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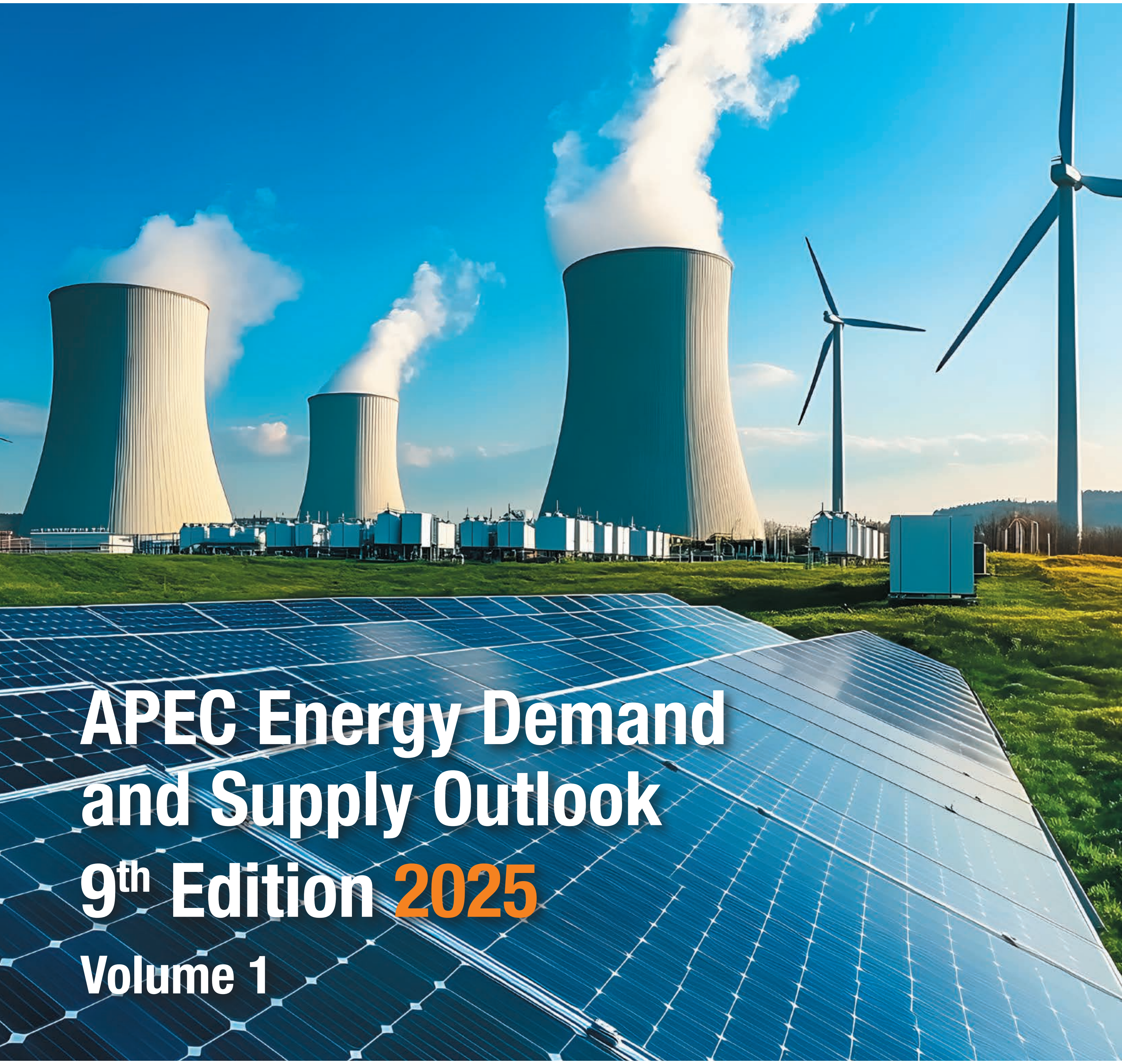

APEC Energy Demand and Supply Outlook

9th Edition 2025

Volume 1

APERC
Asia Pacific Energy Research Centre

APEC Energy Demand and Supply Outlook

9th Edition

Volume 1

APEC Energy Working Group

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Foreword

The first *APEC Energy Demand and Supply Outlook* was published in 1998, when the Asia Pacific Energy Research Centre (APERC) was just two years old. Since then, the *Outlook* has continued to evolve, providing projections and analysis through periods of unprecedented growth and numerous changes in the energy sector across the Asia-Pacific Economic Cooperation (APEC) region.

Today, the global energy system is undergoing profound changes as individual economies address the energy trilemma and strive to balance energy security, affordability, and sustainability. The *APEC Energy Demand and Supply Outlook, 9th Edition* underscores the fact that energy policy decisions made by APEC economies will have far-reaching implications for the individual economies, the APEC region, and the world.

The primary aim of the *Outlook* is to support APEC economies in achieving their individual and collective energy goals. It also serves as a valuable reference for those seeking to better understand recent and prospective energy developments within the APEC region.

This edition is comprised of two volumes: **Volume 1** highlights key trends and insights for the APEC region as a whole. **Volume 2** presents detailed energy outlooks for each of the 21 APEC economies. The analysis is anchored in two scenarios designed to explore the opportunities and challenges across the diverse energy systems of the APEC member economies. The **Reference Scenario (REF)** offers a projection based on historical trends and APERC's assumptions about the continuation of those trends in each APEC economy, while acknowledging technical constraints. The REF Scenario provides baseline results to compare with the **Target Scenario (TGT)** projections, which explore a hypothetical pathway where each economy achieves energy-related policy targets, assuming implementation regardless of cost-effectiveness.

Reflecting the shifting global energy landscape, this edition of the *Outlook* sharpened its focus on three key energy issues: 1) The costs associated with decarbonisation of the power and hydrogen sectors of each APEC economy; 2) The effects of increased variable renewable energy (VRE) sources, such as solar and wind, on electric grid reliability; and 3) The increased electricity requirements of data centres, including artificial intelligence (AI) workloads. We hope these enhanced analyses provide stakeholders with useful insights into critical issues that will shape the future of energy in the APEC region.

For its base year, the *Outlook* utilises data submitted by APEC economies to APEC's Expert Group on Energy Data and Analysis (EGEDA).

This 9th Edition of the *Outlook* is the result of three years of planning, rigorous analysis, and collaboration by the APERC research team, under the leadership of Senior Vice President Glen E. Sweetnam. It also reflects the valuable contributions of experts across APEC's 21 member economies and beyond.

It is my pleasure to present this edition of the *APEC Energy Demand and Supply Outlook*.

Kazutomo Irie

Dr. Kazutomo IRIE

Chairman & President, Asia Pacific Energy Research Centre (APERC)

Acknowledgements

The development of the *APEC Energy Demand and Supply Outlook, 9th Edition*, would not have been possible without the valuable contributions of numerous individuals and organisations across APEC's 21 member economies and beyond. We extend our sincere gratitude to all those whose support made this edition possible, particularly the participants of the APERC Annual Conference and the individuals and organisations acknowledged below.

We would like to express our deep appreciation to the Ministry of Economy, Trade and Industry of Japan for its generous sponsorship and financial support of this project.

We would also like to express our gratitude to members of the APEC Secretariat, the APEC Energy Working Group (EWG), the APEC Expert Group on Energy Data and Analysis (EGEDA), the APERC Advisory Board, along with numerous government officials, for their valuable insights and feedback throughout preparation of this report.

Please note that the *Outlook* is an independent study conducted by APERC and does not necessarily reflect the views of APEC member economies.

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DISCLAIMER: Volume 1 of the *APEC Energy Demand and Supply Outlook* is based on modelling assumptions developed prior to January 2025. Consequently, legislative and policy developments in the United States introduced after this date are not captured in the aggregated APEC projections. Volume 2, however, incorporates these developments into the Target scenario in the United States chapter, providing modelling assumptions based on current U.S. energy policies as of October 2025.

1. Introduction

1.1 Overview of the Outlook

The global energy landscape continues to evolve, with new challenges and opportunities emerging in often unpredictable ways. The APEC region plays a crucial role, accounting for 60% of global energy consumption and production. Environmental objectives remain critical; however, APEC economies are placing increased emphasis on energy security and affordability—priorities that align with long-term economic development goals. The *APEC Energy Demand and Supply Outlook* highlights recent developments shaping the energy sectors across APEC economies and provides detailed energy projections for two future scenarios.

To navigate a rapidly evolving landscape, APERC has identified four critical, interrelated aspects shaping future energy systems: the trajectory of CO_2 emissions, dependence on energy imports, power grid reliability, and power system costs. Progress in one area often influences outcomes in others, underscoring the importance of multifaceted and integrated analysis. By examining these factors collectively, readers can better understand the trade-offs and opportunities that define the pathway toward a sustainable, resilient, and affordable energy future.

Volume 1 of the *Outlook* examines these factors in the context of APEC's aggregate energy demand and supply. In addition, this volume delves into the estimated costs associated with APEC's future power and hydrogen sectors, as well as projected CO_2 emissions. Volume 1 also examines APEC's collective energy goals to reduce the energy intensity of total final energy consumption and to double the share of modern renewables in the energy mix, as well as APEC's ambition to assist in tripling the world's renewable energy capacity. For greater insights on individual APEC member economies, please refer to Volume 2 of the *Outlook*.

1.2 About APEC

The Asia-Pacific Economic Cooperation (APEC) is a regional economic forum established in 1989 to leverage the growing interdependence of the Asia-Pacific. APEC's 21 members aim to create greater prosperity for the people of the region by promoting balanced, inclusive, sustainable, innovative, and secure growth and by accelerating regional economic integration.

The word "economies" is used to describe APEC members because the APEC cooperative process is predominantly focused on trade and economic issues, with members engaging with one another as economic entities.

APEC's 21 member economies are Australia; Brunei Darussalam; Canada; Chile; People's Republic of China; Hong Kong, China; Indonesia; Japan; Republic of Korea; Malaysia; Mexico; New Zealand; Papua New Guinea; Peru; The Republic of the Philippines; The Russian Federation; Singapore; Chinese Taipei; Thailand; United States; Viet Nam.

1.3 Scenarios

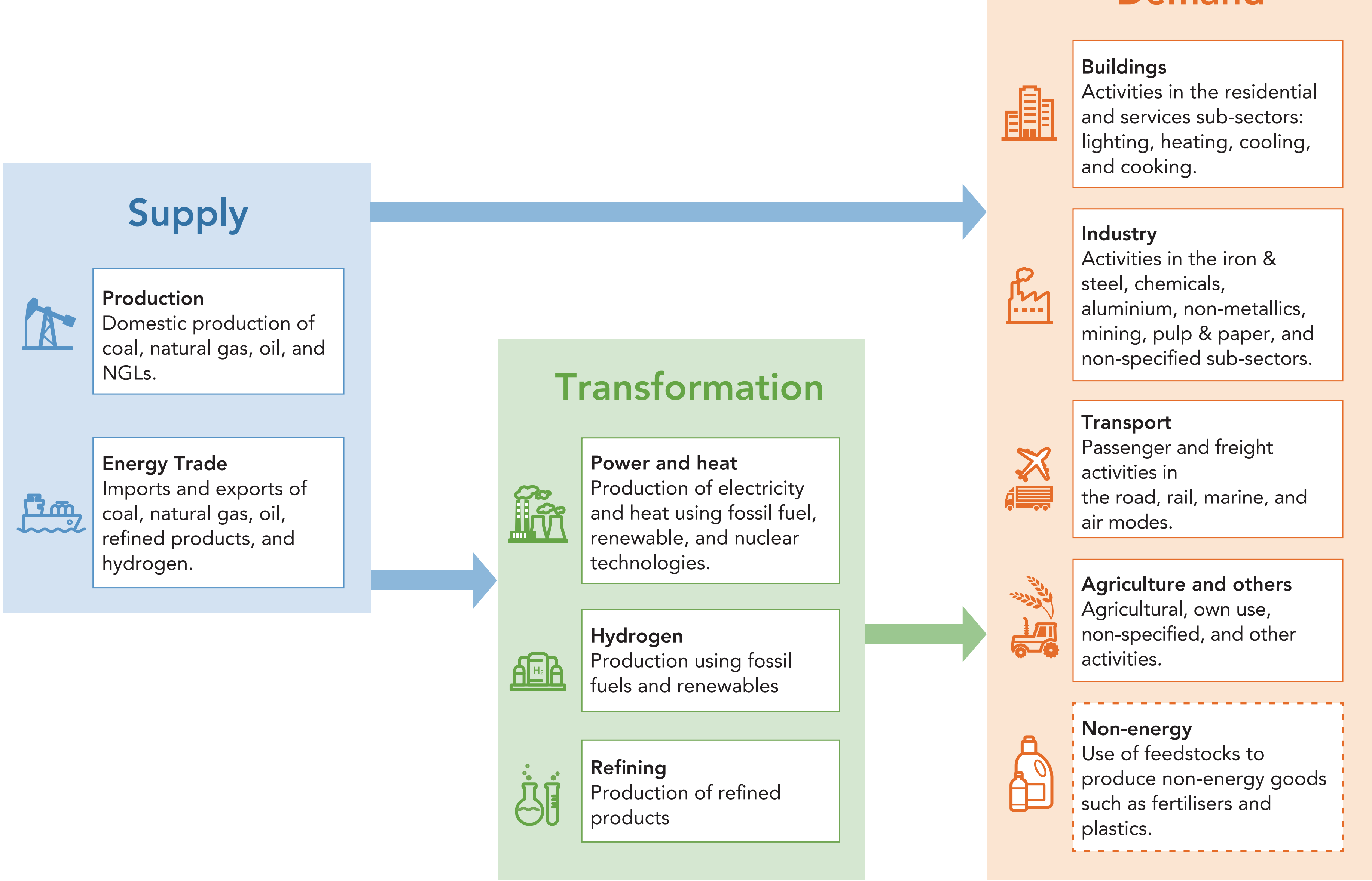
In the *Outlook*, APERC projects energy demand, transformation, and supply, as well as estimated costs and CO_2 emissions. The **Reference Scenario (REF)** offers a projection based on historical trends and APERC's assumptions about the continuation of those trends in each APEC economy, while acknowledging technical constraints. The REF Scenario offers a baseline to compare with the **Target Scenario (TGT)** projections, which explores a hypothetical pathway where each economy achieves energy-related policy targets, assuming implementation regardless of cost-effectiveness. When implementation details are lacking, assumptions are inferred from the targets themselves or emissions-related goals.

1.4 Summary – Key Results for APEC

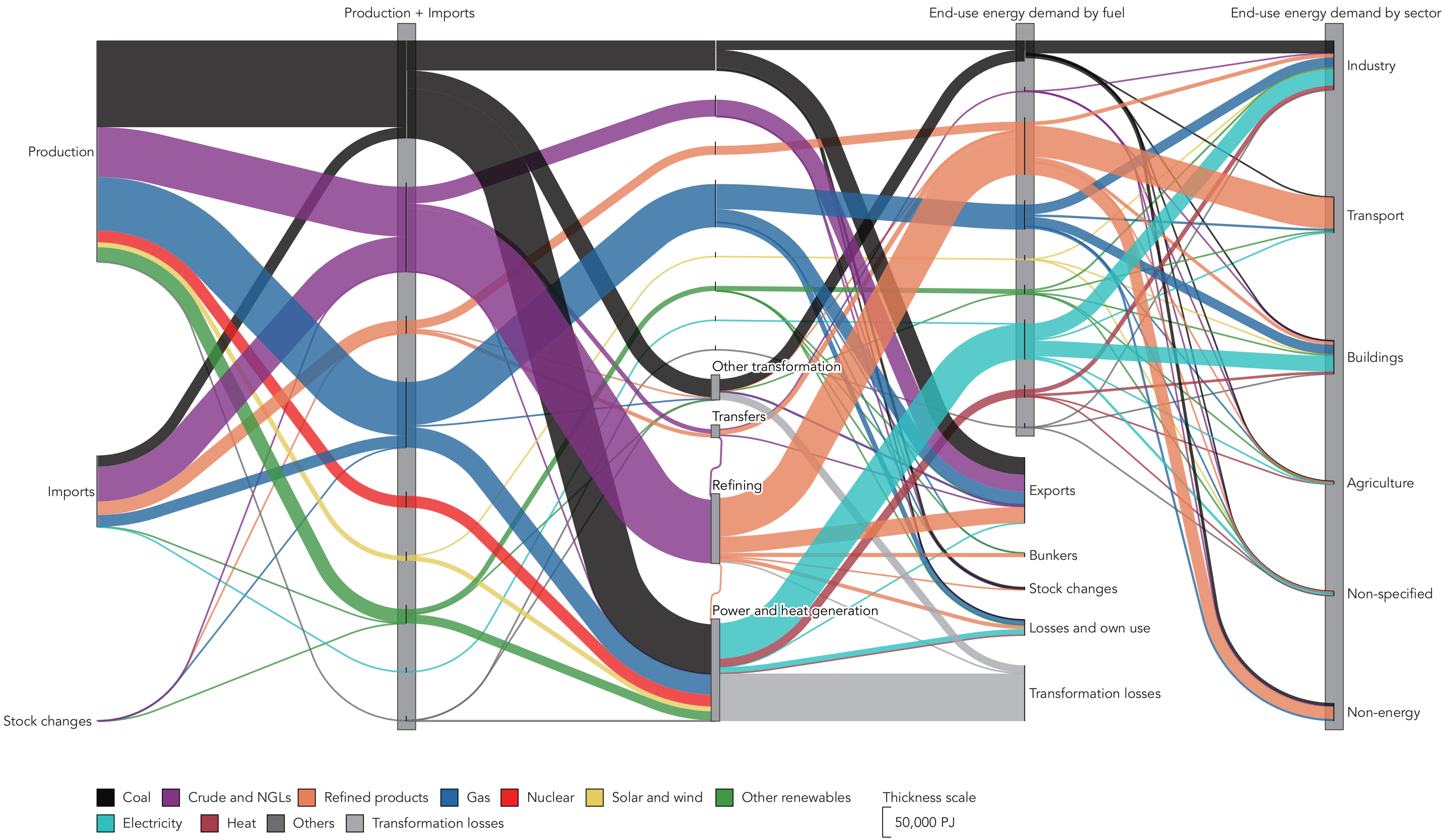
	Reference			Target		
	2022	2060	% Change	2022	2060	% Change
Macroeconomic						
Population (million)	2976.8	2830.7	-5%	2976.8	2830.7	-5%
GDP (billion 2017 USD, PPP)	75,411	177,430	135%	75,411	177,430	135%
Energy Demand						
Agriculture & fisheries (PJ)	4,685	5,272	13%	4,685	4,251	-9%
Buildings (PJ)	56,161	74,562	33%	56,158	63,307	13%
Industry (PJ)	82,128	93,767	14%	82,128	86,039	5%
Non-energy (PJ)	30,253	43,522	44%	30,253	38,970	29%
Transport (PJ)	59,620	59,359	0%	59,623	35,962	-40%
Modern renewables share of TFEC (%)	11	28	155%	11	46	318%
Energy intensity of TFEC (PJ/GDP, billion USD)	2.8	1.4	-50%	2.8	1.1	-61%
Electricity						
Generation (TWh)	18,971	32,690	72%	18,971	37,193	96%
Renewables share of generation (%)	26	55	115%	26	64	146%
Generation capacity (GW)	5,426	14,915	175%	5,426	19,008	250%
Total Primary Energy Supply (TPES)						
Coal & coal products (PJ)	129,237	57,100	-56%	129,240	33,736	-74%
Natural gas (PJ)	86,184	136,572	58%	86,276	90,548	5%
Petroleum liquids (PJ)	98,863	91,902	-7%	98,860	45,853	-54%
Low-carbon & waste energy	52,787	139,699	165%	52,787	221,948	320%
CO_2 intensity of energy supply ($MtCO_2$/PJ)	0.055	0.037	-33%	0.055	0.019	-65%
Net CO_2 Emissions (million tonnes)	20,198	15,725	-22%	20,204	6,699	-67%

The term "modern renewables" refers to all renewable energy sources excluding solid biomass in the buildings sector. The term "low-carbon & waste energy" includes all bioenergy, waste-derived energy, renewables, nuclear, and hydrogen-based fuels. Total primary energy supply (TPES) numbers include international bunkers. Net emissions are calculated as gross energy sector combustion CO_2 minus CO_2 captured and stored through carbon capture and storage (CCS). Historical energy balance data is provided by the Expert Group on Energy Data and Analysis (EGEDA) for 2000 through to 2022. Unless otherwise stated, the base year is 2022, with the exception of Russia, which uses 2021. Projections continue to 2060.

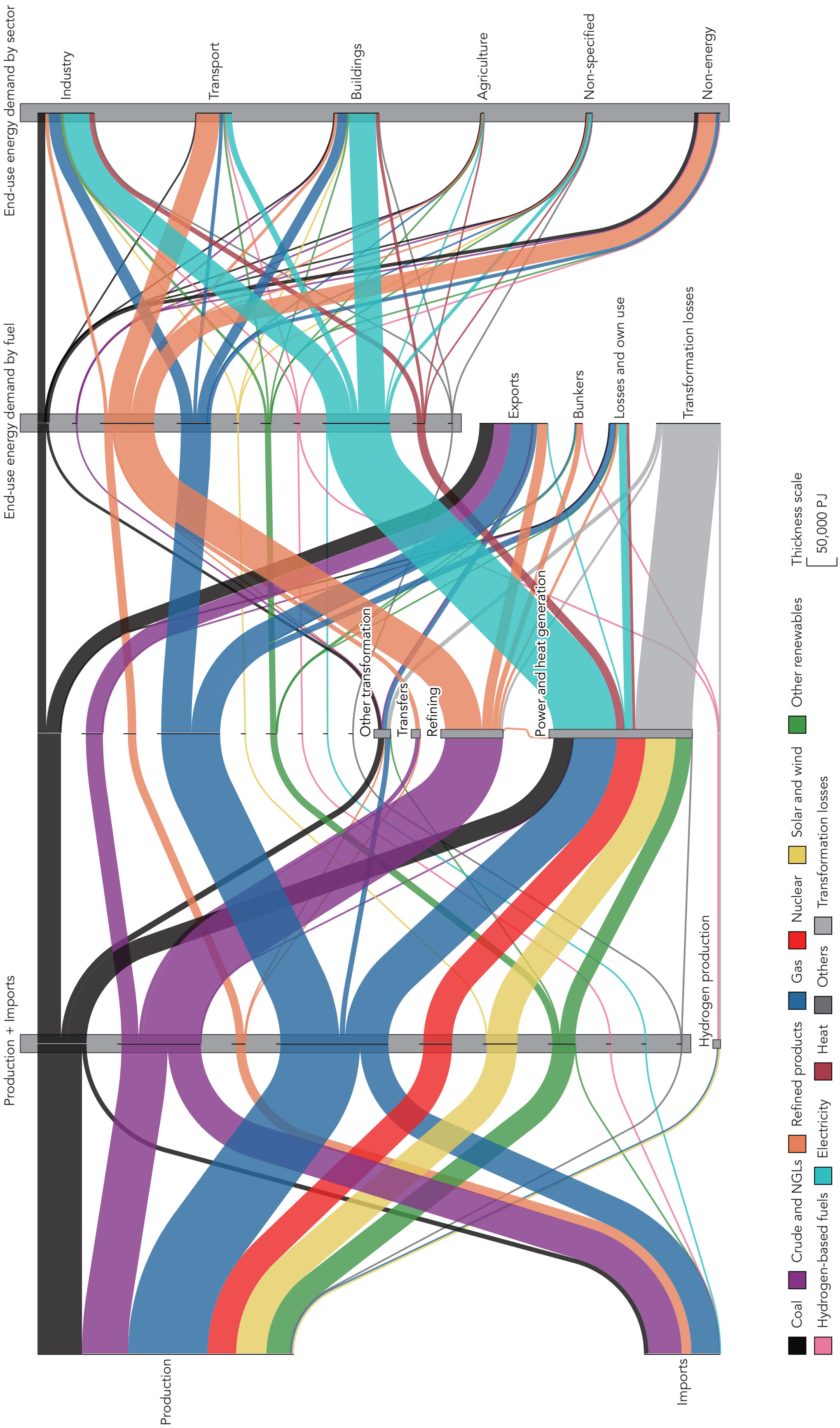
1.5 Components of the APEC Energy System



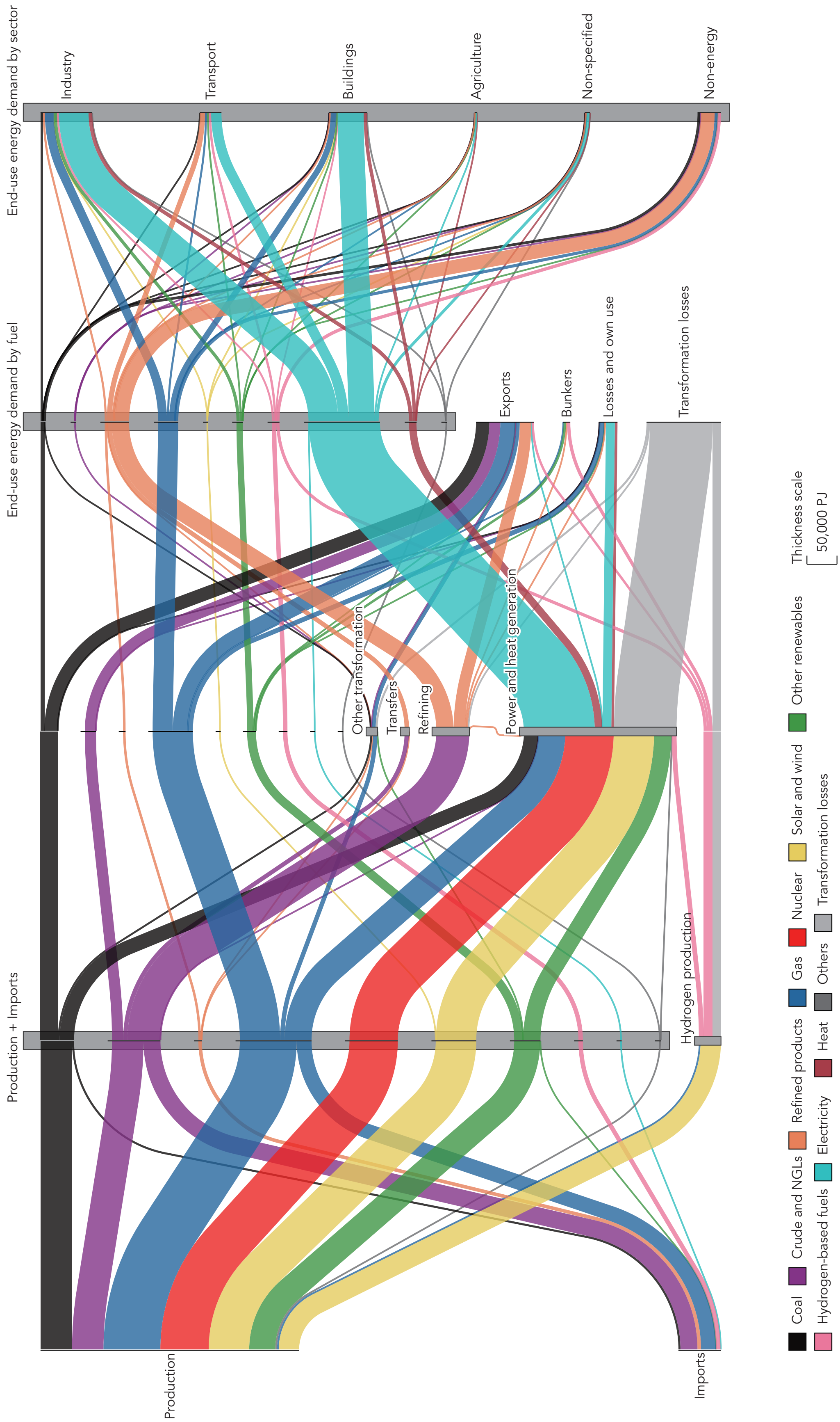
1.6 Energy Flows (2022)



Energy Flows (2060, Reference Scenario)

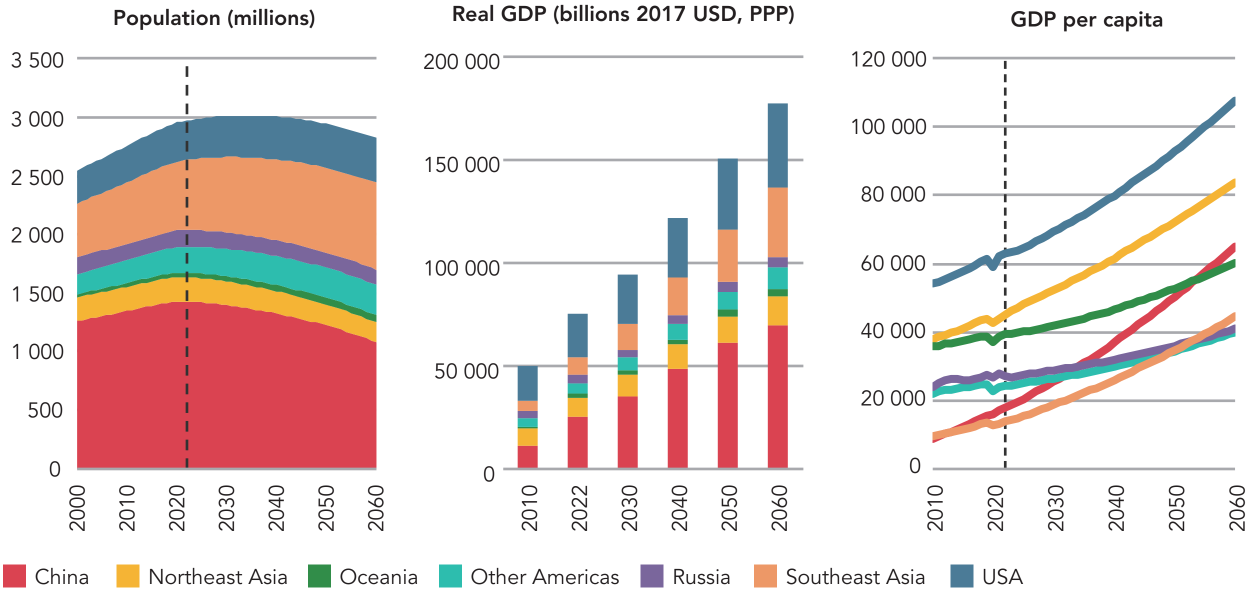


Energy Flows (2060, Target Scenario)



1.7 Demographic and Macroeconomic Assumptions

Figure 1.1: Population, real GDP, and GDP per capita by APEC subregion



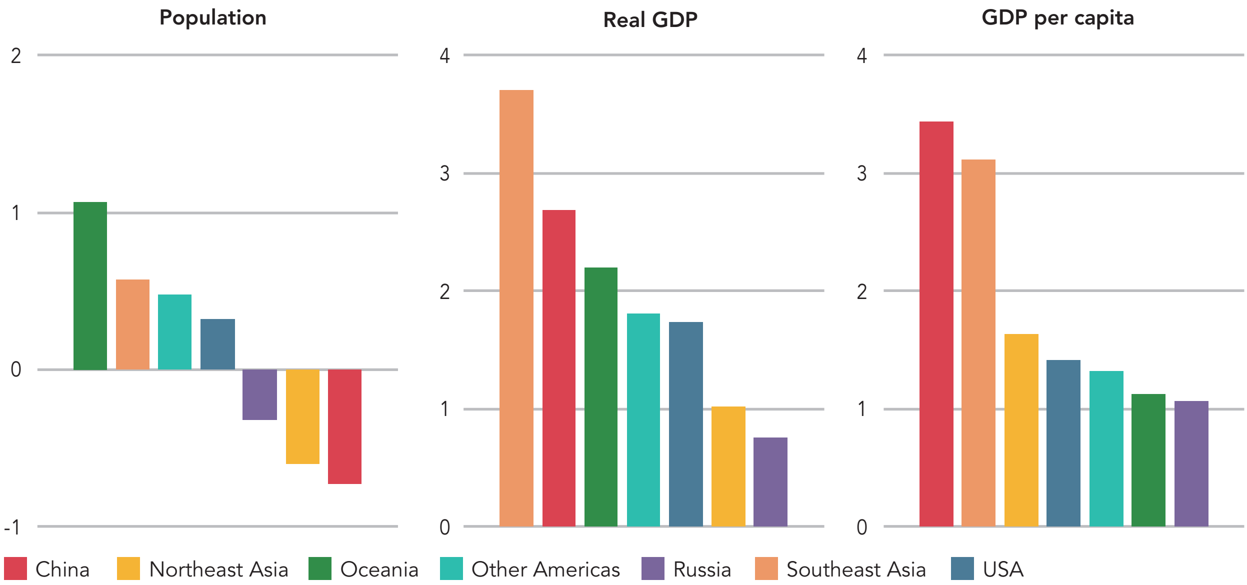
Population and GDP are key determinants of energy use, alongside changes in economic structure and energy intensity. The population projections used in this edition of the *Outlook* are based on economy specific forecasts produced by the United Nations Department of Economic and Social Affairs in the World Population Prospects 2022.[1] In most cases, midpoint forecasts were selected for each economy.

The GDP assumptions underlying this edition of the Outlook through 2027 are based on economic forecasts produced by the International Monetary Fund in the World Economic Outlook (October 2022). Economic forecasts from 2028 through 2060 are based on APERC estimates using a Solow-Swan production model with a constant elasticity of substitution Cobb-Douglas specification for each economy.

GDP and population are treated as fixed, exogenous inputs in both scenarios. While the scenarios produce significantly different projections of energy investment and energy trade balances, these effects are not fed back into GDP or its components in the scenario projections; the GDP and population trajectories are the same in both REF and TGT.

1 GDP and population projections are primarily derived from IMF and United Nations data; however, alternative sources were utilised where necessary. To note, government-reported population estimates were used for Russia and Hong Kong, China; and government-reported GDP estimates were used for Chinese Taipei.

Figure 1.2: Compound annual growth rate (CAGR) of population, real GDP, and GDP per capita by APEC subregion, 2022-2060 (%)



Given these assumptions, population is expected to decline from 2.97 billion in 2022 to 2.82 billion in 2060, with reductions in China and Northeast Asia offset by growth in Southeast Asia, the Other Americas, and Oceania (Figure 1.2).

APEC real GDP is projected to rise from USD 75.4 trillion in 2022 to USD 177.4 trillion in 2060, averaging around 2.3% per year. Most of this growth is driven by Southeast Asia, Northeast Asia, and China, while the United States and Northeast Asia grow more slowly and account for a smaller share of aggregate APEC GDP by the end of the projection period.

For APEC as a whole, income per capita nearly doubles from about USD 33,000 in 2022 to USD 63,000 in 2060. In terms of growth rates, China and Southeast Asia lead that parameter with a CAGR in income per capita over 3%.

2. Key Takeaways

2. Key Takeaways

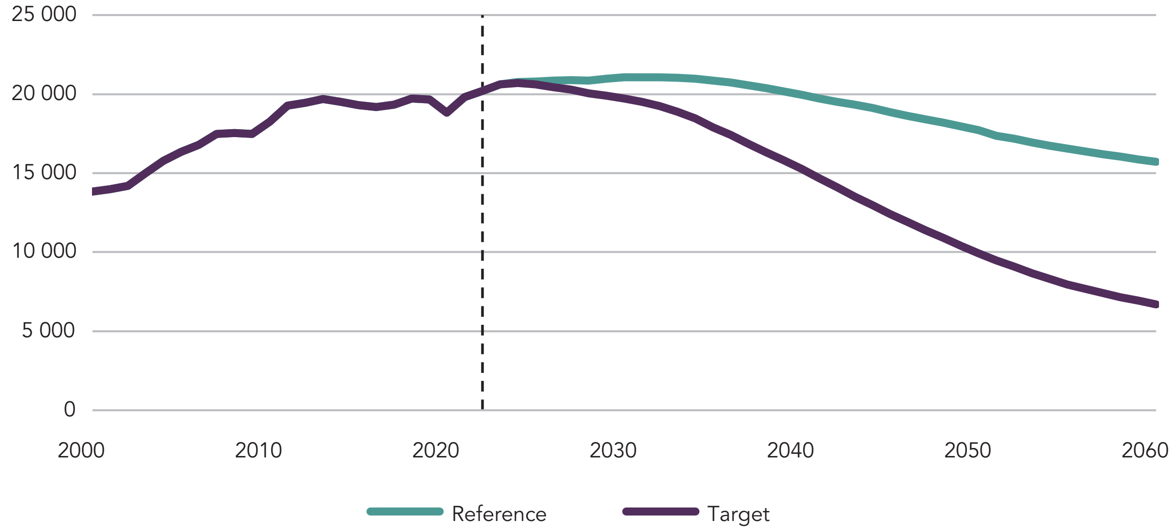
The *APEC Energy Demand and Supply Outlook, 9th Edition* was developed with the recognition that each APEC member economy must address the energy trilemma: What government policies and programs will provide the best balance of energy security, sustainability, and affordability?

To that end, this *Outlook* provides a projection through 2060 of four key parameters:

1. CO_2 emissions as one measure of environmental sustainability
2. Energy import dependence as one component of energy security
3. Electric grid reliability as a dimension of energy security
4. Total costs in the power and hydrogen sectors as a proxy for affordability

2.1 Emissions

Figure 2.1: APEC CO_2 emissions (million tonnes)



- APEC's net CO_2 emissions from fuel combustion are projected to decline from 20,200 million tonnes in 2022 to 15,700 million tonnes by 2060 in the Reference Scenario (REF). In the Target Scenario (TGT), emissions are projected to fall by 67% from 2022, reaching 6,700 million tonnes by 2060.
- The overall reductions in emissions across both scenarios are primarily driven by APEC's increased reliance on low-carbon energy sources. Key measures include increased deployment of wind, solar, nuclear, and natural gas in the power sector. In addition, electrification within the transport sector plays a substantial role in achieving these reductions.
- Analysis based on the Kaya Identity indicates that improvements in energy and emissions intensities collectively more than offset the emissions increases that would be expected in light of per capita GDP growth in both scenarios.
- Carbon capture and storage (CCS) plays a more prominent role in TGT than in REF, but even in TGT, CCS reduces emissions by only 800 million tonnes by 2060.

2.2 Energy Import Dependence

Figure 2.2: Net imports (PJ) and import share of TPES (%) in APEC importing economies

Note: Figures 2.2 and 2.3 present total net imports and the net import share of TPES for APEC's import-dependent economies, without adjustments for bunker fuel consumption. An APEC economy is included in the import-dependent group for a specific fuel if it is projected to have net imports greater than zero after 2030. There are 14 economies included in the import-dependent group for coal, 16 for petroleum liquids, 13 for natural gas, six for hydrogen-based fuels, and five for liquid biofuels.

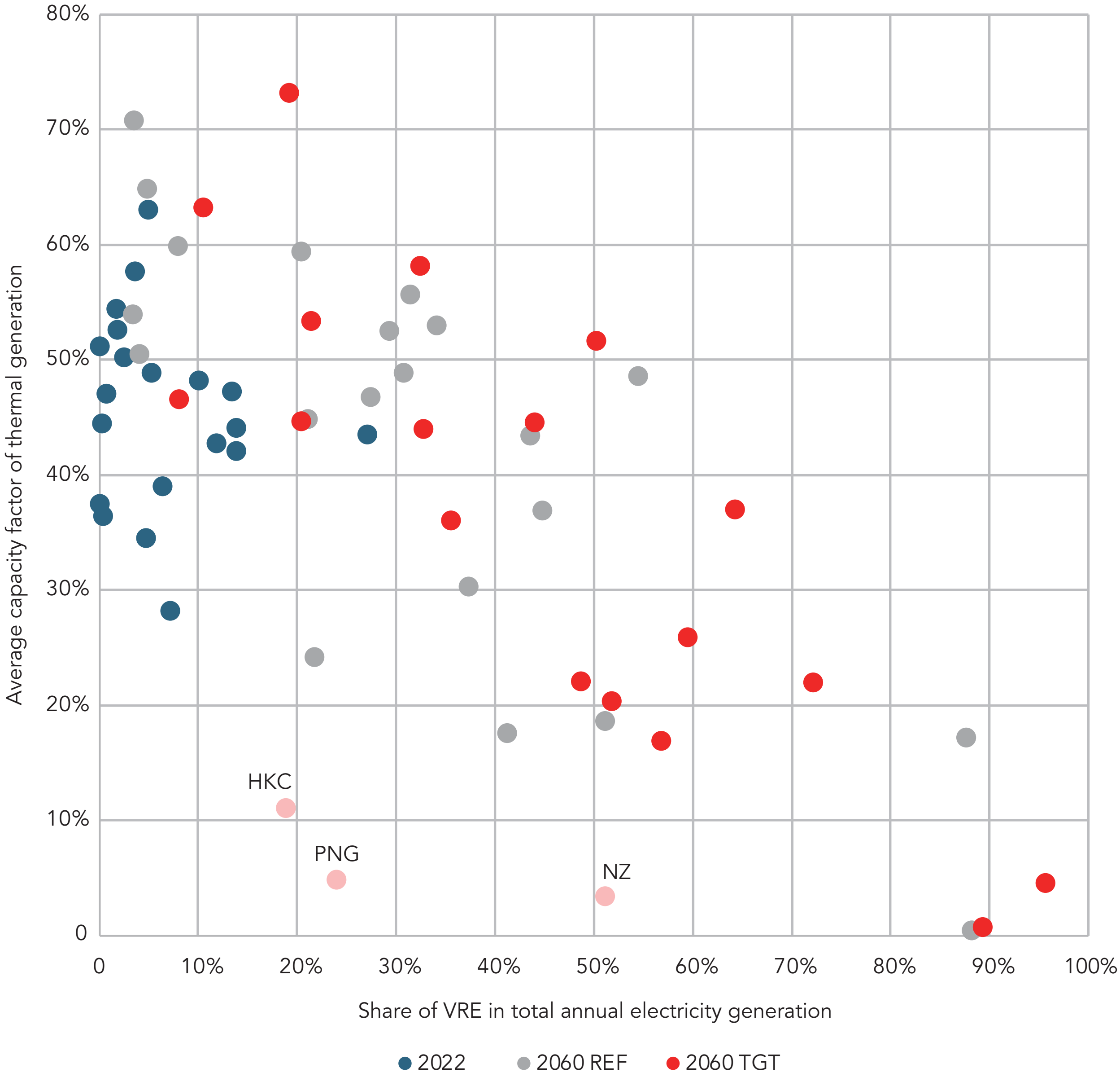
- APEC importing economies exhibit varying degrees of import dependency. Imported fuels include coal, petroleum liquids, natural gas, hydrogen-based fuels, and liquid biofuels.
- For individual economies, declining domestic production of a fuel can create increased energy security risks if consumption of that fuel does not also decline. When evaluating risk, it is important to consider both the quantity of imports and the net import share of total primary energy supply (TPES). For energy security risks for a specific economy, please refer to Volume 2 of the *Outlook*.
- Coal imports remain modest throughout, with little change in import share. Oil starts at very high levels; in TGT, the share for the import group declines to around 70% by 2060, while in REF it increases further above 80%. Gas becomes the most significant energy security risk in REF as both imports and dependency ratios rise substantially, whereas in TGT the risk stays near current levels.

