THE 6TH ASEAN ENERGY OUTLOOK

2017-2040

ASEAN CENTRE FOR ENERGY
ACE

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For Sustainable
Energy

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About ACE

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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.

One of ACE's cooperations is 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 aims to strengthen ACE in its role as a regional centre of excellence for sustainable energy. ACE is grateful to AGEP for its support in the development of AEO6, which builds on the success of the two previous editions, AEO4 and AEO5, also produced with AGEP support.

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Forewords

We are pleased to present the 6th ASEAN Energy Outlook (AEO6), one of the flagship publications of the ASEAN Member States through the ASEAN Centre for Energy (ACE) with support from the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH through the ASEAN-German Energy Programme (AGEP).

AEO6 reflects the ASEAN Member States' desire to understand the current energy landscape and explore different opportunities and possibilities. The COVID-19 pandemic has impacted on the energy sector and undermined various efforts. The complexity of the situation is further heightened by the need to achieve multiple policy aims at once, on energy and other priorities. The energy policy choices made by each AMS will not only determine the sustainability of these countries' economies, but also have implications for the region and the world. As a catalyst for regional energy cooperation, ACE has developed this Outlook to provide a comprehensive reference on energy across ASEAN.

This 6th edition is also special, as it complements and supplements the outcome-based strategies of the ASEAN Plan of Action for Energy Cooperation (APAEC) 2016–2025, Phase II: 2021–2025, which is being launched at the 38th ASEAN Ministers on Energy Meeting (AMEM) in November 2020. The findings can also contribute to concrete action plans for various ASEAN Specialised Energy Bodies and Sub-Sector Networks in their respective Programme Areas under APAEC.

AEO6 includes one more scenario than AEO5: In addition to the Baseline Scenario, the AMS Targets Scenario (based on national targets) and the APAEC Targets Scenario (based on regional targets), we include a new SDG Scenario reflecting the actions needed to achieve Sustainable Development Goal 7, "clean and affordable energy". The scenarios consider every single existing and upcoming policy of every AMS, global commitments under the Paris Agreement (in nationally determined contributions), and the impact of COVID-19 on the energy landscape. The analysis also goes beyond energy to consider socio-economic issues, aiming to provide a comprehensive reference for AMS.

AEO6 is an important step forward, produced by ASEAN experts for the ASEAN people. We hope this report will be a valuable resource to generate more collaborative partnerships to advance the ASEAN energy sector.

ASEAN has made significant progress in achieving a 20% energy intensity reduction by 2020 from 2005 levels, and 30% by 2025. AEO6 lays out several ways to adopt stringent energy efficiency measures and emission standards and accelerate progress despite the economic slowdown caused by the pandemic. Similarly, AEO6 identifies ways to help ASEAN achieve its goal of 23% of renewable energy in its energy mix by 2025, showing significant potential for solar PV growth, among others, and identifying key needs, in line with the ongoing ASEAN Interconnection Masterplan Study (AIMS) III.

As ASEAN's official energy think tank, ACE is continuously building its data and modelling capacity. I highly appreciate our in-house modelling team and all the Working Group Members from each AMS who worked hard to develop this report, and the support from all of our Dialogue Partners and International Organisations. AEO6 is an important step forward, produced by ASEAN experts for the ASEAN people. We hope this report will be a valuable resource to generate more collaborative partnerships to advance the ASEAN energy sector.

Dr Nuki Agya Utama
Executive Director, ACE

Deutsche Gesellschaft
für Internationale
Zusammenarbeit (GIZ) GmbH

The Association of Southeast Asian Nations (ASEAN) comprises 10 countries that are home to over 643 million people and have a combined GDP of more than USD 7 trillion. The region with its shift from agricultural sector to industrialisation, is becoming one of the global growth drivers and important economic force in the world. Due to its rapid economic growth, it is projected that ASEAN's regional GDP will reach USD 20 trillion by 2040, with annual average growth of 5% even after accounting for the impact of COVID-19. This will lead to a significant rise in energy demand.

Although ASEAN still depends heavily on fossil fuels for energy, the ASEAN Member States (AMS) have made a strong commitment towards sustainable energy. The 38th ASEAN Ministers of Energy Meeting (AMEM) approve Phase II of the ASEAN Plan of Action for Energy Cooperation (APAEC) for 2020–2025, which includes pathways for ASEAN to achieve two major targets by 2025: a 23% share of renewable energy in the total primary energy supply by increasing its share in power capacity to 35%, and a 32% reduction in energy intensity from 2005 levels.

To support the AMS in pursuing their sustainable energy ambitions, the ASEAN-German Energy Programme (AGEP) – a jointly implemented project by the ASEAN Centre for Energy (ACE) and Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH on behalf of the German Federal Ministry for Economic Cooperation and Development (BMZ) – has supported ACE in developing the 6th ASEAN Energy Outlook (AEO6).

ASEAN Member States recognise that strong renewable energy and energy efficiency measures are pivotal solutions to reduce dependency on fossil fuels, strengthen energy security and lower GHG emissions.

AEO6 addresses key aspects of energy trends, policies, socio-economic development, and environmental analysis related to energy in the region up to 2040. It aims to provide a thorough and cohesive perspective on the energy supply and demand projections at the regional level, while also providing insights on how to achieve the targets set in the APAEC. If historical trends were to continue, energy demand in ASEAN would be more than double by 2040 and be met mainly by fossil fuels, requiring significant imports and increasing greenhouse gas (GHG) emissions. ASEAN Member States recognise that strong renewable energy (RE) and energy efficiency (EE) measures are pivotal solutions to reduce dependency on fossil fuels, strengthen energy security and lower GHG emissions. In order to reach APAEC targets, AEO6 recommends Member States to have stronger policies and increase their efforts for particularly RE and EE development beyond the existing national targets.

Following the fourth and fifth ASEAN Energy Outlook, AEO6 is the third edition jointly published by ACE and GIZ, with assistance from the Stockholm Environment Institute (SEI) for this edition. This publication required major joint research and development effort by various energy actors in the region. Therefore, we would like to thank the ASEAN Centre for Energy (ACE), ASEAN Member States, as well SEI, for the fruitful collaboration and continuous support in this work.

We trust that the 6th ASEAN Energy Outlook will be of benefit to policy-makers and all stakeholders in ASEAN in the development of policy frameworks to ensure secure, accessible, affordable and sustainable energy in each country and across the region.

Sergey Makarov
Principal Advisor for AGEP, GIZ

Abbreviations

ACCEPT	ASEAN Climate Change and Energy Project
ACE	ASEAN Centre for Energy
AC	Air Conditioner
ADB	Asian Development Bank
AEBF	ASEAN Energy Business Forum
AEDP	Alternative Energy Development Plan
AEDS	ASEAN Energy Database System
AEO	ASEAN Energy Outlook
AFOC	ASEAN Forum on Coal
AGEP	ASEAN-German Energy Programme
AIMS	ASEAN Interconnection Masterplan Study
AMEM	ASEAN Ministers on Energy Meeting
AMS	ASEAN Member States
APAEC	ASEAN Plan of Action for Energy Cooperation
APERC	Asia Pacific Energy Research Centre
APG	ASEAN Power Grid
APGCC	ASEAN Power Grid Consultative Committee
APS	APAEC Targets Scenario
ASCOPE	ASEAN Council on Petroleum
ATS	AMS Targets Scenario
BEV	Battery Electric Vehicle
BGR	Bundesanstalt für Geowissenschaften und Rohstoffe / Federal Institute for Geosciences and Natural Resources
BMZ	German Federal Ministry for Economic Cooperation and Development
BP	British Petroleum
BPS	*Badan Pusat Statistik*
BUR	Biennial Update Report
CAGR	Compound Annual Growth Rate
CAPM	Central American Power Market
CCS	Carbon Capture and Storage
CCUS	Carbon Capture Utilisation and Storage
CF	Capacity Factor
CH_4	Methane
CO_2	Carbon Dioxide
COP	Coefficient of Performance
CSPF	Cooling Seasonal Performance Factor
DOE	Department of Energy
DOS	Department of Statistics
DP	Dialogue Partner
EE	Energy Efficiency
EE&C-SSN	Energy Efficiency and Conservation Sub-sector Network

EI	Energy Intensity
EEP	Energy Efficiency Plan
EER	Energy Efficiency Ratio
EGAT	Electricity Generating Authority of Thailand
ENCON	Energy Conservation and Promotion
EOR	Enhanced Oil Recovery
ESCO	Energy Service Company
EV	Electric Vehicle
FSD	Fixed-speed-drive
Fraunhofer ISI	Fraunhofer Institute for Systems and Innovation Research
GDP	Gross Domestic Product
GHG	Greenhouse gas
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GMS	Greater Mekong Subregion
GNI	Gross National Income
GWP	Global Warming Potential
HAPUA	Heads of ASEAN Power Utilities/Authorities
HELE	High-Efficiency, Low-Emissions
ICA	International Copper Association
ICE	Internal Combustion Engine
ICS	Improved Biomass Cookstoves
IEA	International Energy Agency
IGCC	Integrated Gasification Combined Cycle
IIASA	International Institute for Applied Systems Analysis
IIEC	International Institute for Energy Conservation
IO	International Organisation
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
LCOE	Levelised Cost of Energy
LDV	Light Duty Vehicle
LEAP	Low Emissions Analysis Platform
LED	Light-emitting Diode
LPG	Liquefied Petroleum Gas
LRC	Low-rank coal
LSB	Lao Statistic Bureau
LTMS-PIP	Lao PDR-Thailand-Malaysia-Singapore Power Integration Project
MECS	Modern Energy Cooking Services
MEM	Ministry of Energy and Mines
MEMI	Ministry of Energy
MEPS	Minimum Energy Performance Standards
MME	Ministry of Mines and Energy

Abbreviations

MTEC National Metal and Materials Technology Center
N_2O Nitrous Oxide
NDC Nationally Determined Contribution
NEC-SSN Nuclear Energy Cooperation Sub-sector Network
NEEAP National Energy Efficiency Action Plan
NGO Non-governmental Organisation
NO_2 Nitrogen Dioxide
NO_x Nitrogen Oxides
NREL National Renewable Energy Laboratory
NREP National Renewable Energy Program
NREPAP National Renewable Energy Policy and Action Plan
NSTDA National Science and Technology Development Agency
NUPI Norwegian Institute of International Affairs
P2P Peer-to-peer
PDP Power Development Plan
PHEV Plug-in Hybrid Electric Vehicle
PLN *Perusahaan Listrik Negara*
PM10 Particulate Matter 10
PM2.5 Particulate Matter 2.5
PMC Project Management Committee
PPP Purchasing Power Parity
PV Photovoltaic
R&D Research and Development
RE Renewable Energy
RE-SSN Renewable Energy Sub-sector Network
REPP Regional Energy Policy and Planning
REPP-SSN Regional Energy Policy and Planning Sub-sector Network
SAPP Southern African Power Pool
SC Supercritical
SDG Sustainable Development Goal
SEB Specialised Energy Body
SEER Seasonal Energy Efficiency Ratio
SEI Stockholm Environment Institute
SO_x Sodium Oxide
SSN Sub-sector Network
SSP Shared Socioeconomic Pathway
TFEC Total Final Energy Consumption
TNB *Tenaga Nasional Berhad*
TNC Third National Communication
TPES Total Primary Energy Supply

UN	United Nations
UN DESA	United Nations Department of Economic and Social Affairs
UNDP	United Nations Development Programme
UNESCAP	United Nations Economic and Social Commission for Asia and the Pacific
UNICEF	United Nations Children's Fund
UNSD	United Nations Statistics Division
USAID	United States Agency for International Development
USC	Ultra-supercritical
USD	United States Dollar
VNEEP	National Energy Efficiency Programme
VNEM	Virtual Net Energy Metering
VSD	Variable-speed-drive
vRE	Variable Renewable Energy
WCA	World Coal Association
WDI	World Development Indicator
WHO	World Health Organization
WPP	World Population Prospects

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
TWh	Terawatt hour
W/W	Watts per watt
Wh	Watt hour

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Executive Summary

The Association of Southeast Nations (ASEAN) includes 10 Member States – Brunei Darussalam, Cambodia, Indonesia, Lao PDR, Malaysia, Myanmar, the Philippines, Singapore, Thailand and Vietnam – that are home to about 643.7 million people, with a combined GDP of USD 7.12 trillion in 2017 (2011 constant PPP). It is a diverse group, but collectively, a growing economic force: even after accounting for the impact of the COVID-19 pandemic, the region's GDP is still projected to nearly triple by 2040. Fuelling that growth will require significant amounts of energy.

The 6th ASEAN Energy Outlook (AEO6), prepared by the ASEAN Centre for Energy (ACE) with support from the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH through the ASEAN-German Energy Programme (AGEP), in close collaboration with experts and policy-makers from all 10 ASEAN Member States (AMS), examines how the region can meet the energy needs of its growing economy and population from now until 2040. The choices made today have major implications not just for individual AMS, but also for the region and the world. Hence, AEO6 examines different ways forward and their implications for energy security, development and the environment.

AEO6 can also help policy-makers, energy planners and other stakeholders gauge progress on the targets set in the ASEAN Plan of Action for Energy Cooperation (APAEC) 2016–2025 to strengthen energy security, accessibility, affordability and sustainability, and inform Phase II of APAEC, "Accelerating Energy Transition and Strengthening Energy Resilience through Greater Innovation and Cooperation".

The future is uncertain, but scenarios show what is possible

AEO6 explores four scenarios – three of which were modelled in AEO5 as well, plus a new scenario focused on attaining Sustainable Development Goal 7, "Affordable and Clean Energy". Starting with roughly the same suite of technologies for the same population and GDP extrapolations, the four scenarios explore different strategies and escalating levels of ambition, and their implications:

Baseline Scenario: This scenario assumes ASEAN Member States' energy systems continue to develop along historical trends, with little effort to meet their national or regional targets. Labelled as "Business as Usual" in AEO5, it has been renamed to emphasise that it does not reflect the expected future, but rather historical patterns, as a point of reference for the other scenarios.

AMS Targets Scenario (ATS): This scenario projects the future development of ASEAN energy systems if Member States do what is needed to fully achieve their own national energy efficiency and renewable energy targets, as well as their climate commitments – but do not make adjustments to reflect ASEAN regional targets.

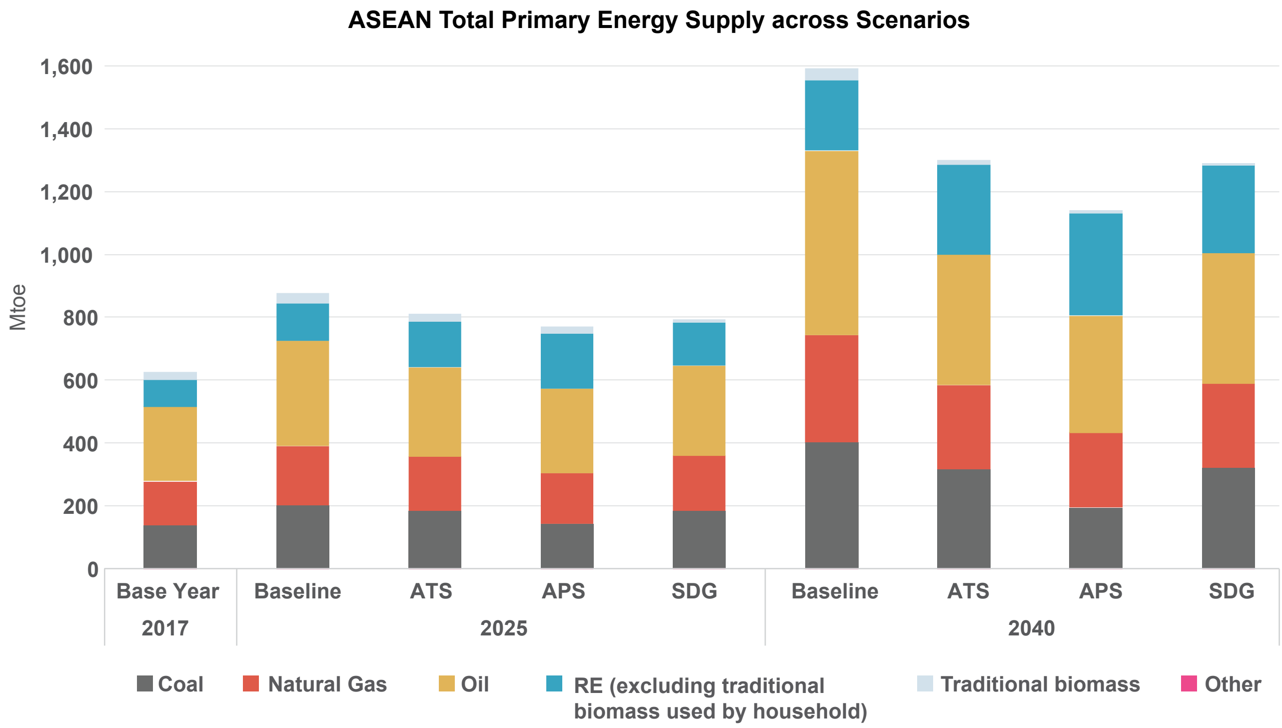
APAEC Targets Scenario (APS): This scenario explores what it would take to achieve the regional targets for energy intensity and renewable energy outlined in APAEC 2016–2025, and how this might transform ASEAN's energy systems even beyond 2025; achieve 23% of total primary energy supply (TPES) from renewable energy and reduce the energy intensity by 30% from 2005 levels, both in 2025.

Sustainable Development Goals (SDG) Scenario: This scenario builds on the **ATS** to explore what ASEAN Member States would have to do to achieve the three targets of SDG 7 by 2030: to ensure universal access to affordable, reliable and modern energy services; increase substantially the share of renewable energy in the global energy mix; and double the global rate of improvement in energy efficiency (from 2015 levels).

AEO6 takes a bottom-up approach in modelling national energy demand in every scenario, which allowed each AMS to adjust and modify the model for each country and ensure that it reflects their expectations, priorities and targets.

	Baseline		AMS Targets Scenario (ATS)		APAEC Target Scenario (APS)		SDG Scenario	
	2025	2040	2025	2040	2025	2040	2025	2040
Population (million persons) – constant across scenarios	698.5	768.2	698.5	768.2	698.5	768.2	698.5	768.2
GDP (billion 2011 USD PPP) – constant across scenarios	10,177	20,252	10,177	20,252	10,177	20,252	10,177	20,252
Total final energy consumption (TFEC, in Mtoe)	518	922	474	714	451	624	459	702
% electricity in TFEC	21.7%	25.7%	22.0%	27.1%	21.8%	25.8%	22.8%	27.7%
Total primary energy supply (TPES, in Mtoe)	874	1589	810	1298	769	1139	790	1281
% coal in TPES	22.8%	25.3%	22.8%	24.3%	18.4%	16.8%	23.4%	25.0%
% oil in TPES	38.2%	36.9%	35.1%	32.0%	35.0%	32.8%	36.1%	32.5%
% gas in TPES	21.8%	21.6%	21.4%	20.7%	21.0%	21.1%	22.5%	21.0%
% RE in TPES	13.6%	14.0%	17.7%	22.1%	23.0%	28.7%	17.2%	21.7%
Electricity generation capacity (GW)	404	713	401	600	412	544	401	600
Electricity generation (TWh)	1,489	3,123	1,379	2,550	1,305	2,118	1,379	2,550
Energy-related GHG emissions (Mt CO_2-eq)	2,228	4,171	1,962	3,002	1,701	2,264	1,965	3,014

Key choices will determine the size and makeup of ASEAN's future energy



In the **Baseline Scenario**, ASEAN's total primary energy supply (TPES) grows by 40% between 2017 and 2025, driven by both GDP and population growth. With improvements in energy efficiency and renewable energy (RE) development both kept at historical levels, except as noted in AMS' Power Development Plans, TPES continues to grow rapidly, reaching 1,589 Mtoe in 2040, more than 2.5 times higher than in 2017. With few efforts to meet national or regional targets, the majority of the energy mix continues to come from fossil fuels – oil, coal and natural gas – as the share of RE remains close to the current level.

In the **ATS**, Member States' efforts to meet national targets on energy efficiency and renewable energy, as well as commitments under the Paris Agreement, slow energy demand growth enough that in 2025, TPES is 7% lower in 2025 and 18% lower in 2040 than in the Baseline Scenario. Though fossil fuels continue to provide the majority of the energy mix, their share is reduced to 79.3% in 2025 and 77.0% in 2040.

In the **APS**, stepped-up efforts to meet the APAEC regional targets reduce TPES by 12% in 2025 and 28% by 2040 compared with the Baseline Scenario. Not only does ASEAN achieve its goal of a 23% renewable energy share in TPES by 2025, but the share continues to grow, reaching 28.7% in 2040. The remainder is mostly supplied by fossil fuels and a small amount of traditional biomass, but with reduced coal use, natural gas becomes the No. 2 fossil fuel, after oil.

Energy demand is evolving, and policy choices can shape it further

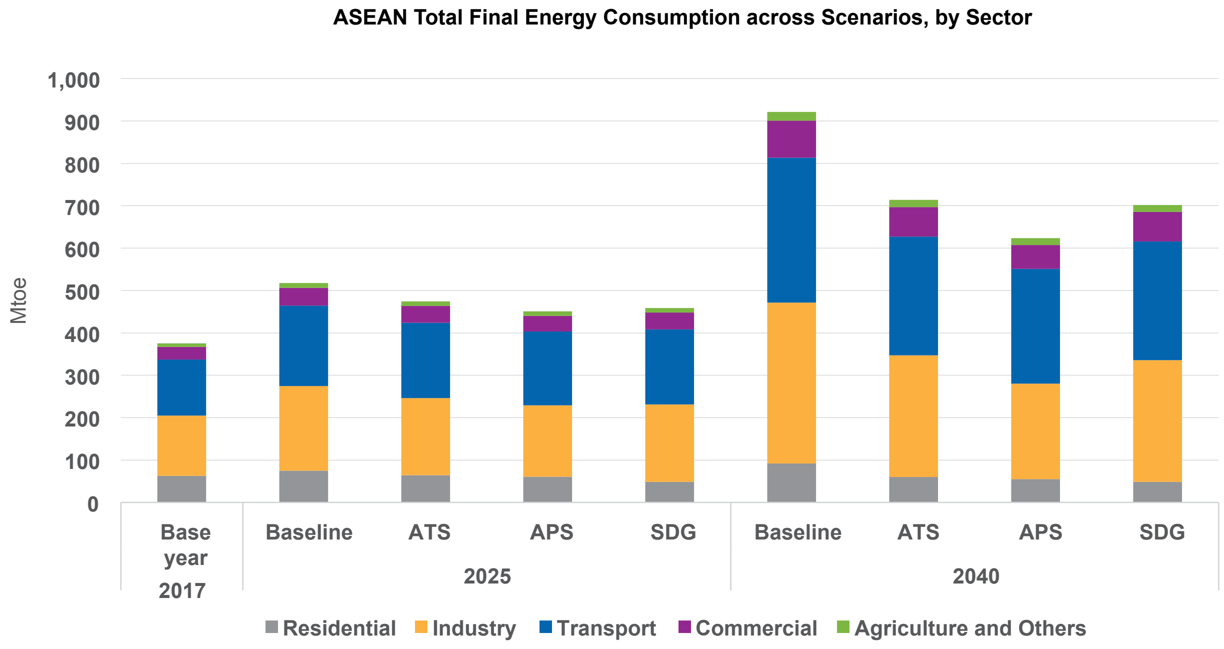
In the **Baseline Scenario**, ASEAN's total final energy consumption (TFEC) is projected to increase by 38% by 2025 and 146% by 2040, from 375 Mtoe in 2017 to 922 Mtoe in 2040, mainly driven by increased demand in industry, transport and households. As with TPES, fossil fuels continue to predominate, holding steady at about two-thirds of TFEC over the projection period. However, natural gas grows faster than other fuels, as it is increasingly used in the region's fast-growing industrial sector. Notably, 58% of industrial energy demand (around 222 Mtoe in 2040) is met by fossil fuels – even without accounting for fossil fuels used to produce electricity used by the sector.

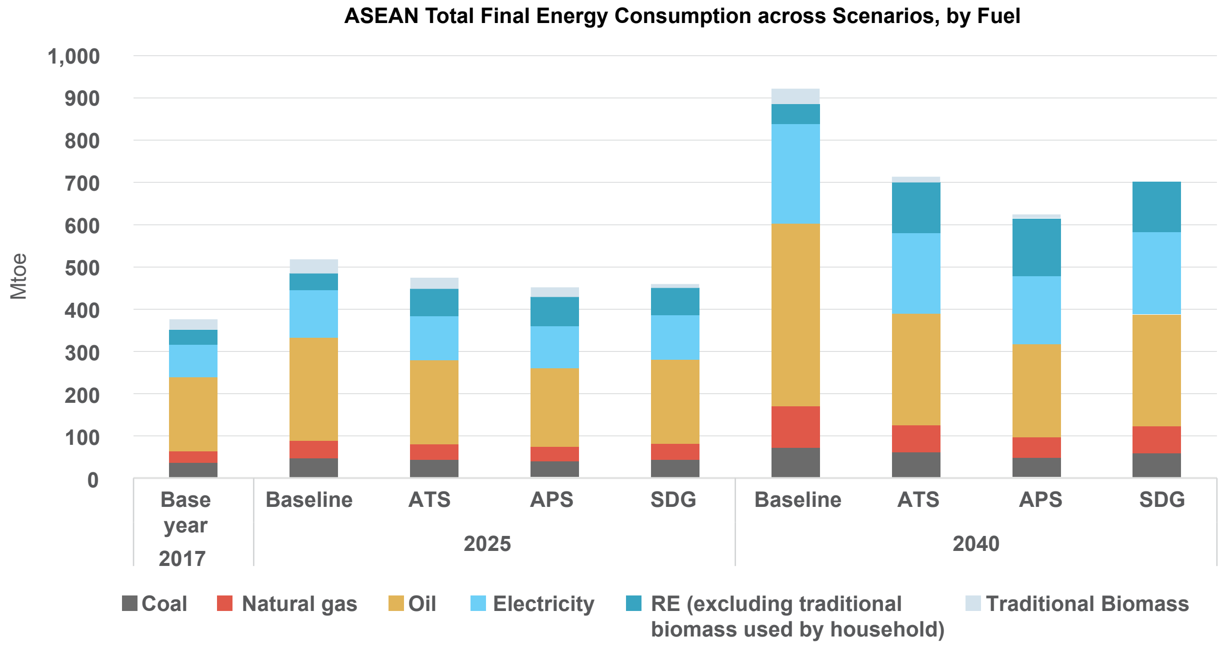
In the **ATS**, AMS' efforts to meet their national targets slow energy demand growth, leading to a TFEC of 474 Mtoe in 2025 and 714 Mtoe in 2040, 8% and 23% lower than the Baseline Scenario, respectively. The largest energy savings are in industry, due to upgrades to equipment and, potentially, a shift to less energy-intensive manufacturing. Energy demand in transport is reduced through efficiency measures and adoption of electric vehicles (EVs). In the residential sector, more efficient appliances, especially air conditioners (ACs) and lighting (by switching to LED light bulbs), make the greatest impact. A sharp increase in biofuel use enables the ASEAN economies to keep gasoline and diesel consumption in road transport roughly flat, even as total energy demand more than doubles from 2017 to 2040. The use of biofuels rises from 5 Mtoe in 2017, to 29 Mtoe in 2025 and 79 Mtoe in 2040. Meeting such high demand would require strong, systematic support across the supply chain.

In the **APS**, energy demand is further reduced, to 451 Mtoe by 2025 and 624 Mtoe by 2040, mainly through deeper energy savings in industry. More ambitious policies in the transport sector also reduce oil demand while sharply increasing the share of TFEC met by biofuels, to 101 Mtoe in 2040, more than 17 times as much as in the Baseline Scenario.

Further reductions in the transport sector can be achieved by adopting stronger demand- and supply-side policies for both biofuels and electric vehicles; continuing to pursue the vehicle efficiency target in the ASEAN Fuel Economy Roadmap; strengthening vehicle emission and fuel quality standards; and investing in public transit and non-motorised transport to reduce the need for driving. It is important to remember that electrification of transport would also increase the share of that sector's TFEC met by electricity.

Given that industry is the sector with the highest energy demand in the region, it is crucial to adopt ambitious energy efficiency measures and emission standards. And as the population grows, incomes rise, and more people move to urban areas, stronger energy efficiency requirements for buildings, enhanced building codes and stricter efficiency standards for appliances – especially lighting and air conditioning – can all help slow energy demand growth.





Renewable energy development needs to accelerate to meet the APAEC target

Renewable energy is crucial to achieving the goals of the Paris Agreement and the Sustainable Development Goals, and is also important for ASEAN's energy security – by reducing the need for fossil fuel imports. Recognising this, every AMS has developed policies and initiatives to drive RE development. At the regional level, APAEC sets a target of having RE make up 23% of TPES by 2025, not including traditional biomass used by households. However, only the most ambitious of the four scenarios meets that target.

In the **Baseline Scenario**, the renewable energy supply increases by a compound annual growth rate (CAGR) of 4.2%, reaching only 13.6% of TPES by 2025; even by 2040, it has only reached 14% of TPES. Stepped-up RE efforts to meet national targets under the **ATS**, meanwhile, push the share of renewables in TPES to 17.7% by 2025 and 22.1% by 2040.

The key insight from the modelling of the **APS**, the only scenario that meets the APAEC target, is that getting to 23% by 2025 requires multiple layers of additional efforts to accelerate RE growth: from more ambitious biofuel mandates, to increased wind and solar development, stepped-up energy efficiency improvements, and strategies to advance disruptive technologies. Manufacturers can also be encouraged to adopt renewable energy – biomass may hold the greatest promise. Together, these strategies would bring the share of RE in TPES to 23% in 2025, meeting the APAEC target, and to 28.7% in 2040.

RE can provide a significant share of electricity, but enabling measures are key

In the power sector, ASEAN has historically relied on fossil-fuelled power generation. In the **Baseline Scenario**, coal remains central to the ASEAN power mix, with installed coal power capacity growing at a CAGR of 3.8% from 2025 to 2040, building on what was already robust growth in 2017–2025. This reliance on coal reflects the region's considerable reserves and the low cost of coal, both of which make it economically attractive. However, except for hydropower, which made up 19.7% of the power mix in 2017, RE generation capacity in ASEAN remains insignificant. If historical trends continued, hydropower would gain a greater share of the power mix by 2025 and continue up to 2040, but other renewables, such as solar, wind, geothermal and biomass, would still have minimal shares. Non-hydropower renewable installed capacity is projected to be about 54 GW by 2025 and 110 GW by 2040. Hence, despite renewable power growing by 5% per year, by 2040 the installed RE capacity in ASEAN would still be less than half the coal capacity.

In the **ATS**, the outlook changes. As many AMS put incentives in place and costs decline, from 2018 to 2040, solar grows faster than any other electricity source, with a CAGR of 10.4%, and by 2040, renewable energy (including hydropower) reaches 37% of power generation capacity.

In the **APS**, with concerted efforts to increase the share of variable renewables, solar capacity and wind capacity are projected to grow by 15% and 12% per year, respectively, from 2017 to 2040. Geothermal and biomass generation capacity would be 25% and 10% higher than in the ATS, respectively, while biogas and waste-to-energy technology would be 20% higher. The APS also envisions the introduction of more biomass/coal co-firing plants, using 5% biomass feedstock, while the coal power capacity of the four major coal-consuming countries would be reduced by 15% by 2025.

As the APAEC regional target is for 2025, AMS will have to hurry to increase their RE capacity. For example, from 2020 to 2025, ASEAN will need to increase its solar PV capacity from 32 GW to 83 GW. This is by far the biggest jump in installed capacity, followed by hydropower, for which capacity needs to increase from 59 GW in 2020 to 77 GW in 2025. Such aggressive capacity development will be crucial to achieving the APAEC target; it is also achievable, as ASEAN aims to seize the momentum in solar PV, especially.

Activities such as improving financial access for renewable energy projects, increasing power sector stakeholders' capabilities, and making the most of opportunities created by the ASEAN Power Grid (APG) can all help accelerate progress. The forthcoming ASEAN Interconnection Masterplan Study (AIMS) III is expected to provide vital insights on how to optimise regional cooperation on electricity and increase the penetration of renewable energy.

It's time for ASEAN to raise the bar on energy efficiency

Energy efficiency (EE) is crucial to the region's sustainable development. The goal is to reduce energy demand cost-effectively, and thus reduce energy costs, CO_2 emissions and other environmental impacts, and boost energy security and overall economic productivity. AMS have steadily increased their EE efforts, and by 2017, ASEAN had already reduced the energy intensity of the regional economy (measured as TPES/GDP) by 21.6% from 2005 levels, surpassing the APAEC target of a 20% reduction by 2020. This was a significant achievement.

Reaching the APAEC target for 2025 – a 30% reduction from 2005 levels – will require additional efforts, however. In the **Baseline Scenario**, only a 23.3% reduction is achieved by 2025. In the **ATS**, Member States' efforts to achieve their own national targets bring the region closer to the APAEC goal, achieving a 28.9% reduction. The more ambitious policies and measures modelled in the **APS**, however, are able to achieve a 32.5% reduction by 2025, and almost 50% by 2040.

Notably, though from a regional perspective, ASEAN would achieve the SDG 7 target of doubling the rate of energy intensity reduction from 1990–2010 levels in 2015–2030 (this corresponds to 0.7% and 1.4%, respectively), from a global perspective, meeting the SDG target would require average annual reductions of 2.6% by 2030. The ATS would only achieve annual average reductions of 1.7%; the APS would achieve 2.2% average annual reductions.

Ambitious energy policies can significantly reduce GHG emissions

In 2017, energy-related greenhouse gas (GHG) emissions in ASEAN countries were about 1,686 Mt CO_2-eq; in the **Baseline Scenario**, they reach 2,228 Mt CO_2-eq by 2025, then nearly double again by 2040, to 4,171 Mt CO_2-eq. The electricity and transport sectors start out as, and remain, the biggest emitters of GHGs and air pollution in ASEAN. Electricity and transport account for about 38% and 25%, respectively, of total GHG emissions from energy consumption in 2025; in 2040, their respective shares are 42% and 25%.

In the **ATS**, ASEAN's total energy-related GHG emissions in 2040 are 3,002 Mt CO_2-eq, 28% lower than in the **Baseline Scenario**. Power generation remains the largest sectoral contributor, accounting for about 40% and 46% of total GHG emissions from energy in 2025 and 2040, respectively.

The measures adopted in the **APS** reduce GHG emissions more sharply, to 2,264 Mt CO_2-eq in 2040, with a 1.3% compound annual growth rate over the modelled period, compared with 2.5% in the **ATS**. The biggest GHG emission reductions are in the power sector, followed by transport and industry.

The SDG 7 targets can help ASEAN align its efforts with global commitments

Both the **ATS** and the **APS** would achieve the SDG 7 target to substantially increase the share of energy demand met by renewables. The ATS would grow the share of RE in TFEC (excluding electricity) from 8% in 2005 (21.2 Mtoe), to 15% in 2030 (80.6 Mtoe) and 17% in 2040 (119.9 Mtoe). In the APS, the increase would be even greater, to 18% of TFEC (88 Mtoe) in 2030 and 26% (135 Mtoe) in 2040. As noted above, both the ATS and the APS would also enable ASEAN to meet the SDG 7 target on energy efficiency, but only at the regional level.

Meeting the SDG 7 target on universal access to modern energy is more challenging. The first aspect – access to electricity – is covered in the **ATS**, as most, if not all, AMS expect to achieve a 100% electrification rate by 2030. However, advances in clean cooking in the **APS** (or **ATS**) would not suffice to meet SDG 7. The **SDG Scenario** models what it would take to close the gap, assuming that households now cooking with traditional biomass or kerosene switch to liquefied petroleum gas (LPG), some biogas and natural gas, and especially in later years, electric stoves. Those efforts would not significantly affect the overall level of TPES relative to the ATS (which it mirrors in everything else), but they would sharply reduce the share of traditional biomass, from 3.9% of TPES in 2017 to only 1.2% in 2025 and zero in 2040.

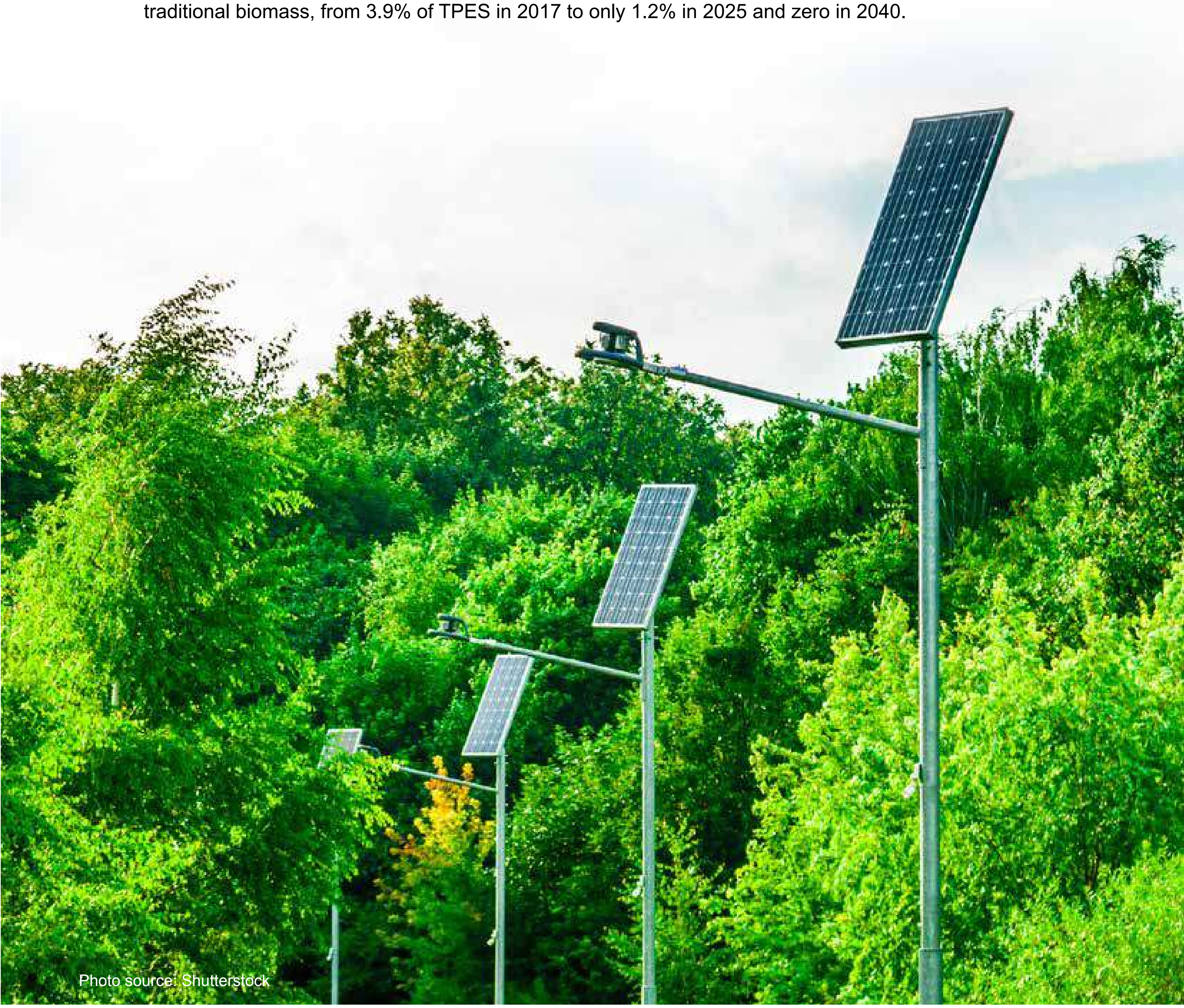


Photo source: Shutterstock

Substantial investment is required, but it will create jobs and reduce the social cost of energy

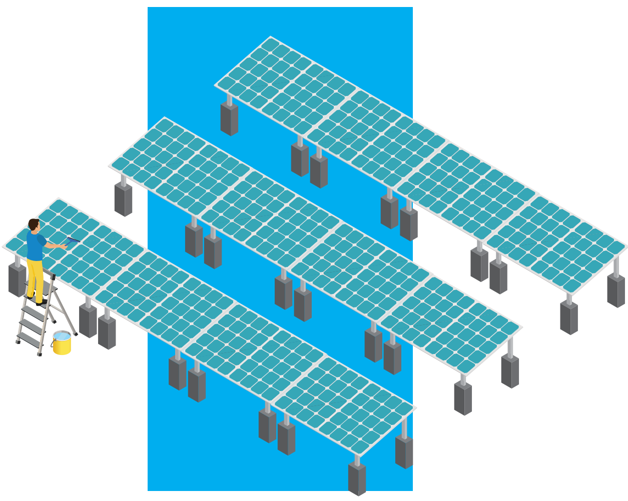
In all scenarios, substantial power sector investments are required. Between 2018 and 2025, the needed investment in the **Baseline Scenario** amounts to USD 281 billion, while in the **ATS**, it rises to USD 283 billion. To achieve the 35% share of RE in ASEAN installed power capacity by 2025 as targeted in the **APS**, the total investment needed is USD 367 billion. In the longer term, however, the APS actually achieves savings. In the **Baseline Scenario**, power sector investments total USD 584 billion from 2018 to 2040, while in the **ATS**, they drop to USD 486 billion; in the **APS**, they total USD 508 billion, as savings in later years offset some of the high costs early on.

The larger investment needs in the **ATS** and the **APS** are driven not by a greater increase in generation capacity, but by the higher cost of cleaner technologies in the first several years. In 2018–2025, 138 of the 179 GW of new capacity comes from renewable sources, and 76.7% of the total investment, USD 281 billion, goes to renewables. In 2026–2040, however, power sector investment requirements more closely align with the amount of capacity being added in each scenario. In the Baseline Scenario, USD 303 billion is needed; in the ATS and SDG Scenario, USD 203 billion; in the APS, USD 141 billion. The required investments in this period also reflect a sharp reduction in the cost of power generation compared with 2018–2025: 2 billion USD/GW in the APS in 2018–2025, but only 1 billion USD/GW in 2026–2040.

Increasing investment in renewable energy, in particular solar and wind, can create jobs. In the **APS**, the increased installation of solar and wind power would add about 223,000 jobs in 2025, the target year of APAEC 2016–2025. This is about 138,000 more jobs than in the **ATS**, which is expected to add 61,000 jobs in solar and 24,000 jobs in the wind energy in 2025. In the **Baseline Scenario**, meanwhile, a total of 81,000 RE jobs are added in 2025, just slightly lower than in the ATS.

In 2040, the employment gains from strong RE promotion policies are even greater. In the **APS**, 303,000 solar and wind jobs would be created – 220,000 in solar and 83,000 in wind energy. In the **Baseline Scenario** or the **ATS** and **SDG Scenario**, meanwhile, only about 174,000 jobs are created in the two sectors combined. Such economic benefits should be considered when designing policies, including those explored in the ATS and APS.

Increased renewable energy penetration would also boost energy security through diversification and self-sufficiency, while reducing GHG emissions and the social cost of energy. Fossil-fuelled power generation has significant externalities – impacts on the environment and society that are not properly accounted for in purely economic decision-making processes. Such externalities are rooted in emissions from fossil fuels utilisation, which pollute air, water and land. This pollution can then impact the health of the population.



The scenario analysis shows how much social costs can be reduced through ambitious energy policies. In the **Baseline Scenario**, the social cost of energy reaches USD 1,558 billion by 2040. The implementation of the **ATS** could reduce the social cost to USD 1,036 billion, while the achievement of **APS** targets would sharply cut the social cost, to USD 766 billion. That reduction would more than offset the higher power sector investment needs in the APS.


Photo source: Shutterstock

ASEAN policy-makers should pay attention to five key avenues for raising ambition

ASEAN Power Grid (APG): The APG is meant to facilitate electricity trading among Member States through strategic interconnections and to enhance the integration of their power systems. Increased power system connectivity through the APG can enable more efficient use of resources, enhance grid stability and service in remote areas, and improve the region's energy security as electricity demand and end uses grow. Regional collaboration through the APG will also play important role in closing the RE gap, as individual AMS may find it challenging to undertake the required efforts on their own. By enabling more cross-border trade, a more interconnected ASEAN could make large-scale RE investments more profitable. Progress can be further accelerated through collective capacity-building, joint studies and proposals, etc.

Address implications of continued fossil fuel use: Given that even in the most ambitious scenario, the APS, fossil fuels would still make up 71% of TPES in 2040, it is crucial to try to reduce the environmental impacts of fossil fuel use. Along with stepped-up efforts to reduce fossil fuel demand through fuel-switching and energy efficiency measures, AMS can work to reduce GHG emissions and other externalities by deploying technologies such as coal upgrading; high-efficiency, low-emissions (HELE) coal power; co-firing systems; and especially carbon capture utilisation and storage (CCUS) and carbon capture and storage (CCS).

Efficient air conditioners: Energy demand for cooling in ASEAN has been rising rapidly over the past three decades. AC ownership is still low in the region, averaging only 18% of households in 2017 (but over 78% in Malaysia, Singapore and Brunei Darussalam). Looking ahead, AC ownership and use are expected to rise significantly, driven by rising incomes, urbanisation, electrification, increasing standards of living and demand for thermal comfort, falling AC prices, and climate change. Policy-makers will need to find ways to ensure that the expected increase in cooling demand and AC ownership is sustainable. Along with adopting higher efficiency standards, AMS may want to consider consumer incentives and education.

Greener transport: In 2017, the transport sector was responsible for 26% of TFEC and 23% of GHG emissions in ASEAN. Two key approaches, adoption of electric vehicles and substitution of oil products with biofuels, can help Member States to reduce oil import dependency and improve energy security. Although ASEAN is only in the early stages of EV adoption, several AMS have set EV targets, and fast growth is projected in the region. Biofuels, meanwhile, already play a prominent role in several AMS' energy strategies, and there is significant growth potential. Looking ahead, it is crucial to ensure that biofuels production is sustainable; a key area for further study is developing second-generation biofuels, which use waste and other non-food feedstock.

Clean cookstoves: As of 2017, about 60 million households in ASEAN, or 240 million people, still cooked with traditional biomass, such as wood, crop wastes or charcoal, or on kerosene stoves, exposing themselves to dangerous levels of indoor air pollution that killed an estimated 345,000 people in the region in 2016. Several AMS have made dramatic progress in bringing clean stoves and fuels to even remote rural households, showing the impact of government policies and programmes. Nations that have established clean cooking priorities and programmes focused on LPG and advanced stoves have advanced most rapidly. The use of electric cookstoves may be promising for the future, particularly in urban and peri-urban areas where electricity access is expanding.

Outline of the Report

▶ CHAPTER 1: INTRODUCTION

Provides background information on the ASEAN energy landscape, challenges, collaboration, and the role of the ASEAN Energy Outlook.

- The economic and demographic growth of ASEAN, and its implications for the energy sector
- The elements of energy security, accessibility, affordability, and sustainability challenges of ASEAN
- The role of energy cooperation under ASEAN Plan of Action for Energy Cooperation (APAEC) to address the challenges
- How the AEO6 supports the creation of pathways for achieving the regional targets and aspirations

▶ CHAPTER 2: SCENARIOS FOR ASEAN`S ENERGY FUTURE

Provides the philosophy behind the AEO6 scenarios, which model the implications of continuing historical patterns or achieving national or regional targets as well as SDG 7. The analysis examines the implications for energy demand and supply, emissions, as well as socio-economic impacts in the ASEAN region.

MODELLING PROCESS OF AEO6:

Demand	Modelling approach (Demand)	Transformation	Supply
Residential[1]	[1] Bottom-up / Technology	Electricity Generation	Oil
Industry[2]	[2] Top-down / Econometric	Oil & Gas Refining	Natural Gas
Commercial[2]		Energy Transmission & Distribution	Coal
Transportation[1]			Modern RE
Agriculture & Others[2]			Traditional RE

Historical data from 2005 – 2017 are projected to 2018 – 2040, based on four scenarios.

THE FOUR SCENARIOS OF AEO6:

The ambition level escalates from Baseline to APS, while the SDG Scenario adopts global-level commitments

Baseline Scenario	AMS Targets Scenario (ATS)	APAEC Targets Scenario (APS)	Sustainable Development Goals (SDG) Scenario
Energy growth kept at constant level as of last historical year	Achievement of ASEAN official national energy targets	Achievement of APAEC's aspirational regional targets on RE and EI	Sustainable Development Goals (SDG) Scenario

Increasing ambitions of RE and EE/EI standards → **Global-level commitments**

▶ CHAPTER 3: THEMATIC ENERGY INSIGHTS

Elaborates on five highlighted energy issues that are deemed crucial to attaining the APAEC targets modelled in Chapter 2, with global perspective and best practices that could benefit future ASEAN development.

- **ASEAN Power Grid**
- **Fossil Fuels**
- **Efficient Air Conditioning**
- **Greener Transport**
- **Clean Cooking**

▶ CHAPTER 4: POLICY IMPLICATIONS AND RECOMMENDATIONS

Provides recommendations for ASEAN Member States on the key energy policies and collaborative actions needed to achieve the APAEC targets, along with institutional and model improvement opportunities for the next version of the ASEAN Energy Outlook.

CHAPTER 1
Introduction

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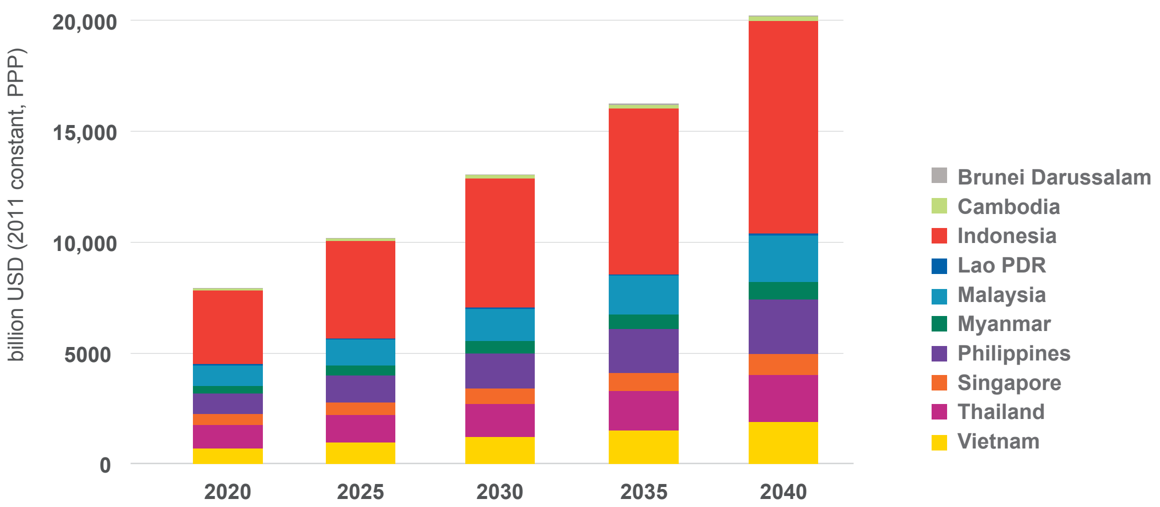
Introduction

The Association of Southeast Asian Nations (ASEAN) comprises 10 Member States (AMS): Brunei Darussalam, Cambodia, Indonesia, Lao PDR, Malaysia, Myanmar, the Philippines, Singapore, Thailand and Vietnam. Together, they are home to about 643.7 million people, with a combined GDP of USD 7.07 trillion in 2017. The AMS have diverse cultures and vary widely in size, population, development levels, average income, urbanisation and other factors. For example, Indonesia, the largest, covers 42% of ASEAN's total land mass, while Myanmar, the next-largest, covers only about 15%. Brunei and Singapore are high- income economies, while the other AMS are in the upper-middle or lower-middle income tiers.[1]

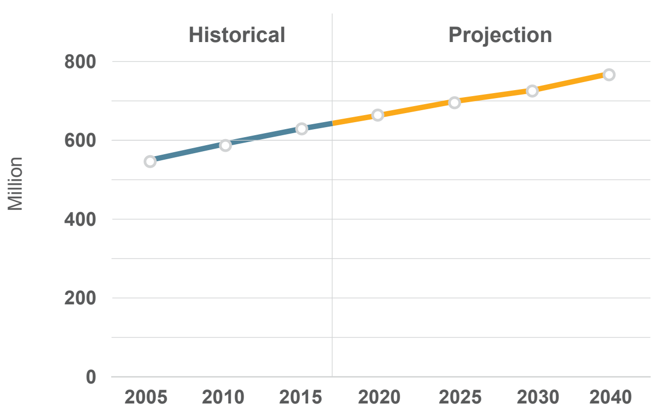
Overall, GDP growth is strong across ASEAN, averaging 5% per year from 2005 to 2017. The 10 countries combined have the sixth-largest economy in the world and the third-largest in Asia; as shown in Figure 1, even after accounting for the impact of the COVID-19 pandemic, the region is projected to reach a combined GDP of USD 20 trillion (in constant 2011 PPP dollars) by 2040.[2] ASEAN's population is also expanding, though more slowly than in previous decades, by just under 1% per year, which would lead to a population of 768 million by 2040, as shown in Figure 2.

Figure 1. Projected ASEAN GDP Growth, 2020–2040



Data source: ACE team projections based on multiple sources; see Appendix for details

Figure 2. ASEAN Population – Historical and Projections



Data sources: Historical (2005–2017) – Brunei Darussalam, Indonesia and Vietnam, national census data; Cambodia, Malaysia, Myanmar, Philippines, Singapore and Thailand, World Development Indicators, http://wdi.worldbank.org. Projections (2018–2040), UN DESA (2019), medium variant, except for the Philippines, for which national projections are used. Note: The chosen source for historical data was based on each ASEAN Member State's suggestion.

1. See World Bank classifications and accompanying gross national income (GNI) data: https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups.
2. Detailed references and assumptions made on GDP and population are provided in the Appendix.

These trends in population and economic growth, combined with a shift away from agriculture and towards greater industrialisation and service-based economies, have defined the ASEAN region's development trajectory. They also impose numerous challenges, including how to meet a fast-growing demand for energy. Ensuring prosperity and resilience across the region will require careful consideration of both energy equity and environmental sustainability concerns. To achieve this, the ASEAN nations are focusing on four priorities: energy security, accessibility, affordability and sustainability, as outlined in the ASEAN Plan of Action for Energy Cooperation (APAEC) 2016–2025. Below we describe each of those four elements, which are recurring themes throughout this Outlook.

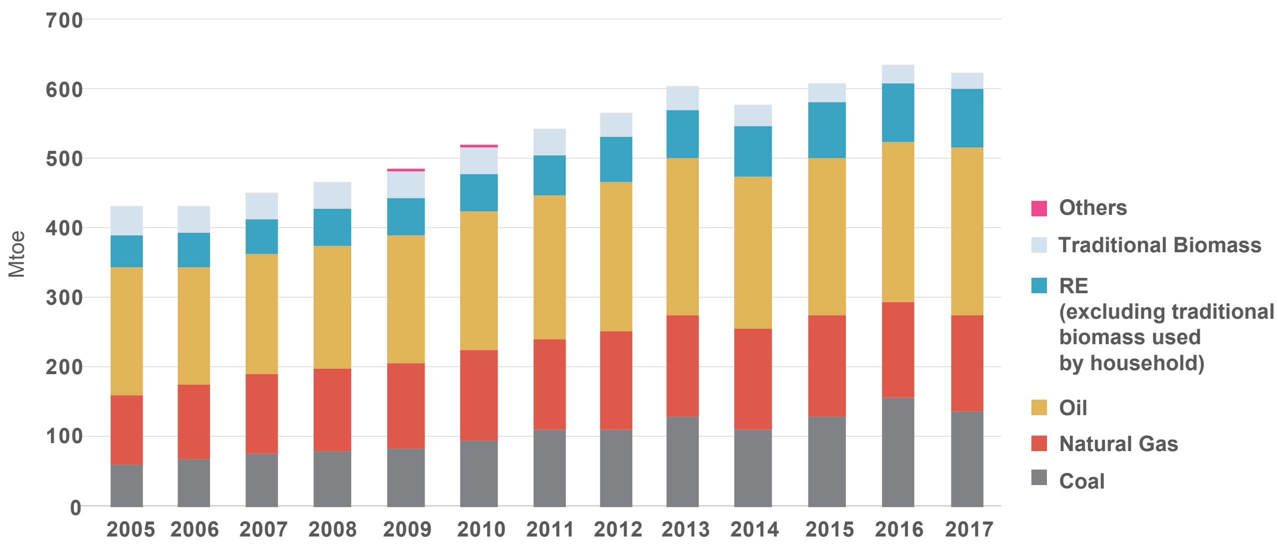
Photo source: Shutterstock

1.1 Energy Security

Energy security is a complex concept that can encompass multiple dimensions, such as energy availability, infrastructure, energy prices, societal effects, environment, governance and energy efficiency (Ang et al. 2015). Stakeholders may prioritise different aspects depending on the context (Cherp and Jewell 2014). The International Energy Agency (IEA) defines energy security as "ensuring the uninterrupted availability of energy sources at an affordable price".[3] In the long term, countries can ensure their energy security by making timely investments to maintain an energy supply aligned with their economic and environmental needs. In the short term, the goal is to be able to withstand and quickly recover from abrupt changes in the supply-demand balance – for instance, if there is a natural disaster or a geopolitical conflict.

The APAEC does not provide a single definition for all Member States, but energy availability is clearly a key common concern, as it underpins many other energy and socio-economic issues. A growing energy supply has fuelled the region's recent growth, and Member States have pushed strongly to further improve it. Meeting increasing demand for energy will be crucial to sustaining the ASEAN countries' collective growth. Yet as shown in Figure 3, the existing energy supply is heavily fossil fuel-based, dominated by oil, with a growing proportion of coal.

Figure 3. ASEAN Historical Energy Supply by Fuel



Data source: ASEAN Energy Database System (AEDS), https://aeds.aseanenergy.org.

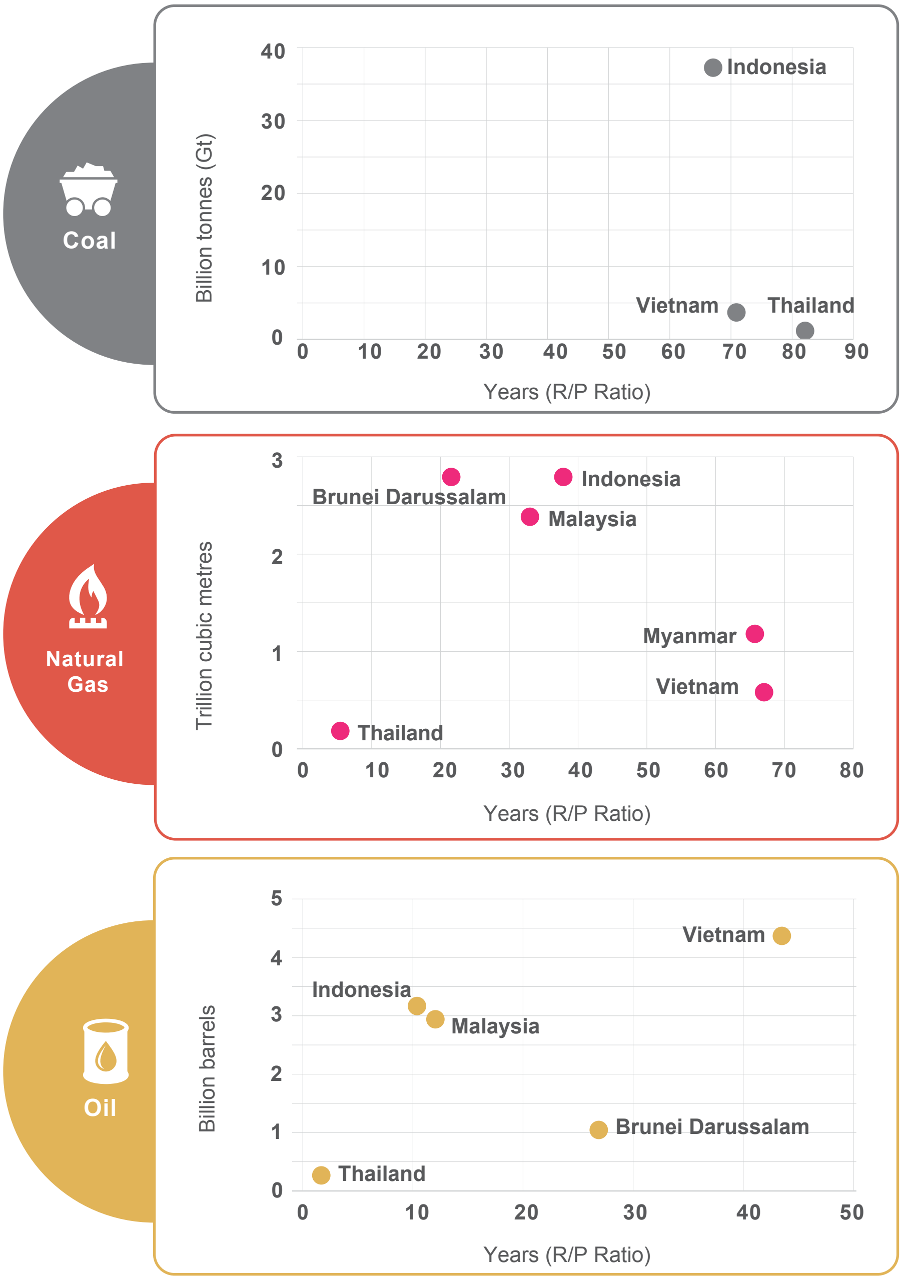
Indeed, the ASEAN region's reliance on fossil fuels is growing, and Member States that have fossil fuel reserves have been optimising the use of those resources, while others continue to build infrastructure to support fossil fuel imports to meet their domestic demand. Some countries with fossil fuel reserves are exploiting them at a very rapid rate, for domestic use or export revenue; Figure 4 shows the ratio of reserves to annual production ratios (R/P), based on with total proven reserves in 2018 for oil, natural gas and coal for ASEAN countries. The ratio allows us to estimate how many years the reserves would last if current production rates were to continue.

