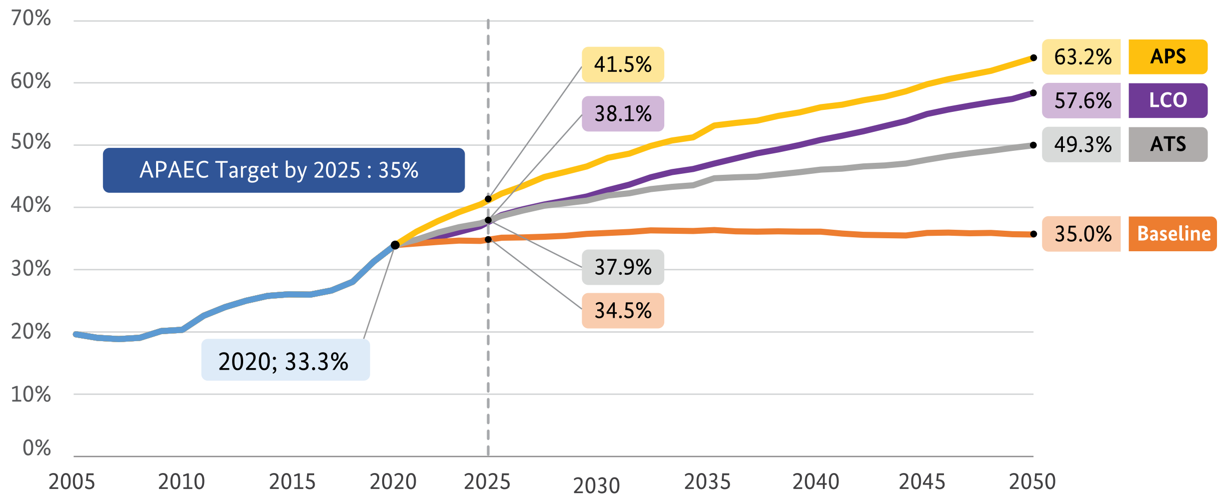
**Figure 3.23 ASEAN Installed Power Capacity by Fuel Across Scenarios**




The power plant capacity and mix needed to supply the respective demands changes with policies as well. In the ATS, 787 GW of power plant capacity is needed to supply the electricity demand, which is dominated by hydropower (27.9%), natural gas (25.3%), and coal third at 20.5%. Based on the PDP of AMS, 60% of the newly installed capacity between 2021-2025 will come from renewables [22]. Solar contributes the greatest total addition until mid-century with 53 GW in ATS and an additional 17 GW in APS.

Despite fossil fuels remaining dominant, ASEAN is on track to achieve the regional target of 35% RE share in installed power capacity by 2025, under various trends. Renewables in the 2020 power capacity amounted to 97.5 GW, equivalent to 33.3%, rising 1.7%. As shown in Figure 3.24, by 2025 the RE installed capacity in the Baseline Scenario reaches 34.5%, whilst the ATS projection shows a 5.1% improvement compared to what was projected in the ATS of AEO6 for 2025 (32.8%). The improvements are the resultof new policies for coal plants and increased RE targets, coupled with reduced electricity usage due to EE&C policies implementation. The RE share projections noted that the regional target will be exceeded by 37.9% (+2.9%) in ATS and 41.5% (+6.5%) in APS by 2025. In the longer term, the RE share by 2050 is projected to reach 35% in the Baseline Scenario, 49.3% in the ATS, and 63.2% in the APS.

**Figure 3.24 Renewable Energy Share in Installed Capacity (2005-2050) Across Scenarios**




The APS required 719 GW of capacity to supply its respective electricity demand with a hydropower dominating the mix at 35.4% capacity share. Solar power also sees an increased share in the mix, rising from the current share of 7.9%, to 13% in 2050. Natural gas will still be crucial in supplying demand, accounting for 23.6% of capacity, especially given that coal experiences significant reduction in share, reaching just 10.6%.

Overall, the RE share in installed capacity is projected to follow incremental growth under all scenarios. Fossil fuel-based installed capacity should decrease, especially with regard to coal and natural gas. Further utilisation of geothermal and hydro would create more momentum for fuel shifting in ASEAN installed capacity (Figure 3.25 and Figure 3.26).

A sufficient power capacity generates the required electricity to meet demand. Reduced demand caused by strict EE measures results in less new capacity being built, as compared to the Baseline Scenario. In the near term, fuel shift trends show that renewables could substitute fossil fuels in ATS, and a slight RE decrease in APS. In the longer term, overall installed capacity will be reduced by as much as 25% by 2050 in APS, primarily due to the phasing out of coal.

The LCO Scenario seeks a technology-neutral approach to the power capacity expansion for ASEAN, in conjunction with the deployment of the APG. Meeting the APAEC targets, whilst controlling technology costs and technical performance, and managing expected improvements through the end of the modelling timeframe, highlights the considerable contribution of coal, natural gas, and hydropower in the capacity mix, resources widely available in the region.

**Figure 3.25 ASEAN Installed Capacity Fuel Shifting in 2025 Across Scenarios**

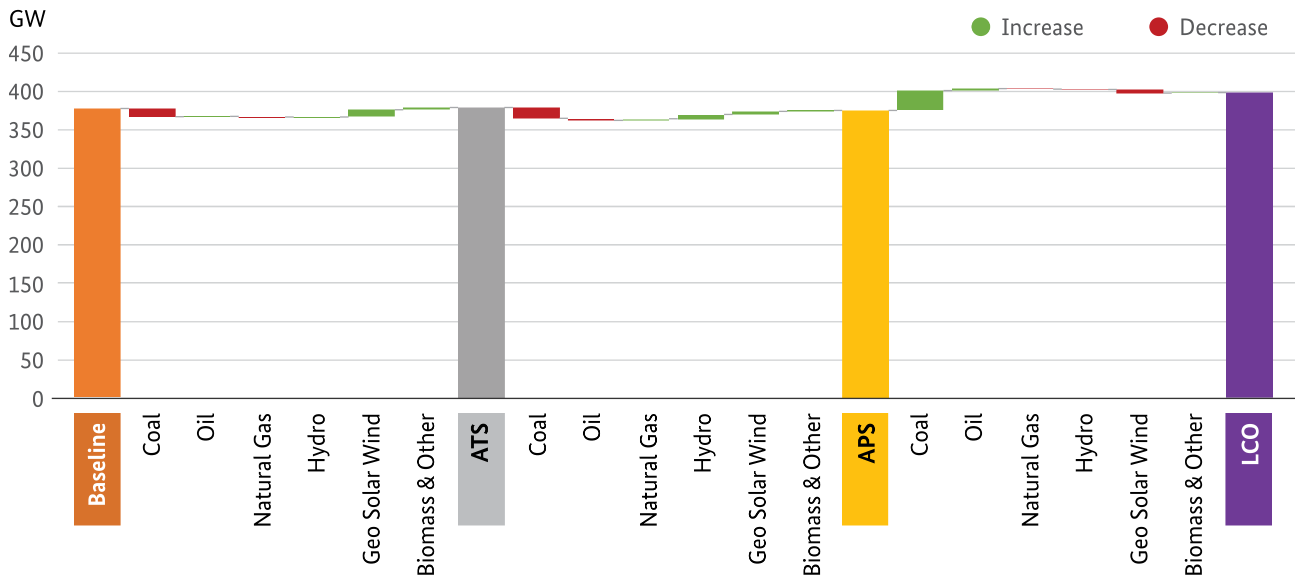
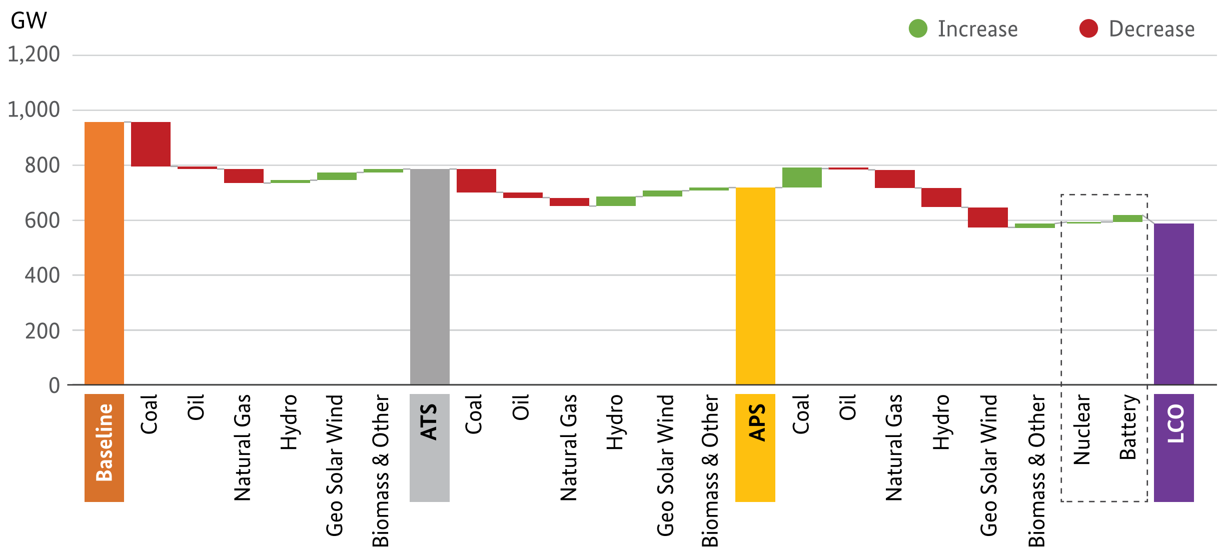



**Figure 3.26 ASEAN Installed Capacity Fuel Shifting in 2050 Across Scenarios**




The installed capacity of coal and natural gas plants is declining as 2050 approaches, which can be attributed to increasing fuel costs as the models progress. For the same reason, the models forecast a shift to building supercritical and ultra-supercritical coal plants rather than less efficient subcritical coal plants. These high-efficiency low emissions (HELE) plants are expected to reach an accumulated 25 GW of installed capacity by 2050. The increasing electricity demand is further served by hydropower and geothermal, with an accumulated capacity in 2050 of 184 GW and 9 GW, respectively. Solar and wind power will also contribute to the mix, reaching an installed capacity of 54 GW and 8 GW, respectively. This increased deployment of renewables implies the need for energy storage (See Section 3.3.5).

The model has a strong preference for lithium-ion batteries over pumped hydro storage. Lithium batteries offer ease of installation, especially attractive for Member States that lack significant hydro resources. The batteries are expected to have an installed capacity of 27 GW by 2050.

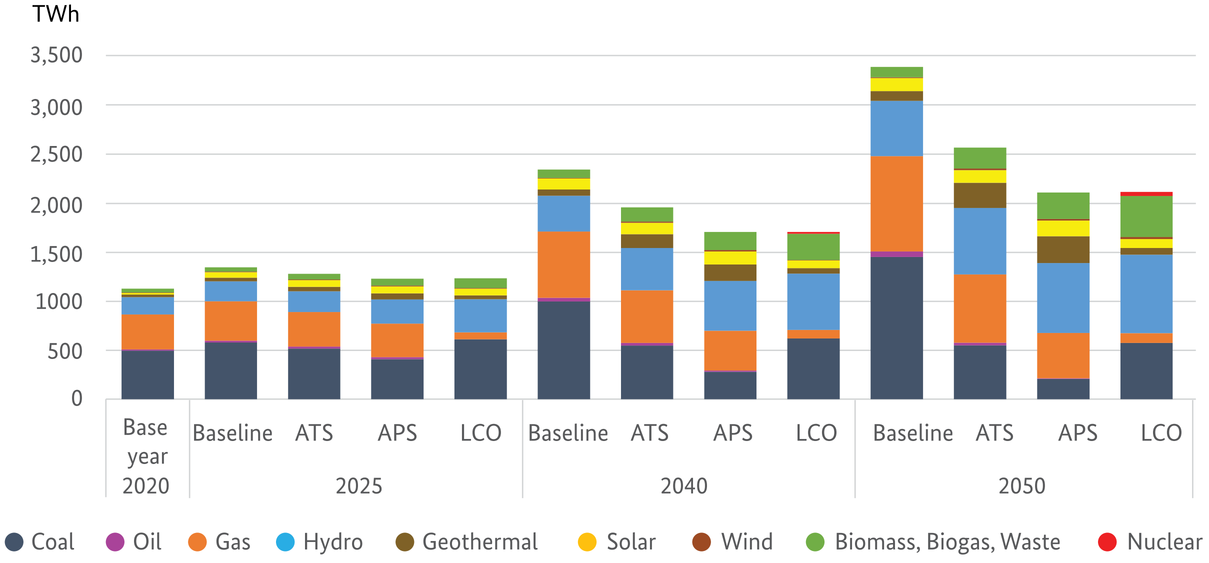
Aside from renewables, deployment of nuclear plants is forecast for later years, reaching about 5.2 GW. Nuclear power was modelled after Generation III reactors, despite higher costs when compared to conventional nuclear technologies currently being deployed in the Asia-Pacific region. However, the preference for nuclear was observed based on the high energy content of the nuclear fuel, offering lower cost for the electricity generated.

Carbon capture and storage retrofits to coal plants were not considered in the LCO Scenario, which is to be expected based on the additional costs, expenses, and energy penalties that it contributes to existing and new coal plants. However, given that CCS could potentially cut 90% of coal plant emissions, future policies on carbon pricing would advance the deployment of this technology.

### 3.3.2 Power Generation

The projections show that AMS will need to generate 1,278 TWh in 2025, to meet the required electricity demand and realise national targets, with ATS running 5% less than the Baseline Scenario (Figure 3.27). By 2050, ASEAN will generate double the 2025 level at 2,565 TWh, for a reduction of 24% relative to the Baseline Scenario. With concerted efforts to reduce fossil fuel usage by 597 TWh, whilst adding 138 TWh of RE-based power, ASEAN will have 2,106 TWh of electricity generation in APS. Improving power sector policies at the regional level such as reduction of thermal dispatch by at least 10% and prioritising RE dispatch and capacity additions in displacing retired plants, ASEAN could substantially reduce fossil-fuel power generation.

**Figure 3.27 ASEAN Power Generation by Fuel Across Scenarios**




Fossil fuels remained the largest share at 76.7% in 2020, and are projected to decline to 4.7% by 2025 in ATS as compared to the Baseline Scenario. A further potential reduction of 6.9% in the APS is also possible. The reduction will primarily come from coal, which is reduced by 62 TWh in ATS, and an additional 107 TWh in APS. The reductions in 2050 are two-thirds for ATS, and even reach seven times less for APS, as compared to the Baseline Scenario.

A significant contributor to the diminished coal trend is the phase-down of existing coal capacity, and pledges during COP26 in 2021, for adherence to the Paris Agreement, where countries began setting specific years in which to stop building new coal power plants. Despite renewable generation projected to grow at 27% in ATS, the share will only overtake fossil fuels by mid-century. It can be accelerated to as early as 2034, if AMS aligns with APS.

Of the three scenarios, only the Baseline Scenario projects coal remaining the single largest energy source. In ATS, natural gas will overtake coal by 10 TWh in 2042. The APS projects the same trend, with natural gas overtaking coal earlier, beginning in 2031. However, natural gas gives way to hydro within five years, outgrowing natural gas by 36.5 TWh.

For renewables, ATS and APS project geothermal to grow exponentially at approximately 87%, as compared to 2020 levels, followed by large hydro plants. Contrary to the Baseline Scenario, all coal technologies (subcritical, supercritical, and ultra-supercritical) and natural gas grow with similar trend lines, ranging from 59% to 72%. Geothermal generation grows with a CAGR of 7.9% in ATS, and 8.1% in APS.

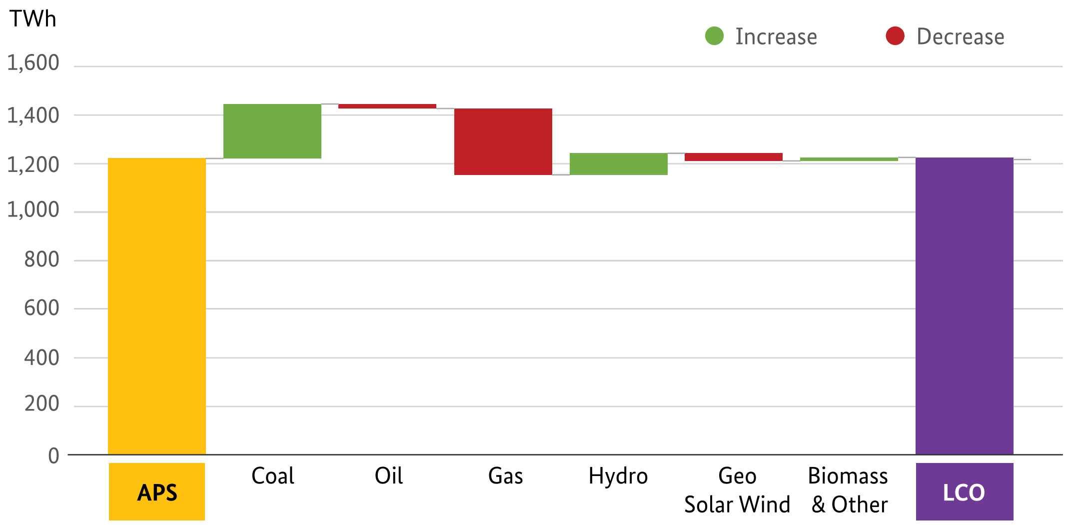
The overall RE share in power generation has an upward trend with different growth rates depending on the scenarios and respective technologies. The average growth in APS is 1.5%, which is somewhat higher compared to ATS at 0.9%, with little significant progress in the Baseline Scenario over the same period. Over the period, RE share in all scenarios is dominated by hydro, equivalent to more than half of the total RE share. The hydro generation rate showed significant growth leading up to 2050, due to the unprecedented capacity addition of variable renewable energy (VRE) between 2018-2020. Solar shows a CAGR of 6.8% in ATS and 7.6% in APS, placing second after geothermal.

Existing national policies enable this progress, but setting a higher target could boost RE penetration. Nuclear would also play a vital role in providing baseload energy, bolstering the utilisation of geothermal and hydro, especially in a carbon-constrained future.

The model maximises the utilisation of coal, hydropower and biomass instead of oil and natural gas, on the premise of finding the least-cost pathway to achieving the APAEC target. This is done primarily by varying builds and dispatch in the power sector. The LCO Scenario estimated that the region would require 620 GW of power plant capacity to generate the same electricity demand in APS. The prevailing cost of oil and natural gas as a fuel is a disadvantage to its dispatch, especially in countries that could generate electricity from multiple sources. The interconnection of AMS through APG permits the reduced usage of natural gas plants, since Member States are able to import from neighbouring countries to cover shortfalls.

The high price of natural gas in comparison to coal forces the energy system to shift up to a 27% share in APS, and 4.6% in the LCO Scenario, to fulfil the same level of generation (Figure 3.28). This corresponds to a decrease of 273 TWh of electricity, as the share of coal increases from 32% to 50%, over the same period. The greater share of RE in the LCO Scenario is achieved with the greater dispatch of renewables, particularly hydro and biomass. This resulting in a much lower percentage from geothermal, wind and solar, despite the capacity additions. This is due to the higher capacity factors, particularly hydropower, that allow fewer capacity requirements to supply the same demand.

Figure 3.28 Power Generation Fuel Shifting in 2025, APS vs LCO Scenario

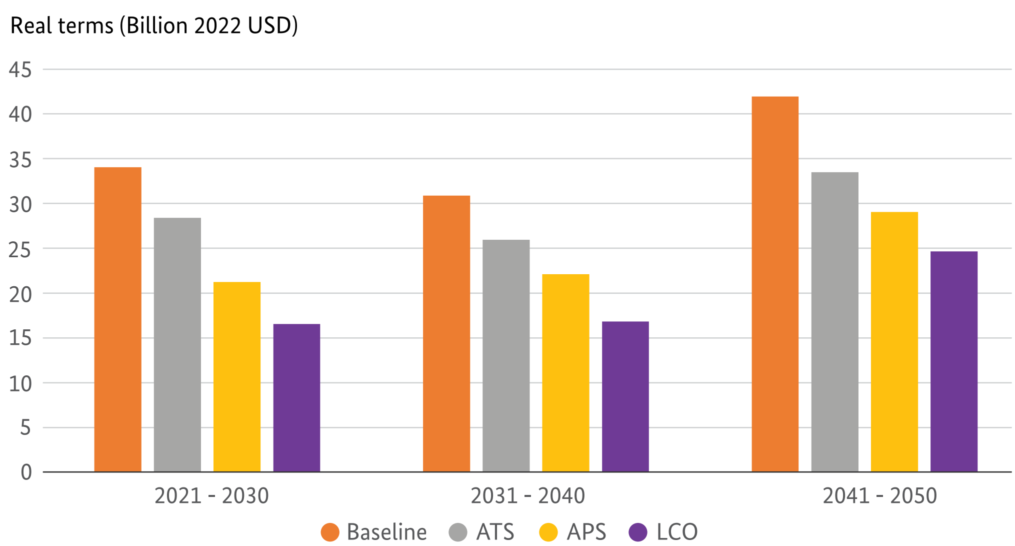



### 3.3.3 Power Sector Investment

Meeting demand growth requires power capacity expansion and investment. According to the Baseline Scenario and ATS, the projected power capacity expansions for ASEAN from 2021 to 2050 will be 636 GW and 454 GW, with the RE share at 35.7% and 60.4%, respectively. In the ATS, solar and coal dominate the capacity addition, with a significant percentage coming from Vietnam. Reaffirming the findings in AEO6, larger investments in the early years of transition are substantially derived by RE, due to higher up-front costs.

The power sector investment cost is strongly impacted by successful implementation of EE strategies by end-users. As shown in Figure 3.29, the APS and LCO Scenario demonstrate the lowest power generation investment requirements in the later years, amongst all scenarios, highlighting lower electricity demand brought about by improved energy intensity, particularly in the industrial, commercial, and residential sectors. In earlier years (2021-2030), the annual power investment requirement varied from USD 16 billion to USD 34 billion. In the mid-term (2031-2040), all scenarios except the APS, follow a declining trend reaching the lowest value of USD 17 billion for the LCO Scenario. In the long-term, as the region requires new builds to meet the higher energy demand, annual power investment ranges from USD 24 billion to USD 42 billion.

Figure 3.29 Annual Power Investment Cost Across Scenarios

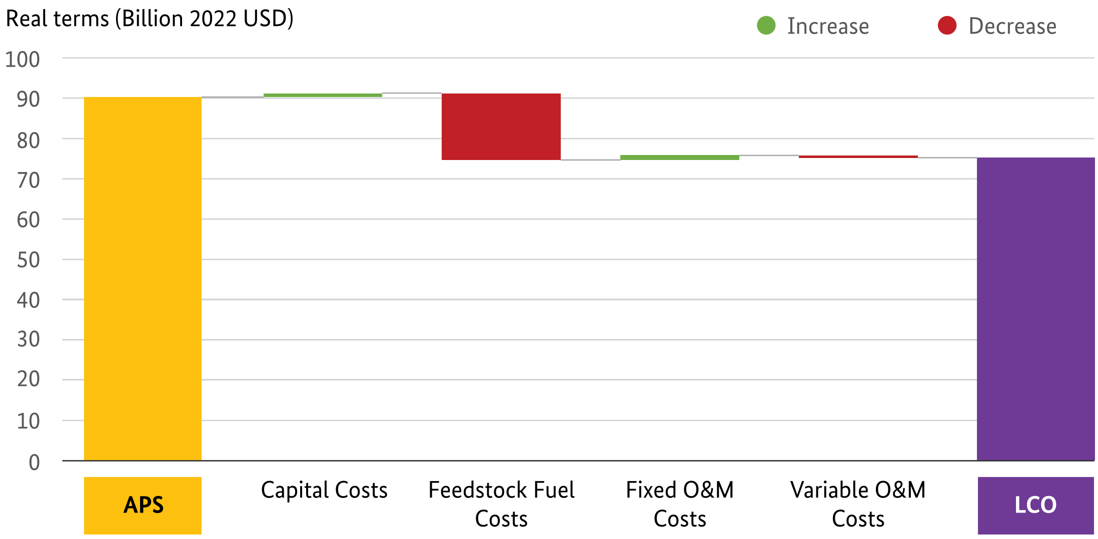


The total required investment to support the power expansion in earlier years is USD 341 billion in the Baseline Scenario, USD 284 billion in ATS, USD 213 billion in APS, and USD 166 billion in the LCO Scenario. In ATS, the investment will peak in 2021 at USD 58 billion, with the ensuing trend continuing to go downwards. APS and the LCO Scenario require higher upfront investment as well, peaking at USD 40 billion and USD 23 billion in 2021, respectively. The cost of RE has increasingly undercut fossil fuels, as compared to a decade ago [23], resulting in a shift in technology utilisation, especially given the recent war in Ukraine that driven higher fossil fuel prices, which are forecast to rise 50%, with the highest projection showing coal prices rising as high as 80% [24].

Overall, the total required investment in 2021-2050 is USD 1,070 billion for the Baseline Scenario. An expected capital requirement reduction resulting from demand-side management could reduce required investment to USD 879 billion and USD 726 billion for ATS and APS, respectively. On average, RE investment accounts for about 59% in ATS and 77% in APS of the total investment required for the power sector. The LCO Scenario only requires USD 582 billion, about 80% of the APS. A notable addition to the investment cost is nuclear energy, which may account for up to 2.9% of power investments in later years.

A cost-optimised energy system posits a production cost of USD 75 billion in 2025, including the cost of developing APG and energy storage. The cost difference in LCO Scenario was significantly driven by cost-savings of USD 16 billion for fuel, which is about 45% lower than APS. The LCO Scenario includes an additional capacity, which results in using less expensive fuel sources, as demonstrated in Figure 3.30.

**Figure 3.30 Power System Cost Shifting in 2025, APS vs LCO Scenario**



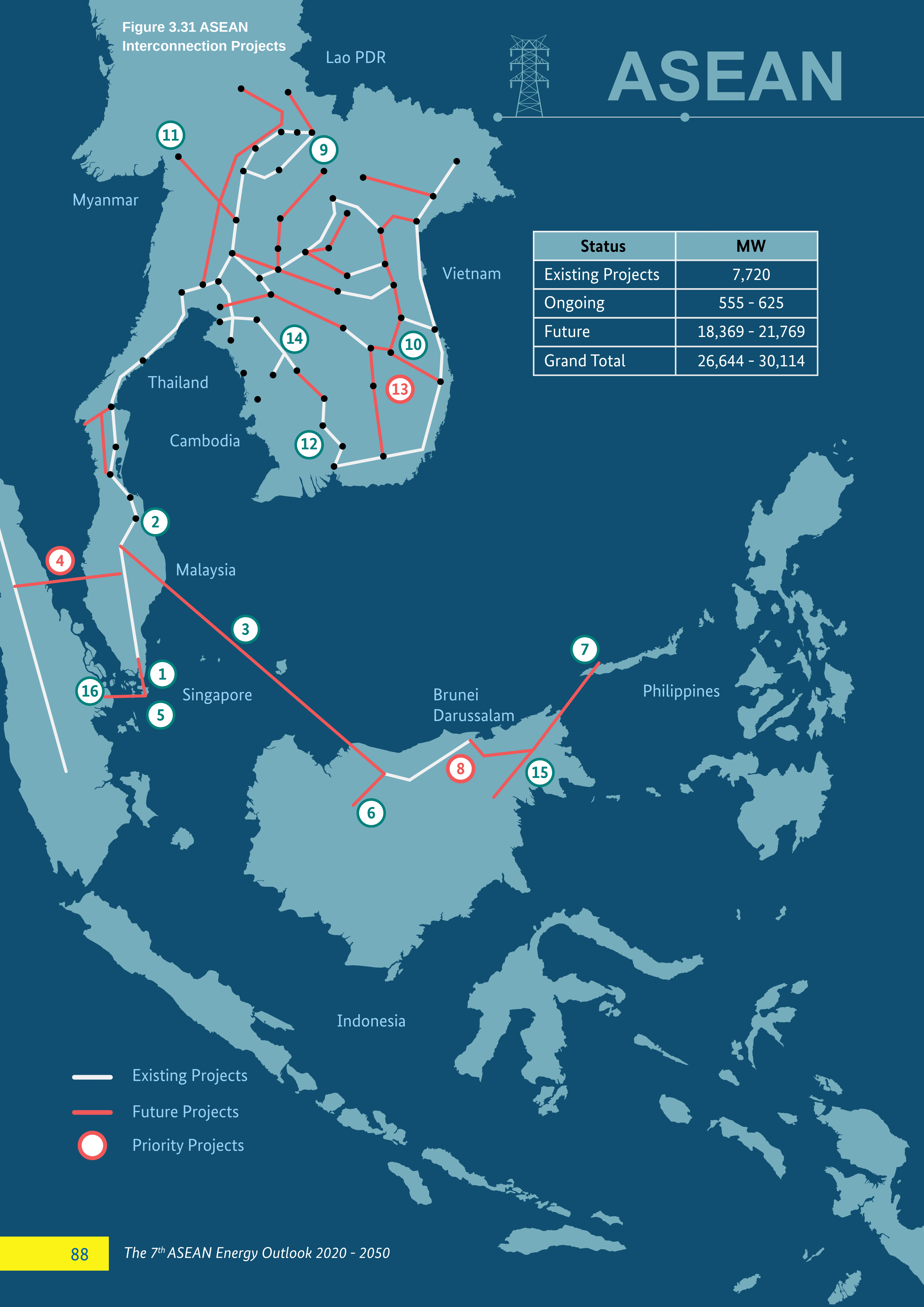

In the long-term, the increase in the overall cost of production is more apparent, with a total cost of APS at USD 338 billion and the LCO Scenario at USD 111 billion in 2050. However, the generation mix of the least-cost pathway shifts utilisation from cleaner natural gas to coal. The LCO Scenario is expected to have higher emissions than the non-optimised scenarios. This, in turn, could potentially increase externality costs placing an unwanted burden on society.

### 3.3.4 ASEAN Power Grid (APG)

Another aspect explored in the LCO Scenario was the impact of APG on the region's power balance. The AIMS III study consolidated and explored the deployment of existing, ongoing and proposed interconnection projects in the region, including their capacity, expected operation dates, and construction cost (Figure 3.31).

Figure 3.31 ASEAN Interconnection Projects

# ASEAN




| Status | MW |
|---|---|
| Existing Projects | 7,720 |
| Ongoing | 555 - 625 |
| Future | 18,369 - 21,769 |
| Grand Total | 26,644 - 30,114 |

# Interconnection Projects

| Number | Country Involved | Project | Earliest COD |
|---|---|---|---|
| 1 | Peninsular Malaysia - Singapore | Plentong - Woodlands<br>Second Link Plentong | Existing<br>2020 |
| 2 | Thailand - Peninsular Malaysia | Sadao - Chuping<br>Khlong Ngae - Gurun<br>Su Ngai Kolok - Rantau Panjang<br>Khlong Ngae - Gurun (Second Phase) | Existing<br>Existing<br>TBC<br>TBC |
| 3 | Sarawak - Peninsular Malaysia | Sarawak - Peninsular Malaysia | TBC |
| 4 | Peninsular Malaysia - Sumatra | Peninsular Malaysia - Sumatra | TBC |
| 5 | Batam - Singapore | Batam - Singapore | TBC |
| 6 | Sarawak - West Kalimantan | Sarawak - West Kalimantan | TBC |
| 7 | Philippines - Sabah | Philippines - Sabah | TBC |
| 8 | Sarawak - Sabah - Brunei | Sarawak - Brunei Darussalam<br>Sarawak - Sabah | 2021<br>2022 |
| 9 | Thailand - Lao PDR | Nakhon Phanom - Thakhek - Theun Hinboun<br>Ubon Ratchathani 2 - Houay Ho<br>Roi Et 2 - Savannakhet - Nam Theun 2<br>Udon Thani 3 - Na Bong - Nam Ngum 2<br>Nakhon Phanon 2 - Thakhek - Theun Hinboun (Exp.)<br>Mae Moh 3 - Nan2 - Hong Sa (3 Units)<br>Udon Thani 3 - Na Bong (Converted to 500 KV)<br>Ubon Ratchatchani 3 - Pakse - Xe Pian Xe Namnoy<br>Khon Kaen 4 - Loei 2 - Xayaburi<br>Thailand - Lao PDR | Existing<br>Existing<br>Existing<br>Existing<br>Existing<br>Existing<br>Existing<br>Existing<br>Existing<br>TBC |
| 10 | Lao PDR - Vietnam | Xekaman 3 - Thanh My<br>Xekaman 1 - Pleiku 2<br>Nam Mo - Ban Ye<br>Luang Prabang - Nho Quan | Existing<br>Existing<br>TBC<br>TBC |
| 11 | Thailand - Myanmar | Thailand - Myanmar | TBC |
| 12 | Vietnam - Cambodia | Chau Doc - Takeo - Phnom Penh<br>Tay Ninh - Stung Treng | Existing<br>TBC |
| 13 | Lao PDR - Cambodia | Ban Hat - Kampong Sralao<br>Ban Hat - Stung Treng | Existing<br>Existing |
| 14 | Thailand - Cambodia | Watthana Nakhon - Aranyaprathet - Nateay Maenchey<br>Thailand - Cambodia | Existing<br>Post-2020 |
| 15 | East Sabah - North Kalimantan | East Sabah - North Kalimantan | TBC |
| 16 | Singapore - Sumatra | Singapore - Sumatra | TBC |

COD stands for Commercial Operation Date
TBC stands for to be confirmed
Existing stands for existing projects as of August 2020
Priority Projects refer to the APAEC 2016-2020, are indicated in red

The model shows a high preference for utilising existing and ongoing interconnections, particularly in neighbouring AMS, rather than building and operating additional plants to generate power requirements in several AMS. Indicative interconnection projects include Thailand – Peninsular Malaysia (2c, 2d), Peninsular Malaysia – Sumatra (4), Sarawak – Brunei Darussalam (8a), Lao PDR – Vietnam (10c, 10d), Thailand – Myanmar (11), and Thailand – Cambodia (14). These projects demonstrate the importance of regional load balancing, with cited projects to be operational as early as 2025, for all except the Philippines – Sabah line in 2030. The model projects least-cost transmission expansion as shown in Table 3.1.

**Table 3.1 ASEAN Interconnection Project Expansion Plan, LCO Scenario**

| Future Projects | Construction Year (Capacity) | Total Construction Capacity (MW) |
|---|---|---|
| Thailand – Peninsular Malaysia | 2025 | 400 |
| Peninsular Malaysia – Sumatra | 2025 | 600 |
| The Philippines – Sabah | 2030 (70 MW)<br>2031 (230 MW)<br>2032 (200 MW) | 500 |
| Sarawak – Brunei Darussalam | 2025 (180 MW)<br>2026 (120 MW) | 300 |
| Lao PDR – Vietnam | 2025 | 4,462 |
| Thailand – Myanmar | 2025 | 1,104 |
| Thailand – Cambodia | 2025 (590 MW)<br>2036 - 2043 (1,604 MW) | 2,200 |

With this configuration, the import-export balance of electricity amongst Member States in relevant years is summarised in Table 3.2.

**Table 3.2 ASEAN Interconnection Projects Electricity Import (+) / Export (-) Balance in LCO Scenario**

| | Net Import/Export (GWh) | | | | % of Domestic Generation | | | |
|---|---|---|---|---|---|---|---|---|
| | 2025 | 2030 | 2040 | 2050 | 2025 | 2030 | 2040 | 2050 |
| Brunei Darussalam | -526 | -3,504 | -3,504 | 875 | 8.34 | 36.89 | 34.12 | 12.27 |
| Cambodia | -2,468 | -71 | -2,055 | -14,197 | 21.71 | 0.61 | 11.46 | 45.01 |
| Indonesia | -1,519 | -624 | 1,115 | 7,271 | 0.45 | 0.16 | 0.22 | 1.15 |
| Lao PDR | -4,575 | -8,349 | -8,901 | -58,326 | 10.09 | 16.33 | 16.29 | 54.26 |
| Malaysia | -1,765 | -686 | -12,215 | -27,851 | 0.95 | 0.35 | 5.62 | 11.07 |
| Myanmar | -6,326 | -8,603 | -7,850 | -7,634 | 22.01 | 23.44 | 19.83 | 17.86 |
| Philippines | 0 | -294 | 2,433 | 4,380 | 0.00 | 0.20 | 1.34 | 1.93 |
| Singapore | 3,199 | 4,225 | 8,067 | 9,198 | 6.09 | 7.68 | 13.74 | 15.69 |
| Thailand | 58,850 | 52,357 | 58,512 | 48,953 | 46.38 | 32.51 | 27.40 | 15.96 |
| Vietnam | -44,869 | -34,451 | -35,602 | 37,330 | 14.71 | 10.64 | 8.95 | 8.37 |

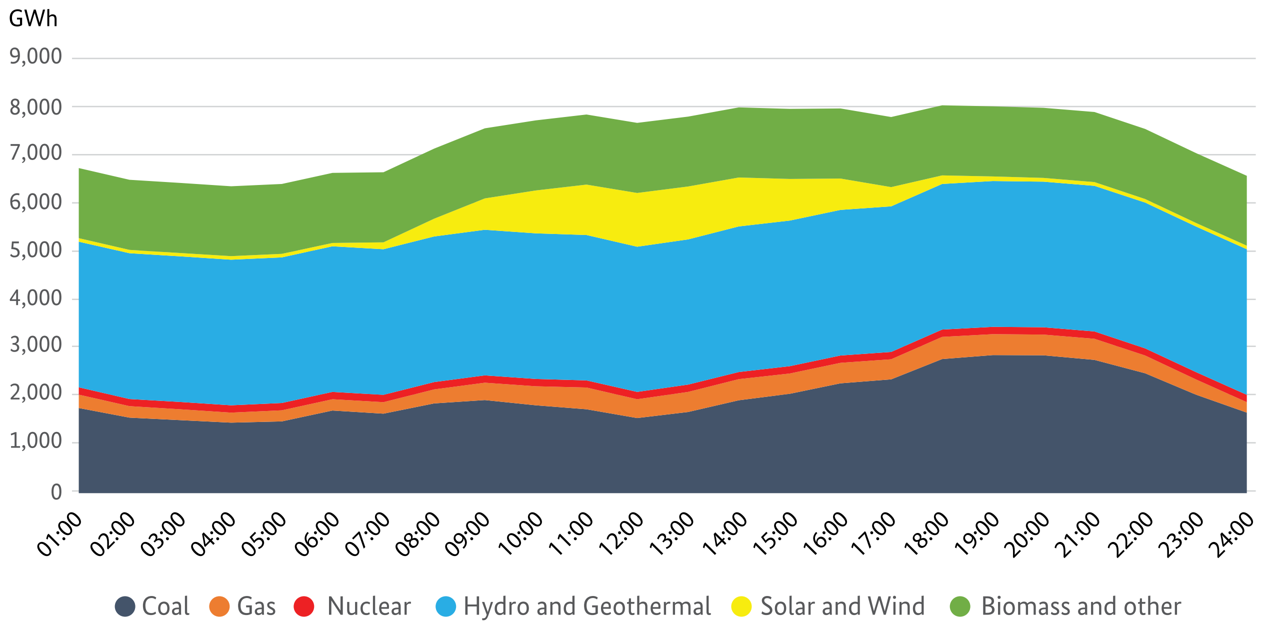
*Note: Result may not necessarily reflect AMS import/export targets.*

The largest electricity importers in the region are seen to be Thailand and Singapore, sourcing around 31% and 11% on average of their electricity demand from neighbouring countries throughout the modelling period. Meanwhile, the largest exporters are Lao PDR, Brunei Darussalam, Myanmar, and Cambodia, which allocate on average 24%, 23%, 21% and 20% of their electricity generation for transmission to neighbouring countries.

### 3.3.5 Battery and Energy Storage Utilisation

Battery Energy Storage System (BESS) is crucial in achieving higher penetration of renewable energy and maintaining the stability of the power grid. In the LCO Scenario, wherein batteries are deployed in parallel with the construction of future APG lines, the observed hourly dispatch behaviour by 2050 is shown in Figure 3.32.

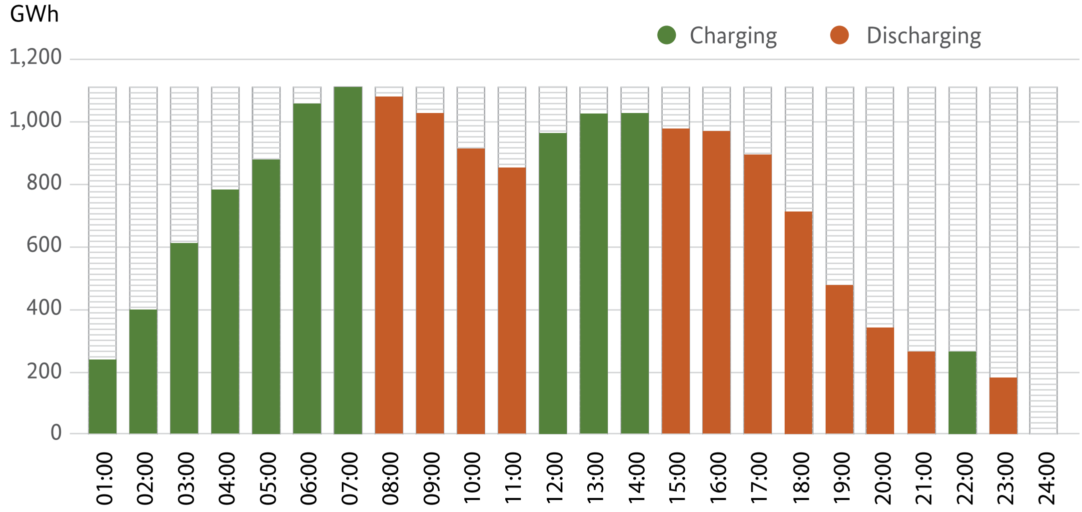
**Figure 3.32 Average ASEAN Hourly Generation Mix**




Hydropower and geothermal plants act as baseload generators, along with biomass and nuclear power plants. Solar and wind, as variable renewables, contribute most during the daytime (07:00 – 17:00), peaking at 12:00 – 13:00. Coal plants remain a consistently large share of power during the daytime, but are expected to generate a larger supply during the hours 18:00 – 22:00. Note that this is time period when people return home from school and work, with the greatest activities at home. At the same time, solar generation is lowest, requiring another source to supplement the deficit. Gas plants are another constant source of electricity but acting more as peaking plants. It dispatches most at 11:00, before the solar and wind power peak, and at 18:00 when solar and wind power decline, whilst residential energy demand peaks.