Figure 2.3: Net imports (PJ) and import share of TPES (%) in APEC importing economies

- Hydrogen-based fuels introduce a new long-term vulnerability for importing economies, with dependency ratios exceeding 85% in both scenarios. By 2040, liquid biofuels imports rise sharply in both scenarios, with dependency ratios maintaining between 40% to 66%.
- Overall, import dependency for importing economies rises in REF, while it is more contained in TGT, with a lower oil reliance and a flatter gas trajectory reducing, but not eliminating import risks.

2.3 Grid Reliability

Figure 2.4: Thermal plant capacity factors decline as VRE increases



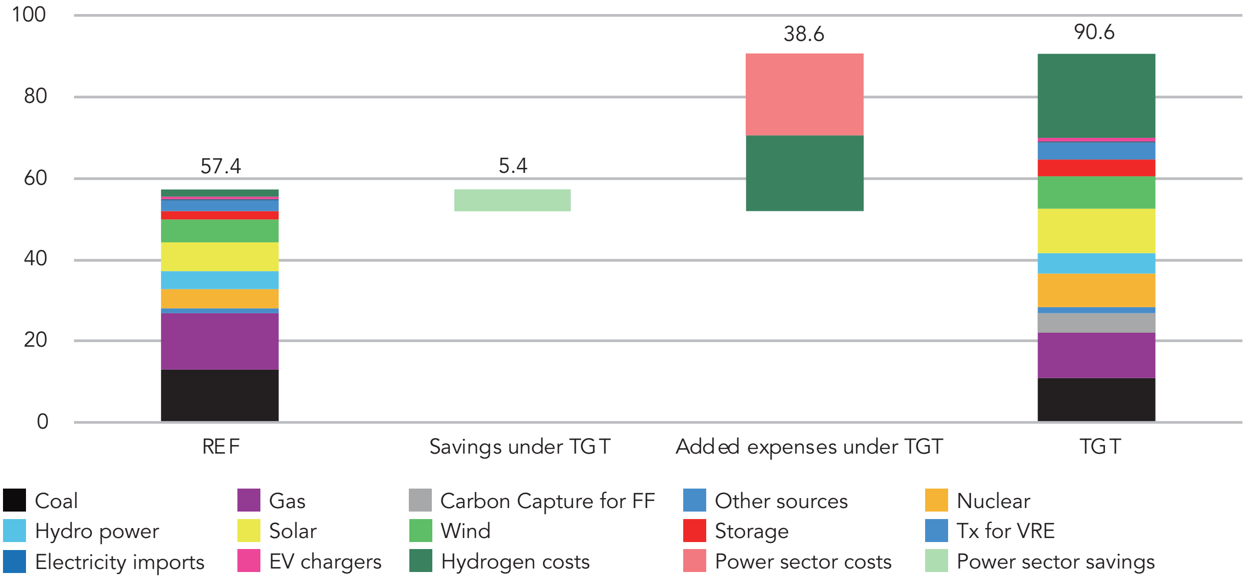
Note: Three economies have power generation plans in TGT that place them outside the trend of the other 18 APEC economies. Hong Kong, China plans to increase its electricity imports which allows it to reduce the capacity factor of its thermal plants and still maintain reliability and affordability. New Zealand and Papua New Guinea plan to rely heavily on hydropower (31% and 70% of generation by 2060, respectively), which is a non-thermal, dispatchable power source, which also contributes to reliability and affordability, although introduces a potential risk from droughts.

- In general, capacity factors for thermal power plants (i.e., oil-, coal-, and gas-fired) decline as variable renewable energy (VRE) generation increases. However, thermal plants remain important for grid stability, providing backup capacity, frequency regulation, and other reliability services, especially when solar and wind generation are not producing at their maximum capacity.
- As thermal plant capacity factors decline, the per unit cost of generation from those units increases.

- Rising shares of wind and solar also lead to much greater variability in the generation required from dispatchable sources, creating larger and more frequent swings that place economic and operational stress on thermal generators.
- Existing grid and market structures face challenges in adapting to high-VRE systems, as they typically fail to adequately incentivise flexibility, storage, and demand-side resources. As a result, reduced and more variable dependence on thermal power plants can degrade grid reliability.

2.4 Cost

Figure 2.5: Costs in the power and hydrogen sectors, 2025 to 2060 (trillion USD, undiscounted)



Note: Transmission for variable renewable energy (Tx for VRE) refers only to the transmission infrastructure required to connect variable renewable capacity to the grid. Electric vehicle (EV) chargers do not include the costs of associated infrastructure or the electric vehicles (EVs) themselves.

- Substantial costs are projected to be incurred by APEC economies in their power and hydrogen sectors between 2025 and 2060—with an estimated USD 57 trillion of expenditures in REF and USD 91 trillion in TGT—as economies strive to achieve decarbonisation objectives while maintaining existing energy assets.
- In REF, 47% of costs are spent on maintaining coal and gas power generation for baseload power generation, with the rest allocated for investment and maintenance of low-carbon technologies.
- As economies increasingly focus on decarbonisation in TGT, USD 5.4 trillion is projected to be saved through reduced fossil fuel generation. However, these savings are offset by USD 39 trillion in costs resulting from the dual cost drivers of increased expenditure on new low-carbon energy sources and the increased use of low-carbon hydrogen across multiple sectors.

3. Energy Demand

3. Total APEC Demand

- APEC energy demand growth decelerates in both the Reference (REF) and Target (TGT) scenarios. Total end-use energy consumption is projected to peak in 2035 in TGT and in 2053 in REF, and decline thereafter.
- The primary drivers of reduced energy use are the decarbonisation policies and programs that cause end-use consumers to switch from coal, petroleum products, and natural gas to electricity. To a lesser extent, biofuels and hydrogen also contribute to this trend.
- By sector, transportation experiences large efficiency gains from electric vehicle adoption, with TGT showing an earlier and sharper decline in oil demand as a result. In industry, energy use rises modestly as activity growth outpaces efficiency improvements, while in buildings, demand increases over the projection period are accelerated by the rapid expansion of data centres.
- By APEC subregion, China and the United States remain the largest energy consumers, although China's demand growth rate slows. Southeast Asia records the fastest increase in demand, driven primarily by industrial expansion in Indonesia. In REF, China, Northeast Asia, and Oceania reach peak demand by the mid-2030s while demand in the remaining economies continues to increase until 2060. In TGT, most subregions, except Southeast Asia, are expected to reach peak demand between the late 2020s and early 2040s.

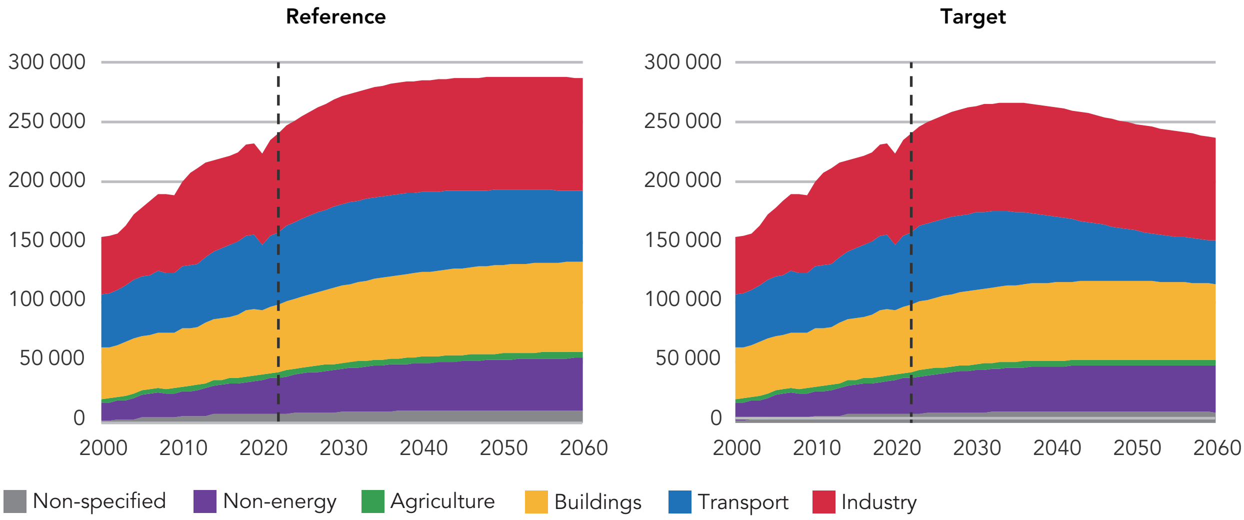
Since 2000, energy demand across the APEC region has expanded significantly, driven by rapid economic growth, industrialisation, and urbanisation. Between 2000 and 2022, APEC's final energy consumption rose by 55% with a compound annual growth rate of 2%. By APEC subregion, China and Southeast Asia contributed the most to this growth. The industrial, transport, and buildings sectors account for the majority of energy consumption in APEC, while the agriculture and non-energy sectors account for the remainder.

Historically, APEC's energy demand has been driven by robust growth, most notably in China, where unprecedented expansion in energy-intensive sectors such as steel and cement fuelled a sharp rise in consumption. Today, China and the United States together account for the majority of APEC demand, while Southeast Asia's share is rising quickly as economies such as Indonesia pursue large-scale industrial growth. Total energy demand in APEC economies in Southeast Asia surpassed that of Other Americas in the mid-2010s and, as of 2022, is approaching that of Northeast Asia.

The APEC region's demand profile reflects a diverse mix of economies with varying levels of development, energy intensity, and infrastructure. In some, transport vehicle ownership has plateaued, whereas in others it continues to rise; similarly, buildings energy consumption is stable in certain economies, but growing rapidly in others. Across the region, some industrial sectors remain dominated by energy-intensive subsectors, while others are not, making direct comparisons across APEC challenging, particularly in terms of the pace of decarbonisation. Efficiency gains, structural economic shifts, policy changes, and differences in technology and fuel priorities all shape these trajectories, resulting in widely varied energy demand pathways across the APEC region.

Total Final Consumption by Sector

Figure 3.1: Total final consumption by sector (PJ)



Although total demand is projected to increase until 2053 in REF and 2035 in TGT, annual energy demand growth is expected to decelerate from the beginning of the projection period. This slowdown is partly due to slightly weaker economic growth and, more importantly, ongoing energy intensity improvements. In TGT, energy intensity improvements are more pronounced, driven by the decarbonisation efforts of individual economies.

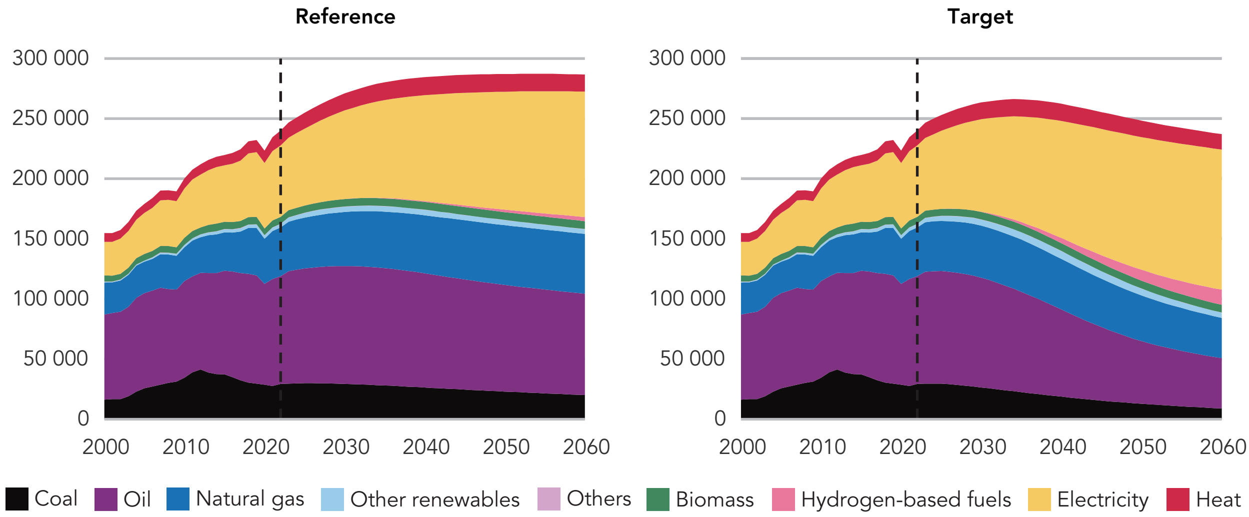
Industrial energy use increases slightly as activity growth outweighs reductions from structural changes and efficiency gains but eventually electrification, technological innovation, and circular-economy practices help reduce the demand. In REF, industrial energy demand peaks in 2054, representing a 40.5% increase relative to 2022. In TGT, greater improvements in intensity result in a smaller increase, with demand peaking in 2038 at only 10.8% above the 2022 level. This trend continues throughout the 2022–2060 projection period, yielding a 14.2% increase in REF and a 4.2% increase in TGT.

The most significant efficiency gains occur in the transport sector, largely due to the uptake of electric vehicles (EVs), especially battery electric vehicles (BEVs). In REF, transportation demand peaks around 2033, increasing by 14.3%, while in TGT it peaks earlier, by 2028, with a smaller increase of 8.0%. By 2060, transportation demand in REF returns to around 2022 levels, whereas in TGT it declines by approximately 40%. By 2060, the total number of vehicles rises by 25.6% in REF but only by 5.3% in TGT, peaking in the 2040s. Despite the overall increase, the share of EVs reaches 60% in REF and 96% in TGT by 2060, up from 5% in 2022. This shift in engine types is expected to be the main driver of reductions in transport energy demand.

In the buildings sector, population growth, higher income levels, and efficiency improvements all influence demand, but the development of data centres is expected to be the largest driver of increased demand. When data centre electricity use is included, buildings sector demand in REF rises continuously, while in TGT it peaks in 2044 at a 16.6% increase relative to 2022 levels. However, excluding data centre electricity demand, building energy demand in REF plateaus by the mid-2050s with an increase of around 19.6%, then begins to decline by the late 2050s. In TGT, buildings demand excluding data centres is expected to peak in 2040, increasing by only 4.4% before beginning to decline. The decrease in energy demand reflects upward pressure from population and higher income levels being offset by downward pressure from efficiency gains.

Total Final Consumption by Fuel

Figure 3.2: Total final consumption by fuel (PJ)



Electrification dominates fuel trends, particularly in TGT, displacing direct use of biomass, coal, oil, and gas. Fossil fuel reductions are also driven by switching to lower-carbon alternatives such as wood pellets in industry and biofuels or hydrogen-based fuels in transport.

Electricity becomes the dominant energy source in REF by 2044 and in TGT by 2035. In both scenarios, electricity demand is expected to continue rising beyond the projection period. By 2060, electricity demand is expected to have risen by 75% in REF and by 96% in TGT, relative to 2022. Most of this growth can be attributed to the electrification of the transport sector. Reductions in energy intensity from electrification are expected to be less pronounced in the buildings and industrial sectors.

In 2022, the transport sector was the largest consumer of oil, leading EV adoption to be the primary reason of future reductions in oil use. In REF, slower EV uptake causes oil use to continue rising until the early 2030s before gradually declining, resulting in only a 6% reduction by 2060. In TGT, more ambitious targets lead to a rapid drop after a peak around 2025, bringing oil consumption to roughly half of 2022 levels by 2060.

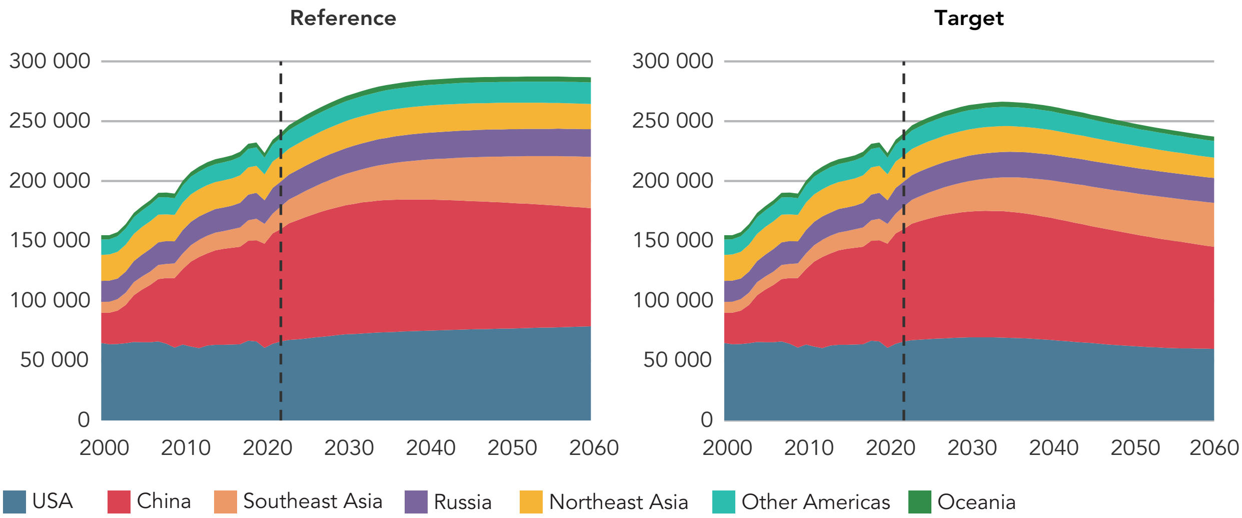
Direct use of natural gas in REF grows by nearly a quarter by 2060, driven mainly by additional industrial demand along with increases in transport and non-energy demand. In TGT, a similar trend occurs but only until the mid-2030s and is only expected to grow by 7.2%. After which, demand in all sectors is expected to decline and by 2060 fall by 17.6% relative to 2022 levels.

Direct use of coal peaked in 2012 and is projected to continue declining steadily in both scenarios, reaching 20,022 PJ in REF and 8,917 PJ in TGT by 2060. This decline is largely driven by reduced industrial coal demand, which falls by 42.2% in REF and 82.5% in TGT by 2060. Coal use in the buildings sector also decreases by 52.3% in REF and 85.5% in TGT. Although agricultural coal demand is relatively low, it is reduced by nearly half in REF and is almost eliminated in TGT. These declines across sectors are due to fuel switching towards electricity, hydrogen, and biofuels.

Other fuels, such as hydrogen and modern biofuels, experience increased use in certain applications, particularly in TGT where governments prioritise emissions reductions. However, their role in replacing fossil fuels remains modest due to high costs and limited applicability. For instance, wood pellets can help decarbonise medium- and low-temperature industrial processes, but their adoption is limited to a few economies. Hydrogen, while versatile, is assumed to remain expensive and is treated as a last-resort decarbonisation option unless directly specified by policy.

Total Final Consumption by Region

Figure 3.3: Total final consumption by region (PJ)



APEC's energy demand is concentrated in China and the United States, which together accounted for 39% and 28% of the 2022 total, respectively. Since 2000, China's rapid GDP growth, averaging around 8.4% per year, has driven a continual upward trend in APEC energy use, fuelled by expansion in energy-intensive sectors such as cement and steel. Looking ahead, China's energy demand is tempered by slower economic growth, structural shifts toward less energy-intensive industries, and efficiency gains.

China's share of APEC demand is projected to decrease in both scenarios, falling to 35% in REF and 36% in TGT. In REF, demand continues to rise, reaching 18% above 2022 levels by 2036 before gradually declining, nearly returning to 2022 levels by 2060. In TGT, peak demand occurs earlier, around 2032, increasing by only 13% before falling to 9% below 2022 levels by 2060. This overall decline reflects various structural changes in the economy. Although building demand is projected to grow, by 56% in REF and 27% in TGT, most of the reduction stems from industrial demand. In REF, industry demand is projected to decrease by 18% and transport demand falls by 6%. In TGT, changes are more pronounced: industry demand drops 24% and transport demand declines by 31%. Despite these declines, China's energy demand remains the highest in APEC.

The United States' share of APEC demand is projected to remain roughly unchanged in REF but decline to 25% of total APEC demand in TGT. In REF, U.S. demand is expected to rise through the end of the projection period, reaching 19% above 2022 levels. In contrast, in TGT, demand peaks by 2030 at just 5% above 2022 levels, and falls to 9% below 2022 levels by 2060. In REF, only the transport sector shows a slight decline, by just 6%. However, in TGT by 2060, energy demand in the transport sector drops by more than half, and all other sectors also decline, leading to a reduction in total demand relative to 2022.

Southeast Asia's share of APEC demand is projected to nearly double, rising from 8% in 2022 to 15% in both REF and TGT. In REF, demand climbs 127% by 2060, while in TGT it still grows a substantial 94%. Indonesia drives much of this expansion: its industrial demand starts at 3,194 PJ in 2022, already on par with Japan, and surges by 207% in REF and 200% in TGT. Malaysia; the Philippines; Thailand; and Viet Nam also record large increases in both scenarios, making these five economies the main engines of Southeast Asian energy demand growth.

Russia holds one of the largest energy demand shares in APEC after China and the United States, accounting for 9% in 2022. By 2060, this proportion is maintained at 9% in TGT, but declines slightly to 8% in REF. In REF, demand continues rising through 2060, while in TGT, demand grows until the late 2040s before declining, and by 2060, the demand is roughly the same as 2022 levels. In both scenarios, changes in demand are distributed across all sectors, except for agriculture where demand increases minimally in REF and declines in TGT.

Northeast Asia accounted for 9% of APEC energy demand in 2022, but its share is projected to decline to 7% in both scenarios by 2060. In REF, demand peaks in the mid-2030s, rising only 6% above 2022 before returning to roughly the same level by 2060. Under TGT, the peak occurs in the late 2020s at just 2% above 2022, then falls to 21% below 2022 by 2060. As a result, Northeast Asia's share falls below Russia's by 2060, ending at 7% in both REF and TGT. Nearly every sector contracts. In REF, only the industry and non-energy sectors show modest gains, while in TGT even industry declines by 2060. Transport demand shows the largest drop, shrinking by 30% in REF and 61% in TGT.

Other Americas, comprising Canada; Chile; Mexico; and Peru, accounted for 6% of APEC energy demand in 2022. In REF, demand continues to rise through 2060, reaching 21% above 2022 levels, driven by a 39% increase in industrial consumption and additional demand from data centres. In TGT, demand peaks around 2030 at 7% above 2022 levels before declining to 7% below 2022 levels by 2060. This decrease is mainly due to a 40% drop in transport demand, while industry grows moderately by 26%.

Oceania, covering Australia; New Zealand; and Papua New Guinea, accounts for the smallest share of APEC energy demand at 2% in 2022, and this proportion remains largely unchanged through 2060. Overall demand still rises, gaining 10% in REF and 7% in TGT. Growth is primarily driven by stronger industrial use in both scenarios, partly offset by lower transportation demand. While demand in Australia and New Zealand is projected to return to roughly 2022 levels by the end of the projection period, Papua New Guinea's energy demand is projected to increase by 350%.

3.1 Agriculture in APEC

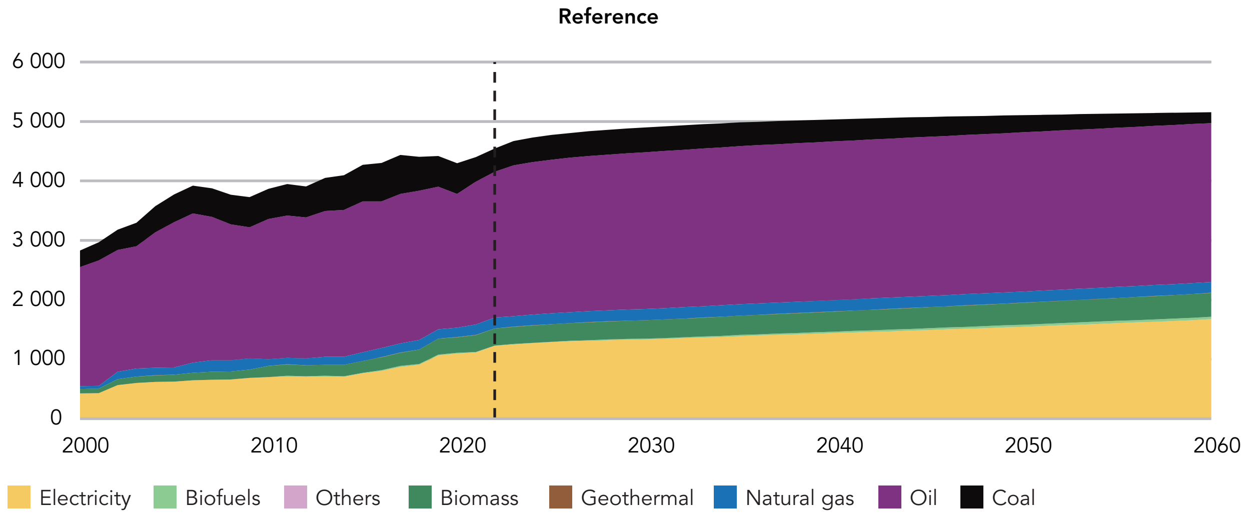
- APEC's agriculture energy demand represents 2% of APEC's total final consumption and is projected to increase by 13% in the Reference scenario (REF) between 2022 and 2060. Oil remains dominant in supporting agriculture activities in APEC, although the share of electricity and biomass is increasing.
- In the Target scenario (TGT), enhanced energy efficiency measures are expected to reduce agriculture energy demand by 9% by 2060, with electricity contributing to more than half of total agriculture energy consumption by the end of the projection period.
- China and the United States are major contributors to APEC's agriculture energy demand in both REF and TGT.
- Agricultural energy demand in APEC is primarily driven by crop yields and harvested areas. Technological advancements enhance crop yields, which helps mitigate limitations on the expansion of harvestable areas.

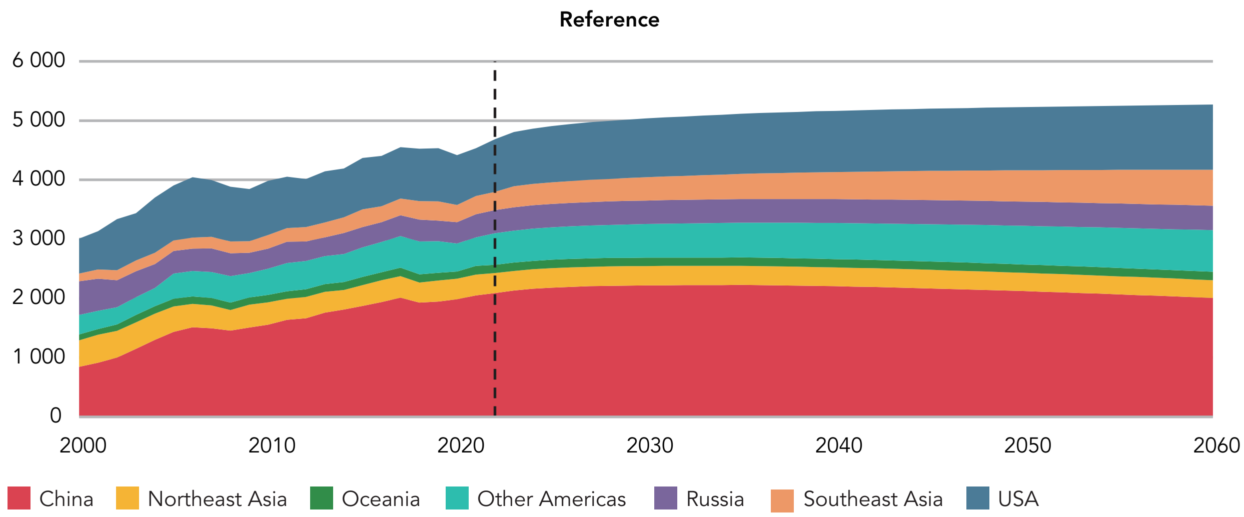
While less energy-intensive than other sectors, representing approximately 2% of APEC's end-use energy demand, agriculture plays a vital role across the APEC region. This sector, which includes fisheries, is distinguished by the production of a diverse range of key crops and commodities. China is the world's largest producer of rice, wheat, and vegetables, while the United States leads in soybeans, corn, fruits, and livestock. Australia is a major exporter of wheat, beef, and wool, and economies such as Indonesia; Thailand; and Viet Nam are significant producers of rice, palm oil, and tropical fruits. Southeast Asia also plays a vital role in the production of soybeans, corn, and seafood. As global demand for protein-rich foods continues to grow, APEC economies are well-positioned to maintain food security and meet export demands, driven by technological advancements that are projected to enhance agricultural productivity and increase crop yields.

Over the *Outlook* period, energy use in the agriculture sector is expected to remain a small share of APEC's total end-use energy demand. Although energy in this sector is consumed both directly and indirectly, APERC projects only the former, which includes energy utilised for machinery, water-pumping motors, and activities such as sowing, irrigating, harvesting, and fishing. Currently, oil supplies the bulk of agriculture energy demand, followed by electricity, while the use of other fuels, such as coal, biomass, biofuels and natural gas, remains minimal.

Agriculture in the Reference Scenario in APEC

Figure 3.4: Agriculture energy demand by fuel and subregion in REF (PJ)



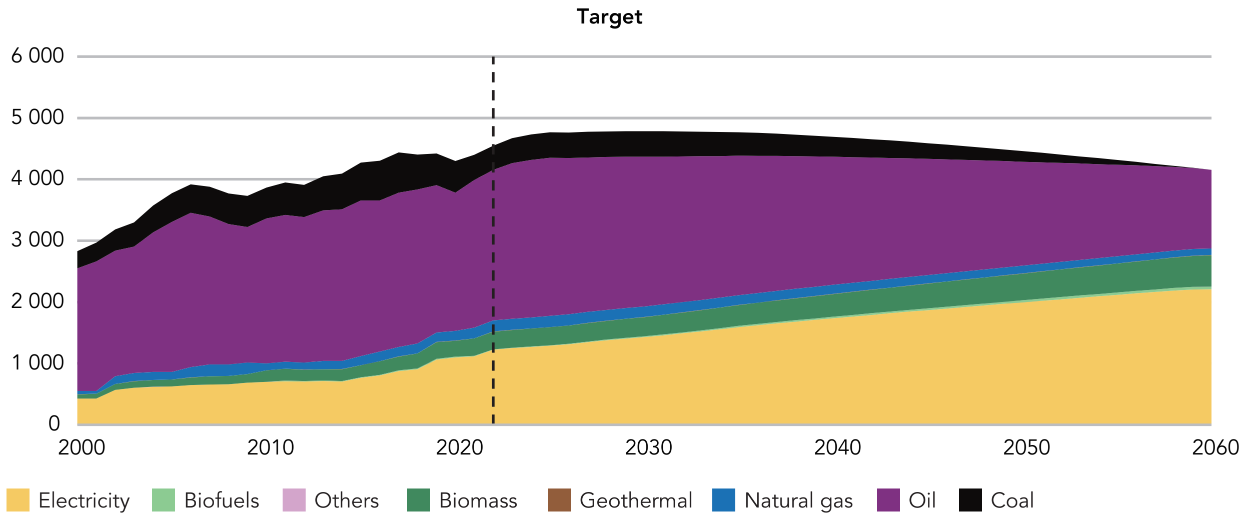


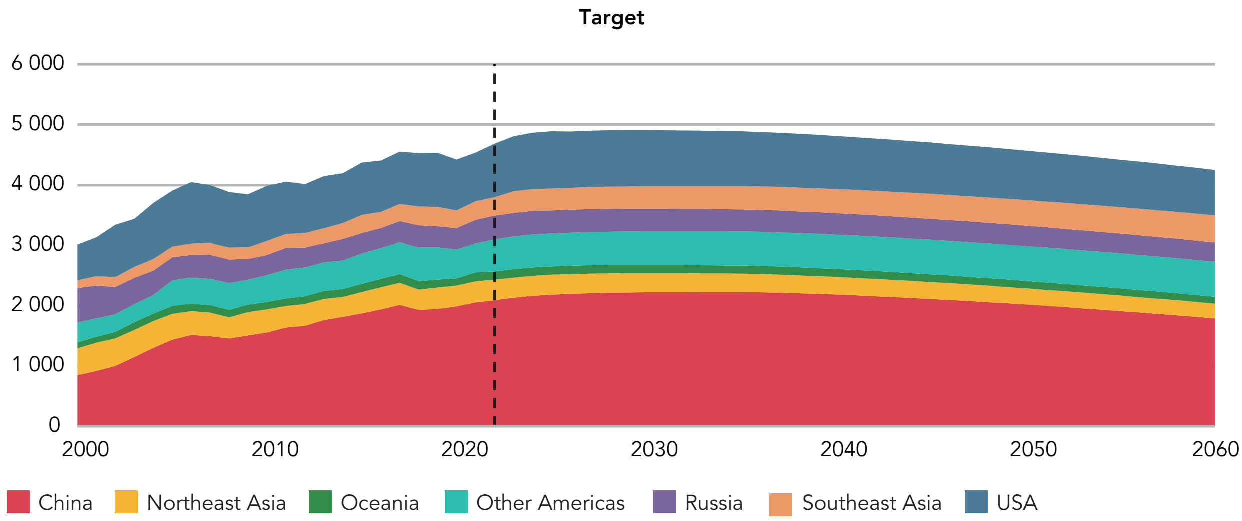
APEC's agriculture energy demand stood at 4,685 PJ in 2022, accounting for just 2.2% of the total energy demand. In REF, the sector's energy demand is expected to increase by 13% over the next two decades, reaching 5,272 PJ by 2060. Oil remains dominant in 2060, although its growth is limited to only 9% between 2022 and 2060, driven by increased penetration of electricity and biomass, which grows by 37% and 39%, respectively. The use of coal, which is limited to a few economies such as China and Russia, is expected to decline the most, with a reduction of 54%.

In 2060, China is projected to account for 38% of the total agriculture energy use in 2060. The United States is expected to account for 21%, while the Other Americas and Southeast Asia subregions are projected to contribute 13% and 12%, respectively. Russia, despite its vast landmass, only accounts for 8% by 2060, mainly due to limited arable land and relatively harsh climate conditions.

Agriculture in the Target Scenario in APEC

Figure 3.5: Agriculture energy demand by fuel and subregion in TGT (PJ)



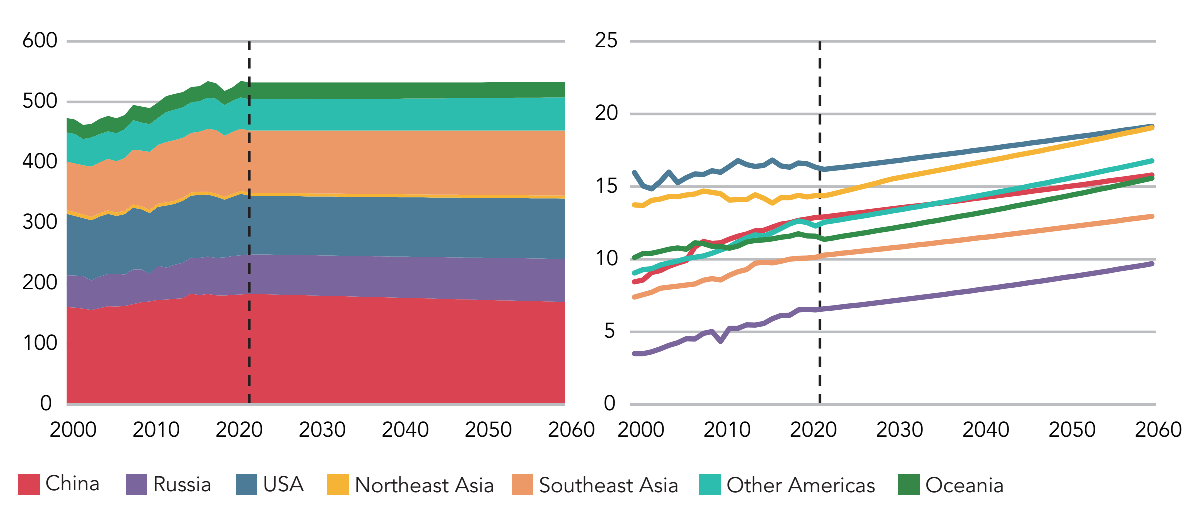


In TGT, enhanced energy efficiency measures are expected to reduce agriculture energy demand by 9% by 2060 compared to 2022 levels. In addition, the sector is expected to become highly electrified. By 2060, electricity is expected to surpass oil as the dominant fuel, supplying over half of the total agriculture demand. This shift can be achieved through the integration of electric-powered technologies into various farming practices, thereby replacing traditional diesel tractors and other machinery. These changes would reduce the demand for oil by 48% by 2060 from 2022 levels. The increased use of biomass also offers a way to reduce reliance on fossil fuels. By 2060, energy from biomass in the agricultural sector is projected to increase by 79%, although its share of total APEC energy consumption remains small.

Crop Yields and Harvested Areas in APEC

In both scenarios, energy demand in APEC's agriculture sector is influenced by crop yields and harvested areas. The growth of harvested areas in APEC is projected to be minimal, increasing by just 0.16% or 0.86 million hectares over the projection period. However, technological advancements are projected to increase APEC's average crop yields by 30% by 2060 compared to 2022 levels, offsetting constraints on the expansion of harvested land.

Figure 3.6: Harvested areas (million ha) [left] and crop yields (tonnes/ha) [right][2]



2 Source: Food and Agriculture Organization of the United Nations (FAO) (2018), 'The future of food and agriculture – Alternative pathways to 2050'. Rome. 224 pp.

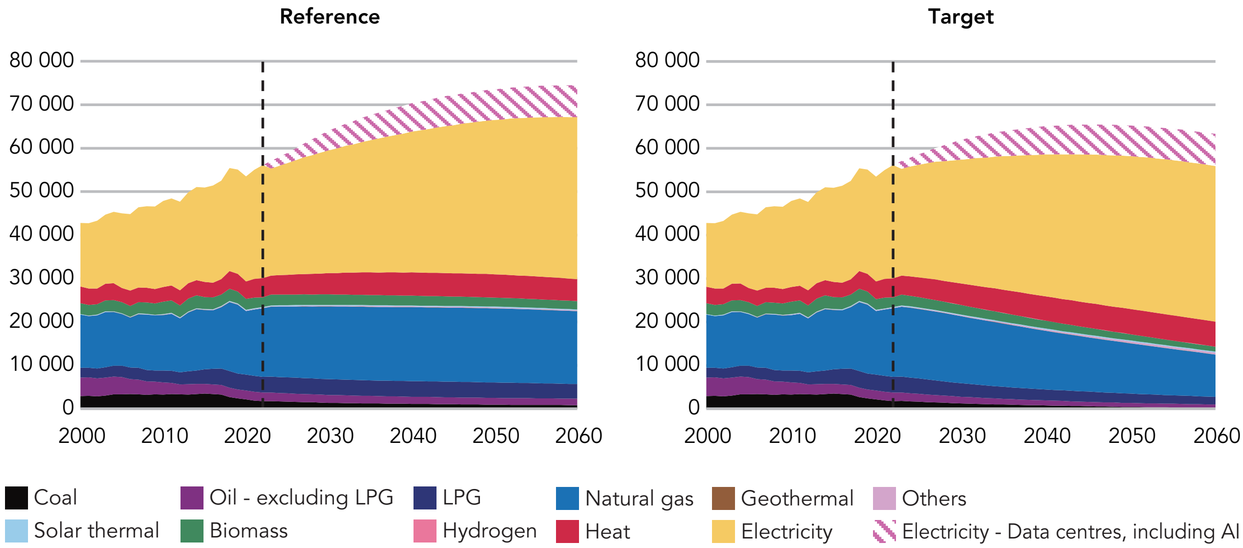
3.2 Buildings in APEC

- Energy use in buildings is a significant driver of final energy demand across the APEC region, accounting for approximately one-quarter of total final energy consumption in 2022. APEC total buildings energy demand increases throughout the projection period in both the Reference (REF) and Target (TGT) scenarios.
- In REF, population growth and rising GDP per capita drive increased end-use demand across many economies, particularly through greater use of appliances and space cooling. Energy efficiency improvements are included but remain relatively modest, offering limited mitigation of total demand growth.
- In TGT, more ambitious energy efficiency measures are incorporated. As a result, buildings sector energy demand peaks around 2040 before gradually declining as the full impacts of these measures increasingly take effect. This delayed impact is largely due to the slow turnover of buildings; however, shorter replacement cycles for end-use technologies, such as appliances, along with the relatively low barriers to implementing certain building envelope retrofits, help moderate demand growth in TGT relative to REF.
- Electricity demand from data centres and AI is included in both scenarios, with the same projected demand level applied to each.

Energy demand in the buildings sector across the APEC region has expanded in tandem with economic growth and improved living standards, which prompt rising demand for space cooling and heating, lighting, and residential appliances. This increased energy use is particularly pronounced in APEC economies undergoing rapid urbanisation and income gains, where energy use in residential and commercial buildings continues to rise. According to the latest data, buildings accounted for approximately 25% of APEC's total final energy consumption. Looking ahead, energy demand in this sector is projected to continue its upward trajectory in both the REF and TGT scenarios for the next 15 years before starting to level-off. A key source of growth is rising electricity consumption from data centres and artificial intelligence workloads, which is assumed to follow a similar trajectory across both scenarios.