As shown in Figure 4, Brunei, Indonesia, Malaysia, Thailand and Vietnam all have proven oil reserves. Vietnam has the largest oil reserves, enough to last 44 years at the current production rate. Thailand, however, only has about two more years' worth of oil reserves.

[3] See https://www.iea.org/areas-of-work/ensuring-energy-security.

The five Member States with oil reserves also have proven natural gas reserves, and so does Myanmar. Vietnam and Myanmar have more than 60 years' worth of reserves at existing production rates. However, surging demand for natural gas for electricity production could speed the depletion of those resources, especially for exports. For example, Myanmar has increased its natural gas exports to Thailand, via a pipeline system, to meet increased demand as Thailand has expanded gas-fired power generation capacity.

Figure 4. Proven Oil, Natural Gas and Coal Reserves and Production Ratios, 2018



Note: R/P is the ratio of proven reserves to annual production, which shows how many years' worth of reserves are left, if current production rates were to continue. Data sources: BGR (2019), BP (2020).

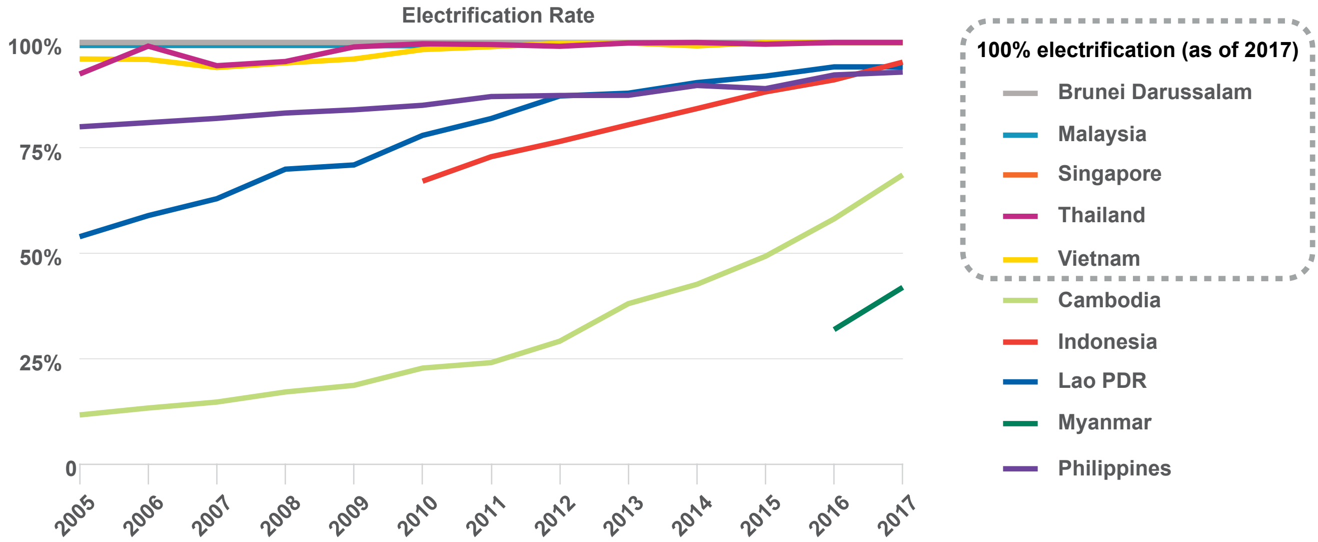
Compared with other fossil fuels, coal is the most abundant resource, especially in Indonesia, but there is increasing pressure to phase out coal to meet the goals of the Paris Agreement and reduce air pollution.

Relative to other fossil fuel-producing countries and regions, ASEAN Member States' resource-to-production ratios and proven reserves are considered moderate. Still, the region imports 40% of its primary energy supply,[4] and there is concern about local resources increasingly falling short, which continues to put pressure on regional energy security.

1.2 Energy Accessibility

Ensuring that energy is accessible to all kinds of consumers (residential, commercial and industrial) is another key challenge for ASEAN. There is no global standard for evaluating energy accessibility, but ASEAN Member States have two main concerns: the share of households with access to electricity, and the share using clean cooking fuels and stoves. Despite years of efforts to expand electricity access, as of 2017, an estimated 17.7 million ASEAN households still lacked electricity, and 138.7 million people still used traditional biomass for cooking. Figure 5 shows electricity access rates for each Member State, as well as the share of different cooking fuels for the region as a whole. Providing access to modern energy sources and ensuring high-quality service even in remote and rural areas remains a priority for ASEAN, both to improve the quality of life and to continue to foster economic growth.

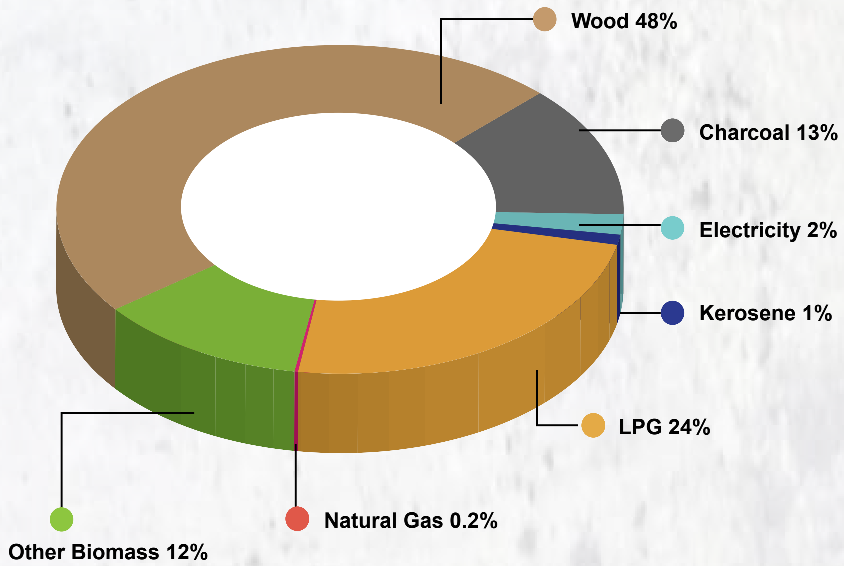
Figure 5: Two Key Indicators of Energy Access in ASEAN Member States



'Note: Only partial data could be obtained for Indonesia and Myanmar.
Data source: ASEAN Energy Database System (AEDS), https://aeds.aseanenergy.org.'

[4] Per data from the ASEAN Energy Database System (AEDS), https://aeds.aseanenergy.org.

Share of Cooking Fuels Used by ASEAN Households, 2017



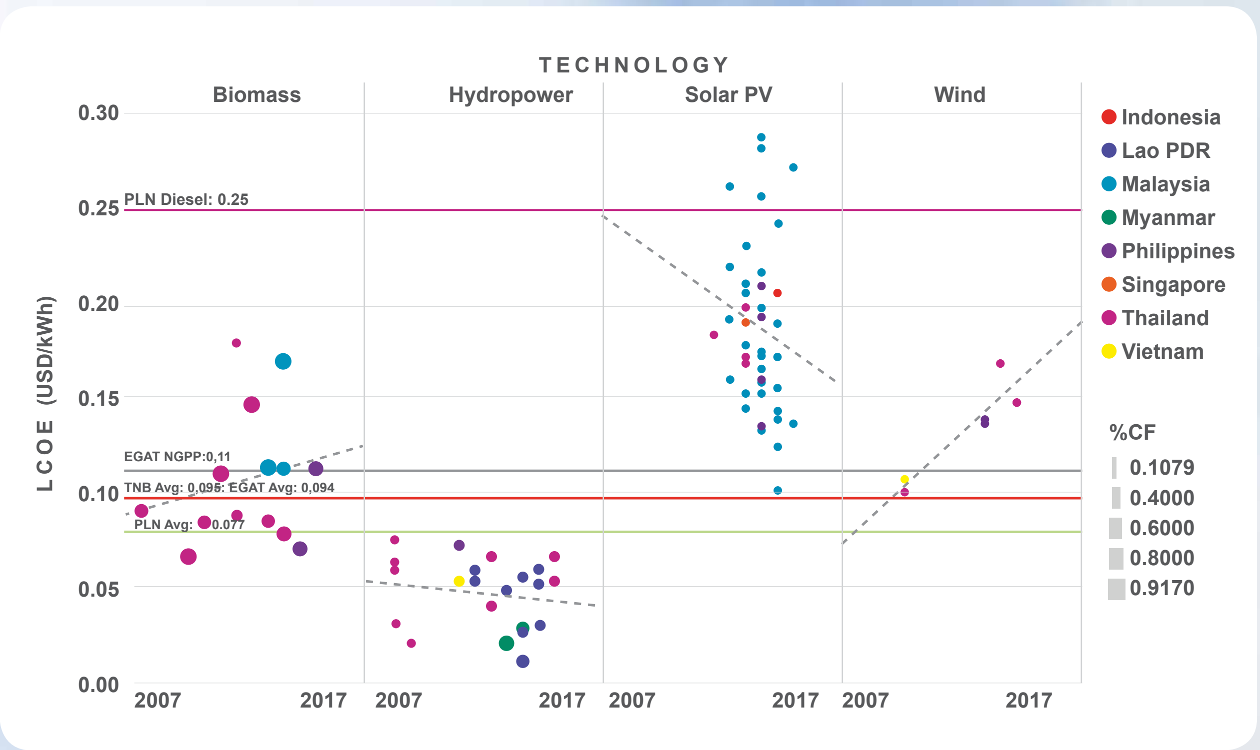
Data source: ACE analysis based on data from WHO Household Energy Database, https://www.who.int/airpollution/data/household-energy-database/en/.

Photo source: Shutterstock

1.3 Energy Affordability

Even if energy is accessible, it may be priced too high for lower-income people to be able to afford it. At the same time, the energy provided must meet quality standards; a low-priced but unreliable energy supply is of limited use. The local availability of energy resources, the quality and availability of infrastructure, and the level of access to energy services all vary greatly among ASEAN Member States. Prices differ significantly as well, as do consumers' per capita incomes. In selecting among energy supply options, it is typical for both individuals and policy-makers to try to find the most affordable, "least-cost" option that meets socio-economic needs. In most cases, those least-cost options still use fossil fuels. For the ASEAN region, this means that efforts to transition to cleaner energy may involve some trade-offs between environmental and economic priorities. However, this is changing rapidly, as the cost of key renewable energy technologies is declining; as a result, ASEAN Member States will increasingly be able provide energy that is both affordable and clean, as shown in Figure 6.

Figure 6. Levelised Cost of Energy for Renewables, Compared with Electricity Retail Prices in ASEAN Member States



Source: Reproduced from ACE (2019), Figure 1. The data show the retail price for electricity (from diesel, natural gas, and on average) from three utility companies in ASEAN Member States (PLN in Indonesia, EGAT in Thailand and TNB in Malaysia). The number of wind power plant samples was insufficient to represent a trend

Photo source: Shutterstock

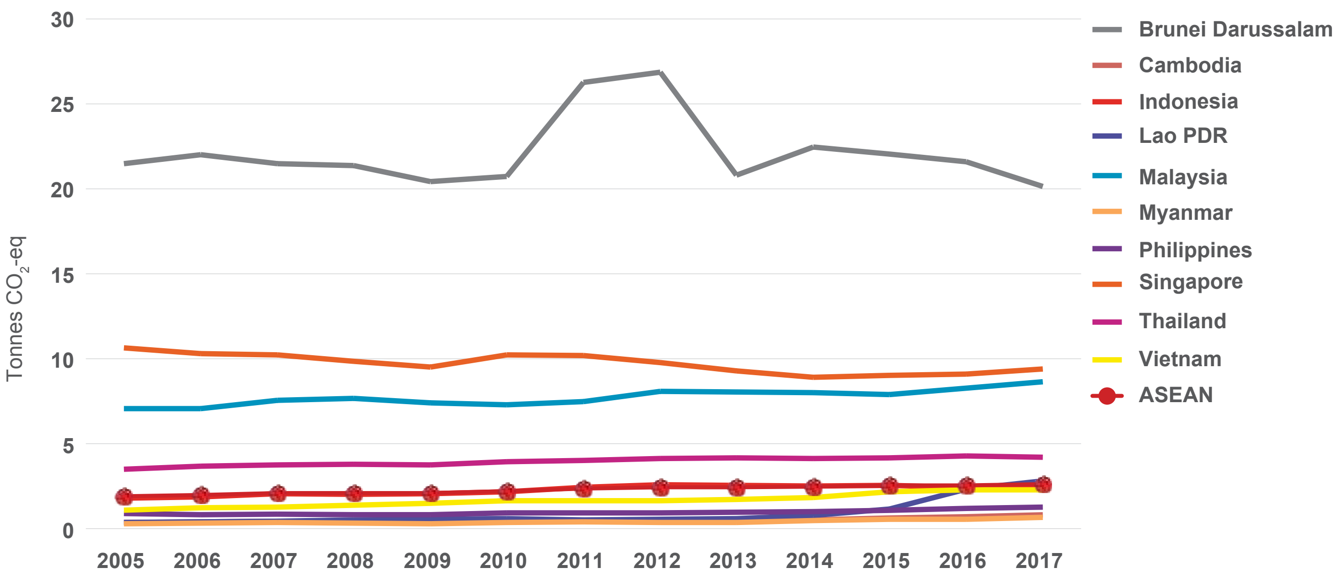
1.4 Sustainability

Given the many environmental impacts associated with energy production, especially climate change and air pollution, there are growing efforts around the world to transform energy systems to be cleaner and carbon-free. The ASEAN Member States, too, have identified sustainability as a core element of their energy planning, with special attention to reducing greenhouse gas (GHG) emissions. This is particularly relevant to the region because several Member States are considered particularly vulnerable to climate change impacts such as sea-level rise and more frequent and severe droughts. ASEAN thus cannot afford to neglect the sustainability implications of its energy systems.

Efforts to reduce the climate impacts of ASEAN's energy sector have prioritised expanding renewable energy production and improving energy efficiency. ASEAN has set out to have 23% of its energy supply come from renewables by 2025, but as of 2017, the RE share was only 13.7%; a rapid expansion will be required to reach the regional target. ASEAN has also set a target for reducing the energy intensity of its economy (the ratio of total primary energy supply, or TPES, to GDP) by 30% from 2005 levels by 2025; as of 2017, the region had achieved a 21.6% reduction.[5]

All ASEAN Member States are signatories to the Paris Agreement and have submitted Nationally Determined Contributions (NDCs). To reduce its GHG emissions in line with the Paris Agreement, the region must make efforts in all sectors, but especially in the energy sector, which is the largest emitter. In 2017, ASEAN emissions per capita were about 2.62 tonnes of CO_2 equivalent (CO_2-eq) – well below those of major Asian economies such as China, Japan and the Republic of Korea, but still rising across much of the region.[6] For context, achieving the Paris Agreement's more ambitious goal of keeping the global temperature increase below 1.5°C with little or no "overshoot" would require CO_2 emissions to decline by about 45% from 2010 levels by 2030 and reach net-zero around 2050 (IPCC, 2018).

Figure 7. ASEAN GHG Emissions per Capita, 2005–2017



Data source: ASEAN Energy Database System (AEDS), https://aeds.aseanenergy.org. Emission factor data sources are outlined in the Appendix.

5 In the plan for APAEC Phase II (2021–2025), which AMS are expected to endorse at the 38th ASEAN Ministers on Energy Meeting (AMEM) in Vietnam in November 2020, the energy intensity target will be updated to increase regional ambition.

6 GHG emissions are calculated using 100-year global warming potentials from the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report, which considers all Kyoto GHGs, but excludes black carbon, tropospheric ozone and hydrofluorocarbons – all of which are short-lived climate pollutants (Myhre et al., 2013; see Table 8.7). For easy comparison with other countries, see the World Development Indicators listing of per capita emissions by country: https://data.worldbank.org/indicator/EN.ATM.CO2E.PC.

1.5 Why Is Aspirational Energy Cooperation Needed?

Ensuring energy security, accessibility, affordability and sustainability at the national and regional levels in ASEAN will be challenging. The Member States recognise that none of them can fully address their energy issues on their own; this is why they see regional cooperation as crucial. The need for energy connectivity across ASEAN has been a particularly prominent issue, given the growing energy demand in the region and its geographic, geological and climatic diversity. Recent achievements such as the first multilateral power trade in the region, successfully initiated under the ASEAN Power Grid (APG) programme between Lao PDR, Thailand, Malaysia and Singapore, demonstrate the commitment to collaboration.

Multilateral energy cooperation and integration can be quite complex, however. It is important to have unified goals and pursue them through unified actions. If done successfully, this could expand trade among ASEAN Member States and improve the region's energy security, access and affordability. Together, the ASEAN Member States can also accelerate the transition to clean energy to ensure a more sustainable future. These considerations have already led the 10 countries to work together and put forward commitments for cleaner energy development, translating many national-level targets (including NDCs) into common regional goals.

The ASEAN Member States' aspirations for regional energy cooperation have been cemented through the ASEAN Plan of Action for Energy Cooperation (APAEC), a series of guiding policy documents aimed at helping ASEAN to achieve the goals of the ASEAN Economic Community. The latest iteration of APAEC spans the 2016–2025 period, broken down into two five-year phases. For the first phase, 2016–2020, the theme is "Enhancing Energy Connectivity and Market Integration in ASEAN to Achieve Energy Security, Accessibility, Affordability and Sustainability for All". For the second phase, 2021–2025, it is "Accelerating Energy Transition and Strengthening Energy Resilience through Greater Innovation and Cooperation"[7]. Over the full 10-year period, the plan aims to address key energy goals as well as the larger goal of becoming an integrated, competitive and resilient region under the ASEAN Economic Community, with the ASEAN Centre for Energy (ACE) mandated to coordinate these efforts.

1.6 The Role of the Outlook in Supporting ASEAN Energy Development

Since 2006 ACE has utilised the ASEAN Energy Outlook (AEO) as one of the most important documents to support ASEAN energy policy and planning. Over the years, the main objective has stayed the same: to support the creation of pathways for achieving the regional targets. As a way of enhancing cooperation and effectiveness in this objective, the Member States' role in preparing the AEO has become more prominent. Aiming to better support both regional and national development, the 5th ASEAN Energy Outlook (AEO5), published in 2017, was based on the energy policies and targets of the 10 Member States. The results were deemed to be in line with the individual countries' expectations of their future economic and population growth.

This 6th ASEAN Energy Outlook (AEO6) aims for further improvement, acknowledging the feedback and needs of the various stakeholders. It is formally guided by the APAEC regional energy policy and planning (REPP) programme area. ACE and REPP Sub-sector Network (SSN) are tasked to regularly publish a regional energy outlook to better profile the region's energy sector. One of the significant improvements in AEO6 is a bottom-up approach in modelling national energy demand. This approach allows each Member State to adjust and modify the model based on the country's characteristics. As a result, a strong involvement of Member States in the development of AEO6 provided policy-makers with a more direct understanding of the energy trends and challenges faced by the region in the coming decades.

[7] Energy transition is defined as a decarbonisation parthway to transform energy systems from carbon-intensive to cleaner energy. Energy resilience is defined as the capability of energy systems to withstand and recover from high-impact events and reduce the duration, cost and impact of outages on critical services. Both involve reducing climate risk, through mitigation and adaptation strategies, respectively.

This distinguishes AEO6 from other energy outlooks: the model is developed based on strong cooperation, coordination, interaction and integration between ACE and the official appointed experts (statisticians, outlook experts and policy-makers) from the 10 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 region overall.

AEO6 is expected to be the main source of energy information, analysis and projections in the region, providing deep and cohesive insights about the trends in energy supply and consumption at both the regional and national levels; 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 three broad chapters after this introduction. Chapter 2 presents the scenarios under alternative targets and techno-economic assumptions. Chapter 3 provides some specific thematic insights on topics of key relevance to ASEAN. Chapter 4 then highlights policy needs and recommendations. The majority of the technical work has been removed from the main text to improve readability, but data sources are listed in the Appendix, and more details on the technical work are available in associated ACE reports.

The Journey of AEO6 Development

DESIGN

In designing the AEO6, ACE actively engaged the national focal points to work together on the model. The collaboration began at a Working Group meeting on 11–15 February 2019 in Yogyakarta, Indonesia. The meeting was attended by energy data and statistics experts from the ASEAN Member States and aimed to verify and complete the data collection needed for the AEO6 modelling, including energy, power and socio-economic data. A second Working Group meeting was held in March 2019 in Phnom Penh, Cambodia. This time, policy-makers from the Member States shared their perspectives to inform scenarios for future ASEAN energy trends. The developed scenarios also aim to reflect the political situation and global considerations to develop mutual understanding and assumptions that are widely recognised in development work modelling parameters.

DEVELOP

ACE then developed the model over several months, using the Low Emissions Analysis Platform (LEAP)[8] system, a widely used software tool for analysis of energy policy and mitigation of climate change. Once we had preliminary results, ACE staff travelled to each Member State in late 2019 to present them and explain the model assumptions. The final country-specific and regional results were presented at a third Working Group meeting in January 2020, in Bangkok, Thailand. There, ACE staff and representatives of the Member States also discussed how to fill the gaps to attain the 2025 regional targets of 23% of renewables in the total primary energy supply (TPES) and a 30% reduction in energy intensity from 2005 levels; AEO6 reflects the strategies identified in that discussion.

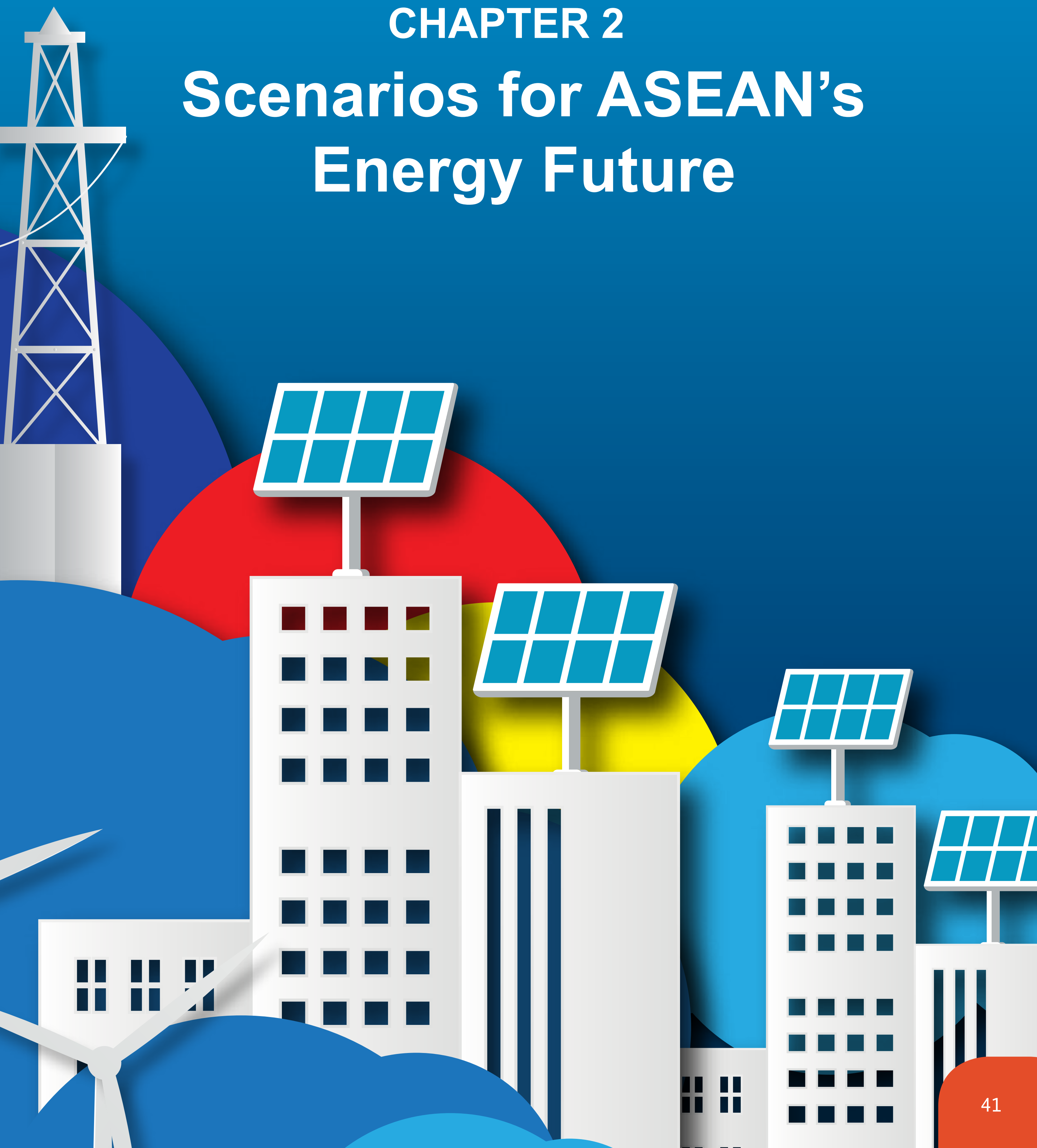
INPUT

Through these direct and virtual interactions, ACE also developed national-level energy models, with input from and in coordination with national experts, who completed the data and information and validated the framework assumptions and modelling projection results. Parameters for every national energy model are based on an in-depth understanding of energy demand and supply trends, as well as knowledge of nationally endorsed energy plans. AEO6 projections have been reviewed by comparing with other energy outlooks, including regional and national outlooks. Data, processes and results are reported in consultation with ASEAN's Regional Energy Policy and Planning Sub-sector Network (REPP-SSN) Focal Points. Their guidelines were used for alignment with the region's priorities and goals under APAEC 2016–2025.

8 To learn more about LEAP, go to https://leap.sei.org.

CHAPTER 2

Scenarios for ASEAN's Energy Future



CHAPTER 2

Scenarios for ASEAN's Energy Future

2.1 Understanding the Outlook

The future is obviously uncertain – but by looking at recent trends and known technologies, it is possible to make projections and test the implications of different policy choices and resource constraints. To help ASEAN energy planners and policy-makers understand the challenges and benefits of emerging energy trends, AEO6 explores four scenarios. Like AEO5, the analysis uses 2040 as an endpoint, which takes the projections beyond the targets of the UN Sustainable Development Goals (SDGs). This is within the typical range of most energy scenarios, with a timeline that allows clear incorporation of technology maturity, policy directions and investment cycles. The scenarios start with largely the same suite of technologies, but each assumes a different set of targets and policies, with escalating levels of ambition, and explores the implications for energy demand, energy supply and CO_2 emissions:

Baseline Scenario

This scenario assumes that the ASEAN Member States' energy systems continue to develop along historical trends, mainly using fossil fuels, without significant changes. It also assumes relatively low efforts are made to meet the recently agreed-upon energy efficiency and renewable energy targets. This scenario is not meant to show "business as usual", but rather allows us to compare the other scenarios with historical progress. It reflects the Member States' most recent national power development plans, and where additional power generation capacity is needed, it is assumed to match historical trends.

APAEC Targets Scenario (APS)

This scenario APS explores the implications if ASEAN Member States collectively strive to achieve the regional targets for energy intensity and renewable energy outlined in APAEC 2016–2025. This scenario assumes a higher level of ambition for energy efficiency beyond 2025, and stronger penetration of renewables, with the most economically feasible efforts to be pursued. This scenario represents a progression from existing national targets to the aspirational targets agreed under APAEC.

AMS Targets Scenario (ATS)

This scenario projects the future development of ASEAN energy systems if the Member States do what is needed to fully achieve their own national energy efficiency and renewable energy targets, as well as their NDC commitments – but do not make adjustments to reflect ASEAN regional targets.

Sustainable Development Goals (SDG) Scenario

SDG 7, "Affordable and Clean Energy", challenges countries to "ensure access to affordable, reliable, sustainable and modern energy for all". The SDG Scenario projects the future development of the ASEAN energy systems if the Member States raise their ambition beyond their national targets to achieve SDG 7, which has three targets for 2030: to ensure universal access to affordable, reliable and modern energy services; increase substantially the share of renewable energy in the global energy mix; and double the global rate of improvement in energy efficiency (from 2015 levels).

Table 1. Summary of AEO6 Energy Scenarios and Key Assumptions

	Energy Efficiency	Renewable Energy	Power Capacity	Focus on NDCs
Baseline	Kept constant at the level for last historical year	Growth rate based on last historical year	Consistent with ASEAN Power Development Plan (PDP)	Only to the extent reflected in National Power Development Plans
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 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	Accelerate deploy-ment of RE capacity, based on each coun-try's potential	Energy-related NDCs, including EE, RE and energy access targets, but scaled up where possible
SDG Scenario	Doubling the global rate of improvement in energy efficiency by 2030.	By 2030, increase substantially the share of renewable energy in the global energy mix.	Same as in ATS	Energy Access By 2030, ensure universal access to electricity (electrification) and clean cooking

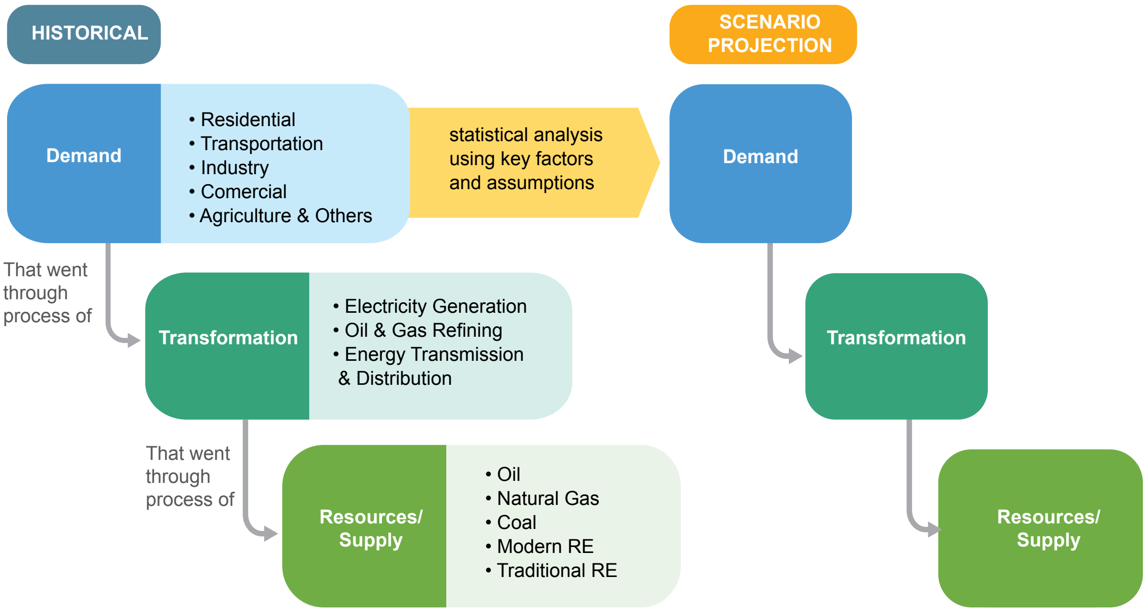
2.1.1 Modelling Methodology

Modelling the energy systems of a group of nations requires significant, reliable and appropriate data and mathematical models. This section provides a very brief description of the modelling methods used; more details are provided in the Appendix. AOE6 relies on a hybrid methodology that combines "top-down" and "bottom-up" approaches to estimate changes in energy demand from different end-use sectors in ASEAN economies. The specific approach for each sector was determined based on data availability and reliability.

The top-down approach, which is commonly used to develop regional and national energy models, looks at the relationships between time-series data on energy consumption and key macroeconomic data – GDP per capita, population and urbanisation rate – to forecast changes in demand based on historical behaviour. The top-down approach is also used to model individual sectors, except for residential and transport. Those two sectors were modelled using a bottom-up approach, due to the availability of usable data at the sub-sectoral technology level (e.g. specific types of equipment used in the residential sector or specific vehicle classes in the transportation sector).

To calculate the required energy supply, the model works backwards. It starts with energy demand from all end-use sectors, calculated through both top-down and bottom-up approaches. Then the model estimates the energy lost in the transformation processes – e.g. burning coal or natural gas to produce electricity, as well as power transmission and distribution – required to meet that energy demand. The model's estimate of energy supply is the sum of energy use inputs to transformation and energy demand, after accounting for the balance of energy exports and imports.

Figure 8. How Historical Data are Used to Develop Projections



The data for each of the estimates were obtained from a variety of sources and screened for accuracy and reliability. Where possible, sources from national statistical bureaus were used, and Member State representatives were consulted to further identify and validate the appropriate data. In each of the scenarios, the population and GDP extrapolations stay the same, while energy intensity, energy efficiency and the use of certain technologies vary to reflect the policies in place in each scenario.

The key drivers at the macroeconomic level are consistent across the four scenarios and are briefly described here, with further details provided in the Appendix. GDP, which is presented in constant 2011 purchasing power parity (PPP) dollars, is strongly correlated with energy demand projections. AOE6 reflects the expected impact on GDP of the COVID-19 pandemic between 2020 and 2021, as estimated by the Asian Development Bank (ADB). 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, correlates with household sizes, electricity penetration rate, projections for the number of vehicles, etc.).

2.2 Modelling Results: Baseline Scenario

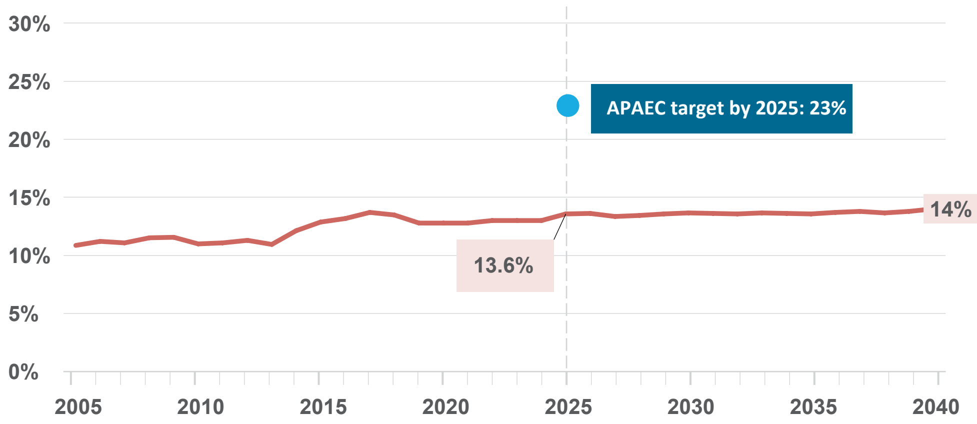
ASEAN has shown rapid growth in energy demand across all Member States and end-use sectors, particularly since 2005, reaching 375 million tonnes of oil equivalent (Mtoe) in 2017.[9] This trend is expected to continue until 2040, in conjunction with growth in the region's GDP and population. As noted above, in the Baseline Scenario, progress on energy efficiency and renewable energy in the Member States continues at a constant level from the latest historical year of reporting (so, for example, if the share of renewable energy was increasing by 1% per year, it continues to increase by 1% per year). Those levels of progress may fall short of the countries' own national targets, and they are significantly less ambitious than the commitments made in APAEC 2016–2025. However, power generation capacity is consistent with the ASEAN Power Development Plan (PDP), and if a country's national Power Development Plan includes additional efforts on energy efficiency or renewables, those are reflected in the scenario.

[9] Source: ASEAN Energy Database: https://aeds.aseanenergy.org.

This scenario makes it possible to examine how a direct continuation of historical energy performance, without further changes in policies or technologies, compares with different options when it comes to achieving the APAEC 2016–2025 targets. Member States have set out to provide 23% of total primary energy supply (TPES) from renewable sources, excluding traditional biomass (wood, charcoal, bagasse, and agriculture waste) consumed by the residential sector. The second target considered in the analysis is to reduce energy intensity – measured as the ratio of TPES to GDP, in constant 2011 international dollars – by 30% from 2005 levels.[10]

As Figure 9 indicates, in the Baseline Scenario, ASEAN falls far short of the renewable energy target, with renewables accounting for only about 14% of TPES. There is also virtually no further improvement up to 2040. This indicates that ASEAN has not been developing RE fast enough to reach the regional target.

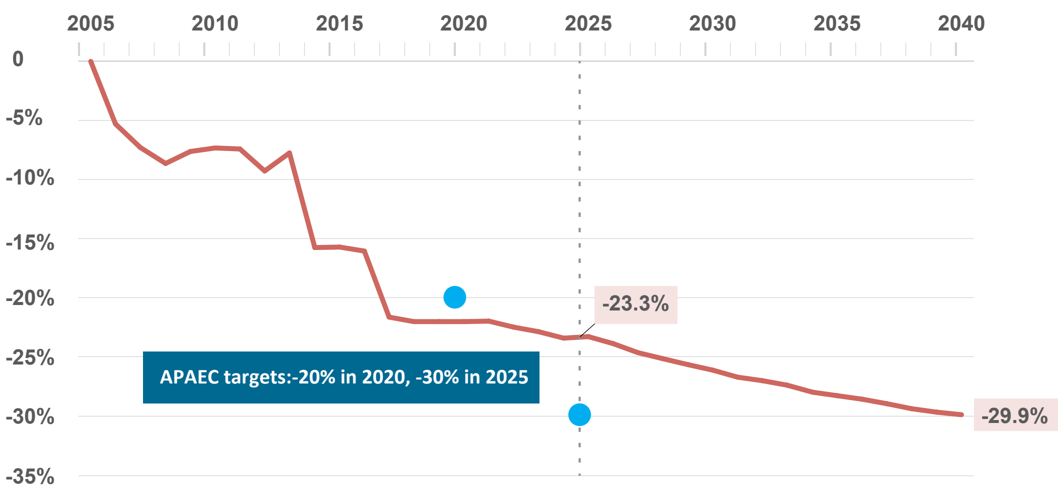
Figure 9. Renewable Energy Share in TPES, Baseline Scenario



Source: ASEAN Energy Database: https://aeds.aseanenergy.org.

Similarly, as shown in Figure 10, although the energy intensity of the ASEAN economy had been declining, and seemed to be on track to meet the 2025 target, progress has slowed, and in this scenario, the energy intensity reduction would fall short by more than 7 percentage points. At this pace, the 2025 target would only be reached around 2040.

Figure 10. ASEAN Energy Intensity Reduction from 2005 Level (TPES/GDP), Baseline Scenario



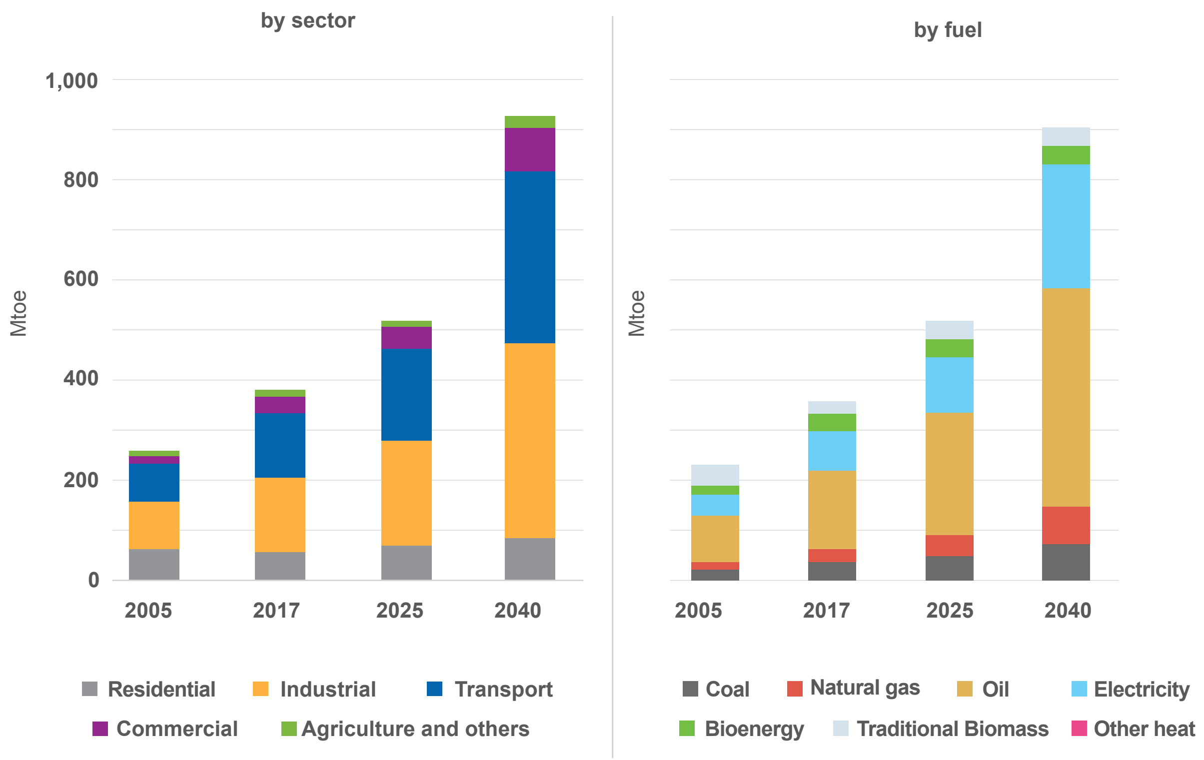
[10] In the plan for APAEC Phase II (2021–2025), which AMS are expected to endorse at the 38th ASEAN Ministers on Energy Meeting (AMEM) in Vietnam in November 2020, the energy intensity target will be updated to increase regional ambition.

2.2.1 Final Energy Demand by Sector and by Fuel

The first model output examined is total final energy consumption (TFEC) – that is, the amount of energy consumed each year across all end-use sectors of the economy. It is important to note that TFEC reflects the breakdown of energy carriers ("fuels") as used directly by end-users, not for production of another fuel or power for resale. For example, coal used directly in industrial processes would be categorised as "coal", while coal used in an electrical utility's coal-fired power plant would fall under "electricity".

In the Baseline Scenario, TFEC in ASEAN is projected to increase by 146% by 2040, rising to 922 Mtoe from 375 Mtoe in 2017 (see Figure 11). With no policy interventions, fossil fuels continue to predominate. Reflecting extensive development in recent years, natural gas grows fastest throughout the projection period, with a compound annual growth rate (CAGR) of 5.7%, followed by electricity (5%) and oil (4%). However, oil and electricity still make up the largest share in TFEC, despite the lower growth rate. Oil is shown leading through 2040, at 47.1% of TFEC, followed by electricity (25.7%), natural gas (10.6%) and coal (7.6%).

Figure 11. Total Final Energy Demand (TFEC) by Sector and by Fuel, Baseline Scenario

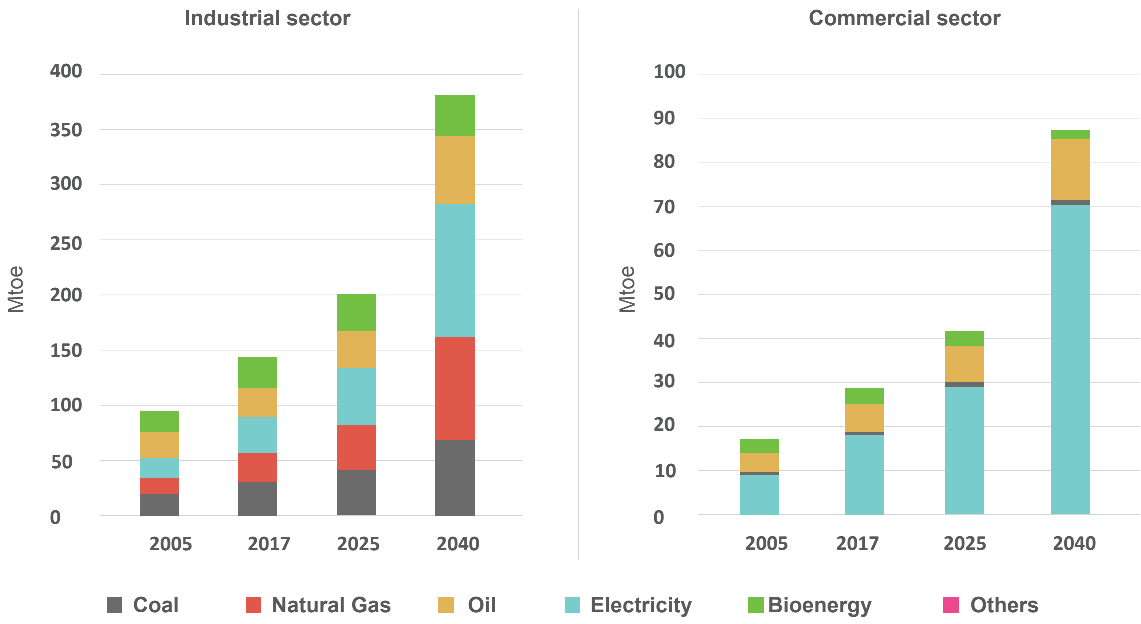


Another reason why natural gas consumption is growing so rapidly relative to other fuels is that gas is increasingly used in the region's fast-growing industrial sector. Industry and transport – both energy-intensive sectors – account for the vast majority of TFEC share until 2040, with shares of 41.2% and 37.1%, respectively; the residential sector is a distant third, with 10%. A comparison of the two figures highlights how much the needs of individual sectors drive not only energy demand, but the type of fuel used. The model findings for key sectors are explored below.

2.2.1.1 Industry and Commercial

The model shows industry as the sector with the highest projected demand, though demand in the commercial sector grows faster. Because a top-down approach is used for projections in both these sectors, the projected growth rates are driven to a large extent by projected GDP, an independent macroeconomic variable. As shown in Figure 12, with a continuation of the slow historical rate of improvement in energy efficiency, both sectors show notable demand growth, with CAGRs of 4.8% and 4.4%, respectively. Though the commercial sector accounts for a relatively small share of TFEC, its energy demand is projected to triple, to 87.4 Mtoe in 2040, from 29.5 Mtoe in 2017.

Figure 12. Final Energy Demand of Industry and Commercial Sectors, Baseline Scenario

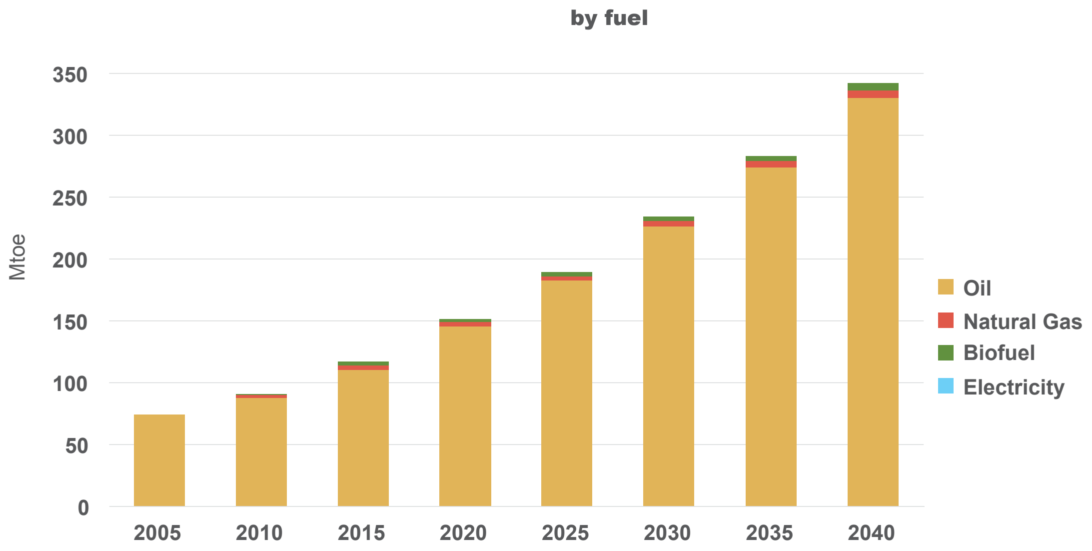


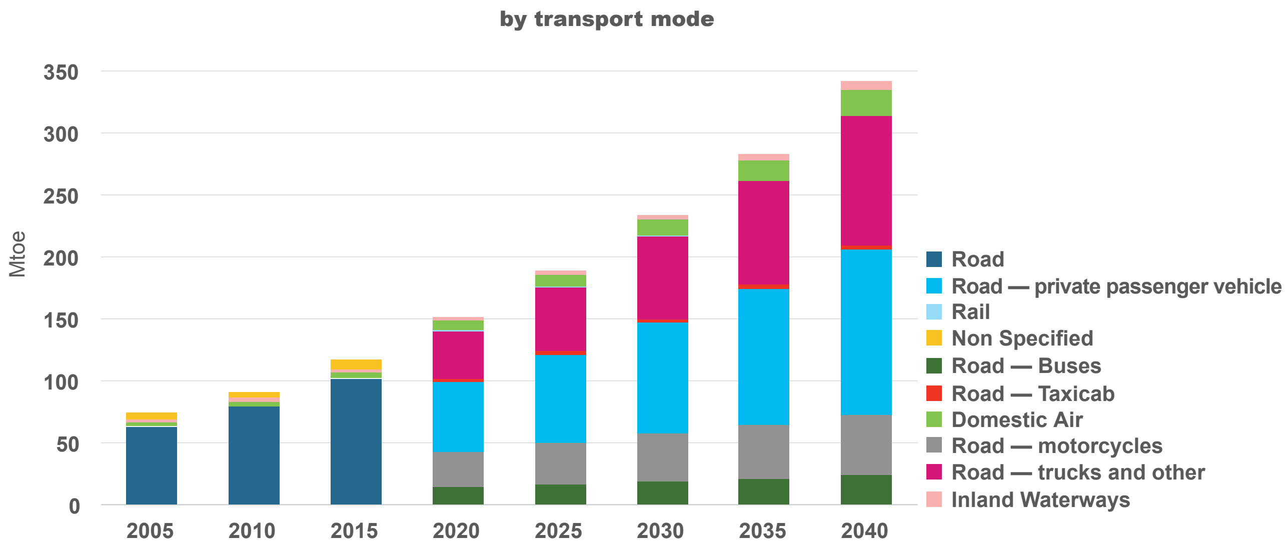
While industry uses a very diverse mix of fuels, the commercial sector relies mainly on electricity, which accounts for 81% of the sector's TFEC in 2040. Notably, the majority of industrial energy demand (58%, or around 222 Mtoe in 2040) is met by fossil fuels – even without accounting for fossil fuels used to produce the electricity consumed by the sector.

2.2.1.2 Transport

Transport is second only to industry for energy consumption in ASEAN, predominantly oil, and its energy demand continues to grow rapidly, at a significant cost to many Member States. Transport accounted for about 70% of oil demand in 2017, and the model shows this rising to 76% in 2040. Continuing historical trends, without efforts to shift away from current technologies, would lead to continued high dependence on fossil fuels. Figure 13 presents the energy demand by type of vehicle. Starting from 2018, fuel demand is broken down by type of vehicle, using a bottom-up modelling approach. From 2017 to 2040, it can be observed that private passenger vehicles and trucks are expected to be responsible for most energy consumption in the transport sector (39% and 31%, respectively).

Figure 13. Transport Energy Demand, Baseline Scenario

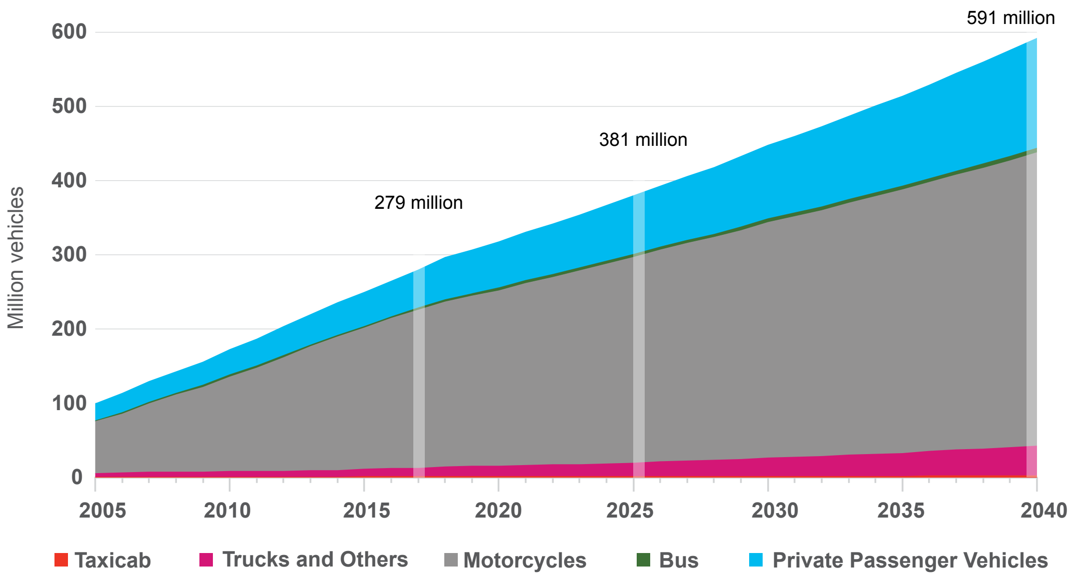




The energy share is related to the number of vehicles and the efficiency of those vehicles. The average number of kilometres travelled per vehicle per year is assumed to be constant.[11] The total number of vehicles in ASEAN is projected to more than double from 2017 levels, reaching 591 million in 2040. Motorcycles and private passenger vehicles are expected to dominate, with 67% and 25% shares, respectively. Though trucks make up only 6.8% of vehicles in ASEAN, they account for an outsized share of transport energy demand, due to their far-lower fuel economy: around 3–5 km/litre for trucks and 30–47 km/litre for motorcycles in 2017. Motorcycles are the most common type of vehicle in ASEAN, historically and in future projections. It is also important to note that the region's energy consumption excludes the international aviation and maritime sectors, which are often accounted for separately in GHG accounting.

[11] The average annual kilometres travelled are collected from national survey and Focal Point consultations: private passenger cars: 11,000 km, buses: 20,000–22,000 km, motorcycles: 5,000 km, trucks: 15,000 km, taxicabs: 16,000–24,000 km.

Figure 14. Projected Number of Road Vehicles in ASEAN, Baseline Scenario

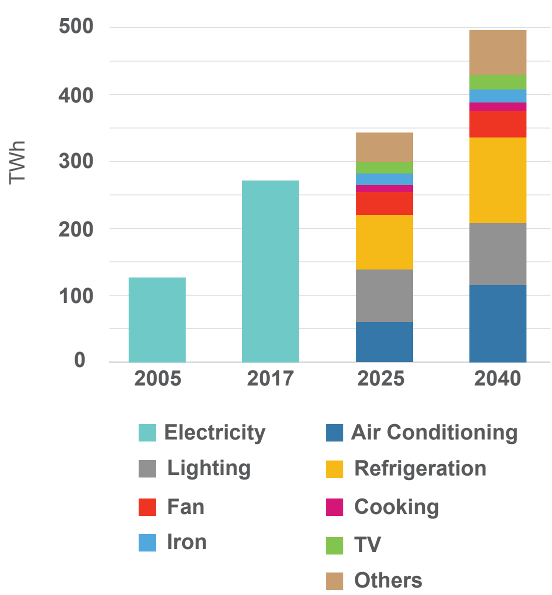


2.2.1.3 Residential Sector

As noted earlier, the residential sector accounts for only 10% of TFEC in 2040 in this scenario, but it shows a very distinct energy demand growth pattern, reflecting the impact of development and changing lifestyles. Electricity use grows a steadily until it makes up the largest share of TFEC for the sector, 46% in 2040, or 43 Mtoe – though traditional biomass still comes in second, at 40% in 2040. The growth in electricity is driven by several factors, including ASEAN Member States' concerted efforts to bring electricity to all households. As access to electricity grows and the quality of service improves, this drives an increase in the number of electrical appliances owned by households. At the same time, the number of households is increasing due to population growth.

The home appliance penetration rate and electricity intensity (energy consumption per appliance per household per year) for each Member State were derived from various official sources, such as household socio-economic surveys, reports and studies. The penetration rate was projected as a function of GDP per capita for some appliances such as air conditioners, water heaters, computers and washing machines, which have a statistically significant correlation. Other appliances, such as televisions and electric fans, are common in almost all ASEAN households, meaning that ownership rates for these items do not change with higher incomes. National surveys show that except in Singapore and Brunei, where refrigerator ownership is near-universal, around half of all households in ASEAN have refrigerators. The final electricity usage category was lighting. The estimate for energy consumption for lighting is based on the number of light bulbs per household, operating hours, lamp wattage and type of bulbs used.

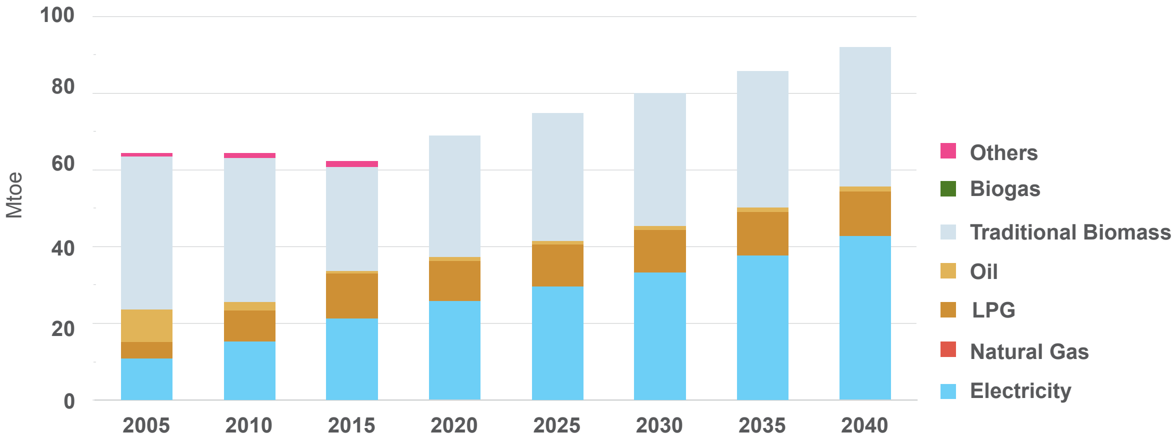
Figure 15. ASEAN Residential Electricity Demand, Historical and Baseline Scenario



Historical data source: ASEAN Energy Database System (AEDS), https://aeds.aseanenergy.org. Note: Disaggregated data for total household electricity demand were not available for 2005 and 2017.

Higher electrification and improved standards of living in ASEAN countries lead to an increase of ownership rates for various electrical appliances, which in turn increases residential electricity demand in the Baseline Scenario, from 272.4 TWh in 2017 to 497.1 TWh in 2040. Figure 16 shows a breakdown of projected residential sector electricity consumption, with cooling taking up a large share in electricity demand: 23% for air conditioning and 8% for fans in 2040; refrigeration uses another 26%. Lighting, meanwhile, accounts for 18% of residential electricity demand. As in the industrial and commercial sectors, the Baseline Scenario reflects the low historical rates of improvement in energy efficiency, so electricity demand keeps growing as population, electricity access and appliance use increase.

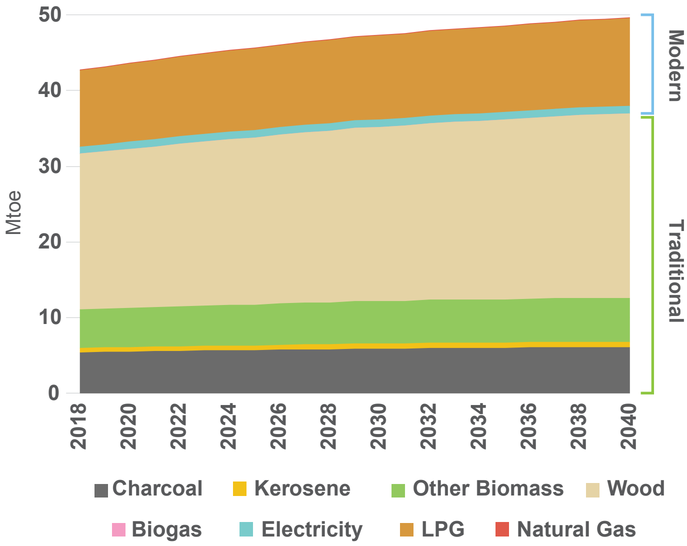
Figure 16. ASEAN Residential Energy Demand Projections by Fuel, Baseline Scenario



Even with significant electrification, traditional biomass continues to play a major role in meeting household energy demand in the Baseline Scenario, mainly for cooking. That demand is also driven upwards by population growth. Data on types of cookstoves used by households, stove efficiency, and use of energy per person per year were drawn from socio-economic surveys alongside national and WHO database[12] reports. At the start of the modelled period, around 74% of residential cooking in ASEAN uses traditional biomass sources, with wood as the most common fuel, and the share of biomass holds relatively steady through 2040.