During the hours when energy demand is low (01:00 – 07:00) in the residential, industrial, and commercial sectors, batteries allow power storage from baseload plants. As shown in Figure 3.33, a 27 GW battery capacity could store an average of 1,100 GWh of electricity during the night hours, which is expended during two specific period: 08:00 – 11:00 and 15:00 – 24:00. Batteries also offer storage during the mid-day when solar and wind generation is at its peak (12:00 – 14:00), holding around 175 GWh from these sources.

Figure 3.33 ASEAN Battery Storage Hourly Usage in 2050, LCO Scenario



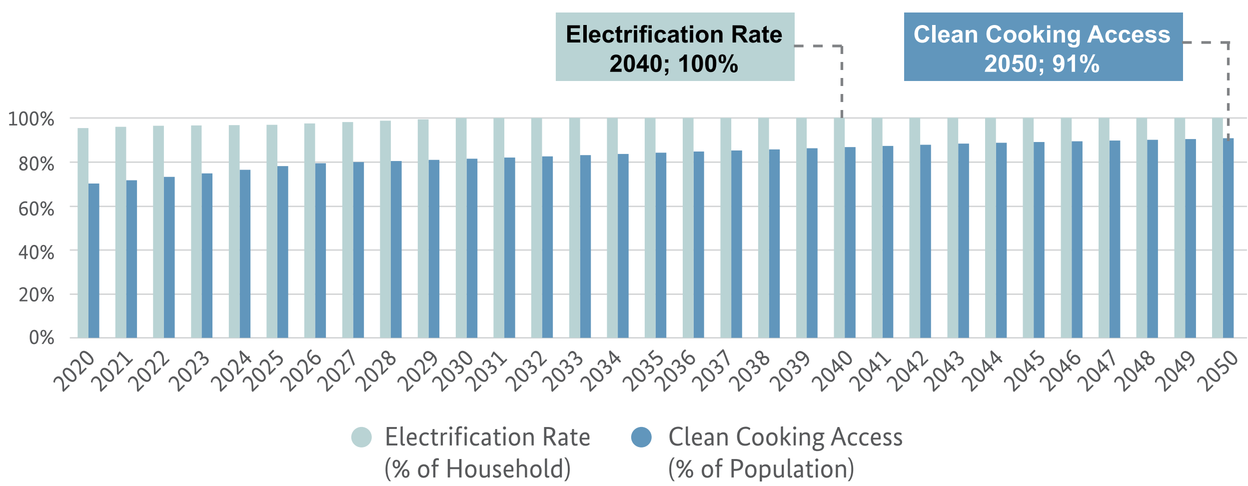

## 3.4 Energy Access

Energy access revolves around projected electrification rates and clean cooking access, which is a critical part of the SDG7 priority, to ensure universal access. According to the Baseline Scenario, ASEAN will shortly achieve the SDG7 target. Seven of the AMS are expected to achieve a 100% household electrification rate by 2030, whilst Cambodia will reach 95%, Lao PDR 98%, and Myanmar 61%.

Myanmar, which had the lowest rate amongst ASEAN countries with a 51.7% electrification rate in 2020, has committed to filling the 48.3% gap in less than a decade. With a focused effort, Lao PDR could fill its 5% gap, pushing the ASEAN electrification rate to 99.9% by 2030. The 0.1% gap can be filled by further encouraging Cambodia's electrification effort from 95% to 100%. The required average annual electrification growth is 0.5%.

Under the ATS and APS, Indonesia and the Philippines are expected to achieve 100% electrification by 2022. Lao PDR and Myanmar are also expected to increase their energy generation to fulfil the demand for universal electrification by 2030, with an average annual growth rate of 0.5% and 6.9% respectively, over the period of 2021-2030. Cambodia will be the final country in ASEAN to fully electrify all households by 2040 under ATS and APS. Thus, the universal electrification of ASEAN would meet the SDG7 target by 2040 (Figure 3.34).

Figure 3.34 ASEAN Electrification Rate and Clean Cooking Access, ATS



The challenge of 100% electrification is enhanced by inadequate transmission and distribution lines, especially for the most remote and difficult-to-reach communities. This is due not only to geographical barriers, but also issues of quality of electricity, reliability of power supply, and affordability of price, which aligns with the modern energy minimum [25]. In addition, diversification of electrification measures, such as grid extensions, stand-alone power systems, and mini grids could boost this effort.

Access to electricity and improved standards of living have led countries to increase their reliance on electrical appliances, including clean cooking. For low-income households in the ASEAN region, the cost of clean cooking solutions remains a significant barrier. Besides inefficiency use of wood, the transition to cleaner cooking technologies could also avoid unregulated deforestation, habitat loss, higher risk of landslide, and flood damage, hence slowing climate change. Out of the seven AMS that have not yet reached universal clean cooking access as of 2020, only four countries (Cambodia, Lao PDR, Myanmar, Vietnam) have set specific targets.

In ATS, Indonesia is expected to reach 100% clean cooking access by 2026, before the SDG7 target year. Vietnam is set to achieve universal access to clean cooking by 2036. Another four countries, specifically Cambodia, Lao PDR, Myanmar, and the Philippines, will not achieve 100% before 2050. Hence, there are still significant efforts to be made, since the accumulation of clean cooking access in the ASEAN region is expected to be 90.7% by mid-century.

Indonesia, Thailand, and Vietnam will only achieve 100% clean cooking by 2050, though this may be accelerated under APS. Assuming biomass will not be used at all by 2030, LPG will prominently supply roughly 70% of cooking demand in ASEAN, followed by electricity. Advances in clean cooking in ATS would not suffice to meet SDG7 targets.

In APS, the energy demand for cooking amongst all AMS is projected to decline from 36.2 Mtoe in 2021 to 22.3 Mtoe in 2050. This is primarily due to a reduction in traditional fuel consumption, including bagasse, charcoal, coal, kerosene, other biomass, and wood. Wood had the second largest share at 28.2% of total energy demand for cooking in 2020, but is projected to have only a 4.4% share in 2050.

The contribution of clean fuels, such as electricity and LPG, is expected to grow 28.2% and 57.2% respectively, by 2050. The projected energy demand for cooking in APS sees clean fuels rising to over 85%, whilst roughly 24% will be supplied by traditional fuels by 2050.

According to APS, universal clean cooking in Indonesia will be deployed with a near term AAGR of 4.3% from 2020 to 2024, and 0.2% in Malaysia for the period 2020-2025. Although more than 50% of the overall AMS population will be able to afford clean cooking by 2030, Lao PDR remains at the low end with 13.9%. Thailand will achieve 100% clean cooking access by 2036, with a steady AAGR of 1.13% in APS. APS projects universal clean cooking access in Myanmar and Vietnam by 2044. However, ASEAN is not expected to accomplish SDG7 targets until 2050, due primarily to total clean cooking access reaching 36.7% in Lao PDR, and 66.1% in the Philippines. Although APS does not forecast 100% clean cooking access in ASEAN by 2050, it does project a higher penetration rate of 90.28%, as compared to 78.6% in the Baseline Scenario and 85.2% in ATS, for the same period.

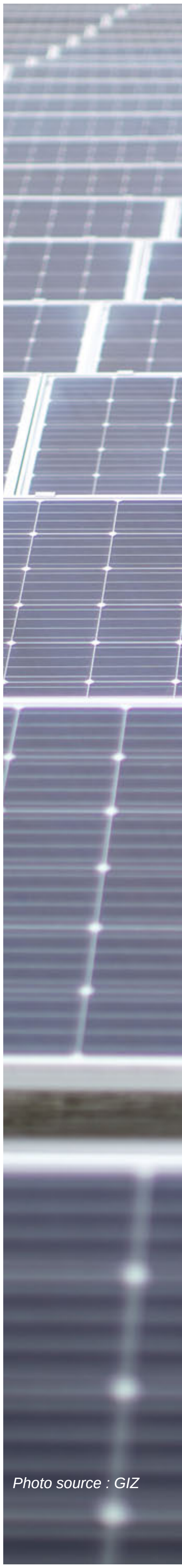
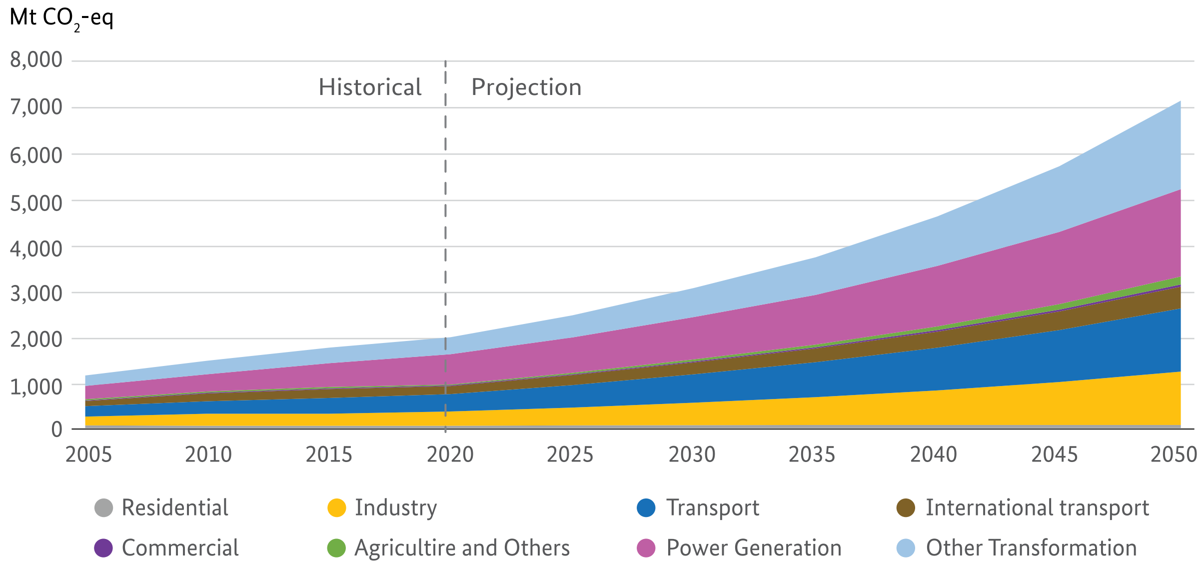


*Photo source : GIZ*

## 3.5 GHG Emissions

The rapid growth of fossil fuel consumption and air pollution raise environmental concerns related to $CO_2$ emissions that harm public health. In 2020, energy-related GHG emissions in the ASEAN region were approximately 1,991 Mt $CO_2$-eq. With regard to the expected outlook for the near term, energy-related GHG emissions in the Baseline Scenario are predicted to reach 2,471 Mt $CO_2$-eq by 2025, with electricity and transportation contributing the highest share through 2050 (Figure 3.35). Electricity, including power generation and transformation processes, accounts for about 51% of total GHG emissions from energy consumption in 2025, followed by transportation with 20%. Without significant reductions in global GHG emissions, the risk in AMS is vulnerability to severe climate change impacts. Some countries have already faced severe weather, including droughts, floods, and typhoons. The Philippines ranked first in terms of the number of people affected by natural hazards, followed by Thailand and Vietnam [26], and there may likely be additional regional risks from natural disasters in the future.

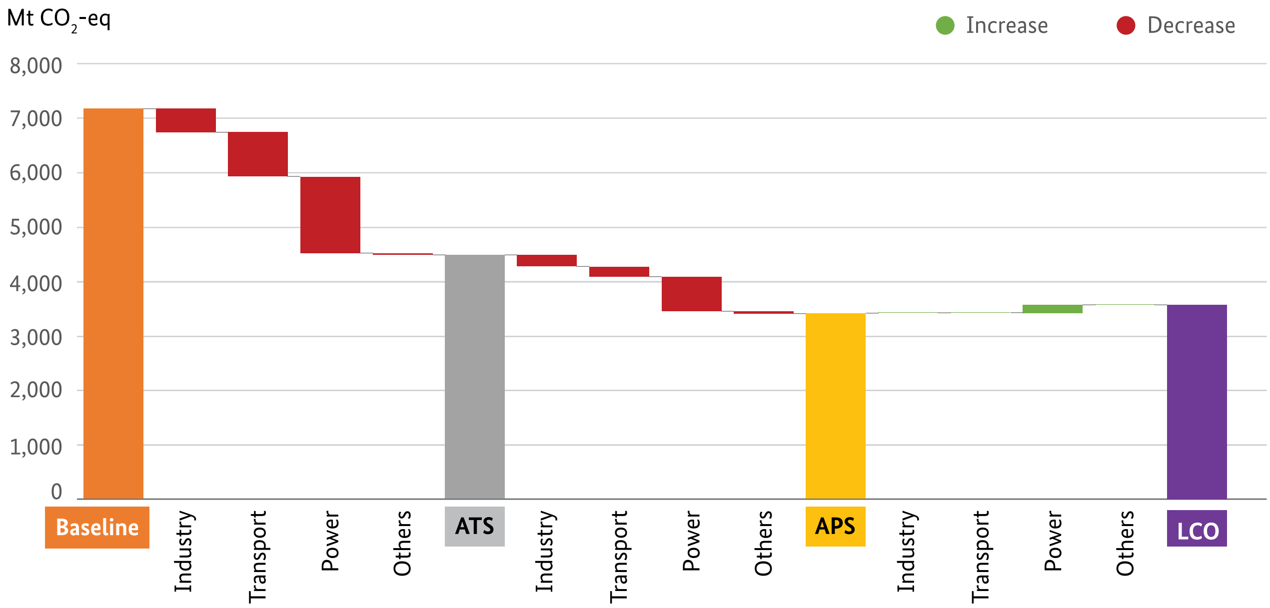
**Figure 3.35 GHG Emissions Produced by Sector, Baseline Scenario**




Under ATS, the ASEAN region is expected to produce total energy-related GHG emissions of 4,503 Mt $CO_2$-eq in 2050, across all sectors. This represents a 37% decrease from the Baseline Scenario (Figure 3.36). The power sector will contribute the highest share of GHG emissions at 54% in 2050. In contrast, the commercial sector is expected to hold a marginal share in direct GHG emissions in 2050 with less than 1% in 2050. On the other hand, the commercial sector could significantly reduce emissions by greening its transportation. For example, large corporate vehicle fleets and deliveries from retail stores could be electrified, and the commercial sector could play a leading role in accelerating the decarbonisation of the transport sector. The emission reduction in ATS can be realised by adequately implementing existing policies in the AMS, with reference to their emission targets stated in their respective NDCs.

With regard to APS, where the APAEC targets are realised by 2025, a more apparent trend in data can be observed. The ASEAN region is projected to produce 3,440 Mt $CO_2$-eq GHG emissions in 2050, which represents a reduction of 23.6% over ATS. From the analysis, the Power sector under APS will be expected to contribute roughly 53% to total GHG emissions, followed by the industrial sector at 15.3%.

**Figure 3.36 GHG Emissions Reduction by Sector in 2050 Across Scenarios**




*Note: Others include Residential, Commercial, and Agriculture. Power includes Power Generation and Other Transformation.*

There is significant potential to reduce GHG emissions in APS by 2050 in the power, transportation, and industrial sectors, assuming proper policy execution and strong planning with regional cooperation. Lower emissions in the power sector come from an increase in the share of electricity generation from RE sources, enhanced by EE measures on the demand side. In the transportation sector, emission reductions are realised from lower diesel and gasoline consumption in road transportation, resulting from electrical transportation shifting.

In order to identify the relative importance of various GHG emissions drivers in the scenario analysis, a decomposition analysis was conducted based on the Kaya identity equation [27]. This makes it possible to quantify the assessment and relative impact on GHGs identified from population growth, income (as GDP per capita), energy intensity (as TPES/GDP), and carbon intensity of energy (as energy GHGs/ TPES). The detailed equation can be found in Appendix D.4.3. Under the Baseline Scenario (Figure 3.37), the analysis shows that GDP growth is by far the strongest driver of energy emissions growth in 2050, at approximately 7,101 Mt $CO_2$-eq, with some contributions from increased population and energy supply carbon intensity, accounting for 476 Mt $CO_2$-eq and 389 Mt $CO_2$-eq, respectively. At the same time, a reduction in the economic energy intensity offsets the emissions increase by about 1,940 Mt $CO_2$-eq. However, this is not enough to avoid a sharp overall rise in GHG emissions.

The analysis identified the key drivers that lead to lower GHG emissions in the ATS relative to the Baseline Scenario in 2050. Figure 3.38 shows that decreases in GHG emissions from 7,178 Mt $CO_2$-eq in the Baseline Scenario to 4,503 Mt $CO_2$-eq in ATS are due to reductions in the energy intensity of the economy as the largest contributor at 1,545 Mt $CO_2$-eq, and the carbon intensity of the energy supply by 1,129 Mt $CO_2$-eq. This shows that the measure of the EE policy will have a significant effect on reducing GHG emissions.

**Figure 3.37 Decomposition Analysis of GHG Emissions**

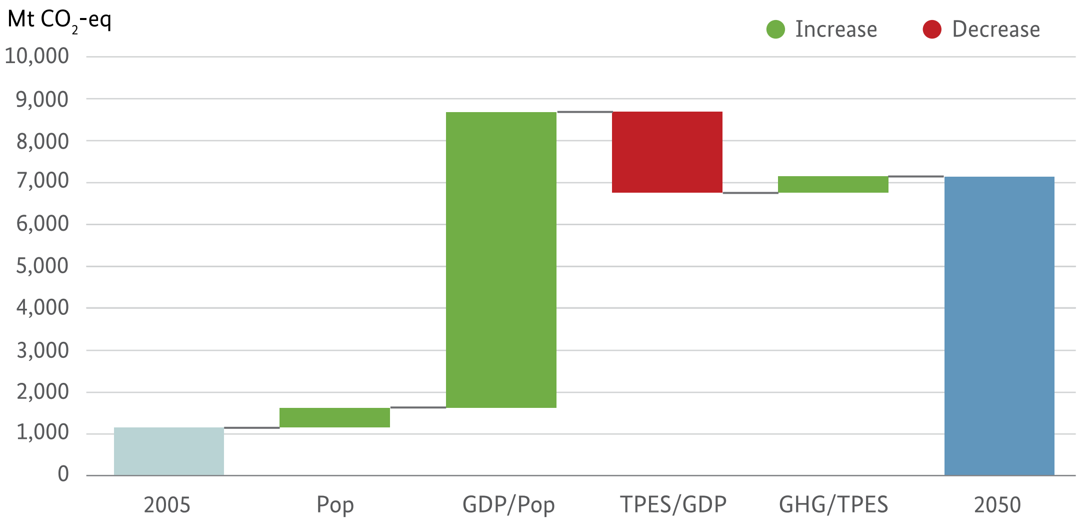
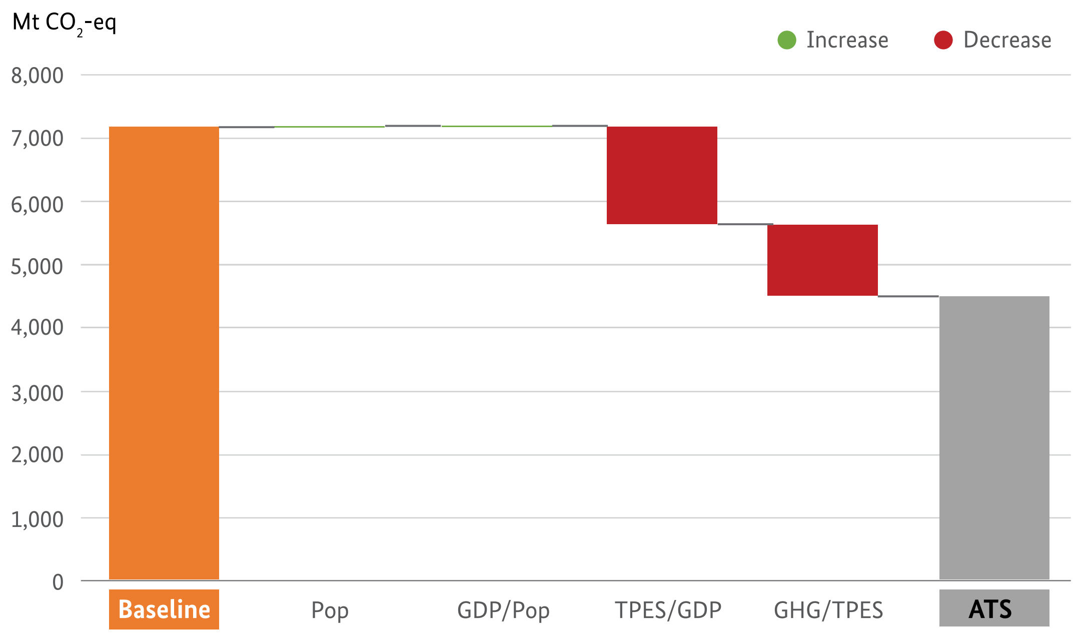



**Figure 3.38 Key Drivers of GHG Emission Reduction from Baseline to ATS in 2050**




In the alternative LCO Scenario, a secondary analysis for the socio-economic implications of its implementation in the region was included. The least-cost pathway offered significant cost savings by maximising the use of existing coal and hydropower plants, instead of building new RE plants and coupling existing fossil fuel-based plants with CCS facilities. In turn, this increases emissions, especially as compared with APS, which has shown strong emission reduction potential amongst all scenarios.

Analysis indicates that the LCO Scenario would result in 3,590 Mt $CO_2$-eq by 2050, which is about 4.8% higher compared to the total emissions estimated for APS. APS has a higher dispatch of renewables in the power sector, but both have the same emission reduction from the demand side, with improved energy and electrification efficiency. This demonstrates the importance of pursuing emission reduction measures in both the end-user and power sectors, preventing the emissions from one sector from offsetting the emission reductions from another.

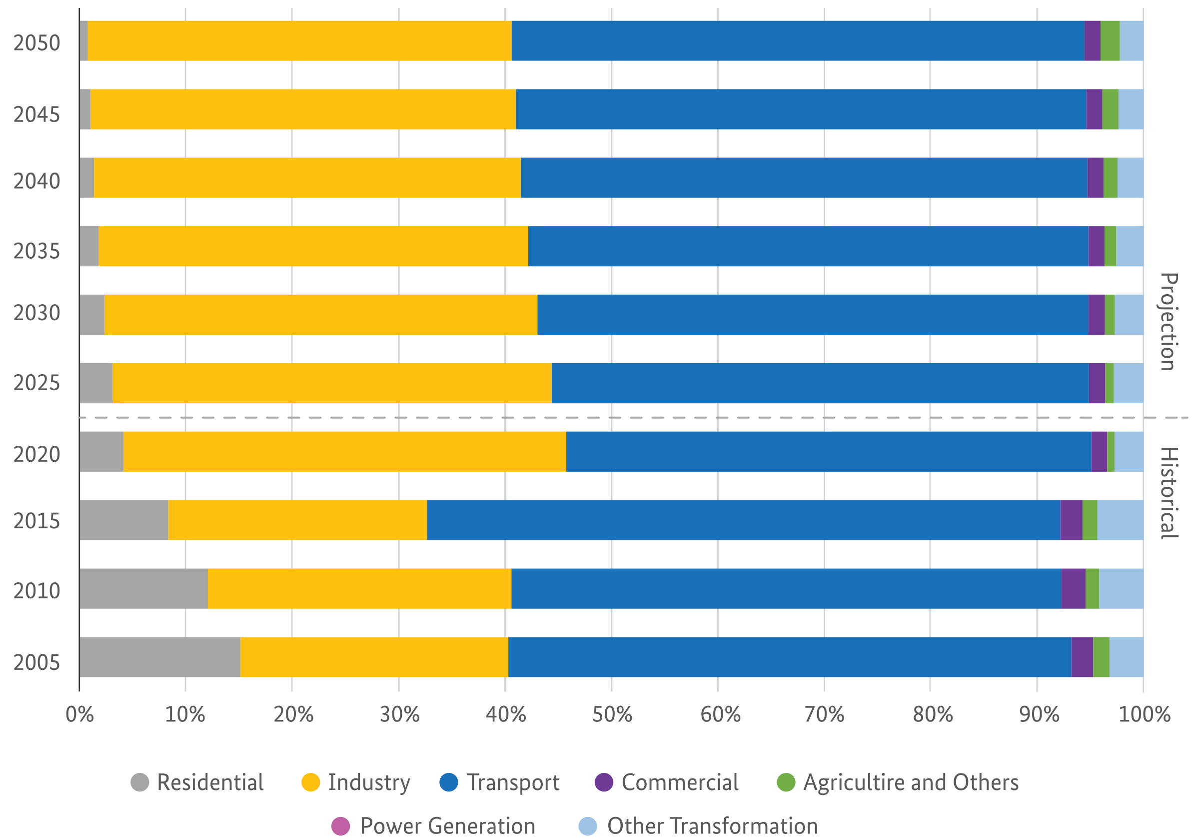
## 3.6 Social Cost of Energy

The AEO7 calculates the social cost of all scenarios, which indicates the cost impact on society when implementing each scenario. It can further be disaggregated into three sub-categories – demand, transformation, resources – representing the analytical flow inside the model. Including social costs in any policy design helps policymakers better compare policy options with lower social costs, in addition to economic and investment costs, particularly when meeting long-term goals. It can also provide insights into the extent to which social cost needs to be considered in calculating long-term investment needs for the ASEAN energy sector.

The findings for the Baseline Scenario show that the total social cost in 2005 was about USD 859 billion. The total social cost within Member States under the Baseline Scenario increases significantly from 2005 to 2050, by about six times. In 2020, the total social cost was seen to decrease under the Baseline Scenario from the previous year, by USD 1,543 billion, or roughly -4%. This was likely due to reducing energy demand and the Covid-19 pandemic. The total social cost under the Baseline Scenario begins to increase from 2021 to 2050 with a projected value of USD 5,457 billion. This represents an increase of approximately two and a half times over the 2020 value.

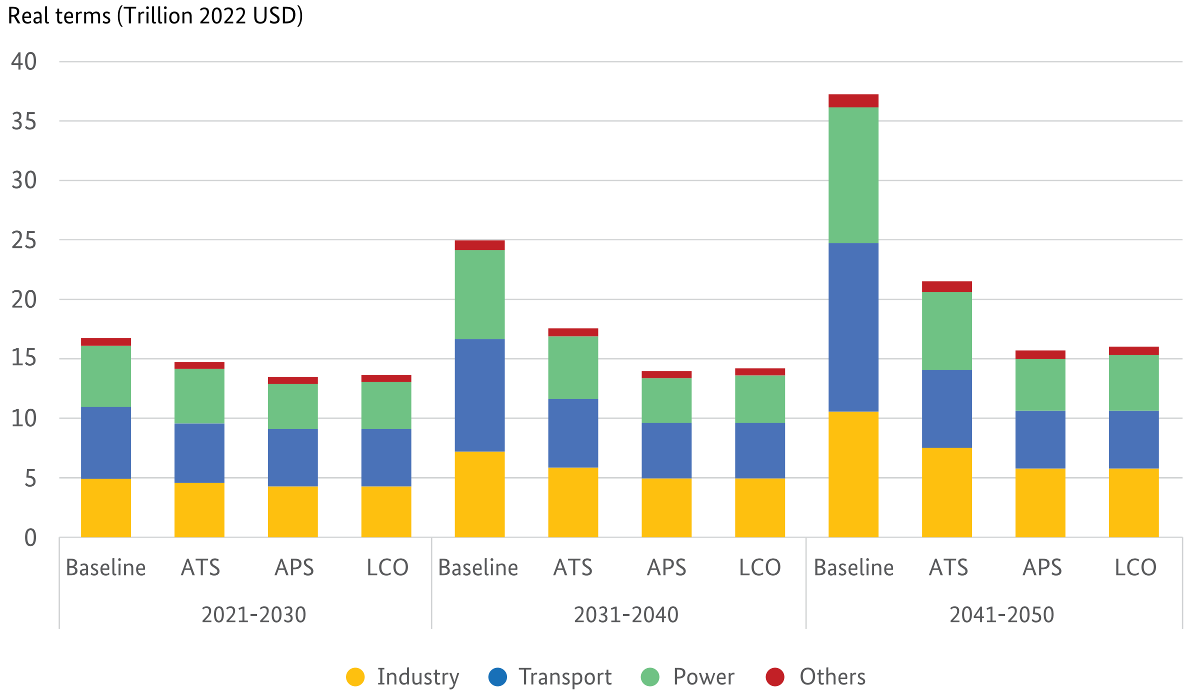
Amongst the three branches – demand, transformation and resources – the social cost generated from demand comprises the largest share of total social cost from 2005-2050. It indicates that energy consumption in AMS depends more on the demand side than the supply side. The social cost from demand is about 2.2 times the social cost generated by transformation. Amongst sub-demand branches, social costs from the transportation and industrial sectors accounted for about 94% of the total social cost of the demand branch in 2020. The social cost from the residential sector accounts for a small portion of the total social cost of the demand branch from 2005-2050 (about 4% in 2020). Social costs from all three branches follows the increasing trend of total social cost (Figure 3.39).

**Figure 3.39 Composition of Social Cost by Demand Sector Historical and Baseline Scenario**



The modelling result shows that implementation of ATS and APS may reduce social costs by about -43% and -57%, respectively, from the 2050 value in the Baseline Scenario. The simulated sock represents the measures implemented under AMS and APAEC targets, beginning in 2021. By 2050, the total social cost under ATS is projected to be USD 3,113 billion and under APS USD 2,358 billion. In 2025, the social cost from the transportation sector represents the largest share of the total cost under all scenarios, at about 35% of the total cost. Interestingly, the social cost of the transportation sector in 2050 is found to be lower than the industrial and power sectors under three scenarios, specifically ATS, APS, and LCO Scenario. Under the ATS in 2050, the social cost from industrial and power sectors accounts for the largest share of total social cost, at approximately 34%. Under the APS, the social cost from the industry sector is higher than from the power sector, due to the strong implementation of the regional RE targets in the electricity sector.

**Figure 3.40 Cumulative Social Cost Projection Across Scenarios**




*Note: Others include Residential, Commercial, and Agriculture. Power includes Power Generation and Other Transformation.*

Figure 3.40 shows that social costs would continually increase, with later years driven by emissions due to technology deployment. Cumulative social cost in the earlier years (2021-2030) could reach USD 13.6 trillion up to USD 16.7 trillion. In the mid-term (2031-2040) where adoption of most national policies are effected, the difference in social cost becomes most apparent. In ATS and APS, cost-savings from the Baseline Scenario can reach up to USD 7.4 trillion and USD 11 trillion, respectively – representing a 30% and 44% reduction. The gap widens in the later years (2041-2050) with further implementation of EE&C and RE strategies. By this period, ATS and APS show a cumulative social costs of energy of USD 21.5 trillion and USD 15.6 trillion – yielding savings of about 42% and 58% respectively, from the Baseline Scenario.

Although cost was a major driver of the LCO Scenario, the impact of externality cost was excluded from determining the least-cost dispatch. Hence, although APS and LCO Scenario are comparable with regard to cost, a small difference in estimated social costs can be observed. The LCO Scenario demonstrates a slightly higher emission than the APS due to the higher dispatch of coal power.

## 3.7 Renewable Job Creation

The impact of RE capacity expansion and investment is seen in employment, which benefits the economy and supports the overarching objectives to decrease emissions and improve energy security. The current model tracks employment from RE through gross job addition and yet to include the job loss over the period. The results obtained are not directly comparable to the trends previously reported in the AEO6 [1]. This accounts for both direct and indirect jobs applied to solar and wind generation. Direct jobs are linked to the primary activities of generating a given amount of capacity.

This projection is limited to only calculating direct jobs linked to solar and wind generation, as well as hydro and geothermal. It implies a higher number of RE jobs in 2025 than the AEO6 results. It also more precisely represents conditions by adding dynamic parameters.

**Added Installed Capacities**
from 2020 level

| | ATS | APS |
|---|---|---|
| 2025 | 41 GW | 51 GW |
| 2050 | 225 GW | 311 GW |

**Total RE Job Creation**

| | | |
|---|---|---|
| 2025 | ATS | 857 Thousand |
| | APS | 1 Million |
| | LCO | 960 Thousand |
| 2050 | ATS | 4.5 Million |
| | APS | 5.5 Million |
| | LCO | 3.2 Million |

**Job addition dominated by Vietnam and Indonesia**

| | ATS | APS | LCO |
|---|---|---|---|
| VN | 29% | 31% | 22% |
| ID | 27% | 27% | 21% |
| Others | 44% | 42% | 56% |

(2050)

**Hydro makes up the most RE jobs, followed by Solar**

| | ATS | APS | LCO |
|---|---|---|---|
| Hydro | 3 Million | 3.7 Million | 2.5 Million |
| Solar | 851 Thousand | 1 Million | 526 Thousand |

(2050)

The AMS are projected to generate almost 850,000 jobs by 2025, 31% higher than the Baseline Scenario and an additional 25% for APS. By mid-century, the member nations are projected to create about 4.5 million jobs, 16% more than the Baseline Scenario of almost 4 million jobs. In contrast, in APS, RE jobs reach nearly 5.5 million, equivalent to an additional 15% from ATS. Greater AMS efforts to achieve the regional target results in more RE jobs.

Similar to the projected capacity-added trends, job creation will be greater in the near term, especially in manufacturing and construction, as new plants are established. This is in line with ASEAN goals of having labour-intensive supply chains, where informal work is prominent than machinery. This leads to AMS having a higher employment capacity, as compared to developed countries. However, it also raises concern about the sustainability of RE job, and whether the available RE jobs would compensate for job losses in the fossil-fuel industry.

RE deployment demonstrates an upward trend into 2050, with the employment trend based on these technologies being the same in all scenarios. Hydro generates the largest share, ranging at around 64%. It is followed by solar at 23.5%, in both ATS and APS, as utilisation gains traction due to fiscal policies within AMS. Once RE projects are completed, job will concentrate in O&M.

Employment remains concentrated in Vietnam, resulting from a significantly increase in solar capacity deployment in 2019-2020, influencing the trajectory in all scenarios. It is also acknowledged that Vietnam hosts the most solar panel manufacturers amongst all AMS [28]. This reaffirms the link between additional RE capacity of up to eight times [22], with higher job creation. Hydro jobs dominate the trends, due to its greater potential. In the coming three decades, Vietnam and Indonesia are projected to generate almost 31% and 27% of total RE jobs, respectively, spanning the period 2021-2050. This comprises more than half of all RE job creation.

In the LCO Scenario where the power sector is optimised, the limited new-build plants result in approximately 961,000 jobs in 2025. This is attributed to the development and operation of hydropower and solar plants in the near term. This is a promising result, given that it surpasses the ATS estimates. However, the value is relatively lower by a 11% margin, as compared to APS.

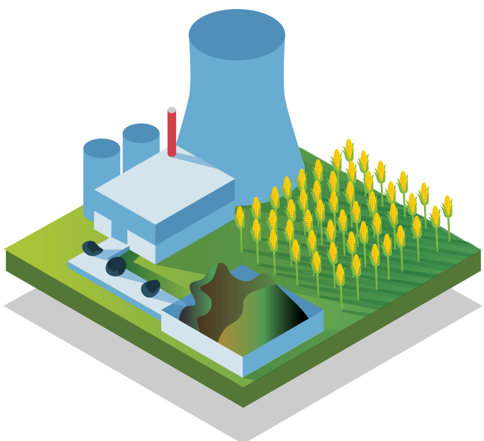
The difference becomes more apparent with least-cost optimisation is maintained until 2050. The result shows a decline in job creation from renewable deployments with an estimated count of 2.1 million jobs. This is roughly half the job creation in ATS, but it is still 1.4 times higher than the Baseline Scenario. It should be noted in the LCO Scenario that job creation through the construction and operation of APG has not been included in the scope of the assessment, which is expected to increase actual job creation.

## 3.8 Land Use for Biofuel

Biofuels have been widely used for a blending in transportation fuel. Two types of biofuels are generally used: biodiesel and bioethanol. As of 2020, five Member States have utilised biodiesel in their energy mix: Indonesia, Malaysia, the Philippines, Thailand, and Vietnam. Meanwhile, bioethanol has been used in the Philippines, Thailand, and Vietnam.

In 2020, total bioethanol consumption amounted to 68.7 million GJ, requiring approximately 712,000 Ha of land to produce. In the same year, approximately 2.2 million Ha were utilised to produce the 339 million GJ of biodiesel consumed in the region. By comparison, there were 14.6 million Ha of oil palm plantations in 2020, in Indonesia alone[10]. Malaysia had 5.9 million Ha of oil palm plantations . Fittingly, both countries were the largest users of biodiesel in 2020. Other than these two, oil palm plantations can be found in the Philippines and Thailand, amongst others.

In the Baseline Scenario, the land required for biofuel production is projected to increase to 3 million Ha of oil palm and 730,000 Ha of sugar cane in 2025. Synchronous with the increasing demand in the end-use sector, the need for biofuel, and thus land use, is also expected to increase. By 2050, an estimated 2.3 million Ha of sugar cane and 8.9 million Ha of oil palm will be required for biofuel production. The increment rate follows the trend of an increasing need for energy for road transportation.



[10] Data retrieved from Statista "Total land area of oil palm plantations in Indonesia from 2011 to 2020" https://www.statista.com/statistics/971424/total-area-of-oil-palm-plantations-indonesia/
[11] Data retrieved from Malaysian Palm Oil Board https://bepi.mpob.gov.my/index.php/en/area/area-2020/oil-palm-planted-area-as-at-dec-2020

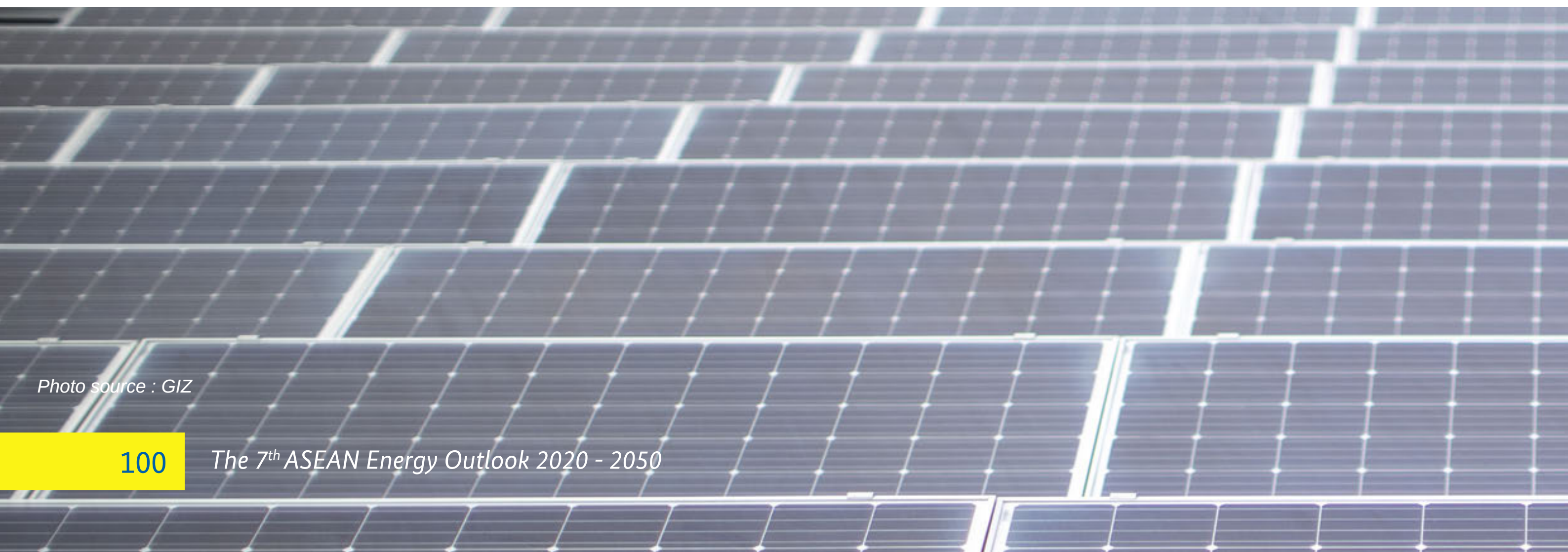
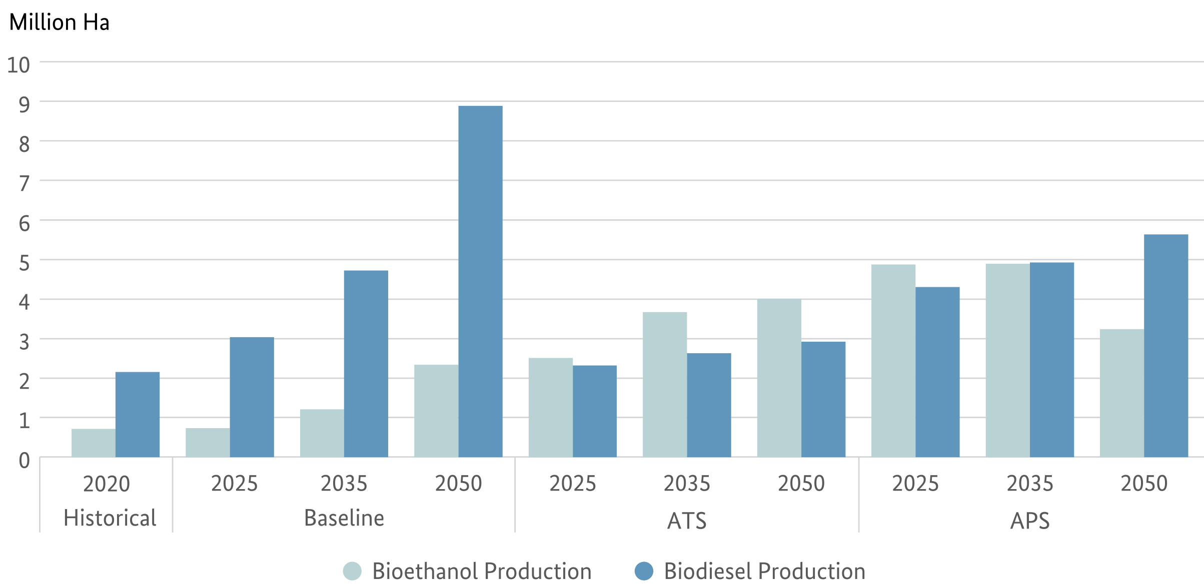


*Photo source : GIZ*

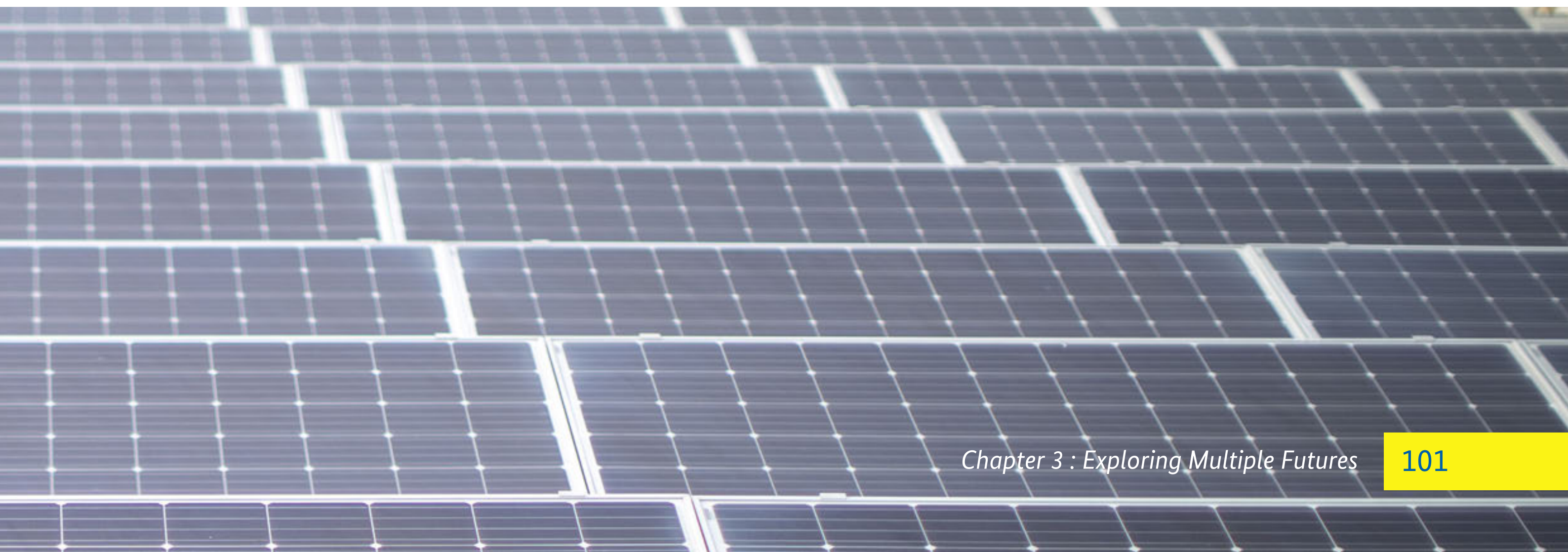
**Figure 3.41 Land Use for Bioethanol and Biodiesel Production Across Scenarios**




*Note: The LCO Scenario and APS have the same value.*

Demand for biofuels does not increase as sharply in ATS, as in the Baseline Scenario. This can be attributed to three factors. First, stronger implementation of EE programmes reduces the need for all types of energy in the transportation sector. A total of 1 billion GJ of energy use for road transportation is avoided in ATS, as compared to the Baseline Scenario. Second, the shift of fuel utilisation from petroleum products, particularly gasoline and diesel, reduces the demand for ethanol and biodiesel as blending fuels. Concurrently, the levels of policies and targets, also affects the increases in biofuel demand as compared to historical levels, especially for bioethanol. Bioethanol has significant blending targets, which are assumed to be achieved in the ATS. This is albeit a limited blending level historically. It is noted that to achieve the blending targets set in ATS, more land use for bioethanol production is assumed, reaching 2.5 million Ha and 4 million Ha in 2025 and 2050, respectively (Figure 3.41).