Buildings Energy Use in APEC

Figure 3.7: APEC total buildings energy demand by fuel (PJ)



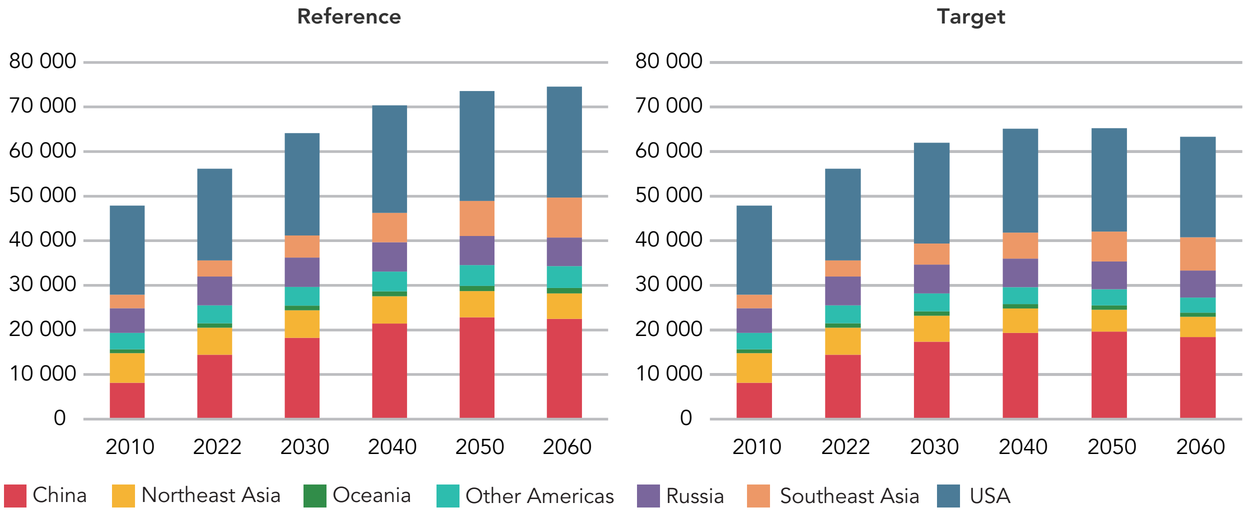
In REF, demand growth is primarily driven by rising GDP per capita and population growth across many APEC economies, which contributes to increased use of energy services such as space cooling and household appliances. In this scenario, efficiency improvements are present but remain relatively modest, offering only limited mitigation of the growth in energy use.

In contrast, TGT incorporates stronger policy interventions and incentives, resulting in greater energy efficiency gains. These measures lead to a peak in total buildings energy demand around 2040, followed by a gradual decline. The lag in impact is largely due to the slow turnover of buildings. However, faster turnover of end-use technologies such as residential appliances, combined with the relative ease of retrofitting certain building envelopes, helps moderate demand growth even in the near term.

Electricity plays an increasingly central role in meeting buildings sector energy demand in both scenarios. In TGT, fuel switching is more pronounced, with electricity substituting for gas, liquid petroleum gases, and coal. Although natural gas use declines as cooking and space heating are electrified, it remains a key fuel in several economies, accounting for 15% of the buildings fuel mix in 2060 in TGT, compared to 22% in REF.

Buildings Energy Use by Subregion

Figure 3.8: APEC total buildings energy demand by subregion (PJ)



In REF, buildings energy demand in most APEC subregions grows from 2010 to 2060, with the exception of Northeast Asia where demand decreases by about 17%. This decline is driven largely by Japan, where demand falls over 35% due to population decline and continued efficiency improvements. Southeast Asia and China record the largest percentage increases, with demand rising 66% and 64%, respectively. Increased demand is attributed to improved living standards coupled with expanding commercial activities. China's buildings energy demand is expected to peak around the 2040s before declining due to a decrease in population and continued energy efficiency enhancements, while demand in Southeast Asia is expected to continue growing throughout the projection period.

In TGT, China and the United States remain the dominant contributors to buildings energy demand, together accounting for 62% of the APEC total in 2022 and a projected 65% by 2060. Although Southeast Asia undergoes a 144% increase from 2010, its absolute demand remains modest compared to China and the United States. In TGT, Southeast Asia is the only subregion to experience continued growth throughout the projection period, as rising living standards drive higher demand.

Data Centres and Artificial Intelligence (AI)

The development of data centre infrastructure is accelerating, driven by a combination of economic opportunity and domestic security priorities. For many economies, this trend is seen as an opportunity to secure early advantages in market share and technology leadership. Data centres are increasingly regarded as strategic assets that generate high-paying jobs, attract investment, and support broader economic development. Their expansion may also encourage investment in low-carbon electricity, either for use on-site or to offset rising emissions. Data centres have relatively predictable and consistent power demand profiles with stable baseload requirements, making them attractive counterparties for Power Purchase Agreements that help promote investment in new generation.

Alongside these opportunities lies a significant challenge: electricity demand from data centres and AI workloads is expected to rise sharply over the coming decade. While there is broad consensus surrounding their continued growth, the precise scale and timing remain uncertain. One of the main barriers to more accurate projections is the limited availability of current, publicly accessible data on electricity use by data centres. This lack of transparency makes it difficult to establish a reliable baseline and assess how demand may evolve as adoption accelerates.

To contribute to the discourse, the latest edition of the *Outlook* introduces new projections for electricity use from data centres and AI at the APEC economy level. Although these centres existed prior to 2023, historical energy data has not been retroactively disaggregated to isolate their contribution to demand. Instead, starting from the beginning of the projection period in 2023, their demand is captured as a dedicated subsector within the buildings sector. Where possible, projections are based on economy-specific indicators, such as announced capacity or facility floor area. However, when available, these data sources often extend only to the late 2020s. In economies where such details are unavailable, projections are informed by regional benchmarks and assumptions about broader energy system development.

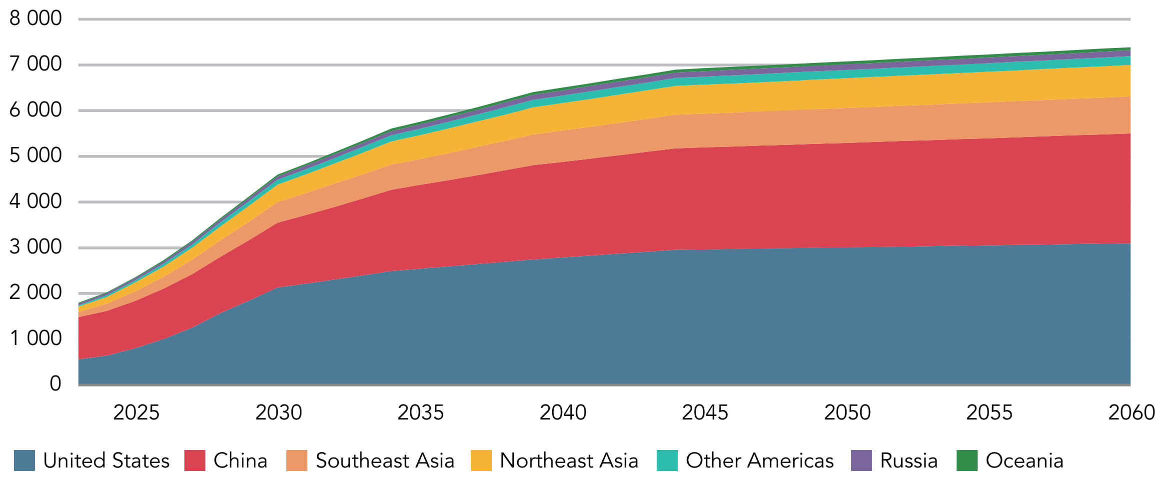
These estimates in the *Outlook* are intended as an exploratory evaluation of how rising demand from AI and data centres could affect future electricity consumption. Developed broadly at the APEC economy level, the projections do not account for potential constraints such as hardware availability, equipment bottlenecks, or local power supply limitations. These factors may significantly affect the pace and scale of demand growth in practice.

Data Centre and AI Projections for APEC

Electricity demand from data centres in the APEC region is projected to increase by approximately 140% between 2025 and 2035. Throughout this period, China and the United States are expected to remain the largest sources of growth. Most other APEC economies are also projected to experience significant growth in electricity use from data centres and AI workloads.

Given the emerging nature of this topic, projections for electricity demand from data centres and AI workloads beyond 2035 are subject to greater uncertainty. In the *Outlook*, several factors are assumed to slow the pace of electricity demand growth after the mid-2030s. These include a shift from energy-intensive AI training toward less demanding inference workloads, as well as continued improvements in energy efficiency. Nevertheless, overall demand is expected to continue rising, based on the assumption that new applications for AI will continue to emerge.

Figure 3.9: Data centre and AI electricity demand by subregion (PJ)



Note: Data centre and AI electricity demand is the same in both REF and TGT.

The trajectory of electricity demand associated with AI will largely depend on the dominant types of applications. If model training continues to play a central role in AI development, electricity demand is likely to remain elevated. Conversely, if the balance shifts toward simpler inference tasks, growth could plateau or even decline, particularly if accompanied by improvements in energy and computational efficiency. The specific nature of AI end-use applications is also a critical factor. For instance, energy demand will vary substantially depending on whether AI is deployed for energy-intensive tasks such as video generation or for less demanding applications like text-based search queries. While AI-powered searches consume more energy than traditional web searches (e.g., Google searches), they remain significantly less energy-intensive than AI generative video workloads.

Navigating the Path Forward

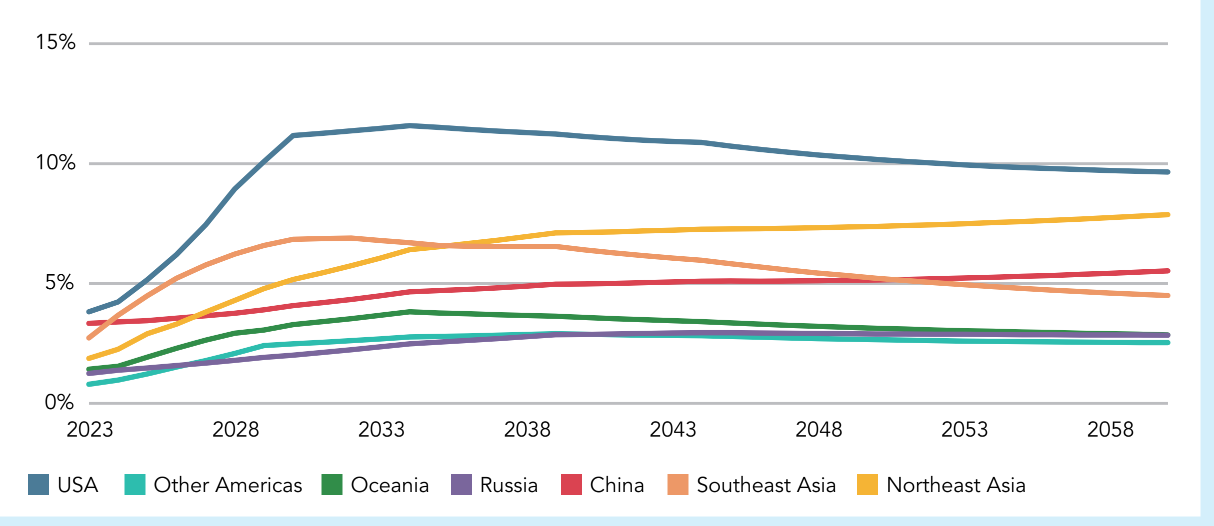
How electricity demand is managed in the coming years will play a critical role in shaping the pace and geographic distribution of data centre rollout. Delays in grid infrastructure upgrades and extended connection timelines are already recognised as significant challenges within the data centre industry.

The initial growth in electricity demand is being driven largely by AI model training, which differs from traditional workloads in that much of it is not latency sensitive and does not necessarily require proximity to end users or real-time responsiveness. This distinction is significant, as it may allow these workloads to be located farther from traditional demand centres, potentially helping to ease the pressure on congested grids and open new opportunities for data centre siting in regions with underutilised capacity.

Furthermore, some operators and jurisdictions are exploring agreements that encourage demand-side flexibility through management methods such as workload migration to locations with available capacity, scheduling computational tasks during off-peak hours, or adjusting consumption in response to grid conditions. Although these approaches can incur additional costs, they may prove essential in regions with constrained grid capacity or where priority is given to other critical energy uses.

If adopted more broadly, demand-side flexibility and strategic siting could ease pressure on grids and reduce reliance on new fossil fuel generation. In some subregions, declining electricity use in the industrial or other services sectors may free up capacity that data centres could leverage, particularly where existing infrastructure is available for repurposing.

Figure 3.10: Data centre & AI electricity demand as a percentage of total electricity demand (%)



As data centres emerge as a significant source of load growth in many economies, their impact warrants consideration in long-term energy planning. While many major cloud and AI providers have set emissions-related targets, ensuring a consistent, low-carbon power supply for data centres remains a significant challenge. Nuclear presents a potential low-emission solution; however, its long development and permitting timelines constrain its near-term viability. As a result, some economies may continue to rely on fossil fuels in the short term to meet immediate demand, even as they pursue broader decarbonisation strategies.

While the *Outlook* primarily focuses on energy issues, there are several non-energy challenges that could also affect the pace of data centre development. Supply chains for critical components are still stabilising, and while disruptions may not be permanent, many data centre facilities are aiming to begin construction immediately. In addition, new tariff structures are introducing added uncertainty around their potential impact on equipment costs and project timelines. Although cooling technologies are advancing, most still depend heavily on water, which can limit siting options or operational reliability in water-scarce regions. Additionally, labour availability presents a growing challenge, as data centre operations and maintenance require a skilled technical workforce. Shortages of qualified labour could contribute to further delays in deployment and expansion.

As data centre and AI electricity demand continues to grow, careful management and strategic planning is going to be essential to balance economic benefits with energy system constraints. Flexible load management, innovative siting strategies, and integration with low-carbon energy sources may help mitigate energy and emissions lock-in risks associated with rapid deployment. Effectively addressing both energy and non-energy challenges will be critical to enabling the continued expansion of data centres across the APEC region.

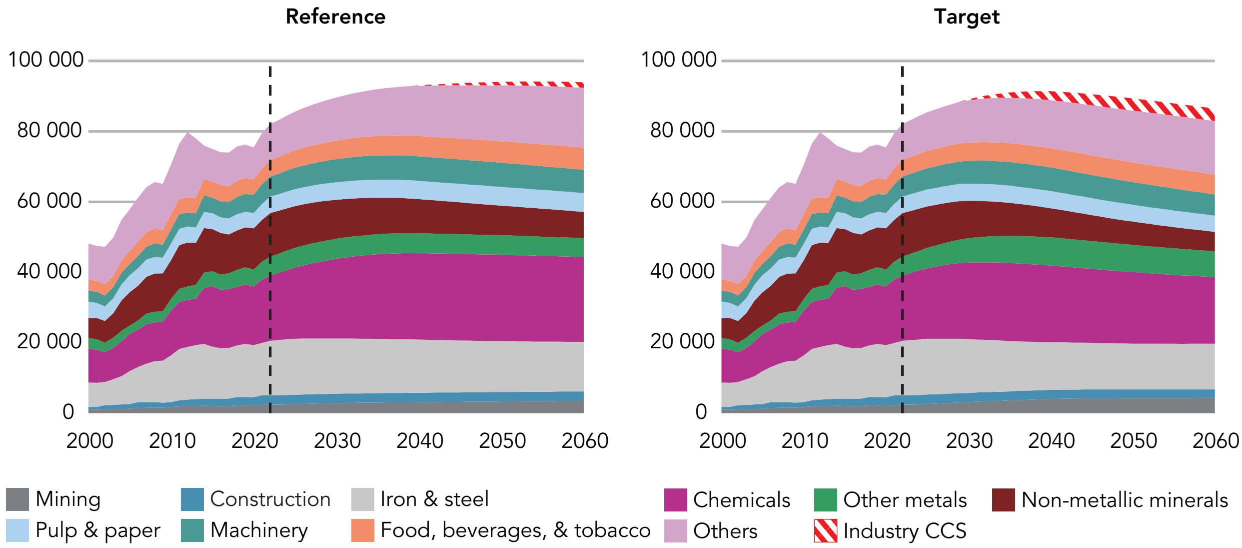
3.3 Industry in APEC

- In both scenarios, the impact of rising industrial activity on energy demand is offset by structural shifts towards less resource-intensive sectors and improvements in energy efficiency. Efficiency improvements are more pronounced in the Target scenario (TGT), leading to lower overall energy use. However, mining, non-ferrous metals production, and machinery activity grow earlier and faster in TGT, driven by rising demand for critical minerals, microchip production, and low-carbon technologies.
- By subregion, China remains the dominant driver of industrial energy demand in APEC; however, its industrial sector's energy demand declines after peaking in the early 2030s, reflecting slower economic growth, a shift away from energy-intensive sectors (such as cement and steel), and widespread efficiency gains, especially in TGT. Conversely, industrial demand in Southeast Asia rises steadily through 2060, led by Indonesia's rapid industrial expansion. In TGT, Indonesia's industrial energy use grows by 200%, from approximately 3,200 PJ to 9,600 PJ, contributing to the region's 154% growth in industrial energy use, far above the APEC average of 4.8%.
- By fuel type, electricity and hydrogen gain significant share in TGT, while coal use declines rapidly and carbon capture and storage (CCS) is selectively applied to the remaining fossil fuel usage. Residual fossil fuel use persists due to technical and economic barriers to full substitution in certain processes.
- Uncertainty in long-term industrial energy projections remains high, as these projections are largely shaped by private-sector dynamics and macroeconomic assumptions rather than direct policy targets.

The industrial sector remains a cornerstone of economic activity across the APEC region, and its evolving energy profile will play a pivotal role in shaping future energy demand and emissions trajectories. From heavy manufacturing to advanced technologies, the sector is undergoing a period of transformation driven by both market forces and decarbonisation policies. While some economies are prioritising electrification, fuel switching, and efficiency improvements, other economies are seeing increased activity in energy-intensive industries. This divergence reflects the complex interplay between structural economic shifts, technology adoption, and subregional policy approaches. As a result, projecting industrial energy demand is particularly challenging, with outcomes highly sensitive to company-level decisions, economic conditions, and technology deployment.

Industrial Energy Demand in APEC

Figure 3.11: Energy demand by industrial subsector in APEC (PJ)

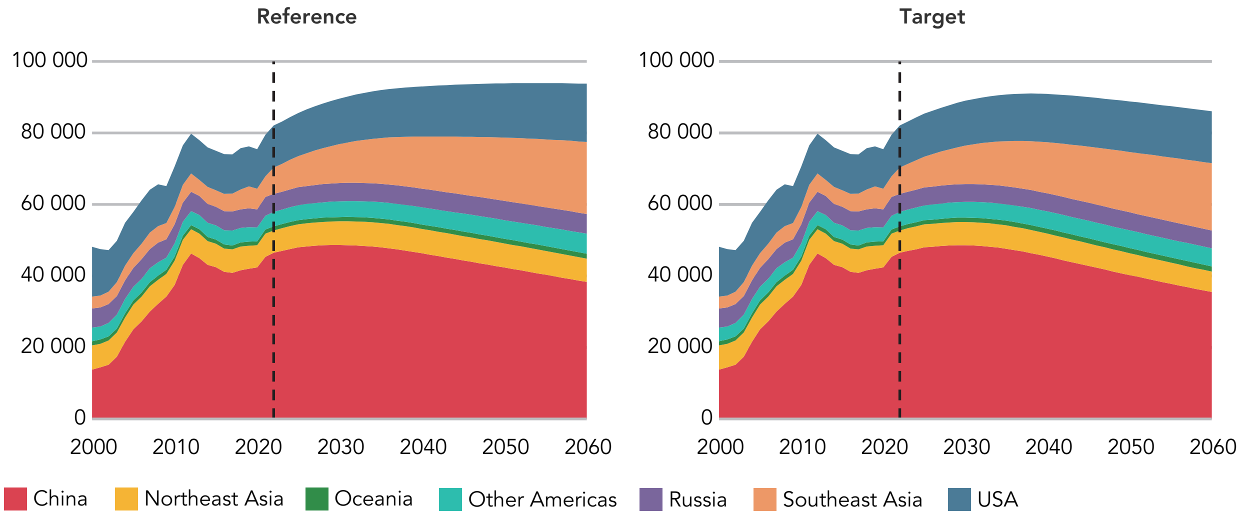


In both scenarios, slower activity growth in energy-intensive industrial sectors such as cement and steel contributes to a gradual structural shift toward less energy-intensive subsectors. This transition, combined with efficiency gains from electrification, technological innovation, and circular-economy practices, helps moderate long-term energy demand. In the Reference (REF) scenario, industrial energy demand nonetheless rises by 14% between 2022 and 2060.

In TGT, these changes progress more rapidly, leading to an earlier peak in industrial energy demand in the early 2030s, followed by a gradual decline. Yet, some industrial activities grow more quickly under TGT, partially offsetting this decline. Mining and non-ferrous metals production expand at a faster pace in the early projection years, reflecting rising demand for critical minerals essential for microchip manufacturing and for low-carbon technologies, including batteries, electric vehicles, solar panels, and wind turbines. This in turn accelerates energy use for both extraction and processing of critical minerals. In addition, the machinery subsector, particularly for the semiconductors and electrical equipment subsectors, also experiences accelerated growth. These trends appear earlier in TGT than in REF, leading to a slight increase in energy use overtime despite broader efficiency gains. Digitalisation and automation further contribute to structural changes across industry, with advanced production systems increasing electricity use in some processes while enhancing overall energy efficiency in others.

Industry Energy Demand by APEC Subregion

Figure 3.12: Industry energy demand by APEC subregion (PJ)



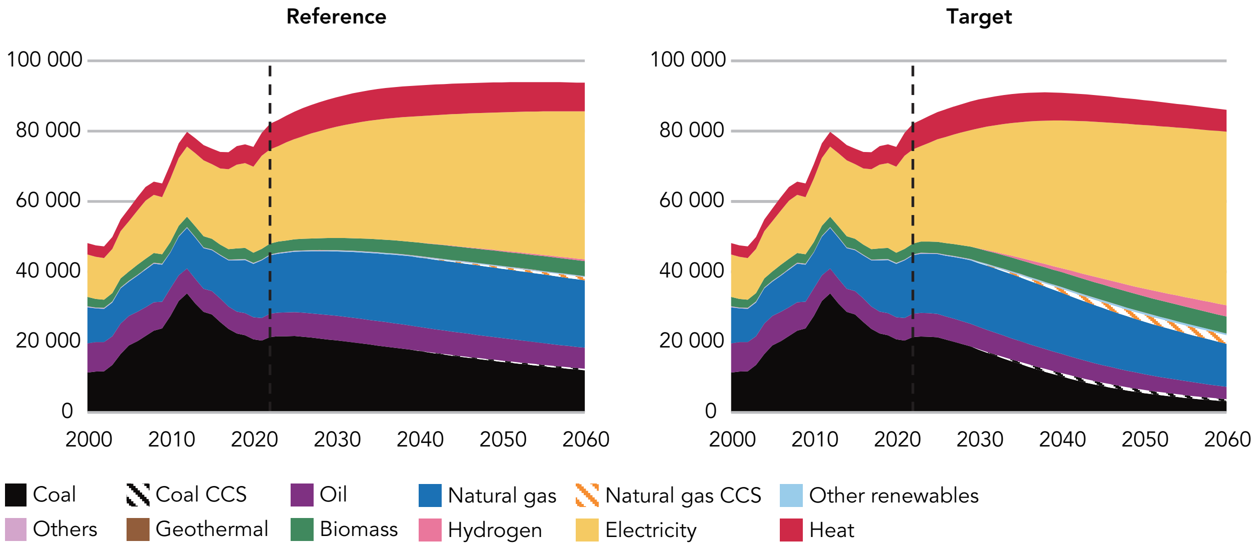
China plays a major role in shaping industrial energy demand across the APEC region. Since 2000, 96% of APEC's total increase in industrial energy use is attributable to China, and in 2022 China represented 57% of APEC's total industrial demand, reinforced by its rapid GDP growth. By 2060, China's share is projected to decline to 41% in both scenarios due to shifts towards less energy-intensive sectors and efficiency improvements, yet it remains the largest single industrial energy consumer. APEC trends are therefore closely linked to developments within China. For instance, the projected peak in APEC's chemical subsector energy use around 2035 is primarily driven by China, which alone accounts for 83% of that peak in TGT. Similarly, the decline in energy use for non-metallic minerals, as well as iron & steel, is also largely attributed to China, as the slowdown in China's domestic construction and infrastructure activity after the early 2030s reduces overall APEC demand for cement, steel, and other related materials.

Looking ahead, Southeast Asia (SEA) will play an important role in driving growth as SEA industrial activity rises rapidly throughout the projection period. Infrastructure development, underpinned by growing populations and rising incomes, leads to growth in the energy-intensive cement subsector and in the iron and steel subsector. SEA industrial development in materials and manufacturing also accelerates, particularly in Indonesia, where industrial energy use in TGT increases by 200% from ~3,200 PJ in 2022 to ~9,600 PJ in 2060. This expansion significantly outpaces the APEC average of 4.8% and contributes substantially to the subregion's overall growth in energy consumption. Evolving international trade dynamics further reinforce this trend: As global supply chains adapt to low-carbon transitions, some energy-intensive production shifts toward economies with lower operating costs, greater access to resources, or more favourable policy environments. Consequently, Southeast Asia's expanding manufacturing base is raising the proportion of energy use tied to export-oriented production.

In contrast, energy demand in most other APEC economies remains relatively flat. The United States, APEC's second-largest industrial energy consumer, experiences only modest growth. In much of Northeast Asia and Oceania, limited increases in activity are largely offset by efficiency improvements and further shifts in industrial structure, resulting in minimal change on average. However, there are exceptions, such as Papua New Guinea, which experiences a ~300% increase in industrial energy demand in TGT between 2022 and 2060 (from 39 PJ to 154 PJ), driven by expanded mining activity.

Industry Energy Demand by Fuel in APEC

Figure 3.13: Industry energy demand by fuel in APEC (PJ)



APEC's industrial fuel mix shifts significantly over the projection period, with changes more pronounced in TGT. Electricity accounts for 33% of industrial energy demand in 2022, rising to 45% in REF and 57% in TGT by 2060.

Coal use declines sharply in both scenarios, falling from over 21,000 PJ in 2022 to around 12,000 PJ in REF and to just under 4,000 PJ in TGT by 2060. The remaining coal use is largely concentrated in subsectors where substitution is difficult, such as in cement production, iron and steel production, and certain chemical processes. In these applications, carbon capture and storage (CCS) or hydrogen is assumed to be deployed to some extent. By 2060, coal with CCS increases to account for 16% of remaining coal demand in TGT, compared to 3.3% in REF. Similarly, gas with CCS reaches 17% of total gas demand in TGT and 4.6% in REF. These technologies are generally applied in locations with large, concentrated industrial facilities, such as integrated steel plants or major chemical complexes, where it is more practical to develop the capture, transport, and storage infrastructure.

Hydrogen use also expands in TGT, reaching 3.7% of industrial energy demand by 2060, compared to 0.5% in REF. A large portion of this hydrogen is used as a reducing agent in low-carbon steelmaking, replacing coking coal in direct reduced iron (DRI) production. Compared to the traditional blast furnace-basic oxygen furnace (BF-BOF) method, which relies heavily on coal, the combination of hydrogen-based DRI with electric arc furnaces (EAF) enables a significant reduction in emissions intensity in hard-to-decarbonise sectors. At the same time, secondary steel production via scrap-based EAF also emerges, particularly in TGT, supported by higher recycling rates and circular-economy policies.

Biomass remains a niche but important fuel source for lowering the carbon intensity of process heat processes. It is most applicable in medium- and low-temperature processes (below 300°C), such as those used in food, pulp & paper, and the textiles subsectors, particularly where local biomass and pellet mills are available to reduce logistics costs. Overall demand rises modestly across most subregions, except Southeast Asia where there is a 220% increase in demand in TGT, reflecting the abundance of agricultural residues that make biomass a cost-effective substitute for fossil fuels.

Although emerging technologies are critical for decarbonising industrial processes, fully eliminating fossil fuel use in the industry sector is not presently feasible. Certain industrial processes require fossil fuels either as feedstocks or to produce extremely high-temperature heat, and substitutes such as hydrogen or electrification are not always technically or economically viable. CCS can mitigate emissions in certain applications, but its deployment is constrained by costs, infrastructure needs, and site-specific limitations. As a result, some residual fossil fuel use is expected to persist. Achieving net-zero emission in the industrial sector will likely depend on a combination of fuel switching, targeted deployment of low-carbon technologies, energy efficiency improvements, and negative emissions in other sub-sectors.

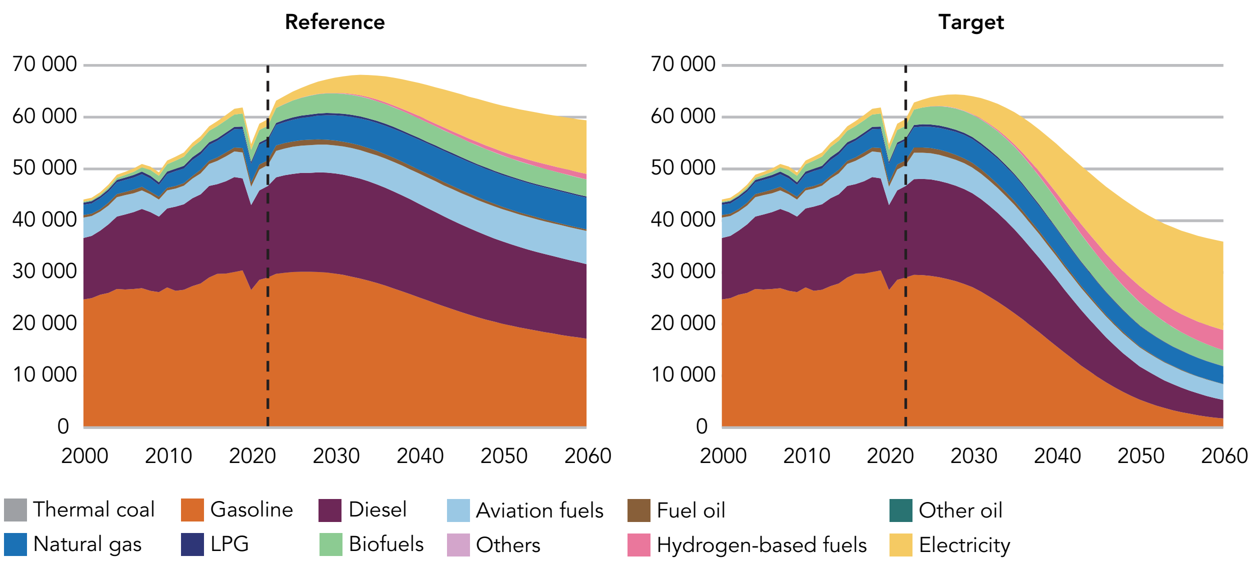
While electricity, biomass, hydrogen, and CCS play important roles in shifting the energy mix, projecting industrial energy demand remains particularly complex. Industrial activity often is largely shaped by company-level decisions rather than direct government policy, and the sector encompasses a wide variety of technologies, processes, and energy intensities, making generalisation difficult. Additionally, unlike sectors such as transport or power, the industry sector commonly does not follow a limited number of clearly defined, low-carbon pathways. Furthermore, trade policies, such as Europe's Carbon Border Adjustment Mechanism (CBAM) and recent U.S. tariffs, further complicate projections by influencing industrial activity and energy use in ways that are challenging to quantify. As a result, the divergence between REF and TGT is less pronounced in industry than in other sectors, reflecting the higher degree of uncertainty.

3.4 Transport in APEC

- The rapid adoption of electric vehicles (EVs), particularly battery electric vehicles (BEVs), is the primary driver of reductions in transport energy consumption and sectoral CO_2 emissions. Additionally, hydrogen-based fuels and biofuels expand, mainly in the Target scenario (TGT), but their impact on emissions reductions remains secondary to that of battery electrification.
- With personal vehicle ownership saturating in many economies, total vehicle numbers level out, shifting the focus to vehicle type. Internal combustion engine (ICE) vehicles remain prevalent in the Reference scenario (REF), whereas aggressive policy and rapidly approaching decarbonisation targets push most economies toward 100% EV sales between 2030-2040 in TGT.
- International aviation and marine bunkers continue their long-term growth trajectory. In TGT, part of bunkers demand shifts to hydrogen and biofuels, consuming nearly 20% of APEC's supply of those fuels, yet technological and cost uncertainties prevent the transport sector from achieving net-zero emissions.
- Transportation energy demand across the APEC region has grown in step with economic development, supporting the expansion of both domestic and international connectivity. The transport sector now accounts for roughly one-quarter of APEC's total final energy consumption and, when international aviation and marine bunkers are included, over half of all refined oil product demand. Road vehicles presently represent approximately 80% of the sector's energy usage. Much of this growth over the past two decades has been driven by China's rapid motorisation. However, the COVID-19 pandemic temporarily disrupted this trend, with domestic transport demand across APEC declining by around 8% in 2020–2021 due to lockdowns. Activity has since rebounded, but the composition of road vehicles is undergoing a notable transformation. The differing pace of EV adoption in REF and TGT results in divergent projections for future transport energy demand.

Transport Energy Use in APEC

Figure 3.14: Transport energy use in APEC (PJ)

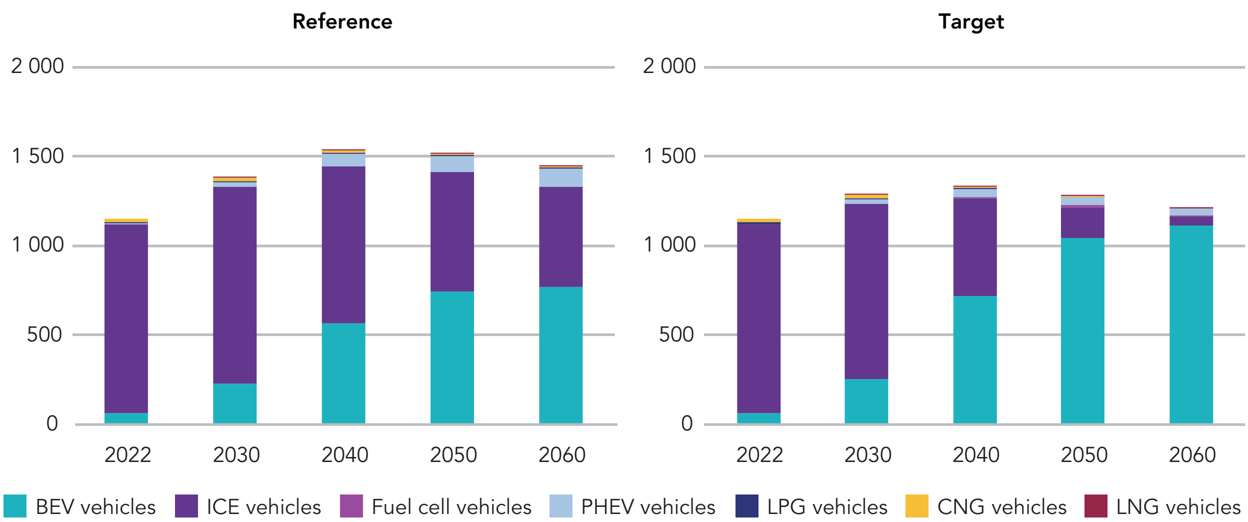


EV adoption is the single largest driver of declining energy use in both scenarios, across nearly all economies regardless of economic development levels. This shift from ICE vehicles to EVs results in a growth in electricity use in the transport sector, rising near 700% from 1,283 PJ in 2022 to 10,322 PJ in REF and near 1,200% to 15,821 PJ in TGT. The transition is particularly rapid in China; Hong Kong, China; and Singapore; where passenger and light commercial vehicles are projected to reach a sales share greater than 85% for BEVs in these economies by 2030 in TGT.

In addition to electricity, hydrogen-based fuels and biofuels also experience growth, particularly in TGT, driven by the gradual roll-out of fuel cell electric vehicle (FCEV) trucks and the substitution of fossil fuels with biofuels and e-fuels in conventional engines. For instance, Indonesia already uses significant volumes of biodiesel in its road transport, while Japan is projected to rely heavily on e-fuels under the TGT scenario, reflecting its technology-neutral approach to emissions reduction rather than an exclusive focus on BEVs.

Vehicle Stocks by Engine Type in APEC

Figure 3.15: Vehicle stocks by engine type in APEC (millions)



Vehicle stock growth plateaus as ownership rates reach saturation across many APEC economies. Current stocks are dominated by ICE vehicles, particularly in the passenger sector. EV adoption is growing, with the bulk presently concentrated in China.

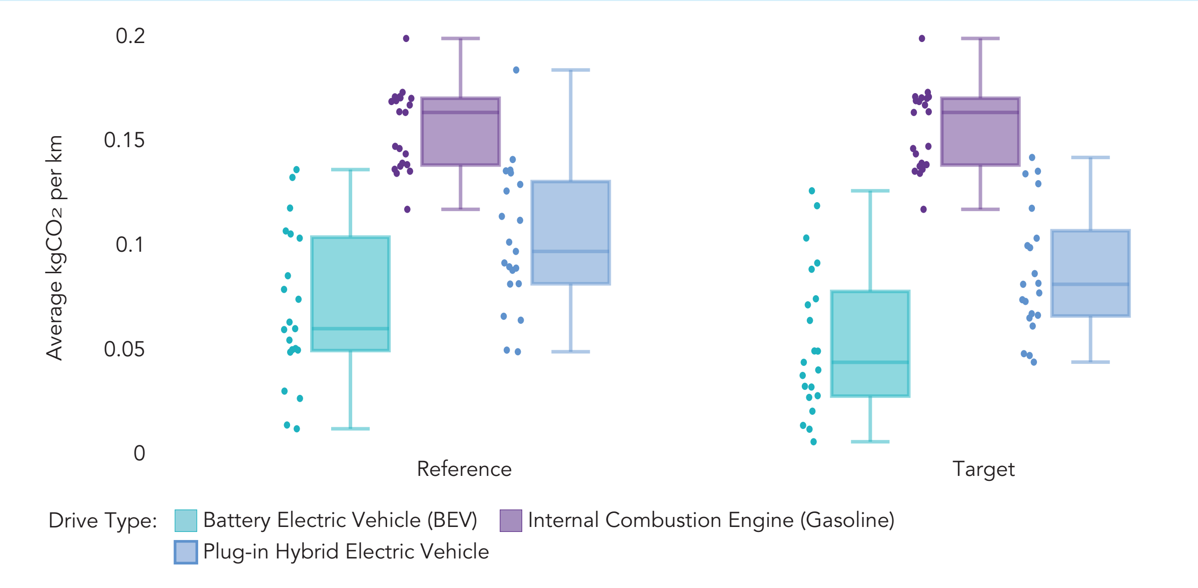
In REF, the transition to EVs remains partial due to slower progress in battery technology and limited investment in charging infrastructure. In contrast, TGT assumes strong government support, enabling many economies to reach 100% BEV sales for passenger cars between 2030 and 2040. Achieving this milestone would likely require technological advances that lower the cost and increase the energy density of batteries.

Engine Type Transitions in APEC

Comparing average car emissions intensity, by drive type

On average, BEVs exhibit the lowest lifecycle CO_2 emissions per kilometre when accounting for power generation and tailpipe emissions, followed by plug-in hybrid electric vehicles (PHEVs), and finally, ICE vehicles performing worst . Given these advantages, BEVs emerge as the most promising technology for future transport due to their higher efficiency (approximately three times that of ICE vehicles), minimal pollution and CO_2 emissions, and increasingly competitive costs (particularly as evidenced in China's market).

Figure 3.16: Average car emissions intensity when including generation emissions (kgCO_2/km)



Generation emission and new vehicle efficiency levels are calculated as the average over the projection period for each economy. Each dot is one economy's average emissions over the projection period for that drive type, and the stick/box shows the range, interquartile range, and median of the dot distribution.

There are still ongoing developments in vehicle technologies. For instance, some PHEVs are now being designed with larger batteries and smaller, range-extending engines. This configuration may be particularly beneficial for freight trucks, where reliable range is critical. This rationale also underpins the assumption of a high PHEV battery utilisation rate, set at ~70% of activity in the model, compared to the current average of around 45%.

Other factors that may affect BEV uptake

The share of new vehicle sales is the key metric determining the pace of EV adoption. Higher-income economies tend to have a larger proportion of new vehicle purchases, which enables an acceleration in the transition to EVs. In contrast, economies with lower average incomes often depend more heavily on second-hand vehicles, delaying the uptake of EVs until these types of vehicles reach the second-hand market. International trade dynamics also influence this trajectory. Economies that protect domestic auto industries may impose restrictions on lower cost, imported EVs, potentially slowing adoption and leading to disparities in energy efficiency and emissions outcomes. On the other hand, economies like Thailand have embraced EV imports while simultaneously pursuing ambitious local production goals, such as the 30@30 initiative, supporting rapid growth in EV sales shares.

Another key factor is the development of charging infrastructure. This presents a classic chicken-and-egg dilemma: without widespread EV adoption, private investment in EV chargers remains limited, particularly along highways and in rural areas. As a result, government assistance is often implemented to address this dilemma. Furthermore, building out charging networks will require significant upgrades to electricity infrastructure, which may be especially challenging in dense urban areas—adding to the broader pressures and costs associated with the electricity transition outlined elsewhere in the *Outlook.*

Drivers of change in energy use and emissions in transport

The evolution of transport systems across APEC economies varies significantly, shaped by diverse economic and demographic contexts. For instance, Japan has already established an extensive public transport network and maintains a highly efficient vehicle fleet. However, its aging and declining population presents challenges for transport demand in the long-term. In contrast, some economies in Southeast Asia have limited public transport infrastructure and less efficient vehicle fleets, coupled with expected growth in both population and income. As a result, vehicle ownership and usage are likely to rise in these economies—unlike in Japan, where demand for vehicles may stagnate or decline.