Without ambitious policy interventions to promote efficient cooking technologies, traditional biomass will likely continue to be the top residential cooking fuel in ASEAN through 2040.[13] This is of concern because most of these stoves and cooking methods are highly inefficient, carry significant health risks due to air pollution, and in many places, they are associated with deforestation. Consequently, following the historical trend on household biomass use raises concerns about both energy security and sustainability. Notably, 91% of the cooking energy from modern fuels used by ASEAN households comes from oil products, such as liquefied petroleum gas (LPG).

Figure 17. Projected ASEAN Household Cooking Energy Demand, Baseline Scenario



[12] See https://www.who.int/airpollution/data/household-energy-database/en/.

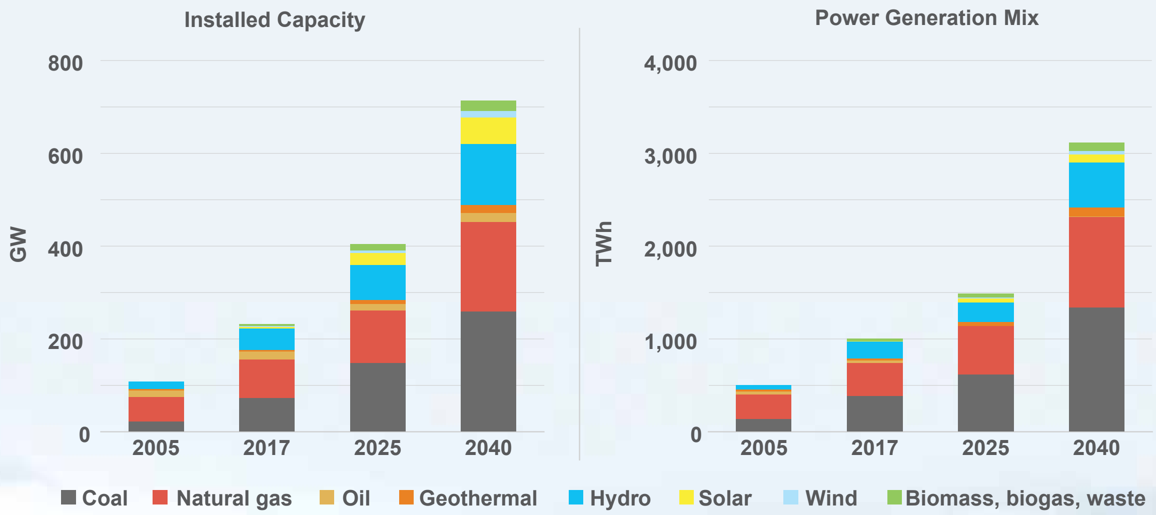
[13] As discussed in Section 3.5, some ASEAN Member States have made major strides in clean cooking in the past two decades, but in others, progress has been very slow.

2.2.2 Power Capacity and Electricity Generation

Electricity generation must be sufficient to meet demand, and power capacity must be sufficient to generate the required electricity. In the power sector, ASEAN has historically relied on fossil-fuelled power plants. This trend is expected to continue in the Baseline Scenario. In 2017, the ASEAN power generation mix was dominated by gas (84 GW), followed by coal (73 GW) and oil (16 GW); these fossil fuels combined made up 73.9% of the total. Other than hydropower, which accounts for 19.7% of the power mix, other renewable generation capacity is still insignificant. In this scenario, hydropower increases and gains a greater share of the power mix by 2040, but other renewables, such as solar, wind, geothermal and biomass, continue to have minimal shares.

Coal will increase its importance in the ASEAN power mix, as installed coal power capacity grows at a CAGR of 3.8% from 2025 to 2040, building on what was already robust growth in the years leading up to 2025. By 2040, ASEAN's coal power capacity is expected to reach 259 GW, up from 79 GW in 2018 and about 3.6 times the current capacity. This reliance on coal reflects the region's considerable reserves and coal's low cost, both of which make it economically attractive to provide electricity in ASEAN countries. By contrast, non-hydropower renewable installed capacity is projected to be about 54 GW by 2025 and 110 GW by 2040 in the Baseline Scenario. Despite renewable power growing by 5% per year, by 2040 the installed RE capacity in ASEAN would still be less than half the coal capacity.

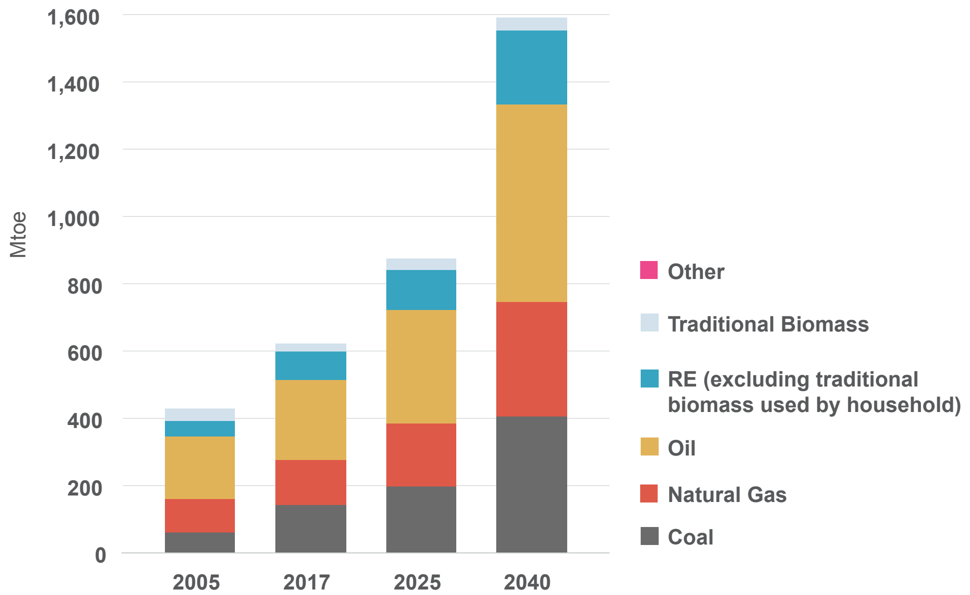
Figure 18. ASEAN Installed Capacity and Power Generation Mix, Baseline Scenario



2.2.3 Total Primary Energy Supply

The analysis above all focuses on total final energy consumption (TFEC). Another key measure is total primary energy supply (TPES) – calculated as energy production, plus energy imports, minus energy exports and international bunkers, and plus or minus stock changes. In the Baseline Scenario, TPES in 2040 is 2.5 times higher than in 2017, 1,589 Mtoe compared with 625 Mtoe (see Figure 19). Most of this growth still involves fossil fuels. Although RE has an annual growth rate of 4.2%, second only to coal (4.8%), gas and oil grow by 4.0% each, so there are only slight changes in each fuel's share of TPES between 2017 and 2040. In 2040, oil still dominates, with a 36.9% share, down slightly from 38.3% in 2017. Meanwhile, coal and gas experience moderate increases in TPES share, from 22.1% in 2017 to 25.3%, and from 20.3% in 2017 to 21.6% in 2040, respectively. Accordingly, fossil fuels still account for 83.8% of the region's TPES in 2040 in the Baseline Scenario, while RE accounts for only about 14% by 2040.

Figure 19. ASEAN Total Primary Energy Supply (TPES), Baseline Scenario



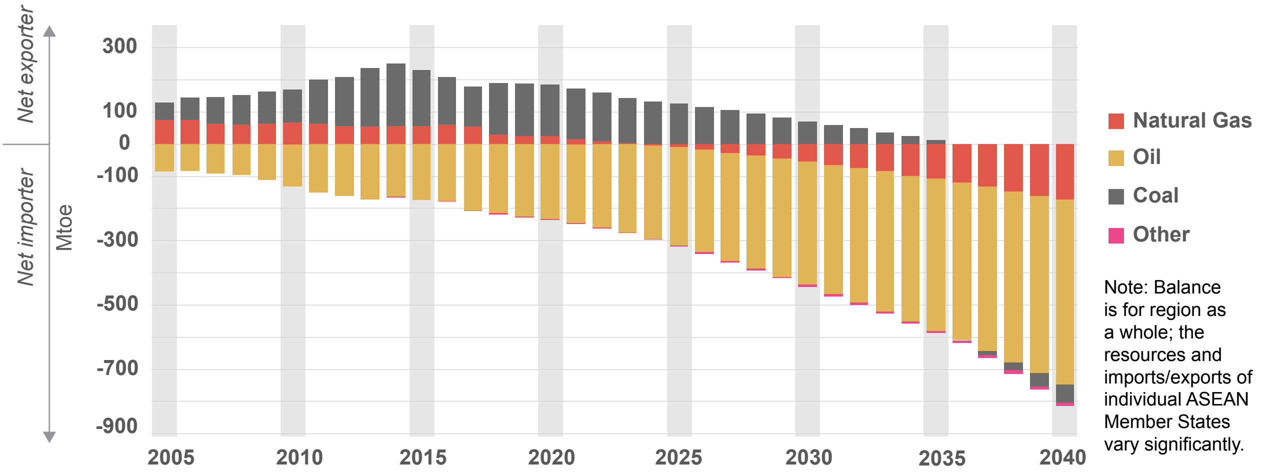
2.2.4 Energy Security, Imports and Exports

A relatively unchanged mix of energy supply in 2040 in the Baseline Scenario poses a significant energy security challenge for the region. Meeting all of ASEAN's demand for fossil fuels through local reserves is beyond the region's capability. This means that with more than four-fifths of TPES coming from fossil fuels, meeting growing energy demand would require increased reliance on fuel imports from other countries and regions. This may put pressure on ASEAN's limited economic resources.

As shown in Figure 20, ASEAN has been a net importer of oil since before 2005, and without significant discoveries and exploitation of domestic resources, imports will increase with projected demand growth. By 2025 it is projected that ASEAN's oil imports will exceed exports by about 304 Mtoe to fulfil its demand, which almost doubles by 2040, to 574 Mtoe, in the Baseline Scenario. The region's demand for natural gas is also expected to surpass local production around 2024; after that, ASEAN becomes a net importer of gas. The same happens with coal, the most abundant fossil fuel resource in ASEAN, in 2035.

With a growing reliance on fossil fuel imports, by 2040, ASEAN could face serious energy security challenges in the Baseline Scenario. Fossil fuel markets are volatile, and fluctuating prices could affect the affordability of fuels needed by the ASEAN economies.

Figure 20. ASEAN Energy Export-Import Balance and Projections, Baseline Scenario



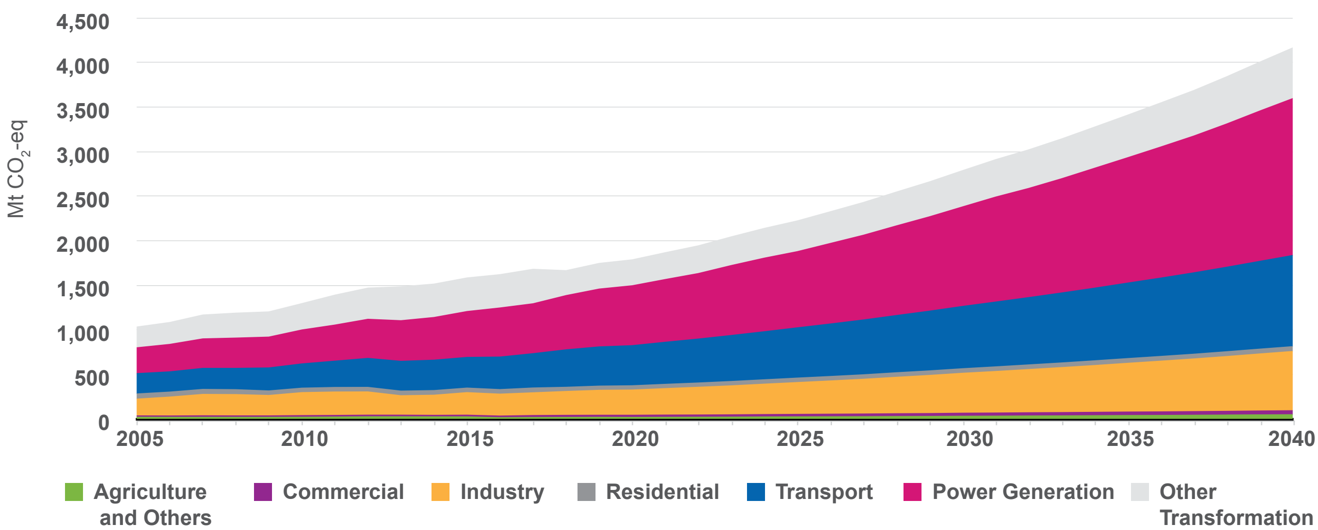
2.2.5 Rising GHG Emissions and Air Pollution

The Baseline Scenario also raises important environmental concerns, especially CO_2 emissions from growing fossil fuel consumption, as well as air pollution – including particulate matter (PM10 and PM2.5), nitrogen oxides (NOx) and other components that harm public health.

In 2017, energy-related GHG emissions in ASEAN countries were about 1,686 Mt CO_2-eq; in the Baseline Scenario, they reach 2,228 Mt CO_2-eq by 2025, then nearly double again by 2040, to 4,171 Mt CO_2-eq. The electricity and transport sectors start out as, and remain, the biggest emitters of GHGs in ASEAN. Electricity and transport account for about 38% and 25%, respectively, of total GHG emissions from energy consumption in 2025, and 42% and 25%, respectively, in 2040.

Given the high vulnerability of ASEAN countries to climate change impacts, allowing GHG emissions to keep rising rapidly, as they do in the Baseline Scenario, is very risky. Without significant reductions to global GHG emissions, as envisioned in the Paris Agreement, ASEAN Member States face ever-more serious climate change impacts over the coming decades, including severe disaster risks such as floods and typhoons, extreme heat, prolonged droughts, and sea-level rise. ASEAN is projected to suffer some of the largest economic impacts from climate change (IPCC 2018a). The Asian Development Bank estimates that climate change could reduce Southeast Asia's GDP by 11% by the end of the century as it damages key sectors such as agriculture, tourism and fisheries, along with human health and labour productivity (Raitzer et al. 2016).

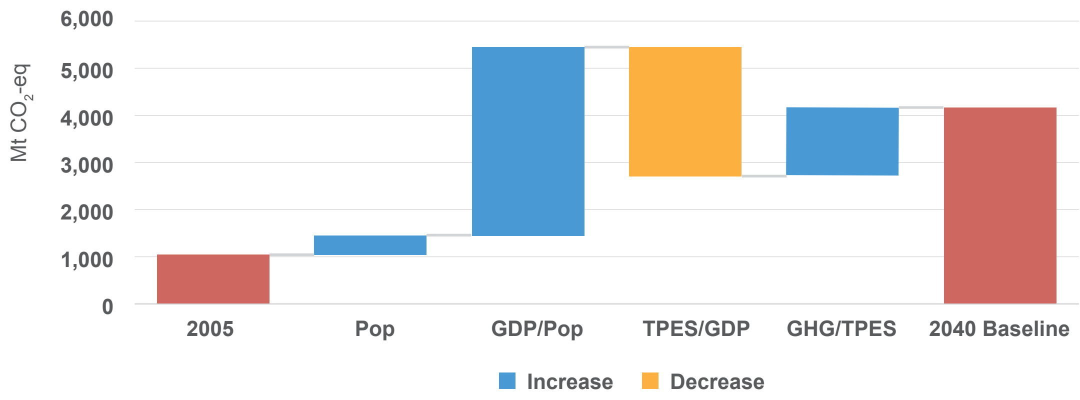
Figure 21. ASEAN Energy-Related GHG Emissions by Sector, Baseline Scenario



In order to identify the relative importance of different drivers of GHG emissions in the Baseline Scenario, a decomposition analysis was conducted based on the Kaya identity equation (Kaya and Yokobori 1997), which makes it possible to quantify the relative impact on GHGs of population growth, income (as GDP per capita), energy intensity (as TPES/GDP), and carbon intensity of energy (as energy GHGs/TPES). The analysis shows that GDP growth is by far the biggest driver of energy emissions growth in the Baseline Scenario, about 4,171 Mt CO_2-eq, with some contributions from increased carbon intensity of the energy supply and population growth as well, accounting for 1,448 and 411 Mt CO_2-eq, respectively. Meanwhile, a reduction in the energy intensity of the economy offsets the emissions increase by about 2,731 Mt CO_2-eq, but nowhere near enough to avoid a sharp overall rise in GHG emissions.

The clear connection to rising incomes has important policy implications for ASEAN Member States. Given that continued GDP growth is central to the ASEAN countries' development, this suggests that if Member States want to avoid a surge in energy-related emissions, they need to make far more ambitious efforts to reduce energy intensity and carbon intensity than they have made until now.

Figure 22. Decomposition Analysis of GHG Emissions



2.3 Modelling Results: National Targets Scenario (ATS)

As a region with many emerging economies, ASEAN cannot afford to adopt measures that slow down economic growth. However, the Member States also recognise that continuing along historical trends, as described in the Baseline Scenario, is not a viable option. Without policy interventions, surging energy demand clearly poses risks to future energy security and emission reduction efforts.

ASEAN Member States have stepped up by proposing national energy efficiency (EE) and renewable energy (RE) targets, and by submitting Nationally Determined Contributions (NDCs) under the Paris Agreement that include GHG emission reduction targets. Tables 2 and 3 summarise those targets, which Member States aim to achieve by changing their energy mix to rely less on fossil fuels and adopting sector-specific measures.[14] In addition, Indonesia and Myanmar have both set targets of 100% electrification – by 2020 and 2030, respectively. The AMS Targets Scenario models the implications of fully implementing these national policies.

[14] Along with reviewing the relevant policy documents, the AEO6 team verified and updated the targets through the country consultation process.

Table 2. Official Energy Efficiency targets of the 10 ASEAN Member States

AMS	Reference	Official Targets
Brunei Darussalam	Discussion with MEMI (AEO6 Country Visit, 30 October 2019)*	30% reduction of electricity consumption by 2035 from 2011 levels in all sectors (residential, commercial, industrial and government)
Cambodia	AEO6 2nd working meeting (26–28 March 2019); confirmed with MME during AEO6 Country Visit, 14 November 2019*	15% total final energy consumption per GDP (value added) reduction in industry by 2030
		15% increase in engine efficiency of buses (transport) by 2030
		15% energy demand reduction by 2030 relative to baseline**
	NDC	Electricity transmission losses reduced to 8% by 2030, from 15.8% in 2017
Indonesia	Government Regulation No. 79/2014: National Energy Policy	1% reduction per year in energy intensity (TPES per GDP) up to 2025
Lao PDR	Lao PDR Policy on Energy Efficiency and Conservation, MEM. Last confirmed with Lao PDR in AEO6 Country Visit, 12 November 2019*	10% reduction in total final energy consumption (TFEC) by 2030, and 20% by 2040, relative to baseline**
Malaysia	National Energy Efficiency Action Plan (NEEAP) 2015	8% reduction (about 12.4 TWh) in electricity consumption by 2025 relative to baseline**
	Third National Communication (TNC)/Biennial Update Report (BUR) 2	Increase the share of efficient vehicles, such as hybrid and electric vehicles, in road transport
Myanmar	National Energy Efficiency & Conservation Policy, Strategy, and Roadmap for Myanmar, ADB (2015)	12% reduction in energy consumption (TFEC) by 2020, relative to baseline;** 16% reduction by 2025; and 20% reduction by 2030
		2.3% reduction by 2020 in traditional biomass use, relative to 2012 levels, from promotion of energy-efficient cooking stoves; 5% reduction by 2025; and 7% reduction by 2030
Philippines	AEO6 1st Country visit to Philippines(16 May 2019)	At least 10% reduction in electricity use across all sectors by 2040 relative to baseline***
		24% cumulative increase of alternative fuel vehicles (hybrid and electric vehicles) by 2040 from 2019 levels
Singapore	Sustainable Singapore Blueprint 2015	35% total final energy consumption (TFEC) per GDP - reduction in 2030 from 2005 level
	Charting Singapore's Low-Carbon and Climate Resilient Future	1–2% annual improvement in industrial energy efficiency
	Land Transport Masterplan 2040	100% cleaner-energy public bus fleet and taxis by 2040 (such as electric or hybrid vehicles)
Thailand	Energy Efficiency Plan (EEP) 2015–2036	30% reduction in energy intensity (TFEC/GDP) by 2036 relative to 2010 level
Vietnam	National Energy Efficiency Programme (VNEEP) for the period of 2019-2030 (Decision280/QD)	• 5–7% reduction in total final energy consumption by 2025 relative to baseline*** • Keep power losses under 6.5%
		• 8–10% reduction in total final energy consumption by 2030, relative to baseline** • Bring power losses below 6%, from 8% in 2018 • 5% reduction of fuel and oil consumption in transportation, relative to baseline**

* Note: Along with reviewing the relevant policy documents, the AEO6 team verified and updated the targets through the country consultation process. Where the reference is listed as a meeting, it is because Member States' official representatives provided updated targets if the latest published official targets were considered to be out of date, but new ones had not yet been published.

** In most cases, when asked to characterise the baseline, country representatives recommended referring to AEO6's Baseline Scenario.

Table 3. Official Renewable Energy Targets and NDCs of the 10 ASEAN Member States

AMS	Reference	Official Targets
Brunei Darussalam	Discussion with MEMI16 (AEO6 Country Visit, 30 October 2019)*	10% renewable energy share in installed power generation capacity by 2035
Cambodia	AEO6 2nd working meeting16 (26-28 March 2019). Last confirmed with MME Cambodia in AEO6 Country Visit, 14 November 2019.*	3% of residential electricity demand met by rooftop solar PV by 2035
Indonesia	Government Regulation No. 79/2014: National Energy Policy	23% RE in primary energy supply by 2025
	Ministry of Energy Regulation 12 /2015 –Mandatory Biofuel; Indonesia Energy Outlook (National Energy Council, 2019)	Biodiesel blending ratio target 30% by 2020, and maintain that level through 2025 and to 2050
	Ministry of Energy Regulation 26 /2016 –Mandatory Biofuel	20% bioethanol blending ratio target by 2025; 50% by 2050
Lao PDR	Vision 2030, Strategic Plan 2025, and 5-year power development plan (2016-2020), MEM. Last confirmed with Lao PDR in AEO6 Country Visit, 12 November 2019*	30% RE share of total energy consumption by 2025, including 20% of electricity from RE that is not large-scale hydro, and 10% biofuel share (blending ratio 5–10%)
Malaysia	National Renewable Energy Policy and Action Plan (NREPAP) 2011	20% RE in the power capacity mix by 2025 (excluding large-scale hydro)
Myanmar	National Energy Master Plan (2015)	12% share of RE in national power generation mix by 2030 (excluding large-scale hydro)
Philippines	National Renewable Energy Program (NREP) 2011 – Sectoral Plans and Roadmap	Triple RE installed capacity by 2030 from 2010 level, to 15.3 GW from 5.4 GW
	Biofuels Roadmap Short Term: 2017 - 2018 - Sectoral Plans and Roadmap	Biofuel blending ratio around 2% for biodiesel and 10% of bioethanol
Singapore	Sustainable Singapore Blueprint 2015 Singapore's Energy Story	350 MWp** of solar capacity by 2020 and at least 2 GWp by 2030
Thailand	Alternative Energy Development Plan (AEDP) 2015	30% RE share in total final energy consumption (TFEC) by 2036, including15–20% renewable electricity in total generation; 30–35% of consumed heat from renewables; and a 20–25% biofuel share in TFEC
Vietnam	Vietnam's Renewable Energy Development Strategy up to 2030 with an outlook to 2050 (Decision2068/QD)	32.3% RE share in TPES by 2030 and 44% by 2050; 32% RE share in power generation by 2030 and 43% by 2050

* Note: Along with reviewing the relevant policy documents, the AEO6 team verified and updated the targets through the country consultation process. Where the reference is listed as a meeting, it is because Member States' official representatives provided updated targets if the latest published official targets were considered to be out of date, but new ones had not yet been published.

** MWp (megawatt peak) denotes a solar installation's nominal capacity; actual power generation is typically somewhat lower than peak power.

2.3.1 Understanding the Translation of the Targets into the Model

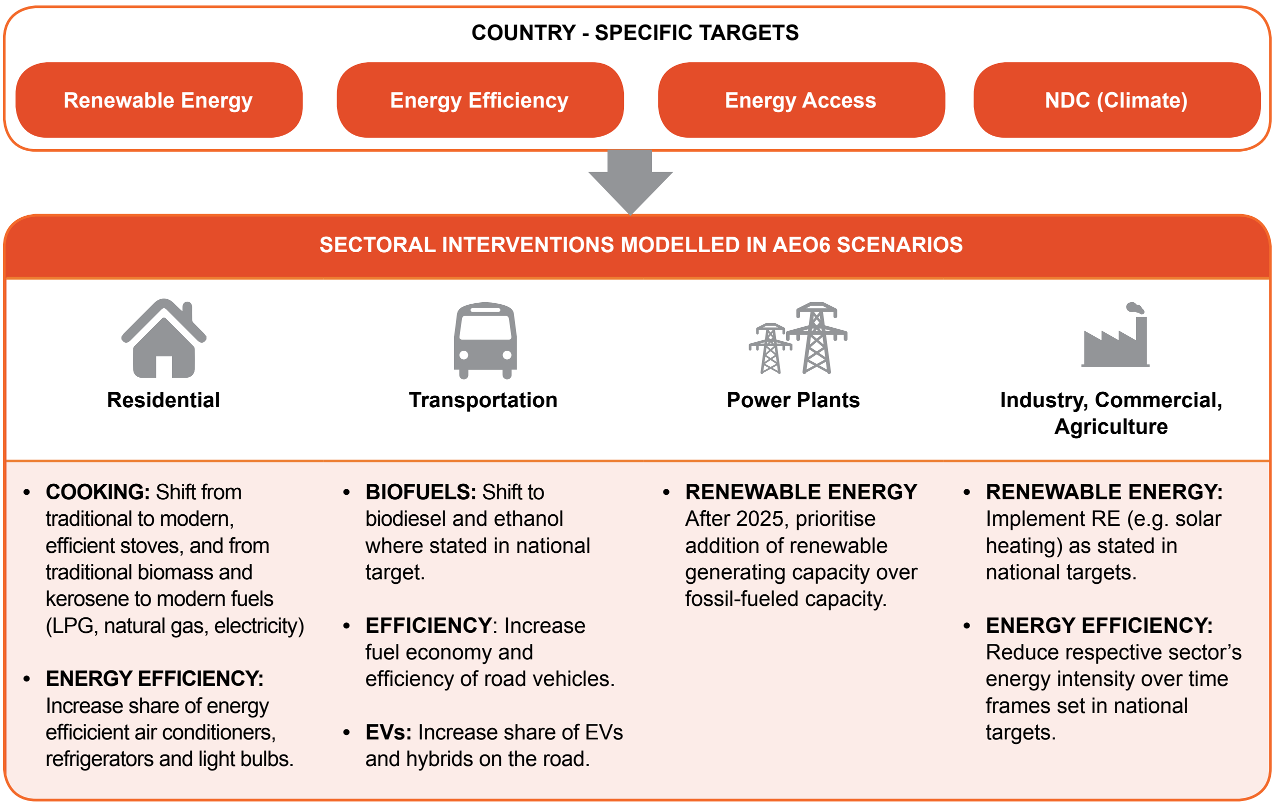
The national targets set by the ASEAN Member States fall into two broad categories: high-level and technical targets. Each requires a different approach to incorporate it into a scenario for modelling.

High-level targets set a goal for the economy or a sector – for example, to reduce energy consumption by 10% by 2025 relative to a baseline scenario – but do not specify the policies or programmes that will be used to attain it. To incorporate those goals into the model, available and feasible market-driven options were explored with experts. Existing technologies and least-cost options were prioritised over complex, immature or emerging technologies and expensive choices. For example, to achieve energy savings in the residential sector, switching from incandescent and fluorescent light bulbs to LED bulbs within the next 5–10 years is a policy priority. This is based on a common bulb lifespan of about 3 years and the price of LEDs already being competitive with fluorescent bulbs. LED manufacturing is also expanding and replacing the production of incandescent and fluorescent bulbs.

Technical targets, meanwhile, specify the technology to be applied in a given sector – for example, switching 50% of conventional gasoline vehicles to electric vehicles by 2030. This type of target could be incorporated into the model directly.

The AMS Targets Scenario assumes that all the Member States' energy efficiency, renewable energy, and energy-related NDC targets are achieved. All actions implemented in the model to achieve the national targets were discussed and verified with Member States' Focal Points at the third Working Group meeting in Bangkok in January 2020, as well as by email, to ensure that the model parameters accurately reflected their countries' policies. The sections that follow explore the implications of achieving national targets for energy systems and GHG emissions across ASEAN.

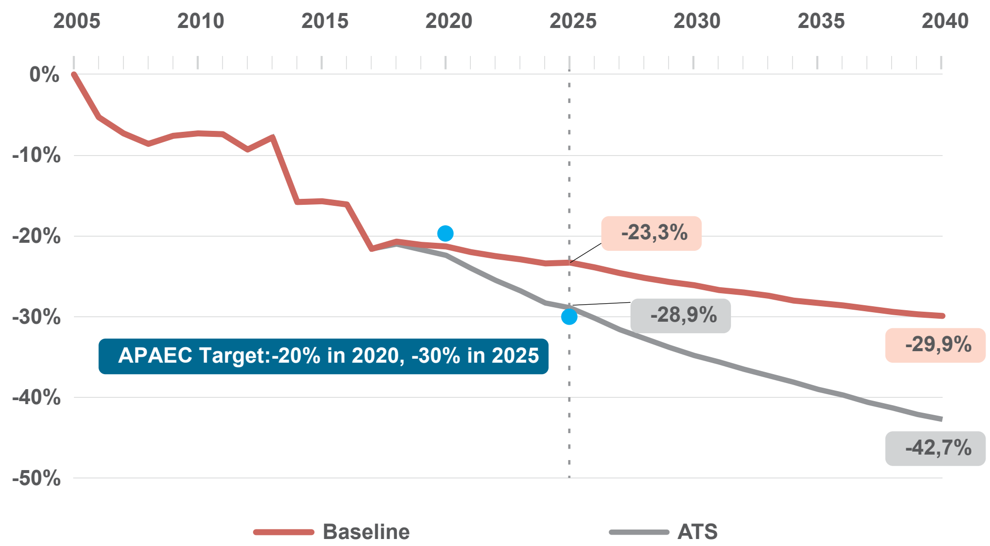
Figure 23. Translation of Targets into the Model



2.3.2 Implications for Energy Intensity and Share of RE

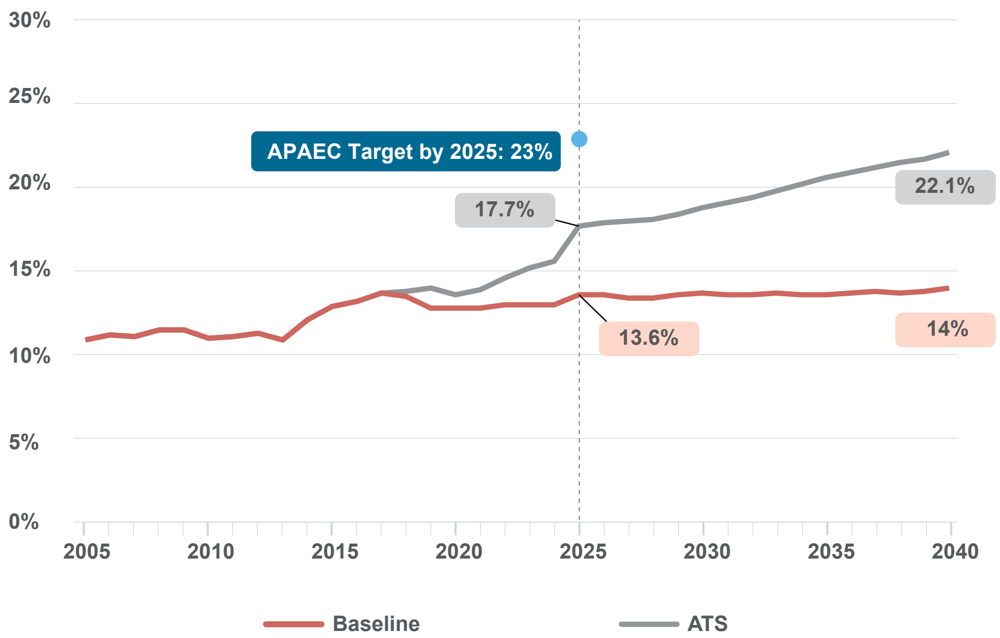
Given that this scenario is built around national energy efficiency and renewable energy targets, the analysis of modelling results begins with a look at the two most relevant measures: the primary energy intensity of the ASEAN economy as a whole, shown in Figure 24, and the share of RE in the total primary energy supply (TPES), shown in Figure 25.

Figure 24. ASEAN Energy Intensity Reduction from 2005 Level (TPES/GDP), ATS



The analysis shows that if the national targets are met, ASEAN will come much closer to meeting the APAEC regional target of a 30% reduction in the energy intensity of the economy – 28.9% instead of 23.3%, and achieve a much larger reduction by 2040, to 42.7% below 2005 levels.

Figure 25. Renewable Energy Share in TPES, Compared with Baseline

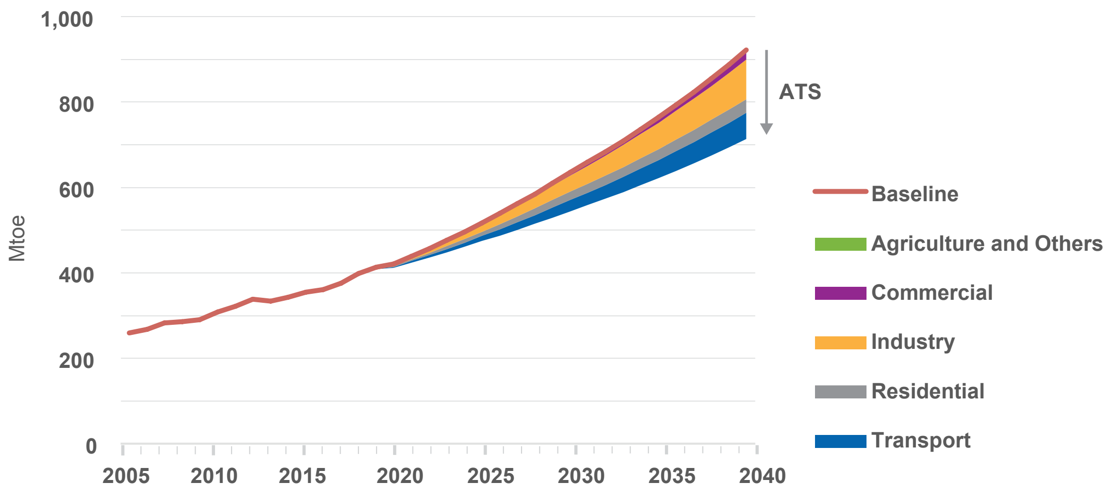


With regard to the share of RE in the total primary energy supply (TPES), the analysis shows that in the AMS Targets Scenario, the share of RE is 4.1 percentage points higher by 2025 than in the Baseline Scenario – 17.7% compared with 13.6%, or 143 Mtoe instead of 119 Mtoe (of a total TPES of 810 Mtoe). By 2040, the difference is 8.1 percentage points, 22.1% RE in the energy mix instead of 14.0%. The gap between the RE share in 2025 in this scenario and the 23% APAEC target is still significant, however. Overall, what these two figures show is that achieving the Member States' national targets would move ASEAN energy systems closer to APAEC vision, beginning to address some of the risks associated with economic growth. The following sections dig deeper into how Member States' national policy interventions could change the trajectories of energy indicators in ASEAN.

2.3.3 Final Energy Consumption and Energy Efficiency

The analysis shows that if ASEAN Member States' national targets are achieved, energy demand growth will decelerate, resulting in a total final energy consumption (TFEC) of 714 Mtoe in 2040, 22% lower than the Baseline Scenario projection of 922 Mtoe. As shown in Figure 26, the largest energy savings are in industry, followed by the transport and residential sectors.

Figure 26. Total Final Energy Consumption by Sector: National Targets vs. Baseline Scenario



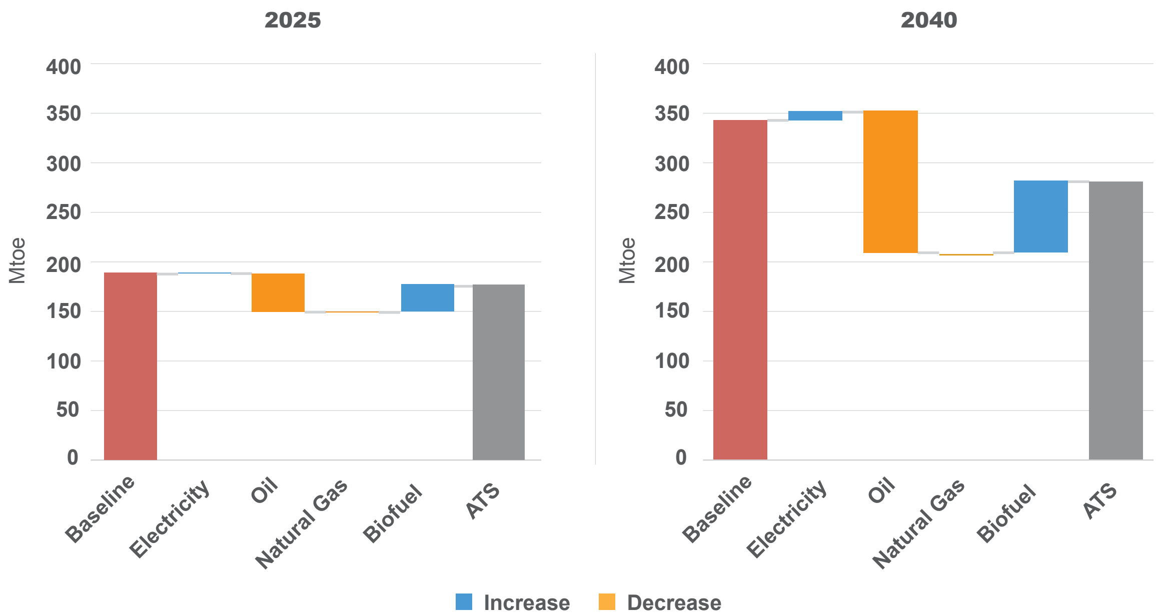
2.3.3.1 Industry

The energy demand reduction in industry is a result of improvements to meet national energy intensity targets by reducing the energy consumption required to produce each unit of value added (GDP). Specific measures would include, for example, adopting higher-efficiency equipment/machinery, heat loss recovery, or industrial restructuring – shifting from energy-intensive to lower-intensity manufacturing. While energy efficiency initiatives typically pay for themselves in the medium- to long term, there are often upfront capital costs that in some cases need subsidies to make them affordable. Changing the industrial structure, meanwhile, takes a concerted cross-sectoral effort and requires consideration of how to incentivise employment and investment in non-traditional industries.

2.3.3.2 Transport

In the transport sector, the model shows an 18% reduction in demand, to 280 Mtoe in 2040, from 342 Mtoe in the Baseline Scenario. The demand decrease results from improving engine performance in all types of vehicles; promoting "eco-cars" (lower-powered private cars); and accelerating the retirement of gasoline/diesel-fuelled vehicles and promoting hybrid and electric vehicles (EVs) among manufacturers and end-users. These vehicle technologies continue to show promising trends in price reduction, making them more affordable for the ASEAN market. Many ASEAN countries – including Indonesia, Malaysia, Thailand and Vietnam – are also leading automobile manufacturers, and some factories are already being overhauled to start producing EVs (see Section 3.4.1).

Figure 27. Transport Energy Demand in the ATS vs. Baseline Scenario



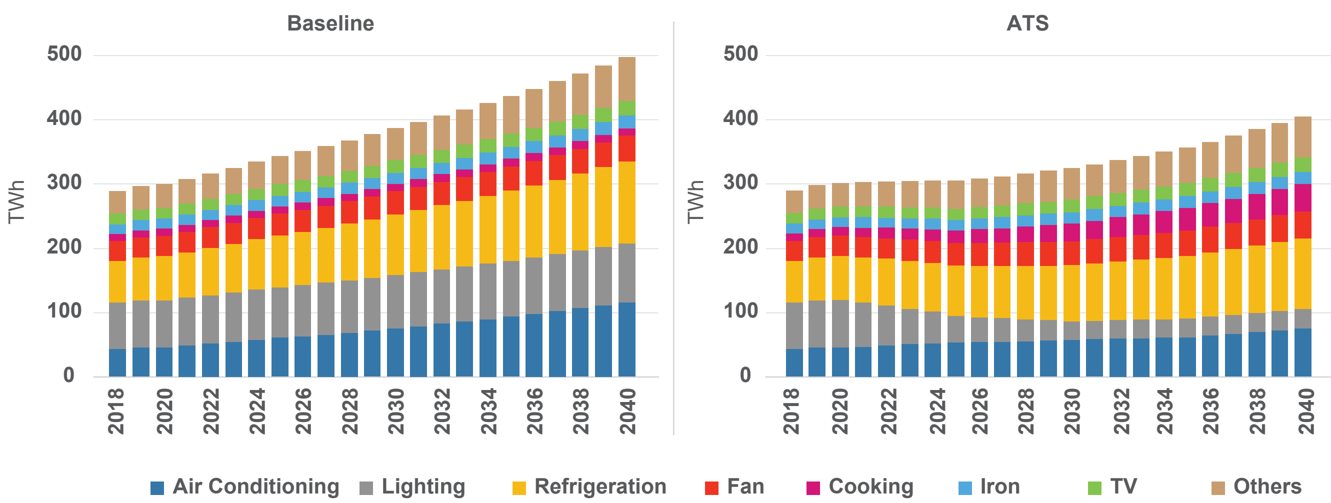
The waterfall charts in Figure 27 show the effects of two sets of policy interventions – energy efficiency measures and biofuel mandates, discussed further below – on energy demand in the transport sector. The charts show the sector's energy demand is lower in the ATS than in the Baseline Scenario – 177 Mtoe vs. 189 Mtoe in 2025, and 280 Mtoe vs. 342 Mtoe in 2040 (the latter an 18% savings). The reduction in oil use is much greater than that, however, to partial substitution with biofuels and electric vehicles; this shift also has a small effect on natural gas demand in the transport sector.

2.3.3.3 Residential

In the residential sector, the AMS Targets Scenario shows savings achieved through energy efficiency schemes focused on home appliances and lighting. Cooling appliances are energy-intensive, with refrigerators, air conditioners (ACs) and fans combined accounting for 57% of total residential electricity consumption in 2040 in the Baseline Scenario. In this scenario, however, energy consumption for cooling is reduced through strategies that encourage consumers to buy efficient ACs and replace older models with more efficient new ones. Increasing the penetration rate of efficient AC can be enabled by competitive price mechanisms and eco-labelling policies (see Section 3.3). As a result of these measures, electricity demand for AC decreases by 35%, from 116 TWh in 2040 in the Baseline Scenario, to 75 TWh in the ATS.

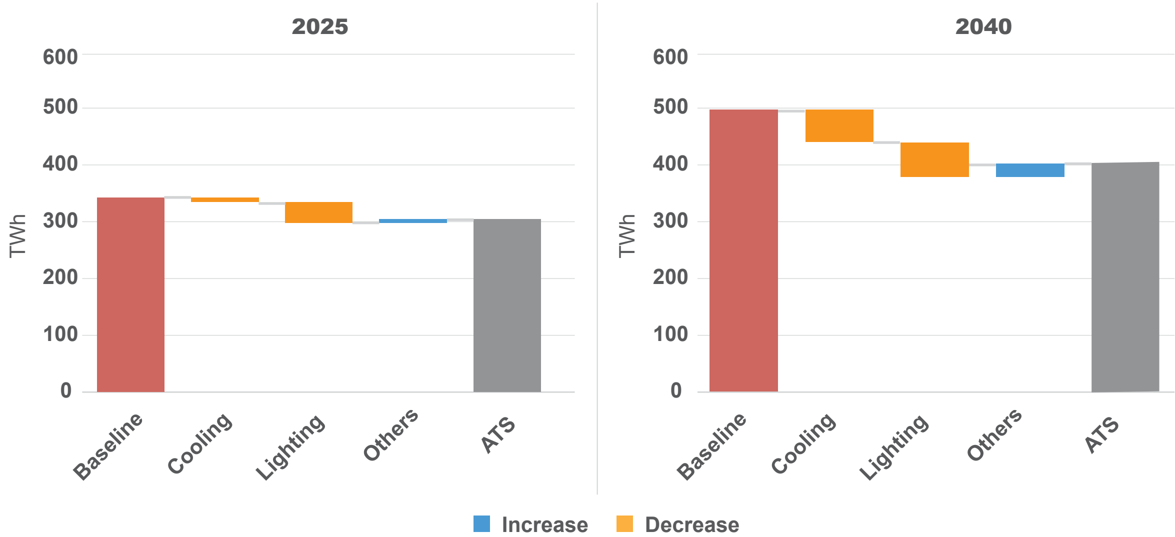
Some Member States have also prioritised improving the efficiency of refrigerators. Given the high cost and long lifespans of refrigerators, eco-labelling policies can be particularly useful, by showing the long-term savings from choosing an energy-efficient model, and not just the refrigerators' retail prices. The AC and refrigeration measures combined would help reduce electricity demand for cooling by 20% relative to the Baseline Scenario, from 283 TWh in 2040, to 227 TWh in the ATS.

Figure 28. Electricity Use for Home Appliances, Baseline Scenario and ATS



The technology with the greatest promise for significantly improving energy efficiency in the residential sector, however, is LED lighting, which benefits from technology and market readiness. The price of LED light bulbs is already competitive with fluorescent bulbs, making the switch to LED both easy and low-cost. Unlike refrigerators or even ACs, light bulbs are changed frequently – especially incandescent bulbs, which often last less than a year. When households replace their light bulbs in coming years, they are increasingly likely to choose LEDs instead of incandescent or fluorescent bulbs. As a result, electricity demand for lighting is expected to significantly decline,[15] to only a third of the level in the Baseline Scenario by 2040.

Figure 29. Residential Electricity Savings in 2025 and 2040, ATS vs. Baseline Scenario



[15] LEDs have lower wattage, meaning they consume less energy to produce the same lumens as fluorescent bulbs. The wattage of light bulbs in our analysis is taken from IIEC (2016)

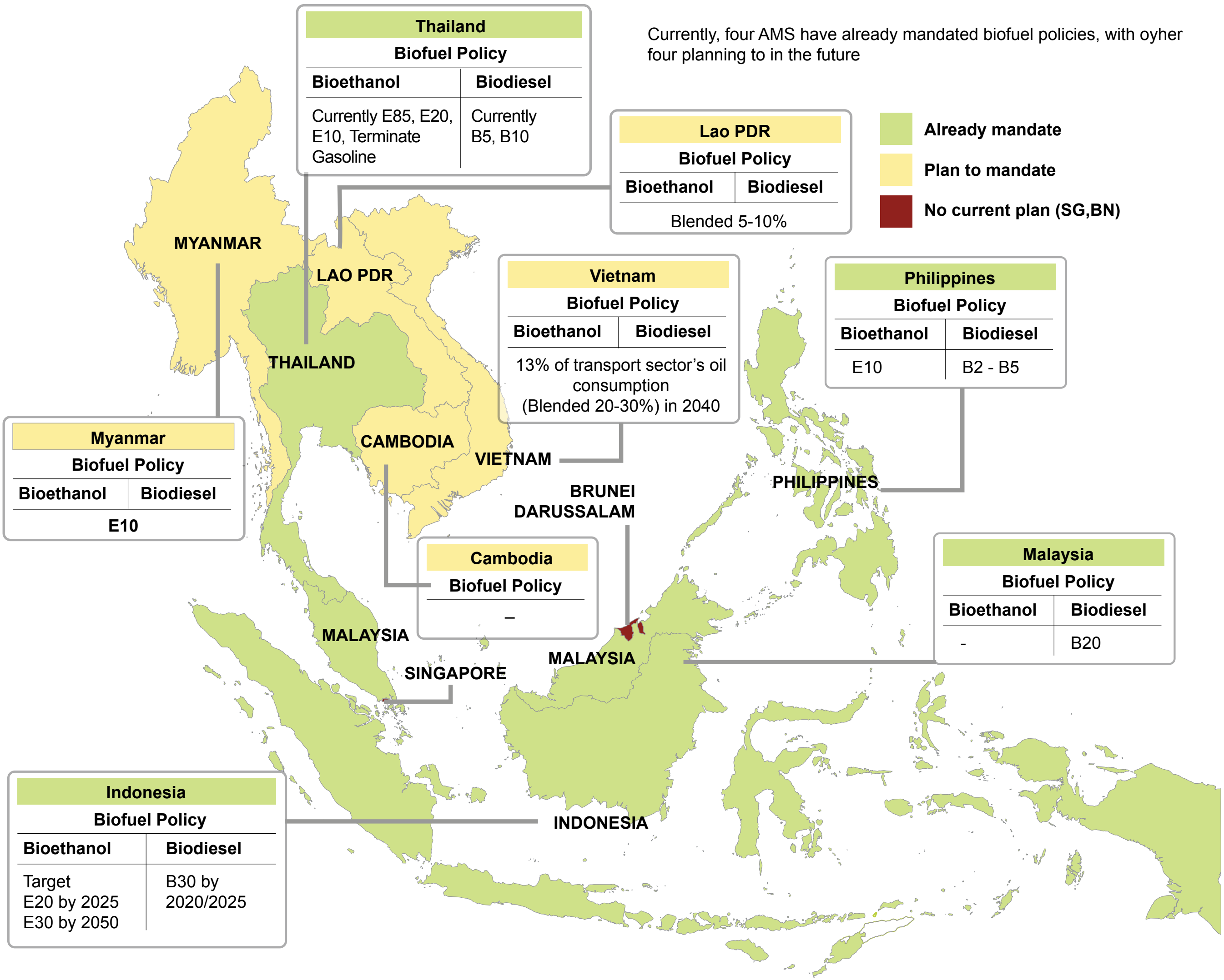
Overall, residential electricity demand in the AMS Targets Scenario is 11% lower than in the Baseline Scenario in 2025, and 19% lower in 2040. The waterfall chart shows that the largest savings would be achieved through more efficient lighting, followed by ACs and refrigerators. These savings are somewhat offset by increased use of certain appliances, especially induction stoves.

2.3.4 Biofuels and Biomass

Along with improved energy efficiency and new technologies, some ASEAN Member States are focusing on biofuels as another way to diversify the energy mix, reduce imported oil usage, and mitigate emissions in the transport sector. At the same time, in the residential sector, they are working to reduce the use of traditional biomass for cooking, to address environmental, health and economic concerns.

Biofuel mandates can accelerate an energy transition toward bioethanol and biodiesel consumption. As of 2019, four ASEAN countries – Indonesia, Malaysia, the Philippines and Thailand – had implemented large-scale commercial bioethanol and biodiesel blending programmes. Vietnam and Lao PDR are in the early stages of this process, while Cambodia and Myanmar are considering biofuel blending. Figure 30 summarises existing biofuel policies in the ASEAN region.

Figure 30. Biofuel Mandates in ASEAN Member States



As shown in Figure 31, in the AMS Targets Scenario, a sharp increase in biofuel use enables the ASEAN economies to keep gasoline and diesel consumption in road transport roughly flat, even as total energy demand more than doubles from 2017 to 2040. The use of biofuels rises from 5 Mtoe in 2017, to 29 Mtoe in 2025 and 79 Mtoe in 2040. Meeting such high demand would require strong, systematic support across the supply chain. Upstream stakeholders such as farmers will require R&D in crop yield improvement and harvesting technologies. Midstream actors such as refineries may need financial support to expand their capacity. Downstream stakeholders may require public awareness campaigns, efficient selling price intervention policies, engine modification services, and other incentives.

Figure 31. ASEAN Energy Demand for Road Transport, ATS

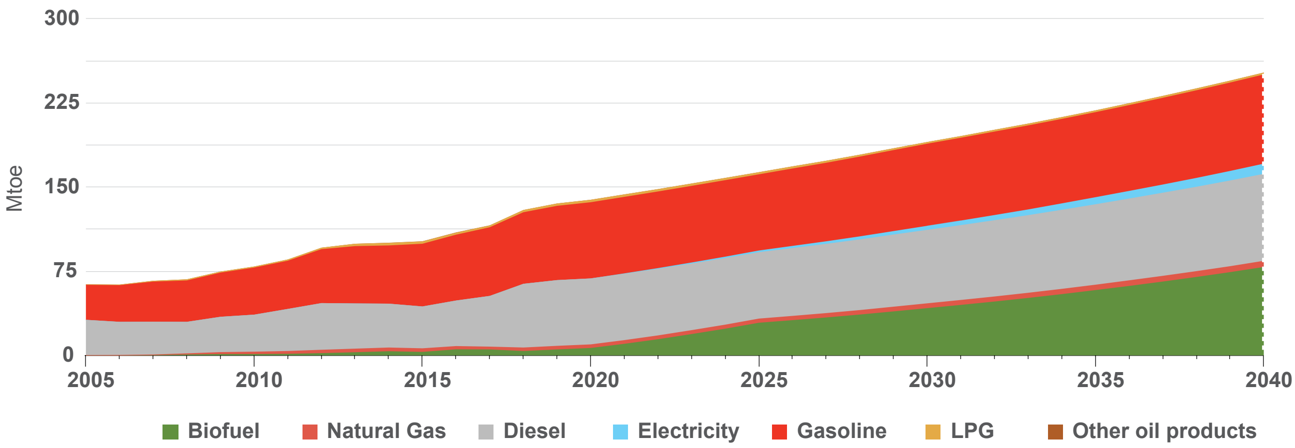
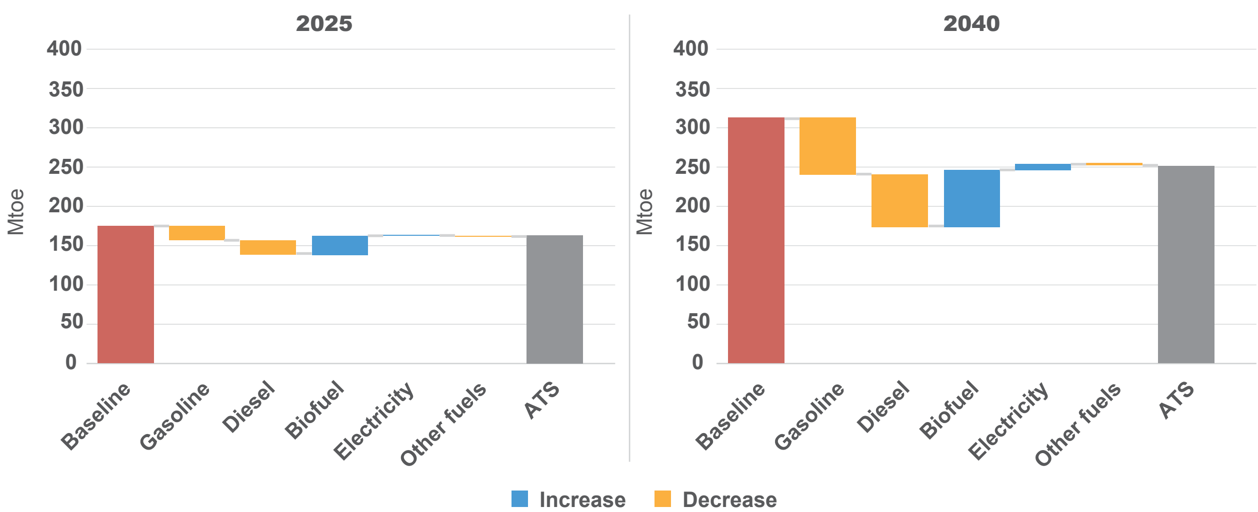


Figure 32. ASEAN Road Transport Energy Demand, ATS vs. Baseline Scenario



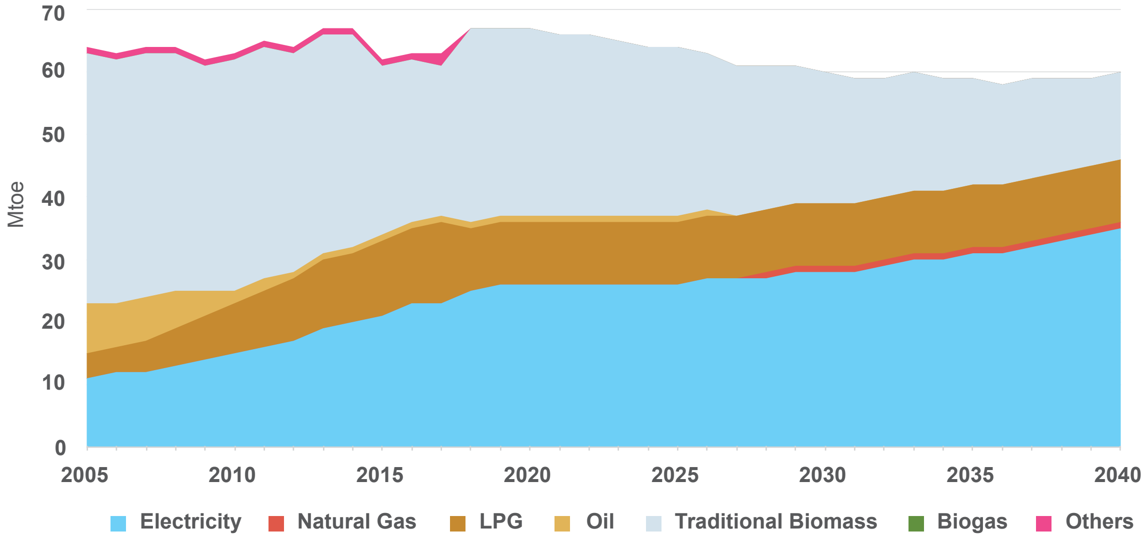
The appeal of large-scale biofuel use is that it would allow ASEAN Member States to reduce their need to import oil and replace it with domestic resources. Several studies have shown substantial potential for biofuels in the region (see, e.g., IRENA 2017b). However, there are trade-offs, as biofuel production may compete with food production, and in some cases may also accelerate deforestation. In the case of biodiesel production, the main feedstock in Indonesia, Malaysia and Thailand is palm oil, while in the Philippines, it is coconut oil. Indonesia and Malaysia are the largest global palm oil producers and leading exporters. One of the advantages of utilising palm oil for transport fuel is the ability to absorb any oversupply due to foreign market fluctuations. Higher blending ratios of biodiesel may be achievable if the palm oil industry can be sufficiently cost-competitive for consumers to invest in vehicle modifications to make such ratios more technologically feasible. That is less likely in the Philippines, however, as coconut oil costs more and has many outlets for higher value-added products.

In the case of bioethanol, only the Philippines and Thailand have commercially blended ethanol in gasoline at a large scale, whereas Indonesia, Malaysia and Vietnam are in the early stages of implementing ethanol fuel programmes. Since the main feedstocks in the region are sugarcane and cassava, which have other routes for higher value-added products, the relative price per unit of energy has been a key factor to justify the blending level. Unlike biodiesel, flex-fuel vehicles, which can use 85% blends of ethanol in gasoline (E85), are commercially available worldwide, so there is no limitation in terms of vehicular technology.

2.3.4.1 Addressing Traditional Biomass Consumption

At the same time as they promote biofuel production, several ASEAN Member States are working to reduce reliance on traditional biomass (wood, charcoal and agricultural residues) in the residential sector, mainly for cooking. As of 2017, about 36% of ASEAN households were still cooking on open fires or with low-efficiency stoves, using biomass or kerosene (see Section 3.5). This generates indoor pollution, leading to illness and premature deaths. As noted earlier, in some regions, firewood is also collected faster than it can grow, so traditional biomass use is contributing to deforestation. Thus, several national governments have prioritised replacing inefficient stoves with either high-efficiency biomass stoves or, preferably, stoves using modern fuels such as LPG or electricity.

Figure 33. ASEAN Household Energy Demand by Fuel, ATS



To some extent, a shift to modern stoves will occur naturally. Economic development drives the expansion of roadways, which can increase modern fuel accessibility. As living standards improve, interest in modern cookstoves increases, while technology advances make the stoves more affordable. However, in rural low-income areas, households may need help to cover the initial cost of switching stoves and overcome a hesitance to change. Some ASEAN Member States have received support from international organisations to improve rural people's livelihoods, which can assist with such efforts.

In the AMS Targets Scenario, countries' efforts to accelerate the transition are reflected in projections of traditional biomass use in the residential sector. Modern stoves use less fuel than traditional stoves or three-stone fires. The average traditional stove efficiency is around 16%, while for LPG stoves it is around 56%, and for electric induction stoves is 75%.[16] Traditional biomass consumption is thus projected to decrease from 24 Mtoe in 2017, or 39% of residential energy consumption, to 14 Mtoe in 2040 (23%). In country consultations, officials from several ASEAN Member States noted that electric stoves have become more popular than LPG due to price reductions, ease of use, lower safety concerns, and electrification. The model shows electricity for cooking tripling from 2018 to 2040. LPG stoves remain at about 17% of total residential energy demand from 2017 to 2040.

2.3.5 The Power Sector in the AMS Targets Scenario

Total installed capacity in the ATS is similar to that in the Baseline Scenario, as both scenarios reflect the Member States' national Power Development Plans. However, the actual need for added capacity will correlate with energy efficiency actions. Greater energy efficiency will reduce electricity demand and thus the need to add capacity. To the extent that capacity is added, the share of fossil fuels and RE will follow the specifications in each country's Power Development Plan.