Under the APS, stringent policies to accelerate RE shares results in a higher share of biofuel demand, especially biodiesel. Around 5.6 million Ha of land is required for biodiesel-producing oil palm plantations. Bioethanol production, on the other hand, is expected to peak around 2030 and decrease in the long term, primarily due to the impact of EE policies in the sector. This is in line with the gasoline demand for road transportation, which has gradually decreased during the historical period. Land use for biofuel in APS is similar to that of the LCO Scenario, as the latter assumes interventions on the demand of APS.



## CHAPTER 4

# ASSESSING MEASURES FOR ENERGY RESILIENCE

# CHAPTER 4
# ASSESSING MEASURES FOR ENERGY RESILIENCE

The theme of this chapter is providing viable plans for ASEAN policymakers to build back stronger and more sustainable from the Covid-19 pandemic or any future crisis that may arise. The strategies laid out in this chapter are expected to support energy resiliency in ASEAN by looking at the capabilities of each AMS. Energy resilience is defined as the capability of an energy system to withstand and recover from high-impact events and to reduce the duration, cost and impact of outages on critical services. This chapter, written by various external experts, includes several topics to cover the seven programme areas of APAEC: (1) ASEAN Power Grid, (2) Trans-ASEAN Gas Pipeline, (3) Coal & Clean Coal Technology, (4) Energy Efficiency & Conservation, (5) Renewable Energy, (6) Regional Energy Policy and Planning, and (7) Civilian Nuclear Energy.

## 4.1 Exploring Technologies for Grid Integration

***Authored by Clean, Affordable and Secure Energy for Southeast Asia (CASE Project), Universiti Teknologi Malaysia (UTM), and ASEAN Centre for Energy (ACE)***

### 4.1.1 Sector Coupling for Grid Integration of Variable Renewables

The clean electrification of energy end-use sectors plays a central role in the decarbonisation efforts to keep global warming well below 1.5°C. Increasing the use of electricity across the economy can strengthen energy security, improve EE, empower consumers, and facilitate the clean energy transition in the power system. Sector coupling can be considered an option to increase the power systems' flexibility and facilitate the integration of VRE sources.

Sector coupling refers to the idea of interconnecting the power sector with broader energy uses in other sectors, such as mobility in transportation, cooling and heating in buildings and heat supply in the industrial sector. The viability of sector coupling solutions to directly or indirectly replace fossil fuels with renewable electricity is gaining momentum, primarily due to the declining costs of wind and solar.

Four emerging energy transition trends are commonly referred to as the four Ds: decarbonisation, digitalisation, decentralisation, and democratisation. Each trend fundamentally changes how societies buy, use, sell and supply energy. As electricity increasingly becomes the default energy used throughout a decarbonised economy, it will require digitising numerous processes to synchronise supply and demand. By nature, a decarbonised power system will rely on a variety of new decentralised actors, both generators and users, and reach a new market player in an increasingly interconnected and democratised system. Sector coupling represents both a consequence of the transition and an enabler. It sits at the heart of these trends.

As the share of VRE increases, the power system gradually faces greater variability and uncertainty that challenge existing approaches to balanced supply and demand. The success of the power transition will therefore be determined by the strategies to integrate higher shares of VRE. The power system transition process can be described in phases characterised by the appearance of specific challenges marked by increasing shares of VRE in the power mix and measures to support system flexibility. Whilst early phases of VRE integration have minimal system impacts and do not require significant changes, advanced stages of renewable integration will require more profound structural changes.

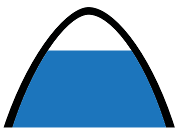
Power system flexibility is the capability to cope with sudden and unpredictable fluctuations in power supply and demand on different timescales. Although dispatchable power plants traditionally provide system flexibility, other system actors will become essential to provide flexibility, including the interconnected grids, storage and demand.

### 4.1.2 Flexibility in Sector Coupling

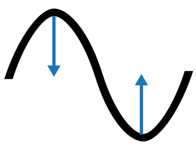
The significant increase in electricity demand due to sector coupling can either be a useful source of flexibility or a burden to the power sector if not well planned and managed. A 'plug-and-forget' approach can lead to a sharp increase in peak demand, grid congestion, undermined supply security, and increased supply costs, amongst other issues. Smart electrification can unlock flexibility options to integrate VRE into the grid with cost efficiency.

Where possible, electricity consumption should arise in times of abundant cheap electricity generation (e.g., with VRE). It absorbs excess supply and modulates consumption in response to system needs. The power system should transition from one where supply is adjusted to meet the demand to one that takes advantage of power demand as a source of flexibility to balance the system.

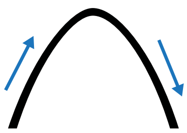
Flexibility from sector coupling involves providing incentives to reduce, increase or shift a portion of electricity demand over a specific period. Provided it is observable and controllable, electrification of end-use sectors with smart approaches unlocks particular opportunities:



**Load shedding** – Voluntarily reduce peak loads to ensure system adequacy. This mechanism encourages large consumers to shed load if the system requires, especially if the system is under stress (e.g., extreme peak demand, grid congestions affecting reliability).



**Load shifting** – Re-shape load profiles to match the availability of generation resources. Actively controlling electricity consumption allows consumers to shift their load during specific time intervals to benefit the power system, e.g., from peak to non-peak demand periods or from periods of low VRE to hours with high availability to absorb the excess of RE.



**Load following** – Modulate consumption to follow fluctuations in power generation to keep the system in balance. Power consumers can provide reserve services to respond to system operator requests, ramp consumption up or down, and balance the system under contingencies. Load-following flexibility can efficiently support the system's maintenance frequency at nominal levels, especially as VRE penetration increases [29].

In addition to actively and smartly controlling demand, sector coupling often has more inherent flexibility when combined with energy storage, such as batteries and thermal storage. Energy storage permits the decoupling of electricity consumption from energy use, allowing for levelling out of demand, absorbing excess cheap VRE, and storing and using it according to energy needs. A more active role for demand, and the presence of storage, in sector coupling, complements and boosts other sources of flexibility, such as supply or interconnected grids.

Despite its great potential, the success of sector coupling to support grid integration of VRE requires progress in certain critical dimensions. Key enablers to exploit flexibility from sector coupling include integrated planning, technology readiness, and efficient incentives.

| Integrated planning | Technology readiness | Efficient incentives |
|---|---|---|
| • **Cross-sectoral planning**: Comprehensive planning to account for additional demand from electrification and develop strategies to create synergies between end-use sectors and VRE integration<br><br>• **System operation**: Adjust system operation practices to include active role of demand<br><br>• **Supportive infrastructure**: Electrification requires planning and development of new infrastructure in end-use sectors (e.g., EV charging) | • **Electrification technologies:** demand-side flexibility can only be provided with controllable technology<br><br>• **Control and monitor:** enhance the ability to control and monitor demand to ensure reliability (e.g., smart meters)<br><br>• **Digitalisation:** digital and smart technologies to support distributed energy resources and turn them into flexibility providers (e.g., aggregators)<br><br>• **Storage:** storage absorbs excess VRE dispatches at a later stage to cover demand when VRE generation is low | • **Market design:** valuing power systems beyond energy supply (e.g., energy security, resilience, reliability, adequacy) to unlock demand-side response<br><br>• **Regulatory framework:** Incorporate demand into markets and remove fossil fuels subsidies that perturb the competitiveness of sector coupling<br><br>• **Business models:** Establish business models that empower consumers to be more active (e.g., revenue streams from demand response, savings in energy bills) |

### 4.1.3 Flexibility Options in the Industrial Sector

Industrial demand-side flexibility requires manufacturing processes to adapt their load in response to system needs. Existing industries that already use electricity, such as for mechanical processes, are technologically ready to provide demand flexibility, often with little impact on operations. In addition, the electrification of heat supply processes can expand available flexibility options. However, new technologies emerging for the electrification of various processes, such as controllable heat pumps or systems coupled with thermal storage, will be needed to unlock further flexibility. Estimating the potential for demand-side flexibility in different end-use sectors is a complex task that requires deep quantitative analysis, consideration of national circumstances, energy markets, and a detailed understanding of individual industrial processes.

Industrial **load shedding** can be deployed to ensure power adequacy and stability during critical situations, such as a sudden loss of available power, exceptionally high peak demand hours, or instances of grid congestion (redispatch). Load shedding is typically limited to those industrial processes with mechanical, non-continuous, or modular processes that can be interrupted without damage to machinery or product loss. Load shedding is a voluntary agreement with the system operator to reduce the load if needed in exchange for economic compensation[12].

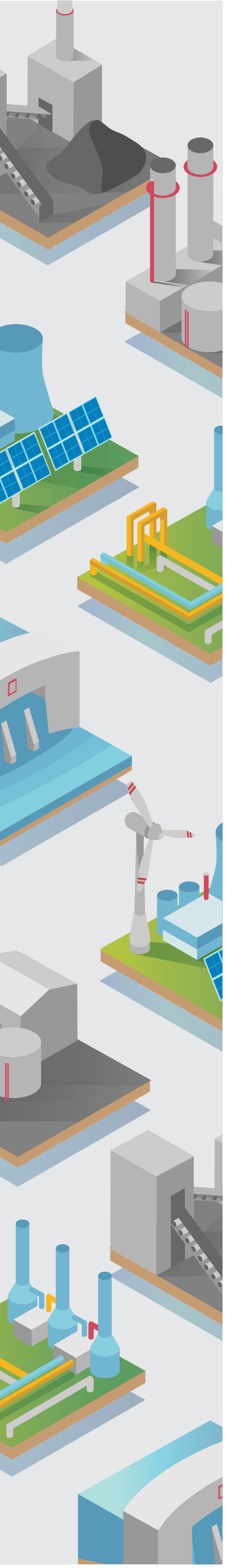
Industrial **load shifting** is not a new concept and has already been implemented in several industries. By postponing an industrial process to other times of the day, industries can garner returns through cost savings or participation in a demand-side market. Although similar, load shifting differs from load shedding in that load shifting does not result in a reduction of the overall energy used. Many industrial processes have, by design, a contingency margin in place to allow for scheduled maintenance or failure of a component without the loss of the entire production stream. This contingency margin can be exploited for demand response. Alternatively, the inherent inertia, often thermal, within a process could also be used to modulate and shift energy consumption. The cooling applications in the food industry can participate in load shifting. The thermal inertia in refrigerated warehouses, including cold and frozen storage, can be a buffer for shifting cooling power consumption [30].

Additional potential exists in heating processes, especially in low-temperature heat applications <100°C, like those used for drying, liquid concentration, or pasteurisation. Although many heating processes rely on burning fossil fuels, heat pumps can offer increased efficiencies, especially if processes are designed to complement cooling. For example, a malting plant in Vietnam has installed heat pumps to utilise waste heat from the cooling system in the barley germination process and channels it to the kilns, where the geminated malt is dried. Switching to electricity for heat would open up many industrial processes to load shifting opportunities.

The mechanical crushing and grinding of raw materials in the cement industry is well suited to either load shedding or shifting. As these processes are quite efficient and only used a few hours of the day, they can be shifted to low-price periods [30]. As long as sudden interruptions of these processes do not damage machinery or product quality, they are viable load-shedding candidates [31].

**Load following** for industrial applications can be somewhat challenging and depends on the industrial machines and individual process designs. Industrial processes require the ability to adjust energy consumption smoothly. Electrolysis in aluminium smelting potlines can provide two avenues for demand flexibility. First, aluminium factories with multiple smelting potlines can provide load shedding services by turning off the entire potline to reduce electricity consumption on a large scale. Second, the possibility of rotating the on/off states amongst different pots allows for load-following services whilst maintaining the processes in service. The ability to control electricity consumption on short notice could provide frequency support. Similarly, the power-intensive chlor-alkali electrolysis process for manufacturing chlorine, hydrogen gas and caustic soda solutions has the potential for fast-paced demand response [32]. Using the inherent inertia of the process for short-term changes in power consumption can be translated into load-following flexibility in the power system [32].

[12] Note that when the load is involuntarily shed because of reliability issues, it is not demand-side flexibility but a loss of load and thus a flexibility issue of the system.



### Barriers to exploiting flexibility in the electrification of industry

Despite the flexibility potential of industrial processes, it is important to understand that the design, planning and operation are determined by production and efficiency metrics, not by their capability to provide power system flexibility. Failure to understand and align these drivers with efficiency incentives to shape power consumption behaviours could hinder industry electrification and flexibility. This section discusses the technical, economic, and political barriers to unlocking industry demand-side flexibility.

From a technical point of view, some processes have little freedom to manoeuvre. For example, some processes, such as those involving metals, require very high temperatures or need to be constantly consuming energy, which makes it difficult to modulate energy use. For processes that ramp production or toggle on/off modes, modifications may lead to increased abrasion and equipment wear, reducing equipment lifespans. Uncertainties remain regarding the impact of adjusting operations for flexibility on product quality, especially for process efficiency and meeting the demand profile of industrial production.

The economic barriers to flexible operations may include reduced efficiency and the need for new equipment. Whilst flexibility costs are usually modest if the primary production process is not disrupted, they can be high if production and quality are significantly affected. However, they are typically avoided with the optimal operation and efficient remuneration of flexibility services to offset the decrease in production. Investing in additional equipment may be another obstacle, but the same technologies that enable industrial electrification and flexibility, e.g., heat pumps, thermal storage, and IT technology, can also lead to long-term efficiency improvements in the processes.

From the political perspective, the energy and industrial sectors may influence the development of demand flexibility strategies. The vision of a particular industry and its role in the national economy may be reflected in the support – or lack of acceptance – for implementing sector coupling, whether formulated as subsidies or instruments to hedge industrial consumers against price volatility.  It may limit the effect of price signals for active demand response. Coordinating the interests of the power system and industrial sector can be a difficult task and a major bottleneck.

### Measures to unlock flexibility in the industrial sector

Overcoming the barriers requires structural changes and innovations in technologies, regulatory frameworks, and market designs to encourage industrial actors to change and allow them to benefit from behaviours that provide flexibility to the system. The development and adoption of digital technologies in the industrial sector can tap into potential flexibility. Firstly, machine learning algorithms can be used to optimise the electricity load whilst maintaining peak industrial output. Operations optimisation should incorporate flexibility's value through price differences (i.e., load shifting). Some examples are machinery, furnaces, boilers, aluminium smelting, and other electricity-intensive processes. Secondly, digital economies enable improved communication and data processing, which are key enabling technologies to develop smart demand response systems, thus providing grid flexibility. Unlike the residential sector, however, industrial consumers may respond to price signals without a high degree of digitalisation.

With regard to the regulatory framework, allowing industrial consumers to participate in power markets encourages their active response to system needs and increases demand-side flexibility. Demand-side flexibility can be valued and exploited using time-of-use (ToU) tariffs, which provide price signals to consumers to react and adjust their consumption voluntarily. When these signals are based on efficient electricity pricing[13], consumers are incentivised to change consumption in response to system needs. ToU tariffs for electricity-intensive industries can provide cost savings. The competitiveness of these industries depends on the supply of low-cost and reliable electricity. Though increased penetration of VRE may expose them to electricity price volatility, these industries can turn this risk into an economic advantage. By evaluating the flexibility of their electricity usage and investing in solutions that allow them to optimise their electricity consumption, they can realise energy savings. ToU tariffs are also a key application for the economic viability of storage solutions in the industry.

From a market design perspective, shorter scheduling periods open the market for demand-side bids. Demand-side actors, such as industrial consumers, often have limited flexibility options within specific time frames, with the ability to increase or decrease demand for a few hours each day. If the predefined time blocks in the market are too long (e.g., 12 hours, full day, full week), these options are excluded. Exposing industrial consumers to variable electricity prices may encourage changes in energy consumption in the short term. However, these signals alone may not be sufficient to promote long-term investments and participation in demand response mechanisms, especially if it is uncertain whether electricity's variability and price spread will be sustained. This can be partly offset by including demand response mechanisms in markets, such as long-term contracts and capacity-driven markets.

The role of aggregators can further unlock demand-side flexibility and enable individual industrial plants access to electricity markets. In most cases, market actors must fulfil specific prequalification standards, such as technical compliance, minimum consumption, and generation capacity, before they are allowed to trade on electricity markets. These are market barriers that can be addressed via aggregators. An aggregator pools small entities, including industrial plants, to participate in the market by offering energy and flexibility services through a single entity. The aggregation of electricity consumption profiles from different industries may also allow for peak reduction and shared contribution to demand response.

#### 4.1.4 Flexibility Options in the Transportation Sector

As one of the largest electricity consumers, the transportation sector can contribute to increased power system flexibility, and its role can be further enhanced through sector coupling strategies, such as EVs. AMS have shown great interest in EVs and set specific deployment targets [3][33]. EV deployment is expected to increase overall electricity demand, especially during overnight hours, when drivers charge their vehicles. Coupling with VRE means major changes in energy supply and demand profiles can be expected. This will require a new definition for peak and off-peak energy demand.

EVs have been shown to provide grid management solutions, such as peak curtailment and VRE balance, but they require active participation from the user side. Without proper smart grid systems for energy management, accommodating the increasing quantity of EVs would challenge the current grid. Hence, holistic strategic integration planning that encompasses technical, economic, and social sensitivities is required to ensure a successful transition of the transportation sector from conventional Internal Combustion Engine Vehicle (ICEV) to EV.

[13] Efficient electricity pricing reflects the state of the system i.e., low prices when there is abundant cheap renewable energy generation, and high prices when there is a short-fall, thus necessitating more expensive generation units.

EV technology has advanced to solve many past problems, such as slow charging and EV mileage. Currently, fast charging can reach 10,800 Wh to 21,600 Wh, and typical EV mileage can achieve 600 km with a fully charged battery. However, charging station coverage is still lacking. As of September 2021, Singapore has the highest number of charging stations, with 1,800 public charging points. Thailand has 1,000 charging stations, Malaysia 600, and Indonesia has 187. Based on European Union (EU) recommendations, one charging station is required for every 10 EVs.

The total Well-to-Wheel (WTW) efficiency for ICEVs running on gasoline ranges from 11% to 27%. Integration of EVs, assuming the grid is powered by coal-fired power plants, will result in similar WTW efficiency of 13% to 27%. Though EV use is slightly more efficient than conventional vehicles per kilometre basis, relying on conventional power plants for electricity is inefficient and unsustainable. A low-carbon solution for grid power using renewable energy is important to increase the efficiency of EVs, especially when renewable energy supplements the distribution network. It is in line with ASEAN's direction toward higher deployment of RE across the region. Fuelling EVs with RE resources can increase the efficiency of EVs from 40% to 70% [34].

The concept of Vehicle-to-Grid (V2G) is of major importance to drive behaviour toward optimal EV charging. With V2G, users can sell power back to the grid from their EV energy storage system during peak hours. Another added benefit is that in an integrated grid system with VRE, EV storage can also store surplus energy, thus allowing for better balancing of supply and demand. It leads to improved efficiency in power grid operations.

V2G technology faces several challenges, including battery degradation, high implementation costs and connectivity [35]. Recurring charge and discharge cycles can damage batteries and pose a significant obstacle to using lithium-ion batteries in EVs. The high implementation cost of V2G is primarily due to the hardware and software infrastructure required and needs to be improved [36]. A high-tension cable, a complicated controller and a bidirectional charger are required for every EV to access V2G. Bidirectional chargers allow charging and discharging energy from an EV battery [37]. Compared to conventional EV chargers using alternating current (AC), the bidirectional chargers act like an inverter to convert AC to direct current (DC). They are only compatible with EVs that allow bidirectional DC charging.

At this time, EVs remain more expensive amongst ASEAN countries, especially where transportation fuel costs are subsidised, such as Brunei Darussalam, Indonesia, and Malaysia. EVs are still less economical than conventional vehicles; however, as expected, EV costs will decline as cheaper batteries are developed. Though V2G may allow users to gain some revenue from selling electricity back to the grid, so far, no functioning models for V2G financial mechanisms have been implemented in ASEAN. Not only for flexibility in the industrial sector, but ToU tariffs could also be implemented in V2G. The transition from conventional transportation to EVs will not occur overnight, but expectations are for gradual growth over the next few decades.

## 4.2 Utilising Fossil Fuels during the Transition

*Authored by ASEAN Centre for Energy (ACE) and Japan Coal Frontier Organization (JCOAL)*

### 4.2.1 Oil and Gas

Oil and gas, despite emitting GHG, have a critical role in pursuing energy transition. Due to the maturity of the technology and supply chain, the oil and gas industry provides reliable and affordable energy supply, ensuring economic growth that supports the gradual transition to a net-zero world.

The nature of oil and gas allows physical storage, making it a strategic reserve for countries to ensure energy resiliency and a buffer against unexpected events that impact the energy supply chain. Oil and gas, particularly in the ASEAN region, still dominate the energy mix and account for 56% of the 2020 TPES. This will increase to 66% by 2050 due to population growth in the Baseline Scenario. Even the most aggressive RE deployment scenario (APS) predicts that oil and gas will contribute 64% in 2050. It must be admitted oil and gas use is important to support the economic growth of the region, and decarbonising the oil and gas industry is necessary to limit the harmful effects of GHG emissions on the climate.

With a growing population that demands more energy supplies, oil and gas play an important role in maintaining energy security while shifting gradually to RE options. Oil and gas are still dominating most of the energy supply of many countries, including ASEAN nations. Thus, ensuring consistent availability of these fuels is crucial for economic sustainability. The maturity of the oil and gas industry, supply chain and the storability of these fuels make them strategically vital for countries in maintaining energy security. Strategic oil and gas reserves provide a buffer against systems shocks and price volatility, minimising potential disruptions in the energy supply. In the ASEAN region, oil is the primary fuel for the transportation sector demand, accounting for 91% in 2020, and projected to be in a similar proportion by 2050 under the Baseline Scenario. Similarly, natural gas has the largest share in the power generation mix, accounting for 32% of total output in 2020. Whilst shifting energy systems to cleaner solutions, oil and gas are still necessary to fuel economic activities and develop low-carbon options.

In the power system, natural gas is pivotal in ensuring grid stability whilst adding more variable renewable generation options for the grid. Additionally, gas-fired generators are the lowest emission fossil fuel alternative for generating electricity. Rapid ramping capacity and economic competitiveness make It suitable for the high RE penetration scenario. The RE share in the ASEAN energy mix is expected to increase, driven by significant technological cost reductions, combined with ASEAN commitments to promote cleaner energy systems. To meet the regional target of 35% RE share in installed capacity by 2025, ASEAN needs to develop at least 40.3GW of solar and 5.4GW of wind power. Higher VRE penetration will require more mid-merit power and peak generation in the system. This could compensate for the intermittency of renewable power output.

In fulfilling the power demand, gas is an economical choice for mid-merit and peak applications. This is expected to reduce system costs. A combined cycle gas turbine has the least-cost per MWh for mid-merit applications, with a capacity factor of less than 55% [38]. A significant share of solar PV, in particular, included in a system will cause a condition called the “duck curve effect,” where the system needs a rapid injection of power during sunset hours, as solar PVs stop generating electricity, whilst demand typically rises. This effect causes a wide gap in the supply and demand balance, and supply requires a rapid ramp-up. This is where a gas-fired power plant is the best fit. Thus, the future of gas-fired power plants is important in securing the power supply during the transition era, mainly as a peak service in the power system with high VRE penetration.

Considering the use of oil and gas is unavoidable, the effort to decarbonise the oil and gas industry should be an important priority, regardless of transition scenarios, and the industry should support the energy transition process. To reduce emission intensity, several feasible and cost-effective measures should be undertaken. These measures include methane leak monitoring and reduction, minimising gas flaring and associated venting of $CO_2$, and increasing the use of low-carbon electricity in industry development and operations. Currently, 15% of global energy-related GHG emissions come from the oil and gas extraction process and consumption [39].

The oil and gas industry, with substantial capital and development resources, has attributes that can support the development of several low-carbon technologies, including carbon capture storage and utilisation (CCUS), low-carbon hydrogen, and biofuels. By scaling up deployment to bring down marginal costs, these technologies are needed to facilitate the future low-carbon economy, along with RE, to minimise GHG emissions from hard-to-abate sectors like aviation, shipping, metal, and chemical industries. The oil and gas industry, together with the government and other stakeholders, can provide significant progress in CCUS, low-carbon hydrogen, and biofuel deployment through the creation of feasible business models for large-scale investment in these sectors.

### 4.2.2 Coal

ATS is created based on each AMS national policy and power development plan. In AEO6, issued in 2020, the original power development plan was developed circa 2017, when there was a higher dependency on fossil fuels, as compared to the present. At that time, energy transition was still progressing. AEO7 is based on the latest AMS power development plans and reflects the energy transition era from traditional sources to renewables, such as biomass, hydro, geothermal, solar, and wind power.

Comparing AEO6 and AEO7 in installed capacity, AEO6 projected 600GW in 2040, while AEO7 has 598GW, a slight decrease of approximately 0.3% (Figure 4.1). Meanwhile, the projected total power generation in 2040 will be 2,550 TWh for AEO6 and 1,955 TWh for AEO7 (Figure 4.2). In other words, the utilisation rate increased from AEO6 to AEO7, which is a reasonable result considering the increase in RE capacity. The availability factor trend, total capacity per total power generation, was 26% in 2020. However, it is expected to increase to 30% in 2040 and 31% in 2050 in the ATS of AEO7. An increase in the utilisation rate typically means a decrease in electricity costs.

**Figure 4.1 Installed Capacity of AEO6-ATS (left) and AEO7-ATS (right)**

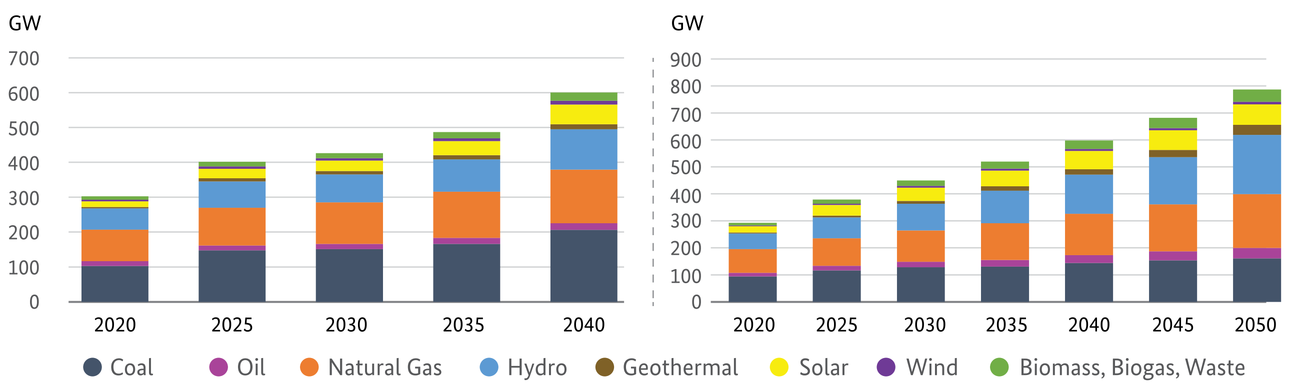
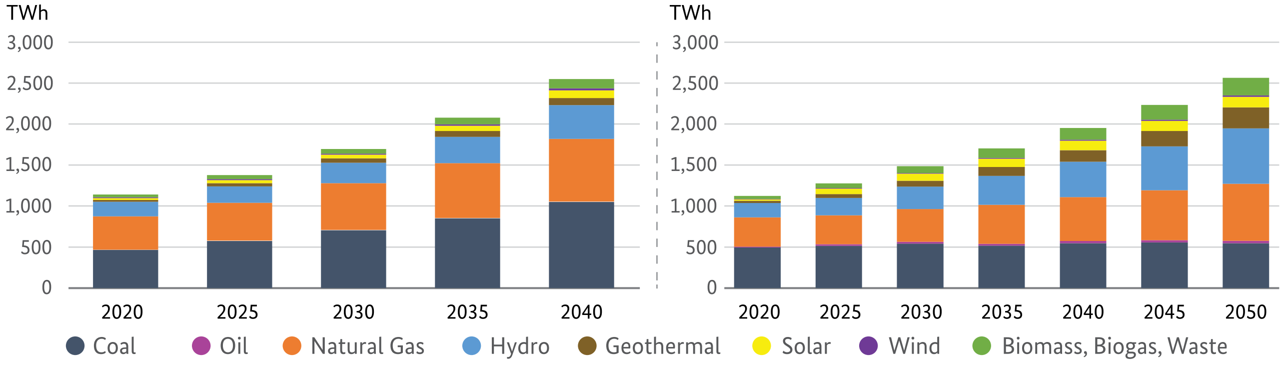


**Figure 4.2 Electricity Generation of AEO6-ATS (left) and AEO7-ATS (right)**




AEO6 had forecasted into 2040, but AEO7 extended the forecast to 2050. In the ten years, from 2040 to 2050, the total capacity and power generation will increase by 120GW and 610TWh, respectively, in the ATS. Broken down by the power generation source, geothermal is forecasted to see the greatest growth during this ten-years-period at 80%, followed by hydro at 57%. Amongst renewables, the introduction of solar power has already run its course, and the growth rate is projected to be about 12%, lower than bioenergy (48%) and gas (30%) but higher than oil (6%). It should be noted here that coal is expected to grow by only 0.2%, but its share in ASEAN power generation by 2050 will still be significant, at about 21%. The reason is that historically coal has been the major fuel in the AMS' electricity generation, together with gas.

It suggests that power source composition is being considered well-balanced when addressing energy demand growth within the ASEAN region. With regard to coal and LNG being balanced with RE, it is necessary to consider supply security from a geopolitical perspective, and in particular, the energy policy trends in other regions, such as India and Africa, where energy demand will continuously grow at a rate similar to the ASEAN region.

The coal-fired power generation share in AEO6-ATS is between 41% and 42% for 2025-2040, but in AEO7-ATS, it is adjusted to roughly 27%- to 1% for the same period, representing a remarkable decrease. The share of gas-fired power is approximately 30% to 33% in AEO6-ATS for 2025-2040, but it has decreased in AEO7-ATS at 26% to 28%. In the availability factor of coal and gas, coal steeply declines from 60% to 45% for 2020-2050, whilst gas gradually declines from 48% to 46% in the same period. In AEO6-ATS, the share of hydropower generation increased from 14% to 16% for the 2025-2040 period, but in AEO7-ATS, it rises from 16% to 22% for the same period. Solar power generation has also increased slightly from AEO6 to AEO7, but its availability is relatively low, thus avoiding excessive dependence on solar power. It should be apparent that total RE capacity, including biomass and geothermal, is expanding to achieve energy transition in the ASEAN region.

Japan Coal Frontier Organization (JCOAL) has been developing a method for predicting and evaluating fluctuations within the power grid using a simplified method. Using an index showing grid fluctuations, the slope of the daily grid fluctuation curve is regarded as a parameter, and the number divided by the total capacity of the grid is called the Grid Fluctuation Index (GFI) [40]. Specifically, the position coordinates with maximum slope are picked up from the country's load curve.

Photo source : wirestock on Freepik

Assuming load curves are available, it is possible to calculate the GFI directly, but such data cannot be obtained from the public domain in many cases. An attempt to predict future grid fluctuations from general data, such as installed capacity and power generation. Analytical data for the predictions were obtained from "International Energy Outlook 2019," as supplied on the US EIA website for multivariate regression analysis [41]. GFI was obtained from the load curve data from the country of publication. The method used is Partial Least Squares (PLS), which is used when the explanatory variables are collinear. As a result of the analysis, the energy availability factors of coal-fired, nuclear, total renewable, and solar energy were adopted as multiple regression variables. The PLS regression equation is:

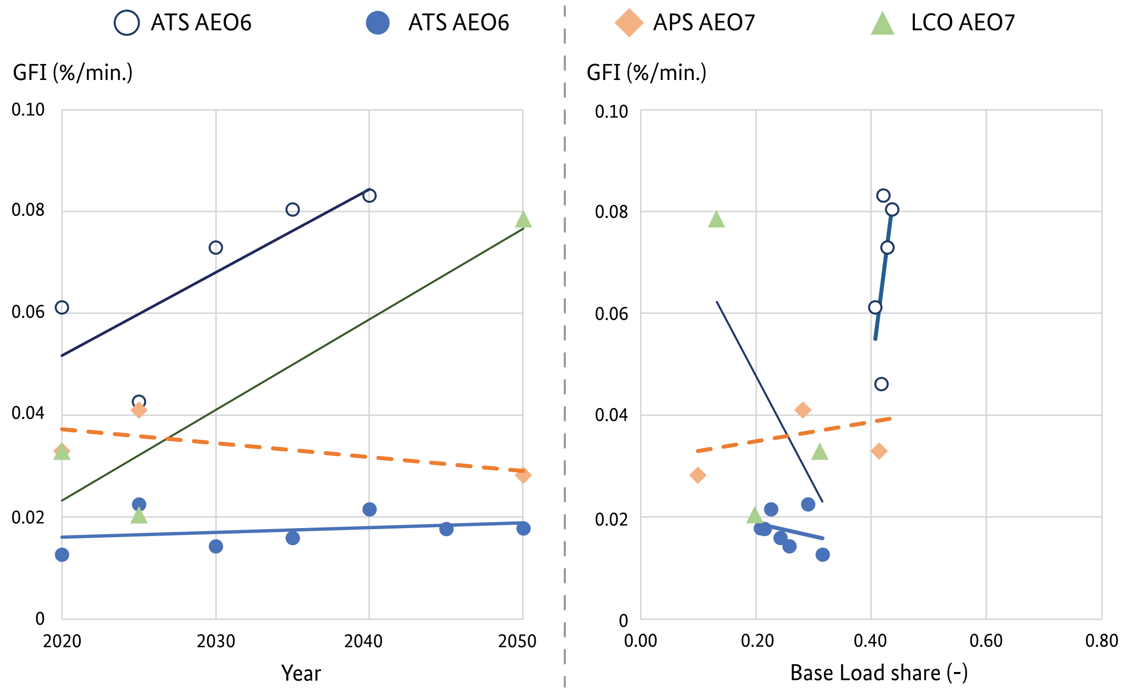
$$GFI = E + w_1X_{coal} + w_2X_{renew} + w_3X_{nuclear} + w_4X_{solar}$$

Where $X_{coal}$ , $X_{renew}$ , $X_{nuclear}$ , and $X_{solar}$ are the availability factors of coal, total renewables, nuclear and solar, respectively. E and $W_1$ to $W_4$ are the residual errors, and the value of the coefficients is E=-0.1258, $w_1$=0.00147, $w_2$=-0.00025, $w_3$=-0.00014, $w_4$=0.00706.

GFI analysis was applied to AEO7-ATS, AEO7-APS, and AEO7-LCO to determine the most cost-effective combination of existing technologies. When GFI values are high, grid fluctuation behaviour is noted as severe [40]. In AEO6-ATS, GFI was noted as high through 2030, at around 0.08. This was based on a contribution by coal-fired generators, coexisting with variable renewable sources, which resulted in increasing grid fluctuation issues.

The current AEO7-ATS is stable at around 0.02 for the entire period up to 2050. The reason for this is the dependence on coal-fired power is reduced and is complemented by plans to develop total RE, such as biomass and geothermal, without being excessively dependent on VRE. The GFI for AEO7-APS was analysed for the years 2025 through 2050 and was found to be slightly higher than AEO7-ATS. At the same time, the GFI for 2050 in AEO7-LCO was set at 0.07, which was also higher than AEO7-APS. This is due to the amount of power generated from coal being higher, whilst the amount of RE was low. Detailed confirmation of LCO data is recommended.

**Figure 4.3 GFI of AEO7-ATS, AEO6-ATS, AEO7-APS and AEO7-LCO**




As previously mentioned, there is a shift in AEO7 to RE sources, which expedites reduced dependence on fossil fuels in each of the AMSs. GFI analysis showed that the entire grid would be more flexible due to a combination of biomass and other variable renewable sources. However, since the analysis used combined ASEAN data, it will be necessary to analyse the situation in each AMS in detail. Grid resiliency usually means the reliability of power services by efficiently adjusting the power grid to meet demand. Flexibility improvements are amongst the most critical factors, especially in the era of diversification of RE power sources. The highest priority is power source composition optimised for each country and each region.

When considering grid flexibility, it is essential to note whether flexible power sources, such as gas and hydro, have sufficient installed capacity to cover variable power sources, such as solar and wind. With regard to AEO7-ATS, the total capacity of gas and hydropower in 2030, 2040 and 2050 is given as 1.9, 1.6 and 1.5 times that of total capacity from solar and wind power. These values are considered to be sufficient. Other factors include fuel supply stability, grid multi-layering, and expansion of reserve margin. Note that these measures also affect power tariffs, so they should be regarded in ASEAN energy policies and the policies for each AMS.

Heads of ASEAN Power Utilities/Authorities (HAPUA) has played a central role in ASEAN grid cooperation. It is important for ASEAN-relevant institutions to work together to further enhance grid collaboration further and supply security throughout the region for the necessary fossil fuels.

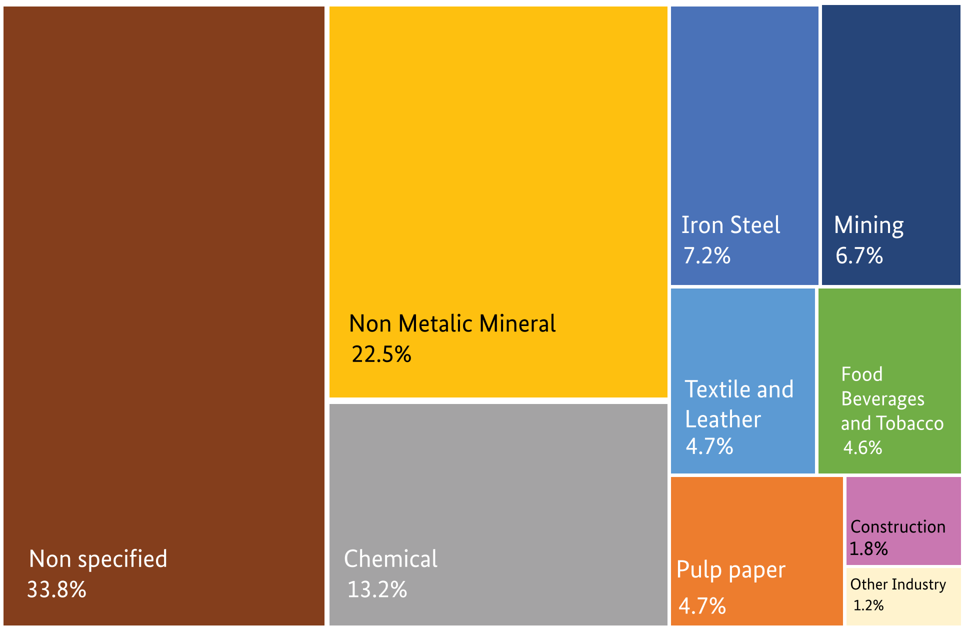
## 4.3 Improving Industrial Efficiency

*Authored by Clean, Affordable and Secure Energy for Southeast Asia (CASE Project) and ASEAN Centre for Energy (ACE)*

### 4.3.1 Introduction

Over the past 20 years, the international industrial sector has grown faster than any other, accounting for nearly one-quarter of anthropogenic GHG emissions [42] and 38% of global final energy use [43]. Manufacturing accounts for the largest share of energy use within the industrial sector and consumes more energy than the combined mining, construction, and agriculture subsectors [44]. In fact, just three heavy industries – iron and steel, cement, and petrochemicals - account for nearly two-thirds of all global industrial energy use. As shown in Figure 4.4, in Southeast Asia, these industries together accounted for 61% of specified energy use in 2020.