Figure 3.17: Illustrative grouping of APEC economies by transport related characteristics

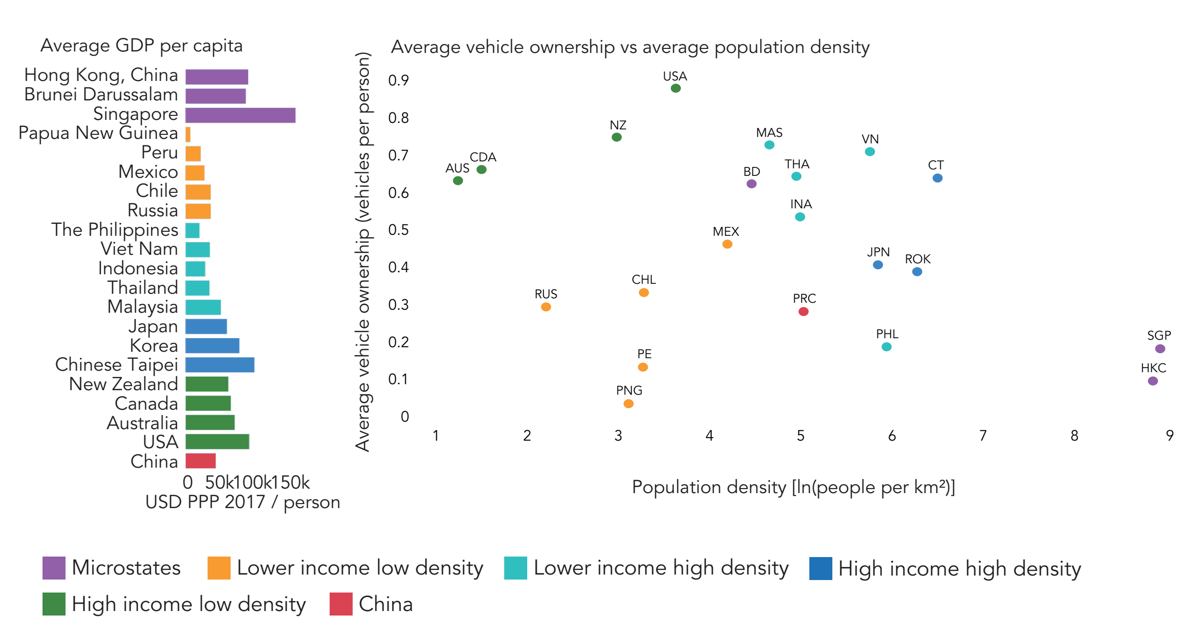
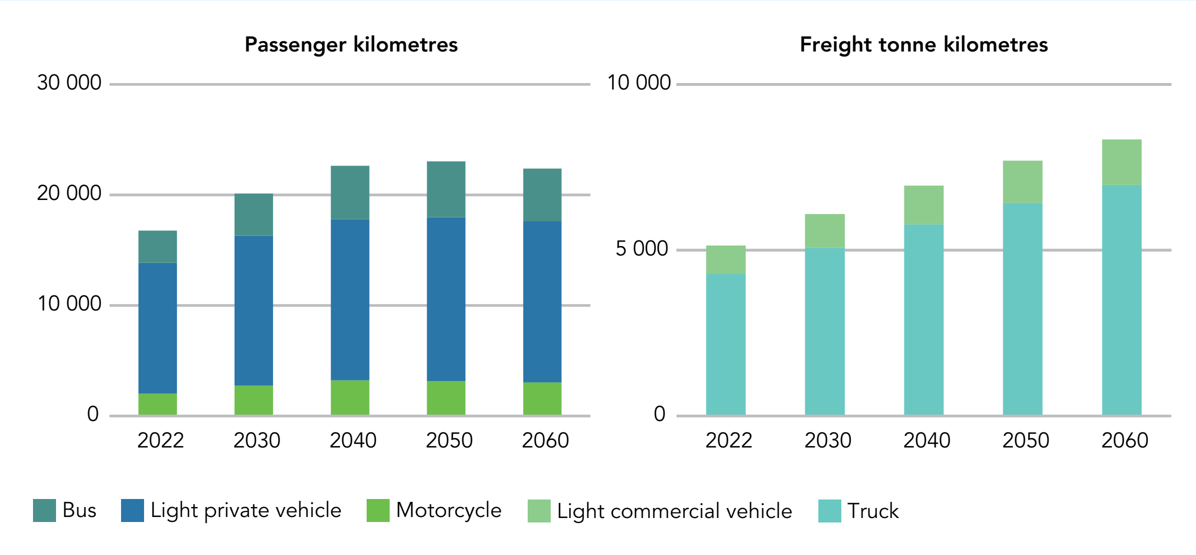


Figure 3.17 highlights key characteristics that facilitate the grouping of transport systems across economies, enabling more effective comparative analysis. APEC economies can generally be grouped into six sets with relatively similar characteristics.

Public transport usage varies widely across the region, largely influenced by population density and level of development. High-density economies, such as Korea, tend to have extensive public transport networks and high usage rates. In contrast, low-density, high-income economies, like New Zealand, face greater challenges in public transport deployment due to higher per capita infrastructure costs and lower ridership potential.

For developing economies, the picture is more complex. Indonesia, for example, has some of the most densely populated cities in the world, yet much of its urban transport relies on motorbikes. While motorbikes offer affordability, flexibility, and efficiency, especially in congested environments, they can dimmish the relative advantages of investing heavily in large-scale public transport. Additionally, Indonesia's geography presents another challenge: major cities are separated by bodies of water, leading intercity transport to be heavily reliant on air travel, as well as requiring a relatively high amount of marine transport.

Figure 3.18: Vehicle activity by type in the Reference scenario across APEC (billions)



Demographic change, particularly population growth, plays a major role in shaping passenger transport demand. In higher-income economies, population stagnation or decline often leads to reduced transport energy use. For example, Japan's transport energy demand is projected to fall by nearly 300 PJ—equivalent to around 15% of its 2022 total—over the next 40 years as a result of demographic decline alone.

In contrast, Thailand's growing population is expected to increase transport energy demand by approximately 800 PJ (66% of Thailand's 2022 level), regardless of EV adoption. This impact is often amplified by rising incomes, which drive higher rates of car ownership until saturation is reached, resulting in strong demand growth over time.

Despite these structural and demographic differences, the most important driver reducing transport energy use is the shift in engine type—particularly the adoption of BEVs. Figures 3.19 and 3.20 below illustrate how these different factors contribute to changes in transport energy use in Japan and Thailand by decomposing the main factors:

Figure 3.19: Thailand's drivers of changes in road energy use (PJ)

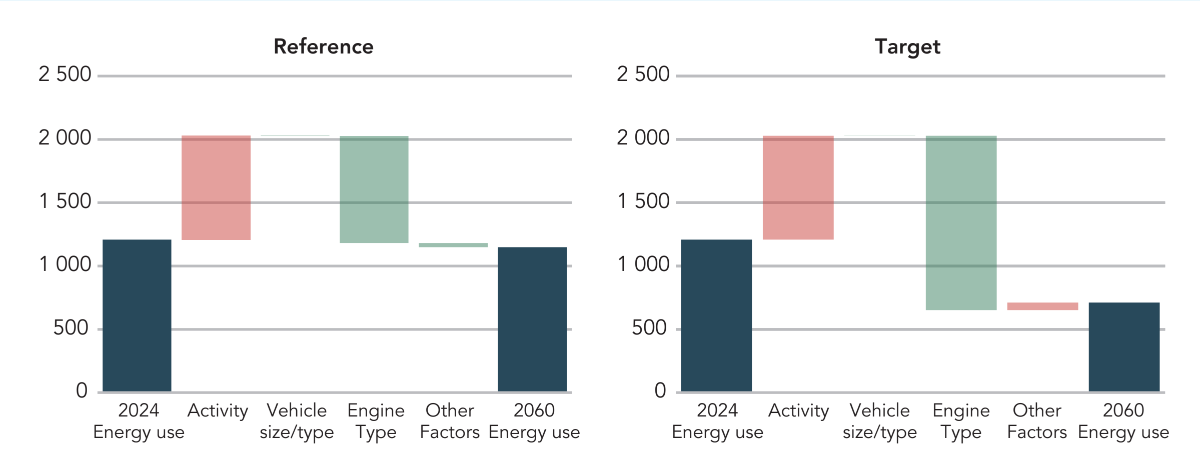
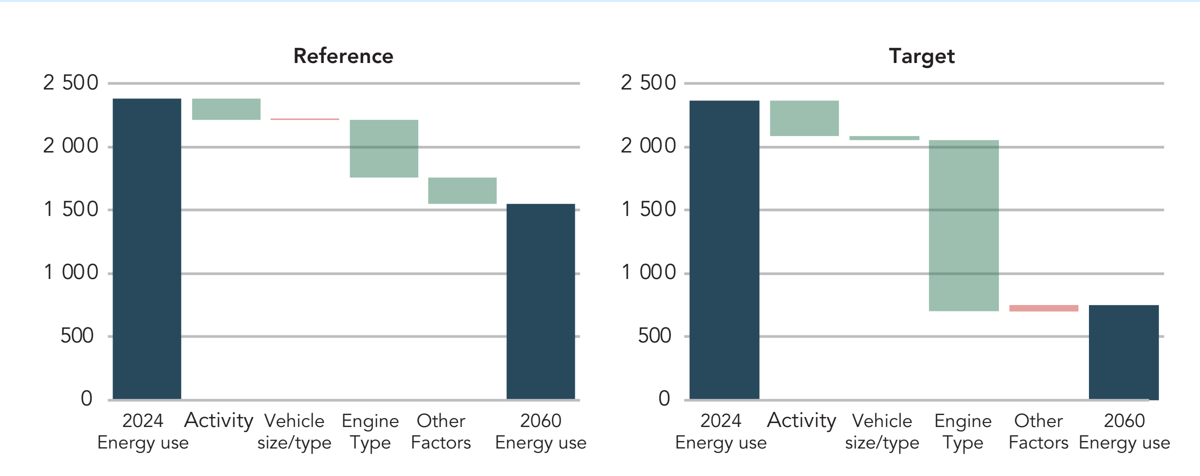


Figure 3.20: Japan's drivers of changes in road energy use (PJ)

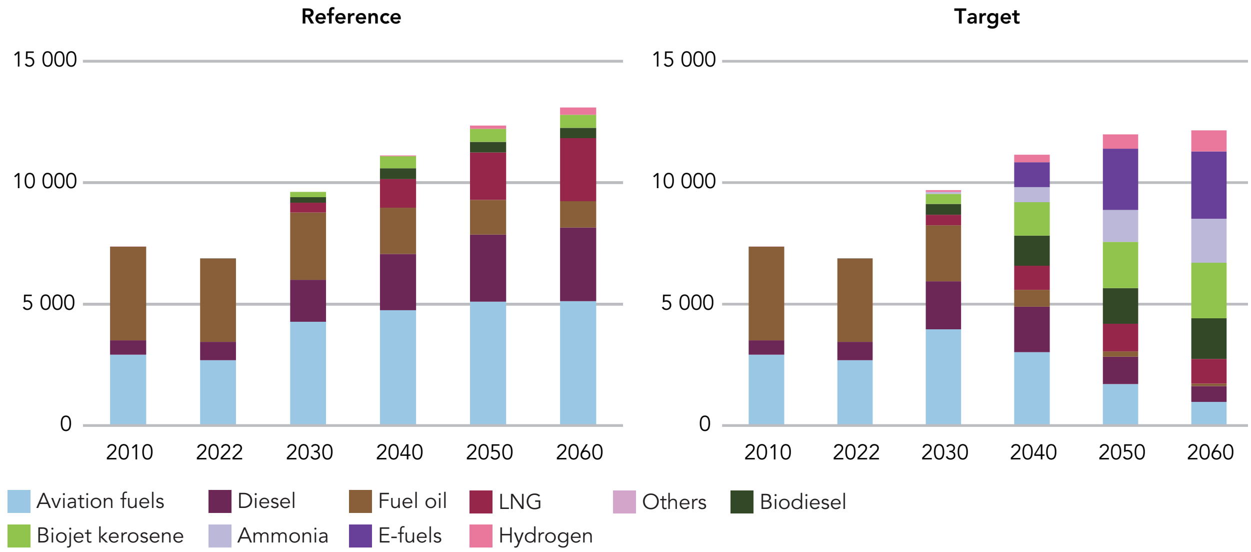


Note: Information on the different drivers in the transport energy decomposition can be found in the *Outlook*'s annex.

These charts illustrate the primary drivers of change in transport energy use and emissions. The adoption of BEVs, represented as *Engine Type*, is the most significant factor in reducing transport energy use and emissions across APEC. While public transport, represented as *Vehicle Size/Type*, does not substantially impact future energy use, it contributes to reducing congestion and offers numerous other benefits. Population and economic growth, shown as *Activity*, will increase energy demand in some economies, while declines in population will lead to reductions in others. While there are other factors influencing energy use, their impacts are relatively smaller than those highlighted in the charts.

International Aviation and Marine Transport

Figure 3.21: International bunkers energy demand for shipping and aviation in APEC (PJ)



International aviation and marine transport activity is projected to continue its historical growth trend over the next several decades, contrasting sharply with the stagnation assumed in the 8th edition of the *Outlook*.

In TGT, international aviation and marine shipping ("bunker") fuels begin shifting toward lower-emission alternatives to align with targets set by international transport organisations. However, net-zero emissions are not achieved, as no single technology currently offers a clear and cost-effective pathway. Instead, the fuel mix remains diversified, including LNG, biofuels, e-fuels, ammonia, and hydrogen, rather than converging on a single fuel.

Even though the size of the bunkers sector within APEC is only 2% of total primary energy supply, nearly 20% of APEC's hydrogen-based fuels and biofuels supply is expected to be used for international transport. As such, some economies who may have minimal use for these fuels domestically may still need to import them for bunkers. This is especially notable for economies like Hong Kong, China and Singapore, which have a relatively large bunkers sector compared to the size of their domestic energy use.

4. Power

4. Power in APEC

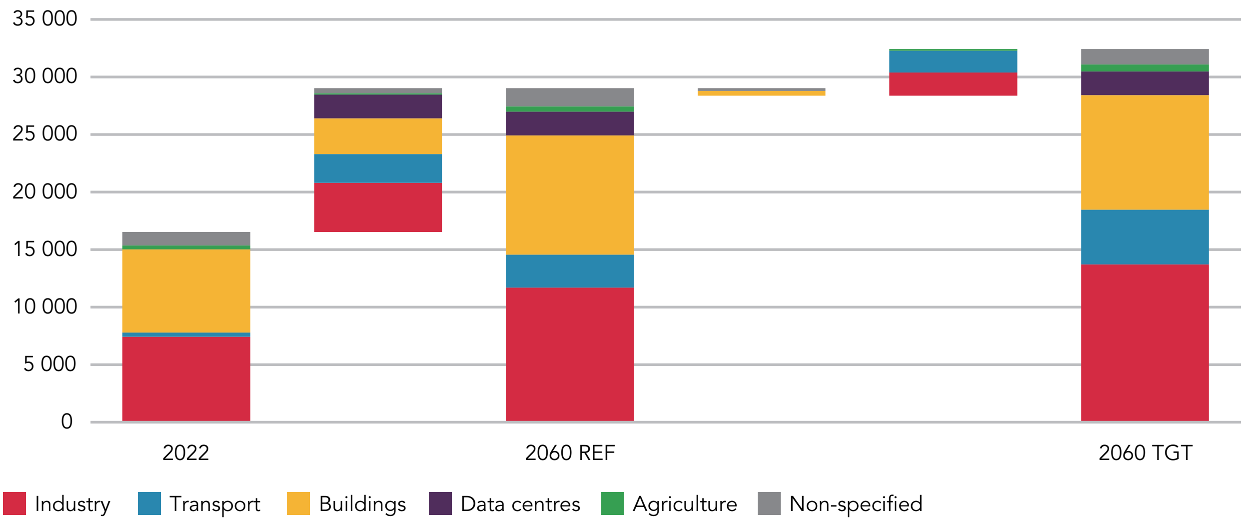
- From 2022 to 2060, electricity demand in APEC is projected to grow 75% in REF and 93% in TGT, driven by industrial and data centre loads, and electrification of transport and buildings.
- Meeting electricity demand from renewables requires a much larger buildout of capacity due to their inherent lower capacity factors. In addition, low-carbon hydrogen production introduces major additional capacity and generation requirements beyond end-use electricity demand.
- The power generation mix is shifting toward low-carbon and variable renewable energy (VRE) sources in response to decarbonisation goals. The growing role of VREs and storage reshape system operations and create cost and reliability challenges for the electric grid.

Current power systems are undergoing profound changes as growing amounts of variable renewable energy (VRE) sources like wind and solar are brought online and generation increases its reliance on decentralised sources. Traditionally, electricity systems were designed around centralised, dispatchable power plants that supplied electricity through an electric grid to consumers. These systems served relatively predictable demand with a combination of baseload plants, often coal-fired, hydroelectric, and nuclear power plants, and a limited number of load following plants, typically oil and gas-fired generators. However, the rapid growth of renewables characterised by zero marginal cost and weather-dependent output has introduced new complexities. Many existing grids struggle to manage these fluctuations in VRE systems due to limited storage capacity and infrastructure constraints. There is increasingly a mismatch between when electricity is generated and when it is needed, leading to situations where renewable energy is curtailed or wasted. Demand-side solutions, such as flexible consumption, demand response technologies, and smart scheduling of electric vehicle charging can help balance the grid. However, as decarbonisation of power systems continues, those systems will need to address through investment and new technologies the cost and reliability challenges associated with these changes.

Electricity Consumption in APEC

Electricity consumption in the APEC region is projected to increase by 75% by 2060 in the Reference scenario (REF) compared to 2022 levels (Figure 4.1). Around half of this growth is driven by rising demand from industry and data centres, which require a stable and continuously reliable power supply. The remaining 45% comes primarily from the buildings and transport sectors, where electricity use is more variable, reflecting daily and seasonal consumption patterns. In the Target scenario (TGT), electricity demand increases 93% by 2060, reflecting more ambitious electrification of the energy systems. The incremental demand for electricity in TGT relative to REF comes primarily from greater electrification of industrial processes and more widespread adoption of electric vehicles.

Figure 4.1: Electricity consumption in the end-use sectors in APEC (TWh)



Electricity Generation Mix in APEC

The electricity generation mix in APEC is projected to undergo major changes. In 2022, dispatchable thermal and low-carbon sources (nuclear, large hydro, and geothermal) accounted for 88% of total electricity generation (Figure 4.2).

In REF, total thermal generation is expected to decline by 12% by 2060, with coal generation falling more rapidly and being largely displaced by natural gas. Regionally, China is the main driver of this decline in thermal, particularly coal-based, generation (Figure 4.3). However, this trend is partially offset by increased fossil-fuel-fired generation in fast growing Southeast Asian economies.

Low-carbon, dispatchable generation in REF is projected to nearly double by 2060, primarily due to large-scale deployment of nuclear and hydro in China, followed by expansions in Southeast Asia.

VRE sources, such as wind and solar, are expected to meet all additional electricity demand after 2040, while also enabling a modest reduction in thermal generation. The share of VRE in total generation rises from 12% in 2022 to 42% by 2060 in REF, representing a sixfold increase in absolute terms. China accounts for about half of this increase, followed by the United States with roughly a quarter.

Even larger changes occur in TGT. Thermal generation is projected to decline by 40% by 2060, driven by a more aggressive phase-out of fossil fuels. This is accompanied by the adoption of carbon capture technologies and fuel switching to hydrogen-based alternatives, including hydrogen in gas-fired power plants and ammonia co-firing in coal-fired units. The reduction in thermal generation in TGT is largely offset by significant nuclear expansion, especially in the United States, Northeast Asia, Southeast Asia, and Mexico.

As in REF, VRE plays an important role in meeting rising demand in TGT. VRE covers nearly all additional demand as well as the moderate decline in both thermal and low-carbon dispatchable generation after 2040, and accounts for 50% of total electricity generation by 2060.

Figure 4.2: Generation by technology, 2000-2060 (TWh)

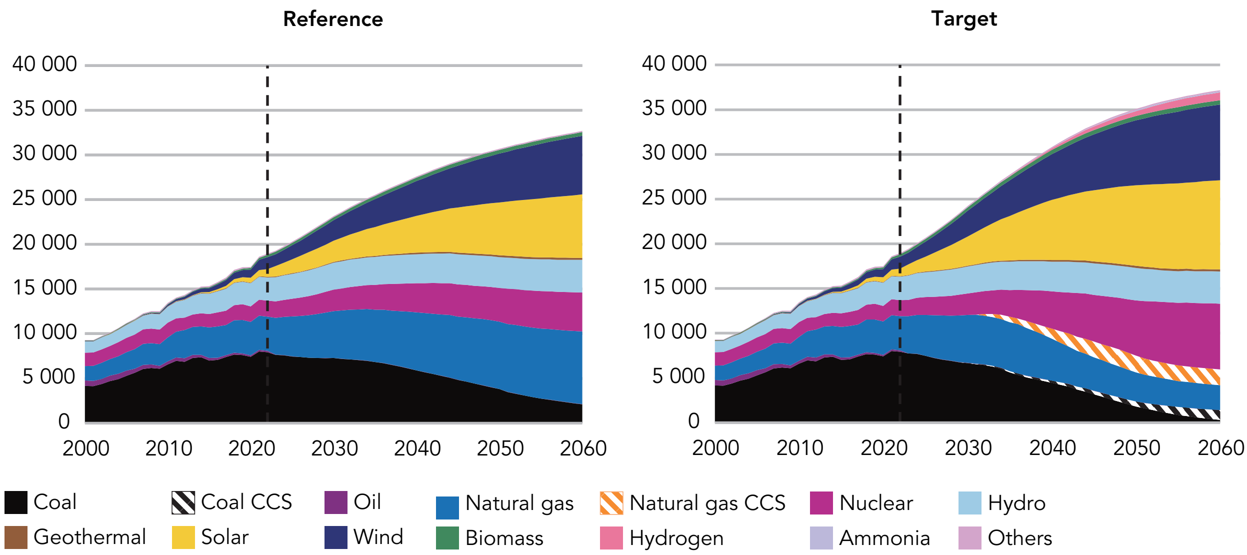
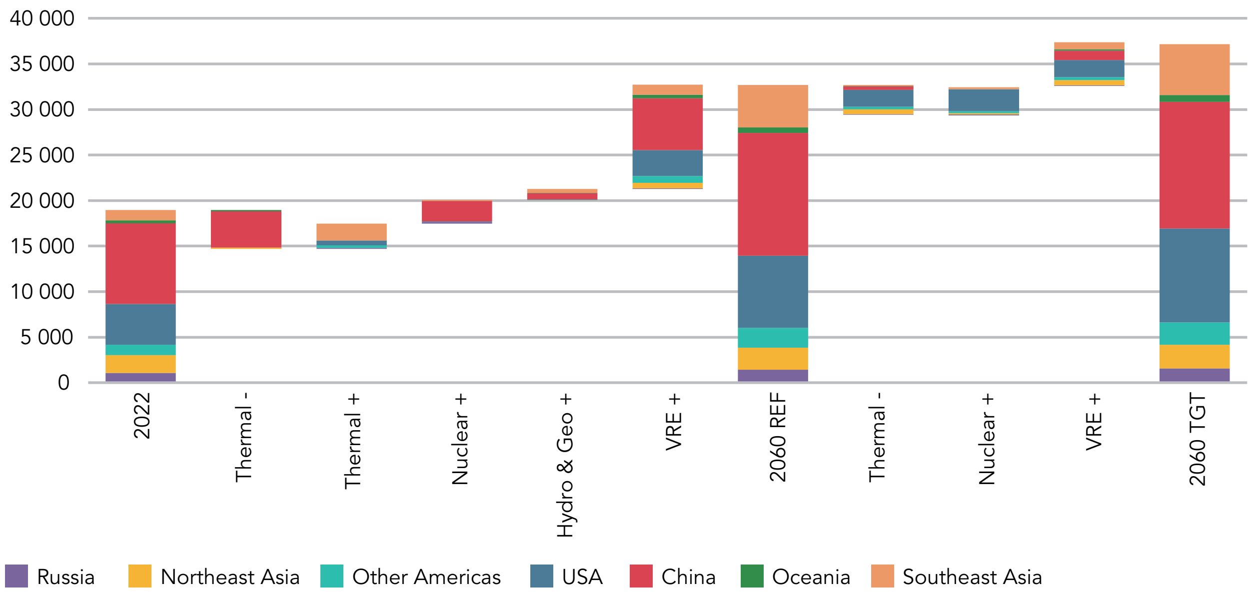


Figure 4.3: Generation by region in 2022 and 2060 (TWh)



Generation Capacity in APEC

Total installed electricity generation capacity in APEC economies is projected to increase significantly through 2060, driven primarily by the expansion of VRE. Due to the lower capacity factors of these technologies, capacity must grow much faster than electricity generation. This trend is especially pronounced in TGT, where deeper decarbonisation and electrification require even larger additions of renewable capacity.

In REF, total installed generation capacity increases by 175% from 5,500 GW in 2022 to 15,000 GW in 2060 (Figure 4.4). The share of VRE in total capacity grows substantially from 24% in 2022 to 60% in 2060. Net additions of VRE from 2022 to 2060 are projected to total 7,700 GW in REF. China contributes 60% of the increase in VRE capacity, followed by the United States with 17% (Figure 4.5). Thermal capacity increases slightly in REF, mainly in Southeast Asia, powering the rapidly growing economies especially in the late 2020s and 2030s. Nuclear and hydro capacity experience moderate growth, largely concentrated in China. Storage, including batteries and pumped hydro, plays an important role in managing VRE generation and stabilising electric grids. Total capacity of all storage technologies is projected to reach almost 900 GW by 2060 in REF.

In TGT, total installed capacity increases by 250% to 19,200 GW in 2060, reflecting both the sharp increase in electricity demand and the system-wide shift toward low-carbon technologies. VRE capacity grows most rapidly, accounting for almost two-thirds of total installed capacity by 2060. Starting from an installed capacity of 1,300 GW in 2022, the REF scenario projects net additions of 7,700 GW by 2060. In comparison, TGT requires 3,200 GW more over the same period, bringing total VRE additions from 2022-2060 to 10,900 GW.

Thermal capacity in TGT declines compared to REF, though some fossil-based units remain in operation with carbon capture additions or alternative fuels such as hydrogen and ammonia. Nuclear capacity grows more substantially in TGT, especially in the United States, Northeast Asia, and Southeast Asia, to support system reliability, firm capacity needs, and decarbonisation goals.

TGT involves widespread use of hydrogen and hydrogen-based fuels, including in the power sector. Producing low-carbon hydrogen at the projected scale could require up to 3,400 GW of additional, dedicated VRE capacity—an amount greater than the entire difference in net capacity additions between TGT and REF. This highlights that a significant amount of new VRE in TGT would be needed not for meeting electricity demand directly, but to support low-carbon hydrogen production.

Figure 4.4: Generation capacity, excluding VRE for hydrogen (GW)

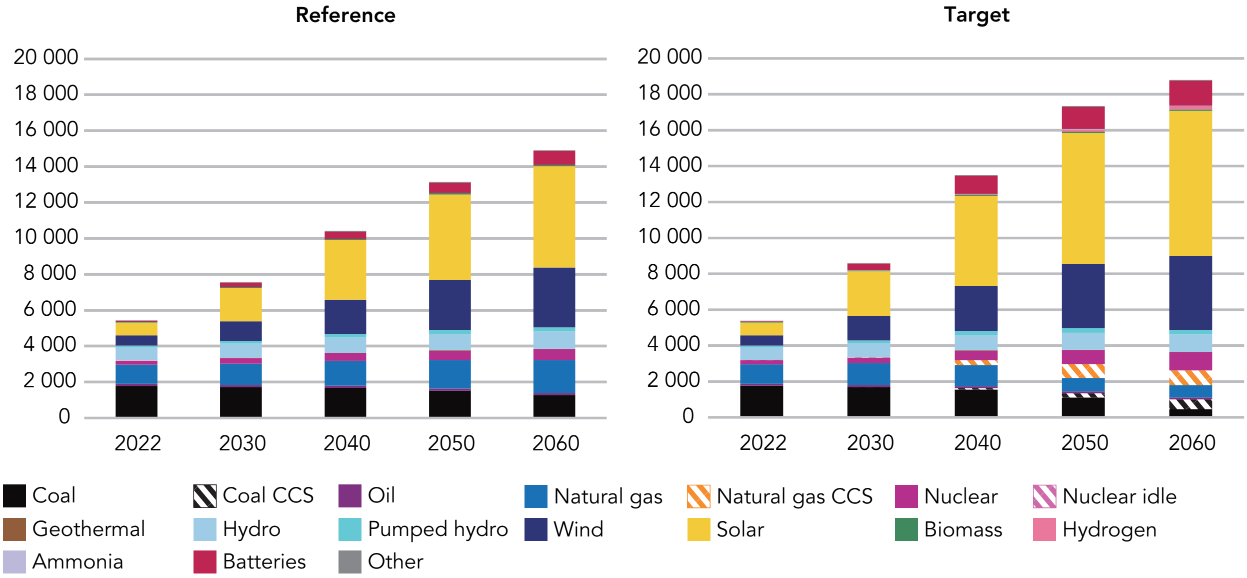
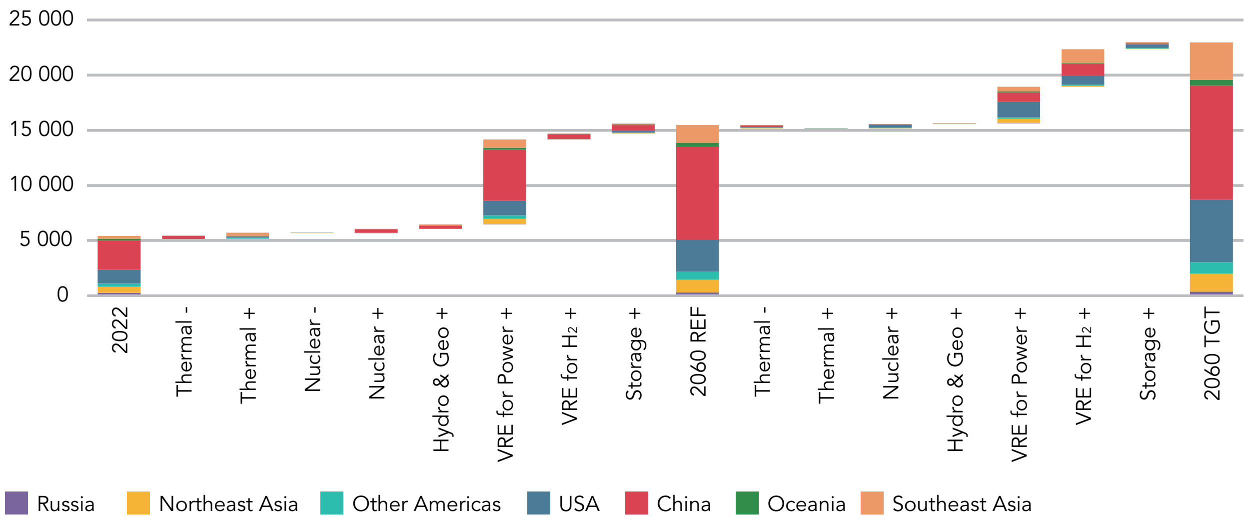


Figure 4.5: Generation capacity by region, including VRE for hydrogen (GW)



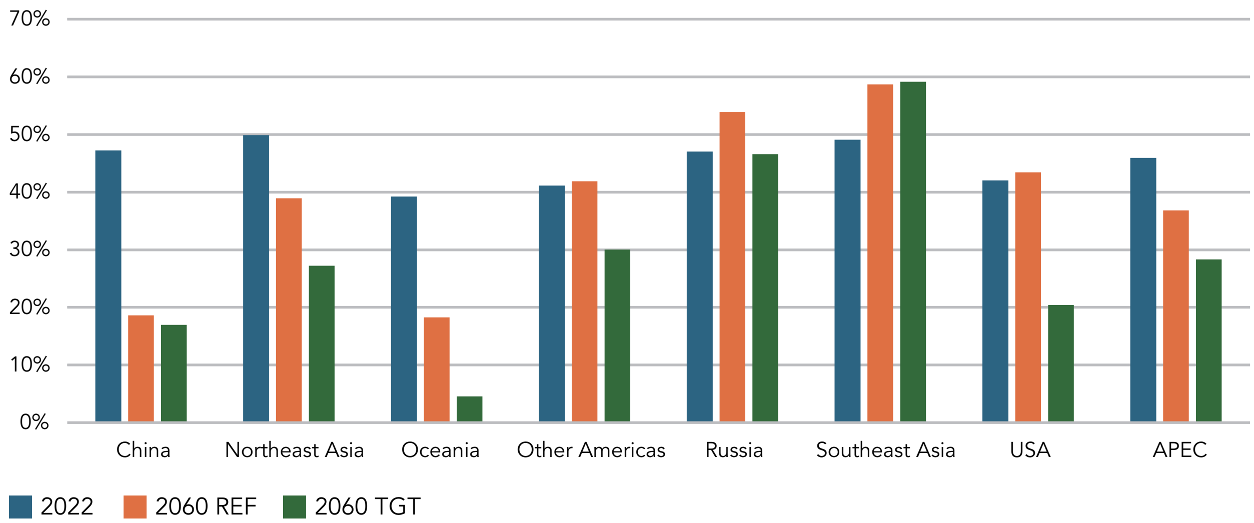
Annual Capacity Factors in APEC

Across APEC economies, thermal power plants, particularly coal and natural gas units, are facing steadily declining annual average capacity factors over the projection period. This trend is largely driven by the growing penetration of VRE, which displaces thermal generation during hours of high wind and solar output. However, even as thermal generation is reduced, the installed capacity of thermal plants remains largely intact. This is because these plants continue to provide essential grid services, such as dispatchable backup, frequency regulation, inertia, and peak capacity support.

In both REF and TGT, while VRE accounts for the majority of incremental generation, especially after 2040, thermal capacity declines only modestly. This results in a significant drop in average capacity factors for thermal assets across the region (Figure 4.6). On average, APEC-wide thermal capacity factors fall from 46% in 2022 to 37% in REF and to only 28% in TGT by 2060. The decline is especially sharp in regions such as China (from 47% in 2022 to 17% in TGT by 2060), Oceania (39% to just 5%), and the United States (42% to 20%). In contrast, some regions maintain higher thermal utilisation. Southeast Asia, for example, holds steady at 59% in both REF and TGT, reflecting continued reliance on thermal assets amid rapidly growing electricity demand. Those economies that experience declining capacity factors for thermal generation are also expected to see a rise in the per unit cost of electricity. While electricity generation from thermal plants declines, the fixed costs, such as capital repayment, maintenance, and staffing, remain largely unchanged and must be recovered over fewer megawatt-hours, resulting in higher per unit costs.

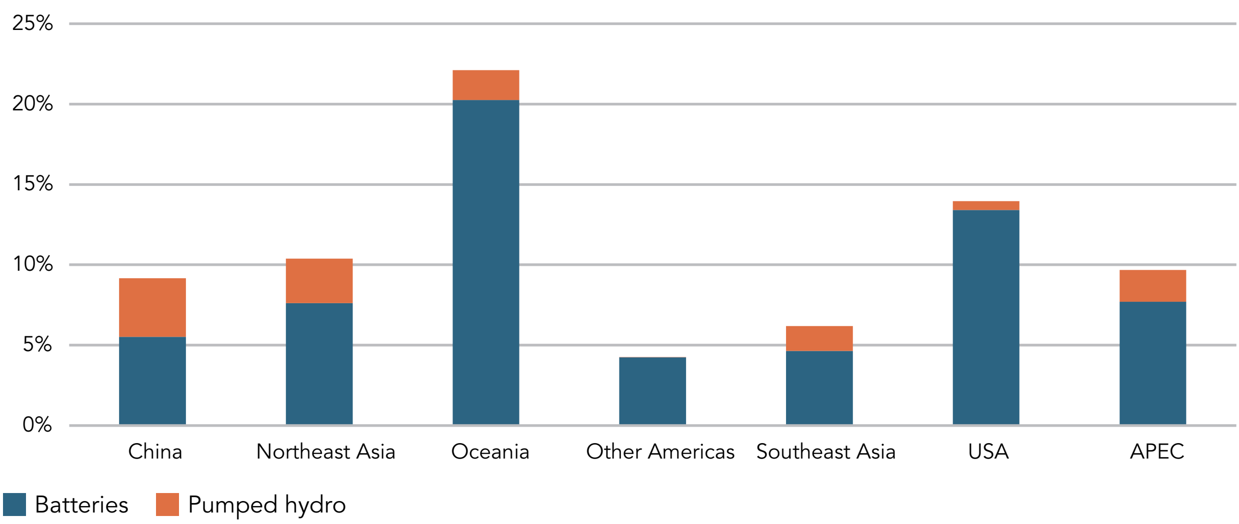
In addition, using carbon capture and storage (CCS) facilities at thermal power plants with low and variable utilisation presents significant challenges. CCS systems are typically designed to operate with a stable and continuous flow of flue gases; when power plant output fluctuates, capture efficiency can decline, and the cost per tonne of captured CO_2 increases due to reduced operating hours and lower throughput.

Figure 4.6: The capacity factor of thermal (fossil-fuel-fired generation) (%)



The share of electricity provided to the electric grid that passes through storage provides insight into how much generated electricity is being shifted in time. In 2060, storage discharged from batteries or pumped storage accounts for 10% of the total electricity provided to the electric grids across APEC. The electricity discharged from storage originates from VRE sources, primarily solar. The share of generation that is time-shifted varies substantially by sub-region (Figure 4.7). High storage shares, such as 20% in Oceania and 13% in the United States, indicate advanced use of storage integrated with VRE to balance generation and daily load cycles. This share represents electricity that is temporarily withheld from immediate use and later discharged to meet demand at different times of the day. However, these shares are not solely a function of installed storage capacity. They are also shaped by the share of generation provided by VRE, the load profile, and the flexibility of the broader system.

Figure 4.7: Share of electricity that passes through storage in 2060 by subregion in TGT (%)



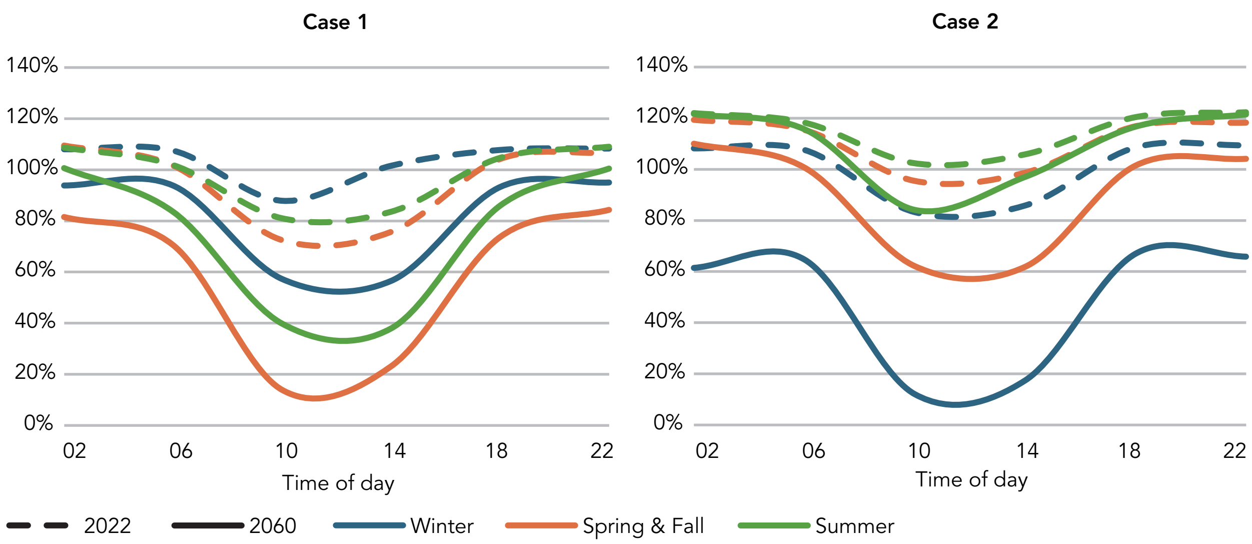
Increased reliance on wind and solar generation will significantly raise the variability of power required from dispatchable sources, including thermal, hydro, nuclear, and storage. Figure 4.8 illustrates this trend using two cases of daily dispatchable power output across three seasons, comparing 2022 (dashed lines) with projections for 2060 (solid lines). In both cases, the variability of dispatchable generation rises substantially.

In Case 1, dispatchable sources provided at least 70% of total load during a typical day in 2022, resulting in relatively modest 20-30% daily swings, depending on season and VRE availability. In Case 2, these fluctuations were even smaller in 2022. During some seasons (winter in Case 1 and summer in Case 2) dispatchable sources fully met the load, highlighting the need to maintain sufficient firm capacity to cover seasonal VRE shortfalls.

By 2060, the share of VRE rises sharply. In optimal weather conditions (sunny and windy midday periods), VRE may meet up to 90% of the load in some seasons. However, this leads to much larger daily swings in dispatchable generation, reaching 50-70%, depending on the location and season. Even in Case 2's summer conditions, despite high VRE penetration, dispatchable sources will still need to supply no less than 80% of total load during some periods due to seasonal variability.

This growing variability poses significant operational challenges. System operators will need to manage more frequent and more extreme shifts in dispatchable output to balance the grid. It also places stress on conventional generators, especially thermal and nuclear plants, whose efficiency and economics can be adversely affected by frequent ramping and reduced utilisation.

Figure 4.8: Dispatchable power vs load (%)



As the share of variable renewable energy (VRE), such as wind and solar, increases across APEC economies, power systems face growing operational and structural challenges. Traditional grids, originally designed for centralised and dispatchable generation like thermal, hydro, and nuclear power, lack the flexibility to handle the intermittency and two-way power flows associated with VRE. Key issues include maintaining grid stability under fluctuating supply conditions, enabling real-time coordination across distributed energy resources, and upgrading infrastructure to support advanced digital controls and storage. Regional challenges are further compounded by fragmented control and different technical standards. Integrating digitalisation, enhancing demand-side flexibility, and promoting regional interoperability could help mitigate all these effects, but those actions introduce additional challenges that must be addressed.

As power systems move toward high shares of variable renewable energy and decentralised resources, existing market designs will likely struggle to keep pace. Market mechanisms, such as marginal cost pricing, were designed for conventional power and often fail to reflect the value of flexibility, reliability, and environmental benefits in this new context. Current regulatory and market frameworks rarely provide sufficient incentives for actions that increase reliability, such as reserve margins and frequency control. Reforming market structures to appropriately value system services, such as fast-ramping capacity, energy storage, demand response, and low-carbon attributes, is essential to ensure reliable, efficient, and sustainable electricity systems.