Figure 34. ASEAN Installed Power Generation Capacity Growth, ATS

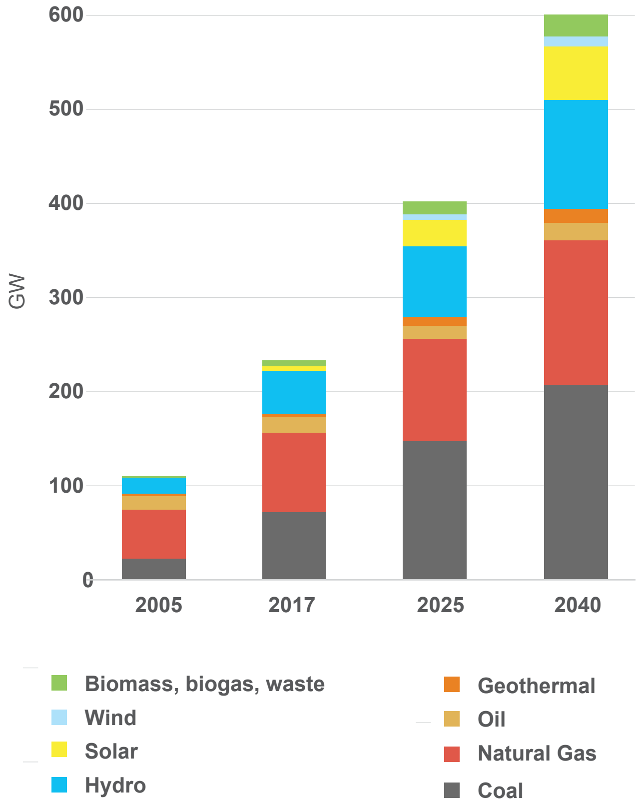


Photo source: Freepik

[16] See WHO Household Energy Database, https://www.who.int/airpollution/data/household-energy-database/en/.

Figure 34 shows that a majority of ASEAN's electricity comes from coal and natural gas power plants. In 2017, natural gas plants had the largest share of total installed capacity, about 36%. The most popular natural gas technology is combined-cycle generation, due to its high efficiency. Natural gas is followed by coal and hydropower, accounting for 31% and 20% of the total installed capacity, respectively. Apart from hydropower, other renewable energies such as solar, biomass, geothermal and wind collectively account for only 6%. However, from 2018 to 2040, solar shows the highest growth rate among renewable energy sources, with a CAGR of 10.4%. In 2040, renewable power plants are projected to make up around 37% of capacity, while coal and natural gas power plants would be 34% and 26% of the total ASEAN installed capacity, respectively.

Figure 35 shows how installed capacity would differ in the ATS in 2040 relative to the Baseline Scenario. In response to lower demand for electricity, less new capacity is built, for a total of 600 GW instead of 713 GW. All types of power generation are affected, with the largest reduction in coal power.

Figure 35. ASEAN Installed Capacity in 2040, Baseline vs. ATS

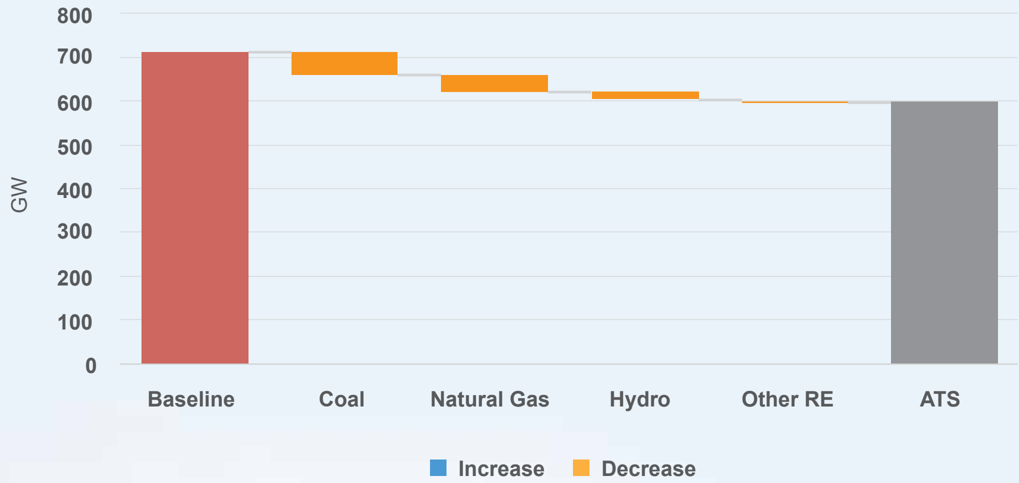
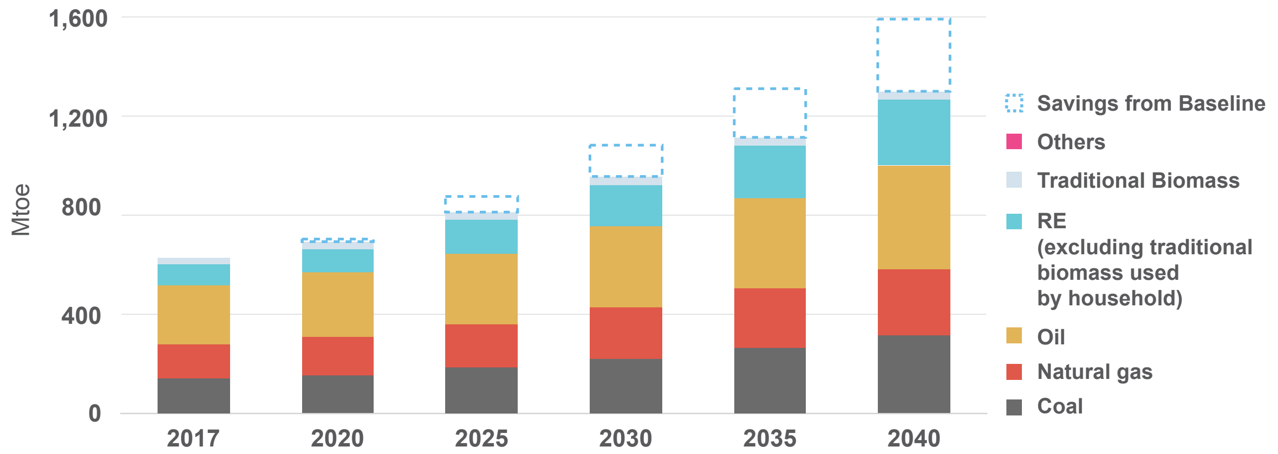


Photo source: Freepik

2.3.6 Impacts on the Total Primary Energy Supply

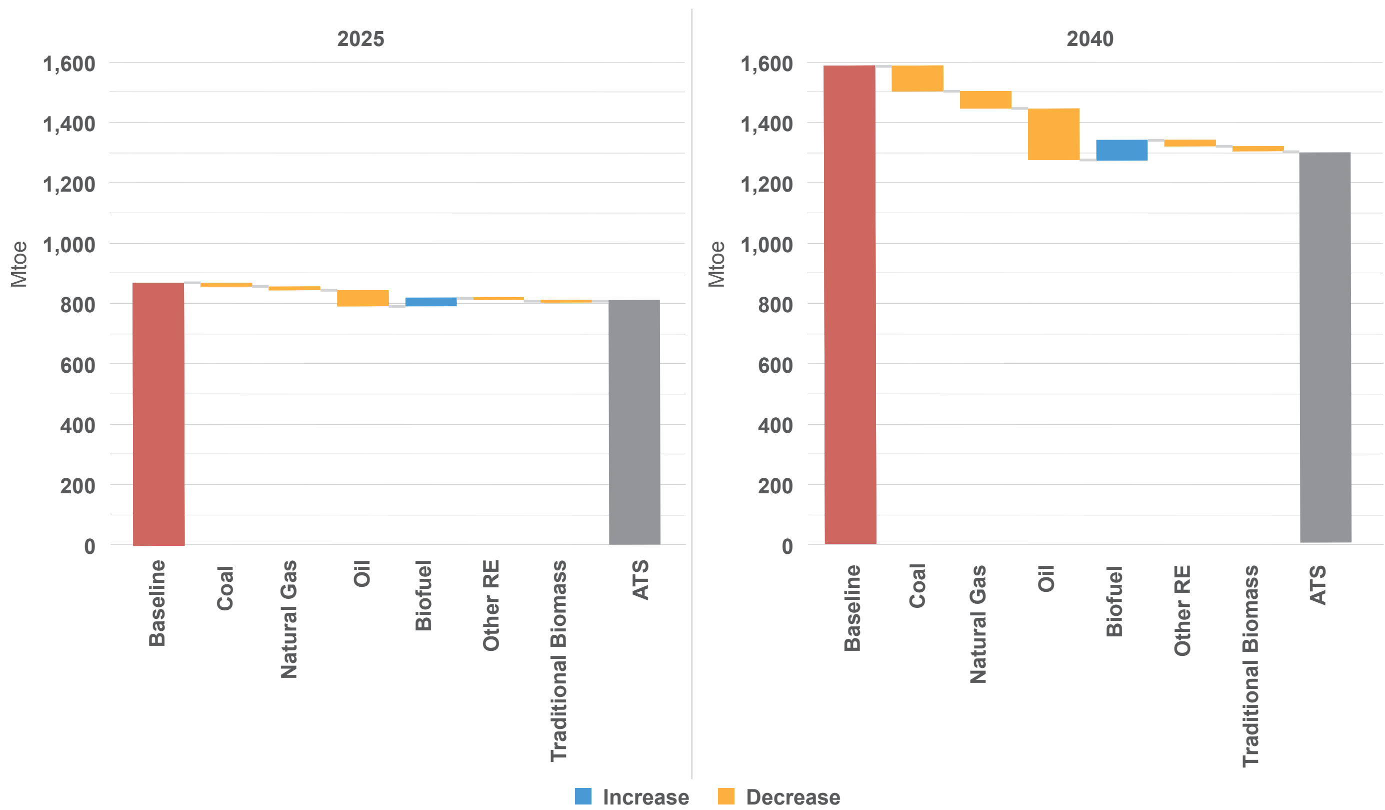
Lowering energy demand with energy efficiency policies in end-use sectors leads to lower fossil fuel supply – for example, lower coal and natural gas use in industry as well as lower oil demand from the transport sector. Moreover, reducing electricity demand also drives a reduction in the needed feedstock for power generation. After accounting for energy transformation processes, the total reduction in TPES relative to the Baseline Scenario is about 7% in 2025 and 18% in 2040.

Figure 36. ASEAN Primary Energy Supply, ATS vs. Baseline Scenario



The analysis shows savings relative to the Baseline Scenario in the use of oil, followed by coal and natural gas. Despite the reduction in fossil fuels, the overall renewable energy supply increases due to renewable energy promotion policies, particularly from the expanded use of biofuels.

Figure 37. ASEAN Total Primary Energy Supply (TPES), ATS vs. Baseline Scenario



2.3.7 Energy Security, Imports and Exports

As shown in Figure 38 and Figure 39, in the ATS, ASEAN countries import less oil and less natural gas than in the Baseline Scenario. ASEAN also continues to be a net coal exporter in 2040, while in the Baseline Scenario, by then it is a net importer. Lower imports are due to energy efficiency efforts and the transition to renewable energy sources, mainly in the transport and power sectors. Overall, it is apparent that meeting the energy efficiency and RE targets of the Member States can reduce the risks associated with fossil fuel imports, thus enhancing energy security for the Member States and the ASEAN region.

Figure 38. ASEAN Energy Import-Export Balance and Projections, ATS

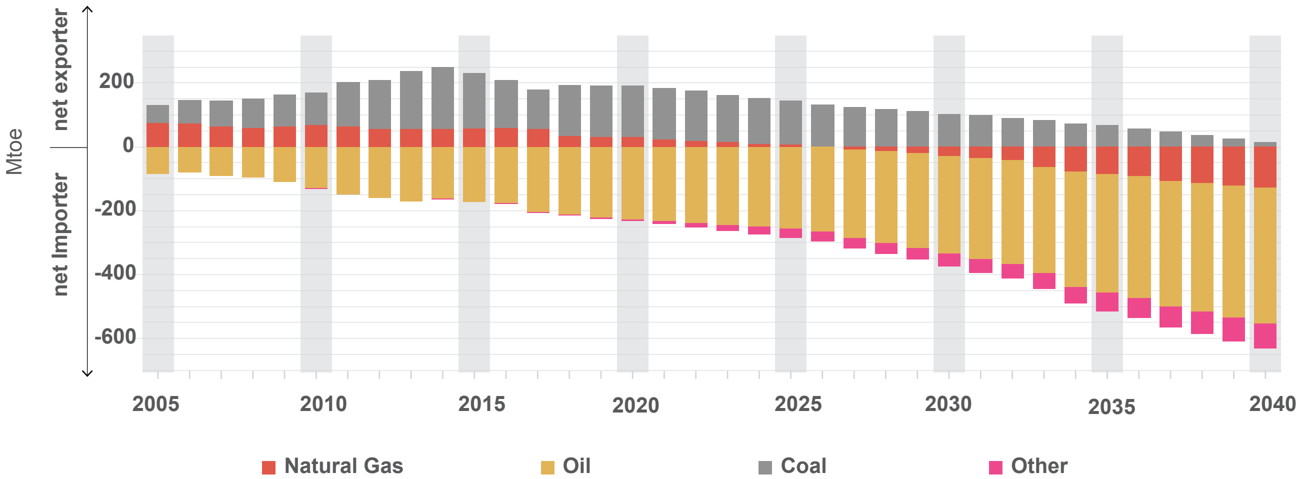
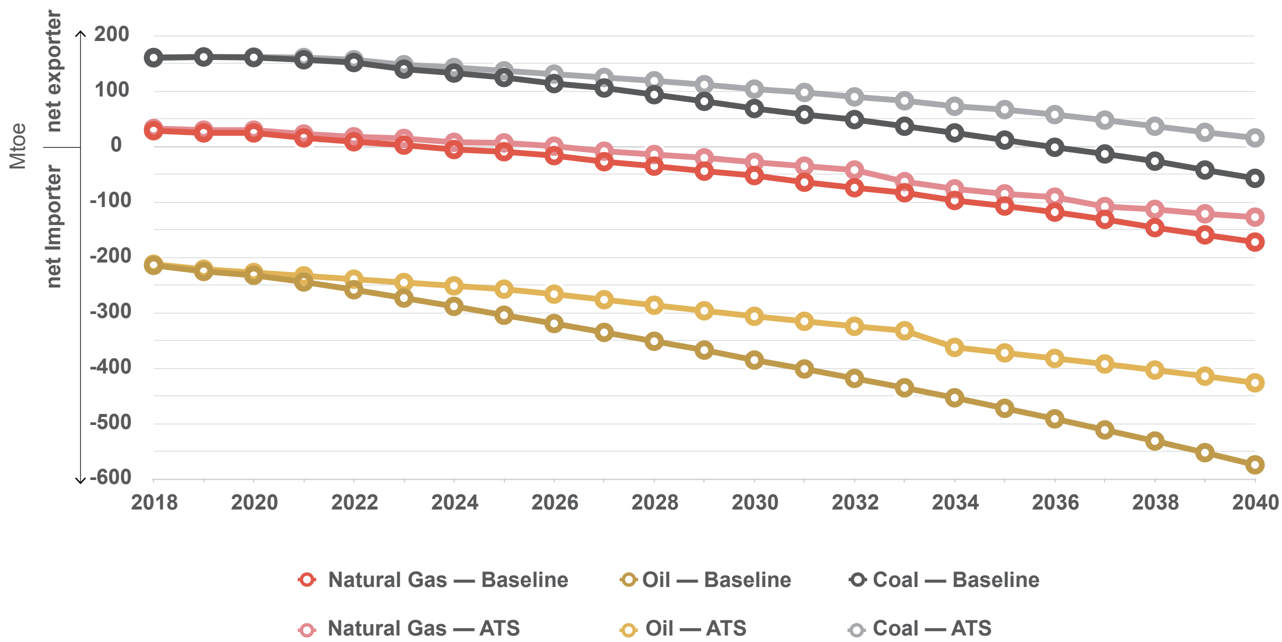


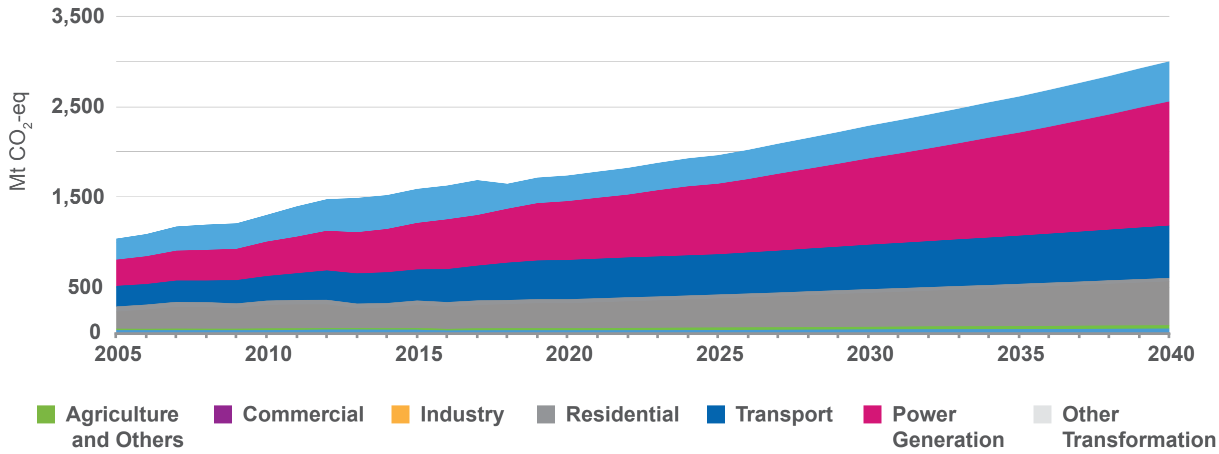
Figure 39. ASEAN Energy Trade Balance by Fuel, ATS vs. Baseline Scenario



2.3.8 Avoided GHG Emissions

In the AMS Targets Scenario, ASEAN's total energy-related GHG emissions in 2040 are about 3 Gt CO2-eq, 28% lower than in the Baseline Scenario. The CAGR of emissions growth is 2.5% in the ATS, with power generation being the largest sectoral contributor, accounting for about 40% and 46% of total GHG emissions from energy in 2025 and 2040, respectively.

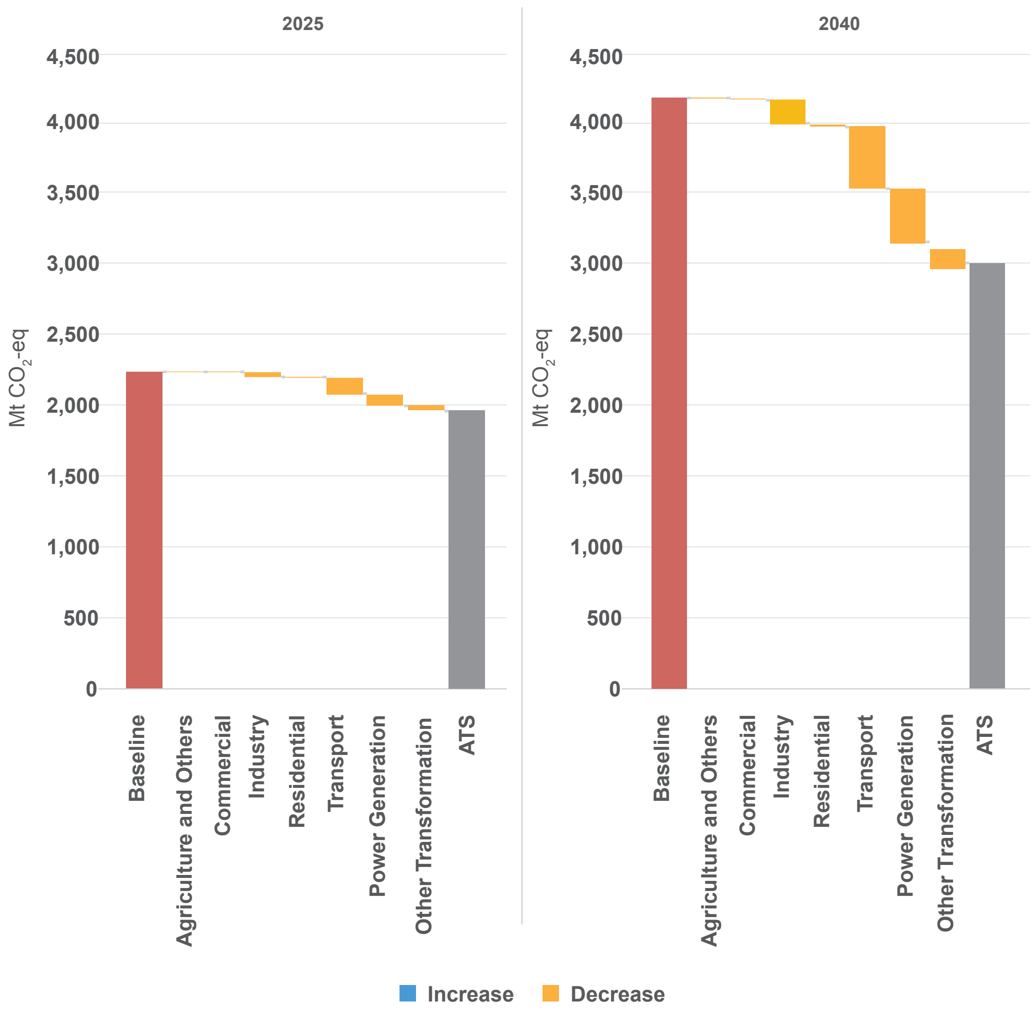
Figure 40. ASEAN Energy-related GHG Emissions by Sector, ATS



Significant GHG emission reductions are achieved in transport, the power sector and industry. Emission reductions in the transport sector are due to lower consumption of diesel and gasoline in road transport, while mitigation in industry comes from energy intensity improvements. Lower emissions in the power sector come from a greater share of electricity generation from renewable energy sources, magnified by energy efficiency measures on the demand side.


Photo source: Shutterstock

Figure 41. ASEAN GHGs Emission Reduction Compared to Baseline in 2025 and 2040



As with the Baseline Scenario, a Kaya decomposition analysis was used to identify the key drivers that lead to lower GHG emissions in the ATS relative to the Baseline Scenario. Figure 42 reveals that decreases in GHG emissions from 4,171 Mt CO2-eq in the Baseline Scenario to 3,002 Mt CO_2-eq in the ATS are due to reductions in both the energy intensity of the economy and especially the carbon intensity of the energy supply, which reduce emissions by 414 Mt CO2-eq and 755 Mt CO_2-eq, respectively.

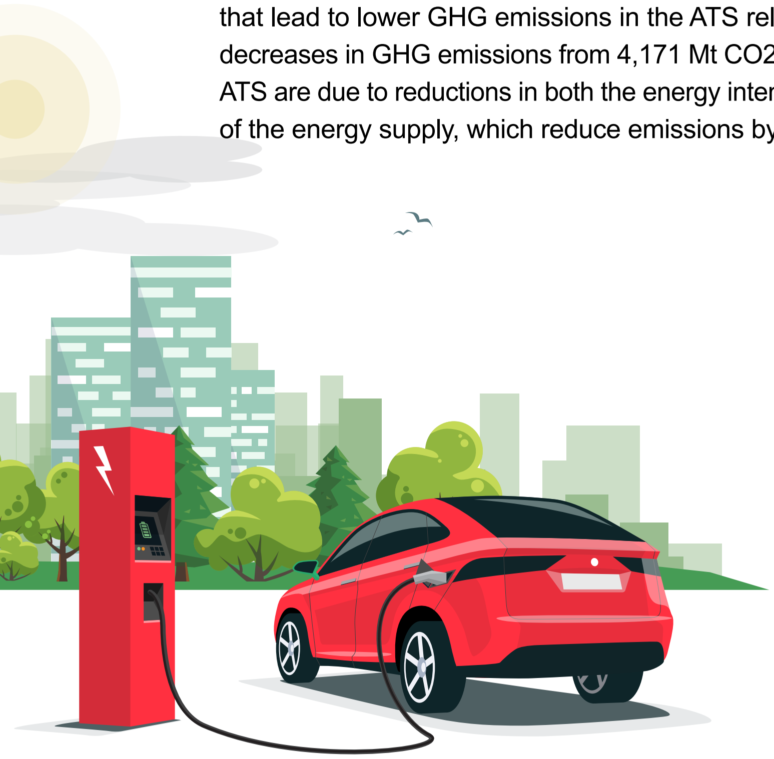
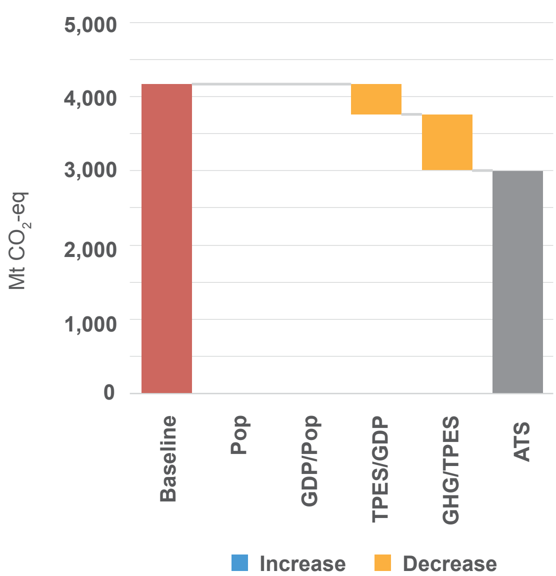


Figure 42. Key Drivers of GHG Emission Reduction from Baseline Scenario to ATS, 2040



2.4 Modelling Results: APAEC Targets Scenario (APS)

The AMS Targets Scenario (ATS) demonstrates that if the ASEAN Member States strive to achieve their own energy-related targets, they can significantly reduce energy demand and GHG emissions relative to the Baseline Scenario. However, those gains are not enough to meet the regional targets the 10 countries collectively agreed to in the ASEAN Plan of Action for Energy Cooperation (APAEC) 2016–2025. Closing that gap by enhancing existing national efforts is the focus of the APAEC Targets Scenario (APS).

The ATS analysis showed that achieving national targets alone would leave ASEAN just short of its target of reducing the energy intensity of the region's economy (TPES/GDP) by 30%. As shown in Figure 43, the policies and measures modelled in the APS enable the region to slightly exceed the target, with a 32.5% reduction in 2025; by 2040, energy intensity has been reduced by almost 50%.

Figure 43. Meeting the APAEC Energy Intensity Reduction Target

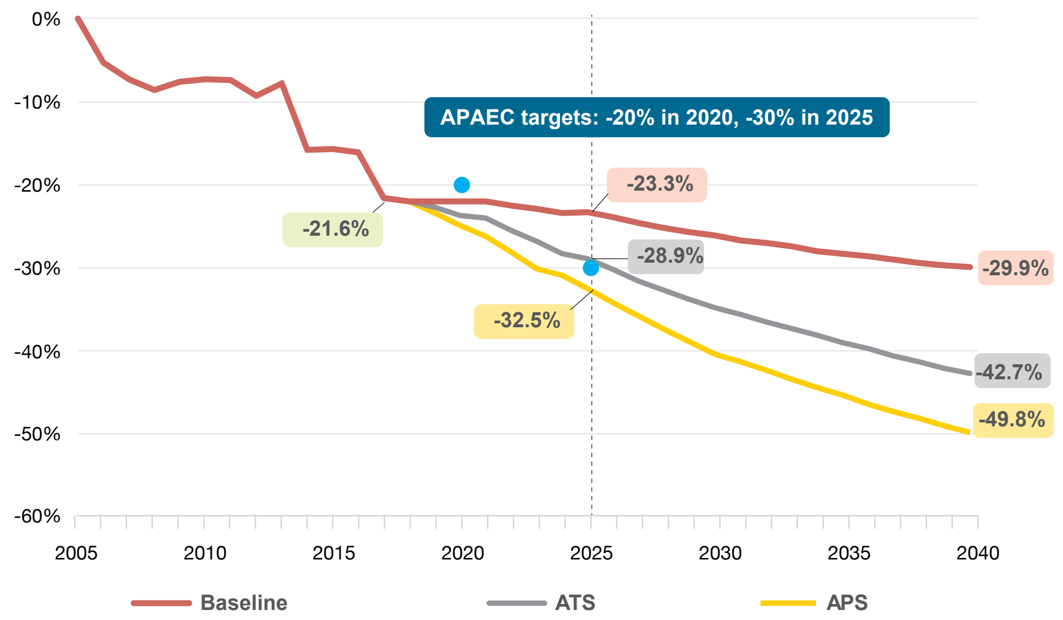


Figure 44 shows how much more effort is needed to meet the regional renewable energy target of 23% by 2025. In the ATS, Member States' collective efforts achieve only a 17.7% share of RE in the total primary energy supply by 2025; the APS closes the 5.3 percentage-point gap and keeps growing RE steadily, achieving a 28.7% share in 2040. The specific efforts needed to meet the APAEC target, which require going beyond existing national targets, were identified in consultation with the Member States; they are discussed in detail in the next section.

Regional collaboration could play an important role in closing the RE gap, as individual ASEAN Member States may find it challenging to undertake the required efforts on their own. Regional collaboration can also help countries achieve economies of scale and address some of the potential challenges that could arise (see Section 3.1). A more interconnected ASEAN enables more cross-border trade, potentially making large-scale RE investments more profitable. Progress can be further accelerated through collective capacity-building, joint studies or proposals, or concept development.

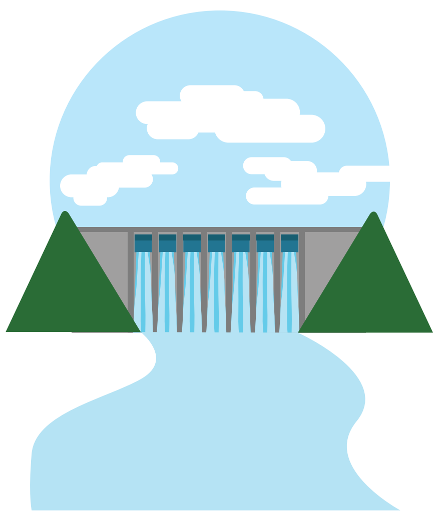
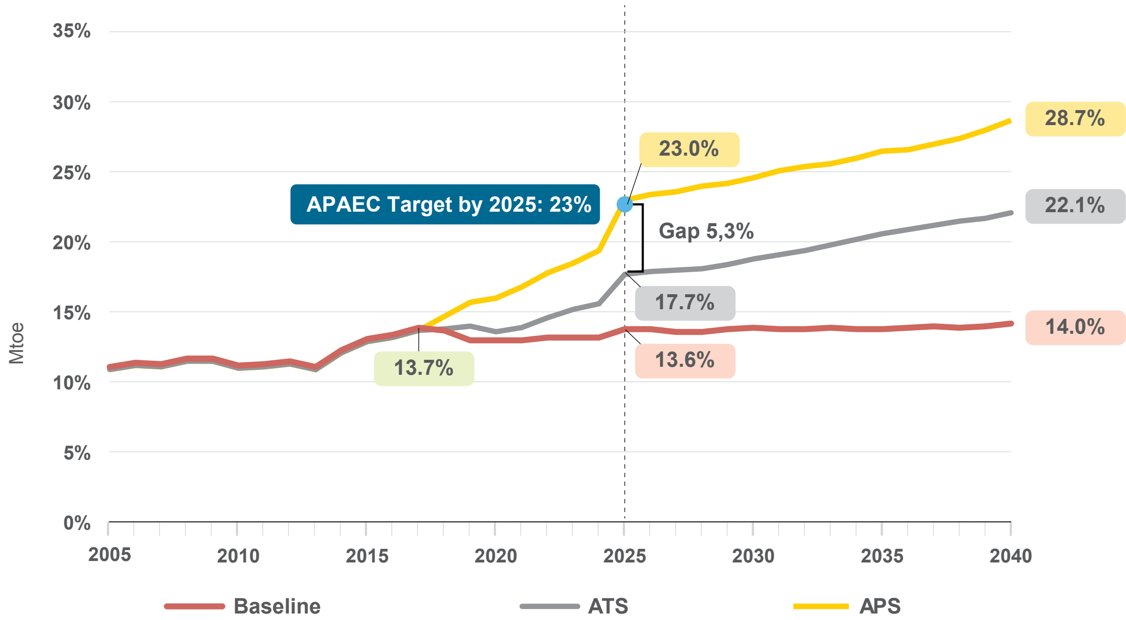


Figure 44. Meeting the APAEC Renewable Energy Target



2.4.1 Key Measures to Achieve the APAEC Regional Targets

The approaches and measures modelled in the APS deliberately build on the Member States' national targets. These interventions were identified through evaluation processes and suggested adjustments by the Member States. The potential for RE power generation was re-evaluated, and efforts were considered to scale up current efforts to increase RE and further improve energy efficiency. The resulting scenario consolidates Member States' national targets, expands on them with more ambitious objectives, identifies areas where improvements can be achieved collectively, and adds some new approaches.

The potential to raise the ambition of existing national targets, such as accelerating biofuel mandates, increasing blending ratios, and investing more in renewable power installation, was evaluated by representatives of the Member States during the third Working Group meeting in Bangkok in January 2020. The feasibility of such intensification efforts was still under evaluation, but given that they arose from discussions with Member States, they are included here as priority actions to fill the gap.

The potential for additional solar and wind power was then evaluated with the AIMS III project, using the National Renewable Energy Laboratory (NREL) resource assessment tool.[17] Forty solar sites (66 GW) and 20 wind sites (8 GW) were selected as candidate locations because they showed the highest potential to connect with existing grid lines. However, the projects' capacities were limited to 20% variable renewable energy (vRE) penetration as a constraint to avoid problems with the grid.[18] This is a widely used assumption for regions where the grid has not been strengthened sufficiently, although there have been examples in developed regions with highly interconnected grids that have demonstrated higher vRE tolerance.

Those efforts would still not suffice to reach the 23% RE target by 2025, so two further actions were integrated. First, additional scaling-up of current RE and energy efficiency efforts was evaluated in consultation with experts and through a review of published reports and articles. Finally, an aggressive-disruptive technology penetration rate was considered, referring to extra-regional global progress and expert consultations. Figure 45 illustrates the systematic process used to select appropriate collective actions to achieve the regional targets.

[17] See https://maps.nrel.gov/rede-asean/.
[18] This is a conservative assumption that ACE will revisit in the future – particularly when the AIMS III results are delivered and in modeling for AEO7.

Figure 45. A Sequential Approach to Filling the Gaps between National and APAEC Targets

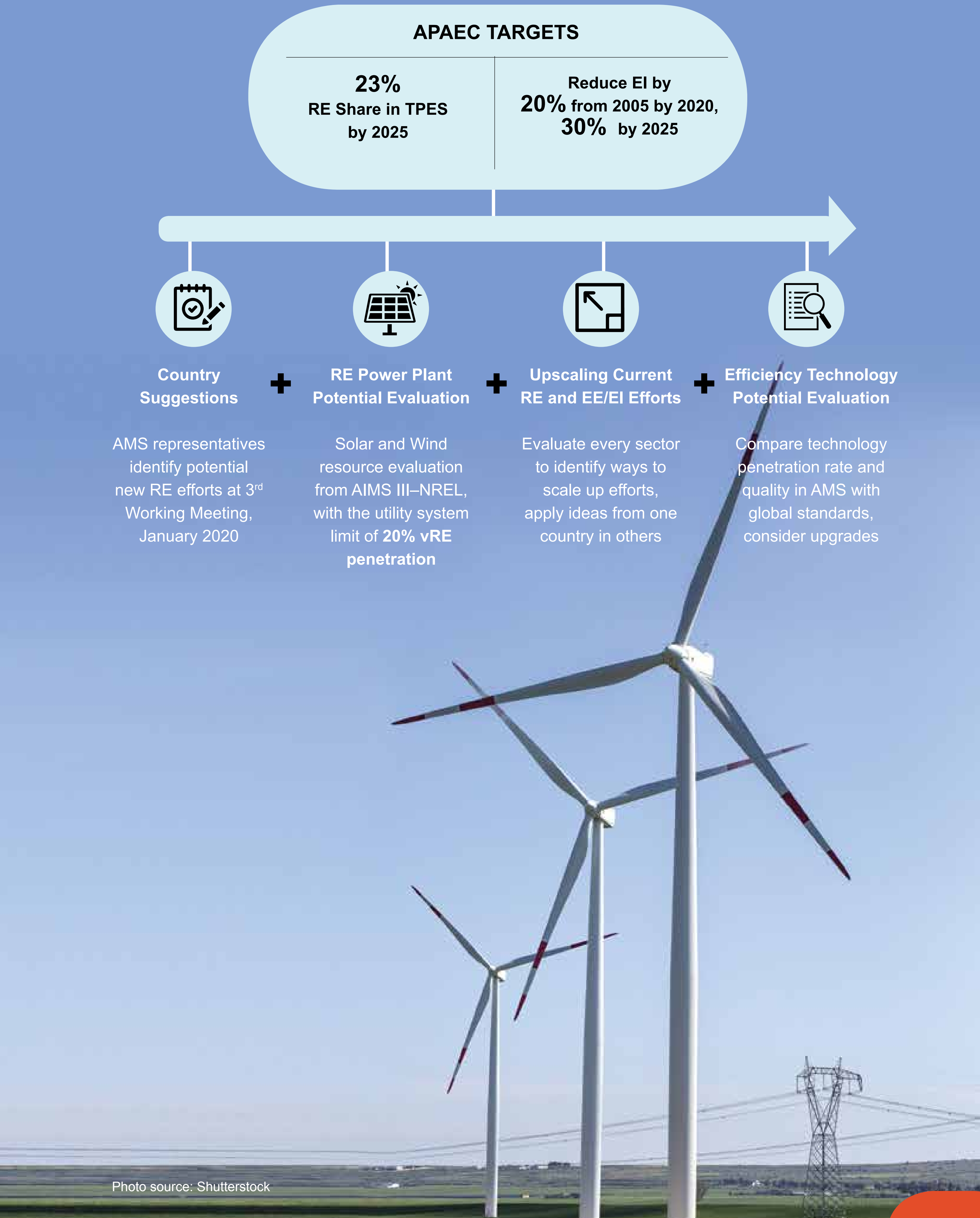
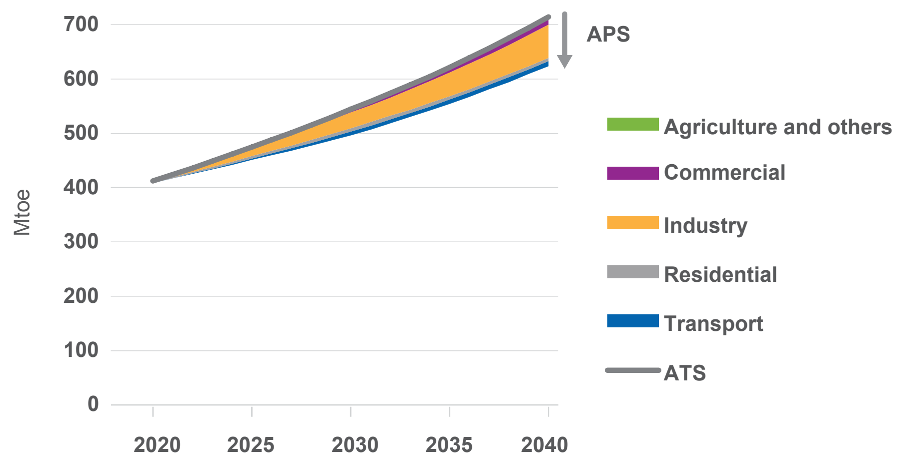


Photo source: Shutterstock

Figure 46. Total Final Energy Consumption (TFEC) Savings by Sector in APS Relative to ATS



2.4.2.1 Industry

As shown in Figure 46, industry offers the largest opportunity for reducing energy demand. The sector includes a wide range of subsectors with different energy demand profiles, which makes it challenging to identify measures to achieve the targeted reduction; there are not sufficiently detailed data on the energy use in these industry subsectors. Statistics from the International Energy Agency (IEA) show that about half of ASEAN's industrial energy consumption is from "non-specified" industries, while the largest subsectors are "non-metallic minerals", "food and tobacco" and "chemical and petrochemical".

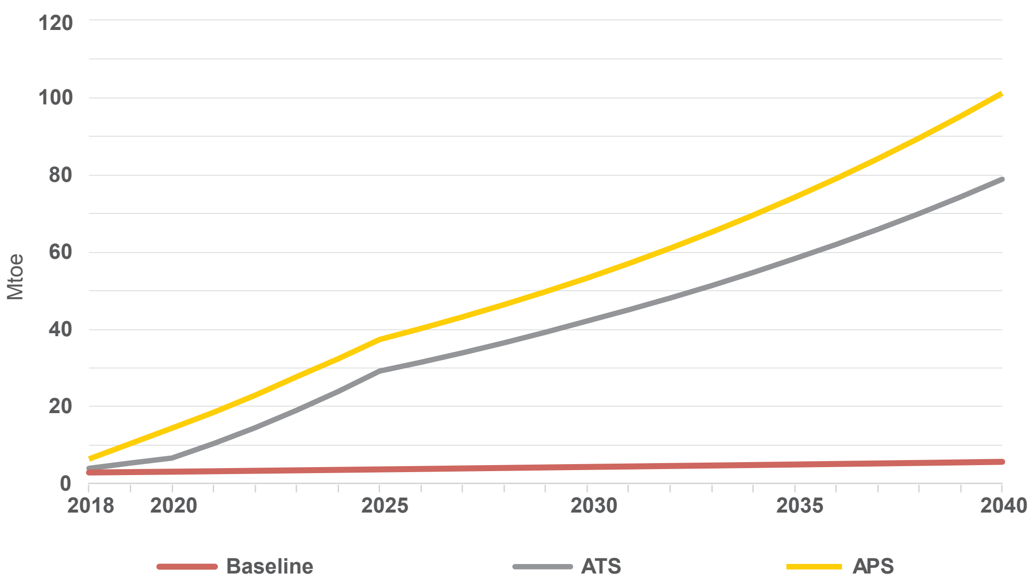
Non-metallic minerals is mainly cement manufacturing. Technological improvements over recent decades, using alternative kiln types and preheating heat recovery, may offer direct opportunities to reduce energy demand from cement production in ASEAN, if capital investments are made. However, this is a low value-adding sector with typically tight margins, making it likely that significant new capital investment would be cost-prohibitive. On the other hand, this sector has been a target for incorporation of greater amounts of renewable energy via biomass and combustible waste products such as tyres.

Overall, about 70% of ASEAN's export value is from manufactured goods,[19] and within that, about 40% of the total export value is from high-skilled and technology-intensive sectors, and a similar share from machinery. Based on this, it can be estimated that machinery and vehicle production are the likeliest targets for energy efficiency improvements in industry. Improving energy efficiency in these high value-adding sectors may also be more economically attractive. Reconfiguration and upgrading of existing factories to ensure energy efficiency and reduce materials loss are strategies which have been investigated globally, and are likely to offer significant opportunities. This type of improvement could be further enhanced by a technological shift in the transport sector, opening opportunities to improve manufacturing facilities for new vehicles to support a transition in the transport sector.

2.4.2.2 Transport

Transport is the second-largest contributor to decelerating energy demand in the APS. In this scenario, biofuel development is accelerated beyond the existing national targets, and in more of the Member States. In discussions with country Focal Points, it was noted that ASEAN is rich in biomass, with much of the tropical region having ideal conditions for high biomass growth rates. If sufficient attention is paid to ensuring the sustainable production of biofuels – whether from waste or from crops – this approach may improve the region's energy security by reducing oil imports (see Section 3.4.2). By 2040, the biofuel supply would rise to 101 Mtoe, 18 times the volume in the Baseline Scenario (5.7 Mtoe) and 28% more than the 79 Mtoe projected in the ATS. Additionally, as newer vehicle technologies take hold in the region, further deployment of EVs is expected, also contributing to the decarbonisation of transport throughout ASEAN.

Figure 47. ASEAN Biofuel Demand Projection in Three Scenarios



It is beneficial to explore these targets further, including the role of regional cooperation in fulfilling them – such as regional R&D on biofuels currently being conducted by ACE and Thailand's National Science and Technology Development Agency (NSTDA). In reaching the 2025 RE share target, a noticeable change in the transport sector starts from the reduction of oil demand. As argued by Rinscheid et al. (2020), an aggressive phase-out of fossil-fuelled cars is crucial to averting dangerous and irreversible changes to the Earth's climate. New regulations and incentives are therefore needed to encourage and accelerate this process. The model shows fast-increasing demand for both EVs and biofuel-powered vehicles, both of which reach significant market shares by 2040.

[19] Based on data gathered and analysed for AEO6.

Figure 48. Transport Fuel Demand in APS vs. ATS, 2025 and 2040

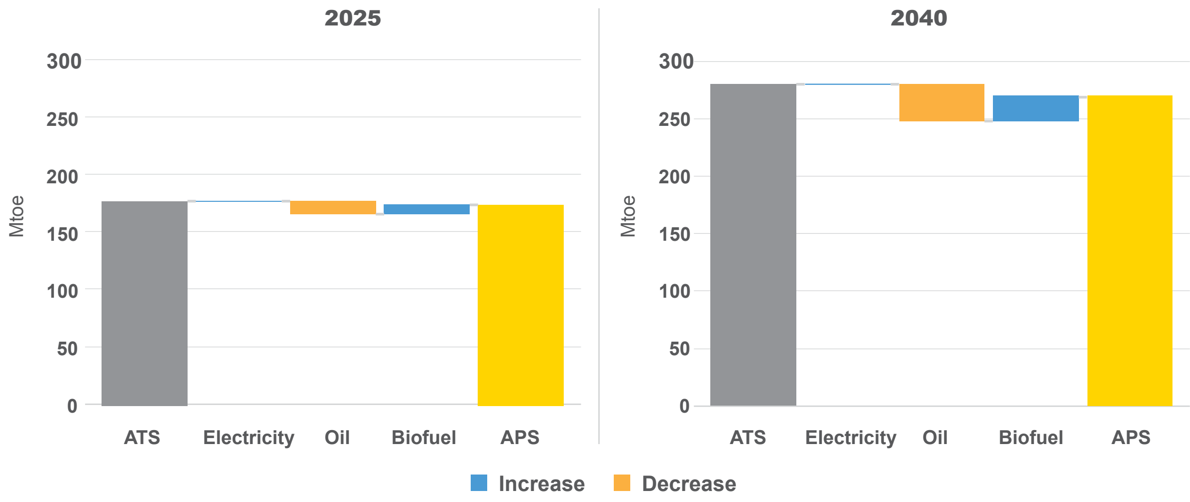
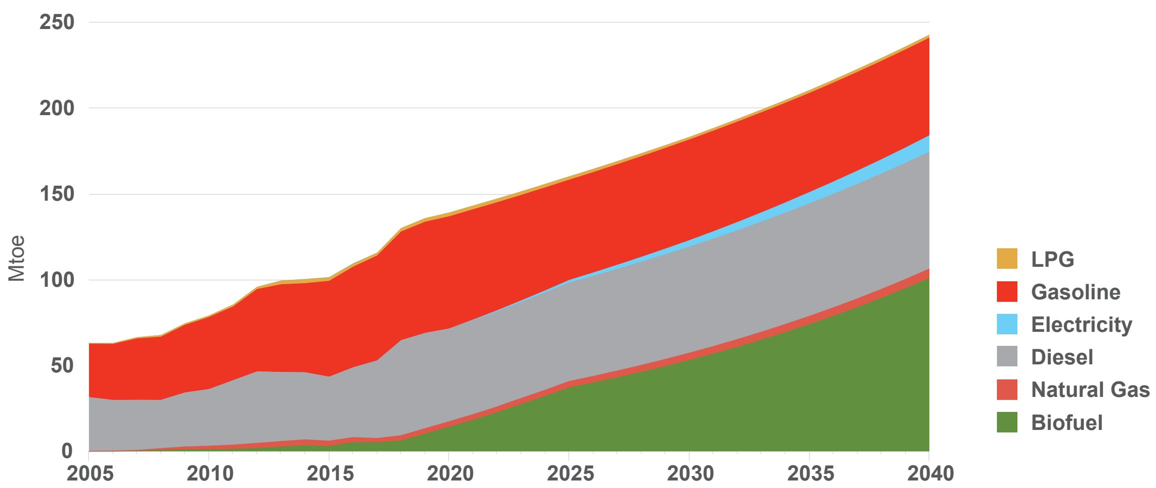


Figure 48 breaks down the factors that contribute to a more than 11.3 Mtoe reduction in oil demand for fuel transport in the APS relative to the ATS. In both 2025 and 2040, the larger supply of biofuels makes the greatest impact, though EVs start to play a more noticeable role in 2040. Figure 49 shows the full picture of projected road transport energy demand in the APS. By 2040, biofuels are expected to be a major source of energy for the sector, at 101 Mtoe. It should be noted that, as discussed further in Section 3.4.1, it is very possible that EVs will take hold far more quickly in ASEAN than envisioned in any of these scenarios. Exploring this in depth should be a priority for AEO7. Should EV growth be much faster, provisions would need to be made to meet increased electricity demand – and to ensure that as much of that demand as possible is met by RE.

Figure 49. ASEAN Road Transport Energy Demand, APS

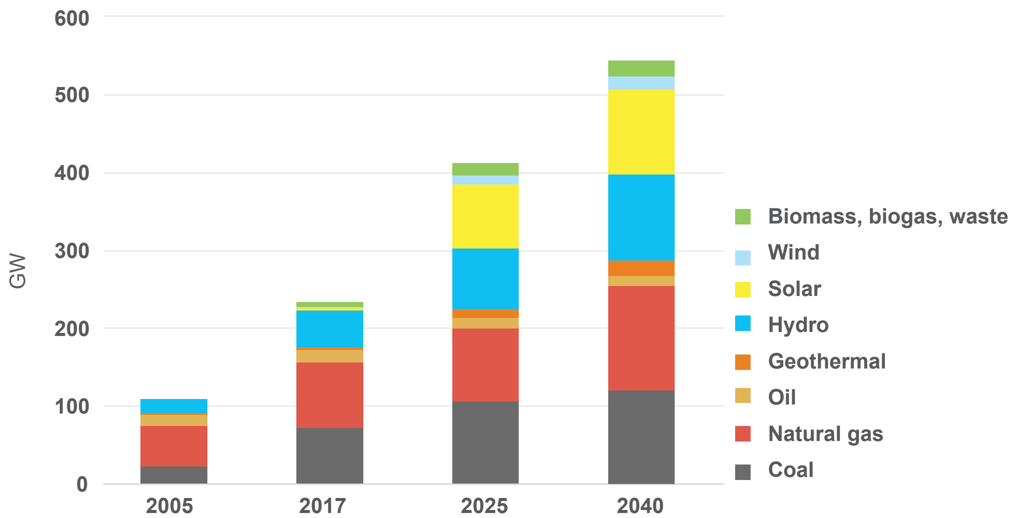


The rise in biofuel use in the APS builds on several ASEAN Member States' already strong commitments to biofuels and growing biofuel production. The regional availability of high-quality biofuels will encourage further adoption, as it decreases both the cost and the risks involved. These examples will lead to increased penetration of new technology, especially in new vehicle sales. Even with the successful phase-out of fossil-fuelled vehicles, it is important to remove barriers to new technology deployment to enhance the progress of the transition. Several policy interventions can help – for example, joint capacity-building, both individual and institutional, as well as a technology needs assessment. With several Member States already far along in biofuel deployment, more research on the region's biomass potential could support an expansion to the rest of ASEAN.

2.4.2.3 Power

One of the biggest tasks for ASEAN in achieving the APAEC regional targets is to increase the share of renewable energy in the power supply. A key aspect of this is to increase the penetration of variable renewables, with a doubling of solar PV and wind capacity. As shown in Figure 50, solar capacity is projected to grow by 15% per year from 2017 levels by 2040, and wind capacity, by 12% per year. Geothermal and biomass generation capacity would be 25% and 10% higher than in the ATS, respectively, while biogas and waste-to-energy technology would be 20% higher. The APS also envisions the introduction of more biomass/coal co-firing plants, using 5% biomass feedstock, while the coal power capacity of the four major coal-consuming countries would be reduced by 15% by 2025.

Figure 50. ASEAN Installed Power Generation Capacity Growth, APS



As the APAEC regional target is for 2025, ASEAN Member States will have to hurry to increase their RE capacity. From 2020 to 2025 alone, the scenario envisions solar PV capacity across ASEAN increasing from 32 GW to 83 GW, a 159% increase. For comparison, the next-largest jump projected in the model is for hydropower capacity, which would increase by from 59 GW in 2020 to 77 GW in 2025, or 31%. Such aggressive RE development is not only viewed as necessary, but also as achievable, as ASEAN aims to seize the momentum in solar PV especially. Activities such as improving access to finance for renewable energy projects, increasing power sector stakeholders' capabilities, and designing a more integrated ASEAN power grid are regarded as important regional interventions to address key barriers to renewable energy development.

Furthermore, just as ASEAN is developing new transport technologies, improving the regional capability to produce crucial RE technologies such as solar PV is important to drive further deployment. With Malaysia, Thailand and Vietnam already acknowledged globally in solar PV component production and assembly, regional collaboration might enhance production and innovation. This, in turn, could encourage the development of mechanisms such as virtual net energy metering (VNEM) and peer-to-peer (P2P), as well as overall growth in RE demand and deployment. As with the transition in the transport sector, all these steps will assist ASEAN in embracing RE technology faster.

However, even with increased RE capacity, fossil fuels would still play a prominent role in this scenario, although the development of new fossil-fuelled power plants is significantly lower than in the previous scenarios. As shown in Figure 51, already in 2025, coal power capacity in the APS is 42.3 GW lower than in the ATS. The gap grows to 87.1 GW in 2040, with coal capacity kept under 110 GW from 2025 to 2035. But achieving the reductions envisioned in the APS requires prompt action: not just introducing more biomass co-firing, but phasing out existing coal power plants and limiting the development of new ones.

Figure 51. How Installed Power Generation Capacity Shifts from the ATS to the APS

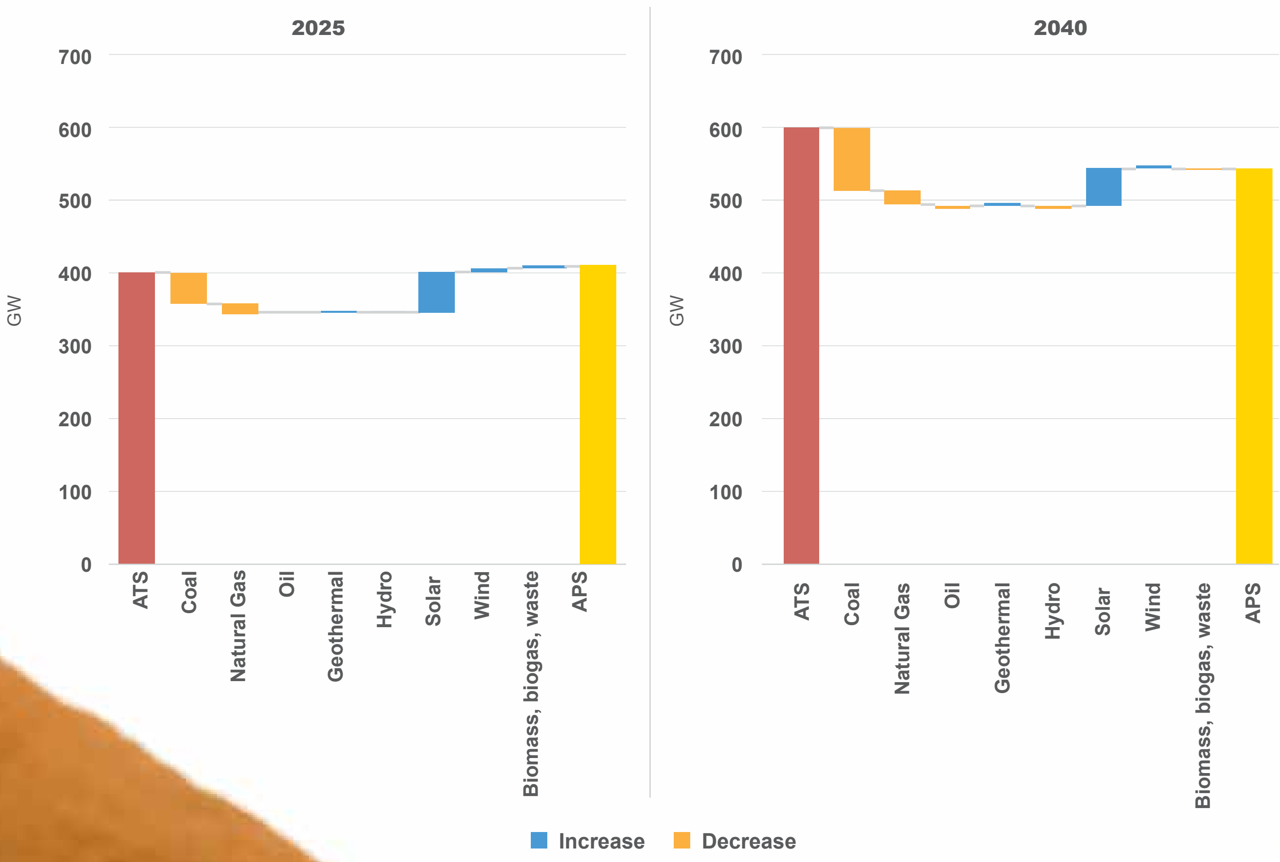
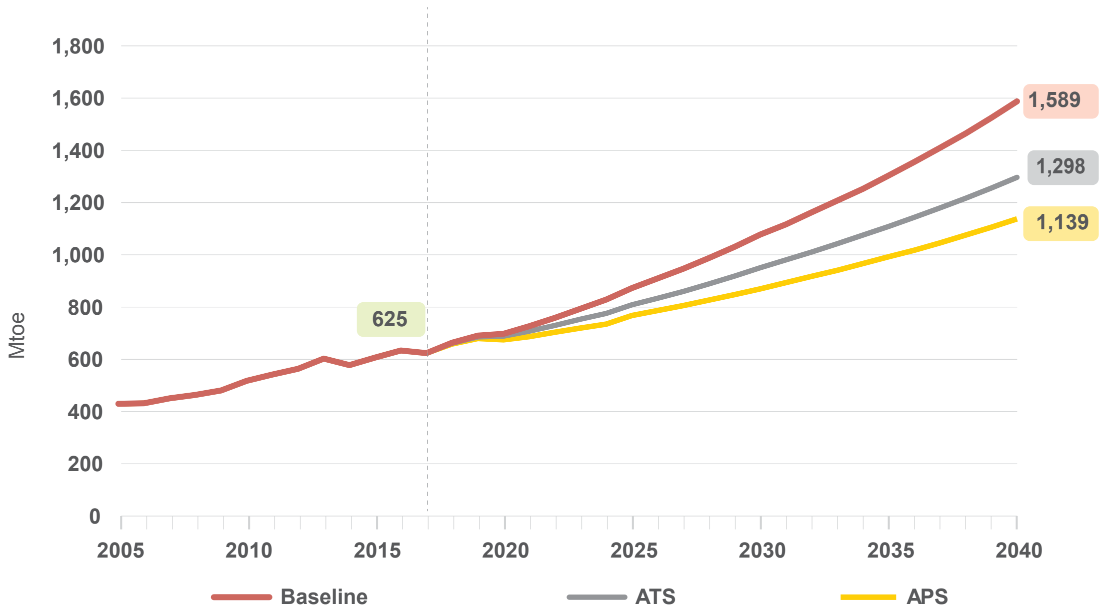


Photo source: Shutterstock

2.4.3 Energy Supply Savings and Avoided GHGs Emissions

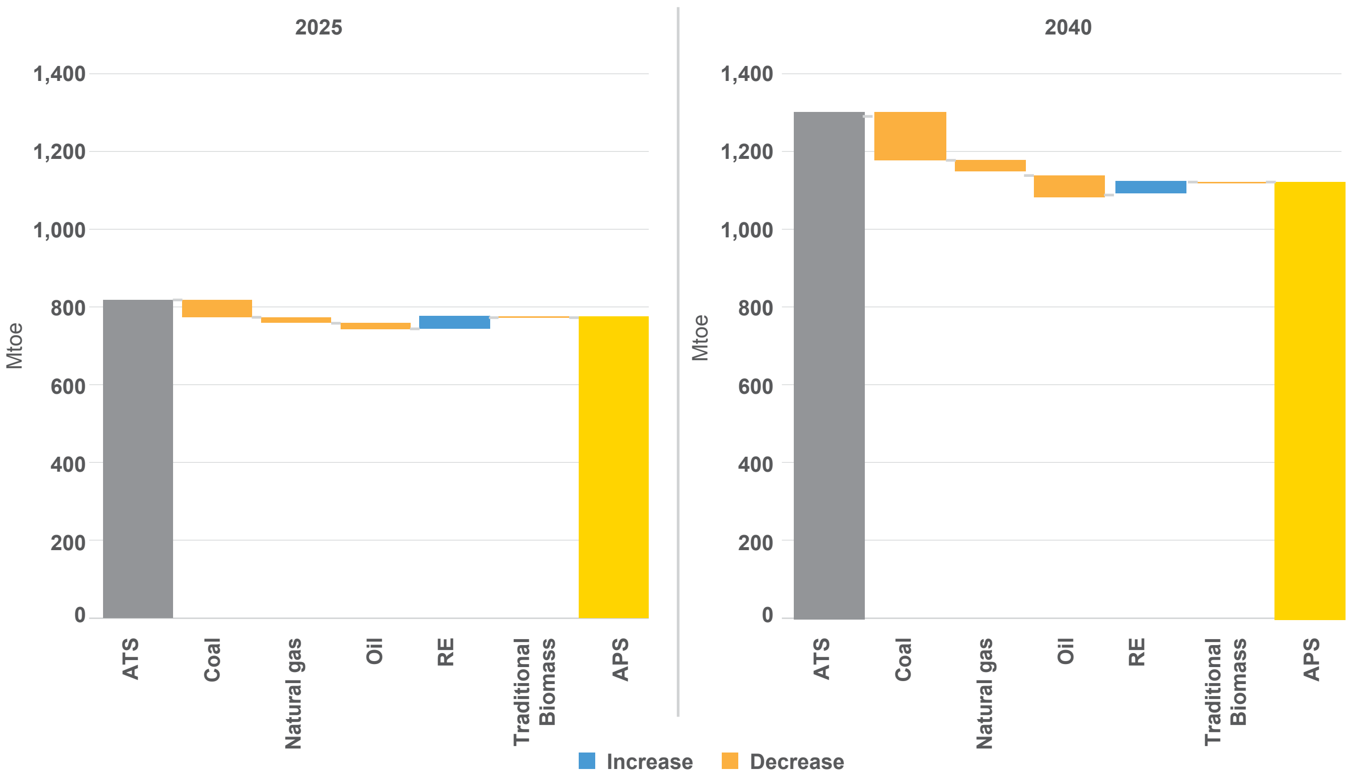
The energy demand reductions achieved in the APAEC Targets Scenario enable the ASEAN Member States to meet their needs with an energy supply that is about 5% smaller than in the ATS in 2025, and 12% smaller in 2040, as shown in Figure 52.