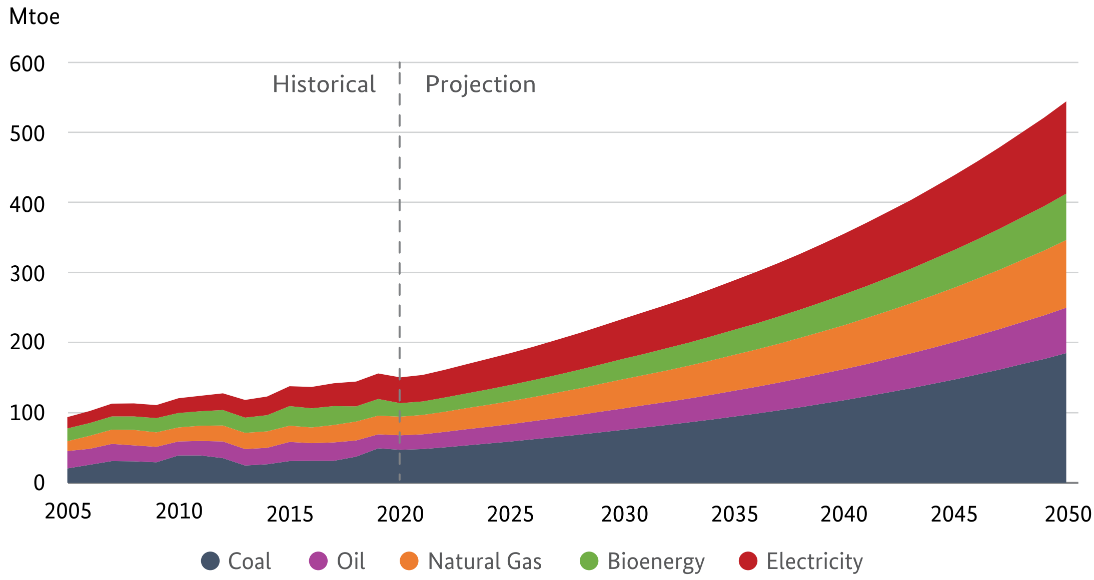
**Figure 4.4 2020 Energy Demand by Industrial Subsector in Southeast Asia**




These energy-intensive industries manufacture the basic materials needed for infrastructure development. As such, their increased use in Southeast Asia has matched the region's rapid economic, population and urbanisation growth trends. Between 2005 and 2020, industrial energy demand grew by over 60% (Figure 4.5). Already dominated by fossil fuels, coal use in industry doubled over that period, primarily driven by increased cement production. Around 62% of ASEAN's energy input to the industrial sector comes directly from burning fossil fuels, whilst electricity accounts for nearly 23%. At the same time, renewables remained less than 10% of the electricity generation mix in 2020 [44].

According to the AEO7 Baseline Scenario, energy demand from industry is expected to triple by 2050, implying that annual demand for fossil fuels could increase by 170 Mtoe (Figure 4.5). The associated economic and climate risks posed by investment into fossil fuel-based industrial technologies could lock ASEAN industries into relying on volatilely priced imports and products. They also could potentially restrict access to some export markets, once trade mechanisms such as the EU's carbon border adjustments are implemented.

**Figure 4.5 Industrial Energy Demand by Fuel, Baseline Scenario**



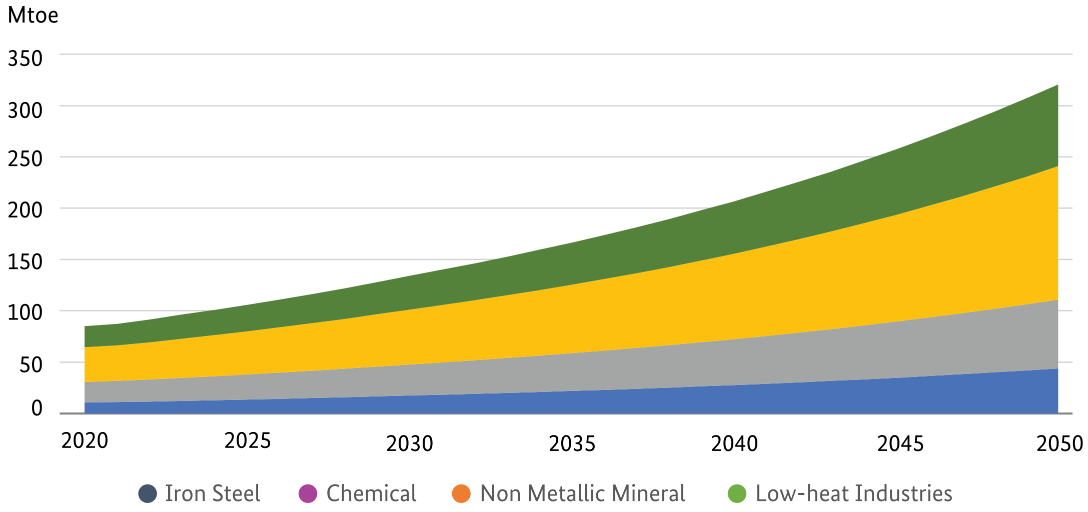

Reducing emissions and fossil-fuel use in the industry poses many challenges. Heavy industries burn fossil fuels to create the high temperatures needed to drive chemical processes, but chemical feedstocks are also derived from fossil fuels. Experience from the power system transition can help define a way forward by focusing on improving efficiencies and incorporating renewable energy. Improving the efficiency of materials and energy usage in industrial processes will enhance the longevity and quality of outputs relative to energy inputs. If coupled with power sector decarbonisation, electrification can eventually replace fossil fuels in a net-zero future, either directly in mechanical and low-temperature processes, or indirectly via hydrogen in high-temperature applications, amongst others.

Many industrial products, especially basic materials used for infrastructure, are globally traded commodities. As such, shifting industries away from fossil fuels will rely on international cooperation and collaboration in technology transfer, capacity-building and financial resources. Emerging new markets for climate-neutral and circular-economy products will further drive the low-carbon transition in the industrial sector. The transition is led by those countries that have pledged net-zero economies by mid-century. Governments will play an important role in setting the appropriate policy signals. Consumers of basic materials are also key players.

Investment decisions made today for industrial infrastructure will have long-term impacts and consequences. For example, steelworks and cement kilns have life cycles ranging from between 40 years to 70 years [45]. In the steel sector, 14% of global steel capacity is under development amongst AMS. This risks stranded assets if these developments continue to rely on fossil fuels [46].

Heavy industries are faced with a complex set of issues. A growing need for materials to support economic growth exists alongside the long-term risks of climate change and fuel supplies. The current global fuel supply crisis highlights the long-term opportunities for green infrastructure and industrial processes. The following sections summarise some of the key actions available to reduce fossil fuel use in industry and discuss cases on how to apply them in the four most energy-intensive sectors, dominated by fossil fuels in the AEO7 Baseline Scenario. These sectors are expected to grow from 94 Mtoe to 347 Mtoe, over the next three decades (Figure 4.6).

**Figure 4.6 Projected Growth in Deep Dive Subsectors of the Industrial Sector**




*Note: Low-heat industries: Pulp and paper, textiles and leather, food and beverages, and tobacco.*

### 4.3.2 Necessary Transformations for Fossil Fuels Reduction in the Industry Sector

***Reduce material demand***

The first step to reducing the demand for fossil fuel in the industry is to increase material efficiencies, either by employing innovative designs to use fewer materials to meet the same demand, or by increasing the use of recycled materials by incorporating designs for non-destructive reuse, longer lifetimes and increased circularity. Industrial plants can only partly address this, as mitigation efforts happen downstream of production processes.

Policies that promote efficient use of materials, such as those that improve durability, multi-use and re-use, can reduce overall demand without directly shifting energy sources. For example, incentives to reduce product lifecycle emissions and embodied energy can impact upstream demand. Material demand management and efficiency are on the global agenda as part of SDG 12 (responsible consumption and production), and the large energy and emission reduction potential via this route is increasingly being recognised despite being poorly addressed from a policy perspective [42].

***Improve industrial efficiency***

Improving industrial energy efficiencies is the most common and best-established measure for reducing fossil fuel use in the sector [42]. This is particularly the case in Southeast Asia, where compared to industrialised countries, the adoption of technologies with the highest possible efficiencies remains limited. The use of lower efficiency industrial technologies coupled with a growing market can create a lock-in, as many plants have long expected lifetimes. Even if the most efficient technology is installed, many plants still require fossil fuels, and there is a risk of fuel lock-in, carbon lock-in and stranded assets. Similarly, retrofitting for better industrial efficiency often extends the lifetime of a plant, potentially extending lock-in risks.

Improving industrial EE often incurs high capital costs. Although the higher costs are offset in the long term due to fuel savings, poor access to affordable capital is a major barrier in ASEAN. At the same time, the narrow profit margins of materials and high competition create additional risks. The risk of lock-in goes beyond fuel use and carbon emissions and includes turnover for new technologies. Although EE efforts alone cannot eliminate fossil fuels and significant decarbonisation, they can achieve near- and mid-term fuel reductions.

Mandatory EE policies, regulations, training, and audits, along with facilitated access to capital, are all necessary measures to address industrial EE. Whilst certain measures to address efficiency are already in place, they lack effective implementation. Nevertheless, the share of global investment in industrial EE in ASEAN grew from only 2% in 2019 to 8% in 2020. Only China and India achieved larger shares in 2020 [43].

***Electrify industry and decarbonise heat sources***

Electrification of end-use demand in all sectors can displace fossil fuels. When combined with the decarbonisation of power supply via renewables, this is a fundamental component of the energy transition. Historically, electrification measures have focused primarily on mechanical (non-heating) operations, e.g., robotic machinery, conveyor belts, pumps, and the like. However, a large proportion of industrial sector energy use goes toward generating low- and medium-temperature process heat.

Temperatures ranging from below 100°C to 1,000°C can be achieved by a wide range of electrically powered technologies, including heat pumps [42]. Nearly 50% of all fuels used in the industry could be replaced by electricity [47]. Only high-heat processes above 1,000°C require further development for direct electrification as commercial alternatives. For these applications, fossil fuels may already be replaced with sustainable biomass, but availability is limited. Future possibilities include solar thermal heat, or electrified indirectly by means of hydrogen.

A key barrier to electrification has typically been the low cost of fossil fuels. Recent trends, however, reflect fuel shortages and price increases, alongside decreasing costs of RE and lowering power prices. New industrial plants could opt for modern electrified technologies, especially given the long service life of industrial technologies. The introduction of carbon pricing could make electric solutions even more attractive.

### 4.3.3 Deep Dive: Iron and Steel

Iron and steel manufacturing is one of the most energy-intensive industries and globally accounts for nearly 8% of final energy demand and 3% in ASEAN [44]. Three-quarters of that energy comes from coal [48]. It is also one of the fastest growing sectors in ASEAN, with energy use more than tripling in the last decade [44]. In just five years, steel production doubled in Vietnam, Indonesia, and Malaysia, whilst Thailand and the Philippines are ranked 3$^{rd}$ and 6$^{th}$ in global imports [49]. By 2050, ASEAN iron and steel energy use is expected to increase at least another 4-fold, to 43.9 Mtoe (Figure 4.6).

***Reduce material demand***

Improved material efficiency can potentially reduce up to 40% of global steel demand [42]. This potential can be realised by designing infrastructure for longer lifetimes, adding corrosion protection, delaying product retirement, or minimising all steel use (e.g., optimally shaped beams, alternative load alignments) [50]. Additionally, better collection, sorting and recycling of scrap steel and reusing steel components can effectively decrease material use. In particular, this provides an opportunity for ASEAN countries, where large amounts of products containing steel are expected to reach their end-of-lifetime in the next decade [48].

### *Improve industrial efficiency*

The EE of steel production improved significantly in recent decades, and state-of-the-art furnaces are near maximum potential [48]. Deployment of efficient furnaces is concentrated in developed countries, thus, opportunities exist in ASEAN to reduce fuel consumption at equal yields. However, the risk of lock-in with fossil fuel-dominated technologies, due to extended lifetimes, needs to be considered.

Depending on the steelmaking and iron production process, hydrogen or biomass can be used to replace feedstock fuels. Basic oxygen blast furnaces make up nearly 80% of planned steel capacity expansion in the ASEAN region [51], with coke as their feedstock fuel. This could be partially replaced by bio-charcoal [52]. However, given the large projected capacity increases and more than 40-year operating lifetimes of the furnaces [48], the challenges of using biomass need to be carefully considered.

### *Electrify industry and decarbonise heat sources*

Heat-generating fuels can be replaced directly through electrified heat, or indirectly using renewable fuels, like hydrogen. Although electric arc furnaces are already widely used in the steel industry, fossil fuels dominate generation for iron production and preheating. The Direct Reduced Iron (DRI) process, where iron is produced at lower temperatures with significantly less fuel, can also use hydrogen as a reducing agent. With lower capital costs than traditional blast furnaces, DRI processes could be well suited for the ASEAN region. Electric heaters, or combining DRI with electric furnaces, are promising means to displace fossil fuels.

Beyond energy used for heat generation, several up- and downstream processes and auxiliary activities are powered by fossil fuels. These can often be electrified much easier but also offer the possibility of being coupled with fossil-fuel furnaces, allowing for a partial replacement and avoiding stranded assets [53].

The international steel market is highly competitive, which makes it sensitive to local energy costs. This is a major barrier to wider electrification, as electricity is often more expensive than fossil fuels. However, an increased understanding of the high volatility of fossil fuel costs has the potential to counter this argument and make it more attractive to consider higher but more stable electricity tariffs.

### 4.3.4 Deep Dive: Cement

Non-metallic minerals, consisting of cement, ceramics, glass, and lime, make up the largest share of industrial final energy demand, at 22.5% in ASEAN (Figure 4.4). Cement has a 70% to 80% share of non-metallic minerals [54], which makes cement the single most energy-intensive sector amongst all industries. Like the rest of the sector, the demand for these materials is expected to increase by more than 3.8-fold by 2050 (Figure 4.6). Although the terms cement and concrete are often used interchangeably, cement is an ingredient of concrete when mixed with water and other aggregates. The vast majority of energy demand occurs in the production of cement.

### *Reduce material demand*

Cement is the second-most globally consumed material [48], so reducing demand can play a large role in reducing material demand and fossil fuel usage. Due to its low costs, strength and adaptability, cement is often overused. It is also difficult to recycle cement, and improving cement material efficiencies is often related to extending infrastructure lifetimes via improved design and reduced renovation rates. Cement use in infrastructure can also be reduced, by optimising its use in concrete mixes and replacement with masonry or timber. Reusing cement components could also play a larger role in the future [45][50][55].

### *Improve industrial efficiency*

The heat generation process consumes the most energy in cement production, requiring temperatures nearing 1,400°C to produce clinker. Energy intensities have continuously declined in past decades as processes have shifted away from wet kilns. These efficient technologies have recently been adopted in ASEAN, especially in Thailand [56]. However, efficiency improvements have stagnated beyond this shift, and further efficiency gains remain limited [48].

Substituting novel cement sources for limestone is typically explored to reduce process emissions. This may also lead to more efficient operations and fuel savings if novel raw materials require lower heat levels than existing processes. Similarly, the increased use of supplementary cementitious materials, such as slag, ash and calcined clays, can partly replace clinker, leading to additional energy savings.

### *Electrify industry and decarbonise heat sources*

The primary energy source in the global cement sector is still fossil fuels. Of that, only 3% of the thermal energy is generated with bioenergy and biowaste [55]. Requiring temperatures up to 1,400°C, biomass and waste are currently the best-suited options to replace the current fossil-fuel sources, currently dominated by coal. There is, however, a limited amount of sustainable biomass supply and using it only makes sense if it can be sourced locally. Despite the additional challenges of biomass, it may make sense to prioritise its use for high-heat generation in the short term, instead of using it in other sectors. Waste brings its own challenges, especially if based on materials such as waste oil, tires, or plastic. Although not directly fossil fuels, these energy sources emit similar levels of carbon emissions when burned.

Pilot projects that go beyond waste and biomass for heat production are underway. In early 2022, a breakthrough was achieved when a concentrated solar thermal receiver generated heat beyond 1,500°C, and produced the world's first solar clinker [57]. Such technologies could be of particular interest to countries in the ASEAN region, due to the high solar yields. Research is also being conducted to use hydrogen, but many technical challenges remain, and using it as a heat source is relatively inefficient.

Switching to direct electrification is more challenging, due to the high heat requirements. Feasibility studies have shown that it is possible, although testing on a large scale has yet to be conducted. Development is still at a very early stage [58].

### 4.3.5 Deep Dive: Chemicals, Petrochemicals, and Plastics

The chemical industry is the largest consumer of oil and gas. Fossil fuels are used to generate medium- to high temperatures, as well as for feedstock. In the ASEAN region, the chemical sector accounts for 13.2% of specified energy use (Figure 4.4), second only to non-metallic minerals, and is projected to grow almost 3.4-fold between 2020 and 2050 (Figure 4.6).

Currently, about 65% of ASEAN energy demand in the chemical industry is met with the use of fossil fuels, comprised of natural gas (40%), oil (19%) and coal (5%) [44]. There is much room to reduce fossil fuel reliance in this sector. Policy incentives support demand-side measures. Supply-side measures support the substitution of feedstock and fuel with renewables and the development of low-carbon technologies.

### *Reduce material demand*

Substantial fossil fuel consumption in the chemical sector is primarily driven by demand for various chemical products, including plastics and ammonia – a precursor for producing fertilizers. Thus, demand-side measures, like recycling and using alternatives, are emphasised as strategies to reduce fossil fuels in the chemical sector [59]. Policies to reduce plastic demand are already in place and becoming increasingly popular. They include incentivising less packaging, banning of single-use plastics, and supporting new materials that replace plastic products. Depending on the use case, alternatives range from glass and stainless steel to bamboo or corn-based products. Chemical recycling and circular plastics would also reduce the use of oil-based hydrocarbon feedstock [60].

Ammonium fertilisers have long been integral to food production across the world. Reducing these products can be achieved through reform of farming practices, using only the necessary amounts of fertiliser and non-petrochemical alternatives.

### *Improve industrial efficiency*

Petrochemical plants are already closely managed to minimise energy costs, which means that best available technologies to achieve energy efficiencies are already widely used. Nevertheless, certain production technologies, like naphtha catalytic cracking, could lead to a 15% savings in process energy usage [61]. Such processes, however, require higher upfront investments, which in the ASEAN region could be a significant barrier if not supported by favourable policies.

Bio feedstocks or synthetic materials could replace natural gas or refined oil. Mature biorefined products are already being transformed into plastics and include biodiesel converted into bio-naphtha, or bioethanol used to produce ethylene. Additionally, direct plant-based materials with high starch content can be used to produce biodegradable plastics [56][62]. It should be noted that a key barrier is that the costs of bio-based plastics are significantly higher. Even if costs are reduced and fossil fuels become more expensive, the gap will only close with the adoption of targeted policy instruments [63].

Synthetic fuels can more easily be produced on a large scale without substantially higher costs, but it requires the synthesis of carbon dioxide and hydrogen [61]. Nevertheless, carbon dioxide capturing technologies (CCS) are not yet commercially available, and clean hydrogen only to a limited extent. Green hydrogen could play an important role in creating non-fossil-fuel ammonium.

### *Electrify industry and decarbonise heat sources*

Generating heat to produce ethylene can be decarbonised by switching from currently dominant fossil-fuel sources to biomass, sustainable biogas, green hydrogen, or ammonia from solar and wind energy. Fuel switching can be done with little to no retrofitting. Although minimal additional capital costs would be needed, the energy sources are significantly more expensive [56][62].

Similar to cement and steel, direct electrification routes for high-heat processes remain at a developmental stage, and though they have been successfully tested, they are not yet widely available at a commercial scale.

#### 4.3.6 Deep Dive: Low to Medium Temperature Heat Industries

Pulp and paper, textiles and leather, food and beverages, and tobacco are rapidly growing industries. In ASEAN, they are expected to grow 3.9-fold in the next 30 years (Figure 4.6). This is partly due to the potential for greater electrification and the use of renewable heat in these sectors. Together they account for a 13.7% of energy demand in these sectors (Figure 4.4). Unlike the aforementioned industrial sectors, these primarily utilise low- to medium-temperature heat, and thus are easier to decarbonise due to fuel switching to alternative renewable heat sources. Such technologies are economically and commercially available at scale.

With a decarbonised power supply, electrification of industrial heat will not only reduce the use of fossil fuels, but can also be operationalised to provide power system flexibility [64]. Industrial heat sources could be electrified through technologies, such as heat pumps, electric boilers and furnaces, infrared light, and the like. For low-temperature industries (below 100°C), heat can be provided by electric heat pumps, which are more efficient than boilers, and consume electricity instead of fossil fuels.

Concurrently, the shift from fossil fuels to renewable heat sources for medium-temperature industries can utilise boilers fuelled by biomass, biogas, renewable electricity, or hydrogen produced with renewable electricity [59].

Bioenergy is considered to be the renewable heat source with the highest potential. Electrification of low- and medium-temperature heat in the industry can also increase the use of RE to replace fossil fuels [65]. Renewable heat in the industry is already being supported with financial incentives in many European countries [66]. Supporting policies and financial incentives, such as carbon pricing, upfront cost subsidies, grant schemes for renewable heat projects, and setting renewable heat targets could be critical for reducing fossil fuel reliance in low- to medium-temperature heat industries.

## 4.4 Enhancing Dispatchability of Renewable Energy

***Authored by ASEAN Centre for Energy (ACE), Universitas Pertamina, and National Science and Technology Development Agency (NSTDA)***

#### 4.4.1 Hydropower

Hydropower is the backbone of the electricity supply in ASEAN, with a 19.8% share of total installed capacity in 2020, along with coal (32.2%) and gas (29.9%). In some countries, such as Cambodia and Lao PDR, hydropower accounts for over 50% of the total capacity mix. In Mekong countries, hydropower contributes directly to economic activity through cross-border electricity trading. And the installed hydropower capacity is estimated to grow further to meet the APAEC target and to support AMS' net-zero commitment.

ASEAN has yet to fully utilise the hydropower potential in the region. To date, most existing hydropower projects are large-scale and debated as environmentally disastrous by some scholars [67]. The smaller-scale hydropower projects could be expanded to support rural electrification. When combined with intermittent renewable energy sources, such as wind and solar PV, it is less recognised than integration with energy storage system. Nevertheless, strict sustainability controls should be enforced to minimise hydropower's carbon footprint, as well as environmental and social impacts.

Extreme weather events and rising temperatures have notably threatened the existing hydropower plant and future expansion in ASEAN. They have caused wider variability in streamflow, shifted seasonal flows, and increased reservoir evaporation losses. Heavy rainfall and associated landslides have delayed the development of several hydropower projects, particularly, Lao PDR's Xe-Pian Xe Namnoy Dam in 2018 and Vietnam's Thua Thien Hue project in 2020. In addition to the disruption of power generation, the weather variability has significantly affected the freshwater services, such as floods protection, water conservation during droughts, and water supply for irrigation and transportation.

With the growing climate-induced risks, resilient hydropower systems have become a more critical issue than ever, but ASEAN's awareness is still low. Climate resilience refers to the capacity to anticipate, absorb, accommodate, and recover from stress and changes caused by climate variations [68]. Examples of resilience measures include enhancing reservoir capacity and improving generation efficiency through more robust early warning and forecasting system. Other examples of system-level measures are diversifying energy mix and utilising hydropower to be used to balance variable renewables to displace expensive gas.

There are few new floating solar plants on hydropower reservoirs, such as the 145 MW Cirata project in Indonesia [69] and the 58.5 MW facility on Sirindhorn Dam in Thailand [70]. These are considered enhanced resilience efforts. The electricity from floating solar PV can compensate for the hydropower production during the low season and reduce evaporation when the ratio of covered water body is significant. The water also helps cool the solar panels, thereby increasing the overall efficiency of both floating PV and hydropower plants. The mutualistic dynamic is even more pronounced when coupled with energy storage systems, such as a batteries or pumped hydro.

No one-size-fits-all solution exists to strengthen the resilience of ASEAN's hydropower. The measures need to be tailored to fit AMS' national circumstances. Generally, resilience can be categorised into "soft" and "hard" measures [71]. Soft measures are related to recovery and operational management planning. Hard measures are associated with technical and structural improvements. The International Hydropower Association have provided several guidance and assessment tools to identify climate risks and to design climate resilience measures, such as the Hydropower Sector Climate Resilience Guide, Hydropower Sustainability Assessment Protocol, and Hydropower Sustainability Environmental, Social, and Governance Gap Analysis [72].

Several AMS have implemented the measures to improve hydropower resilience, including:

a. Lao PDR has assessed the power sector vulnerability and produced a resilience action plan supported by USAID in 2020 [73]. The recommended actions include developing geospatial data for hydropower and future climate projections, strengthening data sharing and coordination across dam operations, and improving the construction codes and dam design.

b. The Malaysia Dam Safety Management Guidelines (MyDAMS) were released in 2017 to provide a detailed safety management guide over the lifecycle of dams, beginning with the water supply, irrigation, flood mitigation, water quality control, sediment retention and recreation, as well as power generation [74].

In 2018, the Mekong River Commission released the Basin-Wide Assessment of Climate Change Impacts on Hydropower Production [75], to inform the development of Mekong Climate Change Adaptation Strategy and Action Plan [76]. Furthermore, the Basin Development Strategy 2020-2030 was approved by the Council of Ministers from Cambodia, Lao PDR, Thailand, and Vietnam and released by the commission in April 2020 [77].

#### 4.4.2 Geothermal

The installed global capacity from geothermal energy in 29 countries was 14.1GW, as of 2020. Of that total, there was a 28% contribution from AMS, including Indonesia and the Philippines [78][22]. The total generated power from geothermal plants provided continuous base-load electricity, serving 63 million people worldwide.

Electricity generation requires high-temperature geothermal resources. Its availability from natural sources is confined to geological locations with concentrated heat near the surface, such as near or above volcanic areas, active tectonic areas, or where the Earth's crust is thinnest. Though the global potential geothermal power generation is between 70 GW and 80 GW, only 19% to 22% of the potential has been utilised, as of 2020 [79].

The high upfront project costs, lack of expertise in drilling or exploration techniques, and various policy barriers contributed to limited geothermal development in ASEAN. The exploration wells cost up to USD 8 million each, with no guarantee of success. Relatively high exploration risks exacerbate the expense of well drilling. The high costs and risks often lead to delays in obtaining project financing and permitting. Due to these factors, project development may take as much as seven to ten years. Additionally, policymakers and the public negatively perceive geothermal energy as costly and risky [80].

The regulatory framework is noted as the primary bottleneck from a policy perspective. In Indonesia, despite significant revisions to Geothermal Law No. 21 in 2014, allowing exploration activities in conservation areas that were previously prohibited, the intricate social and environmental assessment process persists. In Indonesia, the prospective sites for geothermal development are located in conservation areas and tropical rainforest heritage reserves on Sumatra Island. In the Philippines, the wholesale electricity market promotes geothermal to compete with other RE technologies at a much lower cost.

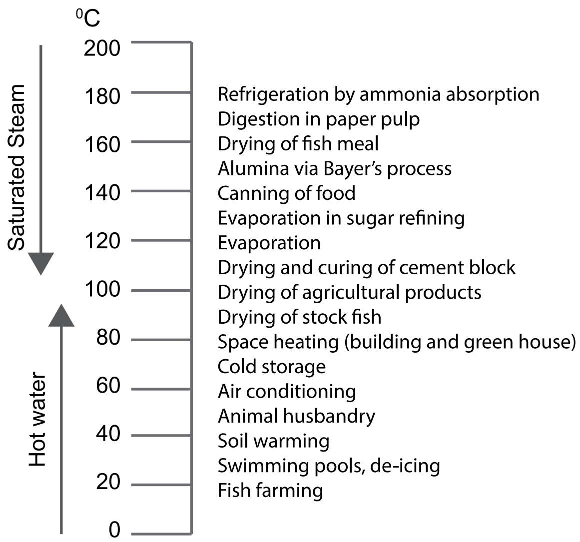
***Outlook of geothermal development: direct usage***

Utilising geothermal beyond electricity generation, e.g., in direct use for heating, offers an attractive option for the ASEAN region to accelerate progress in achieving the 23% renewable energy target by 2025. Direct usage is more energy-efficient than generating electricity. Medium-temperature geothermal sources are also more widely found across the region. ASEAN has many locations with temperature gradients above the global average of 250C/km, or heat flows above 65mW/m2.

Direct geothermal usage can support many industrial activities. Low-temperature geothermal (below 150ºC) is ideal for various agricultural activities, including pasteurising, sterilising, drying, and pickling, as well as hospitality requirements, such as cooking, boiling, cleaning, and washing. By comparison, medium-temperature geothermal (150ºC to 400ºC) may be utilised for more advanced industries, such as steel making and fertiliser production, distilling, nitrate melting, dyeing, and compression. The low- to medium-heat demand from different activities is provided in the Lindal diagram in Figure 4.7.

The utilisation of direct geothermal usage in ASEAN has not been thoroughly monitored. It has been given little attention for industrial applications, despite its significant potential contribution toward reducing dependency on fossil fuel-based heat. The following section covers the most recent developmental status of direct geothermal utilisation in the AMS.

**Figure 4.7 Lindal Diagram**




### *Status of direct geothermal usage in the ASEAN Member States*

#### Indonesia

Direct geothermal utilisation has been adopted for bathing, washing, cooking, spas, and swimming pools, as well as agricultural activities, such as distillation of vetiver oil, pasteurising mushrooms, brown sugar processing, fish farming, and drying coffee beans and tea leaves. An example of direct use of geothermal water is in Lampung, southern Sumatra. A traditional freshwater fishery mixes naturally heated geothermal water (outflow) with fresh river water to farm catfish. The farmer reports that the fish grow better in the heated geothermal and freshwater mixture. Total brine use is about 50 tonnes/hour for fish farming.

Other uses of geothermal for agriculture include copra drying on the islands of Lahendong, Mataloko and Wai Ratai Lampung; mushroom cultivation in Pengalengan (West Java); and tea drying and pasteurisation in Pengalengan. Estimates for use in bathing and swimming are 2.30MWt and 42.6TJ/year, for a capacity factor of 0.587. No data were available on other direct uses [81].

#### Malaysia

So far, only one high-temperature geothermal prospect has been identified in Sabah Province, Malaysia. The project is known as Tawau or Apas Kiri, after the large grouping of hot springs. Beyond that project, the only use of geothermal energy in Malaysia consists of approximately 15 bathing facilities using natural hot springs, across the Malaysian Peninsula, with one located in Sabah and another in Sarawak. These sources are most likely of tectonic rather than volcanic origin.

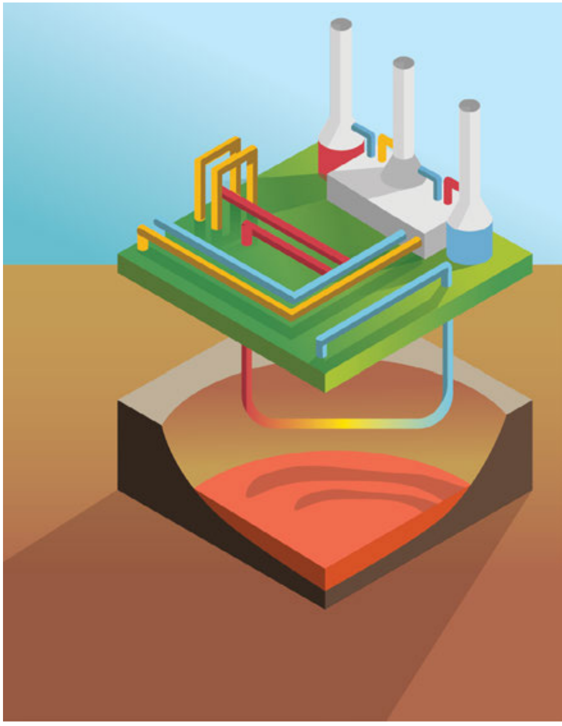
#### Philippines

The Department of Energy (DOE) is currently implementing a local project named "Philippine Geothermal Resource Inventory and Assessment". The primary objectives are to identify and study the potential for the country's indigenous geothermal resources, both for power and direct-use applications. With the commencement of the Philippine Geothermal Resource Inventory and Assessment Project (PGRIA), it has been able to identify six geothermal project areas, which include (1) Buguias-Tinoc geothermal field in Benguet and Ifugao, (2) Tuba-Pugo geothermal field in Benguet and La Union, (3) La Trinidad-Klbungan geothermal field in Benguet, (4) Mt. Sembrano geothermal field in Rizal, (5) Coron geothermal field in Palawan, and (6) Mati-Lupon-Tarragona geothermal field in Davao Oriental.

Drying plants in Palinpinon and the Manito Lowlands was decommissioned in 1997 and 1998, respectively. In assessing the country's potential for utilising direct geothermal energy for bathing, swimming and balneology purposes, the DOE has conducted an inventory of hot spring resorts and pools utilising naturally heated water from the foot of Mt. Makiling in Laguna. Part of the DOE roadmap is to study and promote direct use geothermal in the country. Direct-use application totals (swimming and bathing) are 1.87MWt and 12.65TJ/year [82].

### Thailand

Thailand has more than 1,800 hot springs throughout the country, primarily in the north and extending to the west and south, with surface temperatures ranging from 40$^0$C to 100$^0$C. In 1986, a pilot drying house was constructed in the Sankamphaeng geothermal field to experiment with curing and drying tobacco, bananas, chilli peppers, garlic, maise, peanuts, and other products. Results were positive, compared to using firewood and lignite. A similar drying facility was also constructed at the Fang geothermal field, using the tailwater from a small 77$^0$C binary power plant, which is still in operation. A third drying facility at the Maechan geothermal field was shut down due to maintenance and budget problems. A cold storage plant was built to test the cooling of lemons, onions and lychee fruit.



Hot spring baths have been very popular in Thailand, operated by the private sector and local communities that actively monitor and preserve these hot springs. Seventy-one locations are reported, some with as much as 20MWt of installed capacity, and 80TJ/year of utilisation. Presently, several geothermal heat pump facilities are installed in the country, but the data are unavailable and can only be estimated. The estimated use of geothermal energy for direct-use applications is 0.04MWt and 0.3TJ/year for crop drying, 127.470MWt and 1168.898TJ/year for bathing and swimming, and 1.0MWt and 12.0TJ/year estimated for geothermal heat pumps. The country's total geothermal use is 128.510MWt and 1181.198TJ/year [83].

### Vietnam

Almost all geothermal sources in Vietnam today are only for direct use, such as spas, bathing and hot water swimming pools. Recently, however, people in Quynh Phu and Hung Ha districts of Thai Binh province have started using hot water for warming fish breeding ponds, as well as winter heating for chicken and hog farms. Currently, there are only two Ground Source Heat Pump (GSHP) pilot installations, located in Hanoi, with one at the Vietnam Institute of Geosciences and Mineral Resources.

The calculated coefficient of performance (COP) is 3.1 for cooling and 3.6 for heating. This COP shows that the GSHP installation can bring greater EE to the Hanoi area. One advantage to installing GSHP in northern Vietnam, is that it can be used for both summer cooling and winter heating.

In summary, the installed capacity and annual energy use for the various direct-use applications in the Vietnam are 0.53MWt and 1.66TJ/year for fish farming, 17.64MWt and 185.32TJ/year for bathing and swimming, 0.03MWt and 0.08TJ/year for other uses (animal farming), and 0.01MWt and 1.46TJ/year for geothermal heat pumps, for a total of 18.21MWt and 188.52TJ/year [84].

### 4.4.3 Bioenergy

***Biofuel***

The Covid-19 pandemic has had a significant global impact on transportation fuel, due to travel restrictions and personal fear of travel. Biofuel blending for both ethanol and biodiesel in the transportation sector has inevitably declined , affecting the biofuel production industry.

In ASEAN, the Thailand ethanol fuel industry was initially affected. Travel restrictions reduced fuel demand during Covid-19. It later rebounded by introducing incentives for derivative products, such as waiving excise tax on ethanol fuel, but not the heavy excise tax on alcoholic beverages, as well as regulations that allowed ethanol fuel to be used as a germ-killing agent against Covid-19. In addition, an increase in motorcycle food and parcel deliveries across the region during Covid-19 has contributed to an increase in gasoline consumption (with ethanol blending). Biodiesel consumption did not decline as much due to the need for diesel consumption for commodity logistics, as well as government policies mandating higher levels of blending, especially in Indonesia.

Since the economic recovery and the lifting of travel restrictions in 2021, transportation fuel consumption has recovered. Recent Covid-19 waves and geo-political issues have caused a supply chain bottleneck leading to inflation and higher biofuel feedstock prices. Consequently, biofuel blending levels have not increased as planned, for instance, with B40 in Indonesia. In some cases, blending levels have declined, including 5% biodiesel blending for all diesel grades – B7, B10, and B20 – in Thailand.

Disruptive EV technology is slowly spreading within the ASEAN market, especially in the passenger and motorcycle sectors. This is expected to disrupt ethanol fuel consumption in blended gasoline. This is coming on top of the improving fuel economy and shared/shift-mode mobility trends.

For the diesel market segment, EV options for heavy-duty trucks may not be widely available at price parity. In this case, biodiesel will still be used for transportation decarbonisation. Due to unclear supporting policies, the potential blending increase using hydrogenated vegetable oil (HVO) may not be as promising as previously hoped. Instead, sustainable aviation fuel (SAF), or bio-jet fuel, has received increased attention, especially from the global aviation industry, in response to European policies to decarbonise the aviation sector.

Hydroprocessed Esters and Fatty Acids (HEFA) are commercially produced and available SAF technology made from vegetable oil used as an aero-fuel drop-in at up to 50% blends. Additionally, emerging technologies, such as alcohol-to-jet, gasification/Fischer Tropsch, and Power-to-Liquid, have been developed for use as alternative feedstock with ethanol, biomass and electricity to achieve a greater percentage of reductions in GHG emissions.

The National Science and Technology Development Agency (NSTDA), in cooperation with ACE and ASEAN Renewable Energy Sub-Sector Network (RE-SSN), have conducted a study to map regional biofuel research and development. RE-SSN representatives from AMSs were consulted via a series of focus group discussions to identify priority and key success factors, with a technology readiness rating for biofuel ethanol and biodiesel technologies within the ASEAN context. The ASEAN ethanol and biodiesel R&D roadmaps were then constructed as shown in Figure 4.8 and Figure 4.9.