4.1 Nuclear

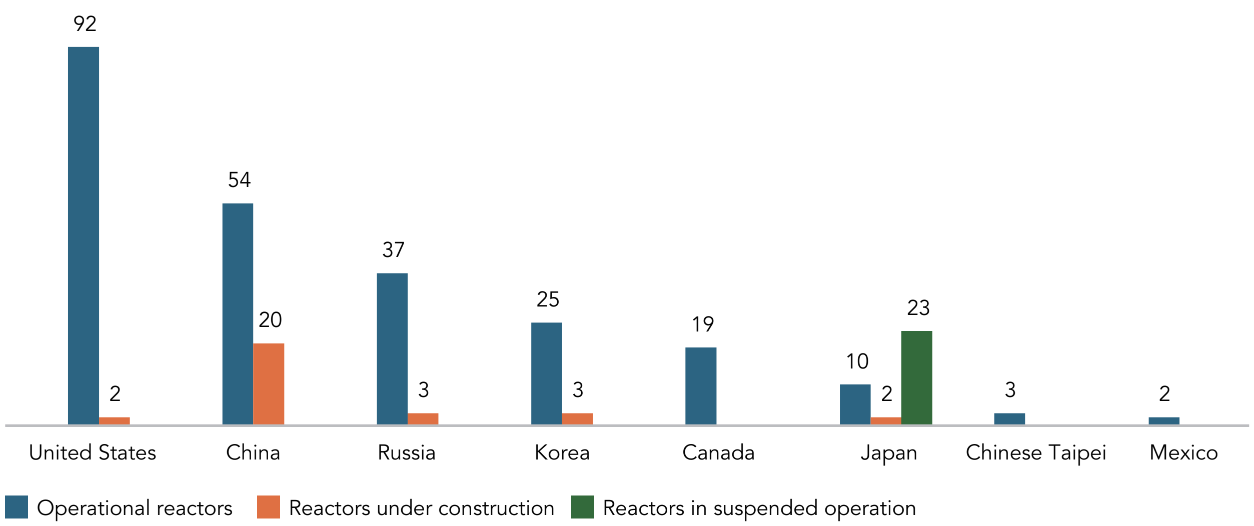
Historical Development

The APEC region holds a pivotal position in the global nuclear energy landscape. As of 2022, the APEC region hosts eight of the 33 economies with operational nuclear power reactors and five of the 18 economies with reactors under construction worldwide. This represents 61% and 54% of the global installed capacity in operation and under construction, respectively. Notably, six APEC economies rank among the top eight globally in terms of the number and capacity of operational reactors. Figure 4.9 illustrates the distribution of existing power reactors within the APEC region.

Regarding fuel supply, as of 2022, APEC accounts for over half of the world's recoverable uranium resources, with Australia; Canada; and Russia collectively holding 90% of APEC's total.[3] Furthermore, the World Nuclear Association estimates that four APEC-affiliated suppliers (Canada; China; Russia; and the United States) own approximately 76% of commercial primary uranium conversion capacity,[4] with China and Russia alone holding 59% of global commercial uranium enrichment capacity.[5]

Regarding technology supply, the United States was a major reactor supplier prior to the 1990s. Since 2000, however, most reactors globally have been built by vendors from China; France; Japan; Korea; and Russia. Canada, specifically, has been a key supplier of commercialised heavy water reactors. Looking ahead, Small Modular Reactors (SMRs) are anticipated to play a major role in achieving net-zero targets, with all six major nuclear operators in APEC actively developing SMR designs.

Figure 4.9: Number of nuclear power reactors by economy as of 31 December 2022



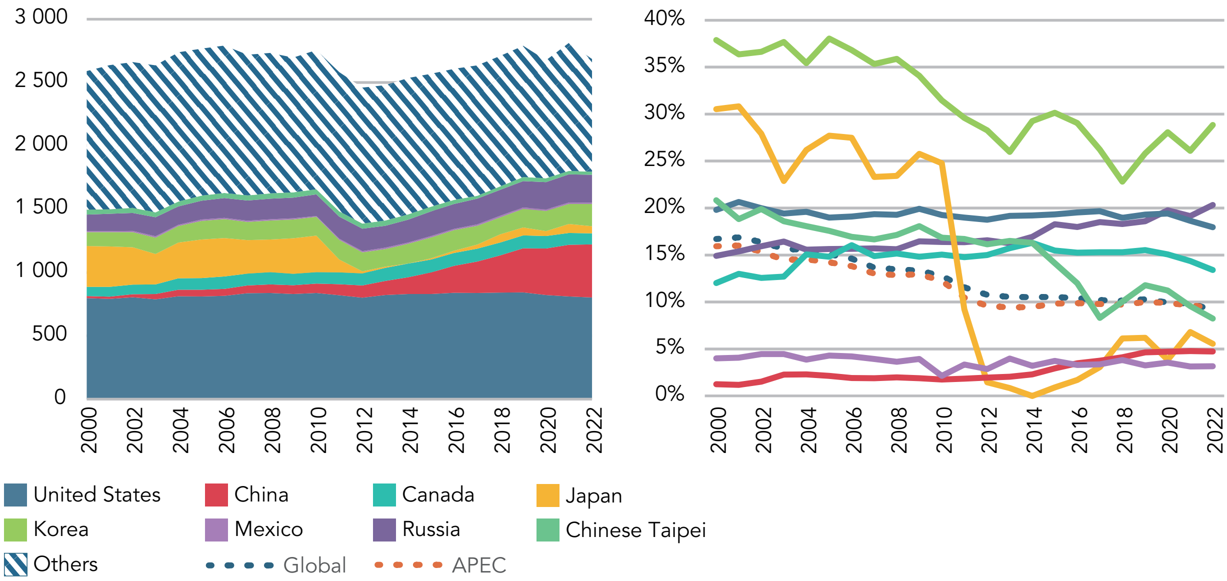
3 Reasonably assured recoverable uranium resources within the cost range of <USD 130/kgU

4 UF6 production from primary converters

5 Effective separative work units (SWU) capacity

As shown in Figure 4.10, APEC economies have contributed more than half of global nuclear power generation in the past two decades. The United States' nuclear power production remained relatively stable, consistently comprising more than half of the APEC total until 2019. During this time, only one new U.S. unit was brought online. Canada and Mexico's share also remained generally steady. Following the 2011 Fukushima-Daiichi accident, Japan, formerly the second-largest nuclear producer, suspended all reactor operations. By 2014, nuclear generation had ceased entirely, and although restarts have since begun, the prolonged shutdown significantly reduced APEC's overall nuclear output. Conversely, China; Korea; and Russia actively expanded their nuclear power fleets. China commissioned, on average, more than three new reactors annually, leading its nuclear power production growth from 2011 to 2022 to exceed the net growth of the entire APEC region. China's nuclear expansion contributed to a ten-percentage-point increase in APEC's share of global nuclear generation.

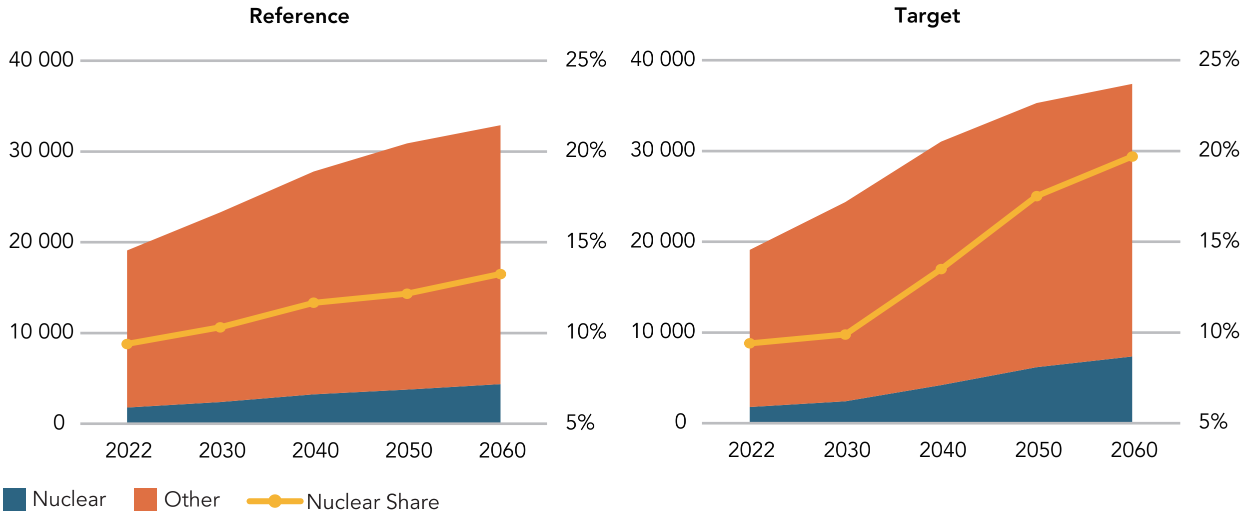
Figure 4.10: Total nuclear power generation and nuclear's share of total power generation in each APEC economy (TWh, %)



The share of nuclear power in APEC's total power generation generally declined from 2000 to 2011, aligning with global trends, as nuclear power capacity remained stagnant while other fuel sources expanded. Over the past decade, however, this share stabilised at approximately 10%, primarily driven by the commissioning of new nuclear units in China. In more recent years, nuclear's share has been slightly impacted by the rapid deployment of solar PV and wind power capacity across the region.

Future Prospects

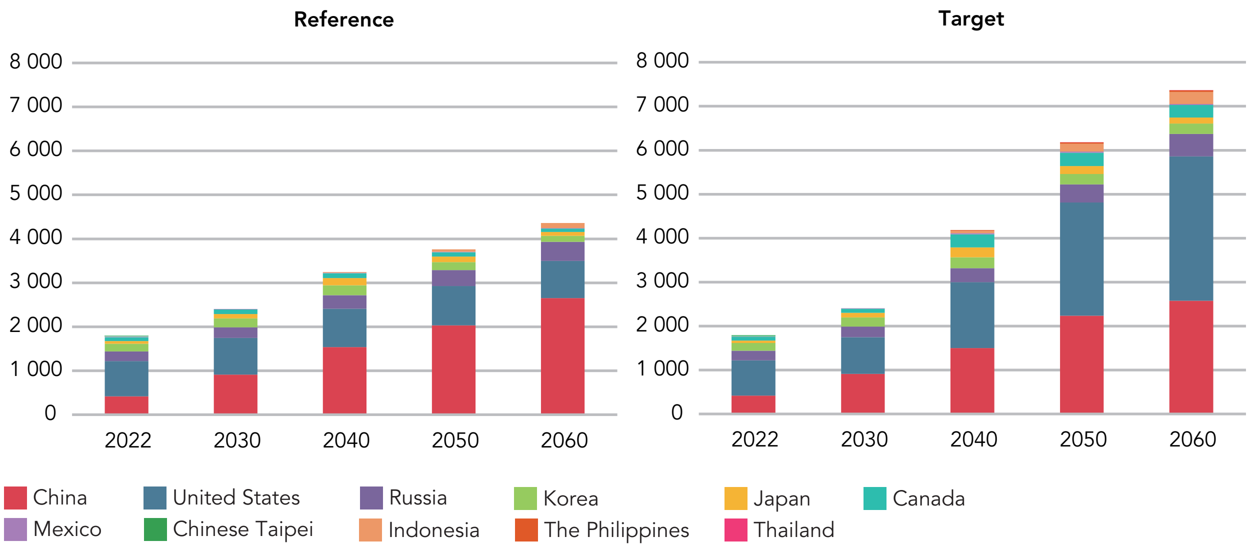
Figure 4.11: APEC nuclear and other power generation, including nuclear's share of total power generation in APEC (TWh)



Looking forward, as electricity demand expands and fossil-fuelled thermal power generation plateaus, nuclear power generation—a dispatchable, low-emission power source—is projected to increase. Nuclear power is particularly well-suited to support the expected increase in data centre power demand. Consequently, in both scenarios, nuclear power is projected to become the largest dispatchable power source in APEC by the end of the projection period.

Figure 4.11 illustrates that total nuclear power generation in the APEC region is estimated to increase steadily in the REF scenario. In the TGT scenario, new reactors are expected to experience more rapid deployment from the mid-2030s onwards, driving total nuclear generation to more than quadruple by 2060 compared to 2022 levels. As indicated in Figure 4.12, the majority of this additional growth in TGT is projected to occur in the United States. By 2060, nine APEC economies are projected to be operating nuclear power plants in TGT.

Figure 4.12: Change in nuclear power generation by economy (TWh)



China and the United States are projected to continue dominating this sector within APEC, collectively contributing over 80% of the total growth in nuclear power generation across both scenarios during the projection period. In REF, China becomes the single largest nuclear power producer from 2030 onwards, while TGT indicates a substantial expansion in the United States, allowing it to surpass China after 2040.

Beyond these major players, several Southeast Asian economies are also embarking on nuclear energy development. Indonesia, for instance, is projected to account for 3-4% of APEC's total nuclear power generation, a share comparable to Canada. In addition, both the Philippines and Thailand are expected to operate multiple nuclear power units in TGT. It is also worth noting that, although not included in the assumptions of this edition of the *Outlook*, Malaysia and Viet Nam are actively considering the introduction of nuclear power into their respective energy systems.

Comparison by APEC Economy

Figure 4.13: Change in nuclear generation capacity and share in selected economies (GW)[6]

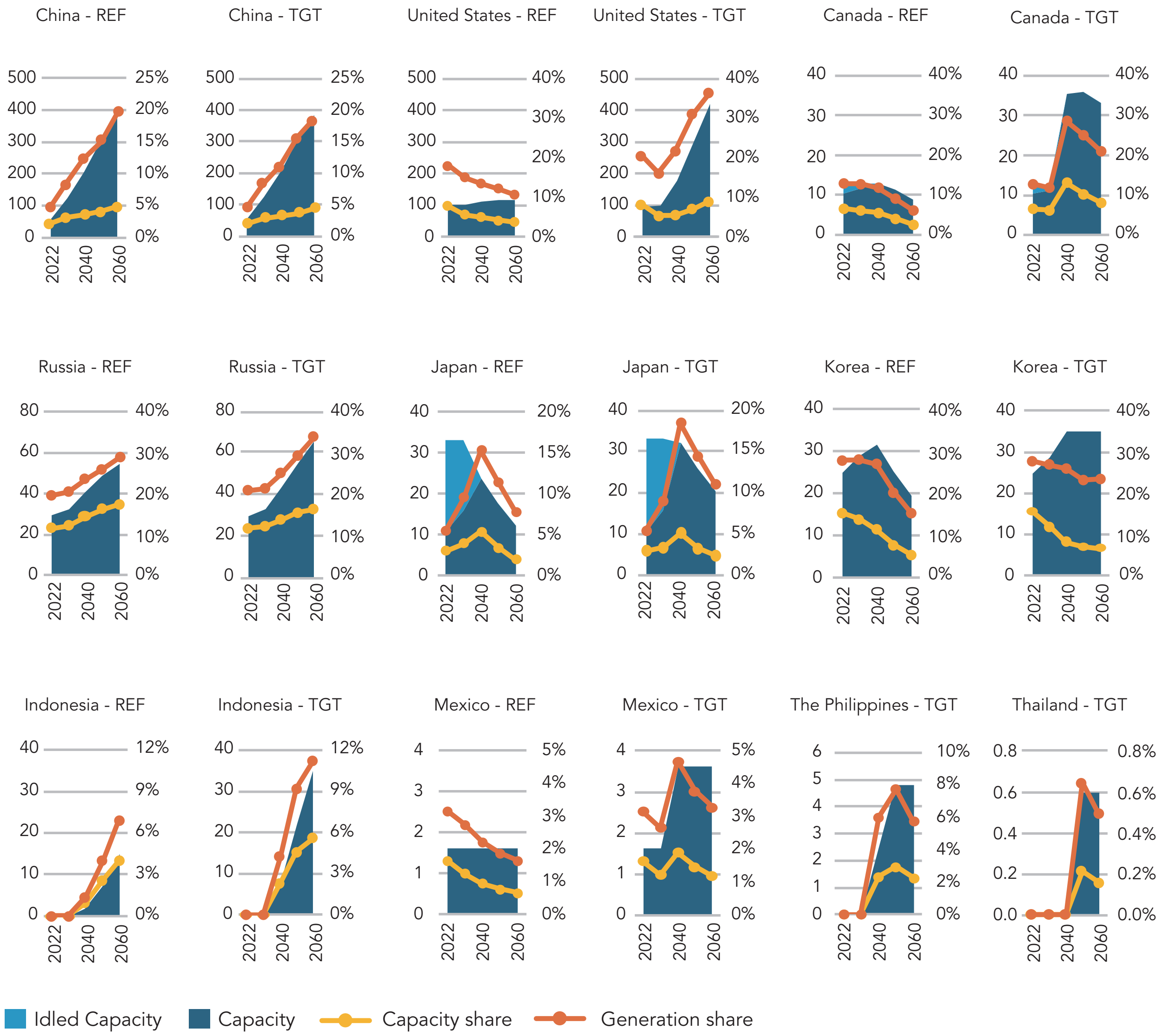


Figure 4.13 illustrates the projected change of nuclear power generation capacity and its share within each economy's power system. Unlike variable renewables, nuclear power, with a relatively high capacity factor, takes up a higher share in generation than in capacity. Chinese Taipei is excluded from this chart as all its nuclear power reactors are scheduled to be shut down in 2025 and remain offline through 2060 in both scenarios.

China and Russia are expected to maintain their current momentum in nuclear construction, elevating nuclear power's importance in their respective power systems. Canada and the United States are projected to begin rapid nuclear capacity upscaling in the 2030s, tripling their operational capacity by 2050 in TGT. Both economies are promoting new reactors deployment and life extension of existing ones. Japan is projected to restart almost all of its suspended reactors by 2040 in TGT, aiming to restore nuclear power's share to 20% of its total power generation. In Korea, extended operation of existing reactors coupled with

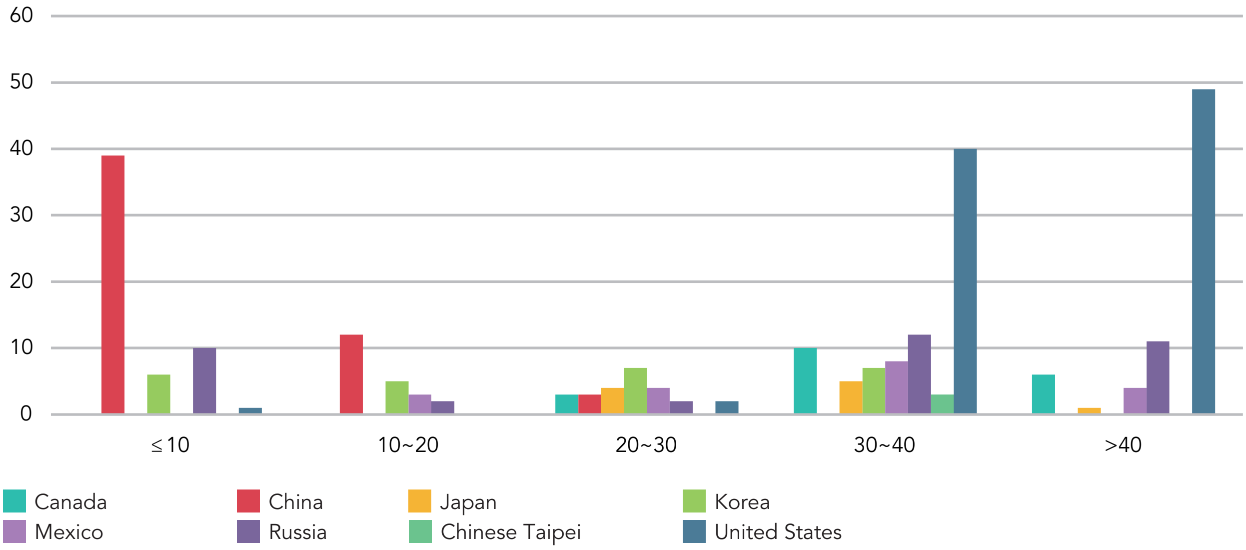
6 Idled capacity refers to existing nuclear power reactors in suspended operation for maintenance or other purposes.

additional new builds in TGT will lead to nuclear power generation levelling off at a 25% share. Indonesia has announced an ambitious target for power generation growth, which includes nuclear. It is assumed to commence utilising nuclear power as early as 2035 and continue building new capacity until the end of the projection period.

Challenges

Nuclear power plants represent some of the most complex engineering systems within the power sector, boasting total life cycles exceeding 100 years, encompassing construction, operation, and decommissioning. In addition to long life cycles, nuclear power projects are characterised by long permitting times, high capital costs, essential infrastructure and supply chains, and additional staffing requirements, including robust legal and regulatory capacity, strong safety cultures, and specialised personnel. Crucially, public acceptance remains a key requirement for the development of nuclear power.

Figure 4.14: Number of operational nuclear power reactors in different age groups, 2022



Compounded by a long-term suspension in new nuclear builds, the operational nuclear fleet in many developed economies, especially Canada and the United States, is ageing. While REF does not project a significant growth in total nuclear power capacity, substantial investments remain necessary for the lifetime extensions of existing reactors and the replacement of those nearing decommissioning. In order to achieve the projected mass expansion in TGT, the aforementioned economies have launched comprehensive plans to revitalise their nuclear energy industries.

For emerging economies, to bring their first nuclear power units online by 2035, contracts would need to be secured in the 2025-2028 timeframe. SMRs are considered promising choices for smaller power grids, data centres, or industrial clusters, offering potential advantages in lower upfront investment and higher flexibility. However, the safety and economic performance of these new technologies are still yet to be fully demonstrated. Developing suitable business models will be essential to facilitate deployment and better distribute the risks associated with first-of-a-kind projects.

5. Energy Supply

5. APEC Supply

- By 2060, the total APEC primary energy supply is projected to increase by 15% in the Reference scenario (REF) and to decrease by 2% in the Target scenario (TGT). The share of renewable energy increases in both scenarios, but fossil fuels remain the dominant energy source in APEC at 85% in 2022, though declining to 68% in REF and to 47% in TGT by 2060.
- Coal supply declines in both scenarios, with a sharper reduction in TGT due to the accelerated phase-out of coal-fired power plants. Natural gas supply increases in both REF and TGT until approximately 2035, but declines in TGT thereafter. Oil supply peaks in 2030 and 2028 in REF and TGT, respectively, with a larger decline by 2060 in TGT than in REF.
- Shaped by diverse regional dynamics, APEC's primary energy supply is projected to grow with China and the United States remaining the key suppliers. Southeast Asia records the highest percentage increase in primary supply, but ranks third in APEC in terms of absolute growth in both scenarios.

APEC's energy supply landscape has continued to evolve amid economic growth, technological shifts, and policy ambitions. From 2000 to 2022, APEC's primary energy supply grew across all major fuel categories, reflecting the region's economic growth and increasing energy demand. Over this period, APEC's total primary energy supply rose by 59%.

Total primary energy supply grew from below 232,000 PJ in 2000 to 370,000 PJ by 2022. Coal contributed the largest share of energy supply in the early years, making up roughly 29% of supply in 2000, but its relative share began decreasing after 2013, even as it remained the dominant single source in 2022. Oil supply also rose during this period and accounted for only 27% of the supply in 2022. Natural gas increased steadily, growing from 50,000 PJ in 2000 to 86,000 PJ in 2022, reflecting increased gas infrastructure and substitution for coal in power generation in some APEC economies.

Although starting from a low base, non-fossil sources also grew. Hydropower grew slowly but steadily, remaining around 2% of the mix by 2022. Wind and solar increased their share of primary energy supply from zero in 2000 to 2% by 2022, reflecting the region's policy support, technology maturation, and cost reductions for renewables.

Nuclear's share, while significant for some APEC economies, dropped over the last two decades from 7% in 2000 to 5% in 2022.

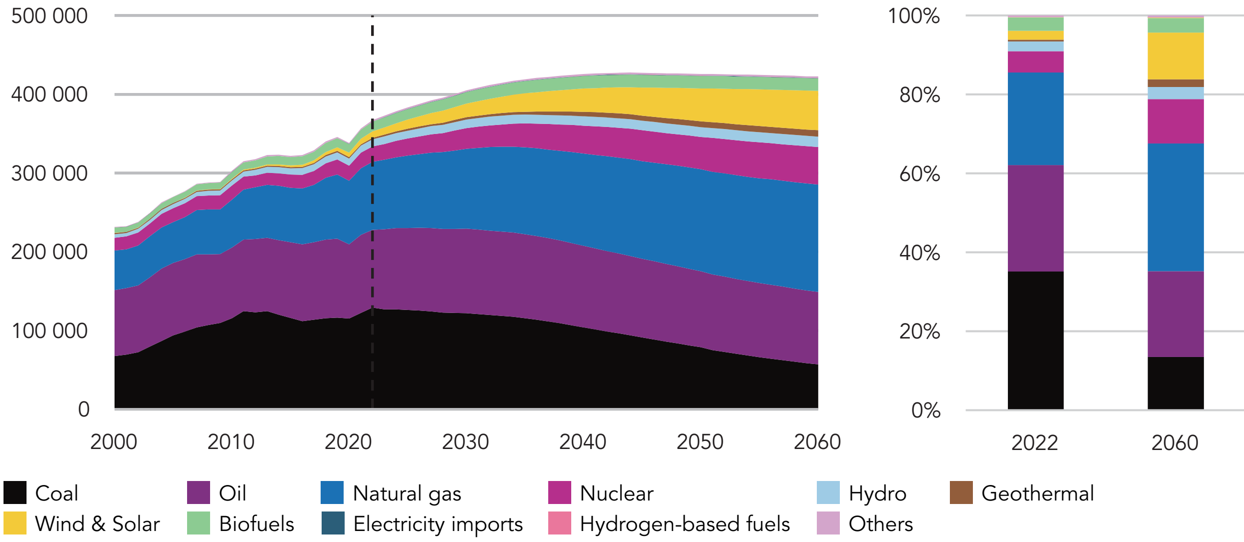
The shares of coal, oil, gas, and renewables exhibited nearly identical growth trends during this period, evidencing stable economic and demographic drivers. The relatively modest changes in the fuel mix can be attributed to existing infrastructure, long asset lives, and incremental uptake of clean energy. Growth in renewables and gas, and a gradual decrease in coal's share post-2013, mirror policy responses to environmental concerns, particularly air quality and early GHG targets.

By APEC subregion, China and Southeast Asia contributed the most to the growth in primary energy supply.

Supply by Fuel Type

Looking ahead to 2060, changes are expected in the composition and scale of APEC's primary energy supply in both the Reference (REF) and Target (TGT) scenarios. Notably, fossil fuels remain a major component of the energy mix even in the TGT scenario, where member economies pursue more ambitious decarbonisation objectives.

Figure 5.1: APEC energy supply by fuel in the Reference scenario (REF) (PJ)



In REF, APEC's total primary energy supply grows by 15% from 370,000 PJ in 2022 to 423,000 PJ in 2060, with projected shifts in the region's energy supply mix. In REF, primary energy supply remains heavily reliant on fossil fuels, accounting for 68% in 2060, with renewables reaching only 21%. Oil and natural gas supply grow modestly across APEC to a peak in 2035 before slowly declining. Imported oil continues to play a central role, while low-carbon hydrogen supplies remain very limited.

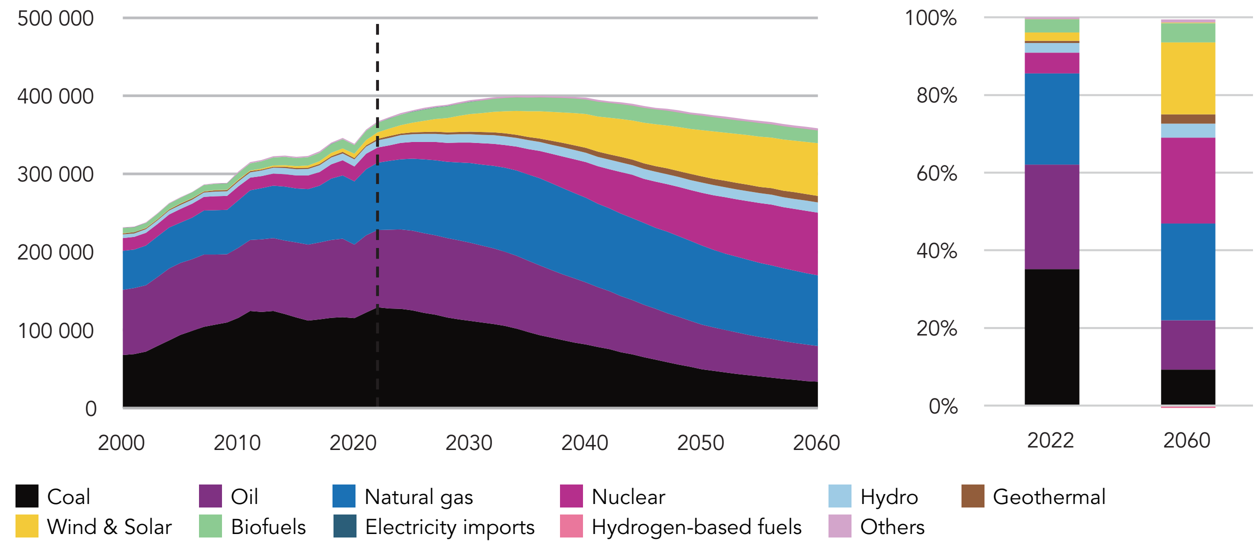
The reduction in coal supply is the largest change, even in REF, where it declines from 129,000 PJ in 2022 to only 57,000 PJ in 2060. This decline is driven by strengthened policies to reduce greenhouse gas emissions, the increasing phase-outs of coal in the power sector, and the growing competitiveness of lower-carbon alternatives such as renewables and natural gas. At the same time, Southeast Asia stands out amongst the APEC subregions with a projected coal demand increase of 2.2 times in REF. Key drivers of Southeast Asia's coal dependence include rapid economic growth, energy security priorities, a young coal fleet, and industrial expansion.

Unlike coal, APEC's oil supply declines only 7% in REF from 99,000 PJ in 2022 to 92,000 PJ in 2060. Oil remains a key energy and non-energy source in the transport and industry sectors. Improvements in fuel efficiency, greater adoption of electric vehicles, and fuel switching in the industry and power sectors contribute to oil's reduced role. However, ongoing growth in transport demand and petrochemical use limits its complete displacement.

Natural gas supply continues to expand, partially substituting for coal in the power and industry sectors. In REF, demand for natural gas is projected to grow steadily from 86,000 PJ in 2022 to 134,000 PJ in 2060, especially in the power sector, driven by economic growth, population increases, and electrification efforts, with Southeast Asia emerging as a central demand centre. Gas is viewed as a "transition fuel" due to its lower carbon intensity and flexibility for balancing variable renewable generation. Continued infrastructure development and supportive policies are expected to sustain robust gas use throughout the projection period.

Prior to 2022, nuclear energy held a modest but stable share of APEC's energy supply and is projected to expand slightly, primarily in economies with existing capacity. In contrast, modern renewables surge to become the fourth-largest energy source by 2060 in REF.

Figure 5.2: APEC energy supply by fuel in the Target scenario (TGT) (PJ)



Note: A *de minimis* quantity of net hydrogen exports is excluded from the stacked area chart for presentation purposes.

In TGT, total primary energy supply is expected to decrease by 2% from 370,000 PJ in 2022 to 360,000 PJ in 2060. In this scenario, APEC's energy supply mix undergoes substantial change between 2020 and 2060, driven by ambitious policy goals addressing decarbonisation and energy security. In 2022, fossil fuels (coal, oil, and natural gas) comprise 85% of the total energy supply, with coal accounting for about 35%, oil for 27%, and natural gas for 23%. By 2060, these shares decline markedly, with coal falling to 9%, oil to 13%, and natural gas to 25%, resulting in fossil fuels supplying 47% of primary energy supplies in 2060. The largest decline is seen in coal, with its share shrinking by 74% relative to its baseline.

Coal and oil, historically dominant fuels, experience sharp declines as governments implement strict emissions targets, retire traditional power plants and invest in lower-carbon alternatives. Nevertheless, fossil fuels are still expected to account for approximately half of APEC's energy supply by 2060. Coal demand in the power and industrial sectors contracts sharply over the projection period, with technologies such as electric arc furnaces and emerging hydrogen-based processes poised to supplant traditional metallurgical coal in steel production.

In TGT, natural gas, acts as a transitional fuel post-2022, and experiences slowing growth before also beginning to recede by 2060, stabilising at a 25% share by 2060, as increasing deployment of renewables and affordable storage curtail further expansion as renewables and storage solutions become more widespread and cost-effective.

Nuclear energy rises significantly, growing from 5% to about 22% over the projection period, reflecting its increasing contribution to low-carbon supply where new capacity is feasible, and expanding from 20,000

PJ in 2022 to 80,400 PJ in 2060. The role of hydro remains relatively constant around 2-3%, shaped by geographic and environmental limitations, rising from 9,000 PJ in 2022 to 13,000 PJ in 2060.

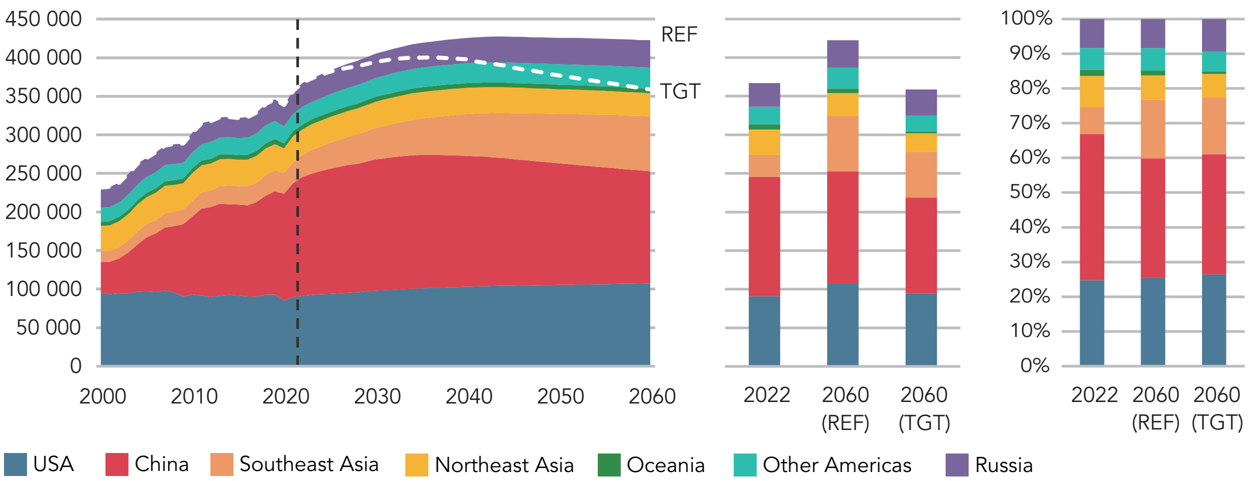
The most pronounced advance is attributed to wind and solar, which grow from 2% in 2022 to 19% of the primary energy supply in 2060, driven by declining costs, supportive policies, and improved grid integration technologies. Biofuels, geothermal, and other types of renewables also register substantial increases, spurred by technological advancements and strong government incentives. Biofuels and 'others' (including hydrogen) more than double their share, reaching 5% combined by 2060, while geothermal remains a minor but growing contributor near 2%. Overall, these changes are propelled by the region's commitment to decarbonisation, greater energy efficiency, and enhanced energy security, creating a future in which renewable and other low-carbon technologies play a central role in meeting APEC's growing energy needs.

Supply by Subregion

From 2000 to 2022, the subregional distribution of APEC's total primary energy supply exhibited substantial changes. During that period, total primary energy supply grew by 76%, but the growth was not equally distributed. The primary driver of this growth was China, whose energy supply more than tripled during this period, from an estimated 40,000 PJ in 2000 to 154,000 PJ in 2022. This exponential trajectory is consistent with unprecedented economic expansion, rapid industrialisation, and mass urbanisation within China's economy, generating immense energy demand.

On the other hand, the United States, which began as the economy with the largest energy supply at 95,000 PJ in 2000, reduced its energy supply to 91,000 PJ in 2022. This trend is characteristic of a mature economy where energy demand growth has decelerated and is accompanied by a concurrent shift in the domestic energy mix towards more energy efficient natural gas and renewable sources. Likewise, other APEC subregions, such as Northeast Asia, maintained a relatively stable supply, while developing economies in Southeast Asia and Oceania experienced notable increases, doubling their supplies from an estimated 13,000 PJ to 29,000 PJ and 5,000 PJ to 6,300 PJ, respectively.

Figure 5.3: Energy supply by APEC subregion (PJ)



As mentioned earlier, total APEC primary energy supply is projected to increase by 15% in the REF scenario and decrease by 2% in the TGT scenario between 2022 and 2060. As in the past, growth or decline trajectories are projected to vary significantly by subregion, reflecting diverse policy goals and stages of development.

China's energy supply projection shows a trend of plateau and eventual decline. Supply is projected to peak around 2035 at 165,000 PJ before falling to 124,000 PJ by 2060 in TGT. This reflects China's ambitious domestic policies to achieve carbon neutrality and peak carbon emissions before 2030, driven by a transition to a more service-based economy and substantial investments in renewable energy.

Notably, Southeast Asia's share of APEC's total energy supply increases more than twofold in both scenarios from 29,000 PJ in 2022 to 71,500 PJ in REF and 60,000 PJ in TGT, reflecting rapid economic expansion and associated demand growth.

The Other Americas subregion is projected to experience a slight decline in supply from 23,000 PJ in 2022 to 20,000 PJ. In contrast, the United States is projected to follow historical trends, with a modest increase from 91,000 PJ in 2022 to 95,000 PJ by 2060 in TGT. Northeast Asia's supply is forecasted to remain relatively stable or slightly decline, reflecting demographic trends and sustained energy efficiency improvements.

The persistence of fossil fuel use across regions is particularly evident in the slower coal decline among some economies. Broader trends toward electrification, alternative fuels, and efficiency improvement are reflected in subregion shifts, with Southeast Asia's growth outpacing other APEC subregions and driving increases in both fossil and non-fossil energy supply.

Given their size, China and the United States will continue to shape aggregate supply trends in APEC, while Southeast Asia's rapid growth accelerates the region's energy transition. The uneven pace of coal phase-down, the sustained role of natural gas, and the gradual emergence of hydrogen and nuclear all underscore the complexity and heterogeneity of APEC's energy supply landscape over the coming decades.

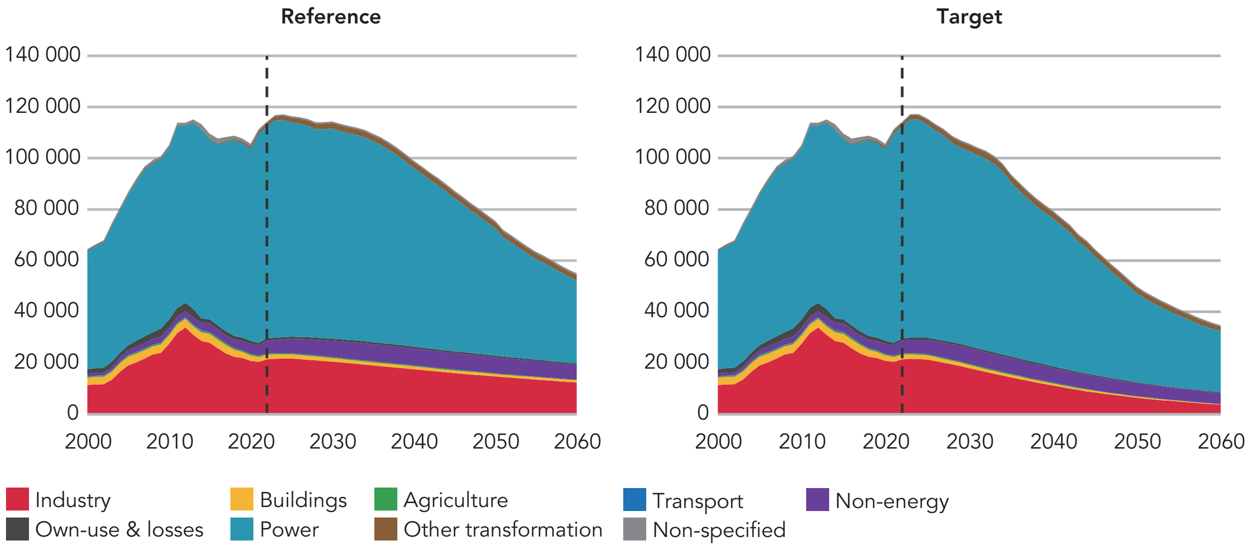
5.1 Coal in APEC

- The power sector accounted for the majority of APEC coal demand in 2022, representing 72% of total consumption, followed by industry as the second-largest consuming sector. Non-energy use of coal as a feedstock is expected to grow significantly due to coal's low cost and stable supply, particularly in the case of China's coal chemical industry.
- In the Target scenario (TGT), coal demand in the power and industrial sectors experiences dramatic reductions over the 2022-2060 period. Technologies, such as electric arc furnaces and new hydrogen-based processes, are projected to displace traditional metallurgical coal in steelmaking.
- Southeast Asia stands out amongst the APEC subregions with a projected coal demand increase of 2.2 times in the Reference scenario (REF) and 1.5 times in TGT from 2022 to 2060. Key drivers of Southeast Asia's coal dependence include rapid economic growth, energy security priorities, a young coal fleet, and industrial expansion. Early retirement of young coal assets in Southeast Asia will require innovative financing mechanisms and "just transition" policies to manage socioeconomic impacts.

Coal is consumed in various sectors of the energy system and in the coal chemical sector, including power, industry, buildings, and non-energy sectors. Coal provides baseload electricity, supports important industrial processes like steel and cement production, and ensures energy security for many economies with abundant domestic reserves. In the APEC region, coal remains a pivotal energy source despite increasing pressure for decarbonisation and the global shift toward lower emissions energy systems. Having experienced dramatic growth from 2000 through the early 2010s, coal consumption across APEC economies has become deeply embedded in the region's energy infrastructure, with the power sector alone accounting for approximately three-quarters of total consumption as of 2022. While projections indicate a substantial decline in coal use by 2060, the phase-out trajectory varies significantly across subregions. Notably, Southeast Asia presents a contrasting trend, with coal demand expected to grow substantially due to rapid economic development, energy security priorities, and a relatively young fleet of coal-fired power plants. This regional analysis examines the complex dynamics driving coal consumption and production patterns across APEC economies, highlighting both the momentum toward decarbonisation and the persistent challenges that complicate the transition away from this carbon-intensive fuel source.

Coal Consumption in APEC

Figure 5.4: Coal consumption by sector (PJ)



Historically, coal consumption across APEC economies experienced dramatic growth from 2000 through the early 2010s, nearly doubling during this period before levelling off in subsequent years. The power sector dominates this consumption, utilising approximately 72% of APEC's coal consumption in 2022, primarily for electricity generation.

Industrial applications represent another significant demand source for coal, driven largely by China's massive infrastructure development requiring substantial steel and cement production. Although industrial coal consumption has decreased from its peak in 2009, coal continued to play a crucial role in energy-intensive industrial processes due to its low cost.

In REF, APEC coal consumption is projected to decline by half between 2022 and 2060. The power sector will drive most of this reduction, with widespread coal power retirement policies expected to cut coal use for power generation by 60% through 2060. Industrial demand shows more resilience, with projections indicating a 42% decline by 2060 relative to 2022. This persistence partly arises from the significant role of metallurgical coal in the iron and steelmaking processes, where substitution by other fuels remains challenging.