Figure 52. ASEAN Total Primary Energy Supply (TPES) in APS vs. ATS and Baseline Scenario



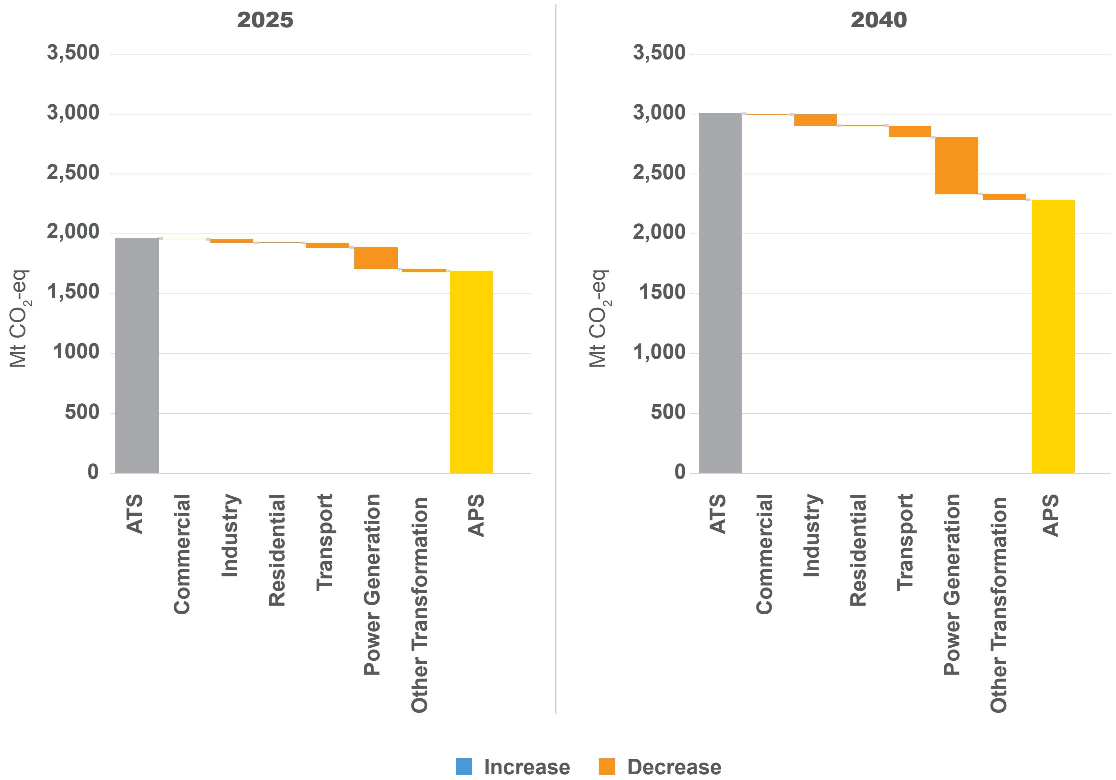
As shown in Figure 53, the greatest savings involve coal, followed by oil and natural gas. The fossil fuels reduction is due to increased ambition in the two realms discussed above: RE deployment in the power sector, and expanded use of biofuels in road transport.

Figure 53. TPES Fuel Shifting from ATS to APS



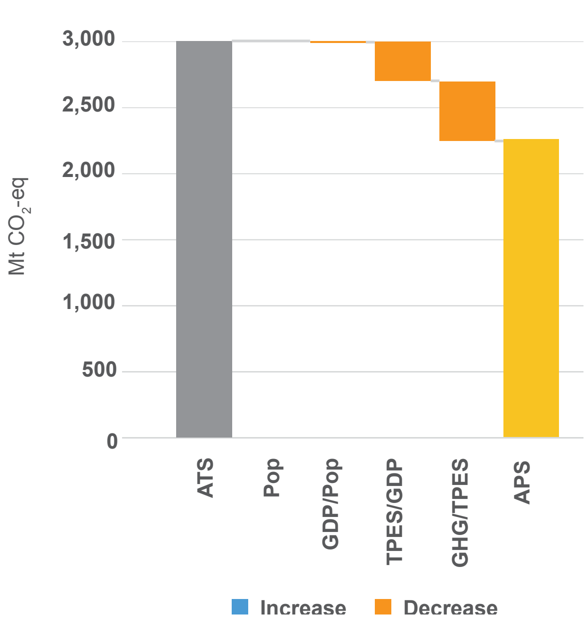
The measures adopted in the APS also reduce GHG emissions more sharply than the ATS would, to about 2.26 Gt CO_2-eq in 2040, with a 1.3% compound annual growth rate (CAGR) over the period 2017–2040, compared with 2.5% in the ATS. As shown in Figure 54, the biggest GHG emission reductions are in the power sector, followed by transport and industry.

Figure 54. ASEAN GHG Emission Reductions in APS vs. ATS, 2025 and 2040



A decomposition analysis based on the Kaya identity shows that the single largest factor driving the GHG emission reductions in this scenario, relative to the ATS, is a lower emissions intensity of the energy supply (GHGs/TPES) – not surprising given the APS focus on increasing the share of RE. Ambitious energy efficiency measures also lead to a significant improvement in the energy intensity of the ASEAN economy, which, in turn, reduces GHG emissions.

Figure 55. Key Drivers of GHG Emission Reductions from ATS to APS, 2040



2.5 Modelling Results: Sustainable Development Goals (SDG) Scenario

The Sustainable Development Goals (SDGs), adopted by all UN Member States in 2015, including all 10 ASEAN countries, lay out "a shared blueprint for peace and prosperity for people and the planet, now and into the future", built around 17 goals to be achieved between 2015 and 2030.[20] SDG 7 is to "ensure access to affordable, reliable, sustainable and modern energy for all", with five targets:

7.1 By 2030	ensure universal **access** to affordable, reliable and modern energy services
7.2 By 2030	increase substantially the share of **renewable energy** in the global energy mix
7.3 By 2030	double the global rate of improvement in **energy efficiency**[21]
7.a By 2030	enhance international **cooperation** to facilitate access to clean energy **research** and technology, including renewable energy, energy efficiency and advanced and cleaner fossil fuel technology, and promote **investment** in energy infrastructure and clean energy **technology**
7.b By 2030	expand **infrastructure** and upgrade **technology** for supplying modern and sustainable energy services for all in developing countries, in particular least developed countries, small island developing States and landlocked developing countries, in accordance with their respective programmes of support

The SDG Scenario in AEO6 models a suite of measures designed to achieve the SDG 7 targets in ASEAN,[22] to provide a global perspective. It should be noted that other SDGs are also relevant to energy systems, including SDG 13 on climate action (which is implicitly addressed by the ATS with its consideration of NDC targets), but the modelling here focuses on SDG 7 in particular.

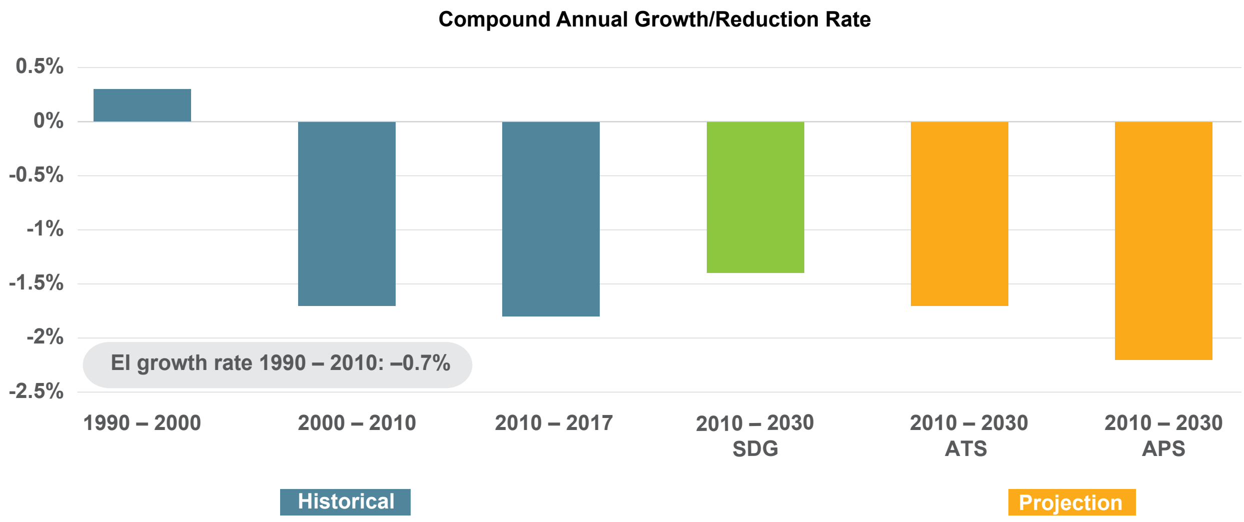
2.5.1 Achieving the SDG 7 Targets

Both the AMS Targets Scenario (ATS) and the APAEC Targets Scenario (APS) already addressed two of the priorities of SDG 7, renewable energy and energy efficiency. As noted earlier, ASEAN Member States have set national targets for both. Through ambitious deployment of renewables in national power development plans, the ATS would grow the renewable energy supply from 47 Mtoe in 2005 to 177 Mtoe in 2030 and 279 Mtoe in 2040, around a sixfold increase. The APS would build on the national targets to enable the region to meet the APAEC target of 23% of renewable energy in the total primary energy supply (TPES) by 2025. Overall, the renewable energy supply would more than quadruple from 2005 to 2030 in the APS.

The ASEAN Member States have also taken steps that would help them meet SDG Target 7.3. Between 1990 and 2010, the energy supply intensity (TPES/GDP) of the region's economy declined by an average of 0.7% per year, which implies that to meet the SDG target, ASEAN would need to reduce the energy intensity of its economy by an average of 1.4% from 2015 to 2030. Figure 56 illustrates ASEAN's energy intensity growth rates, with accelerating improvement over recent decades, showing that the region can double its rate of energy intensity reductions by 2030 in both the ATS and APS.

20 See https://sdgs.un.org/goals.
21. This is measured by the energy intensity of the economy, in terms of total primary energy supply (TPES) and GDP (in 2011 international dollars), relative to the 1990–2010 period.
22 The focus is on Targets 7.1, 7.2 and 7.3, as 7.a and 7.b are about international cooperation, not advances within countries.

Figure 56. Historical and Projected Growth Rate of ASEAN Energy Intensity

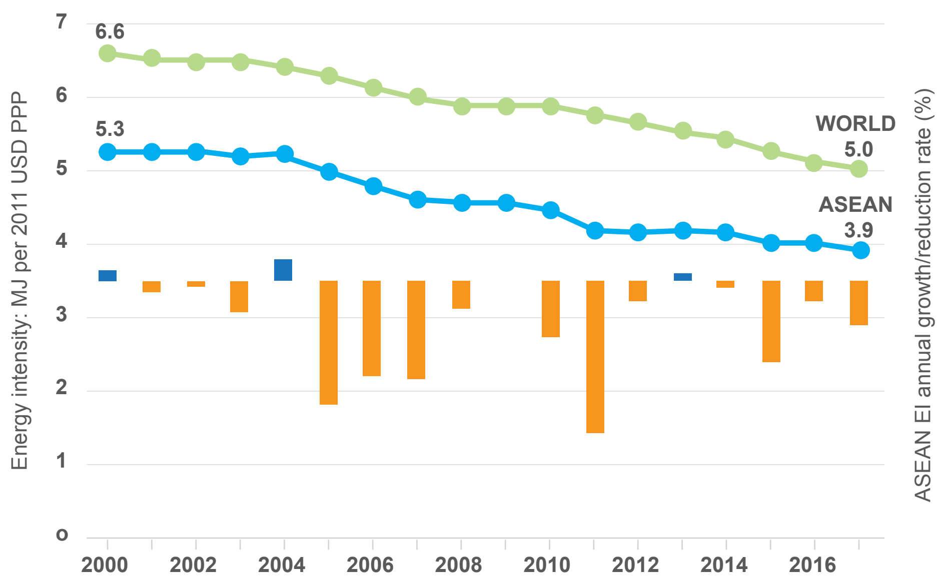


Source: Historical energy intensity data (TPES/GDP) from Global SDG Indicators Database, https://unstats.un.org/sdgs/indicators/database; projections from AEO6 modelling.

However, from a global perspective, ASEAN needs to do much better, as it started from behind. SDG Target 7.3 is based on the world's performance in reducing energy intensity relative to 1990–2010, not on each region's performance. The global energy intensity reduction rate for that period was 1.3%, so doubling it to meet the SDG target would require average annual reductions of 2.6% by 2030. As shown in Figure 56, the ATS would only achieve an annual average reduction of 1.7%; the APS would achieve a 2.2% average annual reduction. Thus, ASEAN would require even more ambitious energy efficiency efforts to align with the global average.

An alternative argument can be made, however, that ASEAN's historical energy intensity was already much lower than the global average on an absolute basis, as shown in Figure 57. From that perspective, it would not be appropriate to expect ASEAN to raise the ambition of its regional energy intensity target.

Figure 57. Historical Energy Intensity Trends, ASEAN and World



Source: Historical energy intensity data (TPES/GDP) from Global SDG Indicators Database, https://unstats.un.org/sdgs/indicators/database.

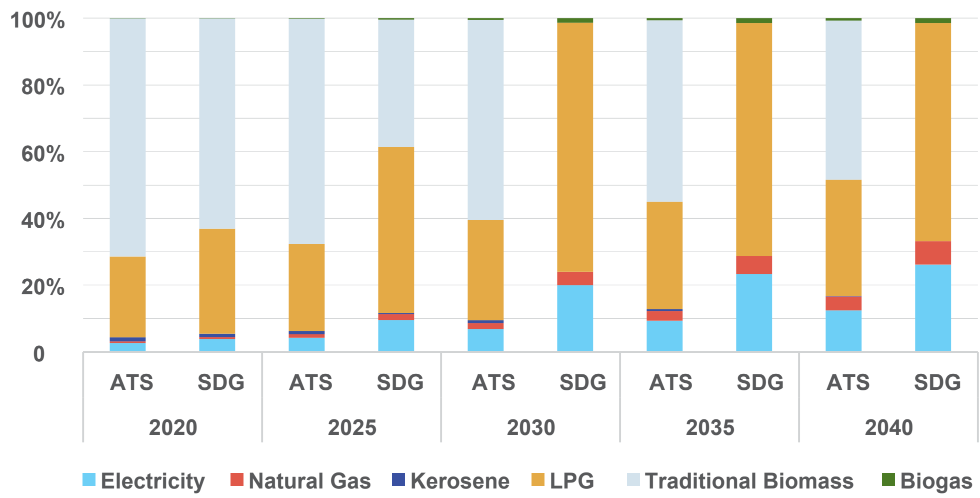
As SDG Targets 7.2 and 7.3 can arguably be achieved under the ATS and APS, the SDG Scenario focuses mainly on adding measures to achieve Target 7.1 – universal access to modern energy. The two indicators for that target are the proportion of the population with access to electricity (see UNSD 2020a for details), and the proportion relying primarily on clean fuels and technology for cooking (see UNSD 2020b for details).[23] The first aspect has been covered in the ATS: most, if not all, ASEAN Member States are expected to achieve a 100% electrification rate by 2030. However, advances in clean cooking in the ATS would not suffice to meet SDG 7.

The SDG Scenario aims to close that gap, starting from the ATS but modelling more aggressive cookstove interventions. In particular, the SDG Scenario assumes that households that now cook with traditional stoves or on open fires switch to LPG, electric, natural gas or biogas stoves by 2030, in proportions matching the share of each clean stove type observed in 2017 in each ASEAN country (see Section 3.5 for a discussion of different AMS' strategies).[24] This is a very simplified model; in reality, consultations with ASEAN Member State representatives suggest that each country will likely use a different mix of modern cooking technologies. Households might also use modern and traditional stoves together, a practice known as "stacking" (see, e.g., Ruiz-Mercado et al. 2011). However, the approach modelled in this scenario successfully achieves 100% clean cooking accessibility across ASEAN, while avoiding potential concerns about the viability of improved biomass stoves, including their emissions and cost.

2.5.2 Residential Energy Consumption Saving and Avoided Emissions from Cooking

Figure 58 shows the difference in energy consumption in the residential sector between the SDG Scenario and the ATS, in both relative and absolute terms. The share of biomass is already significantly smaller in 2025, and by 2030, biomass is not used for cooking at all in the SDG Scenario. Over the next decade, some LPG for cooking is replaced by electricity and gas. Figure 59 shows the fuel savings relative to the ATS, which amount to 18 Mtoe in 2030, 14 Mtoe in 2035, and 11 Mtoe in 2040.

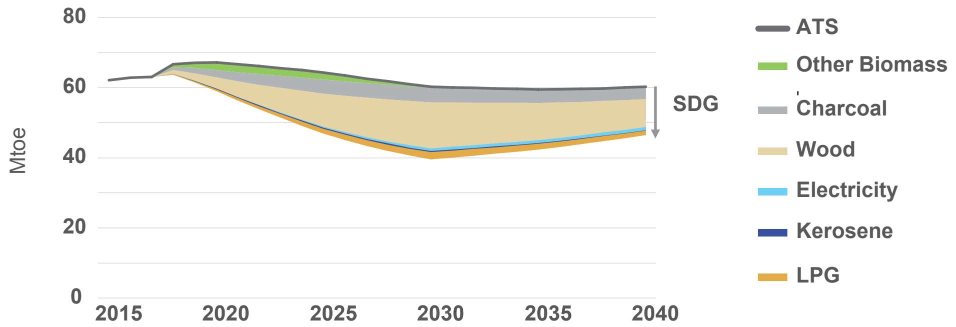
Figure 58. Cooking Energy Fuel Share from Residential Sector, ATS and SDG Scenario



[23] The UN metadata for SDG Indicator 7.1.2 cover "using clean fuels and technologies for cooking, heating and lighting", but the text makes it clear that cooking is the primary focus, due to its large impact on indoor air quality and available data (UNSD 2020b).

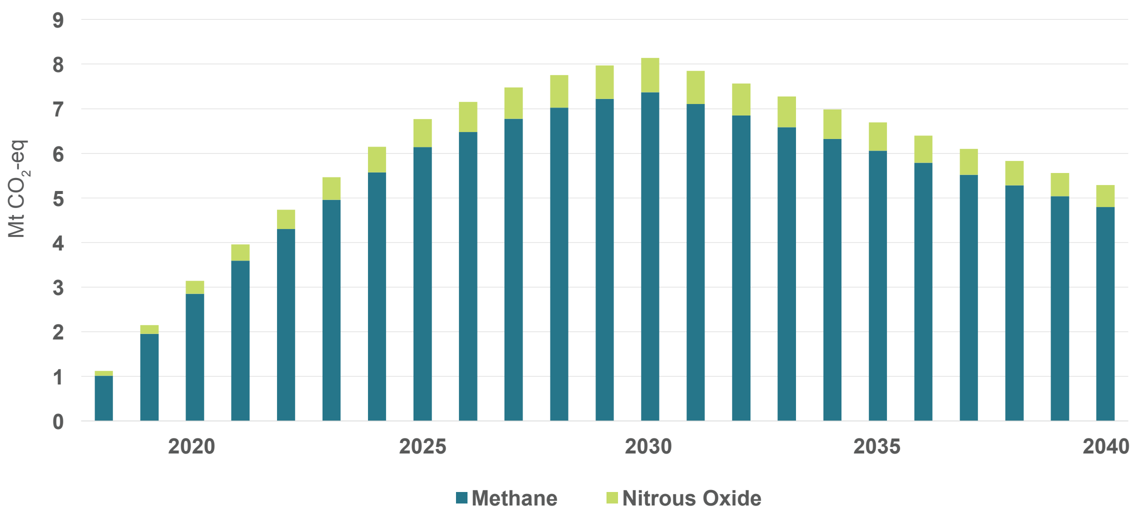
[24] The SDG 7 metadata (UNSD 2020b) specify that to qualify as "clean", stoves must meet the emission rate targets and specific fuel recommendations (i.e. against unprocessed coal and kerosene) in the WHO's normative guidance (WHO 2014). Only the highest-performing ICS meet those standards (WHO et al. 2018; see Box 2.1).

Figure 59. Energy Savings from Residential Sector, ATS and SDG Scenario



When accounting for GHG emissions, CO_2 emissions from using wood feedstock are considered to be zero due to their biogenic nature, but emissions of methane (CH_4) and nitrous oxide (N_2O) released when wood/charcoal/biomass is burnt in traditional stoves must be counted. Replacing all open-fire stoves with modern stove models could reduce methane and nitrous oxide emissions, as shown in Figure 60.

Figure 60. Avoided Non-CO_2 GHG Emissions from Shift to Clean Cookstoves, SDG Scenario



It is encouraging to see that the ATS and APS already align well with the SDG targets. Thus, the ASEAN Member States' achievement of national targets (in the ATS) and regional targets (in the APS) can help them meet global commitments towards a better and more sustainable future for all. Member States can point to this fact to fully integrate the SDGs into their own discussions, to better connect their regional vision with the global vision. This can be done through synchronising policies, parameters and progress reporting, among others.

Given that the SDG Scenario mirrors the ATS in everything except cooking, it is not surprising that it also matches the ATS on almost all indicators, except those related to residential energy demand. Of course, this has some flow-through effects onto total primary energy supply. In the SDG Scenario, the total primary energy supply in 2040 reaches 1,281 Mtoe, which is slightly lower than the 1,298 Mtoe projected in the ATS.

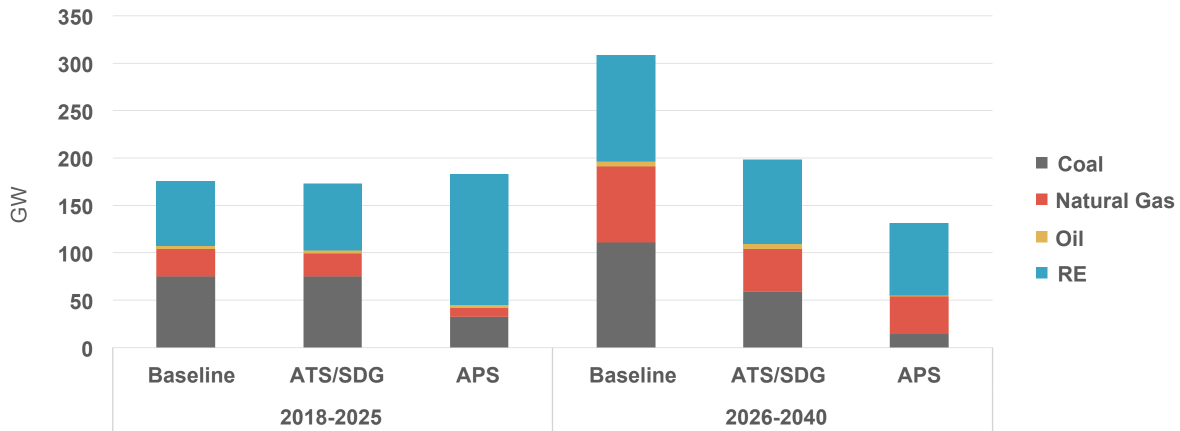

Photo source: Shutterstock

2.6 Energy Affordability and Socio-Economic Analysis

2.6.1 Power Sector Investment Requirements

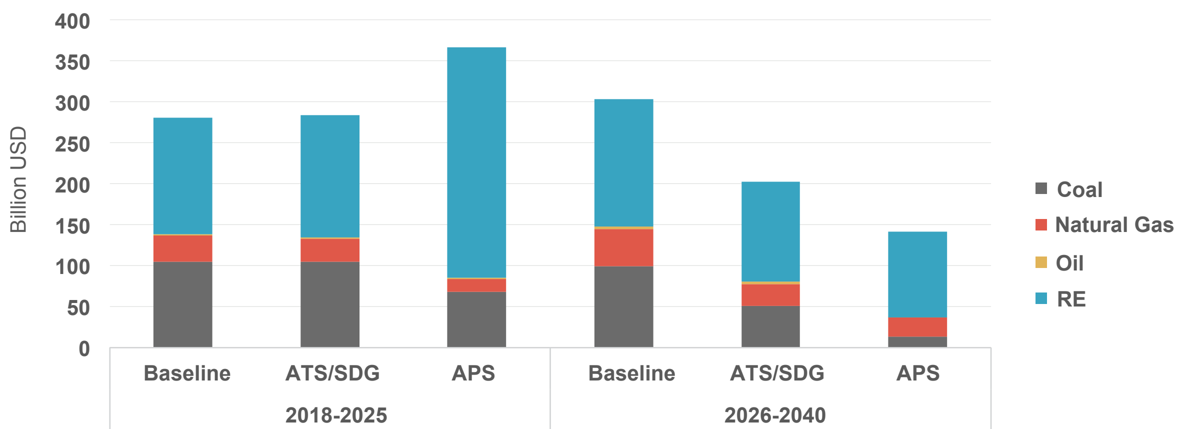
In all four scenarios, the ASEAN region is projected to add significant new electricity generation capacity. As shown in Figure 61, from 2018 to 2025, the additions range from 168 to 179 GW, with the largest additions in the APS. This increase in capacity is needed to keep up with economic and population growth. In the APS, increased electrification and fuel-shifting further increase demand, so more capacity expansion is required than in the other scenarios.

Figure 61. ASEAN Historical and Projected Power Capacity Expansion by Scenario



A significant fraction of the new capacity comes from renewable sources, particularly in the APS. As shown in Figure 61, of the 179 GW added in 2018–2025 in the APS, 138 GW is from renewables. It must be noted that variable RE power generation, mainly solar and wind, has lower capacity factors[25] than conventional fossil fuel-based plants, meaning that for the same level of electricity output, a higher capacity is required. This factor also plays a role in the projected capacity expansion in the APS in the 2018–2025 period.

Figure 62. ASEAN Cumulative Power Sector Investment, Historical and by Scenario



Note: Cumulative investment is discounted at 3% to present value (year 2020).

[25] Capacity factor (CF) is the ratio of the actual generation output of a generation unit to the maximum output that can be generated by that unit within a specific period, typically one year. It can be used to measure the reliability and availability of a generation unit. Variable renewables such as solar and wind typically have lower CFs than thermal power plants due to intermittency.

In the 2026–2040 period, however, the amount of capacity added varies far more dramatically, reflecting the impact of stepped-up efforts to improve energy efficiency, particularly in the APS. Those efforts result in higher energy efficiency in all energy sectors, across the supply chain, and illustrate the value of energy-saving policies and measures implemented under the ATS and APS. While in the Baseline Scenario, 309 GW of new capacity is added, in the APS it is only 132 GW; in the ATS and SDG Scenario, capacity increases by 199 GW.

In all scenarios, substantial power sector investments are required to adequately expand capacity. Overall, the total investment required for capacity expansion in 2018–2040 is USD 584 billion in the Baseline Scenario, USD 486 billion in the ATS, and USD 508 billion in the APS. As shown in Figure 62, between 2018 and 2025, the needed investment in the Baseline Scenario amounts to USD 281 billion (discounted to 2020). In the ATS, it rises to USD 283 billion; for the APS, it is USD 367 billion.

Notably, the larger investment needs in the ATS and the APS are not driven by a greater increase in power generation capacity, but by the higher cost of cleaner technologies.[26] The breakdown by fuel type shows that a large share of the investment goes to renewable energy – in the APS, USD 281 billion, or 76.7% of the total.

In 2026–2040, however, power sector investment requirements more closely align with the amount of capacity being added in each scenario. In the Baseline Scenario, USD 303 billion is needed; in the ATS and SDG scenario, USD 203 billion; in the APS, USD 141 billion. The required investments in this period also reflect a sharp reduction in the cost of power generation compared with 2018–2025: 2 billion USD per GW in the APS in 2018–2025, but only 1 billion USD per GW in 2026–2040.

2.6.2 Job Creation in the Renewable Energy Sector: Solar and Wind

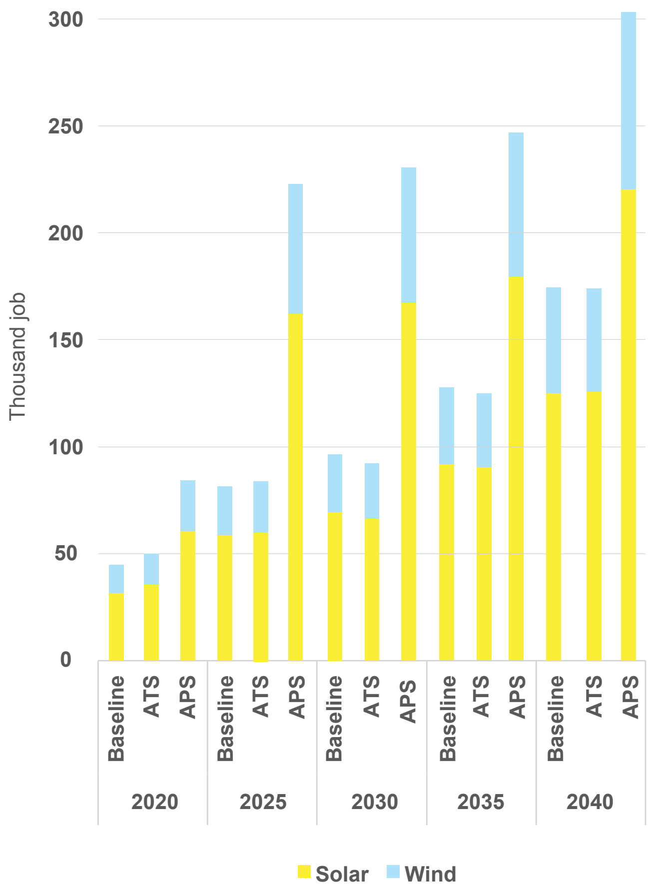
The cost of capacity expansion can be partly offset by the economic benefits of installing and operating that new capacity. One of positive externalities of policies that promote RE development, as modelled in the ATS and APS, is the creation of jobs. This economic benefit is complementary to the positive impacts of decreasing emissions and increasing energy security, which are the main goals of the ATS and APS.

Increasing investment in solar and wind can create direct and indirect jobs. Direct jobs include solar and wind installers, assemblers and engineers who work directly in the solar and wind industries. Indirect jobs include other supporting industries, supply chains of smaller parts and other consumables for the renewables industry, as well as further effects associated with potential spending by those employed. In the APS, the increased installation of solar and wind power would add about 223,000 jobs in 2025, the target year of APAEC 2016–2025. This is about 138,000 more jobs than in the ATS and SDG Scenario, which envision 61,000 added jobs in solar and 24,000 added jobs in wind energy in 2025. In the Baseline Scenario, meanwhile, a total of 81,000 RE jobs are added in 2025, just slightly lower than in the ATS (see Figure 63).

In 2040, the employment gains from strong RE promotion policies are even greater. In the APS, 303,000 solar and wind jobs would be created – 220,000 in solar and 83,000 in wind energy. In the Baseline Scenario or the ATS and SDG Scenario, meanwhile, only about 174,000 jobs are created in the two sectors combined. Such economic benefits should be considered when designing policies, including those explored in the ATS and APS. Nevertheless, it should be noted that the jobs numbers presented in this section do not include lost or forgone jobs related to fossil-fuelled generation. This is due to a lack of necessary data.

[26] Long-term projections of technology costs, both fossil fuels and RE, are not covered in the model. The investment cost is estimated using the AMS latest costs data from a recent LCOE study (ACE, 2019).

Figure 63. Renewable Energy Jobs Created in ATS and APS



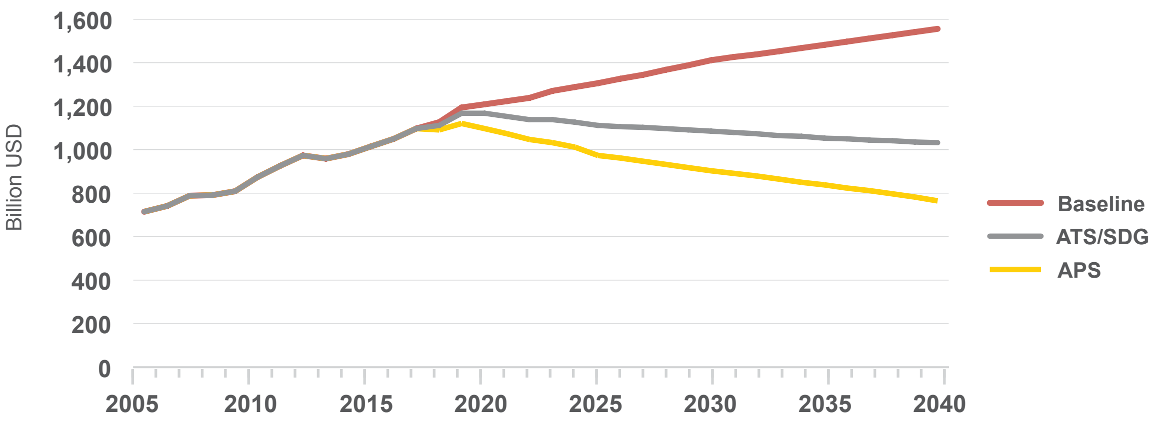
2.6.3 Impacts on Social Cost of Energy

As discussed above, the policies and measures modelled in both the ATS and the APS aim to increase energy security through diversification and self-sufficiency, while reducing GHG emissions. Such aims are in line with global efforts to mitigate climate change. Beyond this, it is well known that fossil fuel-based power generation has negative externalities – impacts on the environment and society that are not properly accounted for in purely economic decision-making processes. Those externalities are due to air, water and land pollution associated with fossil fuels, which can then harm human health, negatively impacting social capital and the cultural assets of a nation and inducing indirect, unaccounted costs.

It is important to account for those externalities to fully understand the implications of different energy policy and investment choices. The scenarios in AEO6 clearly show the high social cost of continuing along historical patterns, and the benefits of adopting the policies modelled in the ATS and APS. AEO6 calculates the social cost as a function of GHG emissions produced across the whole energy system using the social costs value from Shindell (2015). This includes final sectors (residential, commercial, industry, transport) and transformation sectors, mainly electricity generation.

Figure 64 shows the social cost of energy in the scenarios explored in this Outlook. The Baseline Scenario is projected to have a high social cost in the future, reaching USD 1,558 billion by 2040. The implementation of the ATS could reduce the social cost to USD 1,036 billion, while achieving APS targets would sharply cut the social cost, to USD 766 billion.

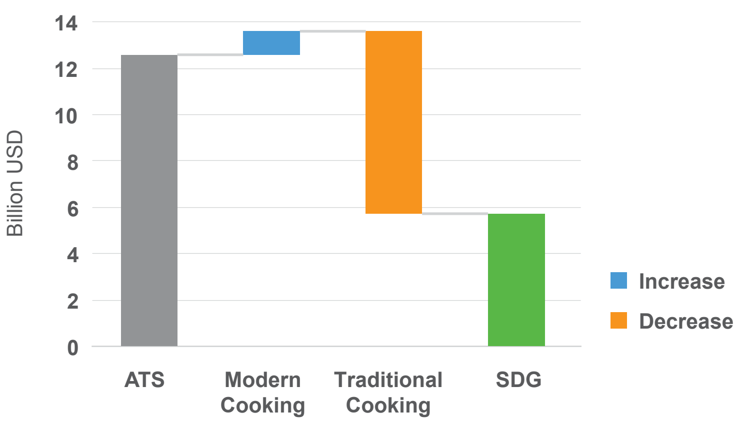
Figure 64. Social Cost of Energy across ASEAN

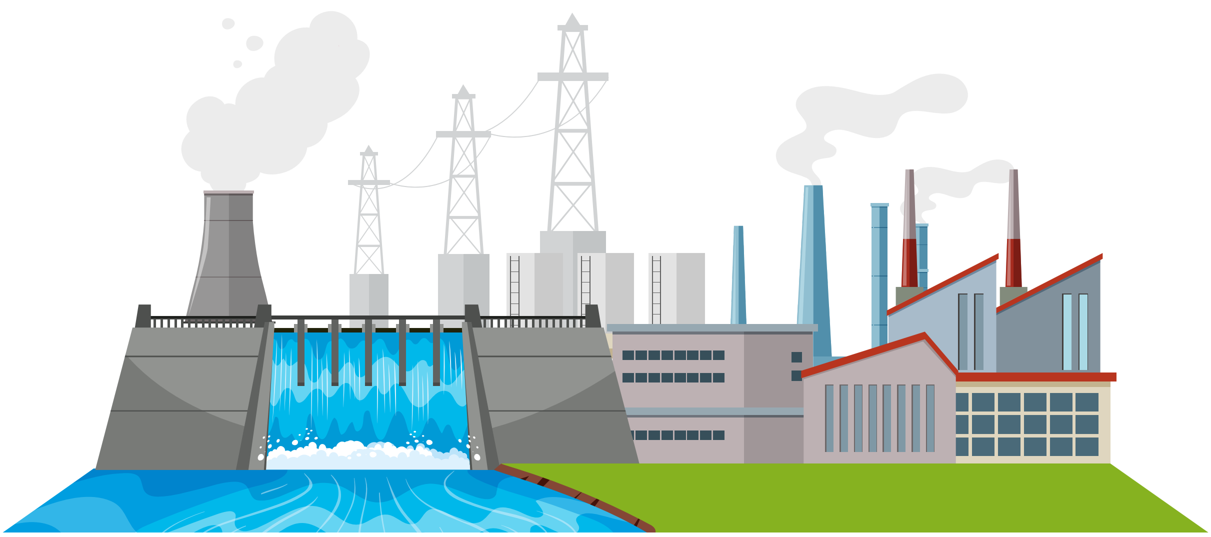


Note: Values are discounted at 3% per year to present value (year 2020).

It must be noted that the ATS and SDG Scenario show a very small difference in terms of social costs when calculated in terms of GHG emissions, as the two only differ in their approach to cooking in the residential sector. In the SDG Scenario, the shift from traditional cooking would reduce the social cost by another USD 6.8 billion in 2030 relative to the ATS (Figure 65). Further analysis is required to evaluate the direct social benefits associated with improved indoor air quality under the SDG Scenario, which is one of the main reasons for investing in a shift to clean cooking.

Figure 65. Social Cost Comparison between ATS and SDG Scenario in 2030





CHAPTER 3

Thematic Energy Insights

CHAPTER 3
Thematic Energy Insights

The previous chapter explored the implications of achieving the ASEAN Member States' national targets for modern energy access, energy efficiency and renewable energy, as well as climate commitments included in their NDCs. It then examined the extra efforts required to achieve the regional targets agreed to in the ASEAN Plan of Action for Energy Cooperation (APAEC) 2016–2025, along with an alternative scenario that prioritises achieving SDG 7, to "ensure access to affordable, reliable, sustainable and modern energy for all". In all three scenarios, ASEAN would make significant investments to improve energy efficiency, particularly in the industrial and residential sectors, and to accelerate the transition to renewable energy, particularly in the power and transport sectors. The share of RE in the electricity supply would scale up, especially solar and hydropower, and biofuel use would increase in road transport, reducing demand for imported oil.

This chapter delves deeper into energy issues and policy challenges of particular importance to the ASEAN region, aligned with the themes of APAEC Phase II: energy transition, resilience and sustainability. It broadens the perspective by examining how other countries and regions are addressing these issues, and how ASEAN might learn from their practices and trajectories. Five topics in particular are explored: the ASEAN Power Grid, the role of fossil fuels in the energy transition, air conditioning, greening transport, and clean cookstoves.

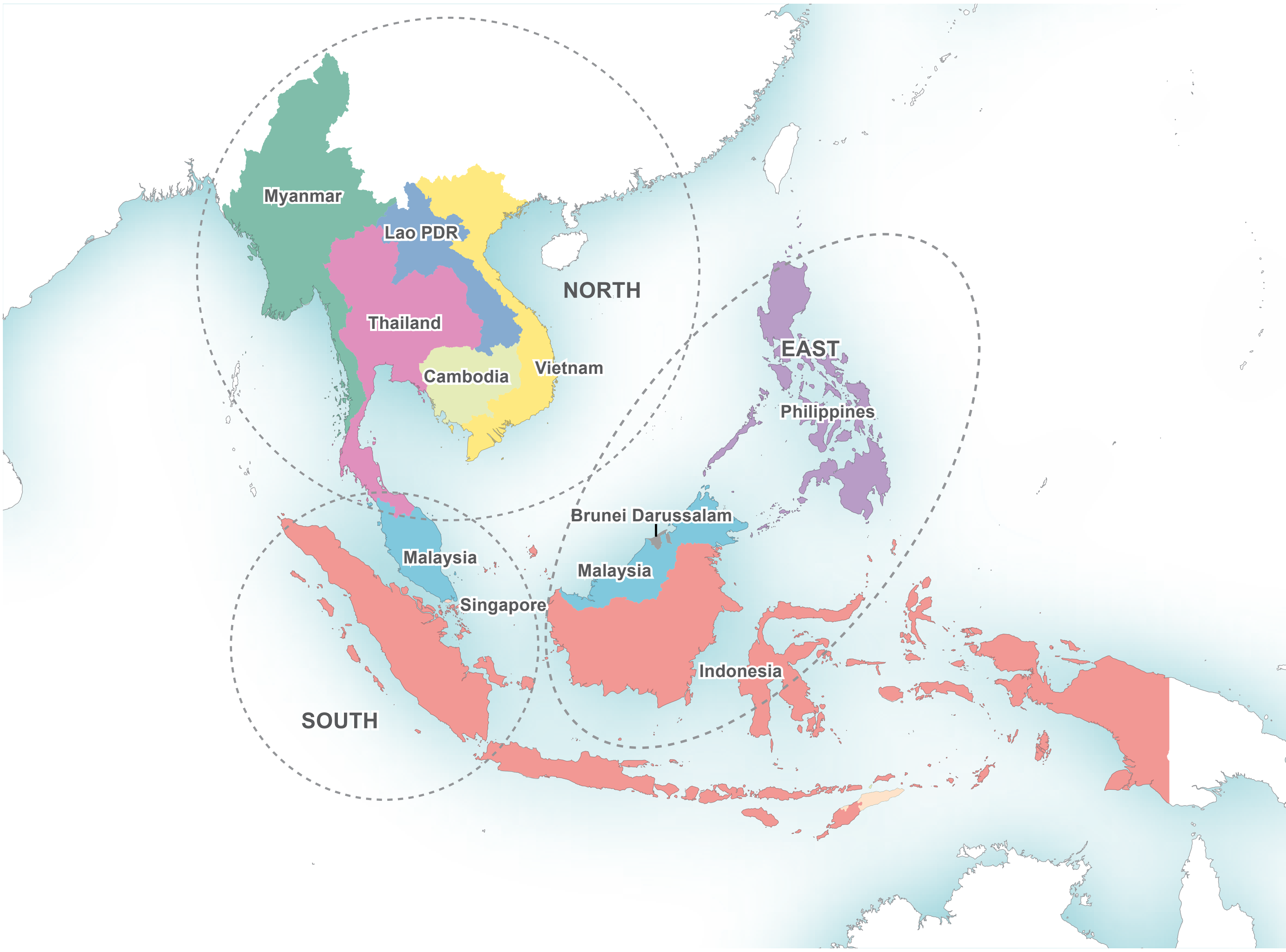
3.1 ASEAN Power Grid

The ASEAN Power Grid (APG) has been one of seven programme areas under APAEC since 1999. It is meant to facilitate electricity trading among Member States through strategic interconnections and enhance the integration of their power systems. The concept includes improvements to both physical infrastructure and procedures and mechanisms for power trade. Increased power system connectivity through the APG offers several potential benefits. It can enable more efficient use of resources, enhance grid stability and service in remote areas, and improve the region's energy security as electricity demand and end uses grow (ACE 2015). The APG can also support better utilisation of renewable energy resources, advancing clean energy and climate protection goals.

The Heads of ASEAN Power Utilities/Authorities (HAPUA) and ACE have investigated these possibilities in a series of ASEAN Interconnection Masterplan Studies (AIMS). Based on various grid integration scenarios, these projects have evaluated the potential for cross-border electricity trade and regional costs and benefits. The most recently completed study – AIMS II in 2010 – validated the APG's efficiency potential, finding that improved integration through the APG could avoid adding 154 MW of capacity, saving USD 1.87 billion, by 2025. A third study (AIMS III) is now under way, slated to be published in late 2020. Among other research questions, AIMS III explores the links between the APG and more ambitious renewable energy targets.

The APG programme calls for concurrent development of transmission and electricity trading. Trading is expected to progress through three levels: from bespoke bilateral exchanges, to trading in subregions, to trading in an integrated regional system (ACE 2015). The intermediate step comprises three subregions (North, South and East) as shown in Figure 66.

Figure 66. ASEAN Power Grid (APG) Subregions



3.1.1 Achievements to Date

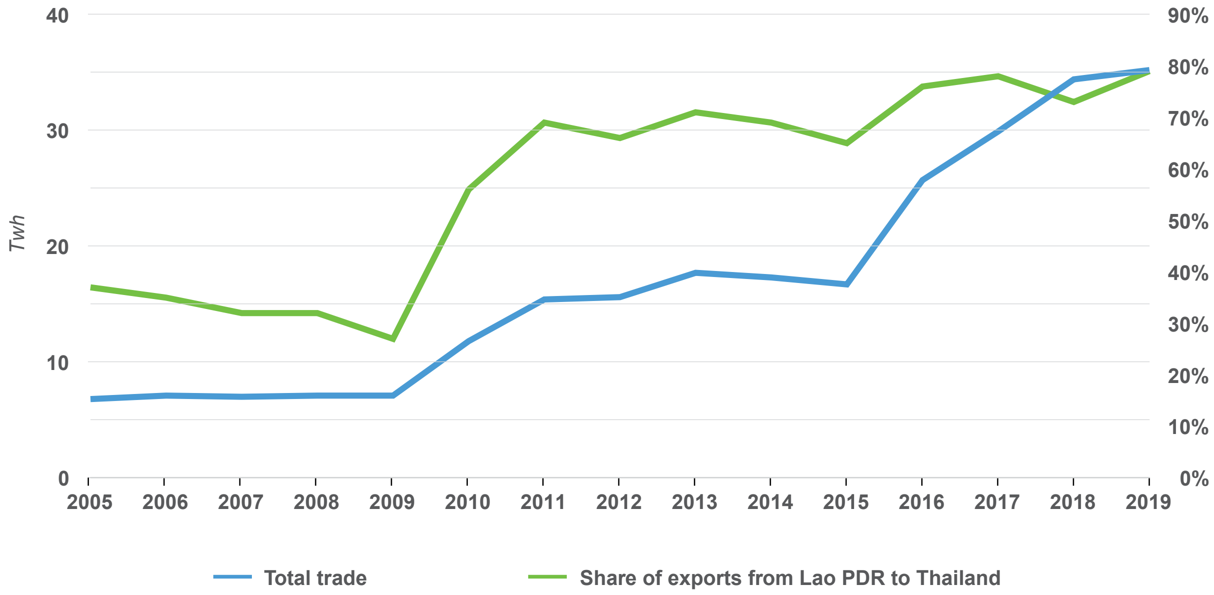
Since the early 2000s, HAPUA, ASEAN Member States and other power system actors have made substantial progress toward realising the APG's objectives. In terms of physical infrastructure, 7 of 16 key power interconnection projects have been completed, increasing regional cross-border transmission capacity to 2,275 MW, as shown in Table 4.

Table 4. Cross-border Interconnections among ASEAN Member States

Interconnection	Max Capacity (MW)
Lao PDR – Vietnam	200
Peninsular Malaysia – Singapore	525
Sarawak – Kalimantan	230
Thailand – Cambodia	120
Thailand – Lao PDR	700
Thailand – Peninsular Malaysia	300
Vietnam – Cambodia	200

Leveraging the improved connectivity, power trade among ASEAN Member States has grown substantially. Over the last 15 years, trade has increased more than fivefold, with 35 terawatt-hours (TWh) exchanged in 2019 (see Figure 67). Power exports from Lao PDR to Thailand have made up an important and growing share of this amount (79% in 2019).

Figure 67. Power Trade among ASEAN Member States



Data source: ASEAN Energy Database System, https://aeds.aseanenergy.org.

At present, most electricity trade within the APG occurs through bilateral agreements. However, since 2018 there has been a small demonstration of multilateral trading in the Lao PDR-Thailand-Malaysia-Singapore Power Integration Project (LTMS-PIP). Conceived as a pilot and an opportunity to address technical, legal and financial issues raised by multilateral trade, LTMS-PIP is premised on wheeling up to 100 MW of supply from Lao PDR through Thailand (Lao PDR Ministry of Energy and Mines et al., 2014) Currently the power is delivered to Malaysia, although the intention is ultimately to connect to the market in Singapore. Through March 2019, 25 gigawatt-hours (GWh) of electricity had been traded under the project (IEA 2019a).

LTMS-PIP is a limited foray into multilateral trading, since it is based on a unidirectional flow of electricity, involves only a few countries, and has not established a market to pair new buyers and sellers. Still, the project has laid a foundation for further efforts on multilateral trading in ASEAN. In particular, participants have devised a methodology for calculating wheeling charges and demonstrated collaborative approaches to developing trading rules and processes (IEA, 2019a).

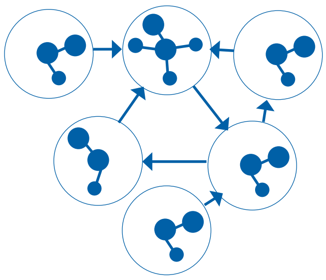
Alongside these advances in grid infrastructure and trade, HAPUA, ACE, and others have conducted a number of planning studies for the APG. These include AIMS; an assessment of strategies for multilateral power trading in ASEAN, led by the IEA (2019a); and other studies of the APG's technical, regulatory and financial implications (ACE 2015).

3.1.2 The Road Ahead

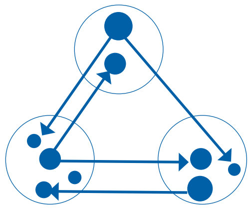
Recent trends in the APG's development are expected to continue in the near term. Additional priority interconnection projects involving 1,205 MW of capacity are planned by 2025; when completed, they will bring cross-border transmission capacity in the region to 3,480 MW. Further growth in bilateral power trade is anticipated, and the implementation of LTMS-PIP will continue – potentially including an expansion of the arrangement to Singapore. As indicated above, findings from the AIMS III study should shed light on the next stage of the APG, particularly on the relationship between grid integration and renewable energy deployment.

Looking beyond these activities, a key step towards exploiting the full potential of the APG is to develop market mechanisms supporting wider multilateral power trading. Expanded multilateral exchange will increase economic gains for buyers and sellers and can lower systemic risks through resource and geographic diversification. As shown in a recent study by the IEA (2019b), a multilateral trading regime could take various forms. Power exchange could be one-way (as in LTMS-PIP) or two-way; traded electricity could play a significant or subordinate role in meeting domestic demands; and the time-scale for trades could be longer or shorter (e.g. long-term, day-ahead, real-time). The possibilities are numerous, even though it is clear that ASEAN Member States will maintain separate national power systems with their own national objectives.

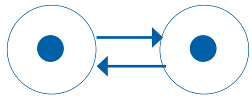
The IEA (2019b) study identifies three potential future trading models for ASEAN:



Harmonised bilateral trading, which would involve bilateral exchanges with some regional coordination and standardisation of contracts and wheeling charges;



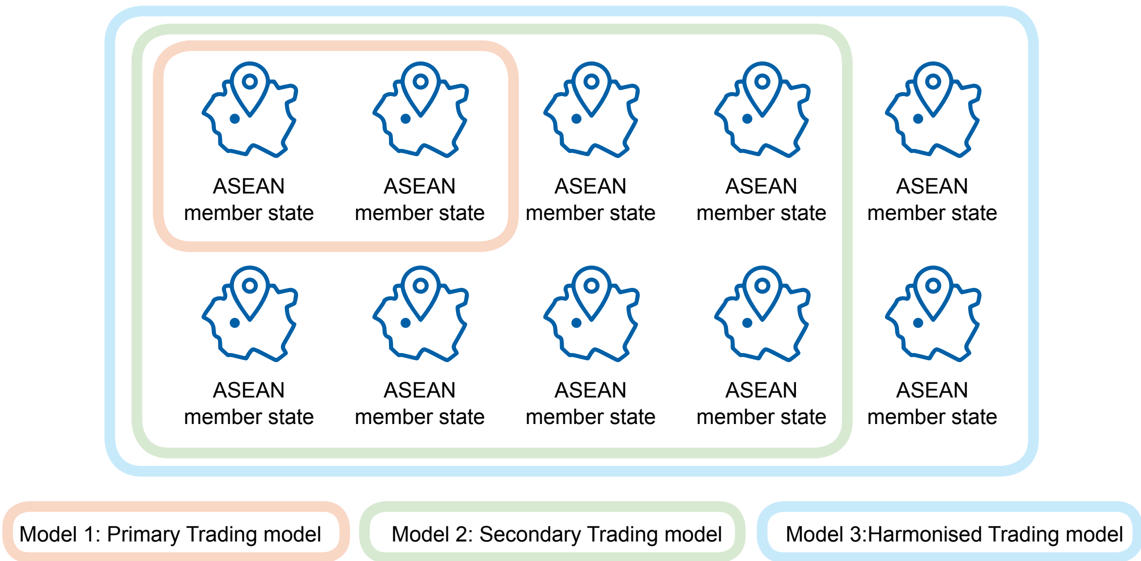
Secondary trading, which would establish a multilateral, multi-directional regional market to supplement domestic generation; and



Primary trading, which would utilise a multilateral, multi-directional regional market as the main source of power for participating countries.

Each of these models would be an evolution from current practices in the APG. Depending on countries' preferences, multiple models could exist simultaneously, each involving certain ASEAN Member States and certain parts of the APG infrastructure. A multiple-model approach would allow individual Member States to opt into the level of integration that made the most sense for their national circumstances. Figure 68, adapted from the IEA report, graphically depicts that situation.

Figure 68. Indicative Multiple-Model Approach for Future Power Trading in ASEAN



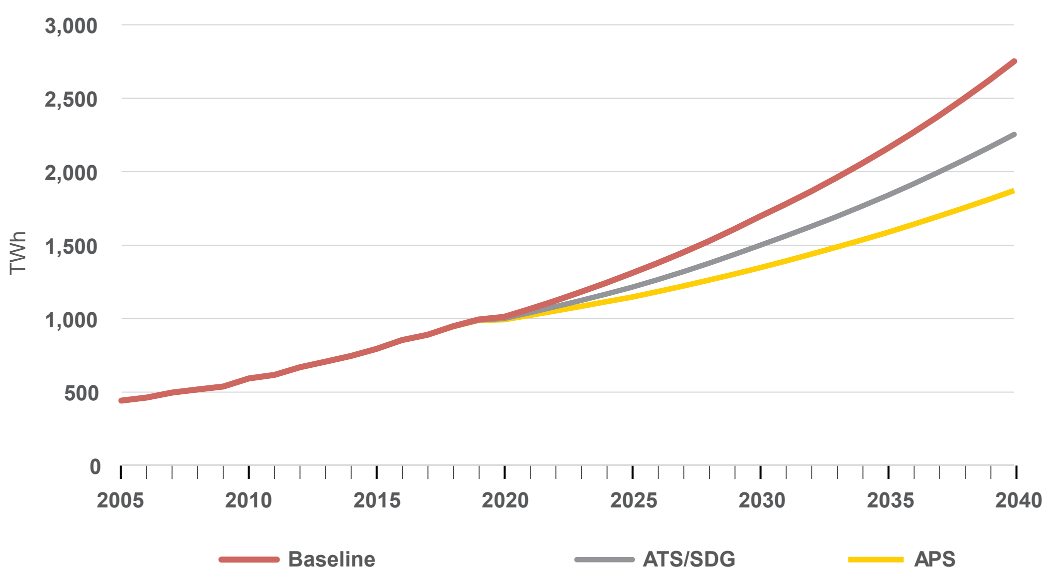
Source: Adapted from IEA (2019b)

ASEAN Member States' current policy positions suggest the most likely future trading paradigm for the region is a combination of bilateral and secondary multilateral trading. The ASEAN Power Grid Consultative Committee (APGCC), a group organised under HAPUA to guide the APG and multilateral trading, has affirmed that trading should be an adjunct to domestic generation and nationally operated power systems (HAPUA Secretariat 2016). The specific shape of the trading system(s) adopted will depend on the participating Member States and their needs. In any case, enhanced trading will require institutional, procedural, legal and regulatory, information systems, and data management advances, as well as training and capacity development for staff at market participants and coordinating organisations.

Work towards greater trading through the APG should also be coordinated with electricity trading arrangements in the Greater Mekong Subregion (GMS) Program. Five ASEAN Member States (Cambodia, Lao PDR, Myanmar, Thailand and Vietnam) participate in the GMS, along with China. At present, parties to the GMS engage in a range of bilateral electricity trades, but there is ambition to progress to a multilateral trading system (GMS 2020). A number of steps have been taken towards this end, including the preparation of common grid codes. To avoid inefficiencies, work on the APG should take account of these and related developments.

The AEO6 modelling does not explicitly represent power trading and transmission constraints in the APG, but projections of electricity demand in the AEO6 scenarios underscore the scope for future trading in the region. Figure 69 depicts total regional electricity demand in the Baseline Scenario, ATS and APS.[27] Even in the lowest projection – the APS, which goes farthest on energy efficiency – demand nearly doubles in the next 20 years. Responding to this growth while managing costs and externalities from power production is an essential challenge for ASEAN. The APG can play a crucial role in this context, opening new opportunities for clean generation while decreasing overall system costs.

Figure 69. ASEAN Historical and Projected Electricity Demand across AEO6 Scenarios



The forthcoming AIMS III study will update estimates of the APG's costs and benefits in scenarios of future electricity demand. Building on this work, future versions of the AEO are expected to model the APG directly. This will allow assessment of transmission and power trading options within the AEO's integrated energy system analysis.

[27] Demand in the SDG Scenario is essentially the same as in the ATS.