**Figure 4.8 ASEAN Ethanol R&D Roadmap**

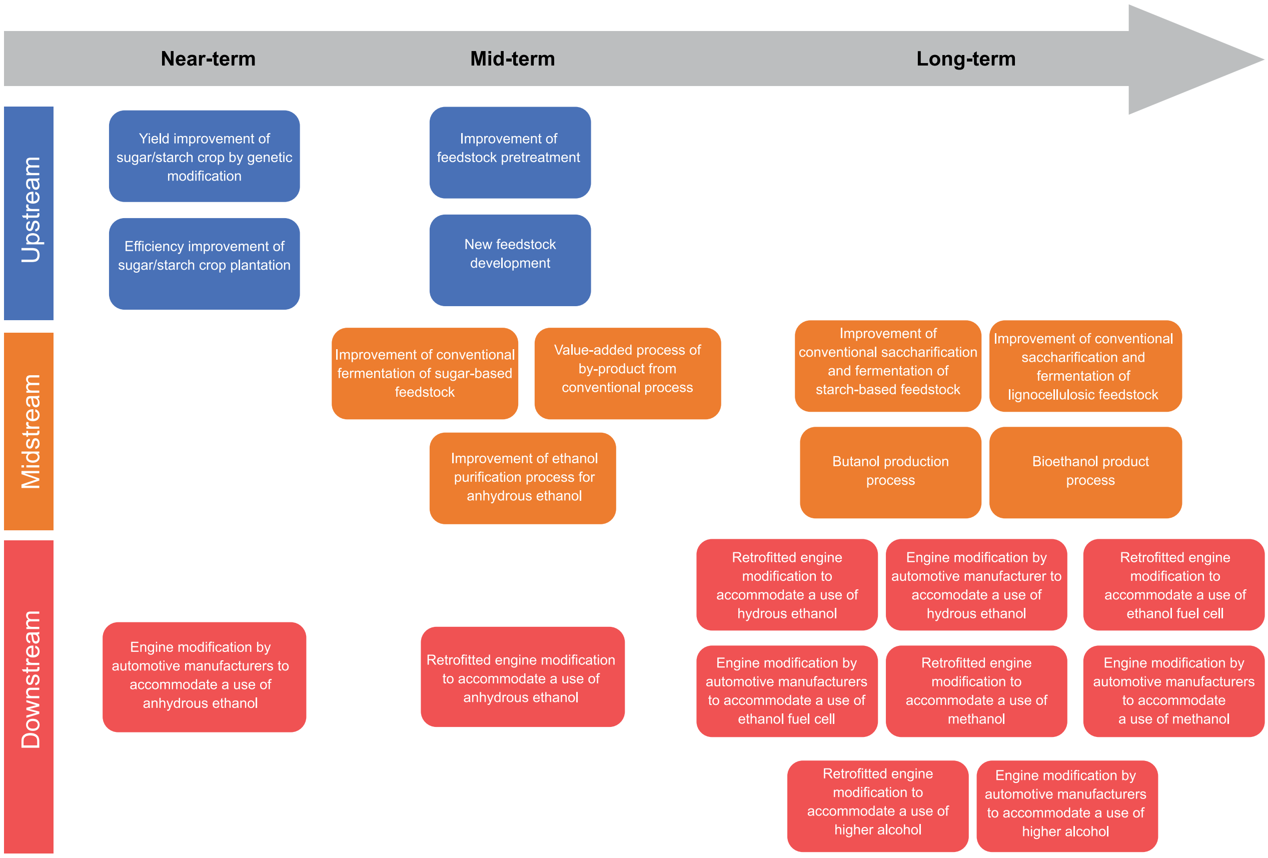
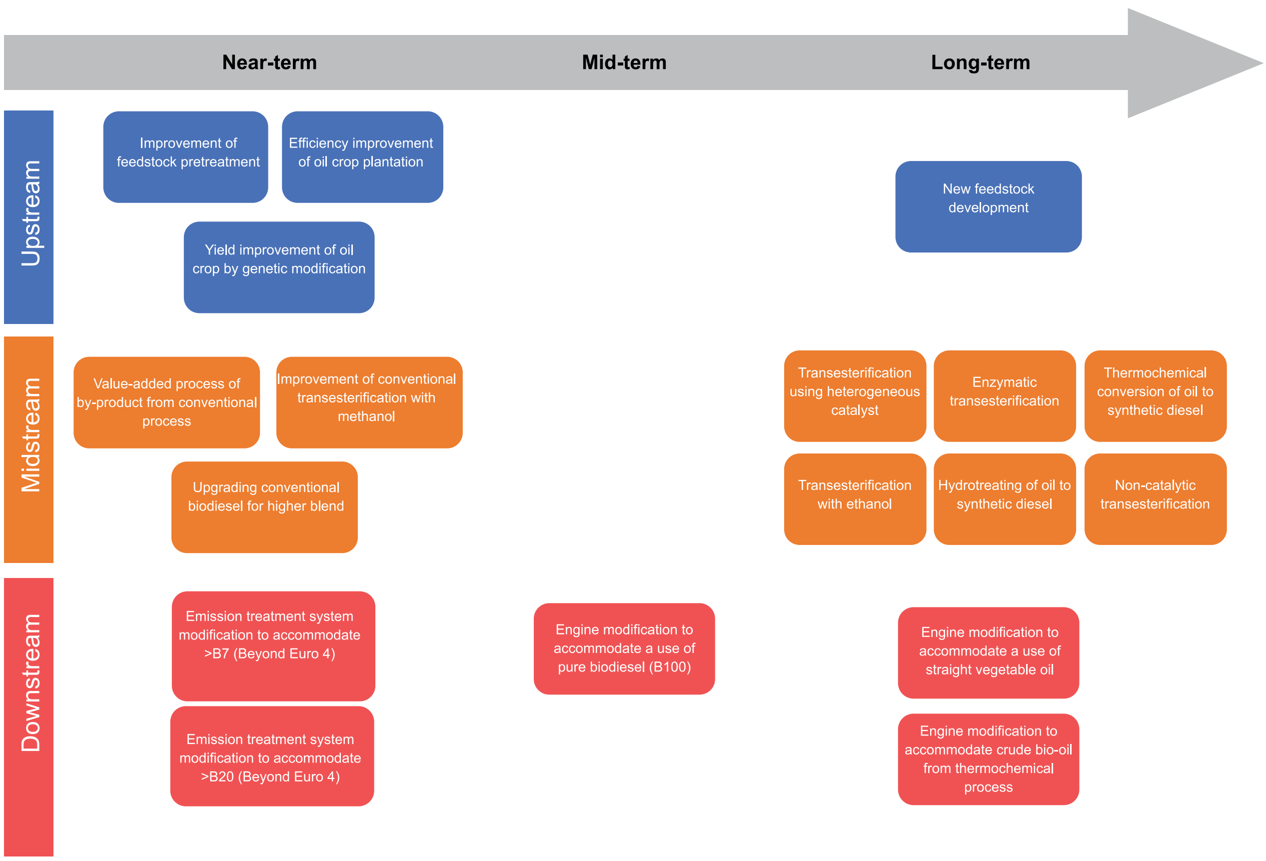



**Figure 4.9 ASEAN Biodiesel R&D Roadmap**

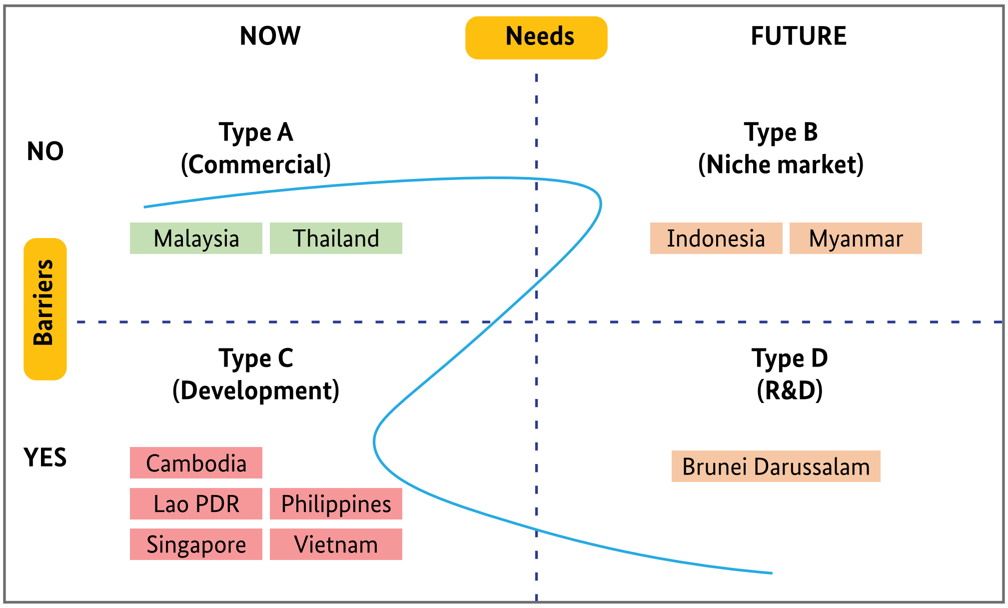


### *Biogas*

Unlike biofuel, biogas development needs more attention from AMS, considering its potential to reduce methane emissions. Six AMS (Cambodia, Indonesia, Malaysia, the Philippines, Singapore, and Vietnam) have joined the Global Methane Pledge that committed to lowering methane emissions by at least 30% from 2020 levels by 2030 [85]. Biogas is also a strategic alternative for AMS to diversify their energy mix to attain national bioenergy targets and 100% electrification.

Biogas utilisation for power generation is still in early development in ASEAN, with only a 0.2% share of TPES as of 2020. The limited feedstock availability, collection, and processing are significant barriers, including insufficient technological knowledge, lack of incentives and subsidies, expensive upfront cost, and unclear policy directives. Based on the observation of existing biogas development from the perspective of legal, technological, economic, political, social, and environmental aspects, the technology readiness levels of biogas-to-electricity are conceptualised in Figure 4.10.

**Figure 4.10 Technology Readiness Levels of Biogas-to-Electricity in ASEAN**




The four stages of "S-curved" technology readiness represent each AMS' needs and barriers to further scale-up biogas-to-electricity. The needs are categorised into two timeframes, Now and Future (5 to 10 years). The countries inside the 'Now' column need direct biogas deployment, whilst the 'Future' indicates the need to address several critical factors for an extended deployment. If no significant barriers exist, for example, countries inside the 'no' row, the need is achievable. However, for countries inside the 'yes' row, the need is unfeasible and therefore requires fundamental changes to allow biogas-to-electricity deployment.

The countries in Type A need immediate solutions to energy shortages that can be solved through biogas commercialisation. Meanwhile, the existing biogas projects in Type B countries are still research-oriented, but their scale is large enough to create niche markets. The economic costs in these two groups are relatively easier to estimate. And the benefits are well acknowledged by the related stakeholders in the respective countries. Hence, the biogas deployment is relatively higher than in Type C and D countries.

Type C reflects ASEAN's readiness primarily in adopting biogas, with half of the member countries within this group. The biogas projects in Type C are unrealistic due to high costs and unpredictable social impacts, preventing the projects to shift from R&D to development. Type D countries have innovative biogas projects with unpredictable costs, thus requiring more R&D activities. Estimating the impacts of biogas in Type C and D countries is more complex and comes with future uncertainty.

Reflecting the current regulatory and non-regulatory barriers (e.g., technological, economic, political, social, and environmental), policy improvement is essential for ASEAN in general. Some enabling policies should be considered, such as tax credits, feed-in-tariff, and loan guarantees. Transparent and precise coordination amongst the key actors is needed to ease the bureaucratic process of mobilising financial aid for biogas development.

Specific recommendations were suggested for each type to move to a higher tier. For example, the fund to support R&D, demonstration projects, and knowledge sharing could help Type C and D countries enter niche markets and the commercialisation stage. Private capital could significantly improve biogas deployment in Type B from the niche market to commercialisation. Policy interventions such as green certification and carbon pricing could further lower the cost of biogas projects, therefore maturing the technology with more commissioned large-scale projects.

### Clean Dispatchable Supply from Renewable Sources

***A view from the International Renewable Energy Agency (IRENA)'s 2$^{nd}$ Renewables Outlook for ASEAN: Towards a regional energy transition***

Clean dispatchable power has been, and will continue to be, a crucial element in the generation mix of ASEAN. Most notably from geothermal and hydropower, delivering power on-demand to balance supply-demand variability and provide a whole host of non-energy services to help secure and stabilise system operation.

To advance both generation sources internationally, the International Renewable Energy Agency (IRENA) have coordinated the Global Geothermal Alliance and the Collaborative Framework on Hydropower to serve as platforms for dialogue, cooperation and coordinated action between policy makers and stakeholders worldwide. This knowledge was used to look deeper into the power sector in ASEAN and develop future pathways for power system for IRENA's *2$^{nd}$ Renewables Outlook for ASEAN: Towards regional energy transition*.

In terms of the power generation mix, in 2020 it was composed mostly of fossil fuel which represented a little over 70% of power generation capacity and nearly 80% of power generation. Geothermal and hydropower combined make up the vast majority of renewable power in the ASEAN region with the remainder made up of solar PV, wind and bioenergy. Geothermal and hydropower contributed around a 20% share of generation capacity and power generation, but this understates the crucial role they perform and can perform going forward. Geothermal is not weather-dependent and can operate at very high-capacity factors. Beyond electricity and ancillary services related to the grid operation, geothermal can also provide heat to industry and buildings. All of these characteristics make it particularly dependable across the entire year, due to its lack of seasonality, and make it a crucial component of the power system. This is particularly because it can mitigate periods of low renewable supply from other renewables and supply interruptions and price volatility from non-renewable sources.

Whereas geothermal tends to operate as a baseload power plant, hydropower is capable of both operating at constant rates and swiftly power ramping to accommodate variable renewables and, overall, contribute to the supply-demand energy balance. In addition, hydropower can be equipped with reservoirs that can act as storage buffers, offering flexibility to variable renewables by allowing upstream resevoirs to save unused energy for later use. These characteristics also see pumped hydro storage facilities often reinforcing the benefits of these storage capabilities by allowing it to store energy sourced from other modes of generation by pumping water to upstream reservoirs. It should be noted, however, that hydropower's flexibility sometimes has project specific limitations related to the multiple uses of water (e.g., mandatory max/min outflow rates due to environmental protection measures and other localised considerations) and may have socio-environmental impacts due to the displacement of water flows. However, they also can have positive impacts via improved management of water availability and flood control.

Geothermal and hydropower are generally considered mature technologies in that their deployment and operational integration are well known. Enhanced Geothermal Systems (EGS) are still in the demonstration stage and could provide nearly unlimited amounts of energy, but challenges still remain in its commercial development [86].

The comparative technological maturity of geothermal and hydropower as a whole (though potential for further innovation remains) stands in contrast to staggering transformation of variable renewable technologies such as solar PV and wind, which have seen rapid cost declines in recent years because of technology learning gained through mass deployment across many regions of the world. For ASEAN, both solar PV and wind hold much promise – most notably solar PV given the sheer scale of the resource available in all ASEAN countries which place it amongst the lowest cost power sources available. This alone sees them feature strongly in long-term power capacity expansion pathways for the region purely on a cost basis, regardless of decarbonisation ambition considered which reach between 2,100 GW and 2,400 GW for the ASEAN in IRENA's 1.5°C climate compatible pathway by 2050. Their modularity can see them deployed in an array of circumstances but also implies a more distributed power system in these pathways. Combined with increased electrification of end-use sectors which would also be widely distributed (particularly notable in high decarbonisation scenarios) indicates a paradigm shift in system operation being needed to operate such a power system.

A challenge in achieving this in national generation mixes stems from increased variability of supply and demand, which geothermal and hydropower are well positioned to mitigate through the application of flexible operational practices.

As a very active volcanic region, geothermal potential is widely spread across Southeast Asia. It is no wonder, then, that Indonesia and the Philippines currently rank second and third respectively in geothermal installed capacity globally, and the former has one of the highest potentials in the world. Hydropower resources are prominent across countries like Myanmar, Vietnam, and regions such as Sarawak (Malaysia) and Kalimantan (Indonesia). So how and where projects are deployed using these resources will be crucial, given that they are not necessarily located near the largest demand centres in the ASEAN region, as shown in Table 4.1. To maximise their system impact, they need to deliver power to where it is consumed. For example, some select countries along the Mekong River – Cambodia, Lao PDR, and Myanmar – have hydropower potential that substantially exceeds their potential peak demand in a climate-compatible pathway by 2050. This implies that such hydropower projects would need to be developed in a regional context with regional expansion of interconnection to facilitate power flow to the large demand centres such as those in Thailand, Vietnam, and other countries. Regionally integrated planning and operation of the power sector with a view to deeper regional integration is a powerful tool in harnessing these resources going forward, propelled by increased system interconnection. This also entails coordinated operation and alignment in regulation and electricity markets.

The benefits of regional integration both nationally and internationally go far beyond this given that it is key to unlocking the lowest cost power system for ASEAN as a whole. It is an enabler of reduced duplication of efforts at the national level to provide the same necessary system services, thus reinforcing regional energy security and mutual reliance.

**Table 4.1 Peak Load 2018 to 2050 in Global 1.5 °C Compatible Pathway and Hydro and Geothermal Power Resource Distribution Across ASEAN (GW)**

| Country | Approximate peak electricity demand in 2018 | Peak electricity demand by 2050 in global 1.5 °C compatible pathway | Hydro potential | Geothermal potential |
|---|---|---|---|---|
| Brunei Darussalam | 0.7 | 4.2 | 0.1 | - |
| Cambodia | 0.9 | 6.0 | 10.0 | - |
| Indonesia | 35.9 | 261 | 75.0 | 29.5 |
| Lao PDR | 0.9 | 6.6 | 26.0 | 0.1 |
| Malaysia | 24.1 | 62.9 | 29.0 | - |
| Myanmar | 2.3 | 17.2 | 40.4 | - |
| Philippines | 12.3 | 89.5 | 10.5 | 4.0 |
| Singapore | 6.9 | 17.9 | - | - |
| Thailand | 27.7 | 116.2 | 15.0 | - |
| Vietnam | 21.3 | 126.4 | 35.0 | 0.3 |

*Source: Handayani et al., 2022* [87] *and IRENA 2nd Renewables Outlook for ASEAN* [88].

## 4.5 Financing Energy Transition

***Authored by ASEAN Centre for Energy (ACE)***

### 4.5.1 Background

Under COP26, the global commitment to emission reductions was strengthened with the announcement of decarbonisation targets. Most AMS had declared energy-related pledges to achieve net-zero emissions, including coal phase-out and methane reduction [89]. According to AEO7 results, the total GHG emissions under the Baseline Scenario are expected to be at 6,671 Mt $CO_2$-eq in 2050. This is roughly four times the increase in total GHG emissions in 2020. The share of GHG emissions from electricity still dominates the total GHG emissions, about 34%, for ASEAN in 2050. Thus, GHG emission reductions from the electricity sector will significantly contribute to the AMS decarbonisation targets. Electricity and industry are two key priority sectors stated in NDC and the Long-Term Strategy documents for the decarbonisation target of AMS (Table 4.2).

**Table 4.2 Current Updates on Climate Issues and National Commitments at COP26**

| Country | Coal Phase-Out | Methane Reduction | Interconnected Green Grid | Product Efficiency | Carbon Neutral / Net Zero Target |
|---|---|---|---|---|---|
| Brunei Darussalam | Yes | No | No | No | 2050 |
| Cambodia | No | Yes | Yes | No | 2050 |
| Indonesia | Yes (partial) | Yes | No | Yes | 2060 |
| Lao PDR | No | No | No | No | 2050 |
| Malaysia | No | Yes | No | No | 2050 |
| Myanmar | No | No | Yes | No | 2050 |
| Philippines | Yes (partial) | Yes | No | No | No target set |
| Singapore | Yes | Yes | No | No | By or around mid-century |
| Thailand | No | No | No | No | 2065 |
| Vietnam | Yes | Yes | No | No | 2050 |

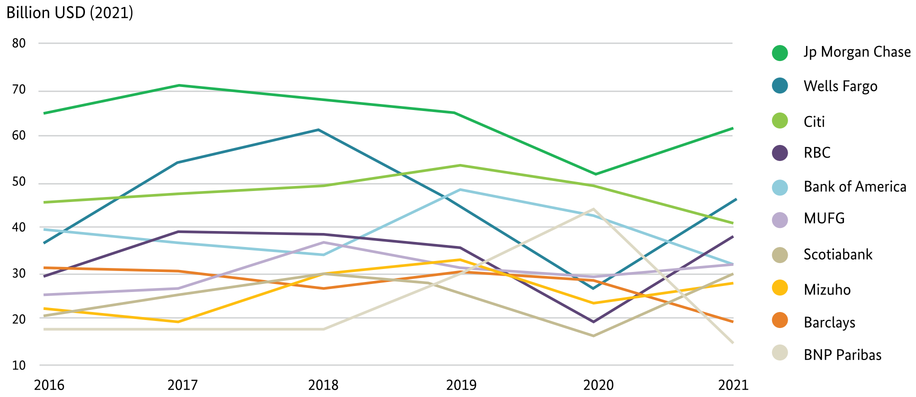
*Source: Safrina (2021)* [90], *With updated data for Methane Reduction Pledge* [91], *Cambodia's Decarbonisation Target* [92], *and Singapore's Decarbonisation Target* [93].

The crucial role of the energy sector has been emphasised in APAEC Phase II (2021-2025). The AMS seeks to achieve a 23% share of RE in the total energy mix and 35% in installed power capacity in ASEAN by 2025 [16]. Moreover, the total percentage of clean energy investment in developing and emerging countries accounts for just one-fifth of the global total [94]. According to the AEO7 result, the share of RE investment is projected to be one-third of the total investment required by AMS by 2050 under the Baseline Scenario. In the ATS and APS, the share of RE investment is expected to be 62% and 80% respectively, of the total investment required by AMS by 2050. This indicates the current investment for RE in ASEAN is inadequate to achieve the regional targets.

The Covid-19 pandemic has slowed the progress of global emissions reduction efforts. It has caused a significant decrease in the GDP of most AMS. The recent instability in global prices for fossil fuels has added barriers for most AMS in managing their national budgets. As a result, public budget allocations for emission reduction programmes, including RE and EE investments, have also been affected. The need for accelerating energy transition pathways from the existing energy system is becoming increasingly crucial. This not only involves meeting decarbonisation targets but also maintaining energy security, accessibility and affordability throughout the region and within the energy sector [95]. The Task Force on Climate-related Financial Closure (TCFD) has been developed to help include climate risk for financial lending institutions to facilitate clean energy investment to meet decarbonisation targets. As a result, banks and financial institutions have been pressured to reduce their lending and investment in fossil fuels (Figure 4.11).

Taking into consideration the urgency to accelerate financing and investment in clean energy in the region, this section presents the current status, needs, and ways forward for potential opportunities that can accelerate financing energy transition in ASEAN.

**Figure 4.11 Bank Lending to Fossil Fuels**




*Source: IEA (2022)* [96]

### 4.5.2 Status and Needs for Financing in the ASEAN Energy Transition

The investment gap in developing countries to meet both SDGs and Paris Agreement requirements was estimated to be USD 2.5 trillion per year [97]. During the recovery period following Covid-19, it was found that just 6% of the total G20 recovery funds have been disbursed for clean energy investment. The challenges and needs of the AMS in the current global situation have doubled, with tighter national budget limitations required to meet several key challenges and targets. Innovations are required to scale up the availability of financial sources, as well as budget allocation and stronger collaboration with the private sector and international donors.

The current reduction of RE cost provides an excellent opportunity to accelerate RE deployment. The cost of RE was found to be the cheapest option for the existing power system. The cost of solar PV has fallen significantly by 85% between 2010 and 2020 [95]. Under the Baseline Scenario, the AEO7 assessment found that about USD 49.6 billion (2022 real price) would be required by AMS for total investment costs for the power sector by 2050. Under the Baseline Scenario, RE investment is projected to account for about 37%, or USD 18.5 billion in total investment cost required by AMS in 2050. It is also found that under the implementation of each AMS national target by 2050, the total investment is lower compared to the Baseline Scenario, which is about USD 40.7 billion (2022 real price). The share of RE investment is also expected to be larger than indicated under the Baseline Scenario, which is to be 62% of the total investment required in the power system by 2050. About USD 700 billion annually from fossil-fuel investment is required to be re-channelled into clean energy investment [95]. Specifically, power sector investment in ASEAN needs to increase by up to USD 350 billion in 2030 [94]. Moreover, the investment in electricity transmission networks should be prioritised due to their multiplier effect and meeting long-term energy security and sustainability in ASEAN. Additionally, channelling the investment into end-user energy sources (demand-side measures) is highlighted. Both RE and EE technologies are expected to contribute to about 50% of total potential emissions reduction by 2050 [95]. According to the AEO7 result, the share of RE installed capacity is projected to be 36% by 2050 under the Baseline Scenario (Figure 4.12).

In terms of financial sources, the largest share of energy investment in emerging and developing countries is through public funding. The large share of public funds in energy investment is not surprising in most AMS. For example, Indonesia, the largest country in ASEAN, obtains approximately 60% of its total NDC and SDG finances from the public budget [98]. A good sign of increasing private sector share has been found in the recent trend of clean energy investment (Figure 4.13).

**Figure 4.12 Share of Total Power Capacity in 2050, Baseline Scenario**

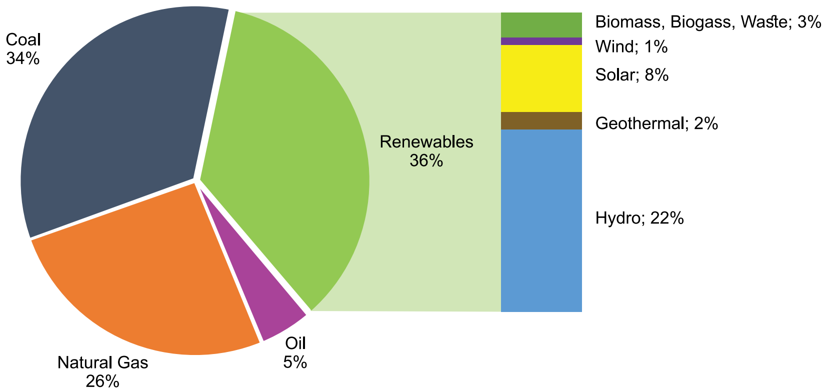
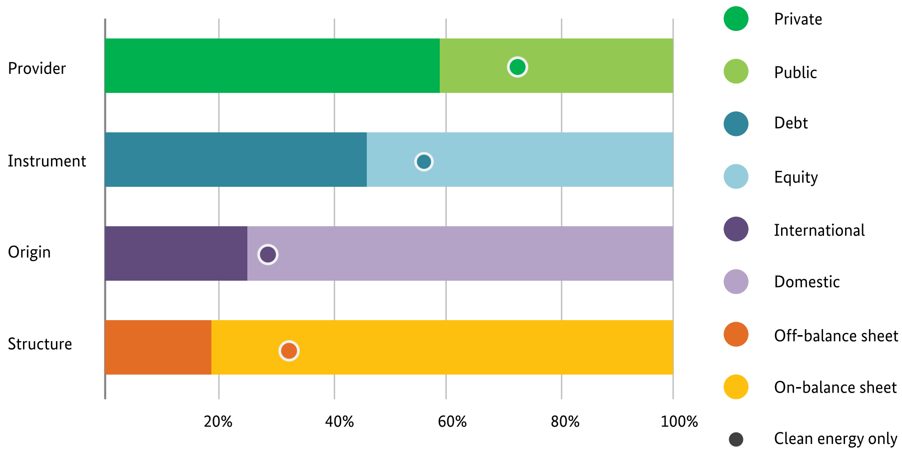



**Figure 4.13 Indicative Financial Sources of Energy in Emerging and Developing Countries under the IEA Climate-Driven Scenario, 2026-2030**




*Source: IEA (2022)* [94].

*Photo source : GIZ*

#### 4.5.3 Potential Opportunities for Upscaling Energy Transition Investment in ASEAN

In summary, the requirements faced by the AMS to accelerate financing for the energy transition to meet energy security and emission reduction targets are increasing. The total investment needed to meet both targets became even more crucial in the wake of the Covid-19 pandemic. The current financial source composition for clean energy investment in ASEAN is dominated primarily by limited public finances. However, recent events and the climate agenda put momentum behind the ASEAN effort to re-set and re-design financial schemes for the energy transition in the region. Several potential opportunities for upscaling energy transition finance in ASEAN can be further explored in parallel.

Initially, private sector funding must be mobilised in combination with the public budget (blended finance) to attract more private investment in energy transition projects. One of the well-defined barriers to clean energy investment is the perceived high risk within the private sector, banking, and lending institutions. Amongst several barriers commonly cited in clean energy investment in ASEAN, the financial factor is given as the single most influential factors slowing the uptake of clean energy investment in ASEAN. As most financial or capital banks in ASEAN have underdeveloped capital market, the high risk and low return of investment has made most of capital banks in ASEAN reluctant to finance clean energy investment [99].

To tackle this financial barrier, the role of the international financial institutions, such as international development banks that are multi-donors funded, can be strengthened to attract private financial institutions to invest in the clen energy finance. The potential contribution of these international development banks can be prioritised at the early stages of projects for emerging and high-risk technologies, to help manage financial risks faced by private institutions in later stages of projects [96].

Under a blended finance scheme, public funding needs to be used as a catalyst to attract private investments, ensuring lower risk (as viewed by private investors). In other words, the public budget needs to be allocated at the initial phase of a project. The remaining project finance will be funded by private investment, which is generally a larger share. Moreover, under the blended finance scheme, private investment can be insured by the public sector and supported by national policies [97].

The second step is public budget realignment to meet the key national targets, known as fiscal policy reform. This option has been implemented in several AMS since 2014, such as fossil-fuel subsidy removal and green fiscal budget tagging. However, fiscal policy reform and budget realignment should be instituted beyond fossil-fuel subsidy reform. It should cover verification of budget spending to reduce overlapping budget allocations and more efficient spending, to achieve key national and APAEC targets. This is commonly referred to as lowering public finance distortion.

The third step is gradually re-aligning planned investments and budgets for fossil fuels into allocations for clean energy investments. In this context, the investment in clean energy or decarbonisation should be viewed and planned as a long-term investment, and other key national development plans, such as green recovery, long-term climate change plans, and others, with a similar timeframe for national and regional net-zero or carbon-neutral targets. This means that the transition period can be utilised for gradual re-channelling of the planned fossil-fuel investments.

The fourth option is regulatory and institutional reform. This should be implemented to support the transition investment period. In practice, regulation and institutional reform take longer to implement than budget reform and rechannelling. However, it can be initiated by enhancing the capacity of related ASEAN stakeholders and financial institutions, not only with the knowledge base but also in managing investment risk in clean energy, known as de-risking.

## 4.6 Managing the Safety and Social Acceptance of Nuclear Power

***Authored by International Atomic Energy Agency (IAEA), World Nuclear Association (WNA), and ASEAN Centre for Energy (ACE)***

Amidst global energy and climate crises, worldwide interest in nuclear power is rising. Countries from Europe and the Americas to Africa and Asia, facing increasing gas and oil prices, are reconsidering the role of nuclear power in today's and tomorrow's low-carbon energy mix. Nuclear power has the potential to address some of the most pressing current concerns of our time, from energy security and climate change to sustainable development and economic well-being. Nevertheless, negative perceptions about nuclear power persist in several countries and need to be addressed if it is to achieve its full potential in contributing to the global transition to clean and reliable energy.

Amongst the challenges is addressing misperceptions and misrepresentations to strengthen the public acceptance and social license for this reliable, safe, low-carbon energy source. We must clearly communicate the scientific facts, which include a solid safety record, despite a handful of severe accidents and a new generation of power reactor technologies that will be even safer. In addition, leaders must effectively engage with the public and a wide range of stakeholders, including policy, decision-makers, and civil society, particularly on concerns about nuclear power safety and radioactive waste. Finally, the nuclear industry, along with governments, national regulators, and financial institutions, needs to make good plans to lower the capital costs of the new nuclear build while shortening construction times.

### 4.6.1 Communicating the Facts

The world's leading authority on global warming, the Intergovernmental Panel on Climate Change (IPCC) [100], has repeatedly made it clear that without a significant increase in nuclear power, the world will struggle to meet its climate goals. Nuclear power installed capacity needs to double by mid-century if the world is to achieve net zero emissions, and without nuclear power, the energy transition will be far more complex, take far longer and be much more expensive [101]. This is about more than electricity production. By producing low carbon hydrogen or providing heat, nuclear power can also play a major role in helping to decarbonise hard-to-abate sectors such as industry, transportation, and buildings—which together account for about 40% of all $CO_2$ emissions. It can also support countries in increasingly hot and arid regions like the Middle East to more cleanly turn seawater into potable water more cleanly. Finally, as countries seek to decarbonise their grids, nuclear power can contribute to robust and reliable energy systems, providing the resilience, reliability and flexibility needed by systems with high shares of variable renewables such as wind and solar, dependent on weather and sunshine. System cost analysis shows that having nuclear energy reduces the cost of the overall energy production system – even if nuclear generation costs are higher than wind or solar on a Levelized Cost of Electricity basis.

As for safety, studies have shown that nuclear power is one of the safest energy sources. According to the WHO, air pollution from fossil fuel emissions contributes to upwards of 8 million deaths per year. But after solar, nuclear is the safest energy source as measured by the death rates per unit of electricity produced [102]. As for radioactive waste, the industry has managed it for over half a century, over which time there have been no major accidents involving spent fuel from civilian nuclear power facilities.

“The advent of deep geological repositories, with the first one set to go into operation in Finland, will be a further game changer for nuclear power”, IAEA Director General Grossi said after visiting the site in 2020 [103].

A wide range of nuclear power technologies can and will help the general population. Existing large reactors can play a critical role in contributing to grid stability and low-carbon electricity provision when their operating lifetimes can be safely extended. In fact, long-term operation remains the most economical source of clean power in the midterm. Large reactors can also provide clean hydrogen from electrolysis and district heating. In addition, Small Modular Reactors (SMRs) under development can furnish additional services (flexibility, cogeneration, hybrid systems with renewables) and will offer lower upfront costs that could broaden access to nuclear power. Indeed, nuclear power will need to expand beyond its historic markets and into the developing world, if we are to have a reasonable chance at meeting our climate goals, according to the IEA’s Sustainable Development Scenario [104].

#### 4.6.2 Nuclear Energy in ASEAN

A number of ASEAN countries have begun planning to deploy nuclear power, but to date, no nuclear power plants are in operation in the region. Countries with significantly advanced plans include Indonesia, the Philippines, Thailand, and Vietnam, while other ASEAN nations have also expressed interest and explored plans to develop nuclear energy.

Indonesia has significant experience with nuclear technology and has already developed much of the infrastructure needed for a programme. Under current national plans, Indonesia expects to operate its first large reactor by 2045. It is also preparing to construct a demonstration high-temperature reactor, and discussions are ongoing regarding purchasing floating nuclear power plants and thorium reactors from different vendors.

In 1976, the Philippines began construction of the Bataan Nuclear Power Plant (BNPP), which is a 620 Pressurized Water Reactor (PWR) unit. Despite its completion in 1985, it was never commissioned and has remained unused ever since. The country is once again exploring the feasibility of a nuclear power programme, including the possible revival of the BNPP and the construction of SMRs. In February 2022, the President signed Executive Order 164, which mandates the adoption of a national position for a nuclear energy programme.

Thailand has had an operating research reactor since 1977 and has shown a strong interest in nuclear technology’s radioisotope and scientific applications. It has signed numerous agreements with vendor nations, including Japan, China, and Russia. A 2015 power development plan envisioned two 1000 MWe plants coming online in 2035-2036 to “diversify fuel sources and mitigate risk.” In January 2016, it was confirmed this would be a pressurised water reactor, but no site was mentioned. Public acceptance issues appear to be hampering the selection of a suitable site.

Vietnam has long studied the introduction of nuclear energy. A firm proposal to develop nuclear plants emerged in 2006. This foresaw a 2000 Mw plant to be in operation by 2020. But despite making significant progress in discussions with a vendor nation, these plans were put on hold in 2016, and the country developed gas and coal assets instead. In June 2022, Vietnam’s National Assembly Economic Committee proposed that the stalled plans to develop two nuclear reactors in the central province of Ninh Thuan should be pursued.

### 4.6.3 Public Perception and Acceptance

Public perception is a major issue that will determine the future of nuclear energy. The success or failure of a civil nuclear power programme strongly depends on public acceptance of nuclear technology. Despite the intense and long-running debate about the pros and cons of nuclear energy utilisation, the Nuclear Power Plant (NPP) is also considered one of the feasible options for expediting electricity generation in a cleaner way in terms of carbon emissions. The level of public support for nuclear varies significantly between different countries. In some established nuclear energy countries, the industry faces stiff opposition. Governments have implemented early phase-out policies that will shut nuclear plants down well ahead of their technical lifetimes – notable examples include Germany and Taiwan (China). However, in most established nuclear countries, public attitudes are much more supportive, and nuclear may even rank close to renewable forms of energy in terms of public preference. Public perception can be convinced of the benefits of the technology, where it addresses societal issues (like power shortages) or aligns with cultural values. Across the world, far more countries are in the process of introducing nuclear energy than are phasing it out.

A study to assess public perception and knowledge of NPP in ASEAN countries based on the online survey has been conducted by ACE. The result of this study is expected to benefit ASEAN countries by providing insights into how people in each country perceive and determine their willingness to accept nuclear energy, as well as the level of knowledge based on several related indicators. According to the result, the majority of respondents from member countries positively perceive using nuclear energy for power generation in the country, where they strongly favour the NPP (42%), as shown in Figure 4.14. Based on the country level, it is primarily from the Philippines and Indonesia, with the highest degree of interest, and both have already prepared national regulation and implementation programmes related to NPP. The primary reasons for supporting NPP, according to the majority of respondents is that it guarantees the security of the energy supply (36%) and contributes to preventing climate change (32%). Meanwhile, some respondents reject NPP in the country primarily because of the possibility of a serious accident (48%) and the uncertainty of the radioactive waste disposal method (29%).

Within a country, views will also vary significantly by region, and clear splits of opinion will be evident between gender, age, and other markers. It is a well-known fact that neighbouring communities often grow to be highly supportive of nearby nuclear facilities over time as they directly experience many of the socioeconomic benefits. These communities are likely to consider themselves well-informed of nuclear impacts. Surveys suggest that the better-informed someone feels about nuclear energy, the more supportive they will generally be (Figure 4.15). While this is good news for education-based outreach approaches, it should also be noted that, in some cases, these approaches can backfire.

Political views tend to be strongly correlated with views on nuclear energy, with those on the political right generally more supportive than those on the left - although this particular difference does appear to be diminishing in recent years as nuclear energy is increasingly recognised as a low-carbon energy source. There are now a number of green groups and non-governmental organisation that openly endorse nuclear energy. In the USA, for instance, the Biden administration has officially embraced nuclear energy in its policies, removing the partisan opposition that has characterised the nuclear debate in that country. It is very important to build multipartisan support for nuclear energy – not just to reduce political risks for nuclear programmes, but also to ensure broad and lasting public support.

Polling shows that most people do not have strong view on nuclear energy. Instead, it is a back-of-the-mind issue which people only think about when given a reason to do so. Therefore, attitudes toward nuclear energy are often shaped by an individual's cultural identity rather than a detailed evaluation of the facts. Recent events and media coverage can heavily influence views, but this will usually be short-lived. For instance, public support globally took a nosedive after the Fukushima Daiichi nuclear accident in 2011, but this recovered in most countries within a year. These loosely held views on nuclear power also mean that survey results can be dramatically changed depending on how a question is phrased or introduced. This must be kept very much in mind when designing or interpreting a survey on nuclear energy. A related effect is that most people overestimate the level of opposition to nuclear energy in others. Whilst they hold neutral or even positive views on nuclear energy, they mistakenly believe that their friends and colleagues are far less supportive.

**Figure 4.14 Civilian Nuclear Energy Public Survey in ASEAN**

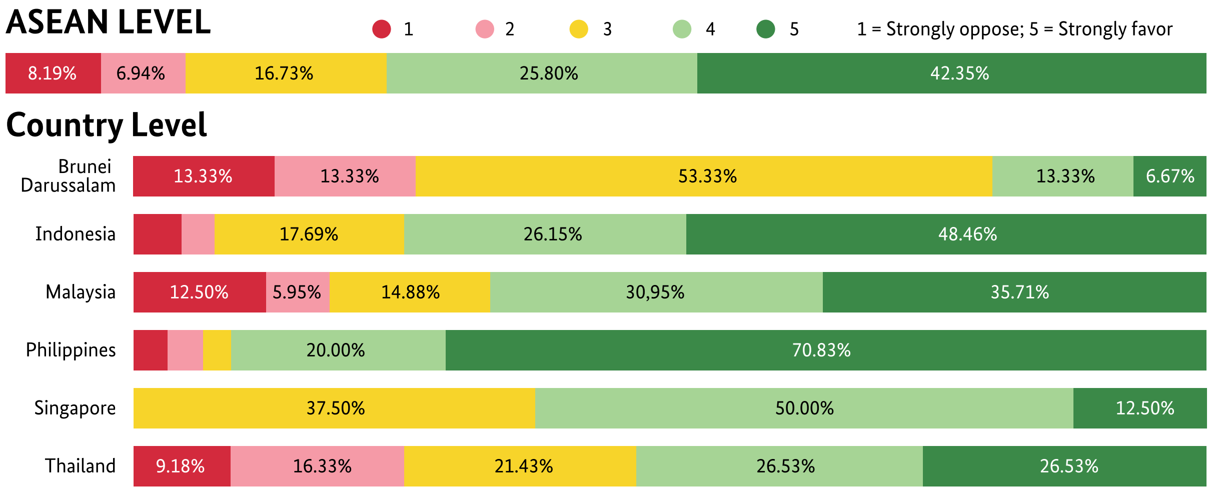
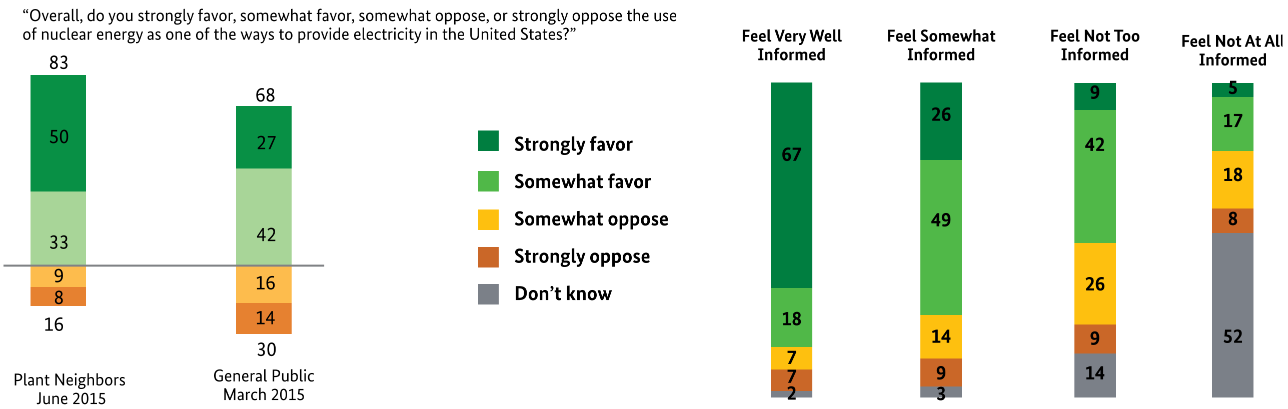



**Figure 4.15 Ann Bisconti Research Carried for Nuclear Energy Institute, Favorability to Nuclear Energy**




The traditional arguments against the use of nuclear energy centre around radioactive waste and nuclear safety risks. It is, therefore, tempting for nuclear energy proponents to try and win support for nuclear by directly countering these concerns. Whilst this may be necessary to some degree, in almost all cases, it will be insufficient to win significant support for the technology or a nuclear programme. For support to truly grow, people must be given a positive reason to change their existing mindset. This means that risk-communication and myth-busting approaches should be combined with discussing nuclear energy benefits.

It is also known that safety communication can backfire. Too much proactive communication on safety without sufficient context or explanation of the benefits can make people more concerned about nuclear safety than they previously were. It is essential to address safety and waste concerns, but care must be taken not to trigger unhelpful cognitive biases. The IAEA provides a practical nuclear communicators toolbox which explains this in more detail. Unfortunately, no magic formula for a communication campaign can be provided that will improve support for nuclear in all countries. A successful approach needs to be worked out on a case-by-case basis. It will require surveying local people to understand better their views and what has shaped them. Some trial and error will be involved, although newcomer countries can look to recent successful examples, such as the United Arab Emirates.

Crucially, building support for a nuclear programme will involve a long-term effort to build trust in the government and the institutions responsible for implementing the nuclear programme. Many countries have recently witnessed steep trust levels decline for public institutions. It has grown harder to implement major infrastructure projects, with ‘not in my back yard’ objections, media, and public backlash a normal response to any policy announcement. Many governments have shifted from announcing decisions to consulting on them, engaging in processes that listen to affected stakeholders and seek to incorporate their views into the development to gain much-needed public support. Such consultation and engagement processes are integral to successfully implementing a modern nuclear energy programme.