Coal usage as a feedstock in the non-energy sector is expected to grow significantly in the coming decades due to its low cost and stable supply for the coal chemical industry. China, in particular, is actively expanding its coal chemical capacity and increasing production of high value-added products while reducing CO_2 emissions.

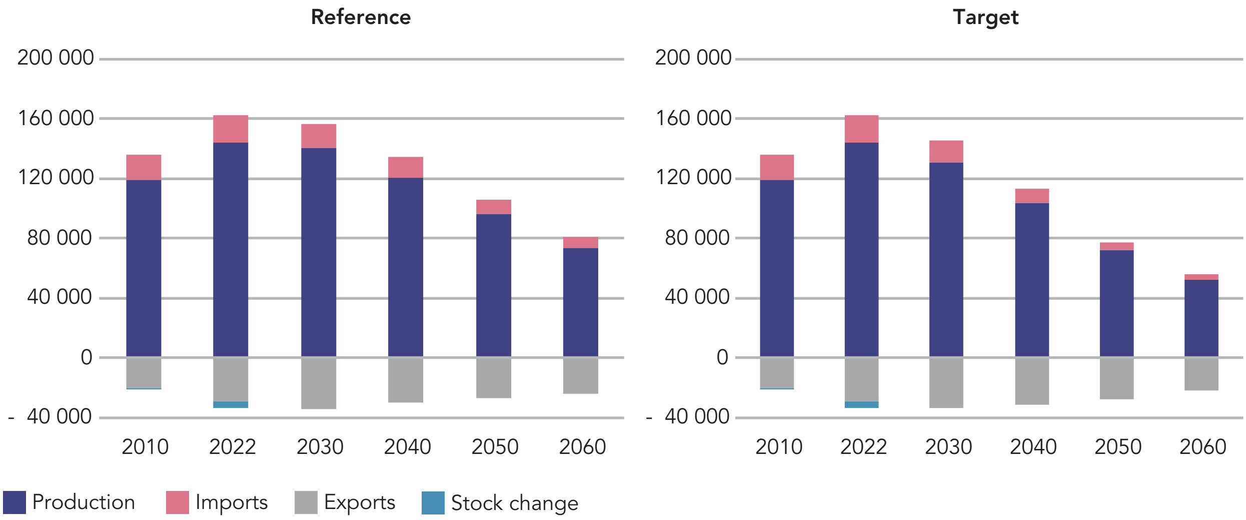
In TGT, APEC coal consumption is projected to drop by nearly 70% by 2060 compared to 2022, with coal use in the industry and power sectors experiencing more dramatic reductions than in REF. Coal consumption in the power and industry sectors declines by 71% and 82% over the 2022-2060 period, respectively.

This substantial decline results from accelerated fuel switching initiatives and increasingly stringent coal phase-down and phase-out policies across the APEC region. The momentum for the coal transition gained international support when nine APEC economies endorsed the Global Coal to Clean Power Transition Statement at COP26 in 2021, pledging to phase out coal-fired power plants by the 2030s or 2040s based on the economic situation of each economy. Despite this pledge, the *Outlook* projects that coal demand in the power sector will remain the largest at 23,860 PJ by 2060, accounting for approximately 69% of the total coal consumption by 2060.

In TGT, industrial coal demand will experience a significant reduction, declining by approximately 82% between 2022 and 2060. Electrification initiatives and alternative fuel adoption drive this transformation, while emerging technologies such as electric arc furnaces and hydrogen-based processes begin displacing traditional metallurgical coal in steelmaking toward the end of the projection period.

Coal Production, Imports, and Exports in APEC

Figure 5.5: Coal production, imports, and exports (PJ)



In REF, APEC coal production has historically mirrored consumption patterns from 2010 through 2022, and this correlation is anticipated to persist as output decreases from 143,900 PJ in 2022 to 73,500 PJ by 2060.

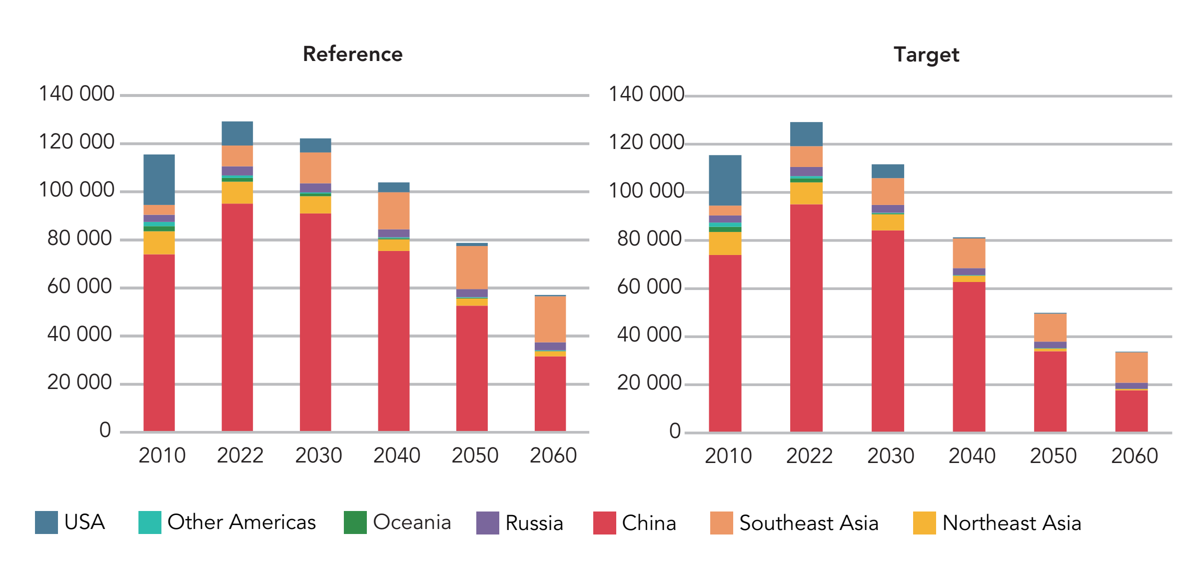
Coal imports experienced substantial growth before 2022. However, coal imports are projected to decline by approximately 60% through 2022-2060, landing at 7,647 PJ by 2060. Major APEC coal importers in 2022 include China; Japan; Korea; Malaysia; and Chinese Taipei, accounting for 80% of total APEC coal imports.

The APEC region includes several of the world's largest coal-producing economies, such as Australia; China; Indonesia; Russia and the United States. Despite reduced domestic output, APEC is expected to maintain its position as a dominant coal supplier to the world, with coal exports projected to be approximately 24,000 PJ by 2060.

In TGT, coal production is expected to decline more quickly with a 15% reduction compared to REF. This reduction is due to the weakness of coal demand both within APEC economies and globally, resulting in a corresponding decrease in international coal trade. Coal imports and exports are projected to decline by approximately 82% and 29% over 2022-2060, respectively.

Coal Usage in Southeast Asia

Figure 5.6: Coal supply by subregion (PJ)



Coal supply is projected to decline in almost all APEC subregions except Southeast Asia, where coal demand is projected to increase substantially in both scenarios. Southeast Asia's coal consumption is expected to grow by 120% in REF and 50% in TGT between 2022 and 2060, with power generation accounting for three-quarters of additional coal use. This growth trajectory is driven by several interconnected factors that distinguish Southeast Asia from other APEC subregions.

First, the Southeast Asia subregion has experienced rapid growth in both economic and energy demand. Energy demand is growing at twice the global average rate, driven by rapid economic development. The subregion stands out as one of the few areas where GDP and emissions continue to rise in tandem, signalling that Southeast Asia's economic development remains highly carbon intensive. Coal-fired power plants currently generate over 40% of the region's electricity, making it a critical component of the region's energy security strategy. At the same time, coal accounts for 80% of power sector emissions, underscoring the challenges of decarbonising the electricity sector in Southeast Asia.

Second, affordability and energy security are top priorities in this subregion. The ongoing dependence on coal is due to its affordability and widespread availability during worldwide energy price fluctuations. Energy security remains a top priority, especially after the recent global energy crisis highlighted the subregion's vulnerability to fuel price shocks. Southeast Asia's commitment to coal reflects a combination of economic pragmatism and the imperative to maintain affordable, reliable energy supplies for growing populations and economies.

Third, most coal-fired power plants in Southeast Asia were built after 2000, creating a young fleet that commits the subregion to significant emissions through 2060. In the REF scenario, around 57 GW of coal-fired power plants will be added between 2022 and 2060 from 103 GW in 2022, representing one of the most significant challenges to rapid decarbonisation efforts across the subregion.

Finally, the demand for coal in the industrial sector is increasing in Southeast Asia, where coal accounts for 30% of industrial energy needs. This trend is exemplified by a rise in nickel production in Indonesia, reflecting the subregion's manufacturing-driven economic growth. Industrial applications account for a significant portion of coal consumption, with new captive coal plants being planned by industrial facilities. These developments persist despite existing regulations, potentially undermining economies' climate commitments.

Overall, these factors underscore both the importance of coal in Southeast Asia, but also the complexities of reducing reliance on this fuel type. Transitioning this subregion away from coal will require a multifaceted approach that balances energy security, affordability, and climate commitments.

5.2 Crude Oil in APEC

- APEC crude oil supply peaks in the 2030s, then declines in both the Reference (REF) and Target (TGT) scenarios, though at different rates. In REF, supply peaks in 2030 and falls gradually to 90% of 2022 levels by 2060. In TGT, supply peaks earlier, in 2028, and drops faster to around 56% of 2022 levels by 2060, reflecting higher electric vehicle (EV) adoption and accelerated decarbonisation measures.
- Shifts in refining capacity and petroleum product demand are expected to reshape crude oil trade flows. Total APEC refining capacity is projected to peak in 2030 and then decline through to 2060. Several APEC member economies are expected to adjust their refinery yields, shifting from transportation fuels such as gasoline and diesel toward petrochemical feedstocks such as naphtha.
- Crude oil import dependence is projected to increase in several APEC subregions, such as China and Southeast Asia, as domestic production declines. This growing reliance on external supplies will amplify exposure to uncertainties and supply chain risks.

Crude oil remains a vital commodity for APEC economies, accounting for 27% of total APEC total primary energy supply (TPES) in 2022, second only to coal at 35%. The scale of crude oil supply and consumption positions APEC as a pivotal player in shaping global crude oil dynamics, as it includes some of the world's largest oil producers, such as China; Russia; and the United States, as well as major consumers, including China; Japan; and the United States.

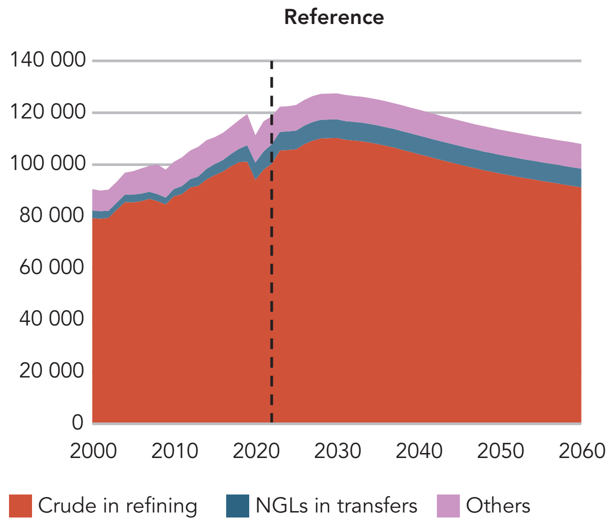
According to the 9th Outlook results, crude oil production, imports, and exports across APEC are projected to rise steadily until 2030, supported by technological advances on the production side, such as unconventional oil production, as well as robust demand from growing Southeast Asian economies and China's rising import needs.

After 2030, crude oil TPES is projected to decline across both scenarios. In REF, it falls by 15% by 2060, while in TGT the decline is steeper at 55%. As a result, by 2060, crude oil's share of TPES is projected at approximately 21% in REF and 13% in TGT.

These trends mark a turning point for APEC economies, which must navigate the dual challenges and opportunities of balancing energy security with decarbonisation goals, while adapting to shifting supply chains and mitigating heightened risks amid the global energy transition.

Crude Oil, NGLs, and Other Hydrocarbon Supply in APEC

Figure 5.7: APEC crude oil, NGLs, and other hydrocarbon demand by sector (PJ)

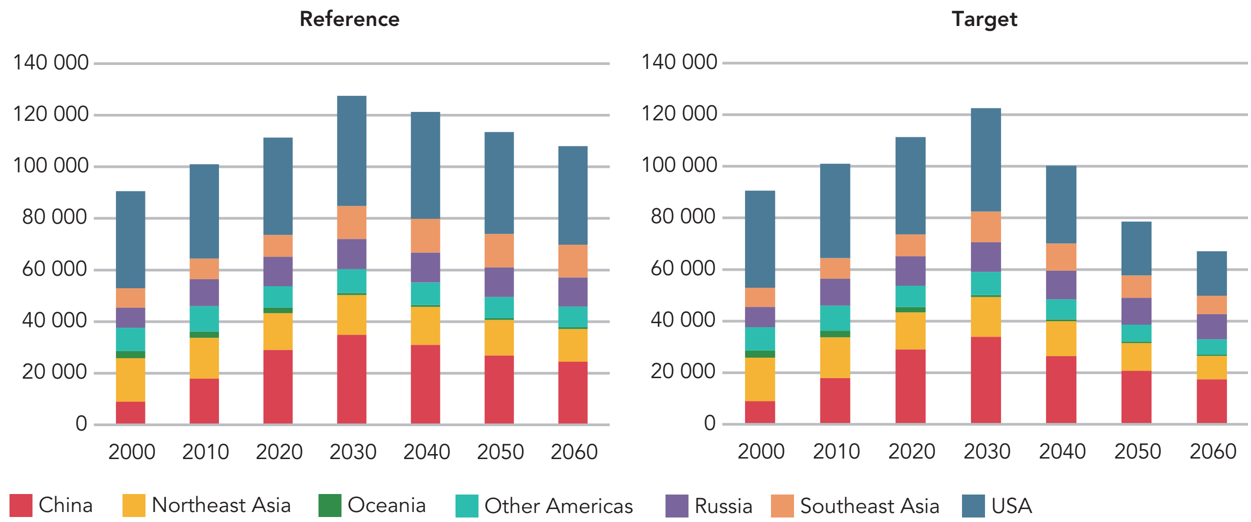


Note: "Others" includes crude oil, NGLs, and other hydrocarbons used in demand sectors, non-refining transformation, losses, and own-use.

In both the REF and TGT scenarios, total APEC crude oil supply is projected to peak around 2030 before gradually declining through 2060. In REF, supply falls to 107,982 PJ by 2060, about 85% of the 2030 peak. In TGT, supply peaks earlier, in 2028, and declines more sharply to 67,085 PJ by 2060, representing just 53% of the 2028 peak. This contrast highlights a more prolonged reliance on crude oil in REF compared with TGT.

Refinery capacity is a major driver of these demand trends. Since crude oil in most APEC economies is primarily used as refinery feedstock, utilisation rates are closely tied to petroleum product demand. Capacity is projected to peak at about 60 million barrels per day (mb/d) in 2030, then decline to 50.1 mb/d in REF and 30.7 mb/d in TGT by 2060. The sharper reduction in TGT reflects faster adoption of electric vehicles and stronger decarbonisation policies, which depress gasoline and diesel demand more quickly.

Figure 5.8: APEC crude oil, NGLs, and other hydrocarbon demand by subregion (PJ)



China and the United States dominate APEC demand for crude oil, NGLs, and other hydrocarbons, together accounting for roughly 60% in 2022. In REF, their combined share stays near this level through 2060. In TGT, however, the share begins to erode after 2030, falling to about 51% by 2060, as demand declines faster in China. Other subregions contribute between 8-13%, while Oceania's share remains marginal at 1-2%.

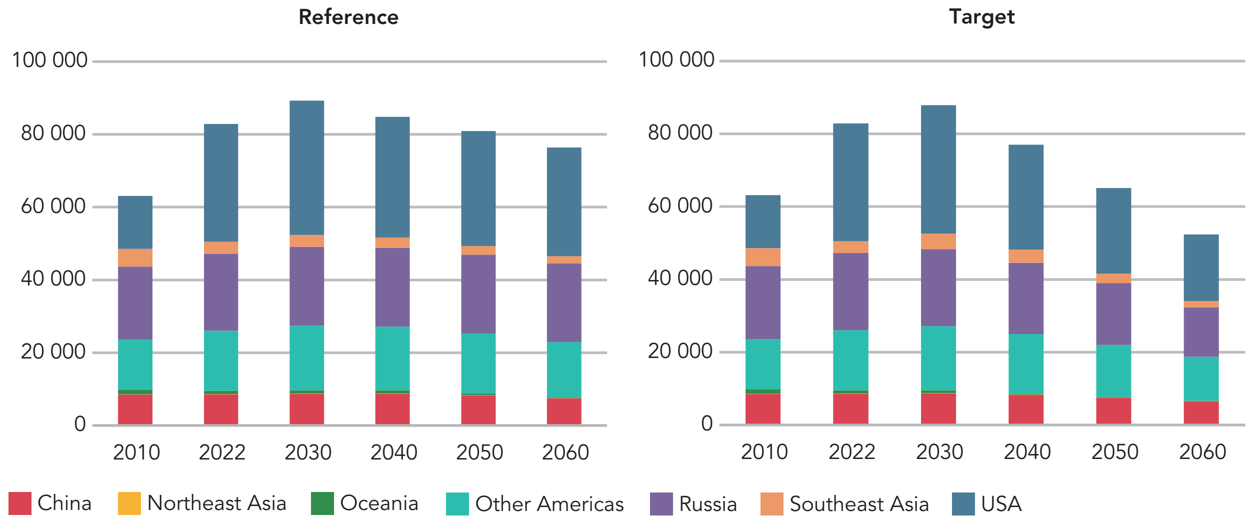
In China, transport fuels drive crude demand, which grows until 2030 before declining as EV adoption accelerates and population growth slows. In the United States, demand falls by about 15% from 2022 to 2060 in REF, in line with a similar reduction in refinery capacity. In TGT, there is a steeper contraction as gasoline and diesel give way to electricity and hydrogen in the transport sector.

Northeast Asia currently accounts for about 13% of total APEC crude oil demand, largely from Japan and Korea. In REF, demand gradually tapers due to shrinking transport fuel consumption. In TGT, however, the subregion's share remains steady as refiners shift yields toward petrochemical feedstocks. Japan's demand steadily contracts, with refinery capacity dropping from 3.2 mb/d in 2022 to 2.2 mb/d in REF and 0.8 mb/d in TGT by 2060. Korea's decline is milder, as it continues exporting diesel and adjusting yields toward naphtha.

Russia's crude oil demand was approximately 11,380 PJ in 2022, representing roughly 10% of APEC total demand. In REF, demand remains broadly stable through 2060, even as refinery capacity declines from 6.8 mb/d in 2022 to 5.6 mb/d in 2060. This stability is supported by shifts in refinery yields that increase jet fuel output while reducing gasoline production. In TGT, transport demand falls more sharply, and refinery capacity contracts further to 4.9 mb/d by 2060. As a result, Russia's crude oil demand is lower in absolute terms but rises in relative share, reflecting the overall regional decrease.

Crude Oil, NGLs, and Other Hydrocarbon Production in APEC

Figure 5.9: Crude oil, NGLs, and other hydrocarbon production by subregion (PJ)



Crude oil production in APEC is projected to peak in 2030 before gradually declining toward 2060. The main contributors to crude oil production are Canada; China; Mexico; Russia; and the United States.

The United States is expected to remain the top producer of crude oil in APEC and likely the number one producer in the world. The high level of production in the United States is supported by advanced technology, such as horizontal drilling, particularly for shale oil production.

Russia is expected to remain the second-largest crude oil producer in the APEC region, with vast reserves in Western and Eastern Siberia, as well as the Arctic region. In addition, its established infrastructure helps to support sustained production levels.

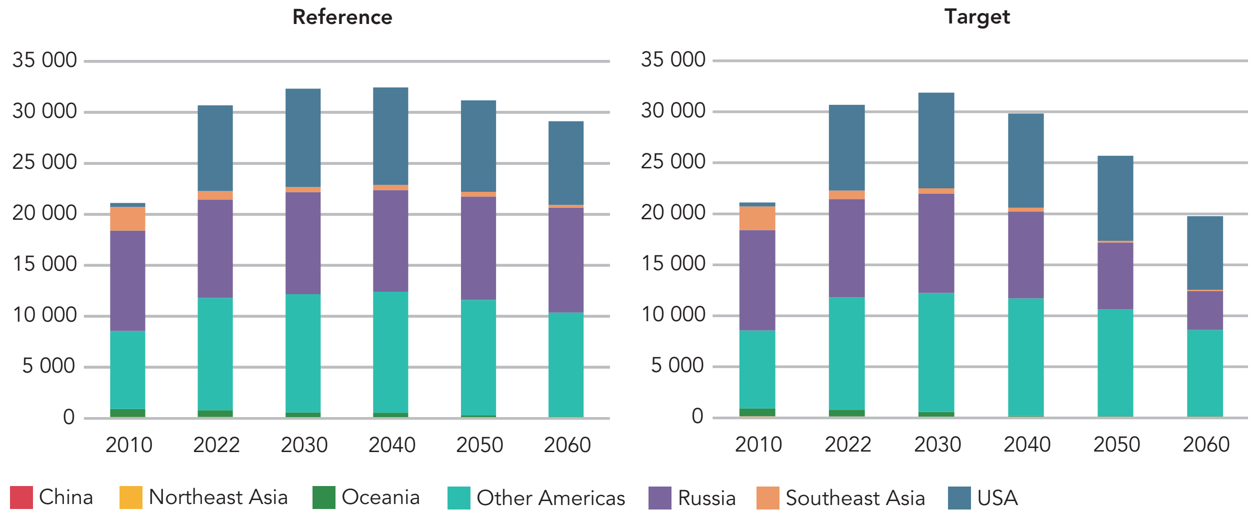
Canada is expected to maintain relatively high production levels due to abundant reserves in the Alberta region. Production is further supported by technological advancements in oil sands extraction and the Trans Mountain Pipeline (TMX) Expansion project, which improve efficiency and economic viability.

Mexico is expected to sustain relatively high production levels and remain a net exporter of crude oil throughout the projection period, supported by abundant oil reserves in onshore conventional, onshore tight oil, and shallow water areas. Production is projected to rise to around 2.4 mb/d before gradually declining to approximately 2 mb/d by 2060.

Despite maturing fields, China's crude oil production is expected to remain significant and is anticipated to peak at around 3.9 mb/d in 2032, before gradually declining towards 2060. China is expected to maintain its high production levels due to domestic energy security needs, as economic growth continues to increase demand for oil in the industrial and transport sectors, leading to a prioritisation of domestic consumption over exports.

Crude Oil, NGLs, and Other Hydrocarbon Trade in APEC

Figure 5.10: Crude oil, NGLs, and other hydrocarbon exports by subregion (PJ)



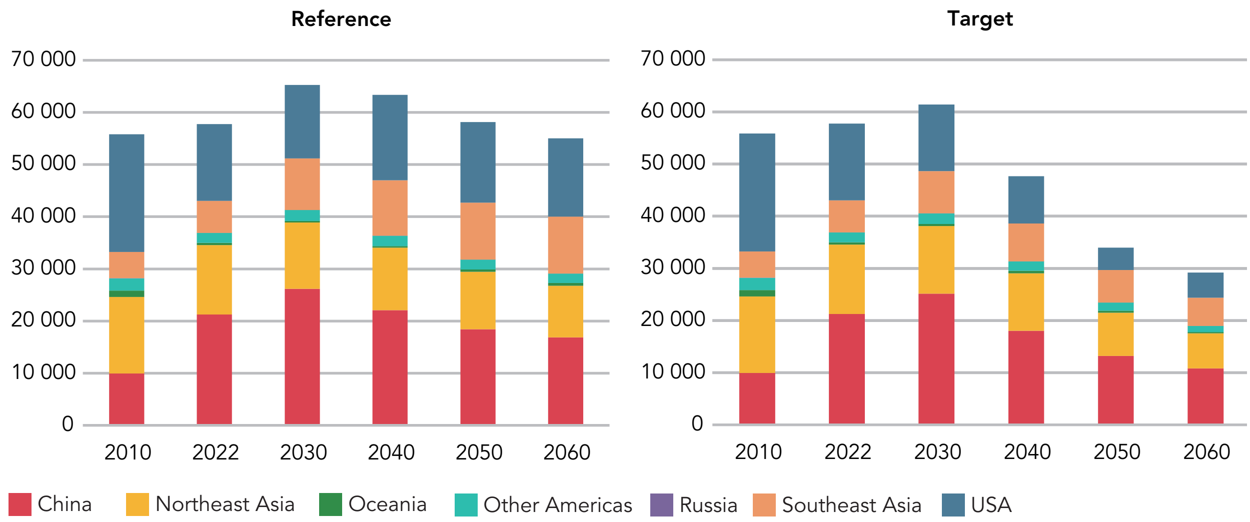
In both the REF and TGT scenarios, the largest crude oil exporters in APEC are Canada; Russia; and the United States.

The United States in REF is projected to maintain its crude oil export level at around 4 million barrel per day, while in TGT, this export level is expected to decline slightly due to declining global oil demand. The United States exports the majority of its light sweet crude oil and imports heavier crude oil to maximise the economics of refining capacity. U.S. crude oil exports are supported by a diverse set of destinations, including Europe, East Asia, Southeast Asia, and the Other Americas, which ensures continued and sustainable export activity.

Russia's crude oil exports in REF are expected to remain steady through 2060, supported by stable production levels and strong demand from China and India. In TGT, exports are anticipated to decline after 2030 due to the global demand decline, particularly from China.

Canada's high crude oil exports are driven by the composition and location of its production. Most of Canada's output consists of heavy crude and bitumen, primarily produced in western Canada, while its eastern refineries are configured for light, sweet crude, necessitating imports for domestic refining and creating a reliance on exports to manage surplus production. Exports are further supported by strong U.S. demand, which accounts for 92-98% of Canadian exports, and emerging opportunities in Asia, including China and Korea, facilitated by the Trans Mountain Expansion pipeline, operational since 2024. In both REF and TGT, Canada's vast oil sands reserves, technological advancements in extraction, and robust transport infrastructure (including pipelines and rail) support exports peaking at over 4 mb/d around 2030, before potentially declining due to weaker global crude oil demand.

Figure 5.11: Crude oil, NGLs, and other hydrocarbon imports by subregion (PJ)



Total crude oil and NGL imports for APEC economies are expected to exceed 60,000 PJ by 2030 before declining towards 2060. The largest crude oil importers in APEC in both REF and TGT are China; Japan; Korea; and the United States. In most APEC economies, imports are driven primarily by the need to supply refineries, ensuring a stable provision of petroleum products for the industrial and transportation sectors.

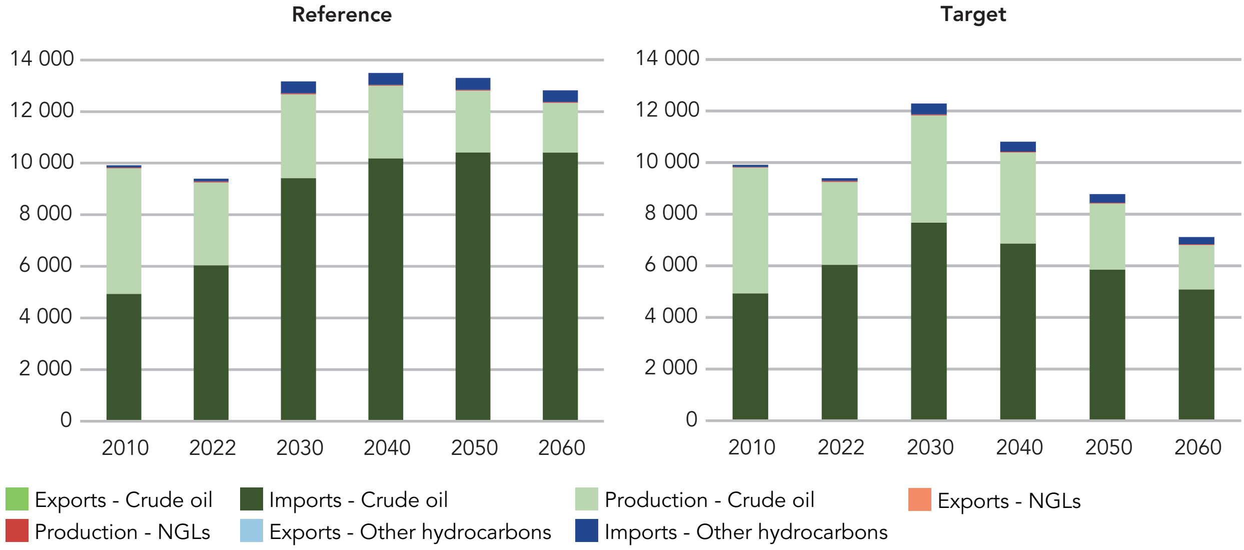
China is projected to become the main importer of crude oil, driven by expanding refinery capacity, which is expected to peak in 2028 and require abundant crude feedstock. After 2030, as demand declines due to high EV adoption and expanded rail networks, refining capacity is projected to fall, reaching 12.7 mb/d in REF and 9.0 mb/d in TGT by 2060. Despite this decline, domestic production will remain below consumption levels, increasing China's reliance on imports and necessitating diversified supply sources from economies such as Canada; Iraq; Malaysia; Oman; Russia; and Saudi Arabia.

Despite significant current and projected production of primarily light crude oil, the United States continues to import substantial volumes of heavy crude to optimise refinery configurations and meet market demand. In REF, domestic gasoline demand declines due to rising EV adoption, while diesel consumption and exports remain relatively stable, and LPG and ethane production steadily increase toward 2060. As a result, U.S. refinery capacity declines by only 15% compared with 2022 levels. Crude oil production peaks in the 2030s and gradually falls thereafter due to reserve depletion, leading to a rise in crude oil and NGL imports that peaks around 2040 before slightly declining by 2060. In TGT, accelerated EV adoption and industrial electrification drive a faster decline in gasoline demand and crude oil production. This results in a more rapid reduction in refinery capacity, reaching only 30% of 2020 levels by 2060, and crude oil imports similarly fall to 30% of 2022 levels.

Korea relies heavily on crude oil imports to supply its six large refineries, which have a combined capacity of 3.4 mb/d. The economy is expected to maintain refinery capacity while upgrading yield ratios to produce petroleum products such as naphtha, diesel, and gasoline. In REF, refining capacity declines by only 17% by 2060, while in TGT it decreases by 21%. By maintaining its refinery capacity, Korea can convert imported crude oil into petroleum products. Gasoline and diesel can be exported, while naphtha can serve as feedstock for the domestic petrochemical industry.

Japan remains a moderate crude oil importer, with volumes declining due to reduced transportation fuel demand, yet it continues to process substantial amounts domestically for petrochemical production. Japan operates 19 refineries and has a strong petrochemical industry presence. Refining capacity is projected to decline from 3.2 mb/d in 2022 to 2.2 mb/d in REF and 0.8 mb/d in TGT by 2060. Refinery yield ratios are expected to shift, producing less transportation fuel such as gasoline and diesel while increasing output of feedstocks like naphtha for the petrochemical sector.

Figure 5.12: Southeast Asia subregion – Production, exports, and imports of crude, NGLs, and other hydrocarbons (PJ)



Many Southeast Asian economies are experiencing declining crude oil production alongside rapidly growing demand driven by demographic and economic expansion, resulting in an increasing dependence on crude oil imports.

Investment constraints are a key barrier to new production in the subregion. The remaining reserves are mostly located in deepwater areas that require significant capital investment and long payback periods. These challenges make projects less attractive, prompting some international oil companies to scale back their involvement in this subregion.

In REF, crude oil imports in Southeast Asia are primarily used for transportation fuels. While Malaysia and Singapore have advanced refining and petrochemical capacity, other economies in the subregion have more limited integration into high-end value chains. With much of the crude oil imported from the Middle East, the subregion maintains strong connections to global supply networks, though there could be exposure to potential supply disruptions near the Strait of Hormuz. Given the heavy reliance on crude oil for transportation, wider adoption of electric vehicles could help reduce import dependence, as reflected in the TGT scenario, where demand is projected to be lower than in REF due to increased EV deployment.

Total crude oil exports from Southeast Asia are expected to remain below 1,000 PJ, considerably smaller than those of leading APEC exporters, such as Canada; Russia; and the United States. These exports mainly originate from oil-producing economies such as Indonesia and Malaysia, which continue to export a portion of their production due to refinery configuration constraints. Most Southeast Asian economies are projected to experience a slight increase in exports toward 2030 as a result of production enhancement and optimisation of existing fields. Beyond 2030, exports are expected to gradually decline through 2060, primarily due to reserve depletion.

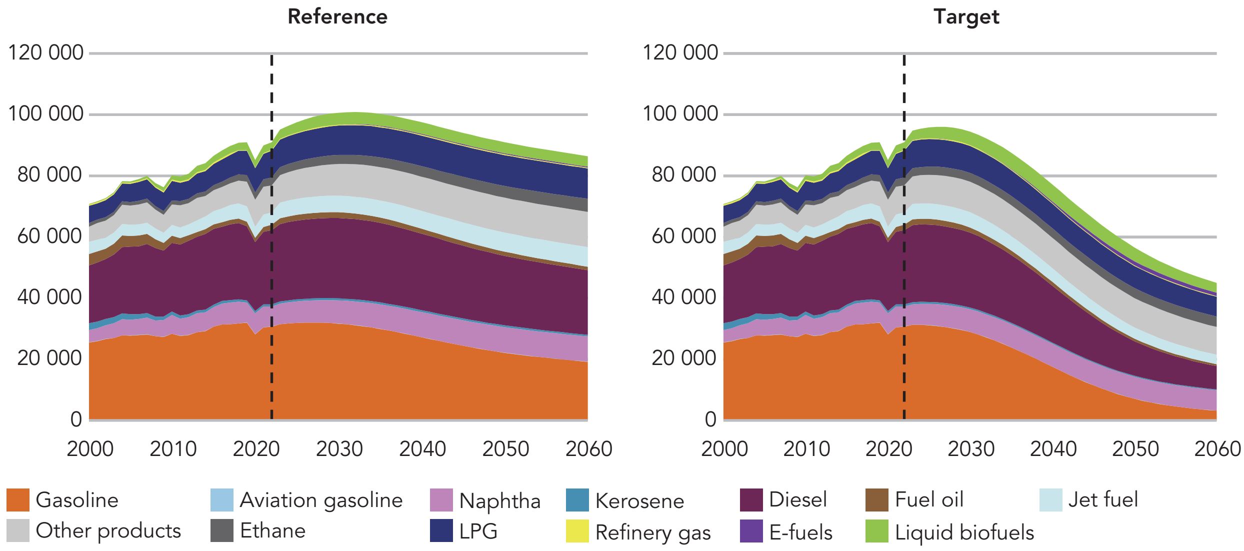
5.3 Refining in APEC

- APEC's refined fuels consumption peaks in 2026 and declines by 55% by 2060 in the Target scenario (TGT), compared to a 2023 peak and a 15% decline in the Reference scenario (REF). Gasoline and diesel, which currently dominate the fuel mix, fall to a combined 24% share by 2060 in TGT due to declining internal combustion engine vehicle use, while demand for petrochemical feedstocks, like naphtha and LPG, remain strong, and liquid biofuels and e-fuels experience significant growth.
- APEC's total refining capacity peaks around 2030 and then declines, especially in TGT where it drops nearly 50% by 2060. Major reductions occur in China and the United States, with refinery capacities in other subregions declining slightly over the projection period.
- Since becoming a net exporter of refined products in 2015, APEC's exports rose to 4,250 PJ (5% of total consumption) in 2022 and are projected to reach 31% by 2060 in TGT, driven by falling domestic demand and strong exports from China; Russia; and the United States, along with subregional differences such as rising import dependency in Oceania and fluctuating dependence in Southeast Asia.

Refined products are comprised of petroleum products, liquid biofuels, and e-fuels. In the coming years, the consumption and production of these products in the APEC region reflect a period of significant transformation driven by shifting consumption patterns, evolving refinery capacity, and ongoing efforts to decarbonise the energy system. In both the Reference (REF) and Target (TGT) scenarios, refined product consumption peaks early, by 2032 in REF and 2026 in TGT, followed by sustained declines through 2060. Gasoline and diesel remain key components of the fuel mix, although their share of refined products diminishes sharply in TGT due to rising electrification in the transport sector. Meanwhile, demand for petrochemical feedstocks, including naphtha and LPG, continues to grow across most APEC subregions. Refining capacity, led by China and the United States, also peaks around 2030 before declining in response to shifting demand and policy goals. Trade flows adjust accordingly: diesel remains the dominant export product, largely driven by the United States and Russia. Imports of products like naphtha and e-fuels vary between the two scenarios, reflecting broader trends in refining efficiency, feedstock demand, and energy transition strategies.

Total Consumption of Refined Products in APEC

Figure 5.13: Total consumption of refined products (PJ)



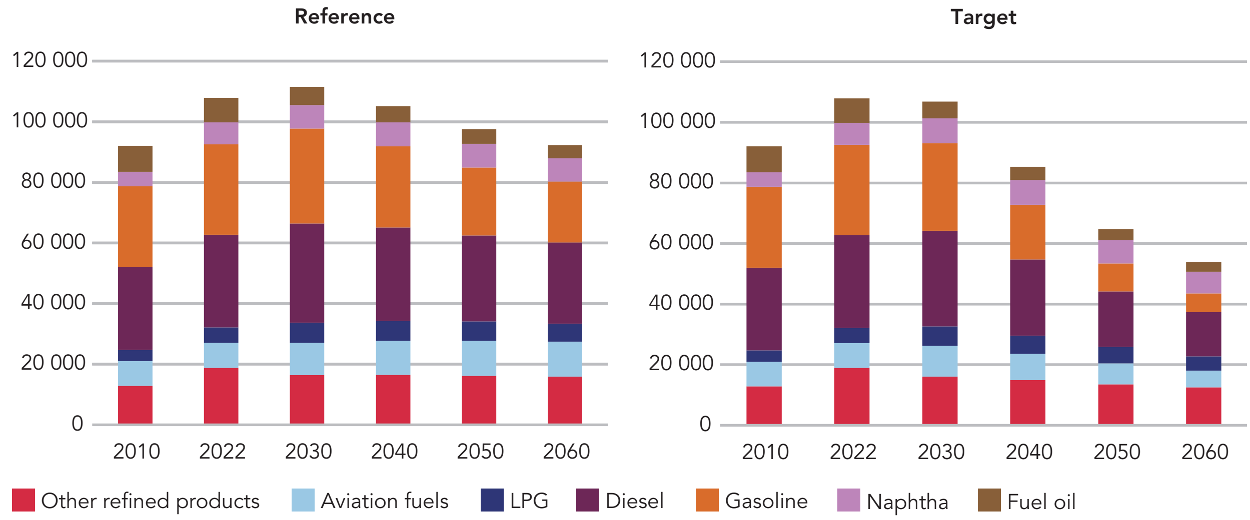
In the APEC region, total consumption of refined products in REF peaks in 2032 at over 100,000 PJ. In TGT, it peaks in 2026 at 96,000 PJ. Following these peaks, total consumption declines 15% in REF and 55% in TGT by 2060.

Gasoline and diesel currently dominate the total consumption mix, maintaining their combined ratio at approximately 50% to 2060 in REF. In TGT, their combined mix declines to 24%, reflecting a rapid decline in internal combustion engine vehicle stock. Consumption of naphtha and LPG continues to be strong due to growing demand for petrochemical feedstocks in most of the APEC subregions.

Consumption of liquid biofuels is projected to increase from 2,500 PJ in 2022 to higher than 3,000 PJ by 2060 in both scenarios. Similarly, consumption of e-fuels is projected to increase to 300 PJ in REF. In TGT, it increases to 1,100 PJ, reflecting a greater effort to decarbonise the transport sector.

Refined Product Outputs in APEC

Figure 5.14: Refined product outputs (PJ)

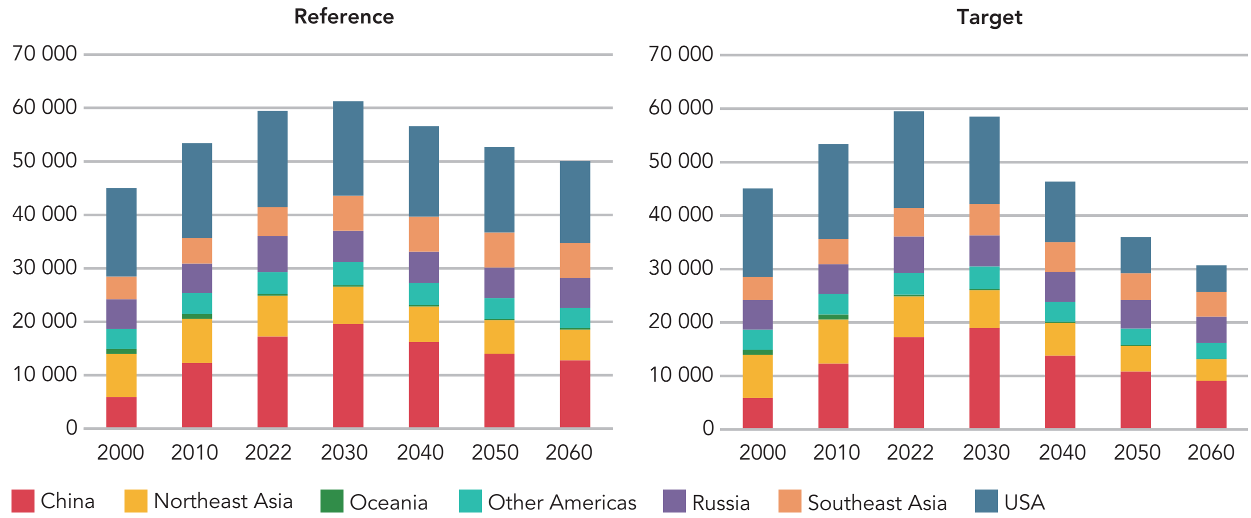


APEC's total refined product output in 2022 was approximately 107,900 PJ. Gasoline and diesel accounted for the largest shares at about 30,000 PJ each, with their combined share reaching 56%. Outputs of gasoline and diesel are expected to remain significant in both scenarios, with more rapid declines in gasoline in TGT due to the increased adoption of electric vehicles across the APEC economies.