3.1.3 Insights from Other Regions

Multinational power system integration projects such as the APG have been undertaken in several regions around the world, and various studies have compared projects to derive overall lessons. Though every region is different, findings from this work provide some context for ASEAN's efforts with the APG. Table 5 summarises success factors for multinational power system integration, as identified in three recent comparative analyses. Altogether, these studies examine eight integration initiatives involving 74 countries:

Central American Power Market (CAPM)
Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua and Panama

Eastern Africa Power Pool
Burundi, Democratic Republic of the Congo, Egypt, Kenya, Rwanda, Tanzania, Libya, Uganda and Sudan

Gulf Cooperation Council Interconnection Authority
Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and United Arab Emirates

GMS
Cambodia, China, Lao PDR, Myanmar, Thailand and Vietnam

Nord Pool
Austria, Belgium, Denmark, Estonia, Finland, France, Germany, Great Britain, Latvia, Lithuania, Luxembourg, Netherlands, Norway and Sweden (main market)

South Asia Regional Initiative for Energy
– Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan and Sri Lanka

Southern African Power Pool (SAPP)
Angola, Botswana, Democratic Republic of the Congo, Eswatini, Lesotho, Malawi, Mozambique, Namibia, South Africa, Tanzania, Zambia and Zimbabwe

West African Power Pool
Benin, Burkina Faso, Côte d'Ivoire, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Morocco, Niger, Nigeria, Senegal, Sierra Leone and Togo

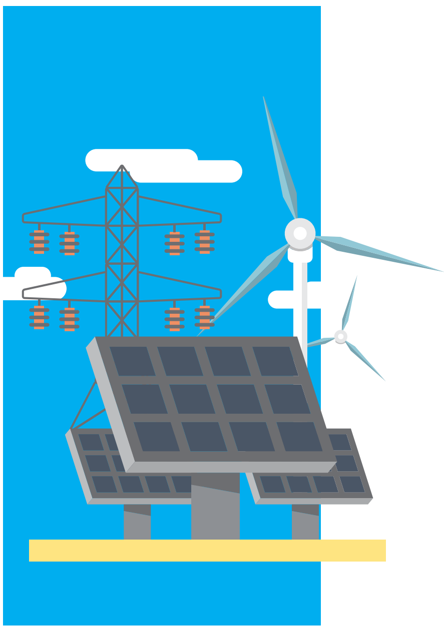
Table 5. Success Factors for Multinational Power System Integration

Category	IEA (2019a)	IRENA (2019)	Oseni and Pollitt (2016)
Political and economic environment		• "Regional mindset" focused on improving welfare regionally (p. 14) • Buy-in from political leadership in participating countries	• Commitment to free trade, generally through a regional trade agreement • Uneven distribution of electricity generation potential and demand across participating countries
Transmission		• Sufficient transmission capacity made available to market	• Sufficient transmission capacity
Institutions	• Regional institution(s) to coordinate/administer integration	• Strong institutions and governance model to coordinate integration	• "Strong, efficient and independent" institution to operate integration/integrated market (p. 635) • Some regulatory oversight, although not necessarily by a new regional institution
Procedures	• Common working language and processes for calculating wheeling charges, settling transactions, and handling disputes and defaults	• Transparent information-sharing	
Technical standards	• Harmonised grid codes, "in particular those that relate to transmission capacity allocation and the secure operation of the grid" (p. 66)		
Data management & information technology	• Agreed, secure mechanism for gathering and sharing data	• Reliable, functional information technology platforms for markets and transmission system	
Trading time horizon		• Shorter-duration markets facilitate integration of variable renewable energy	• Shorter-term trading creates greater efficiencies
Implementation practices			• Cost-benefit analyses of enhanced integration or other changes before implementing them • Agreed timetable for integration • Piloting with a few countries before expanding to additional countries • Support from international organisations, particularly for funding

The authors of these studies approach the problem of multinational power integration from somewhat different angles, but there are clear areas of agreement in their results. Critical enablers of success include embedding integration projects within a larger programme of regional cooperation, co-developing transmission and electricity trading, establishing and empowering institutions to manage the integration effort, and implementing appropriate data systems and information-sharing. The APG already meets several of these (and other reported) success factors, though additional work on certain criteria is needed (e.g. institutional and data system development).

Two of the multinational efforts covered in these studies are particularly relevant for ASEAN, since they are based on both bilateral trading and secondary multilateral trading. As noted above, the APG is evolving towards this paradigm. The first, the Southern African Power Pool (SAPP) connects 12 countries in Southern Africa. It is managed by an executive committee, with subsidiary committees organised under the Southern African Development Community's Directorate of Infrastructure (SAPP 2020). Since its inception in 1995, SAPP has grown to support bilateral trades and competitive, multilateral trading in intra-day, day-ahead, week-ahead, and month-ahead markets. Participants maintain their own national power systems and use SAPP as a secondary resource, principally to sell excess power (IEA 2019a). Currently, 12 national utilities and five private utilities and independent power producers are members of the pool (SAPP 2020).

The SAPP programme encompasses trading and the development of generation and transmission resources. From April 2018 to March 2019, bilateral trades through SAPP totalled 4.3 TWh, while exchanges in the competitive markets reached 2 TWh (SAPP 2020). The value of competitive trades was USD 107 million. The trading volume is only a fraction of total electricity sales in the region (which are currently at least 267 TWh per year), due in part to transmission constraints (SAPP 2020; Oseni and Pollitt 2016). Notwithstanding, SAPP provides a platform for realising significant benefits in the region's power systems. The most recent SAPP Pool Plan finds that through 2040, realistically achievable integration via SAPP could save USD 36 billion in power sector costs[28] compared with following national power development plans only (SAPP 2017). Integration is also projected to increase the share of renewables (including hydropower, wind and solar) in the power mix by a third.



The second integration project, the Central American Power Market (CAPM), involves six countries linked by a 230 kV transmission network. Arising in its current form in the late 1990s, CAPM enables bilateral trading among participants as well as competitive, multilateral trading in day-ahead and real-time exchanges. At present, 281 organisations participate in the system, including generators, distribution companies, utilities, large users, and other traders (Ente Operador Regional, 2020a). CAPM functions as a complement to national power systems and markets in the connected countries, absorbing surplus generation, filling gaps, and helping to lower supply costs overall. Management responsibilities are shared among three main multilateral institutions: the Regional Electricity Interconnection Commission, a regulatory agency; the Regional Operating Entity, which runs the bilateral and competitive markets and handles dispatch; and the Network Owner Company, which owns the regional transmission infrastructure (Echevarría et al. 2017).

Total trading (bilateral and multilateral) through CAPM amounted to 1.9 TWh in 2019 (Ente Operador Regional 2020b). As with SAPP, trading is not large relative to regional electricity demand, which is projected to be 52 TWh in 2020. Even so, the project has delivered economic benefits to participating countries by reducing electricity production costs and providing buyers for surplus power. Echevarría et

[28] Discounted at 6%.

al. (2017) report that net benefits from CAPM between June 2013 and December 2015 totalled USD 131 million, although they were not distributed evenly across countries. Looking prospectively at the period from 2016 to 2025 and comparing the CAPM with a scenario without regional electricity system integration, they find direct power-sector cost savings from CAPM between USD 811 million and 1.4 billion. The range is a function of assumptions about whether generation planning is coordinated, and international transmission capacity is doubled.

The experiences of SAPP and CAPM offer additional evidence that a cross-border power integration regime can feasibly support both bilateral and secondary multilateral trading. Within such a system, participants can realise significant value even if the potential for trading and integration is not fully exploited. Prospective analyses for SAPP and CAPM do calculate higher power-sector cost savings when generation and transmission are planned in a coordinated, regional way. However, the difference in benefits between ideal and achievable integration may not be drastic. In the case of SAPP, for example, projected, discounted power-sector cost savings through 2040 are only 13% higher in a scenario of fully coordinated regional planning than in the realistic integration scenario mentioned above (SAPP 2017). These findings lend support to ASEAN's approach to the APG, suggesting that measured implementation that is consistent with national requirements will still yield valuable results for the region.

3.2 The Role of Fossil Fuels in the Energy Transition and Energy Resilience

As outlined in Sections 2.3 and 2.4, ASEAN Member States have adopted national and regional targets for renewable energy and energy efficiency, aiming to reduce oil imports and increase energy self-sufficiency, expand access to electricity, and address pollution and GHG emissions. Nevertheless, the scenario analysis showed that fossil fuels will provide the majority of the ASEAN region's energy supply even in 2040, and even in a progressive RE and EE scenario such as the APS. As shown in Figure 70, in the APS, 36% of total final energy consumption (TFEC) in end-use sectors is met with oil (222 Mtoe); 26% with electricity (161 Mtoe), and 21% with bioenergy (131 Mtoe). In the transport sector, a sharp increase in biofuel use would still leave oil with a 57% share of demand by 2040. Similarly, LPG, an oil-derived product, is still expected to be one of the main cooking fuels, with a share of 16% of household energy consumption in 2040. Though several energy efficiency measures would be in place in industry, fossil fuels including gas, coal and oil, would still dominate, with a combined 56% share of the sector's demand by 2040.

Figure 70. ASEAN Total Final Energy Demand (TFEC) in 2040, APS

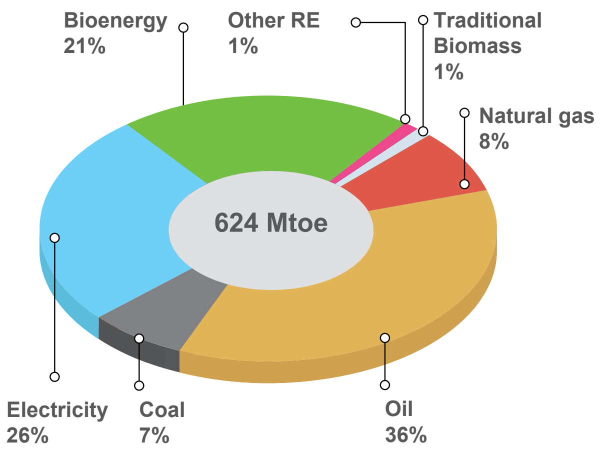
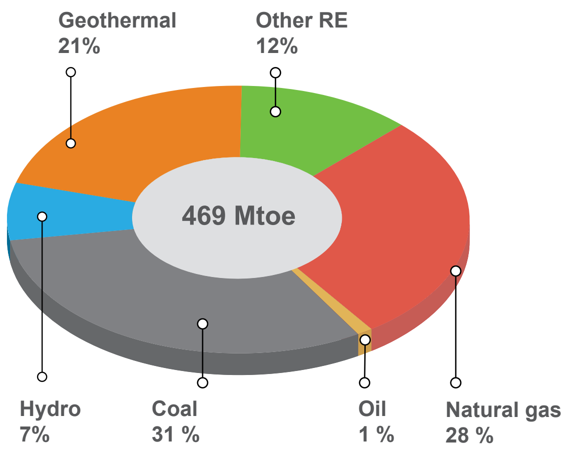


Figure 71. ASEAN Fuel Consumption in Power Sector in 2040, APS



Note: Fuel consumption in power sector means energy inputs into power plants.

Within the power sector, the APS envisions a significant transition to low-carbon sources, to meet the APAEC target of 23% RE in the power supply by 2025 and keep growing the share of RE to reach 51% of the power generating capacity in 2040. To achieve this, about 138 GW of additional RE would need to be added between 2017 and 2025, and another 77 GW installed by 2040. Variable RE sources (solar and wind) would then account for 23% of power generation capacity. With the higher rate of vRE, the role of gas-fired power plants or other flexible generation will be important to maintain grid stability. On top of this, coal will likely remain as the second major fossil fuel due to its availability and affordability. Figure 71 depicts the projected energy consumption in the power sector in 2040; about 60% of the feedstock for ASEAN power plants would still be fossil fuels.

Recognising the large continued need for fossil fuels both in end-use sectors and power generation, it is important to look at how the region can fulfil this projected demand in future years. As shown in Figure 72, the fast-growing demand in end-use sectors and power generation, with CAGRs of 1.3% and 2.2%, respectively, could not be fulfilled by local production in the long run. Hence, ASEAN will depend more and more on fossil fuel imports, a huge concern for the region's energy security.

Figure 72. ASEAN Fossil Energy Production vs. Demand Projection, APS

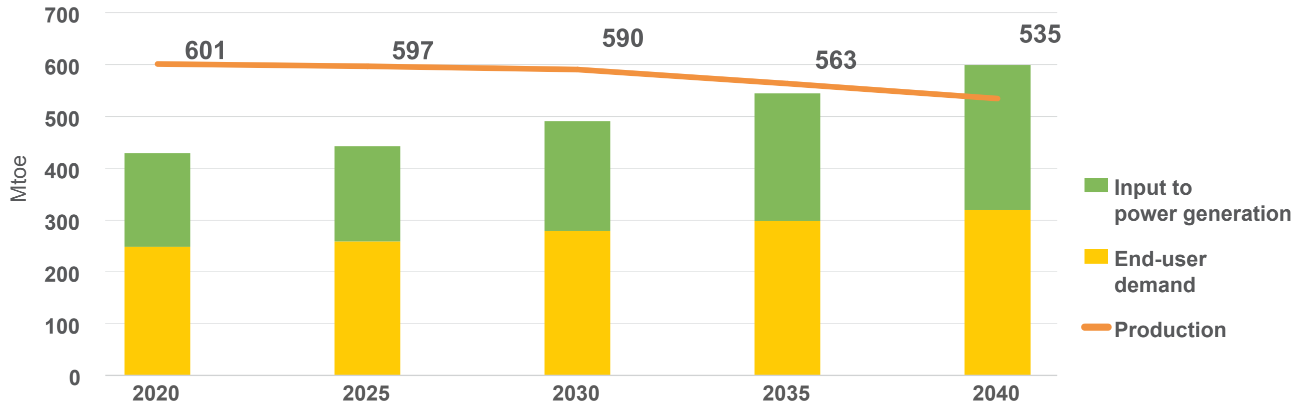
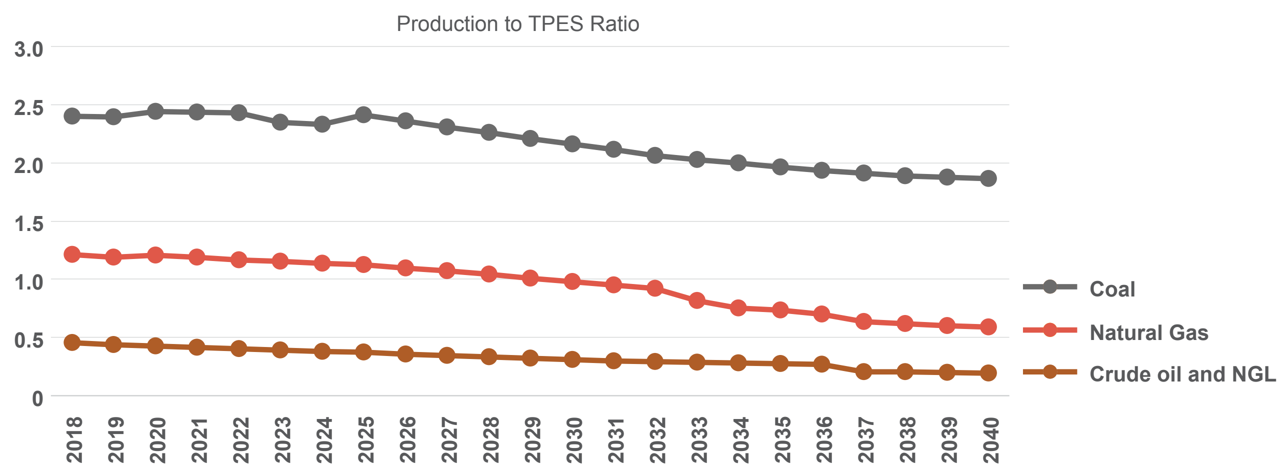


Figure 73 presents a projection of primary energy self-sufficiency, an indicator that provides a very basic indication of the security of energy supply. This indicator is important to gauge a country's or region's energy security in terms of how much of the energy supply can be obtained from local resources (Quantitative Assessment of Energy Security Working Group, 2012). The self-sufficiency ratio here is calculated as primary production over total primary energy supply (TPES). If the ratio is greater than 1, the country's energy supply of a given fuel or fuels is secured through domestic production.

Figure 73. ASEAN Fossil Fuel Energy Self-Sufficiency Projection, APS

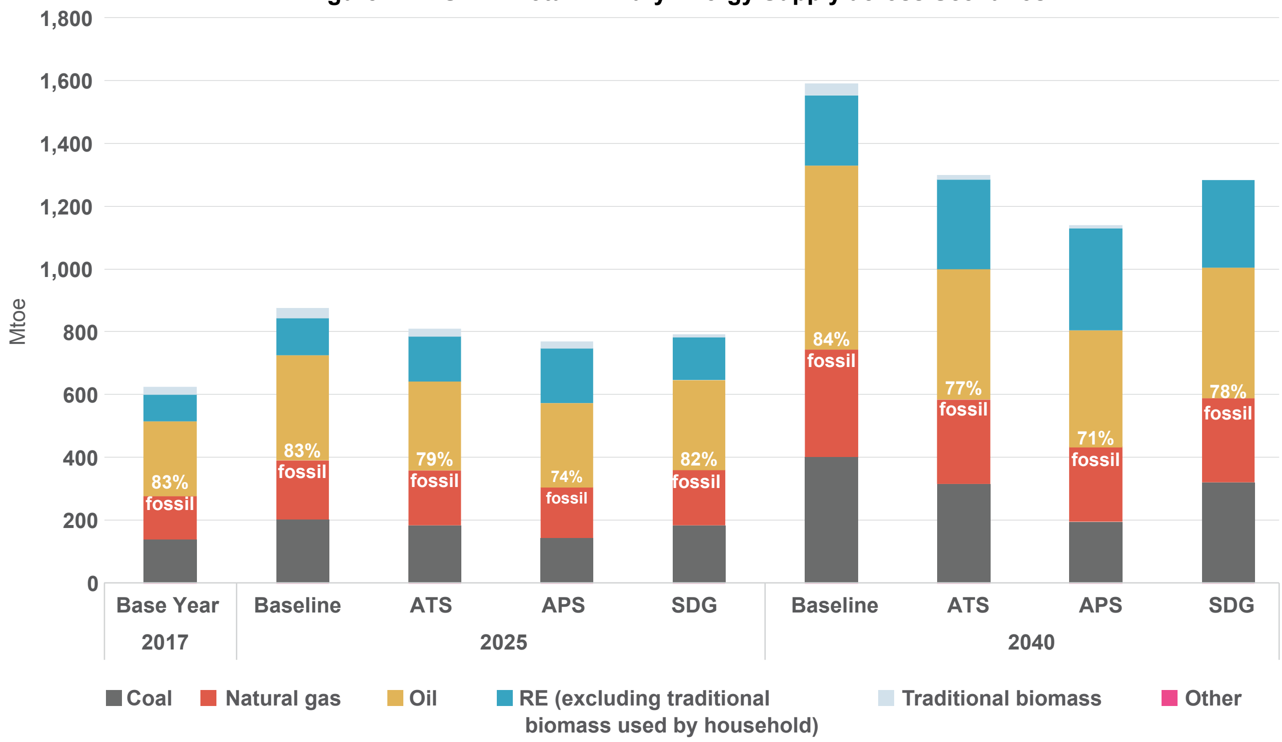


Note: Energy self-sufficiency is defined as the ability of a region to fulfil its own energy needs. It is calculated as domestic production over the total primary energy supply. A ratio of less than 1 indicates that net imports will be needed to ensure an adequate supply.

The analysis shows that TPES is growing faster than domestic production of fossil fuels, so fossil energy self-sufficiency will keep falling over time. The self-sufficiency of total primary energy supply is projected to fall below 1 in 2027, though for coal, self-sufficiency will remain quite high. The figure also reflects significant projected increases in domestic coal and gas production, as both fuels are very important in the power system. Still, maintaining energy self-sufficiency could be a challenge in both the short and long term if ASEAN remains highly dependent on fossil fuels (see Section 1.1).

Figure 74 shows how much of the TPES would come from fossil fuels in 2025 and 2040 in each of the modelled scenarios. Even in the APS, which is most aggressive in slowing energy demand growth and accelerating RE deployment, fossil fuels would still make up 71% of TPES in 2040. This means that even as ASEAN Member States work to accelerate their transition to clean energy, they also need to ensure a steady supply of fossil fuels for the sake of energy security and try to reduce the environmental impacts.

Figure 74. ASEAN Total Primary Energy Supply across Scenarios



3.2.1 Accelerating ASEAN's Energy Transition

The strategies modelled in this report to accelerate ASEAN's energy transition take a two-pronged approach: fuel-switching and improvements in energy efficiency.

3.2.1.1 Fuel-switching

ASEAN Member States cannot switch from fossil fuels to alternatives overnight, but they can adopt policies and investment strategies that reduce the share of fossil fuels in TPES over time. As discussed above, given the significant projected increase in demand for electricity, promoting a higher share of RE in the power mix is very important. This is in line with national policies modelled in the ATS as well as regional targets set in the APAEC and modelled in the APS. The ASEAN region has abundant renewable energy resources, and technology innovation, declining costs and reduced entry barriers are making it easier to develop RE. In the most optimistic scenario, the APS, RE could reach 51% of the total power capacity and 38% of electricity generation in the region by 2040. Nevertheless, issues of intermittency and grid reliability should be properly addressed in order to achieve a high level of fuel-switching in the sector.

In the residential and commercial (building) sectors, fuel-switching can be pursued through modernisation of energy appliances, including electrification. For a portion of the population, fuel-switching also entails clean cooking promotion, which is discussed further below.

In industry, fuel-switching might bring unique challenges because of the specific ways in which fuels are used – for example, high-temperature industrial processes and non-energy use, i.e. fuels as feedstocks. This means some subsectors might need to consider options beyond electrification, such as carbon capture and storage (CCS), hydrogen and biomass use in the steel industry, and waste reuse, e.g. waste tyres, in the cement industry. These strategies may entail higher capital investments.

In road transport, oil products are expected to continue to dominate, but as discussed in Section 2.3, several ASEAN Member States have adopted policies to promote fuel-switching to biofuels and electricity. The prospects for both are examined in a dedicated section below.

3.2.1.2 Energy Efficiency

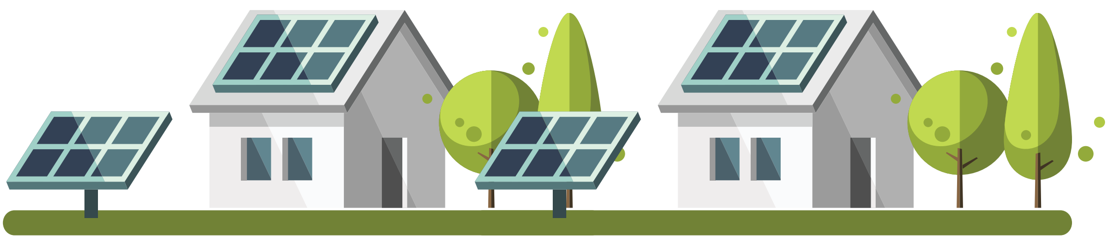
Energy efficiency measures can reduce fuel demand while maintaining the same level of energy service. This approach is also in line with national policies incorporated in the ATS and the regional target set in APAEC and incorporated in the APS.

With respect to electricity, new installations and/or retrofits of equipment and appliances could increase the energy efficiency across the sector. Another approach is improving the efficiency of the electricity generation process, which could benefit from the application of optimisation and integration technologies.

In the residential and commercial (building) sectors, energy efficiency measures can be implemented through both technological and behavioural approaches. In the technological approach, highly efficient appliances can be promoted to consumers. Potential appliances include air conditioners (discussed further below), lamps, refrigerators and cookstoves. As this approach would entail replacement of appliances, proper incentives and public awareness programmes should be properly designed to support it. In the behavioural approach, regulations and public campaigns of best practices, such as turning off unused appliances or choosing appropriate thermostat settings, should be effectively designed and implemented.

In industry, cost is still a significant barrier to adopting more energy-efficient equipment, such as boilers, chillers, motors and transformers. These technologies have high upfront costs that can take years to recover through energy savings, so financing them can be challenging. Strong and clear regulatory supports, capacity-building of key players, pilot project implementation and up-scaling, de-risking mechanisms, and innovative financing schemes can all help to reduce barriers.

In road transport, energy efficiency measures might include technical specifications such as fuel economy standards, emission standards, and maximum age limits of vehicles. In addition, the overall energy efficiency of the transportation sector can be improved by promoting public transport and optimising the use of private transport, as well as maintaining or improving the use of non-motorised vehicles.



3.2.1.3 Improving the fossil fuel itself and its utilisation process

To the extent that ASEAN Member States continue to rely on fossil fuels, they can work to reduce GHG emissions and other externalities by deploying technologies such as coal upgrading; high-efficiency, low-emissions (HELE) coal power; co-firing systems; and especially carbon capture utilisation and storage (CCUS) and carbon capture and storage (CCS).

About half of the coal resources in ASEAN, especially in Indonesia, are low-rank coal (LRC), sub-bituminous coal and lignite, also known as brown coal (ACE et al. 2014). LRC has a high moisture content, low calorific value, and adverse ash characteristics. Producing power from LCR requires more coal and emits more CO_2 per unit of electricity than when higher-quality coal is used. However, it is possible to upgrade LCR by removing moisture and ash.

Moisture content can be reduced relatively simply through drying technologies, such as (i) direct heating with saturated steam, (ii) indirect heating utilising waste heat or recirculated flue gas, (iii) briquetting using simultaneous heat and pressure, and (iv) electromagnetic radiation similar to that used in a microwave. For example, at the Coal Creek Unit 2 power plant in the U.S., drying technology was used to reduce the moisture of the coal by 6.1%, which improved the efficiency of the boiler by 2.6%, and reduced emissions of two important air pollutants: NO_x by 8.52% and SO_x by 2% (Dlouhý 2010).

Ash removal, meanwhile, can be achieved through physical or chemical processes. Examples of physical methods include gravity separation, froth flotation, oil agglomeration, magnetic separation, and electrostatic separation. Chemical methods use agents such as acids, alkaline solutions or organic solvents to selectively remove necessary or unnecessary components from coal.

A number of coal upgrading demonstration projects have been conducted in Indonesia. They found the upgraded brown coal could increase a coal-fired power plant's thermal efficiency by up to 5% while reducing CO_2 emissions by as much as 15% (Afrah et al. 2017).

3.2.1.4 High-efficiency, low-emissions (HELE) coal power

Modern coal power technologies are significantly more efficient than older plants, which enables them to produce more electricity with less coal, and thus reduce GHG emissions. Supercritical (SC) and ultra-supercritical (USC) coal-fired power plants, which operate with steam temperatures between 550°C and 600°C, can have an efficiency up to 42% and 45%, respectively, compared with 38% for subcritical technology (WCA, 2016). Currently 83% of installed coal-fired power capacity in ASEAN uses subcritical technology.[29] By ensuring that all new coal capacity in ASEAN is USC, and retrofitting existing capacity to USC, the region could reduce cumulative GHG emissions from coal power by 1.3 Gt CO_2-eq.

ASEAN has already started deploying HELE coal power technologies. As of 2019, the region had 10,020 MW of installed HELE coal power capacity; more than half of it is USC.[30] Stringent emissions standards and regulatory frameworks to mandate that newly built and retrofitted coal-fired power plants use advanced technologies would be highly beneficial in supporting the transition.

Even more efficient technologies are under development, such as the advanced USC (A-USC), 700°C class USC power plants, and integrated gasification combined cycle (IGCC) plants with a targeted net efficiency of more than 50% (see ACE et al., 2014).

[29] See ASEAN Energy Database System (AEDS), https://aeds.aseanenergy.org,
[30] See ASEAN Energy Database System (AEDS), https://aeds.aseanenergy.org,

3.2.1.5 Co-firing systems

Another way to reduce fossil fuel use in power production is to replace some of the coal or gas with biomass – an approach called “co-firing”. In this process, plants can directly or indirectly mix biomass with coal or gas for combustion. Such power plants could reduce the CO_2 emitted in direct proportion to the increase of blend ratio of biomass to coal, which can typically range from 10% to 30%, depending on the existing system.[31]

Co-firing has played an important transitional role in decarbonisation and extending the lives of some coal-fired power plants in Europe (Zhang, 2019). Mainly due to effective control of CO_2 emissions and policy subsidies such as feed-in-tariffs and renewable energy certificates, large-scale coal-biomass co-firing power generation technology has been well developed in European countries, such as Denmark, the UK and the Netherlands, where biomass is considered as renewable energy. In ASEAN, co-firing biomass in coal power plants could be considered as a short- to medium-term strategy to reduce coal dependency and also to help achieve the APAEC target of 23% RE by 2025.

3.2.1.6 Carbon capture, utilisation and storage (CCUS) and carbon capture and storage (CCS)

Capturing the carbon emitted during fossil fuel combustion and either utilising it as a resource, or permanently storing it, has long been seen as an emission reduction solution for the power sector and carbon-intensive industries such as cement and steel. In practice, however, the deployment of CCUS and CCS worldwide has been limited. CCS for coal and gas power generation has been technically proven, with successful commercial projects. The 240 MW Petra Nova Carbon Capture System, the world’s largest power-based CCS facility, is attached to a coal-fired power station and can capture and store 1.4 Mt CO_2 per year, while making direct use of CO_2 for enhanced oil recovery. The first CCS project in ASEAN is a pilot being developed in Gundih, in East Java, Indonesia (Global CCS Institute 2020).

For CCS applications in the hard-to-abate industry sectors, Abu Dhabi CCS is the world’s first fully commercial CCS facility in the iron and steel industry, launched in 2016. This facility can capture 0.8 Mt CO_2 per year and transport it via pipeline for enhanced oil recovery. In addition, several CCS applications for the cement industry are in the pilot or demonstration project phases.

[31] The emissions will probably not change much, but the biomass component would be considered carbon-neutral.

Photo source: Shutterstock

One of the barriers to the development of CCS is that CCS generates no revenue and requires intensive capital investment. Most successful CCS projects use the CO_2 for enhanced oil recovery (EOR), injecting it into oil reservoirs to improve production. CCS is only partially commercial with the right storage conditions, typically in areas where EOR is done, which adds some value. Moreover, CCS processes require energy, reducing the overall efficiency of a power plant (see, e.g., Budinis et al. 2018, Table 6).

3.2.1.7 Reducing oil demand for road transport

Oil is the most heavily used fossil fuel in the ASEAN region, and even in the ambitious APAEC Targets Scenario (APS), it continues to make up almost a third of TPES in 2040. This is due to a great extent to demand from the transport sector. Given that several ASEAN Member States have no oil reserves, and the region as a whole is a net oil importer, reducing oil consumption is important not just for environmental reasons, but also to ensure energy security and accessibility.

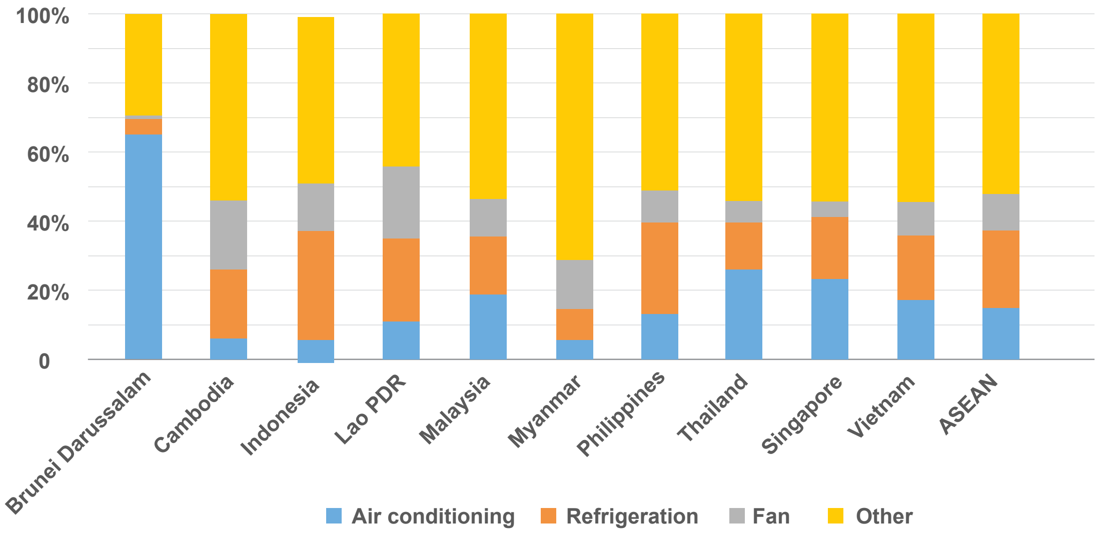
In 2019, ASEAN established the ASEAN Fuel Economy Roadmap for the Transport Sector 2018–2025: With Focus on Light-Duty Vehicles (ASEAN Secretariat 2019). It sets an aspirational target to reduce average fuel consumption per 100 km for new light-duty vehicles sold in ASEAN by 26% between 2015 and 2025. In addition, ASEAN Member States may wish to adopt minimum energy performance standards (MEPS) for vehicles, as well as incentives for manufacturers, consumers and R&D. The potential for biofuels and electric vehicles is discussed in Section 3.4.

Photo source: Shutterstock

3.3 Efficient Air Conditioners

Energy demand for cooling in ASEAN has been rising rapidly over the past decades. Electricity use for cooling in residential and commercial buildings across Southeast Asia jumped from 10 TWh in 1990 to almost 75 TWh in 2017 (IEA 2019a).[32] As shown in Figure 75, in 2018, the use of fans and air conditioning (AC) accounted for around 26% of residential electricity demand in ASEAN; AC alone accounted for 15%, reflecting the high energy usage of AC units.

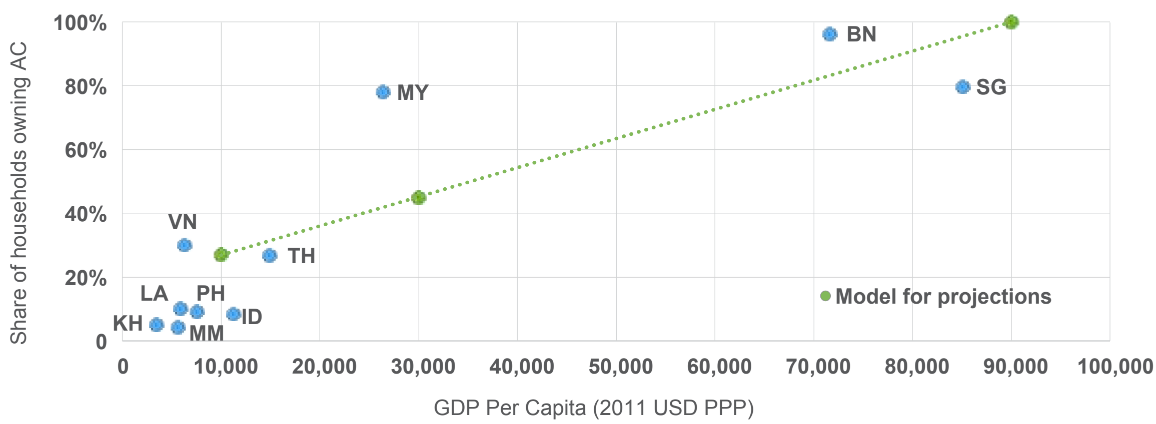
Figure 75. Cooling and AC Share of Residential Electricity Demand, 2017



Source: AEO6 model analysis, based on ACE compilation of historical data.

AC ownership in ASEAN is still relatively low: on average, only 18% of households had it in 2017, data gathered by ACE for the AEO6 model show, compared with more than 85% in Korea and Japan (IEA 2018). However, AC ownership rates (and resulting electricity demand) vary widely across the region: more than 78% in Malaysia, Singapore and Brunei, but less than 10% for Cambodia, Indonesia, Lao PDR, Myanmar and the Philippines. As shown in Figure 76, income levels at least partly explain the differences; AC prevalence is highest in the region's wealthiest Member States.

Figure 76. AC Penetration Rates in Households and GDP per Capita, 2017



[32] Note that the IEA data include Timor-Leste, which is not part of ASEAN.

Looking ahead, AC ownership and use are expected to rise significantly, driven by rising incomes, urbanisation, electrification, increasing standards of living and demand for thermal comfort, together with falling AC prices (Karali et al. 2020). The IEA predicts that emerging economies, where AC ownership is still relatively low, will account for about half of the global cooling demand growth by 2050 (IEA 2018).

Climate change itself may also drive up AC use, as Southeast Asia experiences more extreme heat. A study of AC use in China (Li et al. 2018) found that a 1°C rise in ambient temperature over 27°C would lead to a 9% increase in residential electricity consumption: 8.5% through heavier use of existing ACs in warmer weather, and 0.5% through increased purchases of cooling equipment. AC is thus expected to become an even more critical end-use throughout ASEAN, driving electricity demand in households, particularly during peak hours of the day (Karali et al. 2020). Policy-makers will need to find ways to ensure that the expected increase in cooling demand and AC ownership is sustainable.

3.3.1 Regional Policies and Products Available Within ASEAN

In 2015, the ASEAN Ministers of Energy Meeting endorsed a Regional Policy Roadmap to increase minimum energy performance standards (MEPS) for ACs. Efficiency policies, including MEPS and labels, are already in place in most ASEAN economies, but stringency and coverage vary significantly. Thus, the objective of the Regional Policy Roadmap is to facilitate alignment across the region, while driving market transformation through the promotion of more efficient ACs, greater intra-ASEAN trade in space cooling products, energy savings, and GHG emission reductions.

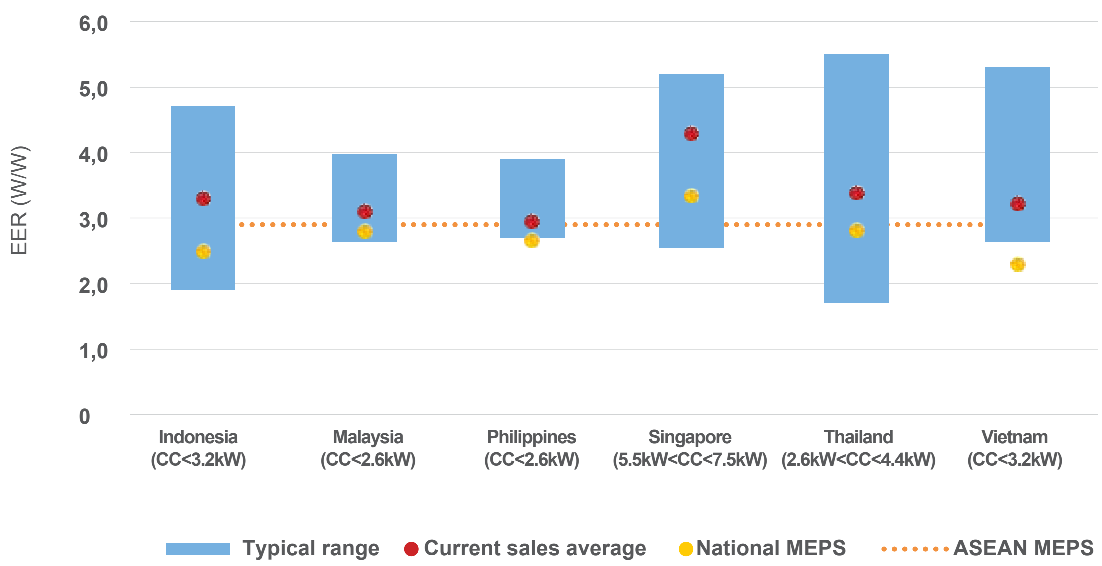
The Policy Roadmap suggests harmonising several components, including metrics and performance standards, across the region. The energy efficiency ratio (EER) and seasonal energy efficiency ratio (SEER) are the main metrics used internationally to rate the energy efficiency of ACs.[33] Considering the increasing number of inverter units available in the ASEAN AC market, and that this AC type performs better at partial load conditions, seasonal metrics are increasingly being used as alternatives to EER to set MEPS and labelling requirements (ASEAN-SHINE 2015).

In terms of performance standards, the Regional Policy Roadmap provides that by 2020, ASEAN Member States should enforce a minimum EER of 2.9 W/W or a SEER of 3.08 W/W as the MEPS for all fixed and variable drive ACs with a capacity below 3.52 kW. The MEPS should be periodically reviewed and revised at an interval of five years or less (ASEAN-SHINE 2015).

Figure 77 shows the EER of the range of products currently available in the market for the most common units and cooling capacities in some of the ASEAN economies, together with the current national MEPS. The current sales average in the ASEAN market is in the range of 2.9–4.3 W/W, while the most efficient models available, inverter units, have an EER of around 5.5 W/W. Except for Singapore, which has the most stringent MEPS, with an EER of 3.3 W/W for single split units with cooling capacity below 10 kW, the other Member States have MEPS below the regional EER of 2.9 W/W. The typical average efficiency of appliances sold in these Member States is between 2% and 48% higher than the mandatory regional MEPS, although there are plenty of more efficient products available, with EERs up to 90% higher than the regional MEPS. Setting more stringent efficiency requirements would drive out the most inefficient products and incentivise the introduction of more efficient products (ASEAN-SHINE 2015).

33. EER is defined as the rated cooling capacity (measured in British Thermal Units, or BTU) over rated cooling power consumption (in Watt-hours, or Wh) at specific given conditions of constant outside temperature, inside temperature and humidity level. Its unit is BTU/Wh or W/W. The EER does not take into consideration part load due to variation in the ambient temperature conditions annually and the occurrence of the temperature variations in terms of number of hours of operation at each temperature condition.
SEER (or Cooling Seasonal Performance Factor, CSPF) is defined as the ratio of the cooling output of an AC unit over a typical cooling season, divided by the energy consumed. It is calculated using a constant indoor temperature and a specific seasonal outdoor temperature range. Therefore, it provides a more representative measure of the performance of AC units over the cooling season.

Figure 77. MEPS and EER of Available AC Units in ASEAN Member States

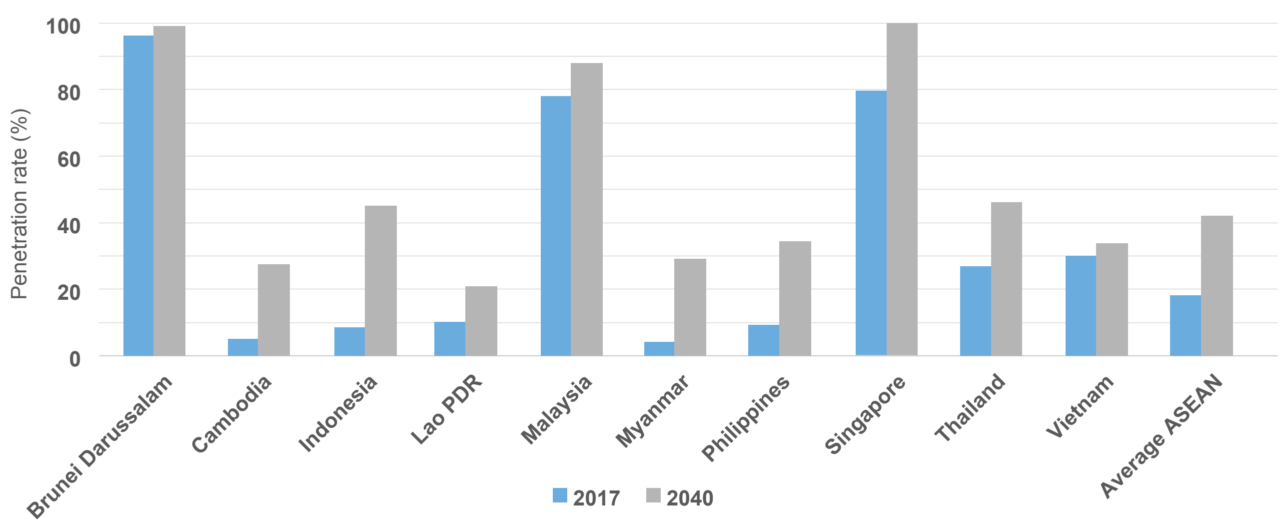


Source: Based on ASEAN-SHINE (2015). Notes: For the national MEPS, the following assumptions were used: Indonesia: non-inverter; Vietnam: single split; Singapore: values correspond to COP (Coefficient of Performance).

3.3.2 Outlook for AC in ASEAN

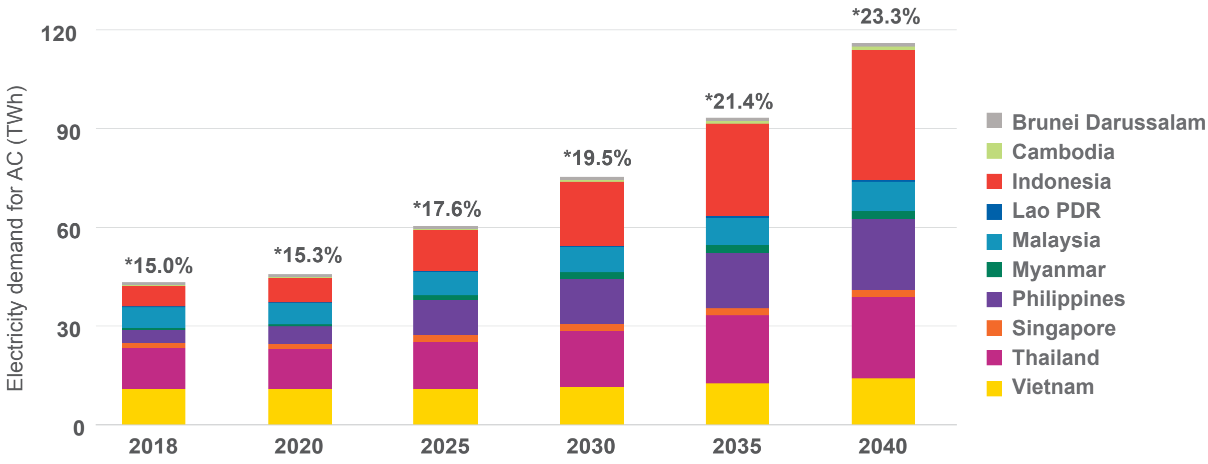
In the AEO6 scenarios, the expected increase in household AC ownership is assumed to be directly linked to rising incomes. The share of households owning an AC was modelled using a linear relationship with income growth expressed as GDP per capita. As depicted in Figure 78, by 2040, about 42% of ASEAN households are projected to have access to AC, which is 2.3 times more than in 2017. Myanmar, Indonesia and Cambodia are expected to have the most dramatic increase – more than fivefold between 2017 and 2040.

Figure 78. Evolution of Penetration Rates of AC in ASEAN Households



In the Baseline Scenario, no improvements in the energy efficiency of AC were considered. Although technological advances could drive up EER values in the future, the EER of the current stock average in each country was assumed constant until 2040. Since ACs now in use were bought several years ago, the EER for the current stock of ACs was estimated as 70% of the EER for the average units being sold now. Figure 79 shows the resulting increase in the electricity demand for AC in ASEAN, which grows from 43 TWh in 2018 to 116 TWh in 2040. The share of AC in the region's total residential electricity consumption increases from 15% in 2018 to about 23% in 2040. By 2040, Indonesia displaces Thailand as the main overall consumer of electricity for AC in the region, accounting for 34% of the region's total.

Figure 79. Electricity Demand for AC and Share of Total Demand, Baseline Scenario



* % Share of AC demand in total residential electricity demand

In the APS and ATS, four levels of AC efficiency were considered in each country: the average EER of the current stock, the EER of units sold now, the best available in each country, and the best available across the region. The ATS assumes that as AC units reach the end of their 10–15 year lifetime, they are replaced by new units with the EER of the current sales average, ranging from 2.7 to 3.5 W/W in all Member States except Singapore, where the current sales EER is 4.3 W/W. Additionally, 50% of households in Brunei and Singapore, and 10–25% of households in the other Member States, adopt inverter-type ACs, which are currently the best available technology in the region, with an EER above 5.6 W/W. In the APS, as older units are retired, they are replaced by units with an EER of 3.5 W/W, which is equivalent to Thailand's current sales average, and a greater fraction of households adopt inverter-type ACs.

In the ATS, the share of AC in total residential electricity demand reaches 19% in 2040. In that same year, electricity demand for AC is 36% (41 TWh) lower than in the Baseline Scenario. In the APS, electricity demand is 44% lower in 2040 (50.5 TWh), and AC accounts for 16% of household electricity demand. In both scenarios, Indonesia is responsible for most of the electricity savings. In 2040, it accounts for about 34% of the reduction in electricity demand in both the ATS and the APS.

The lower electricity requirements in the ATS and APS scenarios result in cumulative cost savings of USD 6.6 billion and USD 7.9 billion, respectively, in power sector investments and O&M costs (discounted at 3% to the year 2020) relative to the Baseline Scenario. Additionally, these energy savings reduce the region's cumulative GHG emissions by 267 Mt CO_2-eq and 306 Mt CO_2-eq, respectively. In 2040, the emission reduction resulting from the use of more efficient AC accounts for 1.5–2% of the total emission reduction in the scenarios.

Figure 80. Projected Electricity Savings for AC in ATS and APS vs. Baseline Scenario

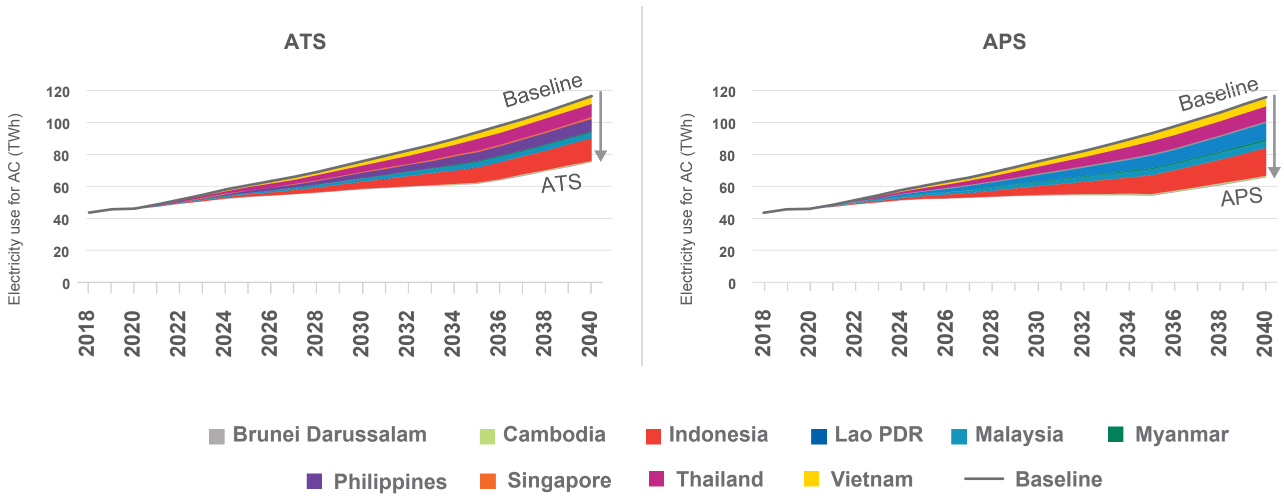
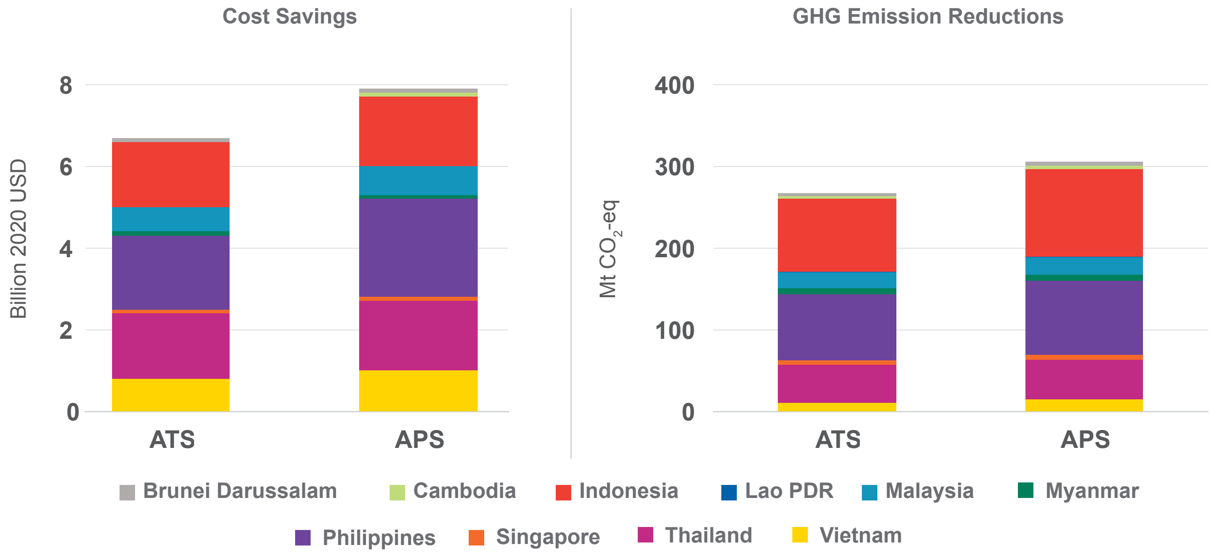


Figure 81. Cumulative Projected Savings from Power Generation, ATS and APS vs. Baseline Scenario



Note: Values are discounted to 2020 at 3% per year.

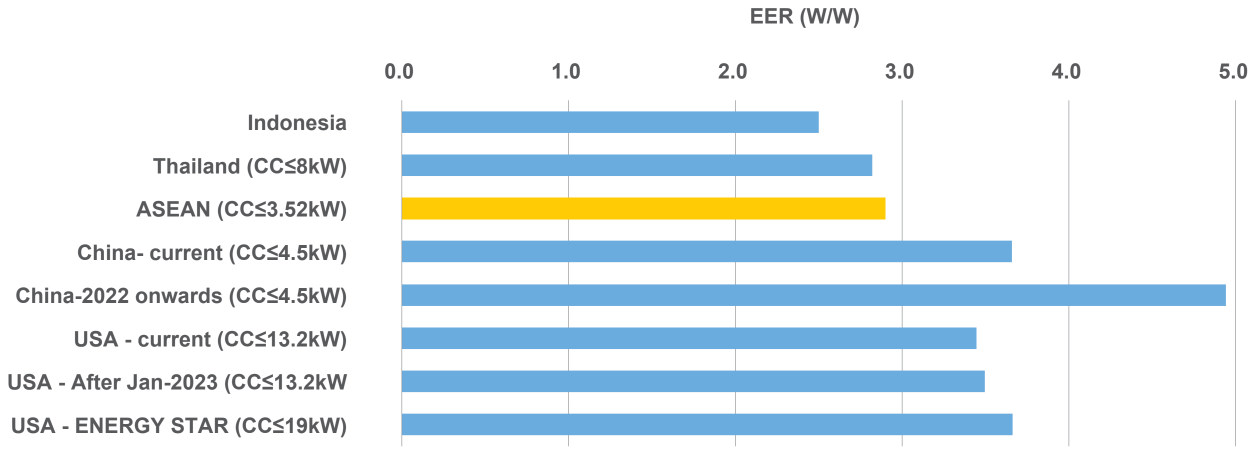
3.3.3 Potential for Greater AC Electricity Savings

Many countries have adopted standards to promote the use and production of high-efficiency ACs. For example, both China and the United States have multiple standards for ACs, covering both domestically manufactured and imported products. Within each country, standards are differentiated by product type (e.g. room vs. central AC), specific technology (e.g. single package vs. split systems) and range of cooling capacity. For central ACs, these standards generally consider metrics that evaluate seasonal performance, such as the SEER. In the United States, standards also differ by region, with more stringent MEPS in warmer regions, where cooling loads represent a larger share of home energy use.

The Chinese and U.S. standards are periodically reviewed, and even provide multiple tiers of MEPS with increasing efficiencies, which are implemented in phases. This allows future performance requirements to be laid out at an early stage, signalling expectations of future requirements in advance, allowing the AC industry to respond by integrating design changes into their normal manufacturing cycles (ASEAN-SHINE 2015). Updating the standards as more efficient technologies become available in the market also ensures that inefficient products are displaced. For example, a recent update to the Chinese national standards for split systems combined the former separate standards for fixed-speed-drive (FSD) and variable-speed-drive (VSD) ACs, the former of which used to have much lower efficiency requirements, into a single, more stringent standard. Having a technology-neutral MEPS level for both FSD and VSD is expected to result in a significant migration from FSD to VSD, inverter-based units, eventually removing the inefficient FSDs from the market.

Figure 82 shows a comparison of Chinese and U.S. MEPS with those in ASEAN, focusing on small residential split-type ACs for cooling only, which are the most relevant to Southeast Asia. Both countries have higher standards than those currently in place in ASEAN, demonstrating that more stringent standards are possible.

Figure 82. MEPS for residential ACs in China, USA and ASEAN



Sources: ASEAN (ASEAN-SHINE 2015); China (Karali et al. 2020); USA (DOE 2013; ENERGY STAR n.d.)
Notes: Indonesia: MEPS for non-inverter units; Thailand: for window and split types; ASEAN: for all FSD and VSD; China: current for split FSD-cooling only. 2022 onwards for cooling only FSD and VSD. SEER was converted into EER using equation from Wu et al, 2006 and Wu and Ding, 2019, as cited by (Karali et al. 2020); USA: for split systems in the Southeast; USA-ENERGY STAR: for central AC split systems. SEER was converted to EER using equation from Wassmer 2003, as cited in Hendron and Engebrecht (2010): EER = -0.02 x SEER2 + 1.12 x SEER, where EER and SEER are in BTU/h/W. (1 kW=3423.142 Btu/h).

International standards may influence the adoption of higher efficiency standards in ASEAN, directly or indirectly. China is of special interest, since it manufactures over 70% of the ACs in the global market and exports about half of its production to other countries, including areas with rapidly growing AC demand, such as Southeast Asia. Because of China's dominant position in the AC market, ambitious national AC policies, including high efficiency standards and transitioning away from high-global warming potential (GWP) refrigerants, could have widespread global economic, energy and emissions implications in the coming decades (Karali et al. 2020).

In the U.S. and other countries, mandatory energy efficiency standards are complemented by voluntary labelling programmes. Together, standards and labels help increase the efficiency of products offered in the market by providing information to consumers that allows them to make more informed decisions and purchase the most efficient available models. For example, ENERGY STAR labels help consumers identify products that meet specified efficiency criteria (e.g. 10% or more above the U.S. minimum standard). The label also provides a basis for publicity campaigns, supports government and/or private purchasing programmes, and gives manufacturers an incentive to design more efficient products and a tool for marketing them (NAEWG 2013).

Like the ASEAN region, China and the U.S. currently have AC technologies that are much higher than the national MEPS. However, according to the IEA (2020a), the average efficiency of currently installed ACs is not improving quickly enough, despite the availability of efficient and affordable technologies. Typical units being sold in major cooling markets are just 10–60% better than the available product minimum requirements, even though there are products available in those markets with up to 50–70% higher efficiencies. Consumer sensitivity to upfront costs, coupled with a lack of awareness of the life-cycle benefits of more efficient AC, remains one of the most significant barriers in adopting more efficient units. The widespread availability of highly efficient products presents a considerable energy savings opportunity.

To explore the potential impact of an enhanced MEPS in ASEAN, the AEO6 team modelled a side case simulating the adoption of the forthcoming Chinese MEPS for small split ACs: an EER of 4.94 W/W. The side case is based on the ATS but assumes the enhanced MEPS applies to purchases of new residential AC equipment. Figure 83 and Figure 84 show the resulting electricity savings for ACs and cost and GHG emissions savings in the power sector. The higher efficiency of the new units results in 55% savings of the electricity used for AC in 2040 relative to the baseline, and 23 TWh more savings in that year than in the ATS scenario. The resulting cumulative cost and GHG savings from the power sector are almost 50% higher than in the original ATS, reaching about USD 10 billion and 400 Mt CO_2-eq saved in the period between 2018 and 2040.

Figure 83. Projected Electricity Savings for AC in Enhanced ATS vs. Baseline Scenario

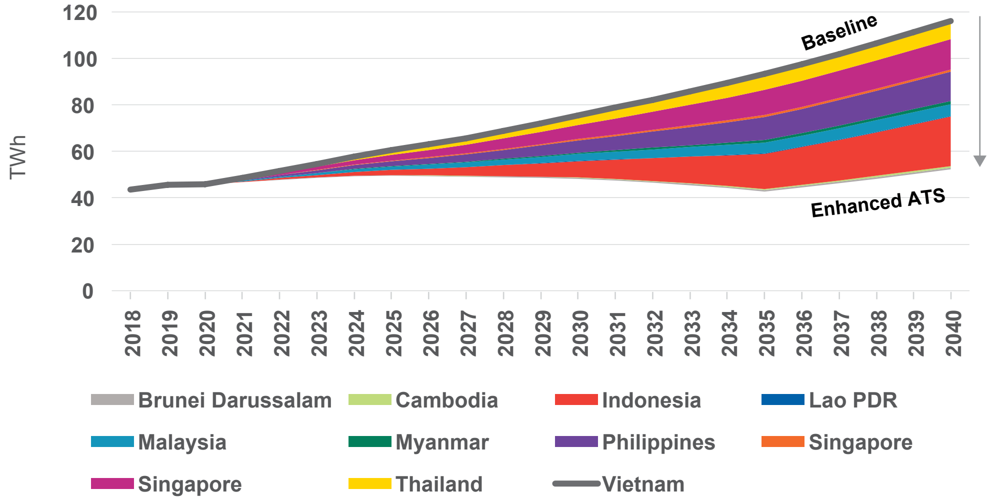
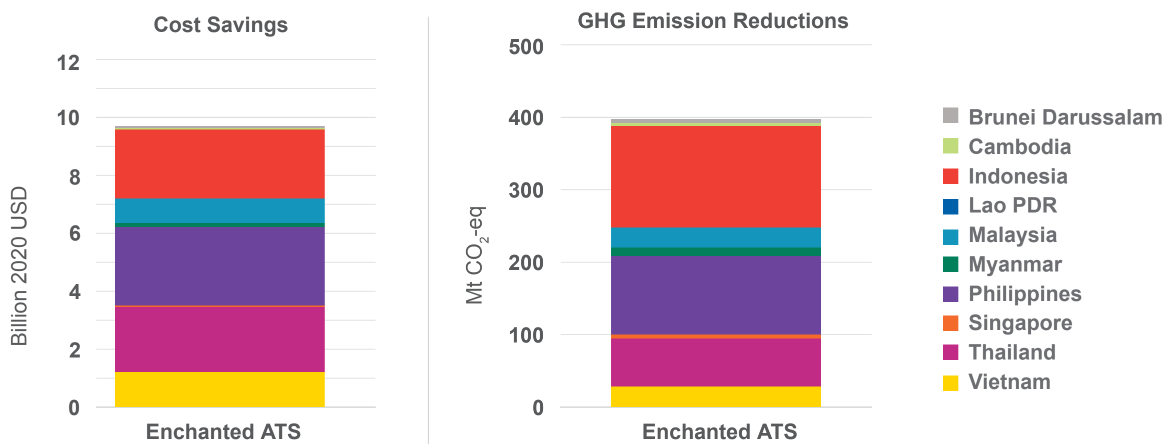


Figure 84. Cumulative Projected Savings from Power Generation, Enhanced ATS vs. Baseline Scenario



Note: Costs discounted to 2020 at 3% per year.