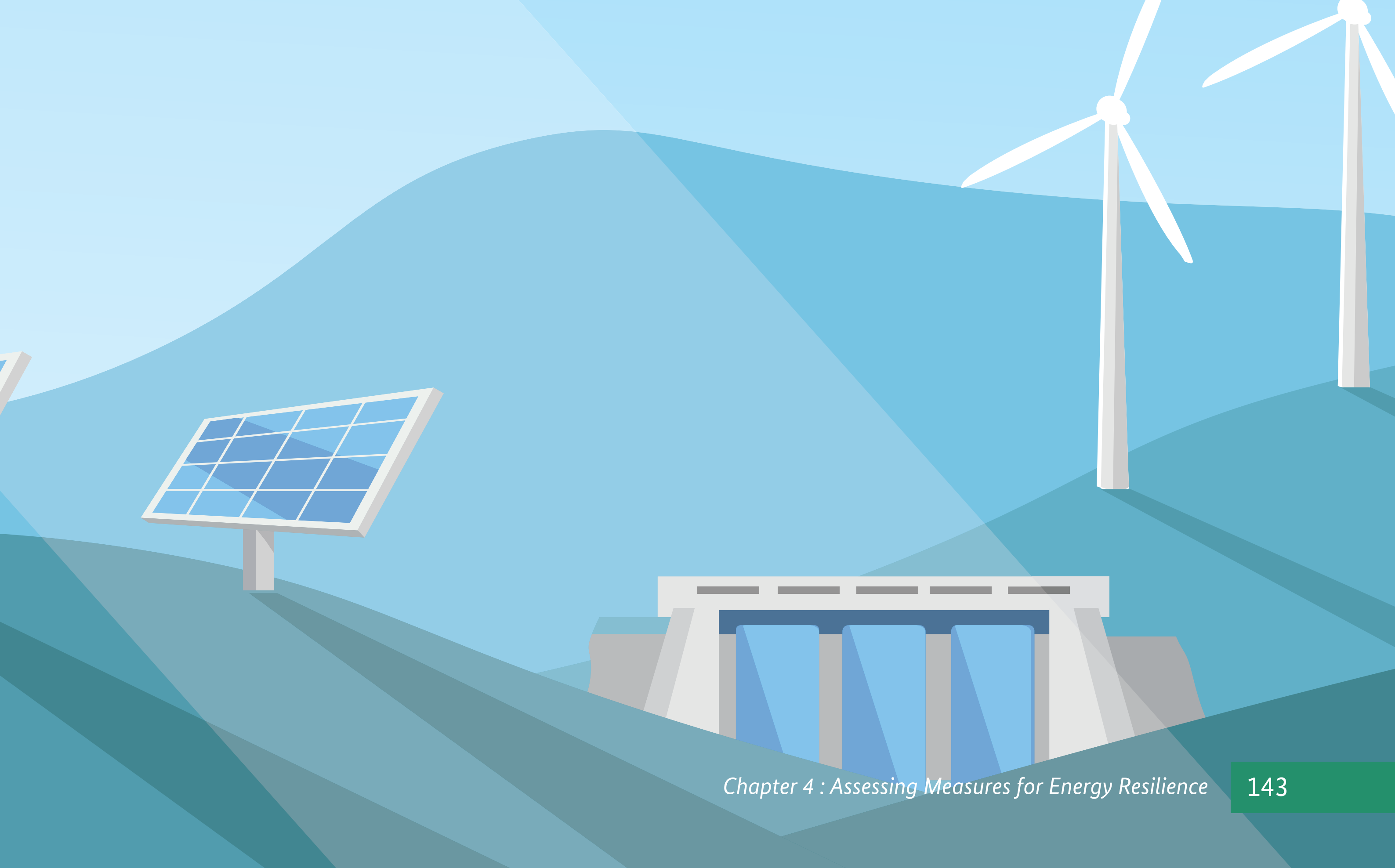
The IAEA notes, “Openness and transparency and understanding that the purpose of stakeholder involvement isn’t always about gaining complete public acceptance. Rather, it aims to help people understand the rationale behind the competent authorities’ decisions.” The process is more like building a relationship than ‘education’ or attempting to fill a knowledge deficit. The critical point is that trust must be earned and continuously maintained.

#### 4.6.4 Engaging Stakeholders

Despite revived interest in nuclear power worldwide, continued efforts to effectively communicate and engage stakeholders will remain vital to helping ensure that ambitions to introduce or expand nuclear power are translated into projects that become a reality. Perceptions of the benefits and risks associated with nuclear power and, in particular, concerns about radiation risks, waste management, safety and proliferation remain the areas that most influence public acceptance. As public opinion plays a significant role in how governments choose to produce energy, increasing global knowledge and understanding of nuclear power and engaging stakeholders from the outset are crucial components for decision making, public acceptance and the success of a nuclear power programme. Building strong, positive, long-term relationships with the public and other stakeholders is a key factor for existing, new, and future nuclear power programmes.

Experience shows that involving stakeholders in decision-making processes, even those stakeholder groups that do not have a direct role in decision-making can enhance public confidence. This includes open and transparent dialogue that builds mutual trust amongst various stakeholders, from the nuclear industry and government institutions to the media, local communities, and non-governmental organisations. Such interaction helps raise awareness and understanding in all aspects of the nuclear fuel cycle, from uranium mining to spent fuel and radioactive waste management. It also allows stakeholders to voice their concerns and influence their communities' decisions.

Engaging stakeholders early, substantively, and frequently will also support developing and deploying new technologies, such as SMRs, as countries assess their technology's viability as an option for low-carbon electricity and non-power applications. Experience from embarking on new projects and operating in various countries, and lessons learned from deploying existing technologies can contribute to the success of new nuclear technologies. Finally, a better understanding by various stakeholders of the important role of nuclear power in providing stability to electrical grids, especially those with high shares of variable renewable sources, could lead to increased public acceptance of nuclear power.



# CHAPTER 5

# RECOMMENDATIONS AND IMPROVEMENTS

# CHAPTER 5
# RECOMMENDATIONS AND IMPROVEMENTS

## 5.1 Policy Recommendations

The AEO7 is designed to complement the regional energy cooperation blueprint, by updating the status of the energy landscape in ASEAN, charting pathways toward the achievement of regional targets, and exploring the future energy landscape through scenarios analyses. The modelling work is highly dependent on the set of key assumptions and modelling approaches, outlined in Chapter 2 and further detailed in Appendix D. Therefore, results presented in the report should not be seen as rigid forecast but more of possible future pathways, given the current situations, modelling assumptions and underlying projection parameters.

Nevertheless, modelling exercises conducted by AEO7 serve as a powerful tool to shed light to the impact of specific policy actions—or inaction. The policy recommendations, therefore, are derived from the analyses of latest statistics, policy frameworks, scenario results, and recent trends in energy sector.

### Addressing energy security issues in energy transition

Amongst the key drivers of energy demand are the population and economic activity; both of which are expected to continue growing in the region. With GDP projected to increase by about 3.5 times during the 2020-2050 period, the AEO7 forecasts primary energy demand in the region will increase from 2.5 times to 4 times during the same period. Noting this significant increase, a sustainable future will require stronger decoupling between economic growth and energy demand growth

Amidst the energy transition, the region should address—and maybe prioritise—the energy security issues. This is also in line with the direction from the APAEC Phase II 2021-2025. The Covid-19 pandemic has impacted economic growth and the energy sector, particularly energy consumption. Both economy and energy use—except for the residential sector—contracted in 2020, the latest historical year of AEO7.

The economy has been recovering since the pandemic started ravaging the region in 2020. And with the return of economic activities, energy demand is on the rise. Unfortunately, the energy supply has not caught up to these surges in demand, resulting in energy price spikes. This is then exacerbated by a number of supply-side issues, most notably the Ukraine-Russia war. The resulting high energy prices have impacted the AMS as well. All these issues have raised concerns over energy security.

Amidst the pandemic, though, ASEAN continued its progress towards the achievement of regional energy targets. Energy intensity reduction reached 23.8% in 2020. It must be noted, though, that the pandemic played a significant role in this. The real GDP PPP declined by 3.4%, as compared to the previous year, whilst the TPES declined by 5.8%. The economic recovery could potentially bring a 'bounce back effect', which would hamper the progress in EE across in the region. AEO7 notes that existing national policies do not necessarily result in the achievement of APAEC targets. With few remaining years to 2025, accelerated efforts in line with economic recovery, along with continuous assessment, will be crucial.

AMS needs to consider two main basic policies covering supply and demand sides: energy diversification and energy demand management. The need for AMS to consider energy diversification is in line with the energy security and sustainability targets within the AMS. Under the Baseline Scenario, the composition of the AMS energy supply by 2050 will be dominated by fossil fuels. This would lead to high import dependence for ASEAN. To diversify the energy supply, the deployment of RE into the mix is seen to increase in the APS. In term of energy demand management, EE measures are shown reducing the overall energy demand in the APS, as compared to the Baseline Scenario.

### Supply Side

In addressing energy security issue, priority should be given to improving energy dependence. Diversification of energy resource should be followed by diversification of energy source. Geopolitics should also be a consideration in energy policy. ASEAN should exercise its regional soft power, improving collaboration and cooperation within ASEAN and with key strategic partners.

Reducing imported fossil fuel consumption and increasing domestic energy use will certainly contribute to maintaining regional energy security. Regional energy networks, such as the Trans-ASEAN Gas Pipeline and the ASEAN Power Grid, and oil stockpiling are recommended to be set up and accelerated to maintain energy supply security. Emerging technologies, such as CCUS, hydrogen and ammonia, nuclear, and storage should all be explored.

Meanwhile, increasing the RE share in the power sector needs to go beyond installed capacity and into electricity dispatch. The higher share of RE in the power sector would also augment the impact of electrification in the end-use sectors.

### Power Sector

Higher dispatch of RE sources can be a crucial strategy for improving RE share in electricity generation and satisfy increasing energy demand. This includes the potential role of RE for baseload generation, including hydropower, geothermal, and bioenergy. These are considered the most viable RE sources for baseload generation due to greater resource availability over solar and wind, which vary throughout the day. Whilst hydropower has been leading the RE share in the region, geothermal has been underutilised, and bioenergy has significant potentials. Technical issues and strategies related to this need to be closely examined.

The AMS should consider capacity expansion for so-called ‘RE baseload’ and the future development beyond power generation. ASEAN has a huge untapped geothermal energy, which supports these flows measured and calculated at the subsurface. High heat flows are also noted, where arc magmatism is not a feasible explanation. This demonstrates that geothermal potential is not only found amongst countries with hydrothermal systems, and it can be utilised beyond energy.

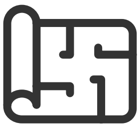
In addition to electricity generation, other uses include heating applications and geothermal heat pumps/geoexchange for direct usage, such as cultural needs, tourism, agriculture, aquaculture, industrial processing, balneology, bathing, and swimming. Utilising depleted and/or abandoned oil and gas wells for geothermal energy extraction is possible.


*Photo source : GIZ*

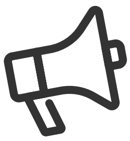
Dependence on fossil fuels for electricity and heat demand can be significantly reduced whilst increasing the nation's economy and reducing environmental harm.

Several barriers to geothermal development have been published throughout the years from different countries [80]. In general, the barriers are seen from three perspectives.

1. Technical barriers:
   - Lack of exploration techniques required to identify and develop undiscovered geothermal resources
   - High upfront project costs due to expensive geothermal well drilling, which is exacerbated by relatively high exploration risks



2. Policy/market barriers:
   - Difficulty acquiring PPA, partly because existing utility procurement practices do not value some of the benefits of geothermal power
   - Extended permitting timelines that can result in 7- to 10-year project development time frames
   - Lack of access to transmission infrastructure
   - Delays in obtaining project financing



3. Social-acceptance barriers:
   - Lack of public awareness and acceptance of geothermal energy
   - Perception of high costs and risks by local authorities and the public.

Solar and wind, known as VRE, are being integrated into the grid system. With the high penetration of VRE, grid stability and resiliency have become an issue. Pursuing a flexible and modern grid would require massive investment, which should be planned and executed in advance. Beyond that, grid modernisation and interconnection with the goals of stability, flexibility, and resiliency is fundamental. Sector coupling can increase the flexibility of the power systems and facilitate the integration of VRE sources. Furthermore, it makes economic sense.

Sector coupling can defer investments into generation and transmission infrastructure by reducing the need to install additional capacity to meet peak demand or alleviate grid congestion. From an operational point of view, smart electrification reduces generation and consumption costs by shifting the load from periods with higher electricity prices to periods with lower prices.

To address the intermittency issues of VRE, storage needs to be fully developed. Storage should include pumped hydro, for which the region has enormous potential. Nuclear power generation always remains an option for securing the energy supply in this region.

### Demand Side

Strategies for the availability of disaggregated data from the AMS, particularly in the industry industrial sector, could provide better opportunities to analyse energy usage, which is crucial to providing more specific recommendations for EE&C policies.

As highly electrified sectors, the residential and commercial sectors could benefit most from using energy-efficient appliances. Higher electrification can also complement this measure.

Strong EE policies are vital for achieving the key energy policy goals of reducing energy bills, addressing climate change, improving energy security, and increasing energy access. The economic benefits of implementing an EE&C plan have been highlighted, and it is highly recommended. The strategic framework for formulating and implementing an EE&C plan should be simple, practical, and cost-effective, and it should also be based on a top-down approach, both from the government's and the private sector's perspectives. The economic component of EE&C strategies will result in promoting the growth of EE&C technology, equipment, and supply of materials. In addition, AMS will benefit from skilled manpower capacity building as a result of EE&C plan implementation, which will generate demand for upgraded levels of skilled employment.

### Regional cooperation towards mid of the century

AEO7 projection can be enhanced by improving and equipping the database function with the region's knowledge hub, such as the ASEAN RE Information and Training Centre. The importance was highlighted on the ASEAN RE-Gender Roadmap, which emphasises several measures for ASEAN to address constraints women face in being meaningfully involved in the RE sector [20]. The projection would be an accelerator for gender mainstreaming efforts in the region. In addition to implementing the ASEAN RE-Gender Roadmap, converting job tracking ambitions into action plans or milestones in the upcoming ASEAN RE Long-Term Roadmap will be imperative.

### Social cost and environmental externalities

The AEO7 results on social cost projection found that without any policies intervention (Baseline Scenario), the social cost in 2050 is projected to increase up to 3.5 times the value in 2020. The largest share of social cost under the Baseline Scenario is found under the demand side. It implies that AMS depends more on energy demand side than supply side.

The social cost of the demand branch is found to be about two times higher than the social cost from transformation (supply side). This implies that the AMS needs to strengthen measures for managing the demand side (energy efficiency). This is in-line with the composition share found under social cost within sectors under the demand branch. The social cost from the transportation and industrial sectors are found to have the largest shares at 54% and 40% respectively, by 2050. This provides key policy insight that prioritising and strengthening energy demand measures for the transportation and industrial sectors provide the largest potential for AMS to achieve energy demand reduction, and mitigating environmental externalities by 2050.

Other key insights that can be derived from the social cost results are within the ATS, APS, and LCO Scenario results. The results show that the implementation of ATS and APS can reduce the social cost up to –43% and –57%, as compared to Baseline Scenario result for 2050. It means that the implementation of national and regional measures on RE and EE (ATS and APS) can reduce the environmental externalities caused by energy demand increases in AMS by 2050.

Interestingly, the social cost result from LCO Scenario is found to be higher than the result under APS. It is likely attributable to the assumptions used in the LCO Scenario, that applied only on power generation systems (transformation branch). However, this provides two insights for AMS policy makers on three fronts. First, the implementation of low-cost optimisation of the supply side (power sector) is not enough to lower costs, when aiming for the same level of environmental externalities found in APS. Second, this result also implies that energy in AMS is more demand-driven than supply driven. Third, the combination of low-cost optimisation for the power sector and the demand side (transportation and industrial sectors) in AMS have greater potential for meeting both low-cost and environmental externalities.

## 5.2 Improving and Optimising AEO

AEO7 expands the modelling framework and enables a more detailed and technology-rich representation of the energy system, allowing a richer analysis of policies and scenarios. It also utilises optimisation as a modelling methodology, increasingly crucial in the era of price uncertainty and balancing energy security, affordability, and sustainability. During these efforts, though, several challenges were found, partly stemming from the unavailability of more disaggregated data, which is essential for better modelling representation and policy design.

In general, potential improvements to the AEO model include more robust information on technological parameters, especially efficiency and cost. Specific to cost, projections should consider more comprehensive factors throughout the lifecycle of the technology. These include materials, end-of-life handling, and other non-technical factors. The robust framework developed in AEO7 should be optimised by developing various scenarios addressing specific issues. Applying national and regional policy-making is recommended.

**Robust and comprehensive cost data and projections.** With the introduction of optimisation in the power sector, cost-conscious policy analysis can be developed. A more robust cost projection is required to note the importance of cost, technical feasibility, and environmental impact. To some extent, this also needs to consider the prediction of contributing factors to cost, such as the availability of materials for production, potential geopolitical issues, and supply chains. There is significant room for improvement by gathering and implementing cost calculations for sectors beyond electricity. This can provide a better analysis of policy options from a cost perspective, such as technological options in transportation.

**Detailed and updated data and assumptions on technologies.** AEO7 has developed better and more detailed representations of the industrial and commercial sectors. Even so, further improvements may include representation of industrial processes, especially for subsectors modelled in AEO7. Data availability, which limits the disaggregation of these industrial subsectors in AEO7, could be addressed as well. The other demand sectors would also require updated data beyond assumptions and benchmarks. These include floor space and building types, technology penetration, and energy uses. Additionally, updates and improvements to existing assumptions must be continuously performed, to keep up with trends in the global energy market.

**Power system modelling.** AEO7 has developed the model for transmission/interconnection and emerging technologies in the power sector, though specific to the optimisation scenario. The transmission system, including the regional interconnection, plays an essential role in optimising the penetration of renewable energies. The requirement for new lines and grid improvements can be analysed, including potential long-term capacity expansion, dispatch analysis, and power trade. Future enhancements include more connection with the updated and derivation studies of AIMS III, which utilise the higher resolution of the power system analysis model. Linking to power system analysis models can also provide competitive advantage, allowing system reliability analysis to the sub-hourly level, if needed. One of the critical emerging technologies explored in AEO7, energy storage, is crucial to balancing the intermittency of renewable energy sources. Nevertheless, more updates can be carried out, including individual AMS-specific daily/seasonal load variations. More emerging technologies, such as hydrogen, can be explored as well.

**Optimisation expansion, scenarios exploration and studies extension.** One key improvement in AEO7 is exploring the optimisation scenario in the power sector. The optimisation method can be further expanded to other sectors beyond power. This will provide better analysis, such as selection of technology options in the transportation sector. The methodology can also be applied to the primary AEO scenarios, such as the ATS and APS, especially for long-term projections. Moreover, AEO7 can be utilised to model various specific policy measures, both at the national and regional levels, based on the interest of stakeholders. Such research can further augment the ‘core’ AEO7 model by delving deeper into specific sectors or countries. Also important is connecting AEO with other studies and activities conducted by AMS or ACE. For example, ASEAN Roadmaps, like Sustainable Building and Cooling Roadmaps, RE-Gender Roadmap, and RE Long-Term Roadmap, may benefit from data-based quantitative analysis derived from AEO. AEO can also extend its connection to AIMS III, RE Outlook, net zero analysis, and other studies.

**Intersectoral and secondary analysis.** AEO model focuses on the energy system by design. It has worked well to address the primary purpose of AEO in supporting regional energy cooperation. Nevertheless, intersectoral analysis with other related systems would further enrich the model and its analysis. These potentially include the agriculture and land use system, water system, macroeconomic system, and climate system. Currently, such correlation is done through secondary analysis, amongst others. Rooms for improvement is also available with these analyses. For instance, job creation projection could be improved with the refinement of methodologies and continuous data improvement to allow a better projection in portraying the region’s workforce amidst the trend shift of energy technologies. These include job trade-offs for fossil fuel generation to illustrate the potential job loss and the gender dimension of the workforce. [98]

**Capacity building on modelling and data.** Improvement and usage optimisation of the AEO model will require capacity-building on energy-related data and modelling. In terms of data, attention needs to be given to the standardisation and harmonisation of data amongst all AMS, as well as expanding the sectoral resolution and additional parameters required for more detailed modelling and policy analysis. To do so, the AEO team has conducted capacity building within the AEO development process. Such activities, though, should be expanded further to the national level with more specific exercises.

# APPENDIX A - ABBREVIATIONS

| | |
|---|---|
| AAGR | Annual Average Growth Rate |
| ACCEPT | ASEAN Climate Change and Energy Project |
| ACE | ASEAN Centre for Energy |
| ADB | Asian Development Bank |
| AEDS | ASEAN Energy Database System |
| AEO | ASEAN Energy Outlook |
| AEO6 | The 6th ASEAN Energy Outlook |
| AEO7 | The 7th ASEAN Energy Outlook |
| AGEP | ASEAN-German Energy Programme |
| AIMS | ASEAN Interconnection Masterplan Study |
| AMEM | ASEAN Ministers of Energy Meeting |
| AMS | ASEAN Member States |
| APAEC | ASEAN Plan of Action for Energy Cooperation |
| APERC | Asia-Pacific Energy Research Centre |
| APG | ASEAN Power Grid |
| APS | APAEC Target Scenario |
| ASCOPE | ASEAN Council on Petroleum |
| ATS | AMS Target Scenario |
| BAU | Business as Usual |
| CAGR | Compound Annual Growth Rate |
| Capex | Capital Expenditures |
| CCS | Carbon Capture and Storage |
| CCUS | Carbon Capture Utilisation and Storage |
| $CO_2$ | Carbon Dioxide |
| COP | Coefficient of Performance |
| COP26 | The 2021 United Nations Climate Change Conference of Parties |
| C&I | Construction and Installation |
| DF | Decline Factor |
| DOE | Department of Energy |
| EBT | Energy Balance Table |
| EE | Energy Efficiency |
| EE&C | Energy Efficiency and Conversation |
| EIA | Energy Information Administration |
| EV | Electric Vehicle |
| FBT | Food, Baverages and Tobacco |
| GDP | Gross Domestic Product |
| GFI | Grid Fluctuation Index |
| GHG | Greenhouse Gas |
| GIZ | Deutsche Gesellschaft für Internationale Zusammenarbeit |
| HAPUA | Heads of ASEAN Power Utilities/Authorities |
| ICEV | Internal Combustion Engine Vehicle |
| IEA | International Energy Agency |
| IPCC | Intergovernmental Panel on Climate Change |
| IRENA | International Renewable Energy Agency |
| LCO | Least-Cost Optimisation |
| LEAP | Low Emissions Analysis Platform |
| LPG | Liquefied Petroleum Gas |
| LTMS-PIP | Lao PDR-Thailand-Malaysia-Singapore Power Integration Project |
| MEPS | Minimum Energy Performance Standards |
| Mtoe | Million tonnes of oil equivalent |
| NDCs | Nationally Determined Contribution |
| NREL | National Renewable Energy Laboratory |

| | |
|---|---|
| NSTDA | National Science and Technology Development Agency |
| Opex | Operational Expenditure |
| O&M | Operation & Maintenance |
| PED | Priority Economic Deliverable |
| PDP | Power Development Plan |
| PM2.5 | Particulate Matter 2.5 |
| PPA | Power Purchase Agreement |
| PV | Photovoltaic |
| R/P | Reserves-to-Production |
| R&D | Research and Development |
| RE | Renewable Energy |
| REPP | Regional Energy Policy and Planning |
| RE-SSN | Renewable Energy Sub-Sector Network |
| RF | Regionality Factor |
| SC | Supercritical |
| SDG | Sustainable Development Goal |
| SEB | Specialised Energy Bodies |
| SSN | Sub-Sector Network |
| SSP | Shared Socioeconomic Pathways |
| TFEC | Total Final Energy Consumption |
| TPES | Total Primary Energy Supply |
| UN | United Nations |
| USD | United States Dollar |
| V2G | Vehicle-to-Grid |
| VRE | Variable Renewable Energy |
| WDI | World Development Indicator |
| WHO | World Health Organisation |
| WTW | Well-to-Wheel |
| YoY | Year on Year |

## *Units*

| | |
|---|---|
| °C | Degrees Celsius |
| BTU | British Thermal Unit |
| BTU/h | British Thermal Unit per hour |
| BTU/h/W | British Thermal Unit per hour per watt |
| $CO_2$-eq | Carbon dioxide equivalent |
| GJ | Gigajoule |
| Gt $CO_2$-eq | Gigatonnes (billion tonnes) of $CO_2$ equivalent |
| GW | Gigawatt |
| Km | Kilometre |
| Km/litre | Kilometre per litre |
| kV | Kilovolt |
| kW | Kilowatt |
| MJ | Megajoule |
| Mt $CO_2$-eq | Megatonnes (million tonnes) of $CO_2$ equivalent |
| Mtoe | Million tonnes of oil equivalent |
| MW | Megawatt |
| MWp | Megawatt peak |
| PJ | Petajoule |
| TCM | Trillion Cubic Meters |
| t $CO_2$-eq | Tonnes of $CO_2$ equivalent |
| TWh | Terawatt hour |
| W/W | Weight for weight |
| Wh | Watt hour |

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# APPENDIX C - DATA BY SCENARIO

## C.1 TPES by Fuel (Mtoe)

| Fuel | Baseline Scenario | | | | | | | | Share of TPES (%) | | | CAGR (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2005 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 | 2020 | 2025 | 2050 | 2020-2025 | 2020-2050 | 2025-2050 |
| Coal | 60 | 184 | 212 | 260 | 311 | 387 | 473 | 584 | 28.1 | 25.9 | 22.1 | 2.9 | 3.9 | 4.1 |
| Oil | 176 | 216 | 307 | 400 | 512 | 660 | 860 | 1,141 | 32.9 | 37.5 | 43.1 | 7.4 | 5.7 | 5.4 |
| Natural Gas | 100 | 143 | 166 | 212 | 272 | 347 | 453 | 599 | 21.8 | 20.2 | 22.6 | 3.1 | 4.9 | 5.3 |
| Hydropower | 5 | 15 | 17 | 22 | 26 | 31 | 39 | 48 | 2.2 | 2.1 | 1.8 | 3.5 | 4.1 | 4.2 |
| Geothermal, Solar, Wind | 14 | 25 | 39 | 49 | 61 | 68 | 84 | 104 | 3.9 | 4.8 | 3.9 | 9.2 | 4.8 | 4.0 |
| Modern Biomass | 28 | 54 | 61 | 76 | 93 | 113 | 137 | 162 | 8.1 | 7.5 | 6.1 | 3.0 | 3.8 | 4.0 |
| Traditional Biomass | 40 | 19 | 16 | 14 | 13 | 12 | 10 | 9 | 2.9 | 1.9 | 1.4 | -3.7 | -2.3 | -2.1 |
| Electricity | -0.5 | -0.2 | -0.1 | -0.1 | -0.1 | -0.1 | 0.0 | -0.1 | 0.0 | 0.0 | 0.0 | -10.7 | -4.0 | -2.6 |
| Total | 422 | 654 | 818 | 1,034 | 1,288 | 1,619 | 2,057 | 2,648 | 100 | 100 | 100 | 4.6 | 4.8 | 4.8 |

| Fuel | ATS | | | | | | | | Share of TPES (%) | | | CAGR (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2005 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 | 2020 | 2025 | 2050 | 2020-2025 | 2020-2050 | 2025-2050 |
| Coal | 60 | 184 | 190 | 207 | 208 | 229 | 246 | 261 | 28.1 | 25.0 | 22.7 | 0.6 | 1.2 | 1.3 |
| Oil | 176 | 216 | 271 | 321 | 384 | 474 | 605 | 799 | 32.9 | 35.7 | 35.3 | 4.8 | 4.5 | 4.4 |
| Natural Gas | 100 | 143 | 152 | 188 | 237 | 298 | 382 | 500 | 21.8 | 20.0 | 20.7 | 1.3 | 4.3 | 4.9 |
| Hydropower | 5 | 15 | 18 | 23 | 30 | 37 | 46 | 58 | 2.2 | 2.4 | 2.6 | 4.4 | 4.7 | 4.8 |
| Geothermal, Solar, Wind | 14 | 25 | 49 | 75 | 110 | 140 | 182 | 247 | 3.9 | 6.5 | 8.2 | 14.1 | 7.9 | 6.7 |
| Modern Biomass | 28 | 54 | 66 | 84 | 101 | 119 | 141 | 163 | 8.1 | 8.7 | 9.2 | 4.4 | 3.8 | 3.7 |
| Traditional Biomass | 40 | 19 | 13 | 11 | 10 | 8 | 7 | 6 | 2.9 | 1.7 | 1.3 | -7.0 | -4.0 | -3.4 |
| Electricity | -0.5 | -0.2 | -0.1 | -0.2 | -0.2 | -0.2 | -0.1 | -0.1 | 0.0 | 0.0 | 0.0 | -4.5 | -1.9 | -1.3 |
| Total | 422 | 654 | 759 | 908 | 1,080 | 1,305 | 1,608 | 2,033 | 100 | 100 | 100 | 3.1 | 3.9 | 4.0 |

| Fuel | APS | | | | | | | | Share of TPES (%) | | | CAGR (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2005 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 | 2020 | 2025 | 2050 | 2020-2025 | 2020-2050 | 2025-2050 |
| Coal | 60 | 184 | 158 | 154 | 137 | 138 | 135 | 133 | 28.1 | 21.6 | 18.3 | -3.0 | -1.1 | -0.7 |
| Oil | 176 | 216 | 246 | 275 | 322 | 397 | 516 | 699 | 32.9 | 33.6 | 32.8 | 2.7 | 4.0 | 4.3 |
| Natural Gas | 100 | 143 | 146 | 172 | 207 | 254 | 323 | 424 | 21.8 | 20.0 | 20.5 | 0.5 | 3.7 | 4.4 |
| Hydropower | 5 | 15 | 21 | 28 | 36 | 44 | 52 | 61 | 2.2 | 2.9 | 3.3 | 7.7 | 4.9 | 4.3 |
| Geothermal, Solar, Wind | 14 | 25 | 64 | 96 | 135 | 166 | 207 | 266 | 3.9 | 8.8 | 11.4 | 20.4 | 8.1 | 5.8 |
| Modern Biomass | 28 | 54 | 83 | 104 | 121 | 138 | 159 | 180 | 8.1 | 11.4 | 12.4 | 9.5 | 4.2 | 3.1 |
| Traditional Biomass | 40 | 19 | 13 | 10 | 8 | 5 | 4 | 3 | 2.9 | 1.7 | 1.2 | -8.0 | -6.0 | -5.6 |
| Electricity | -0.5 | -0.2 | 0.0 | -0.1 | -0.1 | -0.2 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | -23.2 | - | - |
| Total | 422 | 654 | 731 | 839 | 966 | 1,142 | 1,395 | 1,766 | 100 | 100 | 100 | 2.3 | 3.4 | 3.6 |

| Fuel | LCO Scenario | | | | | | | | Share of TPES (%) | | | CAGR (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2005 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 | 2020 | 2025 | 2050 | 2020-2025 | 2020-2050 | 2025-2050 |
| Coal | 60 | 184 | 210 | 223 | 219 | 220 | 221 | 222 | 28.1 | 29.6 | 27.9 | 2.7 | 0.6 | 0.2 |
| Oil | 176 | 216 | 241 | 271 | 318 | 395 | 514 | 697 | 32.9 | 34.0 | 33.8 | 2.3 | 4.0 | 4.3 |
| Natural Gas | 100 | 143 | 81 | 101 | 135 | 175 | 237 | 330 | 21.8 | 11.4 | 12.6 | -10.6 | 2.8 | 5.8 |
| Hydropower | 5 | 15 | 29 | 37 | 42 | 49 | 58 | 69 | 2.2 | 4.1 | 4.6 | 14.8 | 5.3 | 3.5 |
| Geothermal, Solar, Wind | 14 | 25 | 42 | 49 | 56 | 57 | 63 | 72 | 3.9 | 5.9 | 6.1 | 10.4 | 3.5 | 2.2 |
| Nuclear | 0 | 0 | 0 | 0 | 0 | 5 | 7 | 11 | 0.0 | 0.0 | 0.0 | - | -5.1 | - |
| Modern Biomass | 28 | 54 | 94 | 109 | 138 | 171 | 211 | 246 | 8.1 | 13.2 | 13.6 | 12.0 | 8.9 | 3.9 |
| Traditional Biomass | 40 | 19 | 13 | 10 | 8 | 5 | 4 | 2 | 2.9 | 1.8 | 1.3 | -8.0 | - | - |
| Electricity | -0.5 | -0.2 | -0.0 | -0.1 | -0.1 | -0.2 | -0.0 | -0.1 | 0.0 | 0.0 | 0.0 | -23.2 | -3.4 | 1.1 |
| Total | 422 | 654 | 710 | 800 | 915 | 1,077 | 1,314 | 1,649 | 100 | 100 | 100 | 1.7 | 3.1 | 3.4 |

## C.2 TFEC by Fuel (Mtoe)

| Fuel | Baseline Scenario | | | | | | | | Share of TFEC (%) | | | CAGR (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2005 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 | 2020 | 2025 | 2050 | 2020-2025 | 2020-2050 | 2025-2050 |
| Coal | 22 | 48 | 60 | 76 | 95 | 118 | 148 | 185 | 12.4 | 12.6 | 14.5 | 4.6 | 4.6 | 4.6 |
| Oil | 124 | 169 | 218 | 273 | 333 | 406 | 495 | 607 | 43.8 | 46.1 | 47.4 | 5.2 | 4.4 | 4.2 |
| Natural Gas | 15 | 29 | 35 | 44 | 54 | 67 | 82 | 102 | 7.4 | 7.4 | 8.0 | 4.2 | 4.3 | 4.4 |
| Bioenergy | 21 | 33 | 41 | 51 | 63 | 78 | 96 | 118 | 8.6 | 8.6 | 9.2 | 4.1 | 4.3 | 4.3 |
| Traditional Biomass | 40 | 19 | 16 | 14 | 13 | 12 | 10 | 9 | 5.0 | 3.3 | 0.7 | -3.7 | -2.3 | -2.1 |
| Other heat | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0 | 0.0 | 0.0 | 3.6 | 4.1 | 4.2 |
| Electricity | 38 | 87 | 104 | 126 | 150 | 180 | 216 | 260 | 22.7 | 21.9 | 20.3 | 3.5 | 3.7 | 3.7 |
| Total | 259 | 385 | 473 | 584 | 708 | 861 | 1,047 | 1,282 | 100 | 100 | 100 | 4.2 | 4.1 | 4.1 |

| Fuel | ATS | | | | | | | | Share of TFEC (%) | | | CAGR (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2005 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 | 2020 | 2025 | 2050 | 2020-2025 | 2020-2050 | 2025-2050 |
| Coal | 22 | 48 | 55 | 64 | 73 | 84 | 96 | 112 | 12.4 | 12.8 | 14.4 | 2.7 | 2.9 | 2.9 |
| Oil | 124 | 169 | 187 | 203 | 222 | 245 | 274 | 312 | 43.8 | 43.8 | 40.3 | 2.0 | 2.1 | 2.1 |
| Natural Gas | 15 | 29 | 33 | 39 | 45 | 52 | 61 | 71 | 7.4 | 7.7 | 9.2 | 2.9 | 3.1 | 3.1 |
| Bioenergy | 21 | 33 | 40 | 48 | 54 | 60 | 67 | 76 | 8.6 | 9.5 | 9.8 | 4.0 | 2.8 | 2.5 |
| Traditional Biomass | 40 | 19 | 13 | 11 | 10 | 8 | 7 | 6 | 5.0 | 3.1 | 0.7 | -7.0 | -4.0 | -3.4 |
| Other heat | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0 | 0.0 | 0.1 | 20.8 | 13.4 | 12.0 |
| Electricity | 38 | 87 | 99 | 115 | 131 | 150 | 172 | 197 | 22.7 | 23.1 | 25.5 | 2.4 | 2.7 | 2.8 |
| Total | 259 | 385 | 426 | 480 | 534 | 599 | 677 | 774 | 100 | 100 | 100 | 2.1 | 2.4 | 2.4 |

| Fuel | APS | | | | | | | | Share of TFEC (%) | | | CAGR (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2005 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 | 2020 | 2025 | 2050 | 2020-2025 | 2020-2050 | 2025-2050 |
| Coal | 22 | 48 | 51 | 55 | 59 | 64 | 71 | 78 | 12.4 | 12.5 | 13.2 | 1.1 | 1.7 | 1.8 |
| Oil | 124 | 169 | 165 | 164 | 168 | 179 | 198 | 226 | 43.8 | 40.6 | 38.1 | -0.4 | 1.0 | 1.3 |
| Natural Gas | 15 | 29 | 31 | 35 | 38 | 42 | 47 | 53 | 7.4 | 7.7 | 8.9 | 1.7 | 2.1 | 2.1 |
| Bioenergy | 21 | 33 | 52 | 59 | 60 | 62 | 66 | 71 | 8.6 | 12.8 | 11.9 | 9.4 | 2.5 | 1.2 |
| Traditional Biomass | 40 | 19 | 13 | 10 | 8 | 5 | 4 | 3 | 5.0 | 3.1 | 0.5 | -8.0 | -6.0 | -5.6 |
| Other heat | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0 | 0.0 | 0.1 | 20.4 | 13.4 | 12.0 |
| Electricity | 38 | 87 | 95 | 106 | 118 | 131 | 146 | 163 | 22.7 | 23.3 | 27.3 | 1.6 | 2.1 | 2.2 |
| Total | 259 | 385 | 407 | 430 | 451 | 485 | 531 | 593 | 100 | 100 | 100 | 1.1 | 1.5 | 1.5 |

| Fuel | LCO Scenario | | | | | | | | Share of TFEC | | | CAGR | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2005 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 | 2020 | 2025 | 2050 | 2020-2025 | 2020-2050 | 2025-2050 |
| Coal | 22 | 48 | 51 | 55 | 59 | 64 | 71 | 78 | 12.4 | 12.4 | 13.2 | 1.1 | 1.7 | 1.8 |
| Oil | 124 | 169 | 165 | 164 | 168 | 179 | 198 | 226 | 43.8 | 40.6 | 38.0 | -0.4 | 1.0 | 1.3 |
| Natural Gas | 15 | 29 | 31 | 35 | 38 | 42 | 47 | 53 | 7.4 | 7.7 | 8.9 | 1.7 | 2.1 | 2.1 |
| Bioenergy | 21 | 33 | 52 | 59 | 60 | 62 | 66 | 71 | 8.6 | 12.8 | 11.9 | 9.4 | 2.5 | 1.2 |
| Traditional Biomass | 40 | 19 | 13 | 10 | 8 | 5 | 4 | 3 | 5.0 | 3.1 | 0.5 | -8.0 | -6.0 | -5.6 |
| Other heat | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0 | 0.0 | 0.1 | 20.4 | 13.4 | 12.0 |
| Electricity | 38 | 87 | 95 | 107 | 118 | 132 | 146 | 163 | 22.7 | 23.4 | 27.4 | 1.7 | 2.1 | 2.2 |
| Total | 259 | 385 | 407 | 430 | 451 | 485 | 531 | 593 | 100 | 100 | 100 | 1.1 | 1.5 | 1.5 |

## C.3 TFEC by Sector (Mtoe)

| Sector | Baseline Scenario | | | | | | | | Share of TFEC (%) | | | CAGR (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2005 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 | 2020 | 2025 | 2050 | 2020-2025 | 2020-2050 | 2025-2050 |
| Residential | 64 | 63 | 66 | 70 | 74 | 77 | 81 | 83 | 16.3 | 14.0 | 6.5 | 1.1 | 1.0 | 0.9 |
| Industry | 94 | 151 | 186 | 234 | 288 | 356 | 440 | 544 | 39.1 | 39.2 | 42.5 | 4.3 | 4.4 | 4.4 |
| Transport | 74 | 134 | 175 | 220 | 271 | 332 | 403 | 492 | 34.8 | 37.0 | 38.4 | 5.5 | 4.4 | 4.2 |
| Commercial | 18 | 29 | 35 | 42 | 51 | 62 | 75 | 92 | 7.6 | 7.3 | 7.2 | 3.4 | 3.9 | 4.0 |
| Agriculture and Others | 9 | 8 | 12 | 17 | 24 | 34 | 48 | 70 | 2.2 | 2.5 | 5.5 | 6.9 | 7.3 | 7.4 |
| Total | 259 | 385 | 473 | 584 | 708 | 861 | 1,047 | 1,282 | 100 | 100 | 100 | 4.2 | 4.1 | 4.1 |

| Sector | ATS | | | | | | | | Share of TFEC (%) | | | CAGR (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2005 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 | 2020 | 2025 | 2050 | 2020-2025 | 2020-2050 | 2025-2050 |
| Residential | 64 | 63 | 61 | 63 | 65 | 67 | 69 | 70 | 16.3 | 14.4 | 9.0 | -0.4 | 0.4 | 0.5 |
| Industry | 94 | 151 | 172 | 201 | 230 | 264 | 304 | 351 | 39.1 | 40.3 | 45.4 | 2.7 | 2.9 | 2.9 |
| Transport | 74 | 134 | 149 | 162 | 174 | 188 | 203 | 222 | 34.8 | 35.0 | 28.7 | 2.2 | 1.7 | 1.6 |
| Commercial | 18 | 29 | 32 | 37 | 41 | 47 | 53 | 61 | 7.6 | 7.6 | 7.9 | 1.9 | 2.5 | 2.6 |
| Agriculture and Others | 9 | 8 | 12 | 17 | 24 | 34 | 48 | 70 | 2.2 | 2.8 | 9.0 | 6.9 | 7.3 | 7.4 |
| Total | 259 | 385 | 426 | 480 | 534 | 599 | 677 | 774 | 100 | 100 | 100 | 2.1 | 2.4 | 2.4 |

| Sector | APS | | | | | | | | Share of TFEC (%) | | | CAGR (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2005 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 | 2020 | 2025 | 2050 | 2020-2025 | 2020-2050 | 2025-2050 |
| Residential | 64 | 63 | 60 | 60 | 60 | 60 | 60 | 60 | 16.3 | 14.8 | 10.0 | -0.9 | -0.2 | -0.0 |
| Industry | 94 | 151 | 161 | 177 | 192 | 208 | 228 | 252 | 39.1 | 39.6 | 42.5 | 1.4 | 1.7 | 1.8 |
| Transport | 74 | 134 | 143 | 143 | 141 | 145 | 154 | 168 | 34.8 | 35.2 | 28.4 | 1.4 | 0.8 | 0.7 |
| Commercial | 18 | 29 | 30 | 33 | 35 | 37 | 40 | 43 | 7.6 | 7.5 | 7.3 | 0.7 | 1.3 | 1.4 |
| Agriculture and Others | 9 | 8 | 12 | 17 | 24 | 34 | 48 | 70 | 2.2 | 2.9 | 11.8 | 6.9 | 7.3 | 7.4 |
| Total | 259 | 385 | 407 | 430 | 452 | 485 | 531 | 593 | 100 | 100 | 100 | 1.1 | 1.5 | 1.5 |

| Sector | LCO Scenario | | | | | | | | Share of TFEC (%) | | | CAGR (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2005 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 | 2020 | 2025 | 2050 | 2020-2025 | 2020-2050 | 2025-2050 |
| Residential | 64 | 63 | 60 | 61 | 60 | 61 | 60 | 60 | 16.3 | 14.9 | 10.1 | -0.7 | -0.1 | -0.0 |
| Industry | 94 | 151 | 161 | 177 | 192 | 208 | 228 | 252 | 39.1 | 39.6 | 42.5 | 1.4 | 1.7 | 1.8 |
| Transport | 74 | 134 | 143 | 143 | 141 | 145 | 154 | 168 | 34.8 | 35.2 | 28.4 | 1.4 | 0.8 | 0.7 |
| Commercial | 18 | 29 | 30 | 33 | 35 | 37 | 40 | 43 | 7.6 | 7.4 | 7.3 | 0.7 | 1.3 | 1.4 |
| Agriculture and Others | 9 | 8 | 12 | 17 | 24 | 34 | 48 | 70 | 2.2 | 2.9 | 11.8 | 6.9 | 7.3 | 7.4 |
| Total | 259 | 385 | 407 | 430 | 452 | 485 | 531 | 593 | 100 | 100 | 100 | 1.1 | 1.5 | 1.5 |