Outputs of "other refined products", which include heavy ends such as bitumen and base oils for lubricants, remain strong in both scenarios. Outputs of naphtha and LPG are assumed to increase, especially in economies where refinery and petrochemical operations are well integrated. The projected change in refined product mix is achieved by incremental capital investments in refining equipment and changes in feedstock specifications.

Refining Capacity in APEC

Figure 5.15: Refining capacity (thousand barrels per day - kb/d)

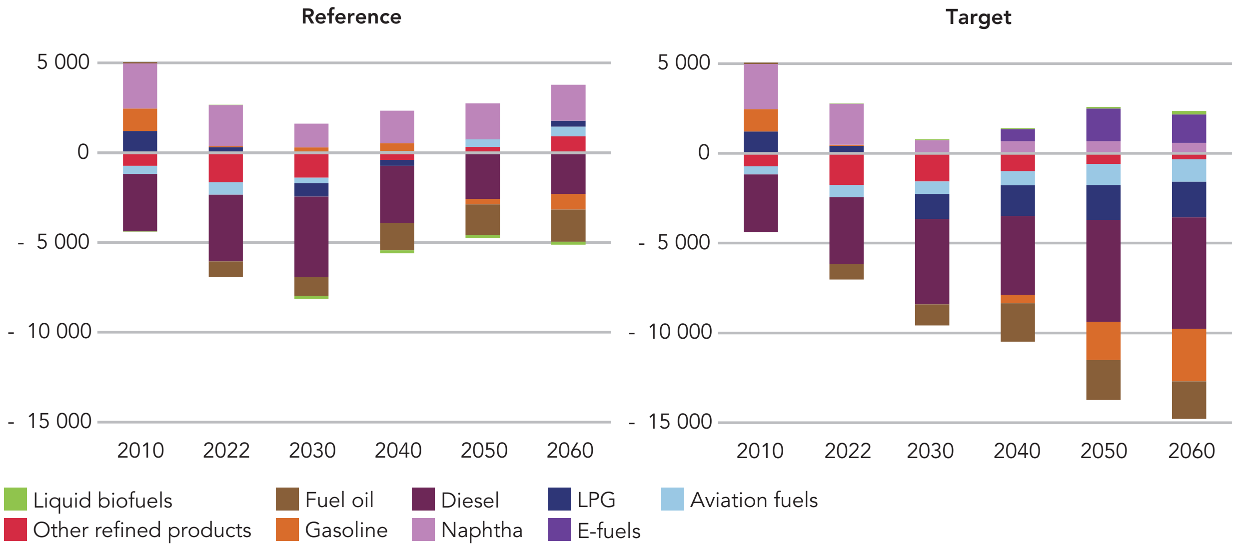


Total refining capacity (crude oil distillation capacity) in APEC refineries is expected to peak in 2028 at 61.3 million barrels per day (mb/d) and 59.9 mb/d in REF and TGT, respectively. After these peaks, capacities decline to 50.1 mb/d in REF and further to 30.7 mb/d in TGT by 2060.

In APEC, China and the United States lead in refining capacity, together accounting for over 50% of APEC's total through 2060 in REF, though their combined share falls to 45% by 2060 in TGT. China significantly increased its capacity from 2000 to 2022, and is expected to peak in 2030. Post-peak, China's capacity declines in both scenarios as less efficient refineries are closed to align with consumption and China's policy goals. U.S. refining capacity peaked in 2019, followed by declining trends in both REF and TGT. The refining capacity of other subregions, which includes Northeast Asia, Russia, Southeast Asia, Other Americas, and Oceania, declines slightly through 2060, except for Southeast Asia in REF where total refining capacity is assumed to maintain its peak level at 6.5 mb/d to support its economic growth.

Imports and Exports of Refined Products and Liquid Biofuels in APEC

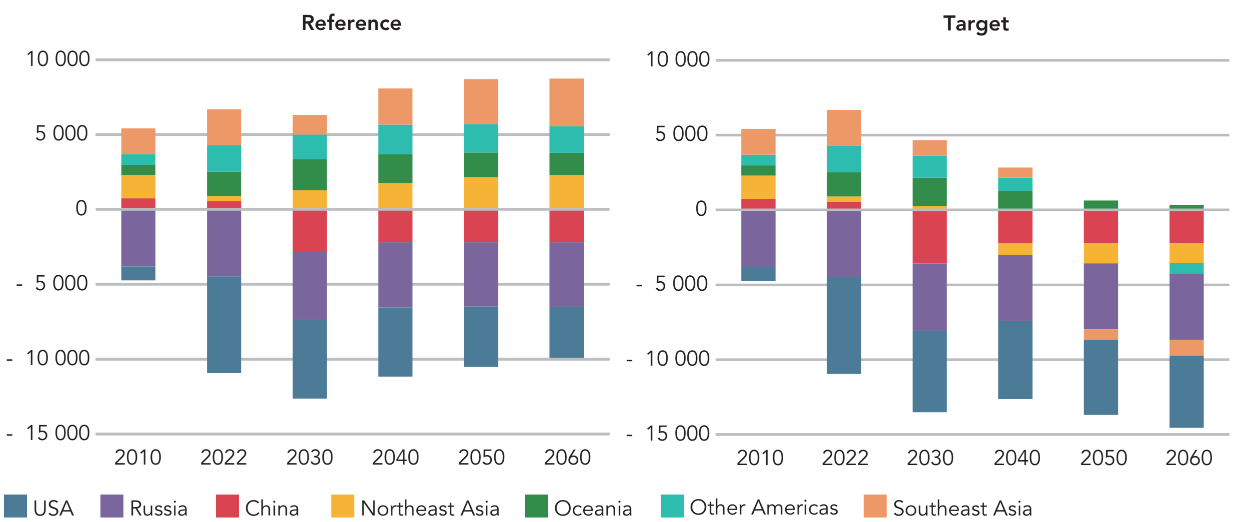
Figure 5.16: Refined products and liquid biofuels net imports (PJ)



Diesel dominates APEC's net exports of refined products in both REF and TGT, largely driven by exports from China; Russia; and the United States subregions. Diesel exports together with "other products" increase significantly in TGT as their domestic consumption declines more rapidly than refinery outputs.

Imports of naphtha for petrochemical stocks remain high in REF, but decline in TGT as refineries are assumed to improve their processes and crude oil input mixes to produce a higher ratio of naphtha. E-fuels imports emerge in TGT in the medium and long term, driven by growing demand and increasing decarbonisation efforts.

Figure 5.17: Net refined product imports by subregion (PJ)



In REF, Northeast Asia, Oceania, Other Americas, and Southeast Asia dominate in net product imports through 2060. In TGT, Other Americas and Northeast Asia experience marginal net exports from excess transport fuels as domestic consumption declines and remaining refineries shift towards producing petrochemical feedstocks.

Russia and the United States are expected to maintain their net exports at current levels through 2060. The exports, mostly in the form of diesel, are driven by these two economies' access to domestic crude oil production and/or large, sophisticated refineries, and are assumed to serve growing markets both in APEC and other regions, including southern Africa and South America. China is expected to become a net exporter of refined products following recent additions to its refining capacity. However, net exports decline in both scenarios as China phases out smaller refineries to improve the overall efficiency of its refining sector.

5.4 Natural Gas in APEC

- Natural gas is currently a key component of APEC's energy mix, accounting for 17% of final energy consumption and 20% of electricity generation in 2022.
- Natural gas supply is projected to grow steadily through 2060 in the Reference scenario (REF), especially in the power sector, fuelled by economic growth, population increases, and electrification efforts, with Southeast Asia emerging as a major demand centre. In the Target scenario (TGT), natural gas demand peaks in the 2030s and declines thereafter due to greater renewables deployment in the power sector and substitution of gas for electricity in the end-use sectors.
- Natural gas production and exports in APEC are led by Russia and the United States, while demand growth in China and Southeast Asia drives gas imports. Gas imports, especially LNG in Southeast Asia, could expose APEC economies to gas market price volatility and energy security risks.

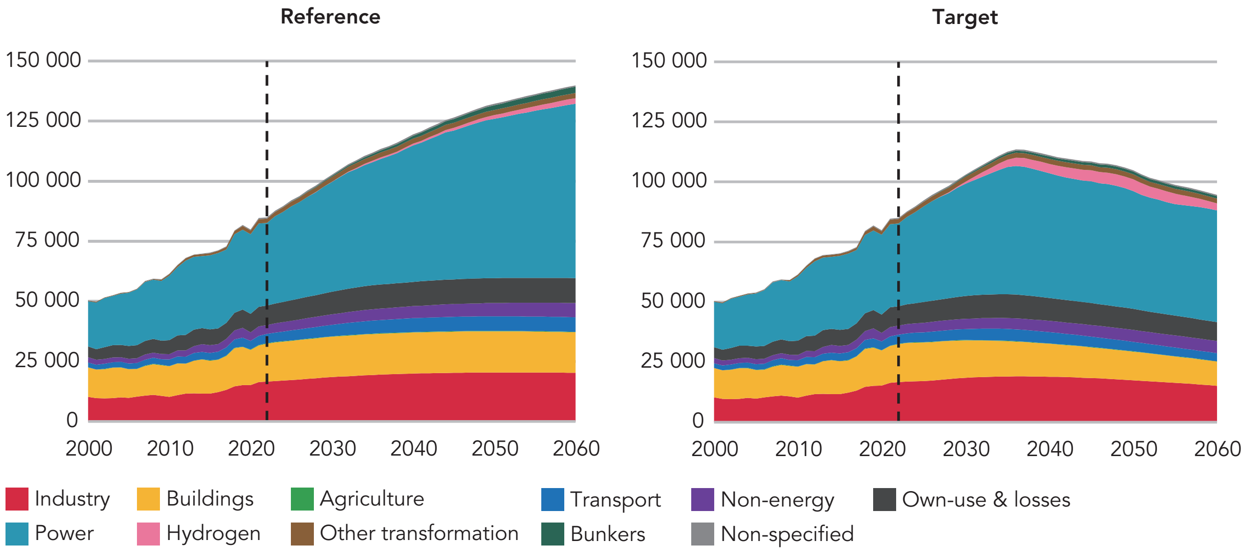
Natural gas is a versatile fuel used in the power generation, industry, buildings, and transport sectors, with power generation representing its primary use in APEC. Gas-fired power plants provide flexibility and reliability to electricity systems and support the integration of variable renewable energy sources. In the industry and buildings sectors, natural gas is widely used for heat applications, while in the transportation sector, it fuels vehicles in the forms of compressed or liquefied natural gas. It also plays a critical role as a feedstock for the chemical industry, enabling the production of fertilisers and various petrochemical products.

Natural gas remains cost-competitive in many economies with strong domestic production or access to pipeline imports. LNG is increasingly expanding access to gas in economies that lack sufficient domestic resources or feasible access to regional natural gas through pipeline connections. While LNG typically involves higher costs and greater infrastructure requirements compared to pipeline imports, ongoing investments in regasification terminals and liquefaction capacity expansion reflect strong demand and will support growth in the LNG market over the coming years.

Compared to coal, natural gas used for power generation can offer significant greenhouse emissions reductions, positioning it as a bridging fuel toward a lower-emission electricity system. The future scale of natural gas demand in the medium to long term will depend on affordability, infrastructure development and evolving energy priorities, including emissions and energy security considerations.

Natural Gas Supply in APEC

Figure 5.18: Natural gas demand (PJ)



Natural gas plays a vital role in APEC's energy mix, accounting for 17% of total final energy consumption in 2022, its share lagging behind only oil and electricity. In the power sector, it ranks as the second most prominent fuel after coal, supplying 20% of the region's electricity generation that year. Natural gas' role is expected to expand as demand for electricity rises in response to population and economic growth, alongside electrification efforts in buildings, industry, and transport. The electrification trends will increase the need for gas-fired power generation, reinforcing natural gas as a key contributor to APEC's future energy system.

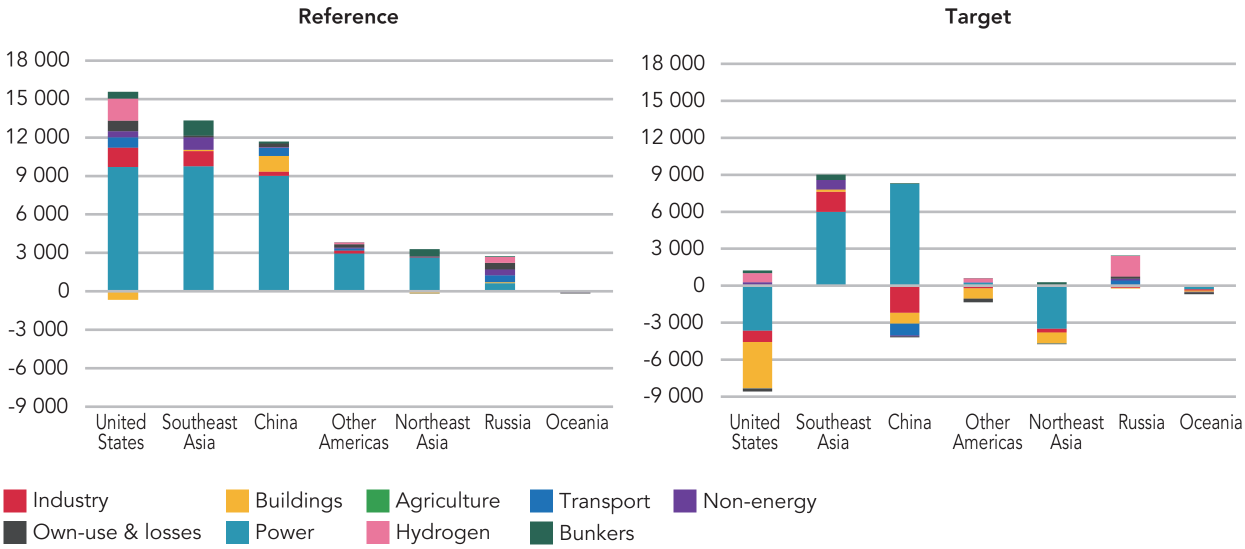
In REF, natural gas demand grows steadily across all major sectors. Overall consumption increases by 65% between 2022 and 2060, led primarily by the power sector, with the industry and transportation sectors also contributing. Demand in the buildings sector remains strong but grows slowly, as electricity plays an increasing role in meeting energy needs in this sector.

In contrast, in TGT, natural gas demand peaks in the 2030s and then declines across all sectors except for hydrogen production and non-energy use. In the non-energy segment, natural gas remains essential as a feedstock for producing olefins, ammonia, and methanol. The decline in natural gas demand in other sectors reflects a more rapid uptake of renewable power generation and widespread electrification, particularly in buildings and industry, while transport also contributes to the reduction through the adoption of electric vehicles.

By 2060, total natural gas demand in TGT is 34% lower than in REF. Nonetheless, even on this lower-demand pathway, it remains above 2022 levels, highlighting the continuing importance of natural gas in APEC's energy future.

Natural Gas Demand Change in APEC

Figure 5.19: Natural gas demand change between 2022 and 2060 (PJ)



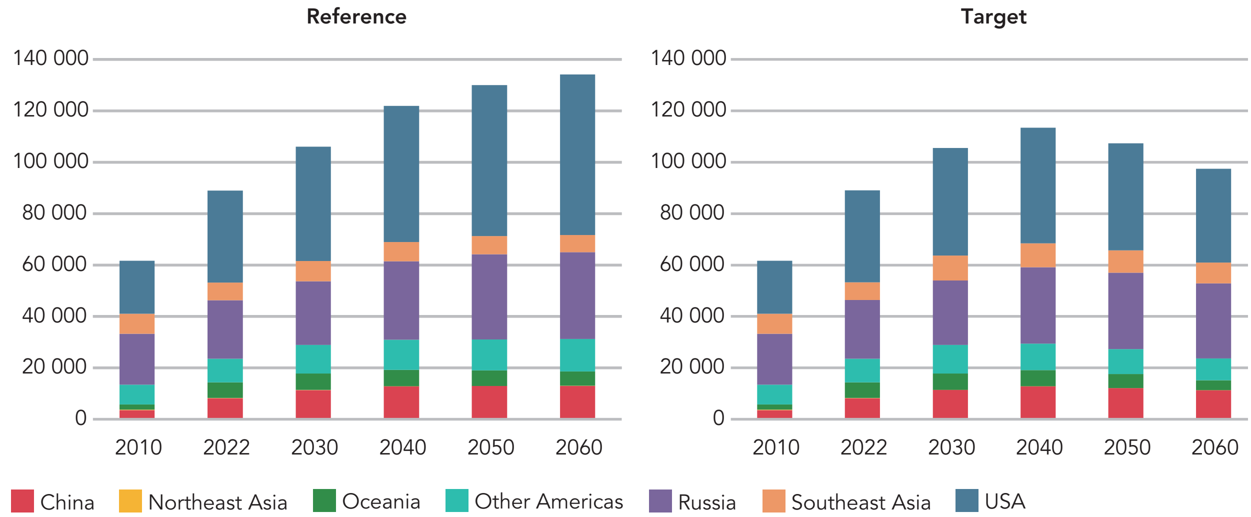
China; Russia; and the United States are the largest natural gas consumers in APEC, while Southeast Asia is rapidly emerging as a major growth area for natural gas demand. This trend is driven by strong economic and population growth, which continues to increase energy needs in that subregion.

In REF, natural gas demand steadily increases through 2060, primarily due to rising gas-fired power generation in the United States, Southeast Asia, and China. Natural gas demand growth in the industry sector, especially in the United States and Southeast Asia, also plays a significant role in driving overall demand growth. Additional growth in natural gas demand in REF is supported by expanding hydrogen production with carbon capture in the United States, greater use of LNG as bunker fuel in Singapore, and the substitution of coal by natural gas in buildings in China.

In TGT, natural gas demand declines through 2060 in several economies, largely due to the expansion of renewable electricity and the electrification of end-use sectors. The most pronounced reductions occur in the power and industrial sectors in the United States and Northeast Asia, as well as in the buildings sector in China; the United States, and the Northeast Asia subregion. Despite these declines, natural gas demand in the power sectors of Southeast Asia and China continues to grow, driven by ongoing economic development and rising energy needs. In Russia, demand increases moderately, reflecting its use in hydrogen production under this scenario.

Natural Gas Production in APEC

Figure 5.20: Natural gas production (PJ)



Note: In Figure 5.20, China's natural gas production includes methane produced from coal gasification.

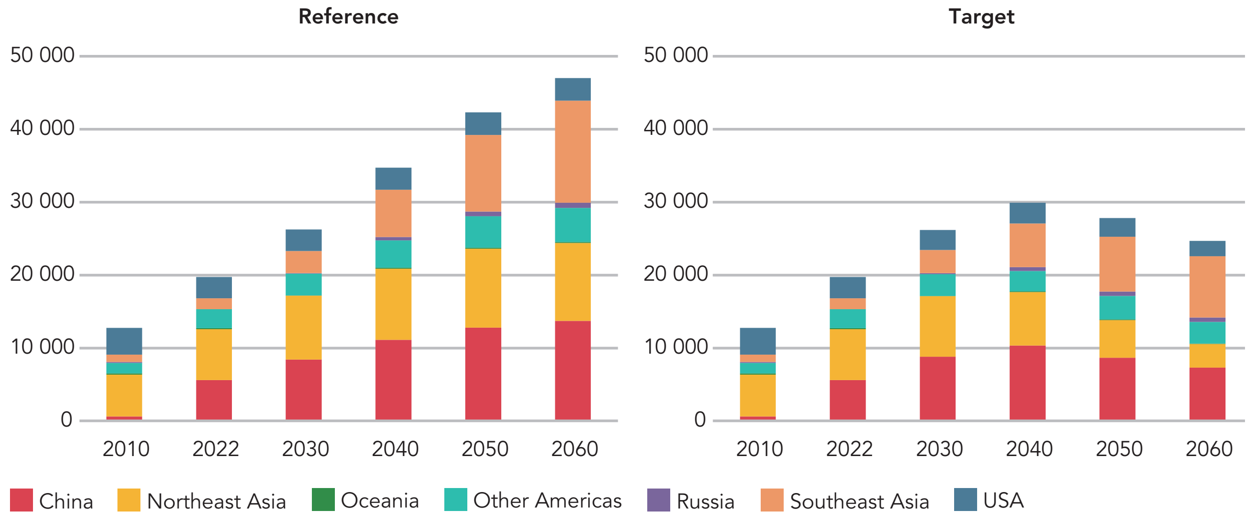
The APEC region includes some of the largest natural gas producers in the world. The United States and Russia are the top two producers, followed by China and Canada. Natural gas production in Canada and the United States is primarily driven by unconventional resources, while China and Russia rely more heavily on conventional reserves.

In REF, most natural gas production growth comes from Russia and the United States, supported by large reserves, strong domestic demand, and increasing exports via pipelines and LNG. In TGT, natural gas production in these economies is lower than in REF as domestic demand weakens and importing economies pursue decarbonisation strategies.

In both scenarios, Southeast Asia's natural gas production is not expected to fully meet growing demand. In the Philippines; Thailand; and Viet Nam, production has stagnated or begun to decline in recent years, widening the gap between supply and demand. While Indonesia and Malaysia plan to boost output through new upstream developments, these efforts are likely to only partially offset rising domestic gas consumption.

Natural Gas Imports in APEC

Figure 5.21: Total natural gas imports (PJ)



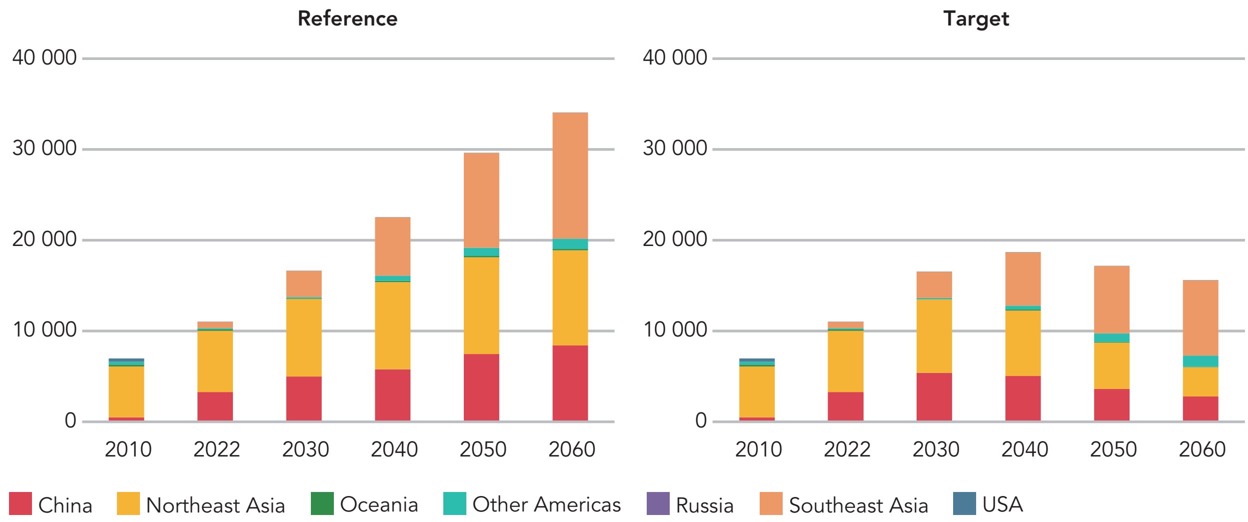
Note: Figure 5.21 includes natural gas imports through pipelines and in the form of LNG.

Several APEC economies currently rely on natural gas imports (both pipeline and LNG) to meet domestic demand. In Northeast Asia, economies such as China; Hong Kong, China; Japan; Korea; and Chinese Taipei, are the largest importers. This is mainly due to limited domestic gas resources, and in China's case, rising consumption that exceeds its already large natural gas production capacity.

In the Americas, Canada; Mexico; and the United States account for the majority of natural gas imports. For instance, Mexico depends heavily on pipeline imports from the United States to meet its growing energy needs. In Southeast Asia, natural gas imports have historically remained moderate. However, strong demand growth, especially in the power sector, is expected to drive a significant increase in natural gas imports in the years ahead.

In REF, total natural gas imports in the APEC region are projected to rise steadily. This increase is largely driven by growing demand in China and Southeast Asia. By the 2050s, Southeast Asia's imports are expected to surpass China's, becoming the primary source of import growth in APEC. In TGT, natural gas imports peak around 2040 before gradually declining as decarbonisation measures reduce demand in Northeast Asia and China. Imports in Southeast Asia continue to grow in TGT, though at a slower pace compared to REF.

Figure 5.22: LNG imports (PJ)



Looking specifically at LNG, it accounted for approximately 55% of total natural gas imports in APEC in 2022, with the remainder delivered via pipelines. Both scenarios project a growing share of LNG in total imports, driven in part by Southeast Asia's increasing reliance on this form of supply. By 2060, LNG is expected to make up nearly 70% of total natural gas imports in REF and around 64% in TGT.

In REF, APEC LNG imports steadily increase through 2060, mainly driven by rising demand in Northeast Asia, China, and Southeast Asia. Southeast Asia experiences the fastest growth in LNG imports due to strong energy demand and declining domestic production of natural gas. In TGT, LNG imports peak around 2040 as decarbonisation efforts reduce demand in the APEC subregions of Northeast Asia and China, especially in the power sector. However, LNG imports in Southeast Asia continue to grow, though at a slower pace than in REF, supported by increases in natural gas production in Indonesia and Malaysia, along with faster integration of renewable energy that help limit import growth.

The increasing reliance on LNG imports across the APEC region, especially among developing economies in Southeast Asia, highlights the importance of maintaining a stable LNG supply. Volatility in global markets may pose affordability risks and could become a greater energy security risk for those economies with rising LNG import dependence.

Challenges to LNG Demand Growth in Southeast Asia

Southeast Asia's natural gas demand is projected to rise significantly in the coming decades, primarily driven by the power sector. At the same time, domestic gas production in key economies like the Philippines; Thailand; and Viet Nam is either declining or unable to keep pace with rising consumption. Consequently, LNG imports are becoming increasingly vital to meet this growing energy need. However, several challenges complicate the sustainable expansion of LNG demand across the subregion.

Affordability remains a significant concern. High and volatile global LNG prices have made governments and utilities cautious about entering long-term LNG supply contracts. Economies such as the Philippines and Viet Nam tend to rely more on short-term or spot market purchases to avoid the financial risks of fixed long-term commitments, despite increased exposure to price volatility. In contrast, Thailand is gradually shifting toward long-term contracts to secure price stability, while Singapore, with its strong financial capacity and established regulatory framework, actively pursues long-term agreements to hedge against volatility.

Energy security challenges in Southeast Asia are amplified by infrastructure limitations and varying institutional capacities. While Thailand and Viet Nam have expanded their LNG regasification facilities, these are still evolving alongside ongoing efforts to strengthen procurement mechanisms and regulatory frameworks. The Philippines is in the early stages of building its LNG import infrastructure, which limits its immediate ability to secure steady supplies. Floating Storage and Regasification Units (FSRUs) have emerged as a preferred option in several economies such as the Philippines and Viet Nam due to their faster deployment and lower upfront cost compared to onshore terminals. This shift helps accelerate LNG access although long-term infrastructure planning remains essential. In contrast, Singapore benefits from advanced LNG terminals and centralised gas procurement, well-positioning it to ensure reliable supplies. Strengthening institutional and regulatory frameworks across the region will be key to encouraging more stable long-term LNG supply arrangements.

In several Southeast Asian economies, LNG is increasingly competing with coal and renewable power in the power generation mix. Gas-fired power plants emit less carbon dioxide and other pollutants compared to coal, which supports efforts to reduce environmental impacts. Economies such as the Philippines; Thailand; and Viet Nam are incorporating LNG into their power mixes partly for environmental reasons. However, coal remains a dominant and usually cheaper source of electricity generation relative to gas because of existing infrastructure, local or regional availability, and lower fuel costs. Additionally, renewable electricity is expanding in the region and may constrain LNG demand growth depending on policy priorities, system flexibility, and grid integration. The competitiveness between LNG, coal, and renewables depends on a combination of global fuel prices, domestic resource availability, and infrastructure readiness. Financing challenges also affect the pace at which LNG can be scaled up, while policy signals such as carbon pricing or emissions targets will influence the relative attractiveness of different power generation options.

At the same time, uncertainties, especially those related to affordability, infrastructure constraints, and the limited number of long-term contracts create headwinds for investment in new liquefaction projects. Without strong long-term offtake agreements, project developers struggle to secure financing and justify the capital-intensive nature of LNG plant development. This could constrain future global LNG supply at a time when many economies including those in Southeast Asia would otherwise increasingly rely on LNG to support growing energy demand.

Looking ahead, Indonesia and Malaysia, traditionally LNG exporters, may become LNG importers during the second half of the 2030s as domestic production is expected to fall short of growing gas demand, particularly in the power and industry sectors. This potential shift underscores the increasing importance of LNG imports and infrastructure development in the Southeast Asian subregion.

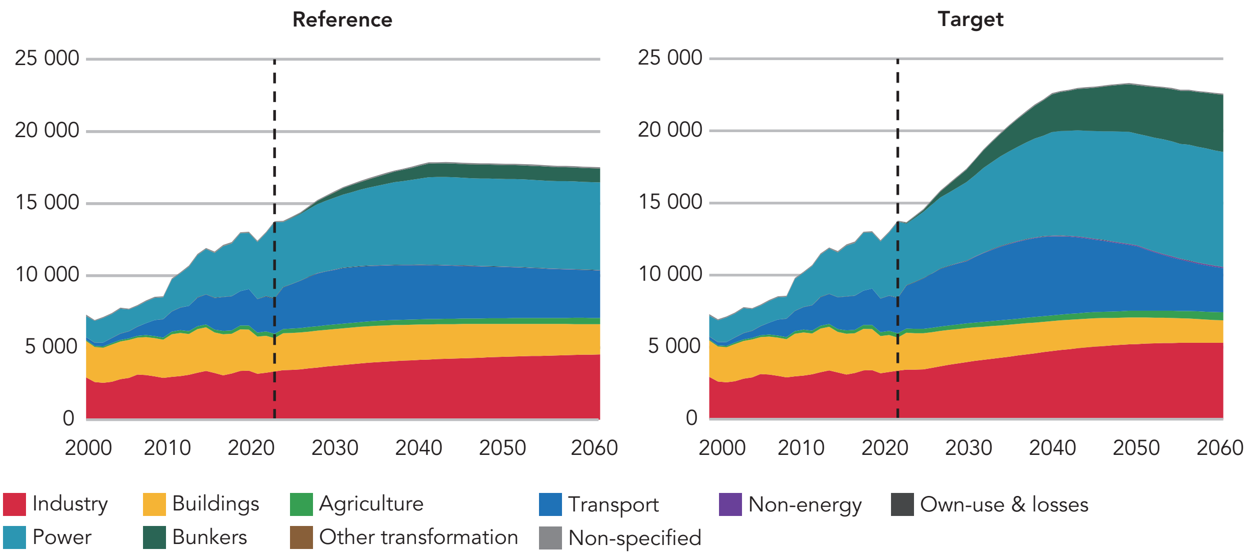
5.5 Bioenergy and Waste in APEC

- APEC bioenergy and waste supply increases substantially until 2040 in the Reference scenario (REF) and the Target scenario (TGT), after which it remains relatively flat until 2060.
- By sector, in both scenarios, the significant deployment of solar and wind, as well as natural gas, constrains the consumption for biomass in APEC's power sector. In the buildings sector, increased electrification reduces the reliance on traditional biomass (fuelwood/woodwaste). Conversely, APEC's industry sector remains reliant on biomass to support its operations. In domestic transport, biogasoline and biodiesel supply growth is limited by the increased deployment of electric vehicles. However, biodiesel and biojet kerosene are essential in displacing diesel/fuel oil and jet fuels in APEC's international maritime and aviation sectors, respectively.
- The United States and Southeast Asia continue to be the largest biogasoline and biodiesel producers in APEC in both scenarios, leveraging abundant feedstock resources.

Bioenergy and Waste Consumption in APEC

Bioenergy and waste consumption in the APEC region increased by 89% between 2000 and 2022, reflecting a general upward trend over the projection period. The power sector, which relies primarily on solid biomass, was the dominant user, with its share of total consumption growing from 20% in 2000 to 38% in 2022. Similarly, the transport sector's share rose to 18%, up from just 3% in 2000, driven by the rapid uptake of biofuels. On the other hand, the relatively slow growth in bioenergy consumption, particularly modern biomass in the industrial sector and traditional biomass in the buildings sector, led to a considerable decline in the bioenergy shares in both sectors between 2000 and 2022.

Figure 5.23: APEC bioenergy and waste consumption (PJ)



In REF, bioenergy and waste consumption is poised for significant growth from 2022 until 2040, reaching over 17,800 PJ in 2040. Biomass uptake in the power and industry sectors contributes to such growth, along with significant blending of biofuels in the transport sector (including international bunkers). On the other hand, the use of traditional biomass in the buildings sector experiences a gradual decline, as both the residential and commercial subsectors become increasingly electrified.

The overall consumption for bioenergy declines marginally after 2040, settling at over 17,500 PJ in 2060. The rapid scale-up of variable renewable energy sources like solar and wind constrains the consumption for biomass in APEC's power sector. In addition, natural gas and nuclear are increasingly favoured over biomass for baseload electricity generation. Similarly, biofuels supply in the transport sector (excluding bunkers) experiences a gradual decline as electric vehicle adoption accelerates. Conversely, the industry sector's reliance on biomass is expected to continue growing, albeit modestly.

In TGT, bioenergy supply is expected to be higher than in REF, reaching over 22,500 PJ in 2060. Almost all sectors are projected to utilise higher levels of biomass and biofuels in TGT, except the buildings sector. The traditional use of biomass for cooking and heating purposes in the buildings sector declines at a more rapid pace than in REF due to easier access to clean cooking solutions and increased electrification for heating purposes. The largest impact will be driven by international aviation and marine bunkering, with biofuels (biodiesel and biojet kerosene) projected to be over four times higher than REF levels by 2060. Separately, APEC's waste supply, which is industrial waste and municipal solid waste, finds uses in the power, industry, and buildings sectors. However, it represents only a minor share of the APEC region's total bioenergy and waste supply.

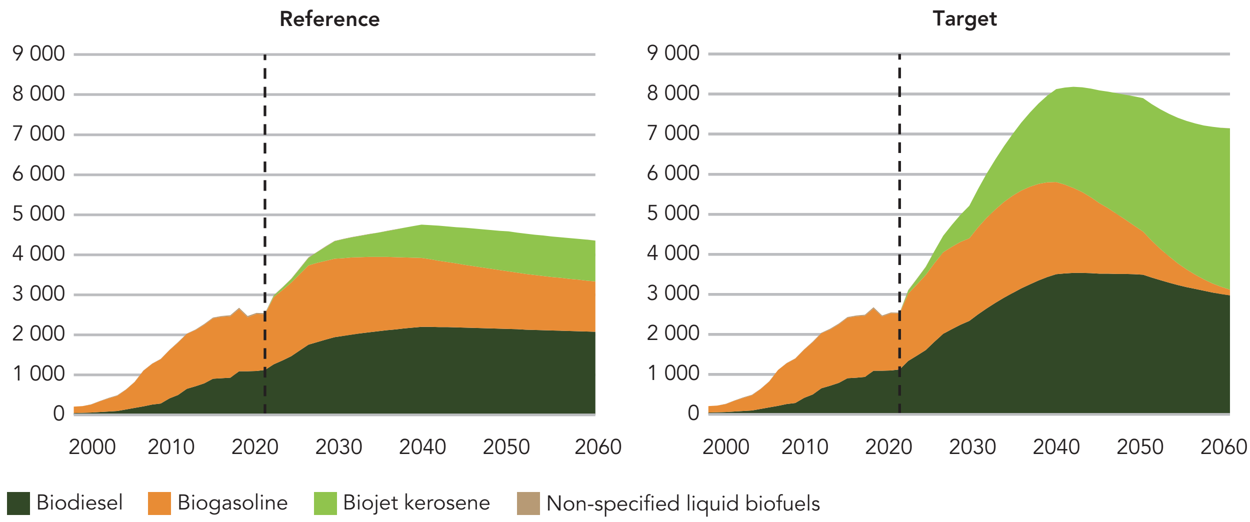
Liquid Biofuels Consumption in APEC

Liquid biofuels play an important role in decarbonising APEC's energy sector, especially for road transport and hard-to-abate subsectors, such as aviation and marine. The average share of liquid biofuels in APEC's transport sector (inclusive of road, rail, and domestic aviation) has grown from just 1% in 2000 to 5% in 2022, driven largely by rapid uptake in Southeast Asia. The share of biofuels in APEC's transport sector is expected to reach 6% by 2060 in REF and rises to 9% in TGT. Southeast Asia continues to lead in biofuels supply, with its share projected to exceed that of the APEC average by 2060, accounting for 10% and 22% in REF and TGT, respectively.

APEC consumed more biogasoline than biodiesel between 2000 and 2022, with the United States being a dominant user due to its abundant domestic ethanol supply. In terms of biodiesel, supply in Southeast Asia has surged driven by regional biodiesel mandates, leading Southeast Asia to overtake China as APEC's largest biodiesel subregional user. Furthermore, several economies in the Southeast Asia subregion have developed biodiesel blending mandates for transport fuels, with Indonesia's being the most ambitious with a biodiesel blending rate of 32%, and plans for further increases. In addition, Malaysia has a biodiesel blending rate of 12%, which is expected to rise to approximately 30% by 2040.

Over the projection period, biogasoline supply is expected to peak in in the late 2030s before declining gradually in REF, with a steeper decline in TGT. This trend reflects the anticipated growing adoption of electric vehicles, which constrains biogasoline use in passenger transport. On the other hand, biodiesel use remains resilient, supported by its continued blending with diesel for freight transportation and its use in the marine sector.

Figure 5.24: APEC liquid biofuels consumption (PJ)



The deployment of biojet kerosene (sustainable aviation fuels) in the aviation sector presents a key opportunity for APEC to reduce cross-border emissions, alongside the usage of hydrogen. Biojet kerosene utilisation is expected to be substantial in both scenarios. In REF, biojet kerosene levels reach over 530 PJ by 2060, corresponding to a blending rate of approximately 9%. The TGT scenario further highlights the potential of biojet kerosene as it reaches almost 2,230 PJ by 2060 or a blending rate of 70%.

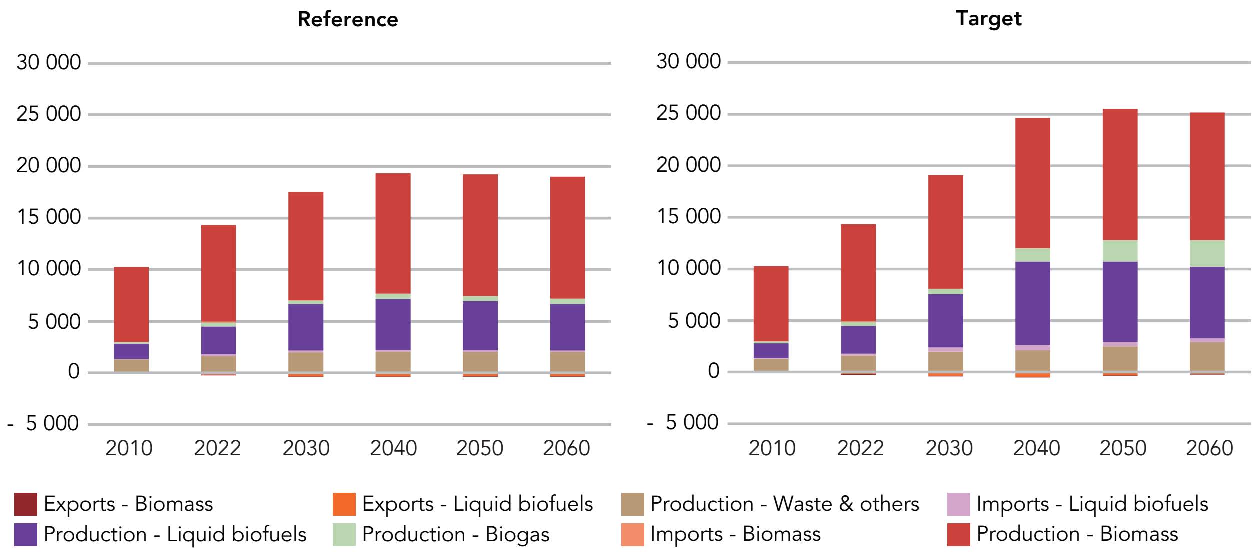
The marine sector has the potential to absorb significant volumes of biodiesel in APEC, thus displacing traditional fuels like diesel and fuel oil, while supplementing other emerging fuels such as LNG, ammonia, and e-fuels. Historically, the biodiesel blending rate in APEC's marine sector remained just under 1%, which was primarily concentrated in the United States. However, in both scenarios, all APEC subregions are expected to see blending rates increasing considerably by 2060. In REF, this increases to over 12% or equivalent to a biodiesel consumption of 426 PJ, while in TGT, this rises to almost 1,700 PJ or about 72% blending.

Bioenergy and Waste Supply in APEC

Biomass production in APEC was recorded at over 9,330 PJ in 2022, with China accounting for the largest volume, followed by Southeast Asia and the United States. Most biomass production consisted of 'other biomass', which comprises various kinds of agricultural wastes (straw, rice husks, nut shells, etc.). Fuelwood/woodwaste is the second largest category but is mainly limited to certain subregions: Oceania (Papua New Guinea), Other Americas (Peru), and Southeast Asia (the Philippines; Thailand; and Viet Nam).

Over the projection period, biomass production in APEC is expected to reach almost 11,800 PJ in 2060 in REF, up by 26% from 2022 levels. In TGT, production is projected to increase by 32% to reach over 12,300 PJ in 2060. The share of 'other biomass' in both scenarios is envisaged to increase between 2022 and 2060 as the contribution of fuelwood/woodwaste production falls due to declining consumption. Much of the projected volumes of biomass production are expected to come from China and Southeast Asia.

Figure 5.25: APEC bioenergy production, imports, and exports (PJ)



Biogasoline and biodiesel production in APEC has largely been concentrated in the United States and Southeast Asia. The United States, a major global player in biogasoline production, accounted for nearly 90% of APEC's total biogasoline yield in 2022, leveraging its abundance of corn as the primary feedstock for biogasoline production. The United States is also a significant producer of biodiesel, which is primarily derived from soybean oil, animal fats, and used cooking oil. Meanwhile, Southeast Asia collectively produced 45% of APEC's biodiesel production in 2022, representing approximately 27% of global biodiesel yield.