Addressing the future of space cooling is clearly important for ASEAN, especially in the Member States most exposed to extreme heat. Policies are required to ensure that growing demand for AC can be achieved sustainably. The ATS, APS and enhanced ATS side case show the great potential of AC energy efficiency improvements for energy savings, reduced costs and GHG emission reductions. Considering that efficient AC units are already available in most AMS, and average efficiency levels are well above the current MEPS, setting more stringent standards could help drive market transformation towards more efficient products. Higher minimum standards would not only remove inefficient products from the market, but also provide a smooth transition for manufacturers to introduce more efficient products.

A gradual increase in efficiency standards over time has been proven successful in several countries, including China and the U.S. A regionally coordinated MEPS ladder, with common medium- and long-term regional targets, can help guide policy-makers in the development of national policy roadmaps to continuously improve MEPS, recognising each country's starting point and national circumstances.

Improved MEPS should be paired with building energy efficiency improvements to reduce the load on ACs, as well as measures to promote changes in consumer behaviour, such as increased awareness about energy efficiency and a greater uptake of high efficiency appliances. Appropriately designed labelling, incentives and consumer education programmes are critical in this regard.

3.4 Greener Transport

In 2017, the transport sector was responsible for 26% of total final energy consumption (TFEC) in ASEAN, and 80% of gasoline and diesel consumption. It was also responsible for 23% of the region's GHG emissions that year. All this has made reducing oil consumption in the sector a priority for the ASEAN Member States. Two key approaches, adoption of electric vehicles and substitution of oil products with biofuels, are seen as viable options to reduce oil import dependency, improve energy security, and address challenges associated with fossil-fuelled vehicles, including GHG emissions, local air pollution, and noise pollution.

3.4.1 Electric Vehicles (EVs)

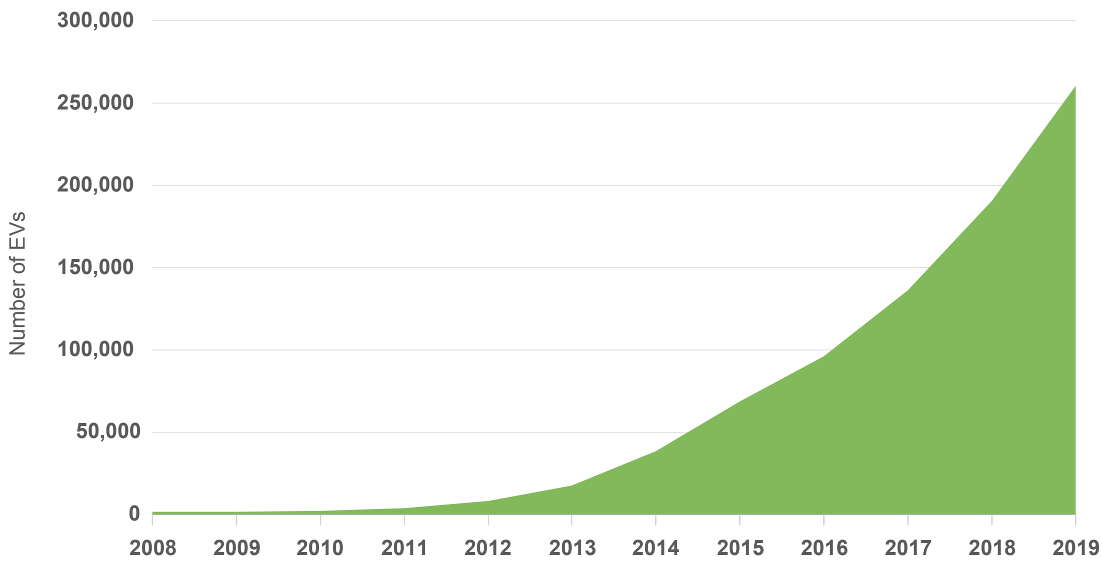
The ASEAN Member States are in the early stages of EV adoption. Thailand is at the forefront in terms of EV share of total vehicle stock, with sales rising since 2017. By the end of 2019, Thailand had 19,000 EVs of various kinds registered, but only 890, or 0.1% of the vehicle stock, were battery electric vehicles (BEVs), while the rest were plug-in hybrids (PHEVs) (IEA 2020b). The Philippines had 4,362 EVs on the road in late 2018 (Government of the Philippines 2019) and Malaysia just over 5,400 in 2019 (Zainuddin 2019). Singapore had just over 1,330 EVs in late 2019, out of a total fleet of 950,000 vehicles (Land Transport Authority 2019).

Several ASEAN Member States have set targets for EVs, directly or indirectly. Singapore has been working for several years to electrify buses and taxis and facilitate private adoption of cleaner energy vehicles (Singapore LTA 2019), and in February it announced it would seek to phase out all fossil-fuelled vehicles by 2040 (Reuters 2020). Indonesia and Malaysia have set targets for private and public transport, and both have ambitious plans for charging infrastructure (Harsono 2020; Zainuddin 2019). Indonesia also aims to start manufacturing EVs in 2022 and have EVs make up 20% of its auto production by 2025 (Reuters 2019). Thailand, meanwhile, is aiming to have 1.2 million EVs on its roads by 2036 (EEP2015). Vietnam has seen limited adoption so far, but VinFast, an automotive startup manufacturer, is planning to launch a domestically produced four-wheel EV by 2021, emphasising the model's strong battery range (Jennings 2020). The same firm has already launched two-wheelers (e-bikes), yet uptake has been slow due to the high unit cost. As car ownership grows in a region historically reliant on two-wheel vehicles, existing congestion and pollution problems might further escalate and incentivise more widespread EV adoption.

3.4.1.1 EV growth rates in selected high-penetration markets

Rapid adoption of EVs was long deemed unrealistic and prohibitively expensive, but the outlook has become far more optimistic due to the rapid reduction in the cost of lithium ion batteries and the expansion of range associated with them. In a variety of markets, relatively simple sets of policy measures have been shown to accelerate the introduction of EVs (Rietmann and Lieven 2019). EV penetration in national and subnational transport systems has skyrocketed in the past decade, although rates vary. Global annual sales, including both BEVs and PHEVs, surpassed 2 million in 2019, more than doubling since 2017 (IEA 2020b).

Figure 85. Electric Vehicles Registered in Norway, 2008–2019



Data source: Statistics Norway (2020).

China and Europe were the leading markets in 2019, with 1.06 million and 561,000 EVs sold, respectively. As of 2019, China had a total of 3.4 million EVs, equivalent to 47% of the global EV stock (IEA 2020b). In terms of share of total new vehicle sales, Norway holds the top spot, with 56% of new vehicles sold in 2019 being EVs. Norway also has the largest EV share of vehicles on the road, 13%. The shift to electrification in Norway happened in the span of a few years. Over 85% of all electric vehicles registered in Norway were sold after 2014 (see Figure 85).

Considering that many of Norway's EV incentives, from exemption of sales taxes to use of bus lanes and toll-free city access, were implemented already in the 1990s and 2000s, technological improvements, notably battery range and durability, were important contributors to the acceleration of EV sales in the 2010s (Zhang et al. 2016). In some markets, such as the Netherlands and Sweden, adoption can be partly explained by environmentalist attitudes in the population (Westin et al. 2018).

3.4.1.2 EV growth trends

There are several signs that EV growth will outstrip expectations by a wide margin, including the growing number of countries that plan to outright ban the sale of new internal combustion engine (ICE) cars. During 2019, there was a large-scale shift towards EVs among traditional ICE automakers, which will lead to greater competition and economies of scale in EV production in the 2020s. Between 2010 and 2019, global EV sales grew on average by 40.9% per year (IEA 2020b).

A particularly important predictor of future developments and prospects for EVs are the high-stakes bets made by financial markets. In June 2020, Tesla became the world's most valuable automaker by stock value, overtaking Toyota, which sold 2,303,495 vehicles worldwide in the first quarter of 2020 (Toyota 2020), while Tesla delivered only 88,400 units during the same period (Tesla Motors 2020). The prediction of financial markets for the prospects of EVs is thus clear.

Key factors in the continuing expansion of EVs are technological innovation and the availability of critical materials, and these two are connected in the sense that the purpose of new technologies is often precisely to reduce the dependency on specific materials. The breadth, scope and diversity of ongoing research is indicative of the likelihood of technological progress that will further reduce the cost and raise the driving range of EVs. While there are some concerns about the balance between supply and demand for critical materials for EVs, there are also signs that these are being addressed by market responses, innovation and increasing recycling (Overland 2019). Current battery research is being carried out into, among other things, lithium-titanite and lithium-iron-phosphate to reduce dependence on cobalt; and magnesium, sodium and lithium sulphur chemistries to reduce dependence on lithium. This is not to mention the many fields of hydrogen fuel cell research, which aim to do away with batteries altogether (Van de Graaf et al. 2020).

3.4.1.3 Market drivers of adoption

The availability and density of charging infrastructure have been deemed crucial in most markets with high EV penetration rates. In the case of Norway, multiple studies have noted the density of charging stations, option of using bus lanes, and road toll exemptions as major drivers for EV adoption (Aasness and Odeck 2015; Figenbaum et al. 2015; Mersky et al. 2016; Sierzchula et al. 2014; Zhang et al. 2016). In particular, government support for charging infrastructure has been deemed crucial to adoption across the country (Figenbaum et al. 2015), which has also been the case in Sweden (Egnér and Trosvik 2018; Westin et al. 2018). In Norway, ownership is more concentrated in multi-vehicle households, who tend to use the EVs to commute to and from work, particularly in the greater Oslo metropolitan area.

In China, the world's largest EV market, consumer surveys indicate that widely available charging infrastructure is vital (Tan et al. 2014). Adoption rates in California, the world's largest subnational market, have been linked to the availability of charging infrastructure as well (Javid and Nejat 2017). Californians have been less concerned than Norwegians with the ability of EVs to travel longer driving distances. However, the low cost of conventional fuels has significantly affected adoption rates (Javid and Nejat 2017), and subsidies by themselves have been deemed insufficient.

Battery durability has also been found to be a key determinant of adoption in most markets, including among prospective ASEAN consumers (Nissan and Frost & Sullivan 2018). In Norway, adoption started to accelerate as BEV technology improved significantly, coming in line with consumer expectations for durability and range. Surveys in China have consistently shown that concerns regarding battery durability and its upfront costs have been key obstacles to broader adoption (She et al. 2017).

Consumer preferences vary across markets. For example, despite similar subsidy levels, Americans are significantly less willing than their Chinese counterparts to purchase a BEV, and prefer PHEVs instead (Helveston et al. 2015). Chinese cities saw strong growth in electric two-wheel vehicles through subsidies coupled with restrictions on other vehicles, but a purely subsidy-focused plan in Taiwan failed to persuade consumers (Yang 2010).

In Southeast Asia, an industry study found consumers' top concern about buying a BEV was running out of power, and the second-biggest issue was concern about the convenience of charging (Nissan and Frost & Sullivan 2018). Still, 37% of regional respondents in a 2018 survey indicated they would be willing to consider buying a BEV, with the highest demand in Indonesia, Thailand and the Philippines. Operating costs were seen as a major obstacle by the more sceptical ASEAN consumers, while the higher purchasing price of EVs was found to be among the least significant obstacles to adoption.

3.4.1.4 Potential impacts of EV adoption

Unsurprisingly, local air pollution, particularly in cities, tends to fall with EV adoption. This is clearly the case in California, but less so in China, due to the high dependency on coal power (Huo et al. 2015). For countries that import oil, as most ASEAN Member States do, EV adoption can also reduce dependency on oil imports and strengthen energy security, as discussed in Section 3.2. China and Norway have incorporated EVs into urban congestion strategies as well, restricting access by non-EVs to city centres or exempting EVs from congestion charges (Yang 2010). This may have synergies with efforts to reduce air pollution in ASEAN's megacities. However, expanding public transport infrastructure – especially with electric buses and light rail – would be more inclusive and yield similar environmental benefits.

EV adoption can also have fiscal impacts. The higher fuel and car-related taxes are in the first place, the more powerful an incentive their exemption is for the adoption of EVs, and, correspondingly, the greater the loss of tax revenue. In California, loss of gasoline tax due to growing EV ownership has been substantial (Jenn et al. 2015). Norway also lost tax revenue due to EV tax exemptions (Aasness and Odeck 2015). In Singapore, which derives significant tax revenue from car purchases, tax incentives for EVs might drive fast adoption, but cause a significant decline in tax revenues. On the other hand, the loss of tax revenue need not be permanent; taxes can be reintroduced once the transport system has been fully electrified.

Regarding EV effects on the power grid, a McKinsey analysis of the German EV market concluded that EVs have not been a burden on the electricity grid and are not likely to become one by 2030, even in a high EV adoption scenario (McKinsey 2018). However, EVs may reshape load curves if their peak charging time is late in the evening, when electricity consumption would normally decline. This would in turn necessitate smart grid solutions and incentives to balance demand, especially in grids with high shares of renewables.

It is important to note that experiences from one EV market cannot straightforwardly be projected onto another market. For example, the dramatic growth in EVs in Norway has not had significant adverse effects on electricity generation and transmission, but Norway started out with higher electricity use than most countries. It has abundant hydropower and uses it for both cooking and heating, as well as for heavy industry, and it has reliable infrastructure. In a poorer country with less well-developed infrastructure, and where electricity consumption is largely limited to lighting, household appliances and air conditioning, large-scale introduction of EVs may lead to a much larger percentage-wise jump in electricity demand. On the other hand, Norway had major first-mover disadvantages. Since Norway started large-scale adoption of EVs, technologies have improved and become cheaper, and knowledge on EV infrastructure has grown. As these trends continue, it will only become easier for other countries to join the EV wave.

3.4.1.5 EVs and renewable energy integration

Another potential benefit of EV adoption is that it may enable greater integration of intermittent renewable energy sources, such as the use of residential solar power for EV charging. EVs can actually reduce cyclical grid imbalances by charging, storing and releasing electricity at appropriate times. In the Netherlands, it has been found that EV adoption can help balance solar power output and incentivise greater adoption of both EVs and solar power by households (van der Kam et al. 2018). EVs can indeed help balance excess electricity resulting from high production from intermittent renewables.

A potential hurdle is that while the use of solar PV is more popular in larger residences further from urban centres, EV adoption is often clustered in urban and suburban areas, where there is more charging infrastructure and driving distances tend to be shorter. Thus, so far there has been limited overlap, although this is gradually changing in many countries.

3.4.1.6 Prospect for EVs in ASEAN

With technology improving rapidly, major consulting firms as well as automakers predict fast growth in EVs in Southeast Asia by 2025 (Bain & Company 2019; Nissan and Frost & Sullivan 2018). These optimistic scenarios envision low-cost two-wheel electric vehicles becoming widely available and meeting the needs of urban ASEAN consumers (Bain & Company 2019). There are multiple potential benefits, as discussed above, including improved urban air quality and reduced dependency on oil imports. However, electricity demand in ASEAN is already skyrocketing, and EVs would put further pressure on already strained grids. The dominance of fossil fuels in ASEAN's power supply also means EV adoption would not necessarily reduce GHG emissions very much. Lao PDR, almost entirely reliant on hydropower, has the best energy mix for EV adoption from a climate mitigation perspective.

3.4.2 Biofuels for Road Transport

As discussed in Section 2.3, biofuels play a prominent role in several ASEAN Member States' national targets for the energy sector, and as discussed in Section 2.4, they are likely to be crucial to meeting the APAEC target of 23% renewable energy in the region's total primary energy supply (TPES) by 2025. Indeed, the APS envisions a compound annual growth rate (CAGR) for biofuels of 27.6% from 2017 to 2025.

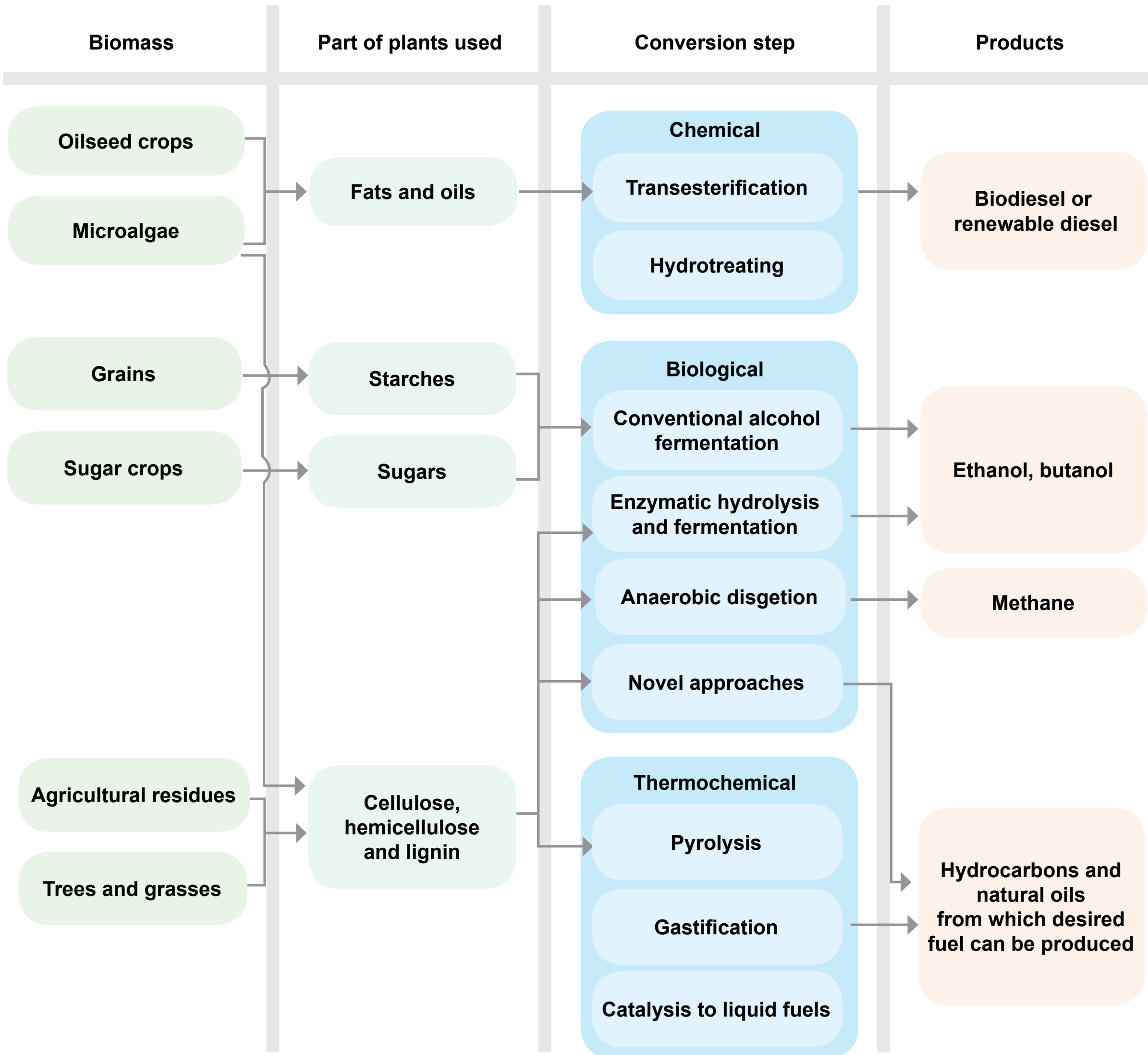
The main feedstock for biodiesel in Indonesia, Malaysia and Thailand is palm oil, which experienced significant price drops after a 2017 EU resolution to phase out palm oil for energy uses for environmental reasons. This caused a regional oversupply in 2017–2019. Indonesia and Malaysia, both large exporters of palm oil to the EU, expedited domestic usage of palm oil for biodiesel in the transport sector, at significant blending ratios, in order to absorb the oversupply. Indonesia used part of the revenue from a levy on palm oil exports to provide domestic biodiesel subsidies and not only succeeded in raising its own biodiesel blending ratio, but also influenced biodiesel use in Malaysia and Thailand.

Looking ahead, there is clear potential for further expansion of biofuel use across ASEAN. A 2017 IRENA study evaluated the biomass resource potential of five ASEAN Member States – Indonesia, Malaysia, the Philippines, Thailand and Vietnam – if they collected half of crop residues, closed the agricultural yield gap, adopted best practices to minimise food waste, and made the most of their forest wood potential (IRENA 2017a). The theoretical potential in that "stretch" scenario was 14,622 petajoules (PJ), or 349 Mtoe, including 5,858 PJ of advanced liquid biofuels (140 Mtoe). In a less-ambitious scenario, in which half those improvements were achieved (so 25% crop residue collection, for example, and closing half the yield gap), the potential was 7,374 PJ (177 Mtoe), including 2,930 PJ of advanced biofuels (70 Mtoe). The study concluded that in the "stretch" scenario, biofuels could meet 40% of the region's transport fuel needs in 2050, but warned that the potential "would be reduced… if significant amounts of solid biomass continue to be used for applications outside the transport sector, particularly for residential heating and cooking". This is why, as noted in Section 2.5.2, ASEAN's clean cooking advances are so crucial.

The IRENA study identifies multiple strategies to help realise the potential, including sharing best practices in cost-effective farm and forest residue collection; improved agricultural extension services; agroforestry approaches; better harvesting techniques and improved handling of food all along the supply chain; and more flexible regulations to reduce food waste (IRENA 2017a).

As the recent increase in biodiesel blending ratios showed, with the right policy incentives, technical modifications can be made to allow higher biofuel use. However, the preferred feedstock for these fuels may evolve over time. The first-generation biofuels now in use are made from food crops, which means that large-scale production can compete with food production – or else accelerate land-use change, with negative environmental impacts. As they expand their use of biofuels over the next two decades, ASEAN Member States may wish to explore a broad range of feedstocks and processing technologies, as also envisioned in the IRENA study. Figure 86 outlines some of the options.

Figure 86. Biofuel Feedstock and Production Processes



A great deal of research and development has already been done, including in ASEAN, on second-generation biofuels – especially drop-in fuels, which are functionally equivalent to petroleum products and can use the same infrastructure. Fuels made from agricultural/municipal waste or non-edible crops have been of particular interest. The price of these biofuels relative to fossil fuels would determine which second-generation options are most viable in ASEAN. For non-drop-in biofuels, vehicle limitations are still an issue, as large-scale use would require modifying conventional engines.

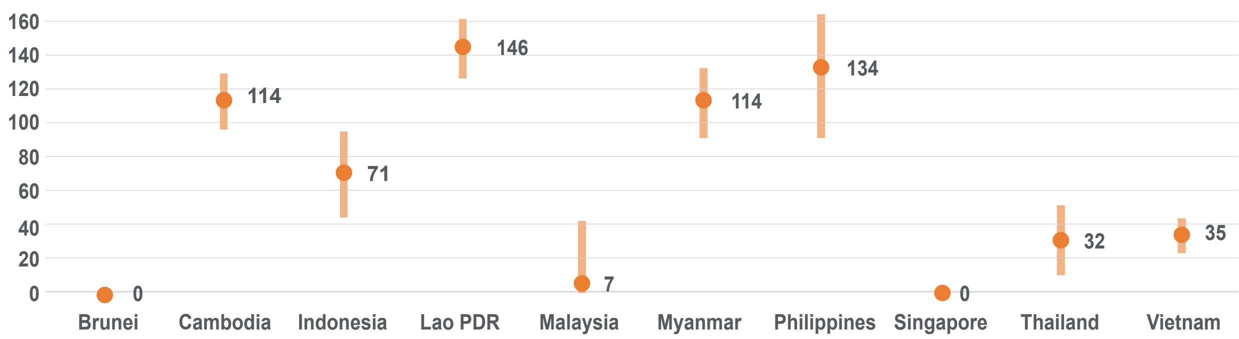
Along with road transport, aviation is another key sector with potential for increased biofuel use. Drop-in jet fuel can already be produced from palm oil via commercial processes, with up to 50% blending (IRENA 2017b). Given that ASEAN has both major global air traffic hubs, and top palm oil producers – Indonesia, Malaysia and Thailand – some feasibility studies have been conducted in those Member States. Economies of scale to justify production costs (relative to conventional jet fuel) with a secured feedstock supply and supporting aviation regulations/incentives may be needed to ensure uptake. Large-scale commercial refineries for biodiesel from palm oil have been established in Singapore since 2010 for export to Europe and North America. In July 2019, the Finnish biofuel producer Neste announced plans to more than double biofuel production, mainly from waste and residues, in its Singapore plant, including jet fuel (Jaganathan and Samanta 2019)

3.5 Access to Cleaner Cookstoves

As of 2017, about 60 million households in ASEAN, or 240 million people, still cooked with traditional biomass, such as wood, crop wastes or charcoal, or on kerosene stoves.[34] Low-income rural households are the least likely to have access to modern stoves and fuels. Cooking on traditional stoves or on three-stone fires exposes households to high levels of soot and other air pollutants that increase the risk of respiratory infections, lung cancer, stroke, and heart disease. Worldwide, about 4 million premature deaths each year are linked to exposure to pollution from cooking (WHO 2018). In 2016, an estimated 345,000 people in the ASEAN region died prematurely due to illnesses linked to household air pollution.[35]

Within families, women bear the brunt of these risks, as they tend to be the ones who cook; they also often gather the fuel, which can be time-consuming and expose them to injury or gender-based violence. As shown in Figure 87, the impacts are not evenly distributed across ASEAN; some countries have much higher rates of traditional biomass and kerosene-fuelled cooking than others. Still, for the region as a whole, it is a priority to ensure universal access to clean cookstoves and fuels, as envisioned under Sustainable Development Goal (SDG) 7 and modelled in the SDG Scenario presented in Section 2.5.

Figure 87. Deaths Attributable to Household Air Pollution (per 100,000 Population) in ASEAN Countries, 2016



Data source: WHO Global Health Observatory database, https://www.who.int/gho. Note: Death rates are age-standardized.

[34] This is based on data compiled for AEO6. See also the WHO Household energy database, https://www.who.int/airpollution/data/household-energy-database/en/.
[35] See WHO Global Health Observatory, "Ambient and household air pollution attributable death rate (per 100 000 population, age-standardized)", https://www.who.int/data/gho/data/indicators/indicator-details/GHO/ambient-and-household-air-pollution-attributable-death-rate-(per-100-000-population-age-standardized).

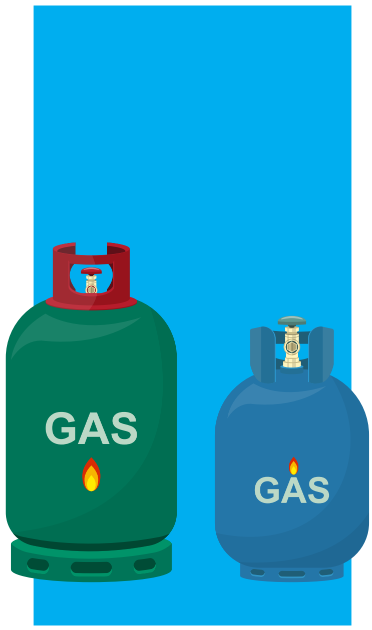
3.5.1 Expanding Clean Cooking in ASEAN

"Modern" cooking can mean include a range of options, starting with improved biomass cookstoves (ICS), which can reduce fuel use and smoke relative to a traditional stove or three-stone fire. A stove that uses liquid or gaseous fuels – and perhaps more advanced technologies – can be even cleaner and more energy-efficient. And in households with electricity, electric stoves are an option. In the context of SDG 7, only the highest-performing ICS are considered clean enough (UNSD, 2020), which is why ICS are not included in the SDG Scenario presented in Section 2.5. Nevertheless, step-wise improvements in cooking fuels and stoves may still be beneficial for households' health and budgets.

While factors such as urbanisation and income may influence cooking choices, experience in ASEAN indicates that government policy and programmes can significantly accelerate the expansion of clean cooking. Nations that have established clean cooking priorities and programmes focused on LPG and advanced stoves have advanced most rapidly. LPG has also been the focus of the greatest clean cooking scale-up activities across the globe (Quinn et al., 2018). Many studies, particularly those in Asia, find that it is the option preferred by rural households. However, it is important to note that most ASEAN countries have to import LPG, creating potential energy security and access issues; indeed, LPG often requires subsidies to be widely affordable.

Still, while improved biomass stoves may require significant behavioural change, and biogas digesters are sometimes met with cultural resistance, LPG in many regions is seen as a more prestigious fuel, and one that households prefer if it is affordable (Smith and Sagar, 2014). Latin America has been very active in implementing LPG subsidies to help communities convert towards modern cooking. There are different models for subsidising LPG, some of which are more progressive than others, but experience in the region suggests that where households are already paying for fuel (instead of collecting firewood or crop residues), making LPG affordable through subsidies can be a highly effective solution.

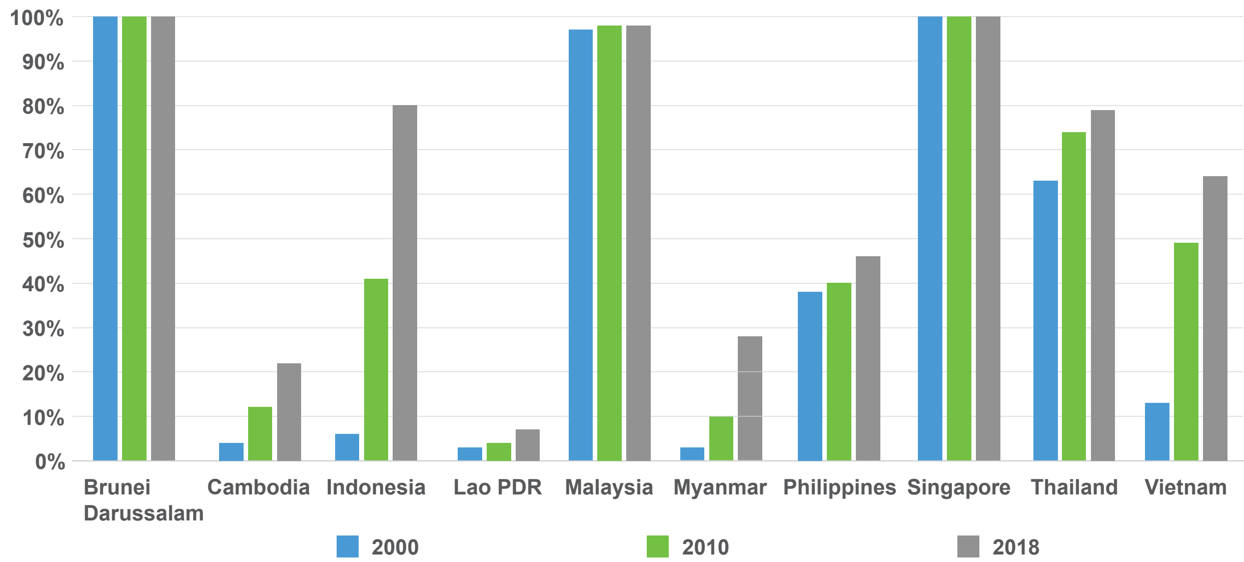
Figure 88 shows the share of each ASEAN Member State's population with access to clean cooking technology in the years 2000, 2010 and 2018.[36] Two countries stand out for rapid progress: Indonesia and Vietnam. Between 2000 and 2018, Indonesia increased clean cooking access by 74 percentage points through an extensive, phased kerosene-to-LPG switching programme. Despite the challenges of being an archipelago, Indonesia succeeded through government prioritisation, planning and investment. The programme leveraged existing kerosene distribution networks to promote the switch to LPG and provided a free basic LPG stove to help households overcome financial barriers.



Over the same time period, Vietnam increased its clean cooking access rate by 51 percentage points. The country has clear targets for the transition to clean cooking and employs a multi-technology approach. Depending on the context, LPG, advanced biomass and biogas stoves are promoted. In addition to government interventions, the private sector, non-governmental organisations (NGOs), and social enterprises are key players in the sector.

[36] Data are from the WHO Household energy database (https://www.who.int/airpollution/data/household-energy-database/en/). Access to clean cooking technology is defined in accordance with SDG 7, meaning primary reliance on clean stoves and fuels that meet WHO guidance (UNSD, 2020). As summarised in WHO et al. (2018), currently available clean cooking options include "electricity, gas, ethanol, solar and the highest performing biomass stoves".

Figure 88. Share of Population with Access to Clean Cooking in ASEAN Member States



Data source: WHO Household energy database, https://www.who.int/airpollution/data/household-energy-database/en/. Access to clean cooking technology is defined in accordance with SDG 7, meaning primary reliance on clean stoves and fuels that meet WHO guidance (UNSD, 2020)

In the absence of strong clean cooking policy and programmes, progress is slow, particularly for rural and low-income areas. Lao PDR, which has the region's lowest clean cooking access rate, just 7% as of 2018, illustrates the correlation between income and urbanisation, and increased prevalence of clean cooking. Notably, however, the most recent national household survey indicates that while modern, clean cookstoves are hardly used, other modern kitchen appliances are common. In Lao PDR, rice cookers and refrigerators are found in the majority of households (Government of Lao PDR and UNICEF, 2019), suggesting that, while socioeconomic factors may hinder uptake, when it comes to choosing clean cookstove technology, additional influencing factors related to fuel or technology access, or household preferences may be present. LPG is imported and expensive in Lap PDR, while firewood and charcoal are plentiful and cheap (World Bank 2018).

3.5.2 Options for Expanding Access to Clean Cookstoves and Fuels

Resource availability and local fuel markets are critical determinants of household cooking choices. Simply put, clean stoves and fuels need to be at least as affordable, reliable and convenient as the traditional stoves and fuels they are replacing. This is particularly challenging in rural contexts where the quality of transportation and power networks influences the ability to establish reliable distribution for modern energy. For example, LPG canisters transported to more remote locations are usually more expensive than in urban areas, and they may not always be available.

The use of electric cookstoves may be promising for the future, particularly in urban and peri-urban areas where electricity access is expanding. In the past, electricity access was often too unreliable or expensive to be used for cooking. With recent improvements on this front, many countries are exploring potential conversion to electric cooking. Recent programmes in countries including Bhutan (Gyelmo, 2020), Kenya (MECS 2019), and Myanmar (Leary et al. 2019) are exploring an expansion of electric cooking. It is important to recognise, however, that where electricity prices are high, and/or the power supply is unreliable, electric cooking is less likely to become a preferred option. Households relying on micro-grids or off-grid electricity may not have enough power to adopt electric stoves. Still, as noted above, electric rice cookers are already widely used in ASEAN countries.

With urbanisation, electrification and rising incomes, some households will switch to clean cooking solutions on their own, but without government-driven policy and programmes, particularly in rural and low-income areas, this transition will not be fast enough to meet the SDG 7 target of universal access by 2030. As has been demonstrated in ASEAN, targeted subsidies for lower-income households, such as for LPG fuel and equipment in Indonesia, can help overcome economic barriers, as can microfinance for stoves. The local production of high-efficiency stoves, such as with advanced biomass gasifier models in Vietnam, can expand clean cooking practices while also building industries and growing local economies. Meanwhile, government investments in infrastructure, whether or not they take into consideration the cooking sector, can support the creation of more efficient energy distribution networks that enable increased fuel availability and affordability. The most effective pathway towards universal access to clean cooking will depend on the national context, but all these measures can help.

3.5.3 Biogas Potential in ASEAN

Biogas has demonstrated potential as a clean option, particularly in the rural residential context. Biogas has great potential at the household scale for ASEAN countries, with plenty of freely available feedstock, such as municipal solid waste, agricultural residues and animal manure. Biogas derived from the fermentation of these organic materials can be used as a cooking fuel in households. The complete combustion of biogas produces low levels of pollution relative to traditional biomass cooking, and is more energy-efficient. In addition, biogas can be produced with a stand-alone system, which means it can be deployed in inaccessible communities or remote areas. For these reasons, many countries have implemented programmes to promote the use of biogas in households to replace wood, charcoal and biomass, including Thailand, Vietnam and Indonesia.

In Thailand, various sizes of small anaerobic systems have been promoted in households as alternatives to LPG. For households, switching to biogas reduced cooking energy costs by three-quarters, from 400 baht (12 USD) per month on LPG to 100 baht (3 USD) per month with biogas (Damrongsak and Chaichana, 2020). Biogas production may also offer new business opportunities for some farmers (see, e.g. Sritrakul and Hudakorn, 2020). The most significant accomplishment of these projects is transferring knowledge of biogas production in pilot areas, teaching volunteers about theory, instruction of equipment operation and the safety and safe use of biogas. Nowadays, volunteers can build biogas system by themselves, and they can also teach others how to build and maintain biogas systems.

However, the barriers to the wide adoption of this technology include high upfront costs as compared to other options, technical complexities to achieve and maintain optimal gas production, and the need for a consistent supply of feedstock. With the expanding mechanisation of agriculture, household reliance on livestock may fall, compromising one of the main feedstock supplies. Large livestock production facilities that can produce biogas on a commercial scale may offer the greatest potential for the region. Additionally, many programmes find that biogas is not financially feasible in the long run. Often the payback period is longer than the life of the equipment. For example, one study in East Java found that while household biogas digesters did successfully reduce reliance on traditional biomass, the digesters were only financially feasible due to a subsidy. Without the subsidies, users would have been unlikely to invest in this technology (Bedi et al. 2017).

There have been many micro-scale biogas inventions introduced into the market, such as HomeBiogas 2.0.[37] This system involves a small tent or gasbag with water and bacteria digesters that can recycle 12 litres of organic waste per day. After putting food waste or animal manure into the digester vessel, the bacteria in the digester will break down the organic matter and convert it into biogas and fertilizer. The gasbag can hold up to 700 litres of biogas and produce up to three hours of cooking gas daily. This technology can help to eliminate households' organic wastes, while producing biogas at the same time. The product has been introduced in several countries, including France, Mexico, Israel, South Africa and the U.S., as well as ASEAN countries.

[37] See https://www.homebiogas.com/Products/HomeBiogas2.

CHAPTER 4

Policy Implications and Recommendations

CHAPTER 4

Policy Implications and Recommendations

The projected growth in ASEAN's energy systems, in both demand and supply, is enormous. In the most optimistic scenario, the APS, by 2040, the total primary energy supply (TPES) for the region is expected to grow by 82.3% from its 625 Mtoe level in 2017; in the Baseline Scenario, TPES would grow by 154%. To put this into context, it took the region 30 years to add 400 Mtoe to its TPES to reach the 2017 level, but it could add twice as much in the next 20 years. It is also possible that the steep growth foreseen in AEO6 is still an underestimate. For instance, air conditioning use could become near-universal, or car ownership and use could approach U.S. levels.[38]

This rapid increase of energy use will bring many benefits, such as economic growth and human development, but as the analysis presented throughout AEO6 shows, it also creates major challenges. One of the greatest concerns is that ASEAN will still meet the majority of its energy demand with fossil fuels even in 2040. This will exacerbate dependency on imports, increasing the cost of energy, adding uncertainty and thus reducing the region's energy security. Continued fossil fuel use will also worsen air pollution, harming human health, and accelerate climate change.

These negative effects can be reduced by transitioning to a cleaner, more sustainable energy supply. This is why the regional renewable energy and energy intensity targets in APAEC are so important, but as the analysis presented in Chapter 2 shows, ASEAN still needs to close noticeable gaps to reach those targets.

4.1 Recommendations for Key Energy Sectors

ASEAN Member States can accelerate the transition to cleaner, more sustainable energy through targeted policies for key energy-consuming sectors:

4.1.1 Transport

Biofuels | **Electric vehicles**

***IN SHORT:* Adopt stronger demand- and supply-side polices for both biofuels and electric vehicles; keep pursuing the vehicle efficiency target in the ASEAN Fuel Economy Roadmap; strengthen vehicle emission and fuel quality standards; and invest in public transit and non-motorised transport to reduce the need for driving.**

Oil is the most heavily used fossil fuel in the ASEAN region, and transport accounts for by far the largest share of oil demand. As discussed in Sections 2.3 and 3.4, several Member States are already working to promote both biofuels and EVs – but with stronger policies, they can accelerate progress.

AMS can boost demand for **biofuels** through tax subsidies for biofuel vehicles; biofuel price subsidies (perhaps using revenue from an oil tax, or reallocated fossil fuel subsidies); and public procurement programmes (e.g. using biofuel vehicles for government fleets). Key supply-side measures include

[38] As of 2018, there were 109.8 million private automobiles registered in the U.S. (FHWA 2019), or about 335 per 1,000 residents, while Thailand, for example, had 9,985,879 private cars registered at the end of 2019, per national statistics, or about 143 per 1,000 residents (using World Bank population data for ease of comparison: https://data.worldbank.org/indicator/SP.POP.TOTL).

regulatory changes to allow greater profit margins for biofuel sales; policies and investments to increase agricultural yields; agroforestry approaches that combine food and fuel crops; and reforms to promote more secure land tenure. There is also a need for increased support for biofuel R&D – particularly focused on next-generation feedstocks such as waste and non-food crops.

With **electric vehicles**, a key priority is to change the cost profile, as buying an EV can still be prohibitively expensive. Subsidies and tax breaks can reduce the cost of EVs; charging infrastructure also needs to be built, initially led by the government, then with greater private-sector engagement, guided by clear standards. Pilot programmes can help demonstrate the feasibility of EVs. Several AMS are gearing up to manufacture EVs for domestic use and export, which could be transformative for the ASEAN market. In the meantime, the ASEAN-China Free Trade Area can facilitate imports of EVs from China, many of which are quite cost-competitive.

The ASEAN Fuel Economy Roadmap for the Transport Sector 2018–2025 aims to reduce average fuel consumption of new light-duty vehicles by 26% from 2015 levels by 2025 (to 5.3 litres of gasoline equivalent/100 km). AMS should keep pushing forward to meet that target; they should also continue to ratchet up vehicle emission and fuel quality standards. Singapore, Malaysia and Thailand are leading the way in this area, as shown in Table 6.

Photo source: Shutterstock

Table 6. How Malaysia, Singapore and Thailand Are Raising Emission and Fuel Quality Standards

Country	Fuel	Standards	Year	Reference
Malaysia	Gasoline	RON97/Euro V-compatible gasoline is available nationwide. RON 94 gasoline is still Euro II-compatible, but refinery upgrades are ongoing	2015	ASEAN Fuel Economy Roadmap for the Transport Sector 2018–2025*
		Euro IVM RON 95 is available nationwide	2020	National Automotive Policy 2020**
		Euro V Gasoline target	2025	
	Diesel	Euro V-compatible diesel has been introduced across Malaysia. Euro II-compatible diesel production remains permitted	2015	ASEAN Fuel Economy Road-map for the Transport Sector 2018–2025
		Euro V diesel mandatory plan (September)	2020	National Automotive Policy 2020
Singapore	Gasoline	Euro VI Emission Standard for new petrol vehicles. Euro IV Emission Standard for new motorcycles.	2017	National Environment Agency policy summary***
	Diesel	Euro VI Emission Standard for new diesel vehicles	2018	
Thailand	Gasoline and diesel	LDVs need to comply with Euro IV standard	2012	ASEAN Fuel Economy Roadmap for the Transport Sector 2018–2025

* See https://asean.org/storage/2019/03/ASEAN-Fuel-Economy-Roadmap-FINAL.pdf.
** See https://www.miti.gov.my/miti/resources/NAP%202020/NAP2020_Booklet.pdf.
*** See https://www.nea.gov.sg/our-services/pollution-control/air-pollution/air-pollution-regulations.

Finally, ASEAN Member States can reduce demand for private vehicles by investing in public transit and non-motorised transport. This includes increased rail and bus coverage, integration of bus and rail systems, and transit travel time monitoring and continuous improvements, as well as cycling networks and pedestrian infrastructure.

Singapore offers examples of what is possible: in 2013, the government vowed that by 2030, 80% of households would be within a 10-minute walk from a train station and 75% of all peak-period journeys would be undertaken on public transport (Singapore LTA 2019); it is now aiming to become a "45-minute city", meaning that 9 in 10 peak-period journeys can be completed in under 45 minutes by walking, cycling and/or public transit. Singapore's density obviously plays a role here, but similar strategies could be deployed in major cities across the ASEAN region.

4.1.2 Industry

Fuel-switching	Energy efficiency	Emission standards

***IN SHORT:* Given that industry is the sector with the highest energy demand in the region, it is crucial to adopt ambitious energy efficiency measures and emission standards. Manufacturers should also be strongly encouraged to adopt renewable energy – biomass may hold the greatest promise.**

Industry is a priority sector both for its high energy demand, and because several Member States in ASEAN are actively working to expand their manufacturing capacities. As discussed in Section 2.4.2.1, the sector is very diverse in terms of facility size, types of production, energy demand and profit margins, so a wide range of policies and incentives may be required, including energy reporting programmes, subsidised energy audits, support for energy service companies (ESCOs), and more.

Thailand, for example, has developed innovative financing schemes under the Energy Conservation and Promotion (ENCON) Fund, which targets industrial plants and projects that incorporate renewable energy and/or energy efficiency measures. The fund provides two types of support, both available to a broad array of industries: (i) cost-based support (financial support determined by investment costs), including direct subsidies, a revolving fund, and an ESCO revolving fund; and (ii) a performance-based programme, in which support is determined by the savings achieved.

ASEAN Member States can also do more to lower the impacts of industrial energy consumption through **fuel-switching**. There are multiple options, from biomass, to electrification, to solar PV and heat. Industrial use of electricity varies greatly in ASEAN, from 7.5% of industrial TFEC in Cambodia and Myanmar, to more than 25% in the Philippines, Singapore and Vietnam, and more than a third in Malaysia (IRENA 2018). Solar PV has also been applied in some industries, but it is still very limited; the much faster-growing industrial fuel is natural gas, as noted in Section 2.2.1.

So far, the most widely embraced form of fuel-switching has been to replace fossil fuels with biomass to produce heat, steam and power, particularly in Thailand (see Box 2.2 in IRENA 2018). For example, residues and wastes provide more than 80% of the process heat in the sugar, pulp and paper, rice milling, timber and palm oil industries. Small agro-processing and food production plants also use biomass for heat, and larger-scale plants use both biomass and biogas for heat and power co-generation. IRENA sees significant potential for bioenergy use for industrial heat generation and in co-generation of power and heat (IRENA 2018) – but also warns that, like policies to promote biofuels in transport, efforts to scale up industrial biomass use must ensure sustainability.

ASEAN may also want to improve **energy efficiency** and **emission standards** for industry, but keeping in mind the diversity of the sector. Improvements to the power supply can also help, as reliable and affordable electricity makes it easier to adopt cleaner industrial technologies.

Photo source: Shutterstock

4.1.3 Residential and Commercial

Appliance efficiency | Green building codes | Renewable energy

***IN SHORT:* Stronger energy efficiency requirements for buildings, enhanced building codes and stricter efficiency standards for appliances can all help slow energy demand growth driven by rising incomes.**

Although residential and commercial buildings' shares of overall energy demand are not as large as those of industry and transport, they are still large in absolute terms. As GDP rises across ASEAN, and living standards improve, energy demand is also likely to rise – unless effective energy efficiency measures are put in place. There are many options, including revised building codes, minimum energy performance standards (MEPS), labelling programmes (for buildings and especially for appliances), consumer education, energy audits, and subsidy and financing programmes for energy retrofits.

As highlighted in Section 2.3.3.3, **appliance efficiency** is a priority for slowing growth in residential energy use; lighting and air conditioning in particular hold great promise. Section 3.3 shows how much potential there is to improve AC efficiency by adopting more stringent MEPS, complemented by labelling programmes and consumer education. ASEAN may also want to adopt enhanced harmonised MEPS.

For commercial buildings, Singapore leads the way in **green building codes** (see, e.g., Baker 2019). Its Sustainable Singapore Blueprint sets a target of having 80% of buildings meet its Green Mark standard by 2030; as of 2019, 38% did. Singapore's third Green Building Masterplan, approved in 2014 and now being updated, includes market-based incentives for building retrofits and Green Mark-compliant new construction, including floor-area bonuses and financing.[39]

ASEAN Member States can also promote more widespread adoption of **renewable energy** (e.g. through subsidies for installing rooftop solar panels), which could help them attain the regional target of a 23% share of RE in the energy supply.

[39] See https://www1.bca.gov.sg/buildsg/sustainability/green-building-masterplans.

Photo source: Shutterstock

4.1.4 Power

Targeted Investment	Incentives	ASEAN Power Grid	Efficiency and emission standards

***IN SHORT:* Invest in grid improvements and technologies such as demand-side management and energy storage systems to facilitate the integration of renewable energy into the power grid; strengthen emission standards for power plants to reduce GHG emissions and protect public health.**

Renewable energy technologies are projected to grow significantly in the near future – especially solar PV, due to its huge potential in the region and its declining cost. However, effective integration of RE will require **targeted investments** to address the challenges posed by intermittent energy sources such as solar and wind, and ensure the reliability of power systems. **Incentives** are also crucial; options include renewable energy or portfolio standards, feed-in tariffs, interconnection rights, production tax credits, streamlined permitting and support for RD&D, among others. About half of ASEAN Member States have adopted feed-in tariffs, with varying degrees of success. In some cases, the tariffs were inadequate, permitting processes were unclear or too complex, and policies shifted. Continuous evaluation and benchmarking will be needed to ensure success.

As discussed in Section 3.1, the **ASEAN Power Grid** (APG) can help Member States achieve greater energy security while also facilitating an expansion of RE. Key priorities include expanding multilateral power trading, and implementing the institutional, procedural, legal and regulatory, information system, and data management enhancements needed to do so; and coordinating with power trading activities under the Greater Mekong Subregion Program.

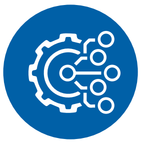
Given that fossil-fuelled power plants, mainly using coal and natural gas, are projected to still provide a large share of ASEAN's power by 2040 in all scenarios (around 48–66%), stronger **efficiency and emission standards** are also crucial. Section 3.2 describes key improvements needed to make coal power more efficient and less polluting; several ASEAN Member States, including Indonesia, Vietnam, Malaysia, Cambodia and the Philippines, have said they plan to shift to supercritical and ultra-supercritical coal power, for instance. Indonesia has also been testing coal and biomass (waste) co-firing, with 1-10% biomass (Asmarini 2020).

Photo source: Shutterstock

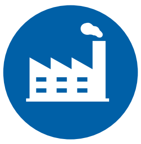
4.2 Model and Institutional Improvements

The AEO6 model establishes a foundation for technology-rich breakdowns for some key energy sectors in the region with standardised and validated data, paving the way to evaluate and project the effect of policies to ultimately reach regional policy targets. In the next AEO, modelling can be further improved by taking several concrete steps.

The AEO model itself can be improved by:

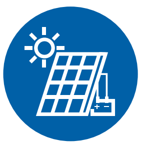


1. **Incorporating costs of all technologies:** In making policy interventions, cost is one of the most important factors to consider, along with technical feasibility and environmental impact. AEO6 has calculated some investment costs for the power sector. However, due to data limitations, there is still significant room for improvement for implementing cost calculations for other sectors, which can lead to a better picture of the cost-benefit analysis of various policy options.



2. **Industrial and commercial sector bottom-up technology breakdowns:** As major contributors to energy demand growth, these two sectors are central to efforts to reach regional energy targets, especially for energy efficiency. For industry, available technologies and energy use in major subsectors such as cement, iron and steel, manufacturing, and others will need to be analysed. Meanwhile, the commercial sector would require breakdowns of various building types' floor space, as well as appliances similar to the residential sector.

3. **Transmission constraints and connectivity:** Transmission plays an important role in determining what renewable resources can be developed. Having details on transmission can help to plan the improvements needed for the grid, as well as explain more about the factors that may hinder interconnection efforts among AMS. The disaggregation of regional grids and modelling transmission connectivity among nodes is necessary for a long-term capacity expansion analysis, since it is able to capture important differences in load and resource availability across the region. Further details will be provided in the AIMS III study.



4. **Capacity expansion modelling and load flow modelling:** Increased penetration of variable renewable energy in the power system will require some adjustments, as production fluctuates throughout the year due to these energy sources' intermittent nature. To balance such variability, energy storage technology will likely be needed. Moreover, individual AMS-specific daily/seasonal variations of load factors should be considered so that the capacity will be able to safely meet peak demand. With the availability of both in the model, the required investments in capacity and energy storage requirements can be projected more accurately.

5. **Updates and improvements on existing assumptions:** In order to keep the projections relevant, it is important to keep up with the changes that are happening in the world and translate them into the model. This includes technological improvements, as well as activity level changes for energy that may happen even in the short run.

With the points specified above, it is clear that improvement of the AEO model will require major efforts in data collection. Capacity-building on energy-related data will be needed, with notable attention placed on the standardisation and harmonisation of data quality among all AMS, as well as expanding the sectoral resolution needed for more detailed modelling and policy analysis. Consistent with the philosophy of AEO, transparency, constant communication, and consultation with AMS experts will be cornerstones of model enhancement efforts.