## C.4 Installed Capacity by Fuel/Feedstock (GW)

| Fuel | Baseline Scenario | | | | | | | | Capacity Share (%) | | | CAGR (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2005 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 | 2020 | 2025 | 2050 | 2020-2025 | 2020-2050 | 2025-2050 |
| Coal | 22 | 94 | 128 | 155 | 182 | 224 | 268 | 324 | 32.2 | 33.8 | 33.8 | 6.2 | 4.2 | 3.8 |
| Gas | 52 | 88 | 103 | 123 | 149 | 174 | 208 | 251 | 29.9 | 27.3 | 26.1 | 3.3 | 3.6 | 3.6 |
| Oil | 14 | 13 | 17 | 21 | 27 | 33 | 40 | 49 | 4.6 | 4.5 | 5.1 | 4.7 | 4.4 | 4.3 |
| Geothermal | 3 | 4 | 6 | 7 | 9 | 9 | 12 | 15 | 1.4 | 1.5 | 1.5 | 6.4 | 4.4 | 4.0 |
| Hydro | 17 | 58 | 76 | 94 | 114 | 135 | 167 | 207 | 19.8 | 20.1 | 21.6 | 5.6 | 4.3 | 4.1 |
| Solar | 0 | 23 | 33 | 41 | 52 | 64 | 70 | 76 | 7.9 | 8.6 | 7.9 | 7.1 | 4.0 | 3.4 |
| Wind | 0 | 3 | 4 | 5 | 5 | 5 | 6 | 7 | 0.9 | 0.9 | 0.7 | 5.8 | 3.2 | 2.6 |
| Biomass, Biogas, Waste | 1 | 10 | 13 | 16 | 19 | 23 | 27 | 31 | 3.4 | 3.3 | 3.2 | 5.0 | 3.9 | 3.7 |
| Total | 110 | 293 | 378 | 462 | 556 | 668 | 798 | 959 | 100 | 100 | 100 | 5.2 | 4.0 | 3.8 |

| Fuel | ATS | | | | | | | | Capacity Share (%) | | | CAGR (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2005 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 | 2020 | 2025 | 2050 | 2020-2025 | 2020-2050 | 2025-2050 |
| Coal | 22 | 94 | 117 | 129 | 131 | 144 | 154 | 161 | 32.2 | 30.8 | 20.4 | 4.3 | 1.8 | 1.3 |
| Gas | 52 | 88 | 102 | 116 | 135 | 153 | 174 | 199 | 29.9 | 26.8 | 25.3 | 3.0 | 2.8 | 2.7 |
| Oil | 14 | 13 | 17 | 20 | 25 | 30 | 34 | 39 | 4.6 | 4.5 | 5.0 | 4.9 | 3.6 | 3.4 |
| Geothermal | 3 | 4 | 7 | 11 | 16 | 20 | 27 | 38 | 1.4 | 1.8 | 4.8 | 10.9 | 7.7 | 7.1 |
| Hydro | 17 | 58 | 77 | 99 | 121 | 145 | 174 | 220 | 19.8 | 20.4 | 27.9 | 6.0 | 4.6 | 4.3 |
| Solar | 0 | 23 | 39 | 49 | 59 | 68 | 73 | 76 | 7.9 | 10.3 | 9.7 | 11.2 | 4.1 | 2.7 |
| Wind | 0 | 3 | 5 | 6 | 7 | 7 | 8 | 10 | 0.9 | 1.3 | 1.3 | 13.1 | 4.5 | 2.8 |
| Biomass, Biogas, Waste | 1 | 10 | 16 | 21 | 26 | 31 | 38 | 45 | 3.4 | 4.1 | 5.7 | 9.6 | 5.2 | 4.3 |
| Total | 110 | 293 | 379 | 450 | 519 | 598 | 682 | 787 | 100 | 100 | 100 | 5.3 | 3.4 | 3.0 |

| Fuel | APS | | | | | | | | Capacity Share (%) | | | CAGR (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2005 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 | 2020 | 2025 | 2050 | 2020-2025 | 2020-2050 | 2025-2050 |
| Coal | 22 | 94 | 102 | 103 | 94 | 95 | 88 | 76 | 32.2 | 27.2 | 10.5 | 1.6 | -0.7 | -1.2 |
| Gas | 52 | 88 | 103 | 116 | 129 | 141 | 154 | 170 | 29.9 | 27.5 | 23.6 | 3.3 | 2.2 | 2.0 |
| Oil | 14 | 13 | 14 | 15 | 17 | 18 | 19 | 19 | 4.6 | 3.8 | 2.7 | 1.3 | 1.2 | 1.2 |
| Geothermal | 3 | 4 | 9 | 14 | 20 | 24 | 30 | 40 | 1.4 | 2.5 | 5.5 | 18.1 | 7.9 | 6.0 |
| Hydro | 17 | 58 | 84 | 111 | 138 | 165 | 200 | 254 | 19.8 | 22.3 | 35.3 | 7.7 | 5.1 | 4.5 |
| Solar | 0 | 23 | 40 | 53 | 66 | 78 | 89 | 94 | 7.9 | 10.7 | 13.1 | 11.7 | 4.8 | 3.5 |
| Wind | 0 | 3 | 5 | 7 | 8 | 9 | 10 | 11 | 0.9 | 1.4 | 1.6 | 15.0 | 5.8 | 3.1 |
| Biomass, Biogas, Waste | 1 | 10 | 17 | 24 | 31 | 38 | 46 | 56 | 3.4 | 4.6 | 7.7 | 11.9 | 7.0 | 5.3 |
| Battery | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0.0 | 0.1 | 0.0 | - | 22.6 | 13.0 |
| Total | 110 | 293 | 376 | 443 | 503 | 568 | 636 | 719 | 100 | 100 | 100 | 5.1 | 3.4 | 2.6 |

| Fuel | LCO Scenario | | | | | | | | Capacity Share (%) | | | CAGR (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2005 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 | 2020 | 2025 | 2050 | 2020-2025 | 2020-2050 | 2025-2050 |
| Coal | 22 | 94 | 128 | 135 | 132 | 134 | 135 | 148 | 32.2 | 32.1 | 23.9 | 6.3 | 1.5 | 0.6 |
| Gas | 52 | 88 | 102 | 97 | 93 | 95 | 98 | 102 | 29.9 | 25.6 | 16.5 | 3.1 | 0.5 | 0.0 |
| Oil | 14 | 13 | 17 | 16 | 15 | 15 | 14 | 12 | 4.6 | 4.2 | 1.9 | 4.7 | -0.3 | -1.3 |
| Geothermal | 3 | 4 | 6 | 7 | 8 | 7 | 8 | 9 | 1.4 | 1.4 | 1.5 | 6.9 | 2.8 | 2.0 |
| Hydro | 17 | 58 | 84 | 103 | 114 | 130 | 155 | 184 | 19.8 | 21.0 | 29.6 | 7.6 | 3.9 | 3.2 |
| Solar | 0 | 23 | 40 | 43 | 45 | 47 | 46 | 54 | 7.9 | 10.0 | 8.7 | 11.5 | 2.9 | 1.2 |
| Wind | 0 | 3 | 5 | 5 | 4 | 3 | 3 | 8 | 0.9 | 1.1 | 1.3 | 11.3 | 3.7 | 2.2 |
| Biomass, Biogas, Waste | 1 | 10 | 18 | 21 | 28 | 37 | 52 | 71 | 3.4 | 4.6 | 11.5 | 13.1 | 6.8 | 5.6 |
| Nuclear | 0 | 0 | 0 | 0 | 0 | 2 | 3 | 5 | 0.0 | 0.0 | 0.0 | - | - | - |
| Battery | 0 | 0 | 0 | 2 | 9 | 19 | 25 | 27 | 0.0 | 0.0 | 4 | - | - | 21.8 |
| Total | 110 | 293 | 399 | 427 | 447 | 491 | 540 | 620 | 100 | 100 | 100 | 6.4 | 2.5 | 1.8 |

## C.5 Power Generation by Fuel/Feedstock (TWh)

| Fuel | Baseline Scenario | | | | | | | | Generation Share (%) | | | CAGR (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2005 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 | 2020 | 2025 | 2050 | 2020-2025 | 2020-2050 | 2025-2050 |
| Coal | 140 | 494 | 577 | 696 | 809 | 996 | 1,195 | 1,450 | 43.9 | 42.9 | 42.8 | 3.1 | 3.7 | 3.8 |
| Gas | 263 | 357 | 403 | 478 | 580 | 674 | 809 | 973 | 31.7 | 30.0 | 28.7 | 2.5 | 3.4 | 3.6 |
| Oil | 35 | 12 | 19 | 23 | 30 | 37 | 43 | 54 | 1.1 | 1.4 | 1.6 | 9.7 | 5.2 | 4.3 |
| Geothermal | 17 | 26 | 37 | 47 | 58 | 64 | 79 | 100 | 2.3 | 2.8 | 3.0 | 7.2 | 4.6 | 4.1 |
| Hydro | 55 | 176 | 202 | 251 | 306 | 366 | 455 | 563 | 15.7 | 15.0 | 16.6 | 2.8 | 3.9 | 4.2 |
| Solar | 0 | 18 | 57 | 72 | 90 | 111 | 122 | 132 | 1.6 | 4.2 | 3.9 | 25.9 | 6.9 | 3.4 |
| Wind | 0 | 4 | 5 | 6 | 8 | 8 | 8 | 9 | 0.3 | 0.4 | 0.3 | 7.3 | 3.3 | 2.5 |
| Biomass, Biogas, Waste | 1 | 39 | 45 | 56 | 70 | 84 | 99 | 106 | 3.4 | 3.3 | 3.1 | 3.0 | 3.4 | 3.5 |
| Total | 510 | 1,126 | 1,345 | 1,630 | 1,950 | 2,340 | 2,811 | 3,388 | 100 | 100 | 100 | 3.6 | 3.7 | 3.8 |

| Fuel | ATS | | | | | | | | Generation Share (%) | | | CAGR (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2005 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 | 2020 | 2025 | 2050 | 2020-2025 | 2020-2050 | 2025-2050 |
| Coal | 140 | 494 | 515 | 542 | 517 | 547 | 557 | 548 | 43.9 | 40.3 | 21.4 | 0.8 | 0.3 | 0.2 |
| Gas | 263 | 357 | 352 | 400 | 474 | 536 | 610 | 697 | 31.7 | 27.6 | 27.1 | -0.2 | 2.3 | 2.8 |
| Oil | 35 | 12 | 21 | 23 | 25 | 26 | 27 | 28 | 1.1 | 1.7 | 1.1 | 12.3 | 2.8 | 1.0 |
| Geothermal | 17 | 26 | 47 | 73 | 110 | 142 | 187 | 256 | 2.3 | 3.7 | 10.0 | 12.2 | 7.9 | 7.0 |
| Hydro | 55 | 176 | 211 | 273 | 352 | 432 | 535 | 678 | 15.7 | 16.5 | 26.4 | 3.6 | 4.6 | 4.8 |
| Solar | 0 | 18 | 67 | 85 | 100 | 116 | 125 | 130 | 1.6 | 5.3 | 5.1 | 30.4 | 6.8 | 2.7 |
| Wind | 0 | 4 | 7 | 9 | 10 | 11 | 13 | 17 | 0.3 | 0.5 | 0.7 | 14.0 | 5.3 | 3.6 |
| Biomass, Biogas, Waste | 1 | 39 | 57 | 84 | 115 | 144 | 180 | 213 | 3.4 | 4.5 | 8.3 | 8.2 | 5.9 | 5.4 |
| Total | 510 | 1,126 | 1,278 | 1,488 | 1,703 | 1,955 | 2,235 | 2,566 | 100 | 100 | 100 | 2.6 | 2.8 | 2.8 |

| Fuel | APS | | | | | | | | Generation Share (%) | | | CAGR (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2005 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 | 2020 | 2025 | 2050 | 2020-2025 | 2020-2050 | 2025-2050 |
| Coal | 140 | 494 | 408 | 374 | 299 | 280 | 245 | 206 | 43.9 | 33.2 | 9.8 | -3.8 | -2.9 | -2.7 |
| Gas | 263 | 357 | 343 | 359 | 386 | 406 | 431 | 463 | 31.7 | 27.9 | 22.0 | -0.8 | 0.9 | 1.2 |
| Oil | 35 | 12 | 20 | 18 | 15 | 12 | 9 | 7 | 1.1 | 1.6 | 0.3 | 10.3 | -1.9 | -4.2 |
| Geothermal | 17 | 26 | 63 | 95 | 136 | 168 | 212 | 276 | 2.3 | 5.1 | 13.1 | 19.0 | 8.1 | 6.1 |
| Hydro | 55 | 176 | 246 | 326 | 423 | 508 | 602 | 712 | 15.7 | 20.0 | 33.8 | 6.9 | 4.8 | 4.3 |
| Solar | 0 | 18 | 69 | 91 | 111 | 133 | 151 | 159 | 1.6 | 5.6 | 7.6 | 31.1 | 7.6 | 3.4 |
| Wind | 0 | 4 | 8 | 11 | 12 | 13 | 14 | 17 | 0.3 | 0.7 | 0.8 | 17.3 | 5.7 | 3.0 |
| Biomass, Biogas, Waste | 1 | 39 | 72 | 107 | 148 | 185 | 228 | 268 | 3.4 | 5.9 | 12.7 | 13.2 | 8.3 | 6.7 |
| Total | 510 | 1,126 | 1,229 | 1,381 | 1,530 | 1,704 | 1,891 | 2,108 | 100 | 100 | 100 | 1.8 | 2.4 | 2.1 |

| Fuel | LCO Scenario | | | | | | | | Generation Share (%) | | | CAGR (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2005 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 | 2020 | 2025 | 2050 | 2020-2025 | 2020-2050 | 2025-2050 |
| Coal | 140 | 494 | 611 | 642 | 626 | 620 | 602 | 573 | 43.9 | 49.6 | 27.1 | 4.3 | 0.5 | -0.3 |
| Gas | 263 | 357 | 69 | 64 | 90 | 86 | 93 | 100 | 31.7 | 5.6 | 4.7 | -28.0 | -4.2 | 1.5 |
| Oil | 35 | 12 | 0 | 0 | 0 | 0 | 0 | 0 | 1.1 | 0.0 | 0.0 | -100 | -100 | - |
| Geothermal | 17 | 26 | 39 | 46 | 54 | 55 | 62 | 68 | 2.3 | 3.1 | 3.2 | 8.0 | 3.2 | 2.3 |
| Hydro | 55 | 176 | 338 | 432 | 491 | 575 | 675 | 800 | 15.7 | 27.5 | 37.8 | 13.9 | 5.2 | 3.5 |
| Solar | 0 | 18 | 69 | 75 | 77 | 80 | 78 | 91 | 1.6 | 5.6 | 4.3 | 30.9 | 5.6 | 1.1 |
| Wind | 0 | 4 | 6 | 6 | 6 | 4 | 5 | 21 | 0.3 | 0.5 | 1.0 | 11.9 | 6.0 | 4.9 |
| Biomass, Biogas, Waste | 1 | 39 | 99 | 120 | 190 | 267 | 351 | 418 | 3.4 | 8.0 | 19.8 | 20.7 | 8.2 | 5.9 |
| Nuclear | 0 | 0 | 0 | 0 | 0 | 19 | 27 | 43 | 0.0 | 0.0 | 2.1 | - | - | - |
| Total | 510 | 1,126 | 1,231 | 1,385 | 1,532 | 1,705 | 1,894 | 2,114 | 100 | 100 | 100 | 1.8 | 2.1 | 2.2 |

## C.6 Emission by Sector (Mt CO2-eq)

| Sector | Baseline Scenario | | | | | | | | Emissions Share (%) | | | CAGR (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2005 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 | 2020 | 2025 | 2050 | 2020-2025 | 2020-2050 | 2025-2050 |
| Residential | 58 | 50 | 60 | 64 | 66 | 68 | 69 | 70 | 2.5 | 2.4 | 1.0 | 3.4 | 1.1 | 0.6 |
| Industry | 194 | 316 | 392 | 495 | 613 | 758 | 941 | 1,170 | 15.9 | 15.9 | 16.3 | 4.4 | 4.5 | 4.5 |
| Transport | 228 | 379 | 493 | 621 | 763 | 935 | 1,136 | 1,385 | 19.0 | 19.9 | 19.3 | 5.4 | 4.4 | 4.2 |
| Commercial | 15 | 16 | 19 | 23 | 28 | 34 | 41 | 51 | 0.8 | 0.8 | 0.7 | 3.7 | 4.0 | 4.1 |
| Agriculture and Others | 27 | 21 | 29 | 42 | 59 | 84 | 121 | 175 | 1.0 | 1.2 | 2.4 | 6.8 | 7.4 | 7.5 |
| International Transport | 113 | 176 | 218 | 260 | 302 | 351 | 407 | 474 | 8.8 | 8.8 | 6.6 | 4.4 | 3.4 | 3.2 |
| Power Generation | 289 | 661 | 776 | 930 | 1,089 | 1,324 | 1,581 | 1,912 | 33.2 | 31.4 | 26.6 | 3.2 | 3.6 | 3.7 |
| Other Transformation | 229 | 372 | 486 | 636 | 825 | 1,084 | 1,439 | 1,942 | 18.7 | 19.7 | 27.1 | 5.5 | 5.7 | 5.7 |
| Total | 1,152 | 1,991 | 2,471 | 3,071 | 3,745 | 4,638 | 5,736 | 7,178 | 100 | 100 | 100 | 4.4 | 4.4 | 4.4 |

| Sector | ATS | | | | | | | | Emissions Share (%) | | | CAGR (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2005 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 | 2020 | 2025 | 2050 | 2020-2025 | 2020-2050 | 2025-2050 |
| Residential | 58 | 50 | 57 | 59 | 60 | 61 | 61 | 62 | 2.5 | 2.6 | 1.4 | 2.6 | 0.7 | 0.3 |
| Industry | 194 | 316 | 361 | 421 | 482 | 553 | 637 | 737 | 15.9 | 16.2 | 16.4 | 2.7 | 2.9 | 2.9 |
| Transport | 228 | 379 | 406 | 430 | 458 | 491 | 529 | 575 | 19.0 | 18.2 | 12.8 | 1.4 | 1.4 | 1.4 |
| Commercial | 15 | 16 | 17 | 20 | 22 | 24 | 28 | 31 | 0.8 | 0.8 | 0.7 | 2.0 | 2.3 | 2.4 |
| Agriculture and Others | 27 | 21 | 29 | 42 | 59 | 84 | 120 | 174 | 1.0 | 1.3 | 3.9 | 6.8 | 7.4 | 7.5 |
| International Transport | 113 | 176 | 218 | 260 | 302 | 351 | 407 | 474 | 8.8 | 9.8 | 10.5 | 4.4 | 3.4 | 3.2 |
| Power Generation | 289 | 661 | 690 | 736 | 739 | 797 | 835 | 860 | 33.2 | 30.9 | 19.1 | 0.9 | 0.9 | 0.9 |
| Other Transformation | 229 | 372 | 455 | 567 | 705 | 904 | 1,185 | 1,589 | 18.7 | 20.4 | 35.3 | 4.1 | 5.0 | 5.1 |
| Total | 1,152 | 1,991 | 2,233 | 2,535 | 2,826 | 3,265 | 3,802 | 4,503 | 100 | 100 | 100 | 2.3 | 2.8 | 2.8 |

| Sector | APS | | | | | | | | Emissions Share (%) | | | CAGR (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2005 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 | 2020 | 2025 | 2050 | 2020-2025 | 2020-2050 | 2025-2050 |
| Residential | 58 | 50 | 54 | 52 | 49 | 45 | 40 | 36 | 2.5 | 2.7 | 1.0 | 1.5 | -1.1 | -1.6 |
| Industry | 194 | 316 | 337 | 369 | 398 | 433 | 475 | 525 | 15.9 | 16.8 | 15.3 | 1.3 | 1.7 | 1.8 |
| Transport | 228 | 379 | 349 | 329 | 325 | 333 | 354 | 388 | 19.0 | 17.4 | 11.3 | -1.6 | 0.1 | 0.4 |
| Commercial | 15 | 16 | 16 | 17 | 18 | 19 | 20 | 21 | 0.8 | 0.8 | 0.6 | 0.6 | 1.0 | 1.0 |
| Agriculture and Others | 27 | 21 | 29 | 42 | 59 | 84 | 120 | 174 | 1.0 | 1.4 | 5.0 | 6.8 | 7.4 | 7.5 |
| International Transport | 113 | 176 | 218 | 260 | 302 | 351 | 407 | 474 | 8.8 | 10.9 | 13.8 | 4.4 | 3.4 | 3.2 |
| Power Generation | 289 | 661 | 576 | 546 | 477 | 467 | 441 | 416 | 33.2 | 28.7 | 12.1 | -2.7 | -1.5 | -1.3 |
| Other Transformation | 229 | 372 | 429 | 516 | 627 | 796 | 1,042 | 1,408 | 18.7 | 21.3 | 40.9 | 2.8 | 4.5 | 4.9 |
| Total | 1,152 | 1,991 | 2,007 | 2,131 | 2,254 | 2,526 | 2,899 | 3,440 | 100 | 100 | 100 | 0.2 | 1.8 | 2.2 |

| Sector | LCO Scenario | | | | | | | | Emissions Share (%) | | | CAGR (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2005 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 | 2020 | 2025 | 2050 | 2020-2025 | 2020-2050 | 2025-2050 |
| Residential | 58 | 50 | 54 | 52 | 49 | 45 | 40 | 36 | 2.5 | 2.6 | 1.0 | 1.5 | -1.1 | -1.6 |
| Industry | 194 | 316 | 337 | 369 | 398 | 433 | 475 | 525 | 15.9 | 16.3 | 14.6 | 1.3 | 1.7 | 1.8 |
| Transport | 228 | 379 | 349 | 329 | 325 | 333 | 354 | 388 | 19.0 | 16.9 | 10.8 | -1.6 | 0.1 | 0.4 |
| Commercial | 15 | 16 | 16 | 17 | 18 | 19 | 20 | 21 | 0.8 | 0.8 | 0.6 | 0.6 | 1.0 | 1.0 |
| Agriculture and Others | 27 | 21 | 29 | 42 | 59 | 84 | 120 | 174 | 1.0 | 1.4 | 4.8 | 6.8 | 7.4 | 7.5 |
| International Transport | 113 | 176 | 218 | 260 | 302 | 351 | 407 | 474 | 8.8 | 10.5 | 13.2 | 4.4 | 3.4 | 3.2 |
| Power Generation | 289 | 661 | 645 | 672 | 653 | 637 | 615 | 580 | 33.2 | 31.2 | 16.2 | -0.5 | -0.4 | -0.4 |
| Other Transformation | 229 | 372 | 417 | 507 | 621 | 790 | 1,034 | 1,393 | 18.7 | 20.2 | 38.8 | 2.3 | 4.5 | 4.9 |
| Total | 1,152 | 1,991 | 2,066 | 2,248 | 2,424 | 2,691 | 3,065 | 3,590 | 100 | 100 | 100 | 0.7 | 2.0 | 2.2 |

## C.7 ASEAN Cumulative Power Sector Investment

Unit : Real terms (Billion 2022 USD)

| Fuel | 2021 - 2030 | | | | 2031 - 2040 | | | | 2041 - 2050 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Baseline | ATS | APS | LCO | Baseline | ATS | APS | LCO | Baseline | ATS | APS | LCO |
| Coal | 99 | 56 | 13 | 30 | 108 | 41 | 10 | 26 | 157 | 58 | 17 | 55 |
| Oil | 13 | 11 | 5 | 0 | 15 | 12 | 5 | 0 | 22 | 15 | 5 | 0 |
| Natural Gas | 69 | 50 | 36 | 13 | 73 | 55 | 35 | 18 | 87 | 60 | 42 | 25 |
| RE | 159 | 167 | 160 | 117 | 113 | 151 | 172 | 106 | 153 | 202 | 228 | 148 |
| Nuclear | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 0 | 0 | 0 | 10 |
| Battery | 0 | 0 | 0 | 2 | 1 | 1 | 0 | 10 | 0 | 0 | 0 | 9 |
| Transmission | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| Total | 341 | 284 | 213 | 166 | 309 | 260 | 222 | 169 | 420 | 335 | 291 | 247 |

# APPENDIX D - MODELLING APPROACHES AND KEY ASSUMPTIONS

## D.1 Socio-economics

The key drivers at the macroeconomic level are consistent across the four scenarios. GDP, which is presented in constant 2017 purchasing power parity (PPP) dollars, is strongly correlated with energy demand projections. Considering the Covid-19 pandemic, AEO7 reflects the expected impact on GDP growth, as estimated by the Asian Development Bank [105]. The slowdown in economic activities has led to declining energy demand. Other drivers of energy demand projections include population, GDP per capita, and urbanisation, which, in turn, correlate with the projections of clean cooking access, electrification rate, and the number of vehicles.

### D.1.1 Population Projections

Population growth is one of the key factors for deriving energy projections. The projection of population by country is shown in Table D.1.

**Table D.1 ASEAN Population Historical and Projection 2005-2050 (Million People)**

| Country | 2005 | 2017 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 | CAGR (2020-2050) |
|---|---|---|---|---|---|---|---|---|---|---|
| Brunei Darussalam | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.4% |
| Cambodia | 13 | 16 | 17 | 18 | 19 | 20 | 21 | 21 | 22 | 0.9% |
| Indonesia | 226 | 265 | 274 | 287 | 299 | 310 | 319 | 326 | 331 | 0.6% |
| Lao PDR | 6 | 7 | 7 | 8 | 8 | 9 | 9 | 9 | 9 | 0.9% |
| Malaysia | 26 | 31 | 32 | 34 | 36 | 38 | 39 | 40 | 41 | 0.8% |
| Myanmar | 49 | 53 | 54 | 57 | 58 | 60 | 61 | 62 | 62 | 0.4% |
| Philippines | 86 | 105 | 110 | 117 | 124 | 130 | 136 | 140 | 144 | 0.9% |
| Singapore | 4 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 0.3% |
| Thailand | 65 | 69 | 70 | 70 | 70 | 70 | 69 | 68 | 66 | -0.2% |
| Vietnam | 84 | 95 | 97 | 101 | 104 | 106 | 108 | 109 | 110 | 0.4% |
| ASEAN | 560 | 647 | 667 | 698 | 726 | 749 | 767 | 782 | 792 | 0.6% |

*Source: World Bank DataBank, ADB.*

### D.1.2 Gross Domestic Product (GDP)

GDP is also a factor affecting energy demand projections. The projection of GDP by country is shown in Table D.2.

**Table D.2 Real GDP PPP at 2017 Constant Price (Million USD)**

| Country | 2005 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 | CAGR (2020-2050) |
|---|---|---|---|---|---|---|---|---|---|
| Brunei Darussalam | 25,480 | 27,230 | 29,771 | 31,914 | 33,542 | 35,253 | 37,051 | 38,941 | 1.2% |
| Cambodia | 28,098 | 69,962 | 92,419 | 129,199 | 167,980 | 206,445 | 243,538 | 275,138 | 4.7% |
| Indonesia | 1,515,974 | 3,130,467 | 4,011,901 | 5,318,370 | 6,820,122 | 8,745,924 | 11,215,517 | 14,382,450 | 5.2% |
| Lao PDR | 20,664 | 56,827 | 65,123 | 72,716 | 81,154 | 90,703 | 101,031 | 112,149 | 2.3% |
| Malaysia | 474,370 | 867,621 | 1,091,704 | 1,360,462 | 1,655,210 | 2,013,816 | 2,450,115 | 2,980,939 | 4.2% |
| Myanmar | 83,824 | 264,290 | 238,887 | 291,481 | 338,563 | 386,053 | 434,869 | 484,145 | 2.0% |
| Philippines | 436,313 | 871,562 | 1,152,058 | 1,498,572 | 1,885,432 | 2,372,162 | 2,984,543 | 3,755,011 | 5.0% |
| Singapore | 273,371 | 546,074 | 677,587 | 804,761 | 928,418 | 1,071,077 | 1,235,656 | 1,425,524 | 3.3% |
| Thailand | 805,168 | 1,207,002 | 1,421,692 | 1,713,138 | 2,044,519 | 2,440,001 | 2,911,982 | 3,475,262 | 3.6% |
| Vietnam | 329,610 | 798,209 | 1,029,688 | 1,326,736 | 1,669,237 | 2,100,155 | 2,642,316 | 3,324,438 | 4.9% |
| ASEAN | 3,992,872 | 7,839,244 | 9,810,832 | 12,547,350 | 15,624,177 | 19,461,589 | 24,256,617 | 30,253,996 | 4.6% |

Sectoral GDP is used to project the energy demand in the Type II category in the industrial sector. The sectoral GDP available data are for industry, service, and agriculture. The projection of sectoral GDP by country is shown in Table D.3, Table D.4, and Table D.5.

**Table D.3 Real GDP Industry at 2017 Constant Price (Million USD)**

| Country | 2005 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 | CAGR (2020-2050) |
|---|---|---|---|---|---|---|---|---|---|
| Brunei Darussalam | 19,258 | 16,522 | 18,117 | 20,005 | 22,113 | 24,447 | 27,026 | 29,878 | 2.0% |
| Cambodia | 6,821 | 23,633 | 33,390 | 46,445 | 64,381 | 89,188 | 123,545 | 171,134 | 6.8% |
| Indonesia | 681,421 | 1,199,922 | 1,324,602 | 1,448,389 | 1,580,432 | 1,723,885 | 1,880,266 | 2,050,821 | 1.8% |
| Lao PDR | 4,314 | 18,464 | 25,919 | 35,967 | 49,812 | 68,971 | 95,498 | 132,225 | 6.8% |
| Malaysia | 238,333 | 315,520 | 324,171 | 327,990 | 330,807 | 333,477 | 336,146 | 338,834 | 0.2% |
| Myanmar | 17,757 | 101,935 | 153,369 | 230,667 | 346,912 | 521,740 | 784,675 | 1,180,119 | 8.5% |
| Philippines | 133,600 | 252,835 | 262,492 | 264,603 | 265,051 | 265,214 | 265,340 | 265,461 | 0.2% |
| Singapore | 65,419 | 123,805 | 128,533 | 129,567 | 129,786 | 129,866 | 129,928 | 129,987 | 0.2% |
| Thailand | 280,512 | 379,032 | 366,897 | 350,715 | 334,366 | 318,641 | 303,638 | 289,341 | -0.9% |
| Vietnam | 119,940 | 278,675 | 394,141 | 554,730 | 779,812 | 1,095,974 | 1,540,267 | 2,164,662 | 7.1% |
| ASEAN | 1,567,376 | 2,710,342 | 3,031,630 | 3,409,077 | 3,903,473 | 4,571,404 | 5,486,327 | 6,752,463 | 3.1% |

**Table D.4 Real GDP Service at 2017 Constant Price (Million USD)**

| Country | 2005 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 | CAGR (2020-2050) |
|---|---|---|---|---|---|---|---|---|---|
| Brunei Darussalam | 7,233 | 10,821 | 11,107 | 11,389 | 11,672 | 11,959 | 12,253 | 12,555 | 0.5% |
| Cambodia | 10,892 | 26,523 | 30,375 | 34,155 | 38,253 | 42,814 | 47,915 | 53,623 | 2.4% |
| Indonesia | 562,837 | 1,400,807 | 1,685,575 | 2,009,347 | 2,390,284 | 2,842,375 | 3,379,792 | 4,018,798 | 3.6% |
| Lao PDR | 8,119 | 23,074 | 27,029 | 31,323 | 36,205 | 41,827 | 48,319 | 55,818 | 3.0% |
| Malaysia | 290,368 | 427,066 | 489,852 | 552,757 | 621,466 | 698,269 | 784,493 | 881,357 | 2.4% |
| Myanmar | 27,138 | 113,893 | 169,984 | 253,762 | 378,838 | 565,560 | 844,315 | 1,260,461 | 8.3% |
| Philippines | 237,806 | 529,962 | 594,726 | 652,226 | 711,745 | 776,034 | 846,031 | 922,331 | 1.9% |
| Singapore | 175,565 | 391,256 | 439,069 | 481,520 | 525,461 | 572,924 | 624,600 | 680,930 | 1.9% |
| Thailand | 436,358 | 725,108 | 771,211 | 806,983 | 841,467 | 876,904 | 913,760 | 952,158 | 0.9% |
| Vietnam | 141,283 | 328,236 | 434,299 | 570,958 | 749,564 | 983,799 | 1,291,187 | 1,694,613 | 5.6% |
| ASEAN | 1,897,599 | 3,976,746 | 4,653,226 | 5,404,420 | 6,304,955 | 7,412,465 | 8,792,665 | 10,532,644 | 3.3% |

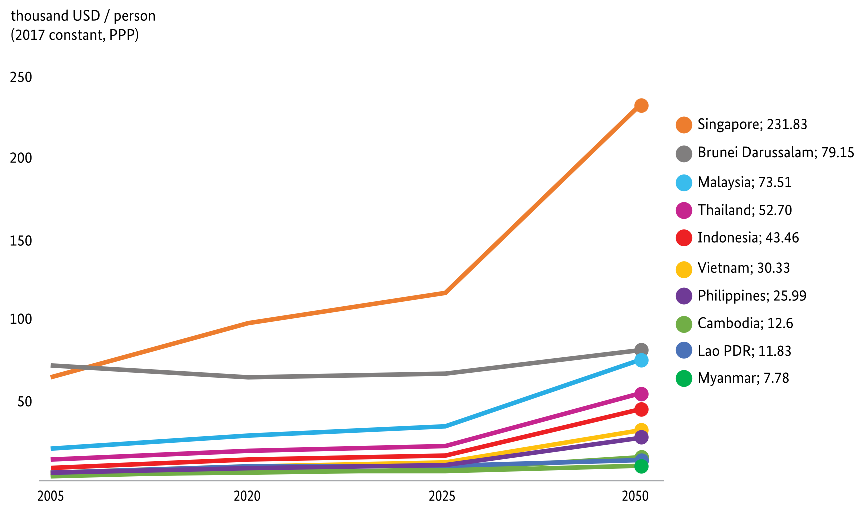
**Table D.5 Real GDP Agriculture at 2017 Constant Price (Million USD)**

| Country | 2005 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 | CAGR (2020-2050) |
|---|---|---|---|---|---|---|---|---|---|
| Brunei Darussalam | 289 | 305 | 341 | 389 | 446 | 511 | 586 | 672 | 2.7% |
| Cambodia | 10,120 | 14,831 | 15,263 | 15,668 | 16,078 | 16,498 | 16,929 | 17,371 | 0.5% |
| Indonesia | 240,998 | 417,006 | 486,726 | 566,573 | 659,118 | 766,696 | 891,820 | 1,037,362 | 3.1% |
| Lao PDR | 5,369 | 8,649 | 9,645 | 10,759 | 12,006 | 13,397 | 14,950 | 16,684 | 2.2% |
| Malaysia | 40,007 | 73,567 | 75,297 | 76,753 | 78,146 | 79,546 | 80,968 | 82,416 | 0.4% |
| Myanmar | 37,276 | 57,481 | 58,484 | 59,686 | 60,941 | 62,225 | 63,536 | 64,874 | 0.4% |
| Philippines | 64,916 | 88,839 | 93,627 | 98,411 | 103,370 | 108,565 | 114,021 | 119,750 | 1.0% |
| Singapore | 123 | 168 | 177 | 186 | 196 | 206 | 216 | 227 | 1.0% |
| Thailand | 88,302 | 102,976 | 106,513 | 109,107 | 111,505 | 113,910 | 116,362 | 118,865 | 0.5% |
| Vietnam | 73,806 | 112,895 | 128,723 | 146,794 | 167,387 | 190,866 | 217,638 | 248,165 | 2.7% |
| ASEAN | 561,205 | 876,717 | 974,797 | 1,084,328 | 1,209,192 | 1,352,421 | 1,517,026 | 1,706,386 | 2.2% |

### D.1.3 GDP per Capita Projection

Based on GDP and population data, the projected trends of GDP per capita show growth through 2050 across all Member States (Figure D.1). The GDP per capita has been used as the dependent variable to forecast the household penetration rate of home appliances (%) and the number of vehicles per capita.

**Figure D.1 GDP per Capita Growth Trends, 2005 - 2050**



### D.1.4 Number of Households and Household Size

The number of households is the population divided by household size. Household size is projected as a function of the urbanisation rate and GDP per capita.