Photo source: Shutterstock

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Annex

A. Scenario Overview Tables

A.1 TPES by fuel (Mtoe)

Fuel	Baseline Scenario							Share of TPES			CAGR		
	2005	2017	2020	2025	2030	2035	2040	2017	2025	2040	2017 – 2025	2017 – 2040	2025 – 2040
Natural Gas	102	138	159	191	231	282	344	22.1%	21.8%	21.6%	4.1%	4.0%	4.0%
Oil	184	239	268	334	408	489	587	38.3%	38.2%	36.9%	4.2%	4.0%	3.8%
Coal	60	138	157	199	260	324	402	22.1%	22.8%	25.3%	4.7%	4.8%	4.8%
Hydropower	5	16	15	18	23	31	41	2.5%	2.1%	2.6%	2.0%	4.3%	5.5%
Geothermal, Solar and Wind	14	21	21	41	55	73	99	3.3%	4.7%	6.2%	9.0%	7.1%	6.0%
Modern Biomass	28	50	48	59	69	73	83	7.9%	6.8%	5.2%	2.3%	2.3%	2.3%
Traditional Biomass	40	24	32	33	35	36	36	3.9%	3.8%	2.3%	3.9%	1.7%	0.6%
Others	-1	-1	-2	-2	-2	-2	-2	-0.2%	-0.3%	-0.1%	9.5%	2.9%	-0.5%
Total	431	625	699	874	1,079	1,305	1,589	100%	100%	100%	4.3%	4.1%	4.1%

Fuel	ATS							Share of TPES			CAGR		
	2005	2017	2020	2025	2030	2035	2040	2017	2025	2040	2017 – 2025	2017 – 2040	2025 – 2040
Natural Gas	102	138	154	174	207	239	269	22.1%	21.4%	20.7%	2.9%	2.9%	3.0%
Oil	184	239	261	284	327	367	415	38.3%	35.1%	32.0%	2.1%	2.4%	2.6%
Coal	60	138	154	184	220	261	316	22.1%	22.8%	24.3%	3.7%	3.7%	3.6%
Hydropower	5	16	15	17	22	28	35	2.5%	2.1%	2.7%	1.2%	3.7%	5.0%
Geothermal, Solar and Wind	14	21	22	40	53	71	90	3.3%	4.9%	7.0%	8.5%	6.6%	5.7%
Modern Biomass (excluding household use)	28	50	57	87	104	129	161	7.9%	10.7%	12.4%	7.2%	5.3%	4.2%
Traditional Biomass	40	24	30	27	21	17	14	3.9%	3.3%	1.1%	1.1%	-2.4%	-4.3%
Others	-1	-1	-2	-2	-2	-2	-2	-0.2%	-0.3%	-0.2%	9.6%	3.2%	-0.1%
Total	431	625	690	810	952	1,110	1,298	100%	100%	100%	3.3%	3.2%	3.2%

Fuel	APS							Share of TPES			CAGR		
	2005	2017	2020	2025	2030	2035	2040	2017	2025	2040	2017 – 2025	2017 –2040	2025 –2040
Natural Gas	102	138	153	161	183	210	241	22.1%	21.0%	21.1%	1.9%	2.4%	2.7%
Oil	184	239	251	269	303	336	373	38.3%	35.0%	32.8%	1.5%	2.0%	2.2%
Coal	60	138	137	141	158	176	191	22.1%	18.4%	16.8%	0.3%	1.4%	2.0%
Hydropower	5	16	16	18	21	26	33	2.5%	2.3%	2.9%	1.6%	3.3%	4.2%
Geothermal, Solar and Wind	14	21	24	64	79	97	123	3.3%	8.3%	10.8%	15.3%	8.1%	4.4%
Modern Biomass (excluding household use)	28	50	68	95	114	140	171	7.9%	12.4%	15.0%	8.5%	5.5%	4.0%
Traditional Biomass	40	24	29	22	14	11	8	3.9%	2.9%	0.7%	-1.0%	-4.5%	-6.4%
Others	-1	-1	-2	-2	-2	-2	-2	-0.2%	-0.3%	-0.1%	9.3%	1.8%	-2.0%
Total	431	625	676	769	871	994	1,139	100%	100%	100%	2.6%	2.6%	2.6%

Fuel	SDG Scenario							Share of TPES			CAGR		
	2005	2017	2020	2025	2030	2035	2040	2017	2025	2040	2017 – 2025	2017 – 2040	2025 – 2040
Natural Gas	102	138	154	178	208	236	269	22.1%	22.5%	21.0%	3.2%	2.9%	2.8%
Oil	184	239	261	285	329	369	416	38.3%	36.1%	32.5%	2.2%	2.4%	2.5%
Coal	60	138	154	185	221	265	320	22.1%	23.4%	25.0%	3.7%	3.7%	3.7%
Hydropower	5	16	16	17	22	28	36	2.5%	2.2%	2.8%	1.4%	3.7%	5.0%
Geothermal, Solar and Wind	14	21	22	40	53	70	84	3.3%	5.0%	6.6%	8.5%	6.3%	5.1%
Modern Biomass (excluding household use)	28	50	56	79	101	127	159	7.9%	10.0%	12.4%	6.0%	5.2%	4.8%
Traditional Biomass	40	24	22	9	0	0	0	3.9%	1.2%	0.0%	-11.5%	-100.0%	-100.0%
Others	-1	-1	-2	-2	-2	-2	-2	-0.2%	-0.3%	-0.2%	9.6%	3.0%	-0.3%
Total	431	625	682	790	933	1,093	1,281	100%	100%	100%	3.0%	3.2%	3.3%

A.2 TFEC by Sector (Mtoe)

Sector	Baseline Scenario							Share of TFEC			CAGR		
	2005	2017	2020	2025	2030	2035	2040	2017	2025	2040	2017 – 2025	2017 – 2040	2025 – 2040
Residential	64	63	69	75	80	86	92	16.8%	14.4%	10.0%	2.2%	1.7%	1.4%
Industry	94	142	158	200	252	310	380	37.9%	38.7%	41.2%	4.4%	4.4%	4.4%
Transport	74	132	151	189	234	283	342	35.3%	36.6%	37.1%	4.6%	4.2%	4.0%
Commercial	18	30	33	42	55	69	87	7.9%	8.2%	9.5%	4.6%	4.8%	4.9%
Agriculture and Others	9	8	9	11	14	17	21	2.2%	2.2%	2.3%	3.8%	4.1%	4.2%
Total	259	375	420	518	635	765	922	100%	100%	100%	4.1%	4.0%	3.9%

Sector	ATS							Share of TFEC			CAGR		
	2005	2017	2020	2025	2030	2035	2040	2017	2025	2040	2017 – 2025	2017 – 2040	2025 – 2040
Residential	64	63	67	64	60	59	60	16.8%	13.6%	8.4%	0.3%	-0.2%	-0.4%
Industry	94	142	154	182	215	248	287	37.9%	38.4%	40.2%	3.2%	3.1%	3.1%
Transport	74	132	150	177	208	241	280	35.3%	37.4%	39.3%	3.7%	3.3%	3.1%
Commercial	18	30	33	40	49	58	70	7.9%	8.4%	9.8%	3.9%	3.8%	3.8%
Agriculture and Others	9	8	9	10	12	14	17	2.2%	2.2%	2.3%	2.8%	3.0%	3.1%
Total	259	375	412	474	544	621	714	100%	100%	100%	3.0%	2.8%	2.8%

Sector	APS							Share of TFEC			CAGR		
	2005	2017	2020	2025	2030	2035	2040	2017	2025	2040	2017 – 2025	2017 – 2040	2025 – 2040
Residential	64	63	66	61	54	53	55	16.8%	13.4%	8.8%	-0.5%	-0.6%	-0.7%
Industry	94	142	152	168	186	205	226	37.9%	37.3%	36.2%	2.1%	2.0%	2.0%
Transport	74	132	150	174	201	233	271	35.3%	38.7%	43.4%	3.5%	3.2%	3.0%
Commercial	18	30	32	37	43	49	56	7.9%	8.3%	9.0%	3.0%	2.8%	2.7%
Agriculture and Others	9	8	9	10	12	14	17	2.2%	2.3%	2.7%	2.8%	3.0%	3.1%
Total	259	375	409	451	496	554	624	100%	100%	100%	2.3%	2.2%	2.2%

Sector	SDG Scenario							Share of TFEC			CAGR		
	2005	2017	2020	2025	2030	2035	2040	2017	2025	2040	2017 – 2025	2017 – 2040	2025 – 2040
Residential	64	63	60	48.86	43	45	49	16.8%	10.6%	6.9%	-3.1%	-1.1%	0.0%
Industry	94	142	154	182.14	215	248	287	37.9%	39.7%	40.9%	3.2%	3.1%	3.1%
Transport	74	132	150	177.33	208	241	280	35.3%	38.7%	39.9%	3.7%	3.3%	3.1%
Commercial	18	30	33	40.03	49	58	70	7.9%	8.7%	9.9%	3.9%	3.8%	3.8%
Agriculture and Others	9	8	9	10.45	12	14	17	2.2%	2.3%	2.4%	2.8%	3.0%	3.1%
Total	259	375	405	459	527	607	702	100%	100%	100%	2.5%	2.8%	2.9%

A.3 TFEC by Fuel (Mtoe)

Fuel	Baseline Scenario							Share of TFEC			CAGR		
	2005	2017	2020	2025	2030	2035	2040	2017	2025	2040	2017 – 2025	2017 – 2040	2025 – 2040
Natural Gas	15	28	32	43	58	75	98	7%	8%	11%	5.7%	5.7%	5.6%
Oil	124	177	198	245	301	362	434	47%	47%	47%	4.1%	4.0%	3.9%
Coal	22	34	36	44	53	61	70	9%	8%	8%	3.2%	3.2%	3.2%
Electricity	38	76	87	112	145	185	236	20%	22%	26%	4.9%	5.0%	5.1%
Bioenergy	21	36	36	40	44	46	46	10%	8%	5%	1.5%	1.1%	0.9%
Traditional Biomass	40	24	32	33	35	36	36	7%	6%	4%	3.9%	1.7%	0.6%
Other heat	0	0.01	0.01	0.01	0.01	0.02	0.02	0%	0%	0%	2.6%	3.5%	4.0%
Total	259	375	420	518	635	765	922	100%	100%	100%	4.1%	4.0%	3.9%

Fuel	ATS							Share of TFEC			CAGR		
	2005	2017	2020	2025	2030	2035	2040	2017	2025	2040	2017 – 2025	2017 – 2040	2025 – 2040
Natural Gas	15	28	31	38	46	54	64	7%	8%	9%	4.0%	3.7%	3.6%
Oil	124	177	192	200	221	241	263	47%	42%	37%	1.5%	1.7%	1.8%
Coal	22	34	35	41	47	53	59	9%	9%	8%	2.3%	2.4%	2.5%
Electricity	38	76	86	104	129	158	194	20%	22%	27%	3.9%	4.1%	4.2%
Bioenergy	21	36	39	64	79	95	115	10%	13%	16%	7.5%	5.2%	4.0%
Traditional Biomass	40	24	30	27	21	17	14	7%	6%	2%	1.1%	-2.4%	-4.3%
Other heat	0	0	0	1	2	3	5	0%	0%	1%	78.9%	31.5%	11.6%
Total	259	375	412	474	544	621	714	100%	100%	100%	3.0%	2.8%	2.8%

Fuel	**APS**							**Share of TFEC**			**CAGR**		
	2005	**2017**	**2020**	**2025**	**2030**	**2035**	**2040**	**2017**	**2025**	**2040**	**2017 – 2025**	**2017 – 2040**	**2025 – 2040**
Natural Gas	15	28	30	35	40	46	52	7%	8%	8%	3.0%	2.8%	2.7%
Oil	124	177	184	186	198	210	222	47%	41%	36%	0.6%	1.0%	1.2%
Coal	22	34	35	38	40	43	45	9%	8%	7%	1.3%	1.3%	1.3%
Electricity	38	76	85	98	115	136	161	20%	22%	26%	3.2%	3.3%	3.3%
Bioenergy	21	36	46	70	86	106	131	10%	16%	21%	8.8%	5.8%	4.3%
Traditional Biomass	40	24	29	22	14	11	8	7%	5%	1%	-1.0%	-4.5%	-6.4%
Other heat	0	0	0	1	2	3	4	0%	0%	1%	76.9%	29.7%	9.9%
Total	**259**	**375**	**409**	**451**	**496**	**554**	**624**	**100%**	**100%**	**100%**	**2.3%**	**2.2%**	**2.2%**

Fuel	SDG Scenario							Share of TFEC			CAGR		
	2005	2017	2020	2025	2030	2035	2040	2017	2025	2040	2017 – 2025	2017 – 2040	2025 – 2040
Natural Gas	15	28	31	38	46	54	64	7%	8%	9%	4.0%	3.7%	3.6%
Oil	124	177	192	201	223	242	264	47%	44%	38%	1.6%	1.8%	1.8%
Coal	22	34	35	41	47	53	59	9%	9%	8%	2.3%	2.4%	2.5%
Electricity	38	76	86	105	130	159	195	20%	23%	28%	4.0%	4.2%	4.2%
Bioenergy	21	36	39	64	79	95	115	10%	14%	16%	7.5%	5.2%	4.0%
Traditional Biomass	40	24	22	9	0	0	0	7%	2%	0%	-11.5%	-100.0%	-100.0%
Other heat	0	0	0	1	2	3	5	0%	0%	1%	78.9%	31.5%	11.6%
Total	259	375	405	459	527	607	702	100%	100%	100%	2.5%	2.8%	2.9%

A.4 Power Generation by Fuel/Feedstock (TWh)

Fuel	Baseline Scenario							Share of Generation			CAGR		
	2005	2017	2020	2025	2030	2035	2040	2017	2025	2040	2017 – 2025	2017 – 2040	2025 – 2040
Coal	140	383	471	618	833	1,058	1,340	38%	41%	43%	6.1%	5.6%	5.3%
Natural Gas	263	357	425	518	631	786	972	36%	35%	31%	4.8%	4.5%	4.3%
Oil	35	26	4	5	5	7	7	3%	0%	0%	-18.1%	-5.4%	2.2%
Geothermal	17	23	22	43	58	76	103	2%	3%	3%	8.1%	6.7%	6.0%
Hydro	55	181	179	212	273	361	476	18%	14%	15%	2.0%	4.3%	5.5%
Solar	0	6	21	37	47	65	91	1%	2%	3%	24.8%	12.3%	6.2%
Wind	0	3	9	12	15	23	33	0%	1%	1%	21.7%	11.8%	6.8%
Biomass, biogas, waste	1	23	25	44	61	71	101	2%	3%	3%	8.3%	6.6%	5.7%
Total	510	1,002	1,154	1,489	1,923	2,447	3,123	100%	100%	100%	5.1%	5.1%	5.1%

Fuel	ATS							Share of Generation			CAGR		
	2005	2017	2020	2025	2030	2035	2040	2017	2025	2040	2017 – 2025	2017 – 2040	2025 – 2040
Coal	140	383	465	575	705	851	1,051	38%	42%	41%	5.2%	4.5%	4.1%
Natural Gas	263	357	406	461	569	669	764	36%	33%	30%	3.3%	3.4%	3.4%
Oil	35	26	4	5	5	5	5	3%	0%	0%	-19.1%	-6.7%	0.7%
Geothermal	17	23	21	40	54	71	87	2%	3%	3%	7.1%	6.0%	5.4%
Hydro	55	181	179	199	250	320	412	18%	14%	16%	1.2%	3.7%	5.0%
Solar	0	6	23	38	45	65	92	1%	3%	4%	25.1%	12.4%	6.1%
Wind	0	3	10	12	14	18	27	0%	1%	1%	21.8%	10.7%	5.2%
Biomass, biogas, waste	1	23	34	49	56	80	111	2%	4%	4%	9.7%	7.1%	5.7%
Total	510	1,002	1,143	1,379	1,698	2,079	2,550	100%	100%	100%	4.1%	4.1%	4.2%

Fuel	APS							Share of Generation			CAGR		
	2005	2017	2020	2025	2030	2035	2040	2017	2025	2040	2017 – 2025	2017 – 2040	2025 – 2040
Coal	140	383	420	434	501	573	631	38%	33%	30%	1.6%	2.2%	2.5%
Natural Gas	263	357	404	410	471	559	667	36%	31%	31%	1.8%	2.8%	3.3%
Oil	35	26	4	5	7	8	7	3%	0%	0%	-18.5%	-5.5%	2.3%
Geothermal	17	23	22	60	74	92	117	2%	5%	6%	12.6%	7.3%	4.6%
Hydro	55	181	187	206	250	302	379	18%	16%	18%	1.6%	3.3%	4.2%
Solar	0	6	47	116	132	151	181	1%	9%	9%	43.9%	15.7%	3.0%
Wind	0	3	13	23	27	32	40	0%	2%	2%	31.5%	12.7%	3.8%
Biomass, biogas, waste	1	23	37	51	62	78	96	2%	4%	5%	10.4%	6.4%	4.3%
Total	510	1,002	1,134	1,305	1,523	1,794	2,118	100%	100%	100%	3.4%	3.3%	3.3%

A.5 Installed Capacity by Fuel/Feedstock (GW)

Fuel	Baseline Scenario							Capacity Share			CAGR		
	2005	2017	2020	2025	2030	2035	2040	2017	2025	2040	2017 – 2025	2017 – 2040	2025 – 2040
Coal	22	73	102	148	161	203	259	31%	37%	36%	9.3%	5.7%	3.8%
Natural Gas	52	84	93	113	124	155	193	36%	28%	27%	3.8%	3.7%	3.6%
Oil	14	16	14	14	15	17	19	7%	3%	3%	-2.1%	0.7%	2.3%
Geothermal	3	4	4	9	10	13	17	2%	2%	2%	11.4%	6.9%	4.6%
Hydro	17	46	61	76	81	102	132	20%	19%	19%	6.4%	4.7%	3.8%
Solar	0	4	14	26	31	41	56	2%	6%	8%	25.9%	12.0%	5.2%
Wind	0	1	4	6	7	10	14	1%	2%	2%	22.4%	11.0%	5.4%
Biomass, biogas, waste	1	6	9	12	14	18	23	2%	3%	3%	10.2%	6.2%	4.2%
Total	110	234	302	404	443	558	713	100%	100%	100%	7.1%	5.0%	3.9%

Fuel	ATS							Capacity Share			CAGR		
	2005	2017	2020	2025	2030	2035	2040	2017	2025	2040	2017 – 2025	2017 – 2040	2025 – 2040
Coal	22	73	103	148	151	166	207	31%	37%	34%	9.3%	4.6%	2.3%
Natural Gas	52	84	90	108	120	132	154	36%	27%	26%	3.3%	2.7%	2.4%
Oil	14	16	14	14	15	17	19	7%	3%	3%	-2.1%	0.6%	2.1%
Geothermal	3	4	4	9	10	12	15	2%	2%	2%	11.4%	6.1%	3.4%
Hydro	17	46	61	76	80	93	116	20%	19%	19%	6.4%	4.1%	2.9%
Solar	0	4	16	27	30	41	56	2%	7%	9%	26.6%	12.0%	5.0%
Wind	0	1	5	7	7	8	11	1%	2%	2%	23.4%	10.1%	3.5%
Biomass, biogas, waste	1	6	10	13	15	18	23	2%	3%	4%	11.0%	6.3%	3.9%
Total	110	234	303	401	426	487	600	100%	100%	100%	7.0%	4.2%	2.7%

Fuel	APS							Capacity Share			CAGR		
	2005	2017	2020	2025	2030	2035	2040	2017	2025	2040	2017 – 2025	2017 – 2040	2025 – 2040
Coal	22	73	87	106	107	109	120	31%	26%	22%	4.8%	2.2%	0.9%
Natural Gas	52	84	88	94	98	111	134	36%	23%	25%	1.5%	2.1%	2.4%
Oil	14	16	14	14	14	14	14	7%	3%	3%	-2.1%	-0.7%	0.1%
Geothermal	3	4	4	12	13	14	19	2%	3%	3%	16.0%	7.2%	2.9%
Hydro	17	46	59	77	82	89	111	20%	19%	20%	6.6%	3.9%	2.5%
Solar	0	4	32	83	85	90	109	2%	20%	20%	45.4%	15.3%	1.8%
Wind	0	1	6	13	13	14	17	1%	3%	3%	33.6%	12.1%	2.0%
Biomass, biogas, waste	1	6	10	15	15	16	20	2%	4%	4%	12.7%	5.6%	2.0%
Total	110	234	301	412	426	459	544	100%	100%	100%	7.4%	3.7%	1.9%

A.6 Emissions by Sector (Mt CO_2-eq)

Sector	Baseline Scenario							Share of Emissions			CAGR		
	2005	2017	2020	2025	2030	2035	2040	2017	2025	2040	2017 – 2025	2017 – 2040	2025 – 2040
Agriculture and Others	26	23	24	30	37	45	54	1%	1%	1%	3.4%	3.8%	4.1%
Commercial	15	22	24	28	34	39	45	1%	1%	1%	3.4%	3.2%	3.2%
Industry	188	255	283	357	448	547	665	15%	16%	16%	4.3%	4.3%	4.2%
Residential	58	54	48	50	51	53	54	3%	2%	1%	-1.1%	0.0%	0.6%
Transport	228	385	450	564	699	847	1,023	23%	25%	25%	4.9%	4.3%	4.0%
Power Generation	290	560	672	855	1,117	1,407	1,761	33%	38%	42%	5.4%	5.1%	4.9%
Other Transformation	233	387	291	345	407	478	569	23%	15%	14%	-1.4%	1.7%	3.4%
Total	1,037	1,686	1,791	2,228	2,793	3,415	4,171	100%	100%	100%	3.5%	4.0%	4.3%

Sector	ATS							Share of Emissions			CAGR		
	2005	2017	2020	2025	2030	2035	2040	2017	2025	2040	2017 – 2025	2017 – 2040	2025 – 2040
Agriculture and Others	26	23	24	27	32	37	42	1%	1%	1%	2.3%	2.7%	2.9%
Commercial	15	22	23	27	30	34	37	1%	1%	1%	2.7%	2.4%	2.2%
Industry	188	255	275	321	374	426	485	15%	16%	16%	2.9%	2.8%	2.8%
Residential	58	54	46	45	43	41	39	3%	2%	1%	-2.3%	-1.4%	-0.9%
Transport	228	385	434	445	492	533	580	23%	23%	19%	1.8%	1.8%	1.8%
Power Generation	290	560	651	781	955	1,140	1,374	33%	40%	46%	4.2%	4.0%	3.8%
Other Transformation	233	387	284	316	361	400	444	23%	16%	15%	-2.5%	0.6%	2.3%
Total	1,037	1,686	1,737	1,962	2,286	2,611	3,002	100%	100%	100%	1.9%	2.5%	2.9%

Sector	APS							Share of Emissions			CAGR		
	2005	2017	2020	2025	2030	2035	2040	2017	2025	2040	2017 – 2025	2017 – 2040	2025 – 2040
Agriculture and Others	26	23	24	27	32	37	42	1%	2%	2%	2.3%	2.7%	2.9%
Commercial	15	22	23	25	27	28	29	1%	1%	1%	1.8%	1.3%	1.1%
Industry	188	255	270	297	325	355	388	15%	17%	17%	1.9%	1.8%	1.8%
Residential	58	54	45	43	38	36	34	3%	3%	1%	-2.9%	-2.1%	-1.6%
Transport	228	385	412	411	437	461	483	23%	24%	21%	0.8%	1.0%	1.1%
Power Generation	290	560	588	600	692	799	899	33%	35%	40%	0.9%	2.1%	2.7%
Other Transformation	233	387	279	298	331	360	388	23%	18%	17%	-3.2%	0.0%	1.8%
Total	1,037	1,686	1,641	1,701	1,882	2,075	2,264	100%	100%	100%	0.1%	1.3%	1.9%

Sector	SDG Scenario							Share of Emissions			CAGR		
	2005	2017	2020	2025	2030	2035	2040	2017	2025	2040	2017 – 2025	2017 – 2040	2025 – 2040
Agriculture and Others	26	23	24	27	32	37	42	1%	1%	1%	2.3%	2.7%	2.9%
Commercial	15	22	23	27	30	34	37	1%	1%	1%	2.7%	2.4%	2.2%
Industry	188	255	275	321	374	426	485	15%	16%	16%	2.9%	2.8%	2.8%
Residential	58	54	45	43	41	39	38	3%	2%	1%	-3.0%	-1.5%	-0.7%
Transport	228	385	434	445	492	533	580	23%	23%	19%	1.8%	1.8%	1.8%
Power Generation	290	560	653	791	961	1,152	1,390	33%	40%	46%	4.4%	4.0%	3.8%
Other Transformation	233	387	282	311	356	396	441	23%	16%	15%	-2.7%	0.6%	2.3%
Total	1,037	1,686	1,736	1,965	2,286	2,617	3,014	100%	100%	100%	1.9%	2.6%	2.9%

B. Modelling Methodology

B.1 Energy Modelling Approach (demand-side)

The 6th ASEAN Energy Outlook uses a hybrid, top-down and bottom-up approach for demand projection, considering data availability in the region

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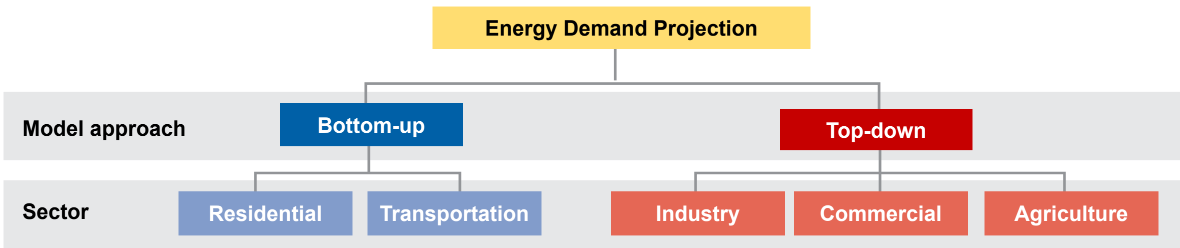
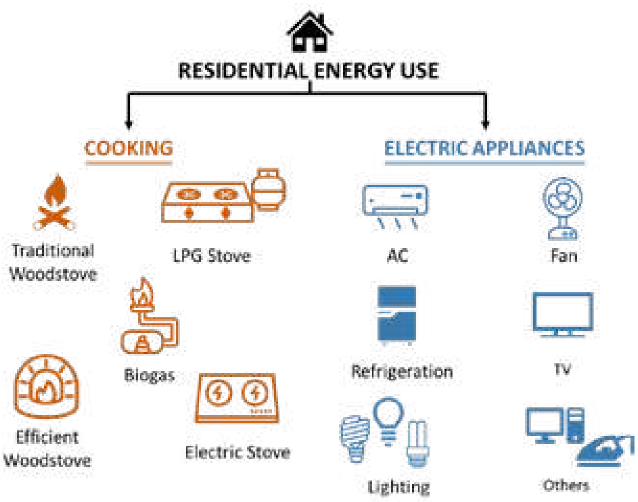
Top-down projects the energy demand by using historical growth and econometric projections for the industrial, commercial and agriculture sectors.

Bottom-up calculates energy demand by disaggregating it by activity level/technology transition, including energy intensity/efficiency and fuel share. This approach is applied to the residential and transport sectors. The bottom-up approach enables a detailed technological breakdown of energy use, which includes details on energy efficiency and fuel types.



For the residential sector, the structure was broken down into cooking, lighting and several kinds of home appliances; air conditioning, washing machines, clothes dryers, refrigeration, kettles, water heating, television (TV), computer, irons, fans, and other appliances.

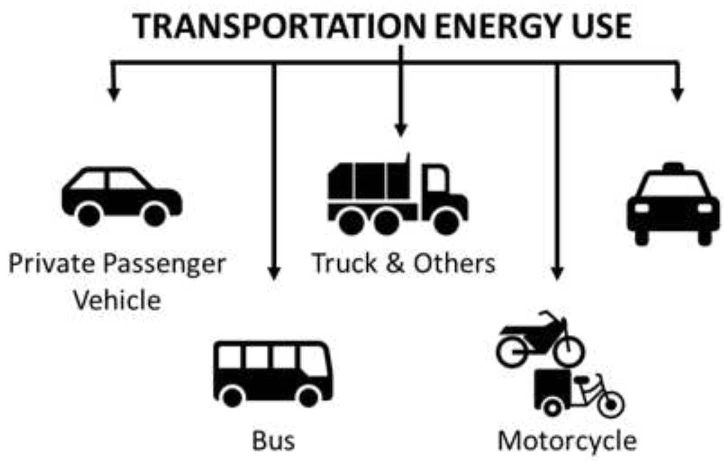


i) Energy demand for cooking = Number of households (hh) * cooking stove type shares* Energy consumption for cooking per household
And
Energy consumption for cooking per household = useful energy divided by stove efficiency

ii) Energy demand of each household appliance is equal to:Electricity demand = Number of households (hh) * Household penetration rate (%) * Energy intensity (kWh/hh)

iii) Energy Demand for Lighting = Electrified household* Number of Lamps per household* Lamp Wattage* operating hours and
Electrified household = Number of HH * electrification rate (%)

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 several types of vehicle namely, passenger vehicles, buses, motorcycles, trucks and others, and taxis. 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 transport roadmaps, the ASEAN-Japan Transport Partnership, Ministry of Transportation sources, etc. Apart from road transport, the other sub-sector transport demand was built using the top-down approach, due to the limited availability of broken-down data.



Energy demand per road transport type = The number of registered vehicles by type* the share of fleets by fuel use (%) * travel distance (km)* fuel economy (L/km)

B.2 Key Assumptions

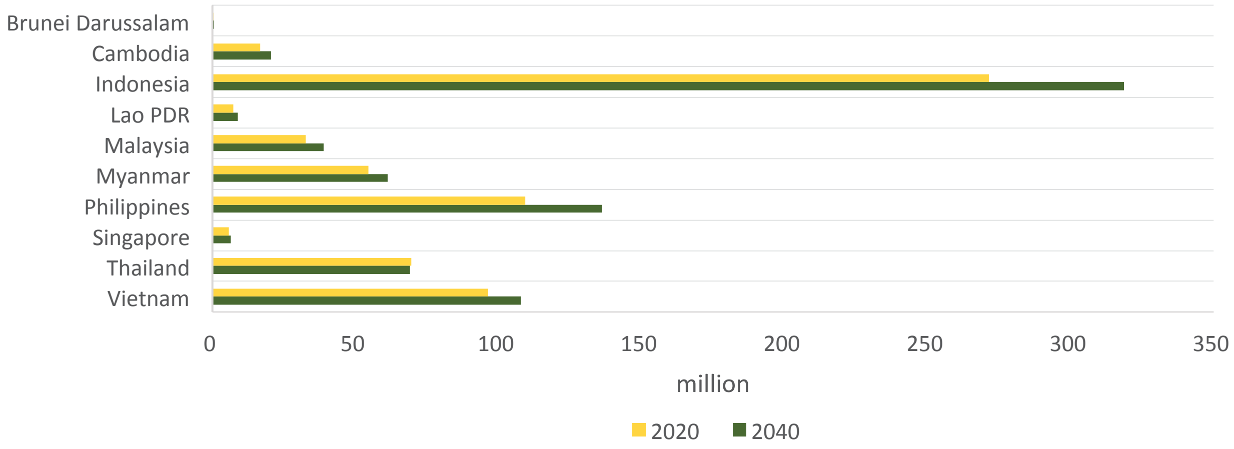
B.2.1 Population Projections

Population growth is also a key factor for deriving energy projections. The projections of population by country for 2020 and 2040 are shown below.

Table B1. ASEAN Population Historical and Projections 2005–2040

Population (Unit: Million Persons)									
Country	2005	2017	2020	2025	2030	2035	2040	CAGR (2017–2040)	CAGR (2005–2017)
Brunei Darussalam	0	0	0	0	0	0	0	0.6%	1.5%
Cambodia	13	16	17	18	19	20	21	1.1%	1.6%
Indonesia	220	262	271	287	299	309	319	0.9%	1.5%
Lao PDR	6	7	7	8	8	9	9	1.2%	1.5%
Malaysia	26	32	33	34	36	37	39	0.9%	1.8%
Myanmar	48	53	55	57	58	60	61	0.6%	0.8%
Philippines	85	105	109	117	124	130	136	1.1%	1.8%
Singapore	4	6	6	6	6	6	6	0.5%	2.5%
Thailand	65	69	70	70	70	70	69	0.0%	0.5%
Vietnam	82	94	96	101	104	106	108	0.6%	1.1%
ASEAN	550	644	664	698.5	726	747	768.2	0.77%	1.3%

Figure B1. ASEAN Population Projections for 2020–2040

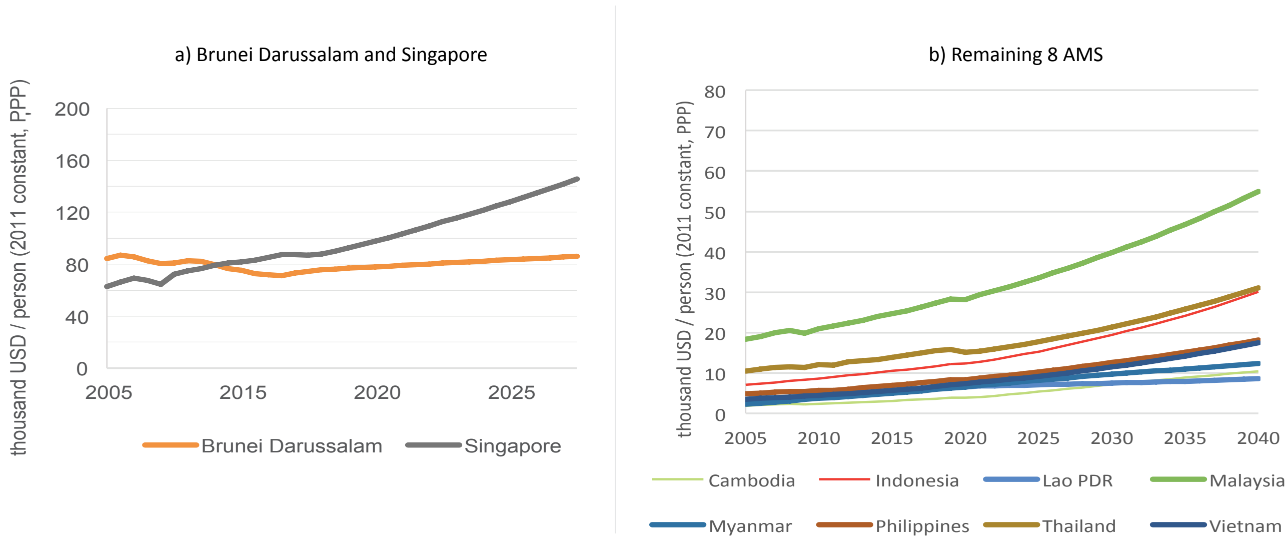


Data sources: Historical (2005–2017) – Brunei Darussalam, Indonesia and Vietnam, national census data; Cambodia, Malaysia, Myanmar, Philippines, Singapore and Thailand, World Development Indicators, http://wdi.worldbank.org. Projections (2018–2040), UN DESA (2019), medium variant, except for the Philippines, for which national projections are used. Note: The chosen source for historical data was based on each ASEAN Member State's suggestion.

B.2.2. GDP per Capita Projection

Using the GDP and population data, the projected trends of GDP per capita show growth through 2040 growth across all Member States (Figure B2). The GDP per capita has been used as dependent variable to forecast household penetration rate of home appliances (%) and number of vehicles per capita.

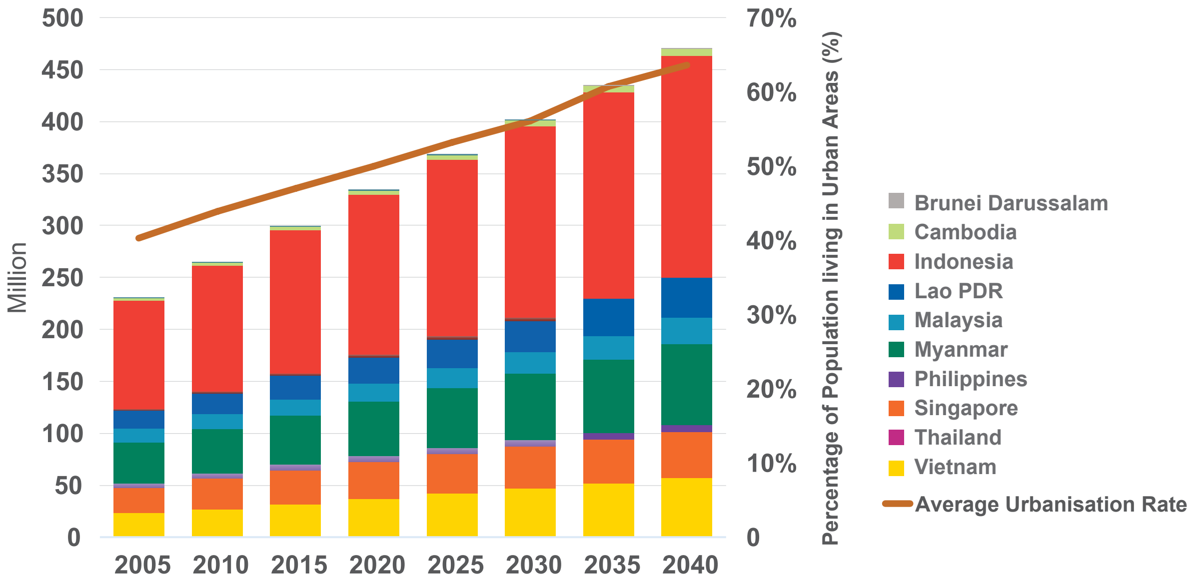
Figure B2. GDP Per Capita Modelled Growth Trends



B.2.3 Urbanisation Rate

The urbanisation rate is a further key variable for demographic projections such as household size. More than 60% of the population in ASEAN is expected to live in urban areas by 2040 (Figure 11). The projections for urban population was taken from UN DESA (2018).[40]

Figure B3. ASEAN Urban Population



B.2.4 Number of households and household size

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

Table B2. Number of Households in ASEAN Member States (millions)

Country	2020	2030	2040
Brunei Darussalam	0.08	0.09	0.09
Cambodia	3.65	4.47	5.13
Indonesia	70.47	80.26	88.15
Lao PDR	1.31	1.49	1.63
Malaysia	8.50	9.39	10.08
Myanmar	12.90	14.21	15.30
Philippines	26.25	35.27	47.97
Singapore	1.75	1.87	1.92
Thailand	22.50	24.93	26.99
Vietnam	29.76	32.14	33.26
Total	**177.17**	**204.12**	**230.52**

[40] UN DESA (2018). World Urbanization Prospects 2018. United Nations Department of Economic and Social Affairs, Population Division, New York. http://esa.un.org/unpd/wup/.

B.2.5 Emission Factors

The emission factors used for sectoral energy demand as well as the electricity generation were collected from various reliable sources, detailed below.

Electricity Generation

Transformation	Emission factor	Units	Per...	Reference source and assumptions
Transformation\Electricity Generation\Processes				
Electricity generation\Other Bituminous Coal and Anthracite				
Carbon Dioxide Non Biogenic	94.6 (a)	Metric Tonne	Terajoule	a) IPCC 2006 Guidelines – Tier 1 default EFs (Vol 2, Table 2.2) b) Derived from EMEP/EEA (2016) Tier 1 emission factors (1.A.1, Table 3-2) c) Bond et al. (2004), Tables 9 & 10 from which central values are used for the technology/emission control mix for India in the mid 1990s (i.e. if a range is given by Bond et al., then upper value taken) d) Battye et al. (1994) defaults (no NOx controls)
Carbon Monoxide	8.7 (b)	Kilogramme	Terajoule	
Methane	1 (a)	Kilogramme	Terajoule	
Non Methane Volatile Organic Compounds	1.0 (b)	Kilogramme	Terajoule	
Nitrogen Oxides NOx	209 (b)	Kilogramme	Terajoule	
Nitrous Oxide	1.5 (a)	Kilogramme	Terajoule	
Sulphur Dioxide	SulphurContent*(1-	Kilogramme	Kilogramme	
Particulates PM_{10}	7.7 (b)	Kilogramme	Terajoule	
Particulates $PM_{2.5}$	3.4 (b)	Kilogramme	Terajoule	
Black Carbon	0.009 (c)	Kilogramme	Metric Tonne	
Organic Carbon	0.001 (c)	Kilogramme	Metric Tonne	
Ammonia	0.00028 (d)	Kilogramme	Metric Tonne	
Electricity Generation\Natural Gas				
Carbon Dioxide Non Biogenic	56.1 (a)	Metric Tonne	Terajoule	a) IPCC 2006 Guidelines – Tier 1 default EFs (Vol 2, Table 2.2) b) EMEP/EEA (2016) Tier 1 emission factors (1.A.1, Table 3-4) c) Assume OC factor is 10 fold higher value than BC (derived from EMEP/EEA (2016) Tier 1) as indicated by Bond et al 2004 (Table 5) d) Battye et al. (1994) defaults (no NOx controls).
Carbon Monoxide	39 (b)	Kilogramme	Terajoule	
Methane	1 (a)	Kilogramme	Terajoule	
Non Methane Volatile Organic Compounds	2.6 (b)	Kilogramme	Terajoule	
Nitrogen Oxides NOx	89 (b)	Kilogramme	Terajoule	
Nitrous Oxide	0.1 (a)	Kilogramme	Terajoule	
Sulphur Dioxide	SulphurContent*(1-	Kilogramme	Kilogramme	
Particulates PM_{10}	0.89 (b)	Kilogramme	Terajoule	
Particulates $PM_{2.5}$	0.89 (b)	Kilogramme	Terajoule	
Black Carbon	0.0223 (b)	Kilogramme	Terajoule	
Organic Carbon	0.223 (c)	Kilogramme	Terajoule	
Ammonia	0.067 (d)	Kilogramme	Metric Tonne	
Electricity Generation\Heavy Fuel Oil				

Carbon Dioxide Non Biogenic	77.4 (a)	Metric Tonne	Terajoule	a) IPCC 2006 Guidelines – Tier 1 default EFs (Vol 2, Table 2.2) b) EMEP/EEA (2016) Tier 1 emission factors for combustion in 'Public Electricity and heat production' (1.A.1, Table 3-5) c) Bond et al. (2004), Tables 9 & 10 from which central values are used for the technology/emission control mix for India in the mid 1990s (i.e. if a range is given by Bond et al., then upper value taken) d) Battye et al. (1994) defaults (no NOx controls).
Carbon Monoxide	15.1 (b)	Kilogramme	Terajoule	
Methane	3 (a)	Kilogramme	Terajoule	
Non Methane Volatile Organic Compounds	2.3 (b)	Kilogramme	Terajoule	
Nitrogen Oxides NOx	142 (b)	Kilogramme	Terajoule	
Nitrous Oxide	0.6 (a)	Kilogramme	Terajoule	
Sulphur Dioxide	SulphurContent*(1-	Kilogramme	Kilogramme	
Particulates PM_{10}	25.2 (b)	Kilogramme	Terajoule	
Particulates $PM_{2.5}$	19.3 (b)	Kilogramme	Terajoule	
Black Carbon	0.04 (c)	Kilogramme	Metric Tonne	
Organic Carbon	0.015 (c)	Kilogramme	Metric Tonne	
Ammonia	0.101 (d)	Kilogramme	Metric Tonne	
Electricity Generation\Diesel				
Carbon Dioxide Non Biogenic	74.1 (a)	Metric Tonne	Terajoule	a) IPCC 2006 Guidelines – Tier 1 default EFs (Vol 2, Table 2.2) b) EMEP/EEA (2016) Tier 1 emission factors (1.A.1, Table 3-6) c) Assume OC = BC/3.33 (Bond et al., 2004 Table 5, OC:BC ratio for Middle dist oil in industry/power) d) Battye et al. (1994) defaults (no NOx controls).
Carbon Monoxide	16.2 (b)	Kilogramme	Terajoule	
Methane	3 (a)	Kilogramme	Terajoule	
Non Methane Volatile Organic Compounds	0.8 (b)	Kilogramme	Terajoule	
Nitrogen Oxides NOx	65 (b)	Kilogramme	Terajoule	
Nitrous Oxide	0.6 (a)	Kilogramme	Terajoule	
Sulphur Dioxide	SulphurContent*(1-	Kilogramme	Kilogramme	
Particulates PM10	3.2 (b)	Kilogramme	Terajoule	
Particulates PM2.5	0.8 (b)	Kilogramme	Terajoule	
Black Carbon	0.268 (b)	Kilogramme	Terajoule	
Organic Carbon	0.0035 (c)	Kilogramme	Metric Tonne	
Ammonia	0.101 (d)	Kilogramme	Metric Tonne	
Electricity Generation\Wood				
Carbon Dioxide Biogenic	112 (a)	Metric Tonne	Terajoule	a) IPCC 2006 Guidelines – Tier 1 default Efs (Vol 2, Table 2.2) b) EMEP/EEA (2016) Tier 1 emission factors (1.A.1, Table 3-7) c) Assume OC factor is 4 fold higher value than BC as indicated by Bond et al 2004 (Tables 9 and 10) d) US-EPA (2004) Emission Inventory Improvement Program: Estimating Ammonia Emissions from Anthropogenic Non-agricultural Sources – Draft Final Report, Table III-1, page32.
Carbon Monoxide	90 (b)	Kilogramme	Terajoule	
Methane	30 (a)	Kilogramme	Terajoule	
Non Methane Volatile Organic Compounds	7.31 (b)	Kilogramme	Terajoule	
Nitrogen Oxides NOx	81 (b)	Kilogramme	Terajoule	
Nitrous Oxide	4 (a)	Kilogramme	Terajoule	
Sulphur Dioxide	SulphurContent*(1-	Kilogramme	Kilogramme	
Particulates PM_{10}	155 (b)	Kilogramme	Terajoule	
Particulates $PM_{2.5}$	133 (b)	Kilogramme	Terajoule	
Black Carbon	4.4 (b)	Kilogramme	Terajoule	
Organic Carbon	17.6 (c)	Kilogramme	Terajoule	
Ammonia	0.043 (d)	Kilogramme	Terajoule	
Electricity Generation\Municipal Waste				

Carbon Dioxide Biogenic	91.7 (a)	Kilogramme	Kilogramme	a) IPCC 2006 Guidelines – Tier 1 default EFs (Vol 2, Table 2.2) b) Assume = EMEP/EEA (2016) Tier 1 emission factors for biomass combustion in Public Electricity and Heat Production. (1.A.1, Table 3-7) c) Bond et al 2004 BC and OC values for Waste (Tables 9 and 10) d) US-EPA (2004) Emission Inventory Improvement Program: Estimating Ammonia Emissions from Anthropogenic Non-agricultural Sources – Draft Final Report, Table III-1, page32...
Carbon Monoxide	90 (b)	Kilogramme	Terajoule	
Methane	30 (a)	Kilogramme	Terajoule	
Non Methane Volatile Organic Compounds	7.31 (b)	Kilogramme	Terajoule	
Nitrogen Oxides NOx	81 (a)	Kilogramme	Terajoule	
Nitrous Oxide	4 (b)	Kilogramme	Terajoule	
Sulphur Dioxide	SulphurContent*(1-	Kilogramme	Kilogramme	
Particulates PM_{10}	155 (b)	Kilogramme	Terajoule	
Particulates $PM_{2.5}$	133 (b)	Kilogramme	Terajoule	
Black Carbon	0.013 (c)	Kilogramme	Metric Tonne	
Organic Carbon	0.002 (c)	Kilogramme	Metric Tonne	
Ammonia	0.6 (d)	Kilogramme	Terajoule	
Transformation\Traditional Charcoal Making\Wood				
Carbon Dioxide Biogenic	542 (a)	Kilogramme	Metric Tonne	All factors are on a per tonne of wood feedstock basis a) Bertschi et al. (2003) Table 3, For earthen charcoal-making kilns (in Zambia). b) Bond et al (2004) Section 5.6.5 Charcoal: para 144 c) Assume 100% of S is retained in the charcoal (1 kg wood makes 0.28 kg charcoal, Bertschi et al (2003)) and wood at 0.015% S produces charcoal at 0.06% S (Smith et al 2000)
Carbon Monoxide	96.8 (a)	Kilogramme	Metric Tonne	
Methane	13.4 (a)	Kilogramme	Metric Tonne	
Non Methane Volatile Organic Compounds	32.8 (a)	Kilogramme	Metric Tonne	
Nitrogen Oxides NOx	0.18 (a)	Kilogramme	Metric Tonne	
Sulphur Dioxide	0 (c)	Kilogramme	Kilogramme	
Particulates PM_{10}	2.6 (b)	Kilogramme	Metric Tonne	
Particulates $PM_{2.5}$	2.6 (b)	Kilogramme	Metric Tonne	
Black Carbon	0.19 (b)	Kilogramme	Metric Tonne	
Organic Carbon	1.29 (b)	Kilogramme	Metric Tonne	
Ammonia	0.37 (a)	Kilogramme	Metric Tonne	

Industry

Branch Path	Units	Per...	Expression	Sources
Demand\Industry\Other Biomass\Carbon Dioxide Biogenic	Metric Tonne	Terajoule	29.9*FractionOxidized*(CO_2/C)	IPCC Tier 1 Default Emission Factor by LEAP
Demand\Industry\Other Biomass\Carbon Monoxide	Kilogramme	Terajoule	4,000	IPCC Tier 1 Default Emission Factor by LEAP
Demand\Industry\Other Biomass\Methane	Kilogramme	Terajoule	30	IPCC Tier 1 Default Emission Factor by LEAP
Demand\Industry\Other Biomass\Non Methane Volatile Organic Compounds	Kilogramme	Terajoule	50	IPCC Tier 1 Default Emission Factor by LEAP
Demand\Industry\Other Biomass\Nitrogen Oxides	Kilogramme	Terajoule	100	IPCC Tier 1 Default Emission Factor by LEAP
Demand\Industry\Other Biomass\Nitrous Oxide	Kilogramme	Terajoule	4	IPCC Tier 1 Default Emission Factor by LEAP
Demand\Industry\Other Biomass\Sulphur Dioxide	Kilogramme	Kilogramme	SulphurContent*(1-SulphurRetention)*(SO_2/S)	IPCC Tier 1 Default Emission Factor by LEAP
Demand\Industry\Diesel\Carbon Dioxide	Metric Tonne	Terajoule	20*FractionOxidized*(CO_2/C)	IPCC Tier 1 Default Emission Factor by LEAP
Demand\Industry\Diesel\Carbon Monoxide	Kilogramme	Terajoule	10	IPCC Tier 1 Default Emission Factor by LEAP

Demand\Industry\Diesel\Methane	Kilogramme	Terajoule	2	IPCC Tier 1 Default Emission Factor by LEAP
Demand\Industry\Diesel\Non Methane Volatile Organic Compounds	Kilogramme	Terajoule	5	IPCC Tier 1 Default Emission Factor by LEAP
Demand\Industry\Diesel\Nitrogen Oxides	Kilogramme	Terajoule	200	IPCC Tier 1 Default Emission Factor by LEAP
Demand\Industry\Diesel\Nitrous Oxide	Kilogramme	Terajoule	0.6	IPCC Tier 1 Default Emission Factor by LEAP
Demand\Industry\Diesel\Sulphur Dioxide	Kilogramme	Kilogramme	SulphurContent*(1-SulphurRetention)* (SO_2/S)	IPCC Tier 1 Default Emission Factor by LEAP
Demand\Industry\Natural Gas\Carbon Dioxide	Metric Tonne	Terajoule	15.3*FractionOxidized*(CO_2/C)	IPCC Tier 1 Default Emission Factor by LEAP
Demand\Industry\Natural Gas\Carbon Monoxide	Kilogramme	Terajoule	30	IPCC Tier 1 Default Emission Factor by LEAP
Demand\Industry\Natural Gas\Methane	Kilogramme	Terajoule	5	IPCC Tier 1 Default Emission Factor by LEAP
Demand\Industry\Natural Gas\Non Methane Volatile Organic Compounds	Kilogramme	Terajoule	5	IPCC Tier 1 Default Emission Factor by LEAP
Demand\Industry\Natural Gas\Nitrogen Oxides	Kilogramme	Terajoule	150	IPCC Tier 1 Default Emission Factor by LEAP
Demand\Industry\Natural Gas\Nitrous Oxide	Kilogramme	Terajoule	0.1	IPCC Tier 1 Default Emission Factor by LEAP
Demand\Industry\Natural Gas\Sulphur Dioxide	Kilogramme	Kilogramme	0	IPCC Tier 1 Default Emission Factor by LEAP
Demand\Industry\Residual Fuel Oil\Carbon Dioxide	Metric Tonne	Terajoule	20*FractionOxidized*(CO_2/C)	IPCC Tier 1 Default Emission Factor by LEAP
Demand\Industry\Residual Fuel Oil\Carbon Monoxide	Kilogramme	Terajoule	10	IPCC Tier 1 Default Emission Factor by LEAP
Demand\Industry\Residual Fuel Oil\Methane	Kilogramme	Terajoule	2	IPCC Tier 1 Default Emission Factor by LEAP
Demand\Industry\Residual Fuel Oil\Non Methane Volatile Organic Compounds	Kilogramme	Terajoule	5	IPCC Tier 1 Default Emission Factor by LEAP
Demand\Industry\Residual Fuel Oil\Nitrogen Oxides	Kilogramme	Terajoule	200	IPCC Tier 1 Default Emission Factor by LEAP
Demand\Industry\Residual Fuel Oil\Nitrous Oxide	Kilogramme	Terajoule	0.6	IPCC Tier 1 Default Emission Factor by LEAP
Demand\Industry\Residual Fuel Oil\Sulphur Dioxide	Kilogramme	Kilogramme	SulphurContent*(1-SulphurRetention)*(SO_2/S)	IPCC Tier 1 Default Emission Factor by LEAP
Demand\Industry\Coal Unspecified\Carbon Dioxide	Metric Tonne	Terajoule	25.8*FractionOxidized*(CO_2/C)	IPCC Tier 1 Default Emission Factor by LEAP
Demand\Industry\Coal Unspecified\Carbon Monoxide	Kilogramme	Terajoule	150	IPCC Tier 1 Default Emission Factor by LEAP
Demand\Industry\Coal Unspecified\Methane	Kilogramme	Terajoule	10	IPCC Tier 1 Default Emission Factor by LEAP
Demand\Industry\Coal Unspecified\Non Methane Volatile Organic Compounds	Kilogramme	Terajoule	20	IPCC Tier 1 Default Emission Factor by LEAP
Demand\Industry\Coal Unspecified\Nitrogen Oxides	Kilogramme	Terajoule	300	IPCC Tier 1 Default Emission Factor by LEAP
Demand\Industry\Coal Unspecified\Nitrous Oxide	Kilogramme	Terajoule	1.4	IPCC Tier 1 Default Emission Factor by LEAP
Demand\Industry\Coal Unspecified\Sulphur Dioxide	Kilogramme	Kilogramme	SulphurContent*(1-SulphurRetention)*(SO_2/S)	IPCC Tier 1 Default Emission Factor by LEAP

Annex

Commercial Sector

Demand\Services	Emission Factor	Units	Per...	Reference source and assumptions
Services\LPG Liquefied Petroleum gas				
Carbon Dioxide Non Biogenic	63.1 (a)	Metric Tonne	Terajoule	a) IPCC 2006 Guidelines – Tier 1 default EFs b) EMEP/EEA (2016) Tier 1 emission factor (1.A.4 Small combustion, Table 3.8) c) Assuming BC/OC ratio as for natural gas in Bond et al (2004): Table 5 d) Assume = factor for natural gas
Carbon Monoxide	29 (b)	Kilogramme	Terajoule	
Methane	5 (a)	Kilogramme	Terajoule	
Non Methane Volatile Organic Compounds	23 (a)	Kilogramme	Terajoule	
Nitrogen Oxides NOx	74 (b)	Kilogramme	Terajoule	
Nitrous Oxide	0.1 (a)	Kilogramme	Terajoule	
Sulphur Dioxide	SulphurContent*(SO_2/S)	Kilogramme	Kilogramme	
Particulates PM_{10}	0.78 (b)	Kilogramme	Terajoule	
Particulates $PM_{2.5}$	0.78 (b)	Kilogramme	Terajoule	
Black Carbon	0.03 (b)	Kilogramme	Terajoule	
Organic Carbon	0.26 (c)	Kilogramme	Terajoule	
Ammonia	0.067 (d)	Kilogramme	Metric Tonne	
Services\Gas Diesel Oil				
Carbon Dioxide Non Biogenic	74.1 (a)	Metric Tonne	Terajoule	a) IPCC 2006 Guidelines – Tier 1 default EFs b) EMEP/EEA (2016) Tier 2 emission factors for reciprocating engines (Table 3-31) c) From Klimont et al (2016) (Table S3.1) GAINS emission factors for diesel generators (no control) d) EMEP/Corinair (1996)
Carbon Monoxide	130 (b)	Kilogramme	Terajoule	
Methane	10 (a)	Kilogramme	Terajoule	
Non Methane Volatile Organic Compounds	50 (a)	Kilogramme	Terajoule	
Nitrogen Oxides NOx	942 (b)	Kilogramme	Terajoule	
Nitrous Oxide	0.6 (a)	Kilogramme	Terajoule	
Sulphur Dioxide	SulphurContent*(SO_2/S)	Kilogramme	Kilogramme	
Particulates PM_{10}	96 (c)	Kilogramme	Terajoule	
Particulates $PM_{2.5}$	96 (c)	Kilogramme	Terajoule	
Black Carbon	40 (c)	Kilogramme	Terajoule	
Organic Carbon	28 (c)	Kilogramme	Terajoule	
Ammonia	0.007 (d)	Kilogramme	Metric Tonne	
Services\Heavy Fuel Oil				
Carbon Dioxide Non Biogenic	77.4 (a)	Metric Tonne	Terajoule	a) IPCC 2006 Guidelines – Tier 1 default EFs b) EMEP/EEA (2016) Tier 1 emission factor (1.A.4 Small combustion, Table 3.9) c) Assuming BC/OC ratio as for industry/heavy fuel oil in Bond et al (2004): Tables 9 & 10 d) Battye et al. (1994) defaults (no NOx controls).
Carbon Monoxide	93 (b)	Kilogramme	Terajoule	
Methane	10 (a)	Kilogramme	Terajoule	
Non Methane Volatile Organic Compounds	20 (b)	Kilogramme	Terajoule	
Nitrogen Oxides NOx	306 (b)	Kilogramme	Terajoule	
Nitrous Oxide	0.6 (a)	Kilogramme	Terajoule	
Sulphur Dioxide	SulphurContent*(SO_2/S)	Kilogramme	Kilogramme	
Particulates PM10	21 (b)	Kilogramme	Terajoule	
Particulates PM2.5	18 (b)	Kilogramme	Terajoule	
Black Carbon	10.1 (b)	Kilogramme	Terajoule	
Organic Carbon	3.8 (c)	Kilogramme	Terajoule	
Ammonia	0.005 (d)	Kilogramme	Metric Tonne	

Residential

Demand\Residential	Emission factor	Units	Per...	Reference source and assumptions
Demand\Residential\Cooking				
Cooking\Kerosene				
Carbon Dioxide Non Biogenic	71.9 (e)	Metric Tonne	Terajoule	a) Zhang et al. (2000) Average EF for household stoves in China. b) Assume a PM2.5/PM ratio of 0.964 for kerosene. Reddy and Venkataraman (2002a) c) Assume 13% of PM10 – Bond et al (2004) Table 5 d) Assume 10% of PM10 – Bond et al (2004) Table 5 e) IPCC 2006 Guidelines – Tier 1 default EFs f) Assume as for industry
Carbon Monoxide	7.39 (a)	Kilogramme	Metric Tonne	
Methane	10 (e)	Kilogramme	Metric Tonne	
Non Methane Volatile Organic Compounds	5 (e)	Kilogramme	Metric Tonne	
Nitrogen Oxides NOx	1.10 (a)	Kilogramme	Metric Tonne	
Nitrous Oxide	0.6 (e)	Kilogramme	Terajoule	
Sulphur Dioxide	SulphurContent*(SO_2/S)	Kilogramme	Kilogramme	
Particulates PM_{10}	0.134 (a)	Kilogramme	Metric Tonne	
Particulates $PM_{2.5}$	0.129 (b)	Kilogramme	Metric Tonne	
Black Carbon	0.017 (c)	Kilogramme	Metric Tonne	
Organic Carbon	0.013 (d)	Kilogramme	Metric Tonne	
Ammonia	0.005 (f)	Kilogramme	Terajoule	
Cooking\LPG				
Carbon Dioxide Non Biogenic	63.1 (c)	Metric Tonne	Terajoule	a) For LPG Indian stove. Venkataraman et al (2010) b) Assume a PM2.5/PM ratio 0.964 for LPG. Reddy and Venkataraman (2002a) c) IPCC 2006 Guidelines – Tier 1 default EFs d) EMEP/EEA (2016) Tier 1 emission factor (1.A.4 Small combustion, Table 3.4) e) Assume as for natural gas
Carbon Monoxide	14.9 (a)	Kilogramme	Metric Tonne	
Methane	0.05 (a)	Kilogramme	Metric Tonne	
Non Methane Volatile Organic Compounds	18.8 (a)	Kilogramme	Metric Tonne	
Nitrogen Oxides NOx	51 (d)	Kilogramme	Terajoule	
Nitrous Oxide	0.15 (a)	Kilogramme	Metric Tonne	
Sulphur Dioxide	SulphurContent*(SO_2/S)	Kilogramme	Kilogramme	
Particulates PM10	0.32 (a)	Kilogramme	Metric Tonne	
Particulates PM2.5	0.31 (b)	Kilogramme	Metric Tonne	
Black Carbon	0.01 (a)	Kilogramme	Metric Tonne	
Organic Carbon	0.06 (a)	Kilogramme	Metric Tonne	
Ammonia	0.01 (e)	Kilogramme	Terajoule	
Cooking\Traditional Stove Charcoal				
Carbon Dioxide Biogenic	2385 (a)	Kilogramme	Metric Tonne	a) Akagi et al (2011) b) Bertschi et al. (2003) for charcoal cooking fires (in Zambia).) c) Smith et al (2000) – For PM assume = TSP value d) Assume 50% of PM is BC and 50% POM (i.e. OCx1.4) Bond et al. (2004)
Carbon Monoxide	189 (a)	Kilogramme	Metric Tonne	
Methane	5.29 (a)	Kilogramme	Metric Tonne	
Non Methane Volatile Organic Compounds	7.31 (b)	Kilogramme	Metric Tonne	
Nitrogen Oxides NOx	2.16 (b)	Kilogramme	Metric Tonne	
Nitrous Oxide	0.24 (c)	Kilogramme	Metric Tonne	
Sulphur Dioxide	SulphurContent*(SO_2/S)	Kilogramme	Kilogramme	
Particulates PM_{10}	2.38 (c)	Kilogramme	Metric Tonne	
Particulates $PM_{2.5}$	2.38 (c)	Kilogramme	Metric Tonne	
Black Carbon	1.19 (d)	Kilogramme	Metric Tonne	
Organic Carbon	0.85 (d)	Kilogramme	Metric Tonne	
Ammonia	0.97 (b)	Kilogramme	Metric Tonne	
Cooking\Traditional Stove Wood				

Carbon Dioxide Biogenic	1548 (c)	Kilogramme	Metric Tonne	a) IPCC 2006 Guidelines – Tier 1 default EFs b) Bertschi et al (2003) c) Akagi et al (2011) (For NOx converted from 'as NO' to as 'NO2') d) Assume PM2.5 = 80% of PM10 as reported for wood and crop waste by Reddy and Venkataraman (2002b)
Carbon Monoxide	77 (c)	Kilogramme	Metric Tonne	
Methane	4.86 (c)	Kilogramme	Metric Tonne	
Non Methane Volatile Organic Compounds	26.8 (b)	Kilogramme	Metric Tonne	
Nitrogen Oxides NOx	2.18 (c)	Kilogramme	Metric Tonne	
Nitrous Oxide	4 (a)	Kilogramme	Terajoule	
Sulphur Dioxide	SulphurContent*(SO_2/S)	Kilogramme	Kilogramme	
Particulates PM_{10}	8.3 (d)	Kilogramme	Metric Tonne	
Particulates $PM_{2.5}$	6.64 (c)	Kilogramme	Metric Tonne	
Black Carbon	0.83 (c)	Kilogramme	Metric Tonne	
Organic Carbon	2.89 (c)	Kilogramme	Metric Tonne	
Ammonia	0.87 (c)	Kilogramme	Metric Tonne	
Cooking\Traditional Stove Vegetal Wastes				
Carbon Dioxide Biogenic	100 (a)	Metric Tonne	Terajoule	a) IPCC 2006 Guidelines – Tier 1 default EFs b) Zhang et al. (2000) Average EF for household stoves in China. (For 'vegetal materials and waste', EF = average for wheat and maize residues) c) EMEP/EEA (2016) Tier 1 emission factor (1.A.4 Small combustion, Table 3.6) d) Assuming PM2.5/PM ratio of 0.8 as reported for wood and crop waste (Reddy and Venkataraman, 2002b) e) From Bond et al. (2004) Tables 9 and 10 f) Bertschi et al. (2003) [Zambian open fires]
Carbon Monoxide	5730 (b)	Kilogramme	Terajoule	
Methane	300 (a)	Kilogramme	Terajoule	
Non Methane Volatile Organic Compounds	600 (c)	Kilogramme	Terajoule	
Nitrogen Oxides NOx	47 (b)	Kilogramme	Terajoule	
Nitrous Oxide	4 (a)	Kilogramme	Terajoule	
Sulphur Dioxide	SulphurContent*(SO_2/S)	Kilogramme	Kilogramme	
Particulates PM_{10}	8.05 (b)	Kilogramme	Metric Tonne	
Particulates $PM_{2.5}$	6.44 (d)	Kilogramme	Metric Tonne	
Black Carbon	1.0 (e)	Kilogramme	Metric Tonne	
Organic Carbon	3.3 (e)	Kilogramme	Metric Tonne	
Ammonia	1.29 (f)	Kilogramme	Metric Tonne	
Demand\Residential\Lighting				
Lighting\Kerosene Lamps				
Carbon Dioxide Non Biogenic	71.9 (d)	Metric Tonne	Terajoule	a) Lam et al (2012) Simple wick kerosene lamp – typical field use b) IPCC Guidelines (IPCC, 1996), Reference Manual, Tier 1 c) Zhang et al. (2000) Average EF for household stoves in China. d) IPCC (2006) Tier 1 default
Carbon Monoxide	11 (a)	Kilogramme	Metric Tonne	
Methane	10 (b)	Kilogramme	Terajoule	
Non Methane Volatile Organic Compounds	5 (b)	Kilogramme	Terajoule	
Nitrogen Oxides NOx	25 (c)	Kilogramme	Terajoule	
Nitrous Oxide	0.6 (d)	Kilogramme	Terajoule	
Sulphur Dioxide	SulphurContent*(SO_2/S)	Kilogramme	Kilogramme	
Particulates PM_{10}	93 (a)	Kilogramme	Metric Tonne	
Particulates $PM_{2.5}$	93 (a)	Kilogramme	Metric Tonne	
Black Carbon	90 (a)	Kilogramme	Metric Tonne	
Organic Carbon	0.4 (a)	Kilogramme	Metric Tonne	
Ammonia	0	Kilogramme	Terajoule	

Agriculture, Fishing and Others

Demand\Agriculture Forestry and Fishing	Emission factor	Units	Per...	Reference source and assumptions
Gas Diesel Oil				
Carbon Dioxide Non Biogenic	74.1 (a)	Metric Tonne	Terajoule	a) IPCC 2006 Guidelines – Tier 1 default EFs b) EMEP/EEA (2016) Tier 2 emission factors for reciprocating engines (Table 3-31) c) From Klimont et al (2017) (Table S3.1) GAINS emission factors for diesel generators (no control) d) EMEP/Corinair (1996)
Carbon Monoxide	130 (b)	Kilogramme	Terajoule	
Methane	10 (a)	Kilogramme	Terajoule	
Non Methane Volatile Organic Compounds	50 (b)	Kilogramme	Terajoule	
Nitrogen Oxides NOx	942 (b)	Kilogramme	Terajoule	
Nitrous Oxide	0.6 (a)	Kilogramme	Terajoule	
Sulphur Dioxide	SulphurContent*(SO_2/S)	Kilogramme	Kilogramme	
Particulates PM_{10}	96 (c)	Kilogramme	Terajoule	
Particulates $PM_{2.5}$	96 (c)	Kilogramme	Terajoule	
Black Carbon	40 (c)	Kilogramme	Terajoule	
Organic Carbon	28 (c)	Kilogramme	Terajoule	
Ammonia	0.007 (d)	Kilogramme	Metric Tonne	

C. Definitions[41]

C.1 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 transport. In AEO6 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 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 with the efficiency of power plant. For non-combustible RE (hydro, solar, wind), the amount of electricity generated is considered as the primary energy equivalent.

C.2 Total Final Energy Consumption (TFEC)

The sum of energy consumption by end-use sectors, excluding non-energy use and international transport. The end-use sectors in AEO6 are agriculture, commercial, industry, residential and transportation.

C.3 Renewable Energy (RE)

Includes bioenergy (bagasse, biofuel, biogas, biomass, and waste), hydro all scale, geothermal, solar and wind. It is further categorized as modern and traditional RE. Traditional RE refers to the use of solid biomass in the residential sector, typically for cooking or heating. Meanwhile, 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.

C.4 Energy Intensity (EI)

The ratio of TPES to GDP, which can be considered as 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 GDP of a year is converted into 2005 constant price PPP, adjusting the effects of inflation and eliminating price level differences across countries created by fluctuations in currency exchange rates.

C.5 Electrification Rate

The share of households with access to electricity in a country.

C.6 Clean Cooking

Refers to 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.

[41] Definitions are based mainly on those of the IEA (see https://www.iea.org/reports/key-world-energy-statistics-2020), as well as EuroStat (see https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Category:Energy_glossary), with some modifications. Individual ASEAN Member States may use different definitions in their own national statistics.

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