**Table D.6 Number of Households in the ASEAN Member States (millions)**

| Country | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|
| Brunei Darussalam | 0.08 | 0.09 | 0.09 | 0.09 |
| Cambodia | 3.40 | 3.82 | 4.18 | 4.45 |
| Indonesia | 1.30 | 1.47 | 1.61 | 1.70 |
| Lao PDR | 68.70 | 75.15 | 80.03 | 83.11 |
| Malaysia | 8.56 | 9.55 | 10.25 | 10.73 |
| Myanmar | 12.65 | 14.21 | 15.30 | 15.56 |
| Philippines | 22.98 | 25.95 | 28.45 | 30.31 |
| Singapore | 1.37 | 1.47 | 1.50 | 1.48 |
| Thailand | 22.30 | 22.48 | 22.05 | 21.07 |
| Vietnam | 29.74 | 31.82 | 32.93 | 33.49 |
| ASEAN | 171.10 | 186.01 | 196.39 | 201.99 |

**Table D.7 Household Size in the ASEAN Member States (people/household)**

| Country | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|
| Brunei Darussalam | 5.50 | 5.50 | 5.50 | 5.50 |
| Cambodia | 4.91 | 4.91 | 4.91 | 4.91 |
| Indonesia | 5.58 | 5.58 | 5.58 | 5.58 |
| Lao PDR | 3.98 | 3.98 | 3.98 | 3.98 |
| Malaysia | 3.78 | 3.78 | 3.78 | 3.78 |
| Myanmar | 4.30 | 4.11 | 4.00 | 4.00 |
| Philippines | 4.77 | 4.48 | 4.48 | 4.48 |
| Singapore | 4.14 | 4.14 | 4.14 | 4.14 |
| Thailand | 3.13 | 3.13 | 3.13 | 3.13 |
| Vietnam | 3.27 | 3.27 | 3.27 | 3.27 |
| ASEAN | 43.37 | 42.90 | 42.78 | 42.78 |

### D.1.5 Energy Access

**Table D.8 Electrification Rate in the ASEAN Member States, Baseline Scenario (%)**

| Baseline Scenario | | | | | | | |
|---|---|---|---|---|---|---|---|
| Country | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
| Brunei Darussalam | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Cambodia | 81 | 88 | 95 | 98 | 100 | 100 | 100 |
| Indonesia | 95 | 98 | 98 | 98 | 98 | 98 | 98 |
| Lao PDR | 99 | 100 | 100 | 100 | 100 | 100 | 100 |
| Malaysia | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Myanmar | 52 | 56 | 61 | 66 | 71 | 75 | 80 |
| Philippines | 97 | 100 | 100 | 100 | 100 | 100 | 100 |
| Singapore | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Thailand | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Vietnam | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

**Table D.9 Electrification Rate in the ASEAN Member States, ATS (%)**

| ATS | | | | | |
|---|---|---|---|---|---|
| **Country** | **2020** | **2025** | **2030** | **2035** | **2040** |
| Brunei Darussalam | 100 | 100 | 100 | 100 | 100 |
| Cambodia | 81 | 88 | 95 | 98 | 100 |
| Indonesia | 95 | 98 | 100 | 100 | 100 |
| Lao PDR | 99 | 100 | 100 | 100 | 100 |
| Malaysia | 100 | 100 | 100 | 100 | 100 |
| Myanmar | 52 | 60 | 100 | 100 | 100 |
| Philippines | 97 | 100 | 100 | 100 | 100 |
| Singapore | 100 | 100 | 100 | 100 | 100 |
| Thailand | 100 | 100 | 100 | 100 | 100 |
| Vietnam | 100 | 100 | 100 | 100 | 100 |

*Note: ATS, APS, and LCO Scenario have the same value.*

**Table D.10 Clean Cooking Access in the ASEAN Member States, Baseline Scenario (%)**

| Baseline Scenario | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Country** | **2020** | **2025** | **2030** | **2035** | **2040** | **2045** | **2050** | **CAGR (2020-2050)** |
| Brunei Darussalam | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 0.0% |
| Cambodia | 37 | 40 | 43 | 46 | 50 | 53 | 58 | 1.5% |
| Indonesia | 9 | 9 | 10 | 11 | 11 | 12 | 13 | 1.5% |
| Lao PDR | 85 | 91 | 98 | 100 | 100 | 100 | 100 | 0.6% |
| Malaysia | 99 | 100 | 100 | 100 | 100 | 100 | 100 | 0.0% |
| Myanmar | 31 | 34 | 36 | 39 | 42 | 45 | 49 | 1.5% |
| Philippines | 48 | 51 | 53 | 56 | 59 | 63 | 66 | 1.1% |
| Singapore | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 0.0% |
| Thailand | 84 | 89 | 94 | 99 | 100 | 100 | 100 | 0.6% |
| Vietnam | 65 | 70 | 76 | 82 | 88 | 95 | 100 | 1.4% |

**Table D.11 Clean Cooking Access in the ASEAN Member States, ATS (%)**

| ATS | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Country** | **2020** | **2025** | **2030** | **2035** | **2040** | **2045** | **2050** | **CAGR (2020-2050)** |
| Brunei Darussalam | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 0.0% |
| Cambodia | 37 | 43 | 49 | 57 | 66 | 77 | 89 | 3.0% |
| Indonesia | 9 | 10 | 11 | 13 | 15 | 18 | 21 | 3.0% |
| Lao PDR | 85 | 98 | 100 | 100 | 100 | 100 | 100 | 0.6% |
| Malaysia | 99 | 100 | 100 | 100 | 100 | 100 | 100 | 0.0% |
| Myanmar | 31 | 36 | 42 | 49 | 56 | 65 | 76 | 3.0% |
| Philippines | 48 | 51 | 53 | 56 | 59 | 63 | 66 | 1.1% |
| Singapore | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 0.0% |
| Thailand | 84 | 89 | 94 | 99 | 100 | 100 | 100 | 0.6% |
| Vietnam | 65 | 72 | 78 | 86 | 94 | 100 | 100 | 1.4% |

**Table D.12 Clean Cooking Access in the ASEAN Member States, APS (%)**

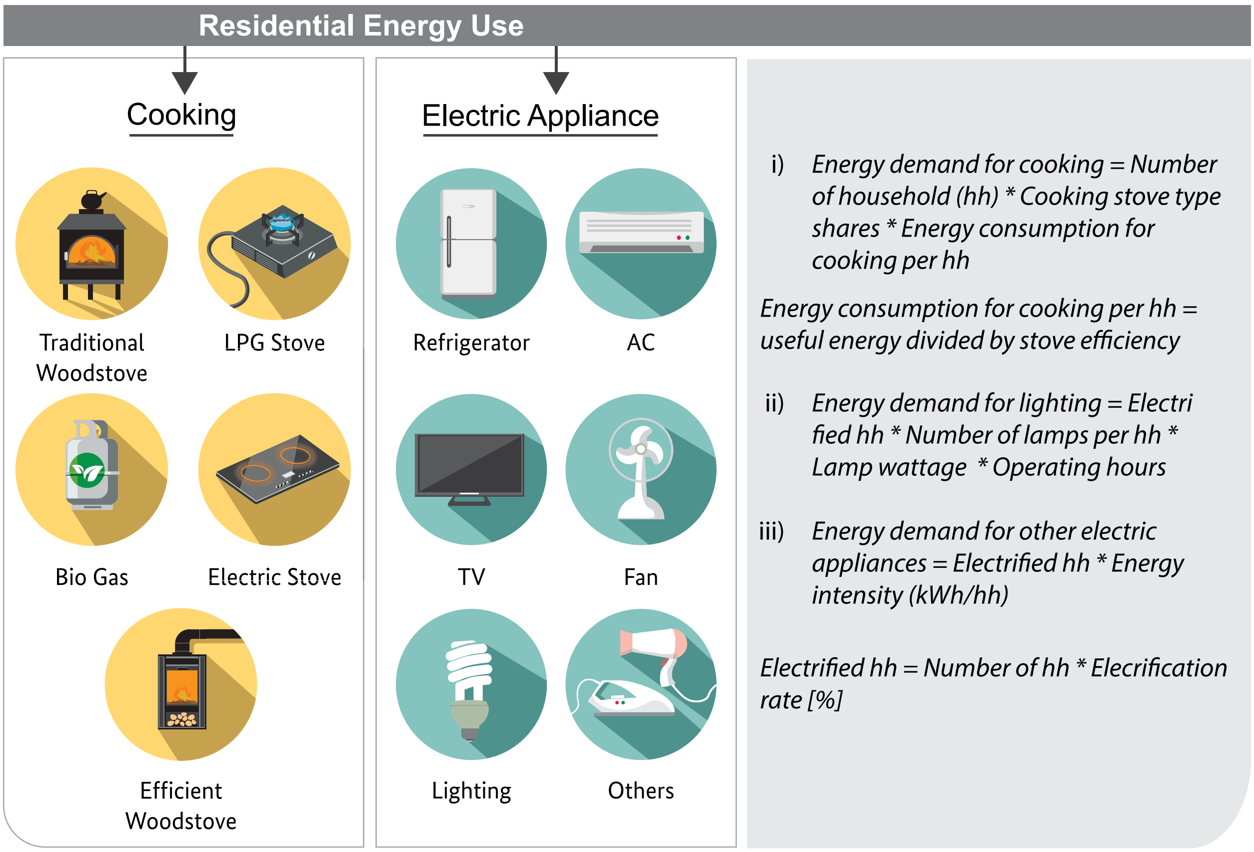
| APS | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Country** | **2020** | **2025** | **2030** | **2035** | **2040** | **2045** | **2050** | **CAGR (2020-2050)** |
| Brunei Darussalam | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 0.0% |
| Cambodia | 37 | 47 | 60 | 77 | 98 | 100 | 100 | 3.4% |
| Indonesia | 9 | 11 | 14 | 18 | 23 | 29 | 37 | 5.0% |
| Lao PDR | 85 | 100 | 100 | 100 | 100 | 100 | 100 | 0.6% |
| Malaysia | 99 | 100 | 100 | 100 | 100 | 100 | 100 | 0.0% |
| Myanmar | 31 | 40 | 51 | 65 | 83 | 100 | 100 | 4.0% |
| Philippines | 48 | 51 | 53 | 56 | 59 | 63 | 66 | 1.1% |
| Singapore | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 0.0% |
| Thailand | 84 | 89 | 94 | 99 | 100 | 100 | 100 | 0.6% |
| Vietnam | 65 | 72 | 78 | 86 | 94 | 100 | 100 | 1.4% |

*Note: APS, and LCO Scenario have the same value.*

## D.2 Demand Sector Modelling

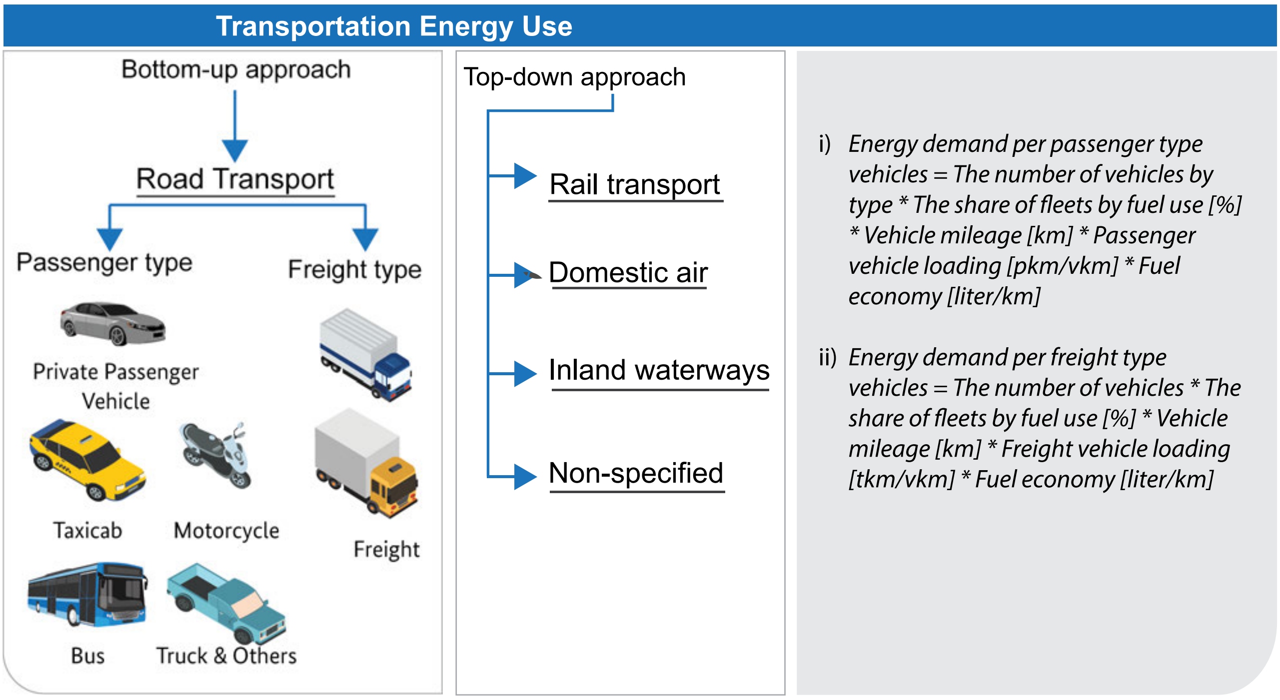
### D.2.1 Residential

For the residential sector, the structure was broken down into cooking, lighting and several home appliances: air conditioning, washing machines, clothes dryers, refrigerators, kettles, water heating, televisions (TV), computers, irons, fans, and other appliances. The energy consumption of each technology was calculated with an approach similar to AEO6, as shown in the following figures.



### D.2.2 Transportation

The transportation sector projections were built with a combination of top-down and bottom-up approaches. The transport sector was disaggregated into sub-sectoral levels. The sectoral energy consumption was disaggregated into the type of transport (road, rail, domestic air, inland waterways, and non-specified transport).



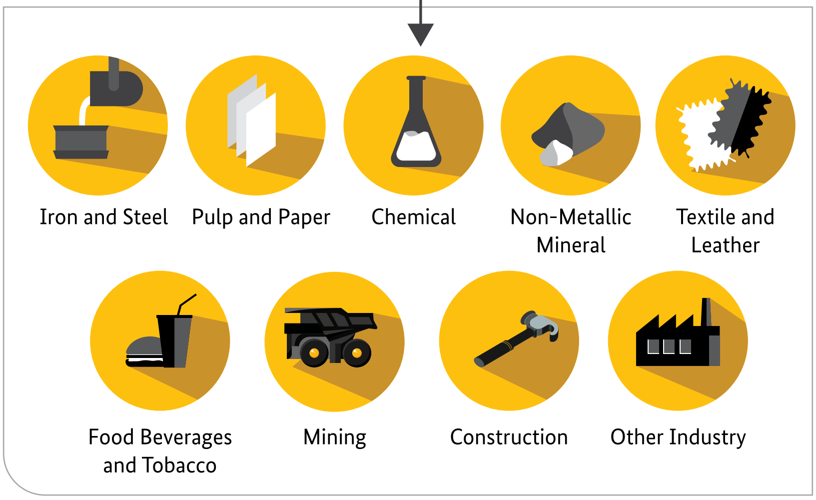

Road transport was then broken down into passenger vehicles consisting of private passenger vehicles, buses, motorcycles, trucks and others, and taxis; and freight vehicles. The number of registered vehicles by type, the share of fleets by fuel use, travel distance and fuel economy were collected from various national reports, such as national transportation roadmaps, the ASEAN-Japan Transport Partnership, and Ministry of Transportation sources. Apart from road transportation, the other sub-sector transportation demand was built using the top-down approach due to the limited availability of broken-down data.

### D.2.3 Industry

The industrial sector's bottom-up approach was an improvement in the current edition, wherein the sector was disaggregated into two types of sub-sectors. Type I includes Iron and Steel, Pulp and Paper, Chemical, Non-Metallic Mineral, and Textile and Leather. Type II includes Food, Beverages and Tobacco (FBT), Mining, Construction, Other Industry and Non-specified. Other Industry is defined as sectors consisting of smaller sectors, such as machinery and woodworkings. Whereas, Non-Specified demands are difficult to allocate to a single sector as indicated in country-submitted energy balances.

In the Type I category, historical production, which served as a benchmark for projection years, was calculated from the energy consumption of a specific sector divided by the average energy intensity of the sector per AMS, where data is available. In the Type II category, energy consumption was estimated based on the gross historical value added to certain sub-sector as these industries are difficult to quantify based on a physical unit. Most countries in the region lack a share of specific sub-subsectors in the total industrial consumption, energy intensity and fuel usage. Hence, regional data still shows a large percentage of Non-Specified despite implementing estimates of consumption for expected sub-sectors, such as FBT and Construction.

**Industry Energy Use**



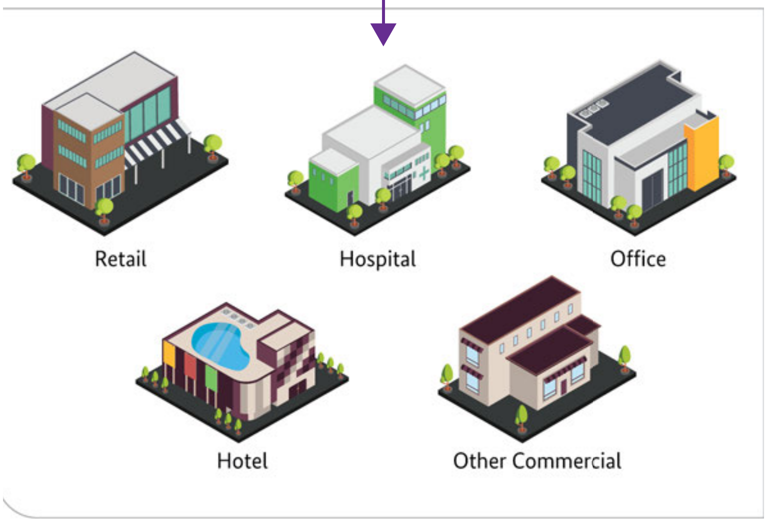

i) *Energy demand of Type I category = Production [Tonne] * Energy intensity [Mtoe/Tonne]*

ii) *Energy demand of Type II category = Gross value added (GVA) [USD$]*Energy consumption per GVA [Mtoe/US$]*

### D.2.4 Commercial

Similar to the industrial sector, the commercial sector was also broken down into sub-sectoral facilities: Retail, Hospital, Office, Hotel and other Commercial spaces, as presented in the following figure.

**Commercial Energy Use**



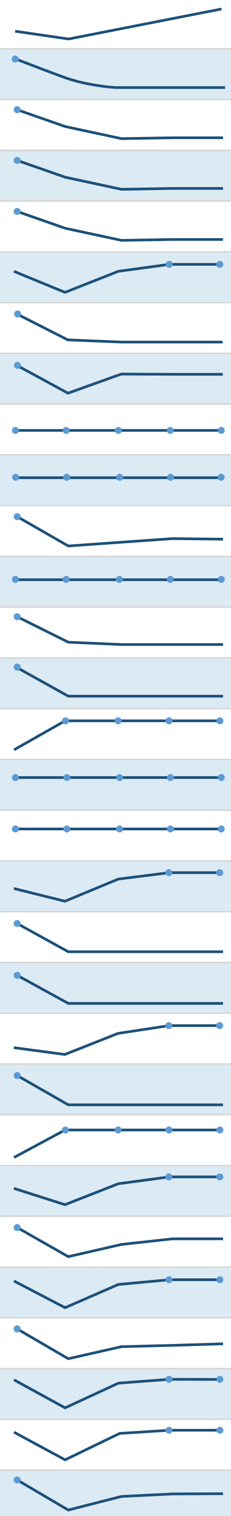

i) *Energy demand of commercial facilities = Share of sector [%]* Total gross floor area [sq.m.]* Energy intensity [Mtoe/sq.m.]*

The historical estimated gross floor area occupied per commercial space, which serves as a benchmark for projection years, was calculated from the total energy consumption of the commercial sector multiplied by the estimated share of a specific commercial space from literature reviews and expert judgement. If data is available, the estimated energy consumption per facility was then divided by the average energy intensity varying per AMS.

## D.3 Cost Data

Fuel cost is an integral input to optimisation modelling. Fuel cost projection considered the historical trend, the impact of the pandemic and recent global events. A summary of fuel costs considered in the model is presented in Table D.13.

**Table D.13 Fuel Cost in 2020 USD**

| Fuel Type | 2010 | 2020 | 2030 | 2040 | 2050 | Trendline |
|---|---|---|---|---|---|---|
| Nuclear | 5.5 | 3.8 | 7.2 | 10.8 | 14.4 |  |
| Coal Anthracite | 15.0 | 9.6 | 6.9 | 6.9 | 6.9 | |
| Coal Bituminous | 11.2 | 7.4 | 5.3 | 5.3 | 5.3 | |
| Coal Sub bituminous | 17.4 | 11.5 | 8.3 | 8.3 | 8.3 | |
| Coal Lignite | 16.1 | 10.7 | 7.7 | 7.7 | 7.7 | |
| Crude Oil | 53.0 | 27.6 | 52.4 | 61.9 | 61.9 | |
| Natural Gas | 42.5 | 28.4 | 27.9 | 27.9 | 27.9 | |
| Natural Gas Liquids | 49.3 | 20.6 | 39.1 | 39.1 | 39.1 | |
| Bagasse | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | |
| Biomass | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | |
| LPG | 9.6 | 3.5 | 4.3 | 4.8 | 4.8 | |
| Hard Coal Briquettes | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | |
| Metalurgical Coke | 6.1 | 3.1 | 2.8 | 2.8 | 2.8 | |
| CNG | 17.5 | 14.5 | 14.5 | 14.5 | 14.5 | |
| Ethanol | 16.4 | 18.4 | 18.4 | 18.4 | 18.4 | |
| Biodiesel | 17.9 | 17.9 | 17.9 | 17.9 | 17.9 | |
| Biogas | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | |
| Petroleum Coke | 2.0 | 1.3 | 2.5 | 2.9 | 2.9 | |
| LNG | 17.5 | 14.5 | 14.5 | 14.5 | 14.5 | |
| Lubricants | 12.2 | 9.4 | 9.4 | 9.4 | 9.4 | |
| Bitumen | 10.0 | 7.7 | 14.6 | 16.6 | 16.6 | |
| Naphtha | 12.9 | 9.9 | 9.9 | 9.9 | 9.9 | |
| Charcoal | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | |
| Avgas | 28.1 | 18.7 | 32.1 | 36.1 | 36.1 | |
| Jet Kerosene | 18.9 | 11.2 | 14.7 | 15.5 | 15.5 | |
| Gasoline | 19.9 | 10.9 | 19.4 | 21.0 | 21.0 | |
| Diesel | 17.8 | 10.2 | 13.3 | 14.1 | 14.1 | |
| Residual Fuel Oil | 14.2 | 7.6 | 13.4 | 14.5 | 14.5 | |
| Oil | 15.5 | 8.2 | 14.6 | 15.8 | 15.8 | |
| Kerosene | 18.5 | 10.6 | 13.9 | 14.7 | 14.7 | |

*Source: EIA, country submissions, AIMS III.*

The LCO Scenario also considered the deployment of BESS and APG made using the NEMO optimising framework. The model incorporated two battery types: lithium batteries and pump hydrostorage, which assumed respective 2 and 8 full load hours, and daily and seasonal storage carryover ability. Transmission modelling of the APG was built upon the results of the AIMS III and considers existing, under construction and proposed interconnection projects – along with their capacity and investment costs. The transmission lines that were considered in the model are listed in Table D.14.

**Table D.14 ASEAN Interconnection Line Capacity and Cost Data**

| Connection | Construction Capacity (MW) | | | Expansion Cost ($/kW) |
|---|---|---|---|---|
| | 2020 | Additional / Ongoing | Future (Max. Flow) | |
| Peninsular Malaysia – Singapore | 525 | 525 | | 300 |
| Thailand – Peninsular Malaysia | 300 | | 400 | 300 |
| Peninsular Malaysia – Sumatra | | | 600 | 225 |
| Sarawak – Kalimantan | 230 | | | 300 |
| Philippines – Sabah | | | 500 | 1,350 |
| Sarawak – Brunei Darussalam | | 100 | 300 | 300 |
| Thailand – Lao PDR | 5,427 | | 1,310 | 300 |
| Lao PDR – Vietnam | 538 | | 4,462 | 300 |
| Thailand – Myanmar | | | 1,104 | 300 |
| Vietnam – Cambodia | 200 | | | 300 |
| Lao PDR – Cambodia | 200 | | | 300 |
| Thailand – Cambodia | 230 | | 2,200 | 300 |

*Source: HAPUA and AIMS III.*

The social cost of energy analysis estimates the impact of fossil fuel reliance in the energy supply on the environment and society. Externality costs are often not properly accounted for in economic decision-making processes due to the complexity of the boundaries to which they are applied. Externalities considered in the AEO include air, water, and land pollution associated with waste and emissions from end-use and power generation that degrades human health and ultimately lowers the welfare, social capital, and cultural assets of a nation.

In the model, emission factors associated with specific sectors, processes and fuels were incorporated as a multiplier to estimate emissions and other by-products generated by utilising a given technology or facility. The social cost of pollutants serves as a factor multiplied by the total emissions of an effect in each year of each scenario. The goal is to yield an overall externality cost for each pollutant. Values used in the model are presented in Table D.15.

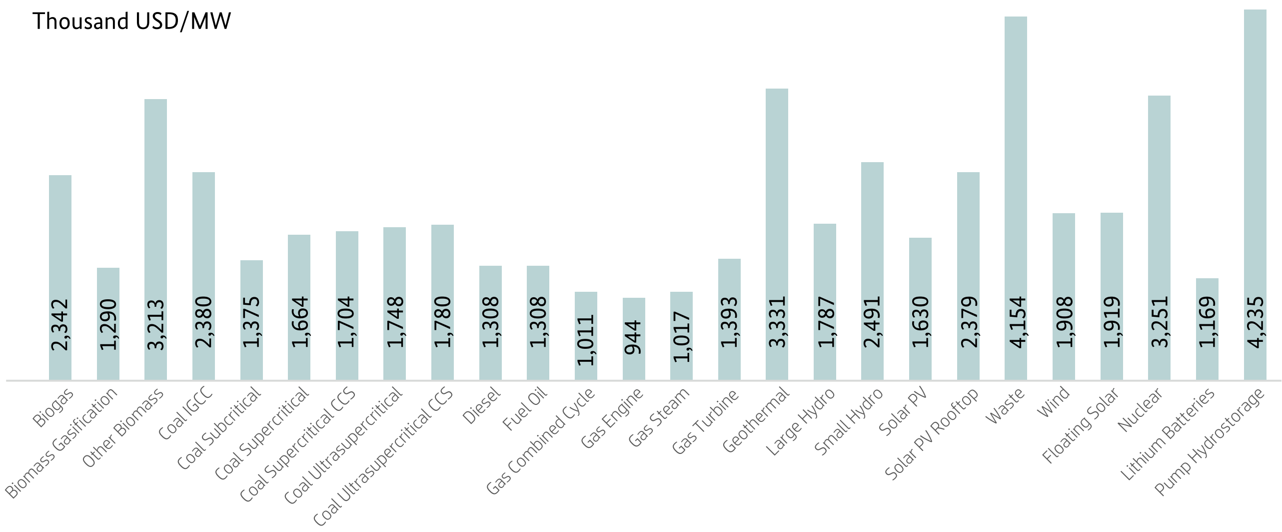
**Table D.15 Social Cost of Pollutants**

| Emission Effect | Cost (USD) | Unit |
|---|---|---|
| Carbon Dioxide | 89.2 | Metric tonne |
| Methane | 4.9 | Kilogram |
| Nitrous Oxide | 39.3 | Kilogram |
| Black Carbon | 276.6 | Kilogram |
| Sulfur Dioxide | 44.6 | Kilogram |
| Carbon Monoxide | 0.7 | Kilogram |
| Organic Carbon | 72.2 | Kilogram |
| Nitrogen Oxides | 71.1 | Kilogram |
| Ammonia | 26.5 | Kilogram |

*Source: Stockholm Environment Institute (SEI).*

Capital costs considered in the model are presented in the following figure.

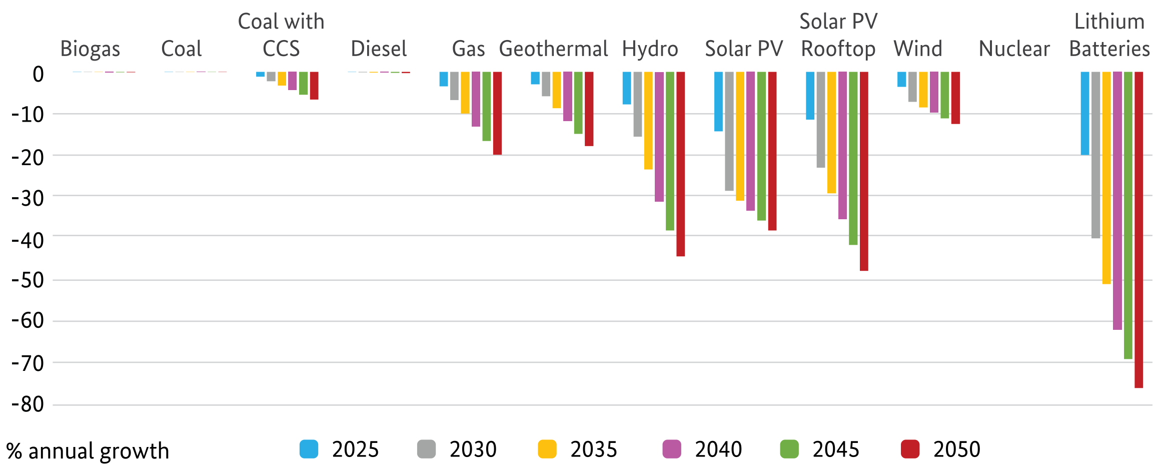
**Figure D.2 Average Capital Costs in ASEAN**




*Source: Enerdata.*

The projection of capital cost reductions in renewable and emerging technologies are presented in the following figure.

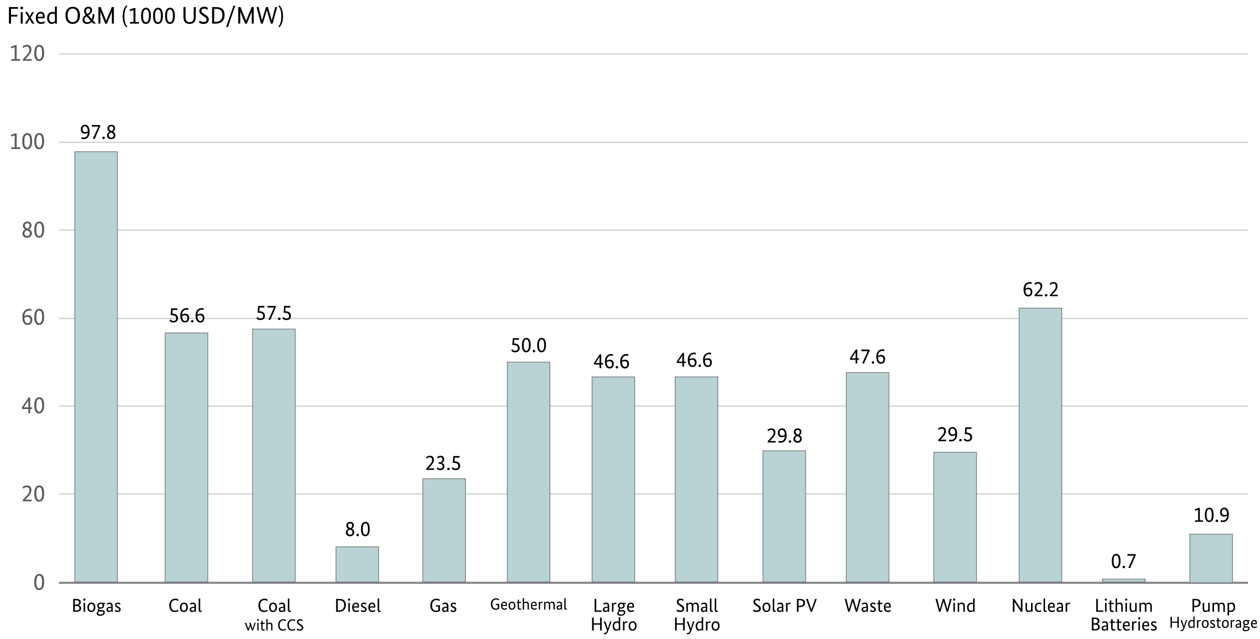
**Figure D.3 Capital Costs Projections**




*Source: Danish Energy Agency, IRENA, ACE.*

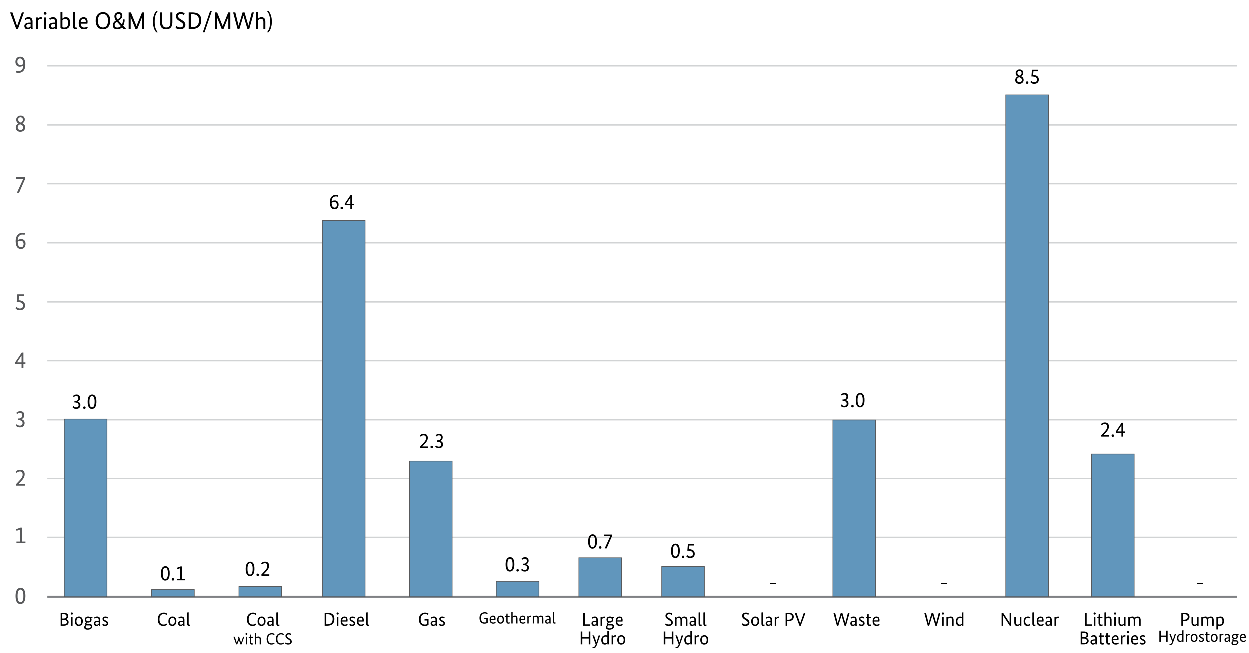
Operating and maintenance (O&M) costs considered in the model are presented in the following figures.

**Figure D.4 Fixed Operational Costs in ASEAN (1,000 USD/MW)**




*Source: Handayani et al., 2022* [87].

**Figure D.5 Variable Operational Costs in ASEAN (USD/MWh)**




*Source: Handayani et al., 2022* [87].

## D.4 Secondary Analysis

### D.4.1 Renewable Job Creation

Job analysis projects direct employment in the RE sector from four technologies: Utility-Scale Solar PV, Onshore Wind, Hydropower, and Geothermal. The analysis is limited to three different job types: manufacturing, construction and installation (C&I), as well as O&M. Some examples of these job types include manufacturing wind turbine blades, solar PV installation, and geothermal maintenance. The model is built by calculating the installed capacity against four factors, given in Figure D.6.

**Figure D.6 Formulas to Calculate the Employment**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Manufacturing** | Added Capacity | × | Employment Factor | × | Decline Factor (CAPEX) | × | Local Manufacturing | × | Regional Factor |
| **Construction** | Added Capacity | × | Employment Factor | × | Decline Factor (CAPEX) | × | Regional Factor | | |
| **Operation & Maintenance** | Cumulative Capacity | × | Employment Factor | × | Decline Factor (CAPEX) | × | Regional Factor | | |

*Note: Adopted from Merdekawati et al., 2022* [106].

The four factors considered are:

**Employment Factor (EF)** – number of jobs per unit of installed capacity divided into manufacturing, C&I and O&M. Manufacturing and C&I represent the number of jobs to generate a unit of power capacity over the plant's lifetime, particularly in the start-up phase. Manufacturing could include imported shares as limited production occurs, whilst C&I and O&M are assumed to absorb all local workforces. Duration of construction is also considered based on each technology, with solar having a one-year period whilst the others are constructed over two years. O&M is interpreted as jobs to run operational activities and maintain standardised conditions for a power plant to generate capacity for a relatively long period. The unit used for O&M is jobs per capacity of power generation. The factors were derived from Rutovitz et al. (2015) [107].

**Table D.16 Employment Factor**

| EF | Solar | Wind | Hydro | Geothermal |
|---|---|---|---|---|
| Manufacturing | 6.7 | 4.7 | 3.5 | 3.9 |
| C&I | 13 | 3.2 | 7.4 | 6.8 |
| O&M | 0.7 | 0.3 | 0.2 | 0.4 |

**Decline Factor (DF)** – gradual deceleration of job creation due to increasing experience and volume of the energy industry, leading to the maturation of technologies over time. Two learning factors are adopted to reflect the decline: Capital Expenditures (Capex) used in Manufacturing and C&I, and Operational Expenditures (Opex) used in O&M. The YoY factors were compiled and interpolated from Ram et al. (2019) [108], based on the cost assumptions developed by Lappeenranta-Lahti University of Technology (LUT) for the Energy System Transition model (Table D.17).

**Table D.17 Declining Factor**

| | 2020 | | 2025 | | 2030 | | 2035 | | 2040 | | 2045 | | 2050 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DF | Capex | Opex | Capex | Opex | Capex | Opex | Capex | Opex | Capex | Opex | Capex | Opex | Capex | Opex |
| Solar | 0.445 | 0.347 | 0.554 | 0.347 | 0.627 | 0.538 | 0.677 | 0.595 | 0.713 | 0.642 | 0.742 | 0.682 | 0.764 | 0.711 |
| Wind | 0.080 | 0.080 | 0.152 | 0.160 | 0.200 | 0.200 | 0.228 | 0.240 | 0.248 | 0.240 | 0.268 | 0.280 | 0.280 | 0.280 |
| Hydro | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Geo-thermal | 0.053 | 0.000 | 0.101 | 0.000 | 0.149 | 0.000 | 0.191 | 0.000 | 0.234 | 0.000 | 0.273 | 0.000 | 0.312 | 0.000 |

**Regionality Factor (RF)** or regional employment multiplier – lower average labour intensity and cost to produce a unit of output (productivity) associated with lower GDP per capita than in OECD countries. The factor is derived from Ram et al. (2019) [108]. The interpolated RF values for 2020-2050 can be found in Table D.18.

**Table D.18 Regional Factor**

| | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|---|
| RF | 2.2 | 1.93 | 1.77 | 1.63 | 1.58 | 1.52 | 1.47 |

**Local Manufacturing Factor** – renewable and storage technologies are still growing in the region as certain import proportions contribute to the market. Consequently, the factor will eliminate employment not absorbed by local labours in an optimistic scenario of 90% for local manufacturing. The value is adopted from Rutovitz, et al. (2015) [107].

### D.4.2 Land-Use for Biofuel

The production of biofuel requires crops as its feedstock. To understand the energy and land use nexus, the model calculates the required land use to produce crops, driven by the demand for biofuel. Two types of biofuels are commonly used and modelled: bioethanol and biodiesel. These biofuels are generally blended with gasoline and diesel, respectively.

The land requirements (in Ha) are estimated based on the specified "environmental loading" (Ha per TJ of energy produced) and biofuel production, which is driven by the demand for biofuels. It must be noted that the land requirements are estimated assuming that there is no export-import of biofuel, meaning only domestically produced biofuels that fully satisfy domestic demand. Environmental loading is derived from region-specific crop yields (kg of crop/Ha), biofuel production process yield (litre of biofuel produced per tonne of the crop), and energy content of the biofuel (GJ per litre of biofuel). An alternative equation would require energy density (tonnes per litre of biofuel) if the energy content is denoted as per mass (GJ per tonne of biofuel).

$$\text{Environmental Loading}\left[\frac{Ha}{GJ}\right] = \frac{1}{\left\{ A' \left[\frac{tonne_{Crop}}{Ha}\right] \times B' \left[\frac{L_{biofuel}}{tonne_{Crop}}\right] \times C' \left[\frac{GJ_{biofuel}}{L_{biofuel}}\right] \right\}}$$

A′ : *Crop yield*
B′ : *Biofuel production yield*
C′ : *Biofuel energy content*

The biofuel parameters are based on the FAO report [108]. For bioethanol, the global value is utilised for both the crop yield and biofuel production yield, where sugarcane is selected as the crop. As for biodiesel, specific values are used for Indonesia and Malaysia, which were reported in the study (Table D.19). Oil palm is chosen as the crop. For other Member States, the average value of Indonesia and Malaysia are used. Biofuel energy content uses the LEAP default value.

**Table D.19 Biofuel Parameters**

| Country | Bioethanol | | | Biodiesel | | |
|---|---|---|---|---|---|---|
| | Crop Yield (Sugar Cane) | Biofuel Production Yield | Biofuel Energy Content | Crop Yield (Oil Palm) | Biofuel Production Yield | Biofuel Energy Content |
| Indonesia | 65 | 70 | 0.0211 | 17.8 | 230 | 0.0376 |
| Malaysia | 65 | 70 | 0.0211 | 20.6 | 230 | 0.0376 |
| Other AMS | 65 | 70 | 0.0211 | 19.2 | 230 | 0.0376 |

### D.4.3 GHG Emissions

***Decomposition Analysis***

Decomposition analysis was conducted based on the Kaya identity equation. The Kaya identity is a useful equation for quantifying the total emissions of the GHG carbon dioxide ($CO_2$) from human sources. The simple equation is based on readily available information and can be used to quantify current emissions and how the relevant factors need to change relative to each other over time to reach a target level of $CO_2$ emissions in the future. The identity has been used, and continues to be important, in the discussion of global climate policy decisions. The Kaya identity states the total emission level of $CO_2$ as the product of four factors:

$$F = P \times \frac{G}{P} \times \frac{E}{G} \times \frac{F}{E}$$

Where :

F = Global $CO_2$ emissions from human sources

P = Global population

G = Global Gross Domestic Product (GDP)

E = Energy consumption

***Emission Factors***

The emission factors used to project sectoral energy demand and electricity generation were collected from the AEO6 [1].

# APPENDIX E - DEFINITIONS

**Clean Cooking:** The use of electricity, liquefied petroleum gas (LPG), natural gas, biogas, solar, and alcohol fuels for cooking. Charcoal, coal, crop waste, dung, kerosene, and wood used for cooking are not considered clean fuels.

**Electrification Rate:** The share of households with access to electricity in a country

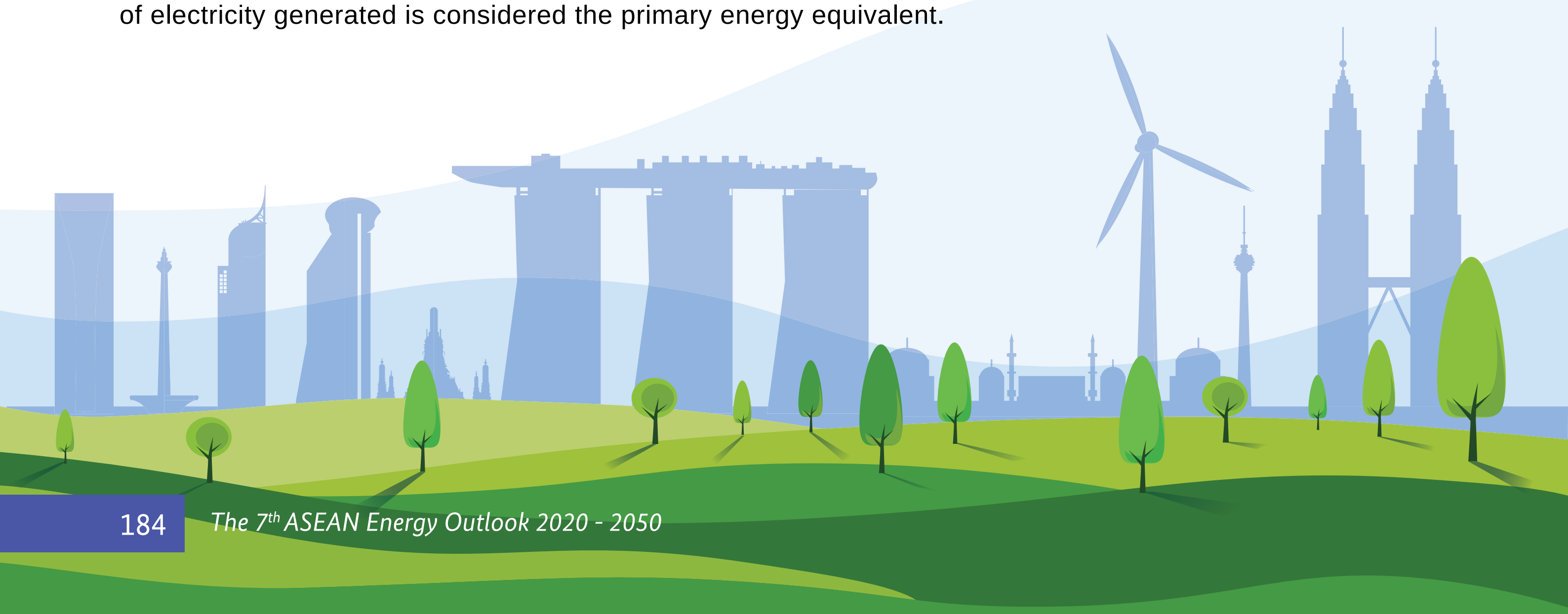
**Energy Dependency Rate:** The proportion of energy that an economy must import. It is defined as net energy imports divided by gross available energy, expressed as a percentage. A negative dependency rate indicates a net exporter of energy, while a dependency rate in excess of 100% indicates that energy products have been stocked. It can be defined for total of all products, as well as for individual fuels (for example, crude oil and natural gas).

**Energy Intensity (EI):** The ratio of TPES to GDP, which can be considered an approximation of the energy efficiency of a country's economy and shows how much energy is needed to produce a unit of GDP. For APAEC's EI target calculation, the annual GDP is converted into a 2017 constant price PPP, adjusting the effects of inflation and eliminating price level differences across countries created by fluctuations in currency exchange rates.

**Renewable Energy (RE):** Includes bioenergy (bagasse, biofuel, biogas, biomass, and waste), hydro all scale, geothermal, solar, and wind. It is further categorised as modern and traditional RE. Traditional RE refers to the use of solid biomass in the residential sector, typically for cooking or heating. Uses of RE in other end-use sectors and electricity generation are considered modern RE. Traditional RE is not considered when calculating the share of RE in TPES for purposes of meeting the APAEC target.

**Total Final Energy Consumption (TFEC):** The sum of energy consumption by end-use sectors, excluding non-energy use and international transportation. The end-use sectors include agriculture, commercial, industrial, residential, and transportation.

**Total Primary Energy Supply (TPES):** The sum of energy production and imports, subtracting exports. It includes non-energy uses and stock changes but excludes international transportation. In the projection years, energy supply is the sum of energy use inputs to transformation and energy demand, after accounting for the balance of energy exports and imports. There are differences in calculating primary energy supply from the electricity generation process. For fossil fuel, combustible RE (bagasse, biomass, and waste), and geothermal, the feedstock is the primary supply, calculated by dividing the generated electricity by the efficiency of the power plant. For non-combustible RE (hydro, solar, wind), the amount of electricity generated is considered the primary energy equivalent.



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