Throughout the projection period in both scenarios, the United States and Southeast Asia are expected to continue being the primary suppliers of APEC's biofuels, including biojet kerosene, through 2060. Growing this supply will necessitate significant expansion or retrofitting of existing biorefineries across the region. Several economies are laying the groundwork to produce sustainable aviation fuels (SAF). For instance, the United States is currently advancing plans to expand SAF production. China has also recently started small-scale SAF production at several refineries with a total output of 870,000 tonnes per annum.

5.6 Hydrogen in APEC

- Clean and low-carbon hydrogen ($CLCH_2$) projects are projected to expand across the APEC economies, potentially producing 18,500 PJ (153 million tonnes) by 2050 in the Target scenario (TGT), which assumes strong and sustained policy support. High costs, infrastructure gaps, and the need for technological advancements are currently significant barriers that could slow the growth of $CLCH_2$ production.
- $CLCH_2$ has potential in multiple sectors, including industrial processes, transport, and power generation. However, its use for electricity generation will be most beneficial in economies that have limited renewable energy potential and would therefore need to rely on imported $CLCH_2$ to decarbonise their power sector.
- There is significant potential for $CLCH_2$ trade in APEC, up to 7,300 PJ (61 million tonnes) annually by 2050, driven by the decarbonisation goals of economies such as Japan; Korea; and Singapore. The development of harmonised standards and certification systems, and technologies for long distance transportation will be essential to facilitate cross-border trade and ensure credibility in emissions accounting.

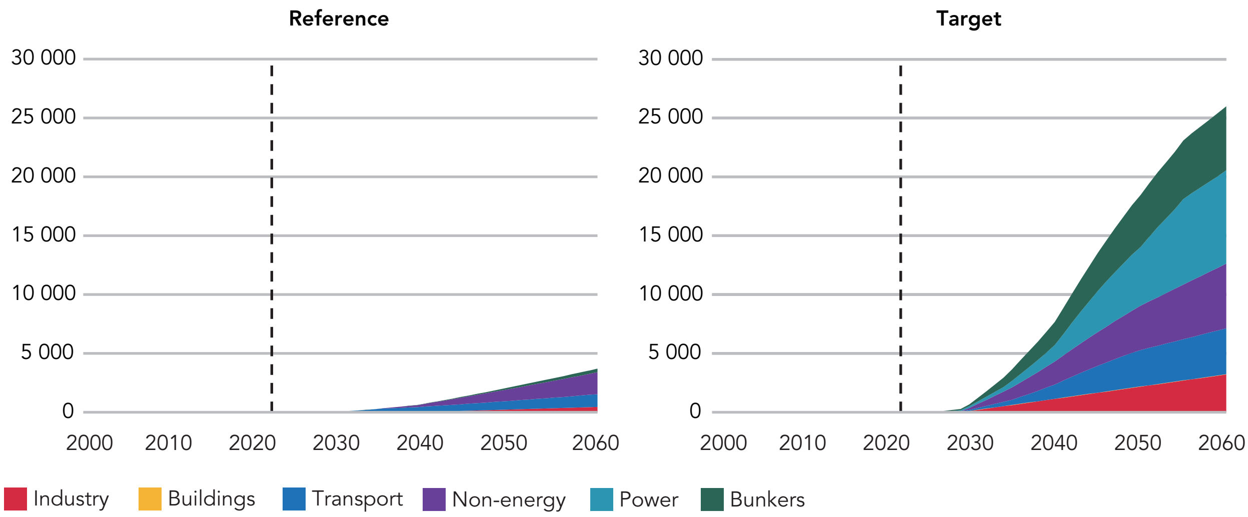
Clean and low-carbon hydrogen ($CLCH_2$) has the potential to be a low-emissions energy vector for decarbonising hard-to-abate sectors. The APEC region leads globally in approved $CLCH_2$ projects; however, high production costs, limited infrastructure, and lack of harmonised standards remain major barriers to large-scale deployment. Unlocking the full potential of $CLCH_2$ will require coordinated policy support, substantial investment in enabling infrastructure (including expanded renewable energy production capacity), and strengthened international cooperation.

Hydrogen Demand

$CLCH_2$ consumption is limited in REF due to its high costs and the energy losses associated with its production and transportation. In REF, $CLCH_2$ accounts for around 1% of total final consumption (TFC) or 3,400 PJ by 2060 (Figure 5.25). This low level of production is based on the assumption that governmental programs and/or subsidies needed to achieve broad commercialisation are not forthcoming. In contrast, the $CLCH_2$ share of global hydrogen production rises to 5%, or 12,600 PJ, in TGT based on an assumption of very substantial government support.

Historically, hydrogen use in APEC has been concentrated in the industry sector, particularly refining and chemical production. In REF, $CLCH_2$ and its derivatives are used to a limited extent in industry, transport, and international bunkering. Given the low level of $CLCH_2$ consumption in REF, the remainder of this chapter will focus on $CLCH_2$ production, transport, and use in TGT.

Figure 5.26: Hydrogen-based fuels demand by sector (PJ)



The industry sector, including non-energy industrial uses, is the largest domestic consumer of $CLCH_2$, accounting for 8,660 PJ by 2060 in TGT. Currently, hydrogen is mainly used as a feedstock in ammonia production (primarily for fertilisers) and oil refining. Future applications include iron and steel production via direct reduced iron (DRI) processes, cement production by replacing fossil fuels in kilns, and industrial mobile machinery. Economies such as Australia and China are actively advancing hydrogen-based steel-making as part of their decarbonisation efforts.

In TGT, the role of $CLCH_2$ and its related fuels expands further to include power generation and greater use in bunkering, reflecting greater decarbonisation efforts by APEC economies. $CLCH_2$ and its derivatives, such as ammonia, are expected to play an increasingly important role in power generation, with total demand near 8,000 PJ by 2060 in TGT. This growth, mainly in Southeast Asia, Japan and Korea, is driven by policies targeting power sector decarbonisation. However, the implementation of these measures creates issues which are briefly outlined in the Challenges section of this chapter. On the other hand, demand for $CLCH_2$ and its derivatives in international bunkering is projected to reach 5,400 PJ by 2060, following the assumption of more stringent international standards for maritime and air bunkers.

The transport sector is projected to be a significant $CLCH_2$ consumer, accounting for over 3,900 PJ of total hydrogen demand by 2060 in TGT, particularly in heavy-duty road transport (trucks and buses), maritime shipping (mainly in the form of ammonia), and aviation (as hydrogen and synthetic e-fuels). The adoption of fuel cell electric vehicles (FCEVs) and hydrogen-powered trucks and buses is a key strategy in China; Japan; and Korea.

Hydrogen Production

While $CLCH_2$ accounted for less than 1% of global hydrogen production in 2023, efforts to increase $CLCH_2$ production are accelerating.[7] The APEC region leads globally in $CLCH_2$ projects that have reached final investment decision.[8] However, high costs, limited infrastructure, and technological gaps still constrain widespread deployment. Strong and sustained policy support from member economies will be critical.

7 IEA, 2024

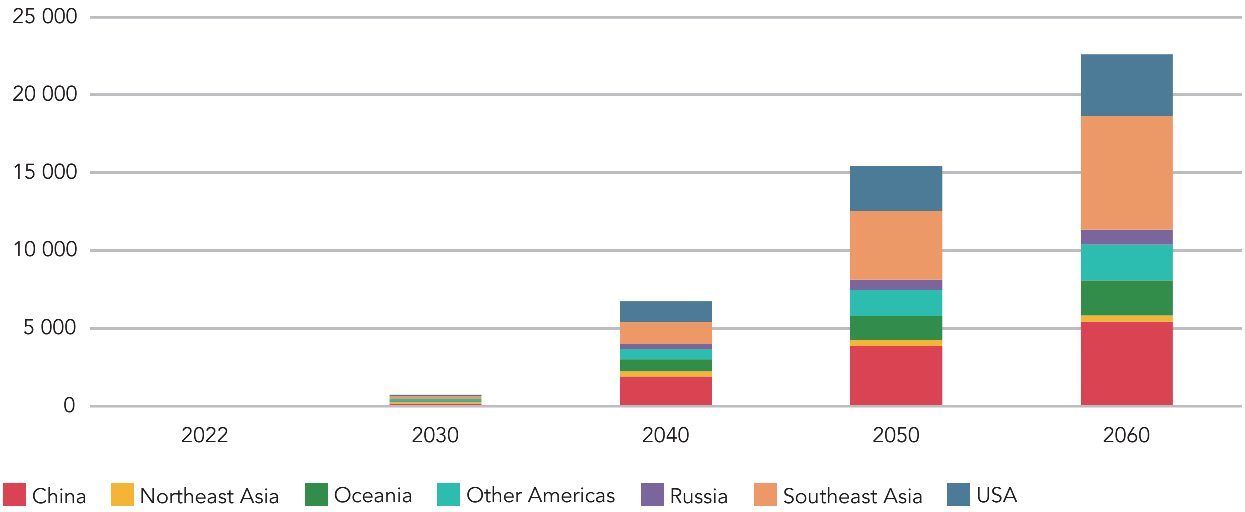
8 APERC, 2025

Hydrogen Production by Economy

In 2023, China was the largest producer of unabated hydrogen, producing approximately 3,360 PJ (28 million tonnes), mainly through coal gasification. The United States follows with about 1,300 PJ (13 million tonnes),[9] and Russia with around 600 PJ (5 million tonnes).[10]

In TGT, total $CLCH_2$ production is projected to reach 22,600 PJ by 2060, driven mainly by the availability of renewable energy resources in some economy members. Southeast Asia, including Indonesia; Malaysia; the Philippines; and Thailand, is expected to produce 7,300 PJ (61 million tonnes), followed by China with 5,400 PJ (45 million tonnes), and the United States with 4,000 PJ (33 million tonnes).

Figure 5.27: Hydrogen-based fuels production by subregion in TGT (PJ)



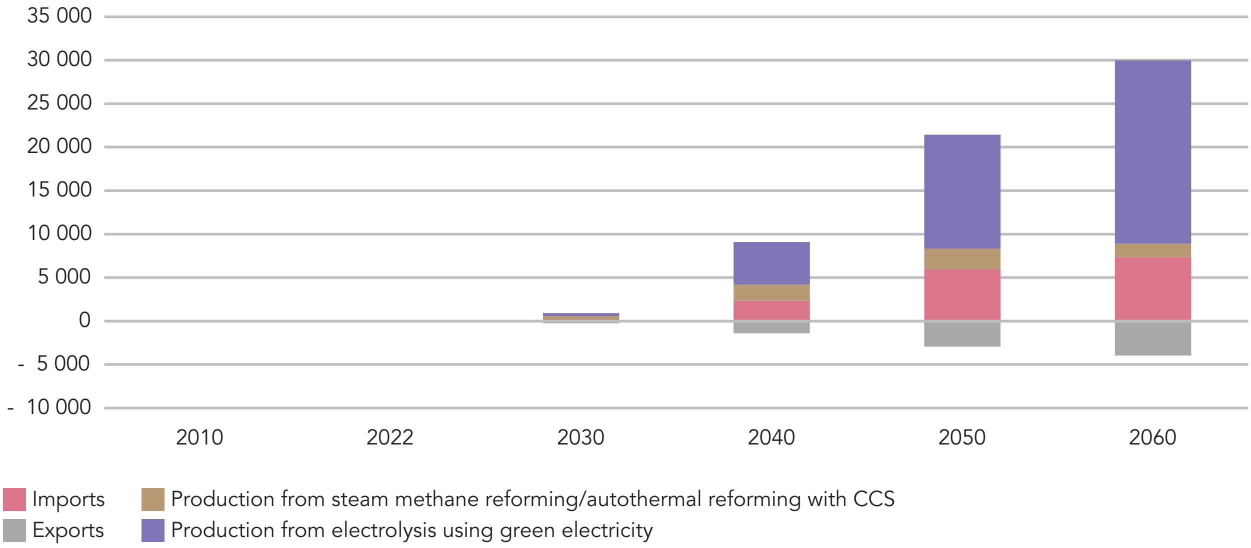
Hydrogen Production by Technology Type

While various hydrogen production pathways exist, the two most mature technologies are electrolysis, which is increasingly supported by multiple APEC economies, and natural gas reforming with carbon capture and storage (CCS), including steam methane reforming (SMR) and autothermal reforming (ATR).

By 2060, in TGT, hydrogen production from natural gas with CCS is projected to reach 1,500 PJ (approximately 12.5 million tonnes). In addition, hydrogen from electrolysis is expected to grow to 21,000 PJ (around 175 million tonnes). Hydrogen imports are expected to reach 7,300 PJ (61 million tonnes), while hydrogen exports are estimated at 3,900 PJ (around 32.5 million tonnes).

9 IEA, 2024
10 Karasevich et al., 2024

Figure 5.28: Hydrogen-based fuels production methods and supply in TGT (PJ)



Achieving this production level will require major investments in renewable electricity generation, electrolyser manufacturing, and carbon capture and storage (CCS) infrastructure. By 2060, more than 1.2 TW of electrolysers and 275 GW of ammonia production capacity will be needed. Nearly half of the electrolysis-based hydrogen production capacity is expected to be installed in China and the United States, while approximately 29% will be located in Southeast Asia.

Energy Inputs for Hydrogen Production

Green electricity demand for hydrogen production, primarily through electrolysis, is projected to reach 33,800 PJ (9,400 TWh) by 2060 in TGT. This represents a 25.7% increase in total electricity demand compared to other sectors. Meeting this additional demand will require not only a significant expansion of renewable energy generation capacity (more than 3 TW of renewable energy capacity additional to the existing capacity in the grid), but also upgrades to grid infrastructure to ensure a reliable and sustainable power supply. Furthermore, the integration of variable renewable energy (VRE) sources with electrolysers will necessitate the deployment of advanced grid management and flexibility solutions.

Although its relative share is expected to decline, natural gas will remain a significant energy input for hydrogen production, particularly in the near to medium term. Natural gas demand for low-carbon hydrogen production is projected to reach 2,900 PJ by 2060 in TGT.

Hydrogen Trade Flows

The development of a global $CLCH_2$ market is vital to the energy transition, with the APEC region positioned as a central hub, hosting both major exporters and importers.

Exporting economies in APEC include Australia; Canada; and Chile, which possess abundant, low-cost renewable resources and are advancing ambitious hydrogen strategies focused on exports.

Economies with high energy import dependence and limited renewable potential such as Japan; Korea; Singapore; and Chinese Taipei are expected to become key hydrogen importers. These economies are actively building international supply chains for clean hydrogen and derivatives. Japan targets 2,400 PJ

(20 million tonnes) of hydrogen use annually by 2050, while Korea expects to import 82% of its hydrogen demand. Chinese Taipei is also planning short- to mid-term imports to support its net-zero goals. Singapore, with limited domestic renewable resources, is positioning itself as a regional hydrogen hub, focusing on imports to support power generation, low-carbon fuels for bunkers, and industrial applications such as refining and chemicals.

Challenges for Hydrogen Development

The high cost of producing $CLCH_2$, along with the uncertainty about government support, infrastructure gaps, and the lack of international standards, makes it difficult to secure long-term offtakers. A substantial portion of CLC hydrogen production costs, between 55% and 75%, is attributed to the energy input, primarily green electricity. Therefore, reducing the cost of green electricity is essential for driving down the cost of green hydrogen. Additionally, in recent years, electrolyser costs have increased, reversing the previous trend of steady cost reductions and affecting overall project economics.

Blending hydrogen or ammonia with fossil fuels in the power sector is being explored in some APEC economies as a potential pathway for emissions reduction. However, this approach requires careful evaluation. For example, operational costs of thermal power plants can increase by USD 15 to 100 per MWh of electricity produced when hydrogen is blended into natural gas at 50% v/v, depending on the hydrogen source and production method.

A significant bottleneck remains the lack of dedicated infrastructure. The long-distance and international transport of hydrogen is still technically complex and costly. Due to hydrogen's low volumetric energy density compared to conventional fuels, existing infrastructure has limited capacity to transport equivalent energy volumes, limiting the effectiveness of measures such as the use of existing natural gas infrastructure, necessitating the development of new hydrogen-specific infrastructure.

The absence of common standards and certification frameworks across APEC for defining and verifying the carbon intensity of $CLCH_2$ introduces uncertainty in international trade, investment decisions, and emissions accounting. Harmonised certification schemes are essential for facilitating cross-border hydrogen markets.

Technologies such as electrolysers and hydrogen-based industrial processes are progressing, but they still require large-scale deployment to drive cost reductions and meet future hydrogen demand across the region.

6. Costs

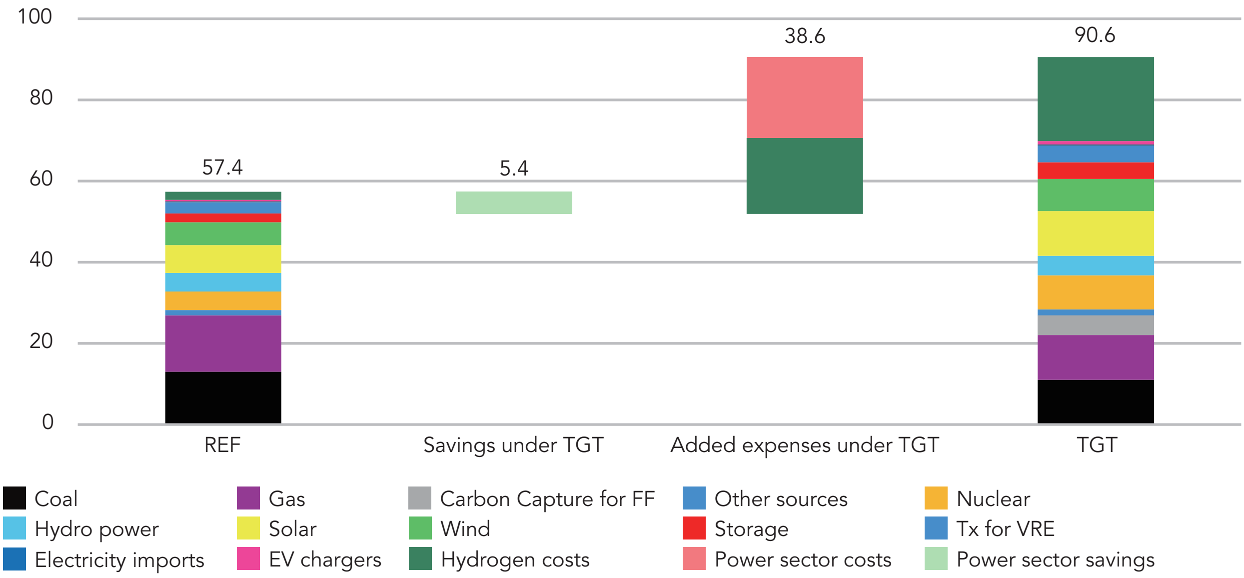
Costs in the Power and Hydrogen Sectors

- APEC economies are expected to incur substantial costs as they decarbonise their energy systems. Costs incurred in APEC's power and low-carbon hydrogen sectors from 2025 to 2060 in the Reference scenario (REF) are projected to be USD 57 trillion, around 1% of APEC's total GDP (2023 USD PPP) during that period. These expenditures rise to USD 91 trillion or around 1.6% of APEC's projected GDP (2023 USD PPP) in the Target scenario (TGT). These costs do not cover other decarbonisation measures outside of the power and low-carbon hydrogen sectors.
- Key cost drivers in TGT are the production and importation of clean and low-carbon hydrogen in APEC, which accounts for approximately 50% of the additional costs in TGT. Additional CAPEX investment in renewable capacity (wind, solar, storage), transmission for additional variable renewable energy, nuclear capacity, and carbon capture technology comprise most of the additional power sector costs in TGT.
- Estimated cost savings of USD 5.4 trillion are expected as economies transition away from fossil fuel usage in TGT. However, this is outweighed by additional expenditures in TGT on the aforementioned technologies.
- CAPEX investment in TGT is approximately 80% higher compared to REF, but operational costs are only 14% higher, suggesting that the relative costs of different pathways will depend on an economy's financing costs.
- For some of APEC's subregions, the cost of generating electricity will rise in TGT as economies begin to blend gas and coal with expensive low-carbon hydrogen (particularly Northeast and Southeast Asia) and increase their adoption of nuclear (namely Russia and the United States).

As APEC economies decarbonise their power sector and reduce reliance on traditional fossil fuel generation, substantial expenditures will be incurred that policy makers will need to carefully consider when formulating decarbonisation pathways. The additional capital and operating costs of variable renewable technology (wind and solar), the infrastructure to support this technology (namely storage and transmission), as well as low-carbon technologies (carbon capture and nuclear) will all be key cost parameters. For many economies, a complete shift to renewables may not be feasible and thus a continued reliance on fossil fuels to some degree is expected to persist into the future in order to provide baseload and peaking support for the grid. This reliance comes with its own costs, namely fuel costs for coal and gas. At the same time, many economies have adopted ambitious low-carbon hydrogen consumption goals. Yet, as a nascent and therefore relatively expensive technology, relying on this fuel source will add to overall system costs for many economies seeking to utilise hydrogen as a decarbonisation pathway. As the costs and benefits of decarbonisation policies become clearer, policy makers may want to consider a range of decarbonisation pathways as they balance energy sustainability, security, and affordability.

Costs in the Power and Hydrogen Sectors

Figure 6.1 Costs in the power and hydrogen sectors, 2025 to 2060 (trillion USD, undiscounted)[11]



Note: Tx for VRE is only transmission infrastructure to connect variable renewable capacity to the grid. EV chargers do not cover the cost of associated infrastructure or electric vehicles (EVs).

The cost of decarbonisation will be substantial for many APEC economies. Total costs for REF are estimated at USD 57.4 trillion, but these costs are expected to rise by 58% in TGT in line with greater decarbonisation efforts. The primary costs considered in Figure 6.1 are the capital and operating costs (fixed and variable) of each economy's power sector for each scenario. As economies transition away from fossil fuel-heavy grids, operational cost savings emerge from reduced coal and gas generation (primarily due to reduced fuel usage); however, these cost savings are offset by increased investments in variable renewable energy and hydrogen production and importation.

The production and importation of low-carbon hydrogen-based fuels (hydrogen, e-fuels, and ammonia) represent a significant cost in TGT, comprising an estimated 23% of total TGT costs. To note, a core assumption made is that hydrogen use amongst APEC economies will be predominately green, with some economies continuing to produce legacy blue hydrogen. The costs of green hydrogen will be very different for "importing" and "producing" economies. As green hydrogen production is a nascent technology, initial expenses are expected to be high and contribute substantially to total costs; however, with improved learning rates, costs could decline over time.

Green hydrogen producing economies are expected to leverage their renewable resources to create green hydrogen both for domestic use and exporting purposes. Doing so would require investments in additional renewable energy capacity such as wind and solar (this capacity would be in addition to what is needed for their electric grids), the capital and operating costs of electrolysers and facilities to convert hydrogen into e-fuel and ammonia (to be used as an export carrier of hydrogen), and the necessary transportation

11 Costs include all power sector costs including all capital, fixed, and operating expenses to generate electricity and heat plus the costs of additional transmission needed for VRE, the added costs of electric vehicle chargers, and the costs of producing and importing clean and low-carbon hydrogen for domestic use and to meet bunkering obligations. Actual costs will differ from estimated costs in the *Outlook* for a variety of reasons, including changing commodity prices, manufacturing costs, and unforeseen technical advances. All costs are in 2023 real terms.

and distribution networks (i.e., hydrogen refuelling stations). Economies with limited hydrogen production capabilities are expected to import low-carbon hydrogen from producing APEC economies to assist with their energy transitions; however, this will lead economies to incur additional fees associated with importation, port fees, and the distribution of hydrogen, e-fuels, and ammonia. Both producing and importing economies are expected to utilise hydrogen for a variety of purposes, namely for blending with gas and coal (in the form of hydrogen and ammonia co-firing), hydrogen fuel cells in transport, industrial uses (namely steel production), and bunkering. Increased adoption of low-carbon green hydrogen in TGT in transport will offset conventional fuel consumption, estimated to save APEC approximately USD 1.5 trillion (not represented in the chart).

Additional expenditures for wind, solar, and hydro power capacity account for 17% of the added costs under TGT as economies seek to achieve net-zero grids. An estimated additional USD 2 trillion will be required for energy storage to ensure that renewable energy can be time-shifted to meet peak loads.

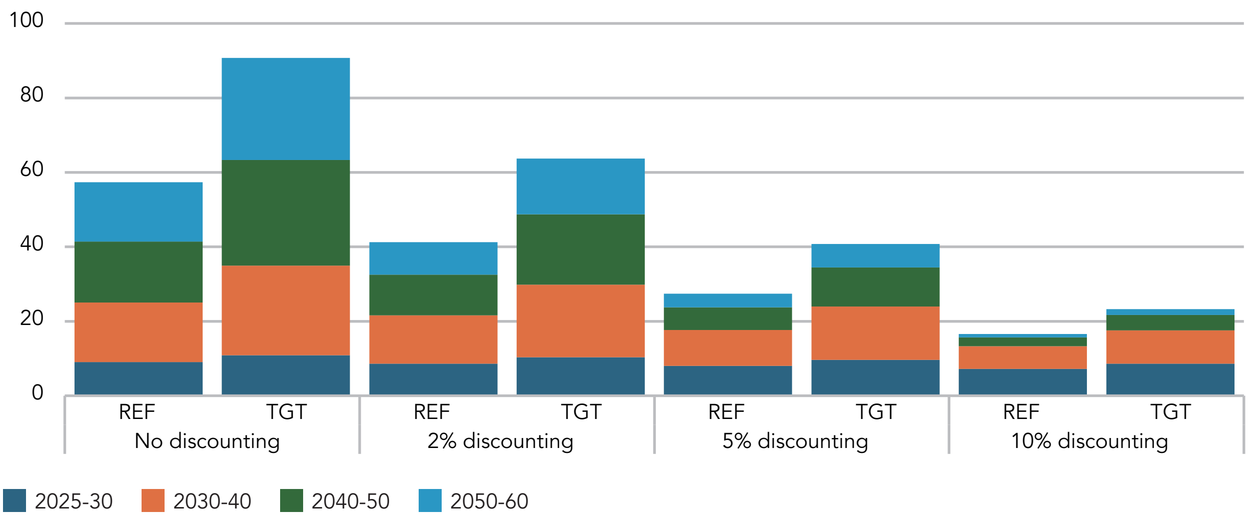
As economies increase their rollouts of variable renewable energy (wind and solar), additional transmission infrastructure is needed in both scenarios. With greater wind and solar capacities required in TGT, an estimated USD 4.1 trillion worth of transmission is required in TGT to support this additional capacity, approximately 46% more than what is required in REF.

Carbon capture technology for coal and gas is projected to be adopted in economies seeking to continue utilising fossil fuel powered generation as a means of maintaining grid stability whilst reducing their emissions. Nuclear costs rise substantially, with the majority of the costs largely stemming from the United States' announcement of substantial nuclear capacity expansion.

Although coal and gas use decline in TGT, some economies continue to rely on these fuels to meet electricity and heat demand. While limited coal and gas capacity is built in both scenarios, their continued operation causes variable costs (fuel usage) to drive total costs upwards in both scenarios.

Effects of Discounting on Costs

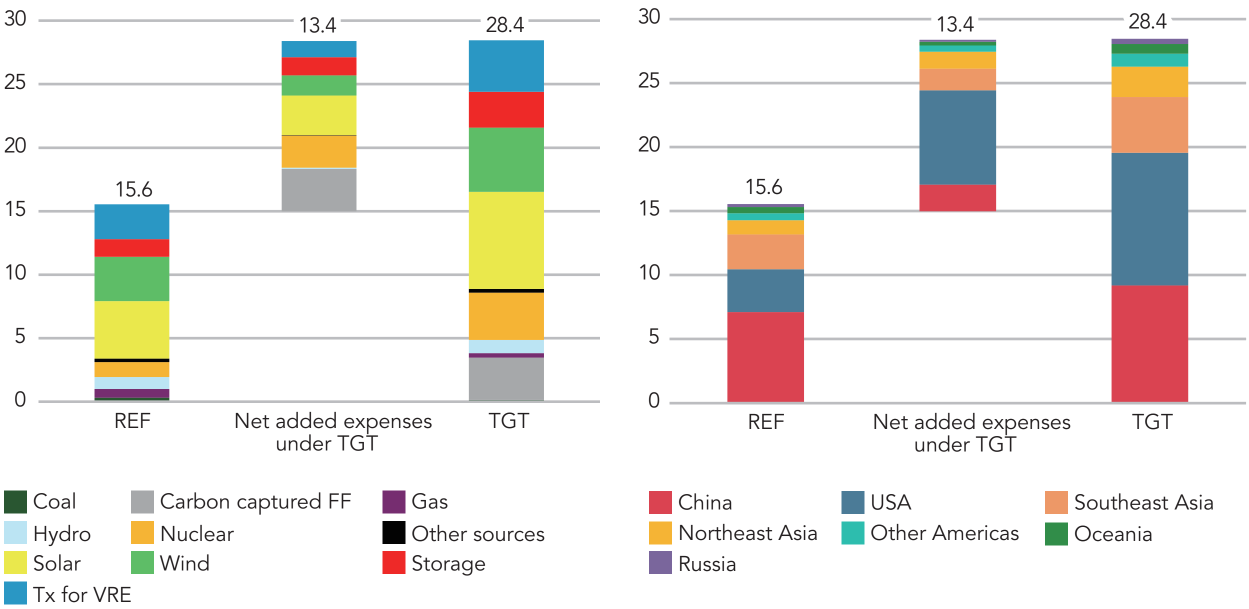
Figure 6.2: Effects of discounting on costs by scenario (trillion USD)



APERC chose to present expenditures in an undiscounted form, as the appropriate discount rate varies widely between APEC economies. When discounting is introduced the cost of expenditures incurred towards the end of the projection period will weigh much less on the evaluation of alternative pathways. Figure 6.2 compares total costs categorised by time period, with different discount rates for each scenario. With higher discount rates, the ratio of TGT to REF costs becomes progressively smaller as late-stage expenditures become heavily discounted. While expenditure across the first ten years is relatively constant across all discount rates, costs for the last 20 years decrease substantially as higher discount rates are applied.

Power Sector CAPEX Costs in APEC

Figure 6.3: Total capital investment (CAPEX) from 2025 to 2060 in the power sector (trillion USD, undiscounted)



Note: Both charts in Figure 6.3 only cover power and VRE transmission sector capital investments. Hydrogen and EV capital investments are not included.

New capacity builds in both scenarios are dominated by variable renewable energy (VRE) investments, along with the supporting energy storage and transmission lines (Tx for VRE) needed to deliver VRE-generated energy in a reliable manner. In TGT, 55% of the additional costs are attributed to this group of investments. In both scenarios, expenditures on VRE (solar and wind) capacity, storage, and transmission for the added VRE account for approximately 75% of the total costs.

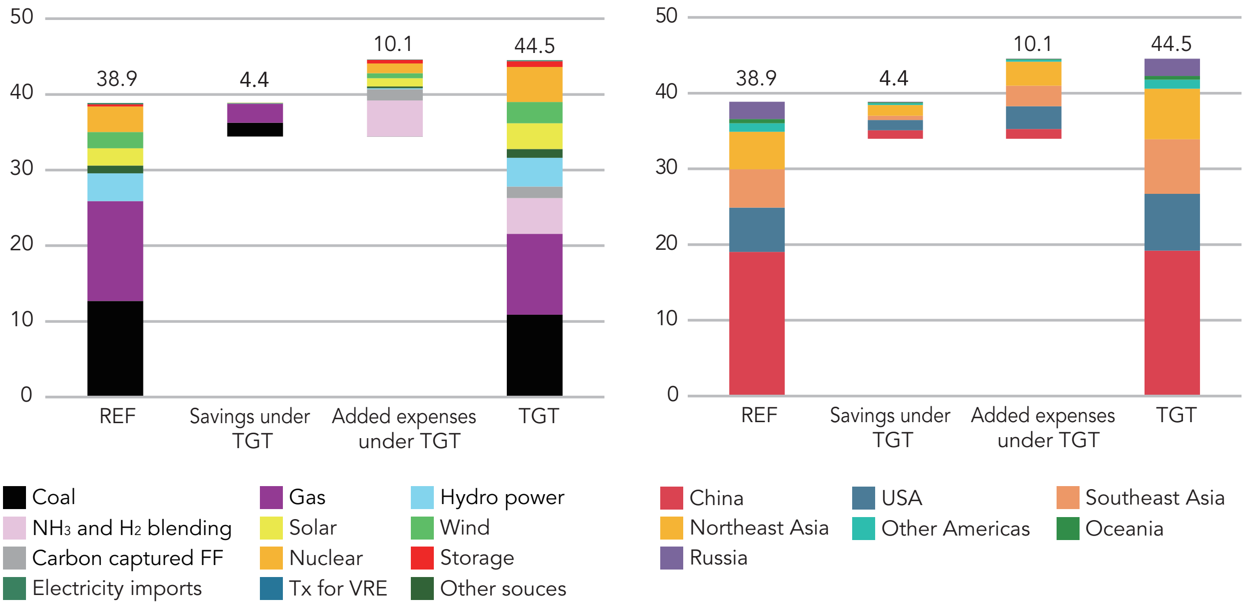
Large spending on carbon capture technology in the APEC subregions of China; the United States, and Southeast Asia results in an additional USD 3.3 trillion in spending in TGT as these subregions seek to reduce their carbon emissions while maintaining thermal baseload power generation for grid stability.

By subregion, the United States displays the greatest increase in CAPEX in TGT, with capital investment in solar, carbon capture use in gas generation, and nuclear, driving these cost differentials. The United States' goal of substantial nuclear capacity expansion comprises the majority of additional nuclear CAPEX costs in APEC.

While China is the largest spender in REF, its CAPEX spending does not increase significantly in TGT. This is due to the relatively small difference in policies and the similarity in decarbonisation pathways when the two scenarios are compared.

Power Sector Operating Costs in APEC

Figure 6.4: Total operating costs from 2025 to 2060 in the power sector (trillion USD, undiscounted)



Note: Both figures only cover power and VRE transmission sector costs. It does not include operating costs associated with hydrogen production and EV charger costs but does include the cost of H_2/ammonia blending in power generation. Electricity importation costs are included here.

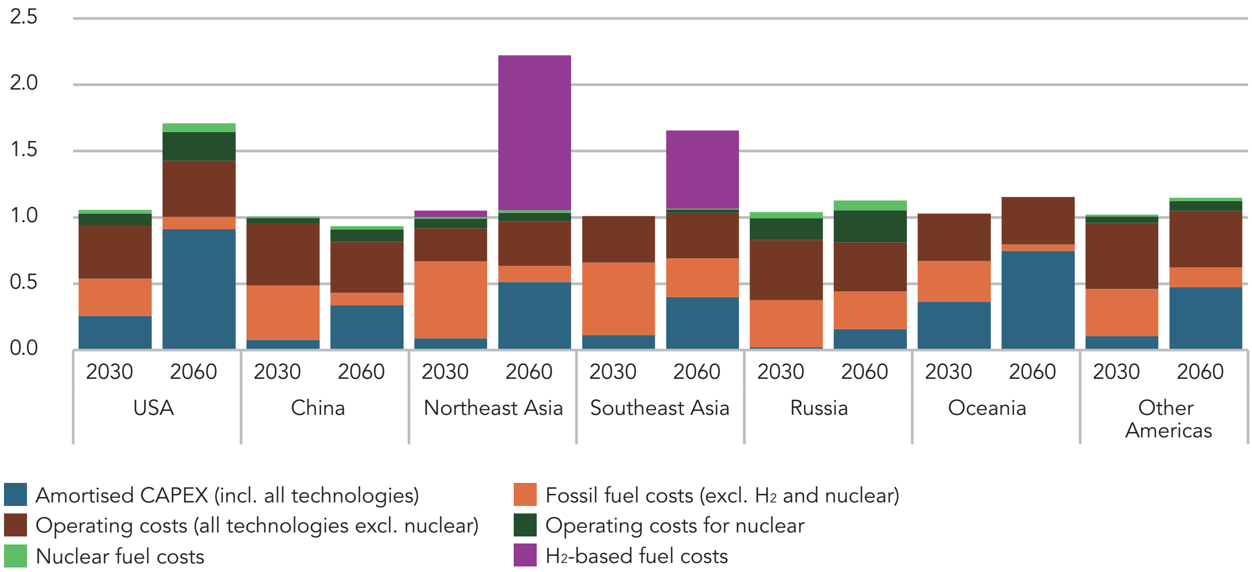
Operational costs include the fixed, fuel, and variable non-fuel related costs involved in operating and maintaining electric grids and meeting heat generation needs. The difference in operational costs between the two scenarios is considerably smaller than the gap in capital costs. This suggests that the cost of capital will have a substantial effect on the attractiveness of different pathways.

For subregions where operational costs are higher in TGT (Northeast and Southeast Asia), the primary driver of cost increases is the fuel cost associated with ammonia and hydrogen blending in gas and coal power generation. These elevated costs stem from the assumption that the hydrogen used will be low-carbon, particularly green hydrogen (a nascent technology with high starting costs). For the United States, the increased operational cost expenditures in TGT are largely attributed to the expansion of nuclear capacity and the associated higher fixed costs of nuclear energy (e.g., maintenance, fuel handling, waste management, etc.).

The net benefits of a shift away from coal and gas fired power generation results in savings. However, these costs are offset by the additional operational costs that are incurred from renewable energy adoption, such as wind, solar, and energy storage (Figure 6.4).

Relative Cost of Generating Electricity in APEC

Figure 6.5: Cost of generating electricity relative to 2025 (2025 cost = 1.00) in the power sector in TGT



Note: Based on our assumptions about future capital and operating costs, Figure 6.5 shows cost compositions over time relative to 2025. It should not be considered an estimate of electricity tariffs and excludes market mechanisms that are too difficult to estimate.

Figure 6.5 illustrates the relative cost of generating electricity in 2030 and 2060 in TGT, indexed to the base year (2025). Economies with values above 1.0 signify that the cost of generating electricity is higher relative to 2025 in those respective years. Total costs are broken down into individual cost components, with the composition of total costs shifting over time as electric grids decarbonise and new low-carbon technologies, such as nuclear and low-carbon hydrogen blending, are adopted.

While the total cost of generating electricity in TGT relative to 2025 does not change for some economies, all economies display a transformation in the composition of their costs—shifting from fossil fuel expenditures towards greater amortisation expenditures as more renewables and low-carbon energy capacity are added to electric grids.

Energy generation costs rise considerably for both Northeast and Southeast Asia as hydrogen blending in gas and coal occurs. As both subregions are assumed to rely primarily on low carbon, particularly green hydrogen (a nascent, expensive technology), electricity generation costs increase considerably, even under the assumption that green hydrogen costs will decline by 35% by 2060 due to improved learning rates.

In the case of the United States, there is an increase in its electricity generation costs by 2060 as its large investments in renewable energy and nuclear power contribute to amortisation costs becoming a larger share of total costs when indexed to 2025. In addition, the expansion of nuclear capacity leads to additional operational costs, including both fuel and non-fuel costs, and thus further raises overall total costs.

7. CO_2 Emissions

7. CO_2 Emissions in APEC

- APEC's net CO_2 emissions are expected to decline from 20,200 million tonnes in 2022 to 15,700 million tonnes and 6,700 million tonnes in the Reference (REF) and Target (TGT) scenarios, respectively, by 2060.
- By sector, the power and transport sectors are expected to provide the largest abatement potential, accounting for the majority of projected CO_2 emissions reductions.
- Decarbonisation efforts across APEC economies, driven by reductions in energy and emissions intensities, are projected to more than offset the impact of rising GDP per capita on emissions. At the subregional level, China, Northeast Asia, and Oceania are expected to make the most substantial contributions to APEC's overall emissions reductions.
- By 2060 in both scenarios, APEC is expected to shift its energy supply mix towards lower-emission sources, and thereby reduce emissions intensity. Carbon capture and storage (CCS) plays a limited role, even in TGT, leaving behind net residual CO_2 emissions that necessitate substantial carbon-removal efforts.

Reference Scenario (REF)

Fuel combustion-related net CO_2 emissions in APEC reached 20,200 million tonnes in 2022, having increased by 2% from 2021 levels. In REF, net CO_2 emissions are expected to increase and peak at just over 21,000 million tonnes in early 2030s, before declining to over 15,700 million tonnes by 2060. The power sector is projected to be the largest contributor of net CO_2 emissions in APEC; however, it is also expected to contribute the most to emissions reduction, with a 28% reduction between 2022 and 2060 due to a decline in coal usage in favour of low-emissions natural gas, nuclear, solar, and wind.

Figure 7.1: APEC CO_2 emissions by sector, REF (million tonnes)

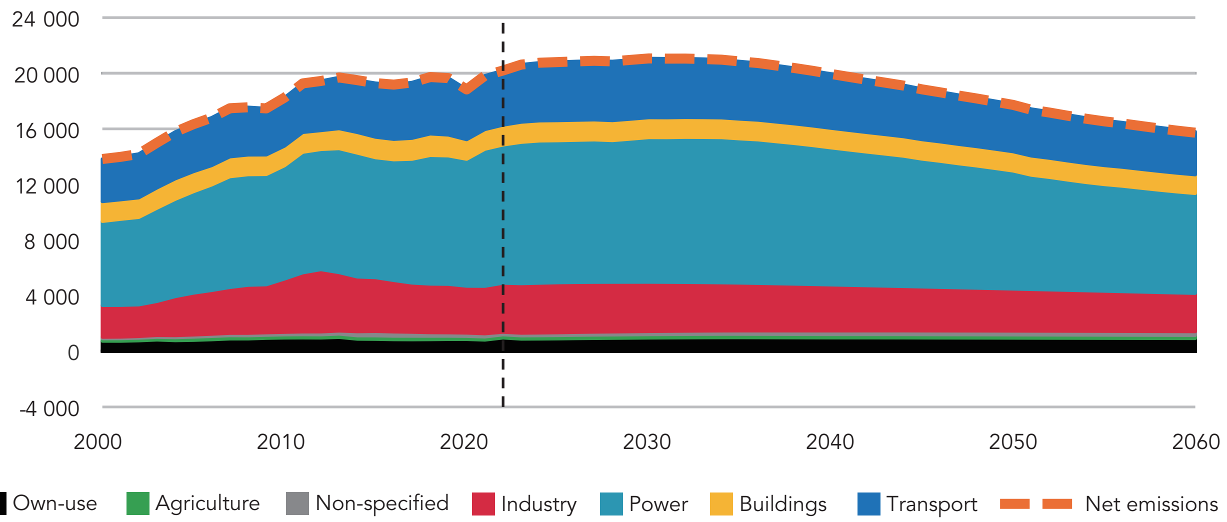
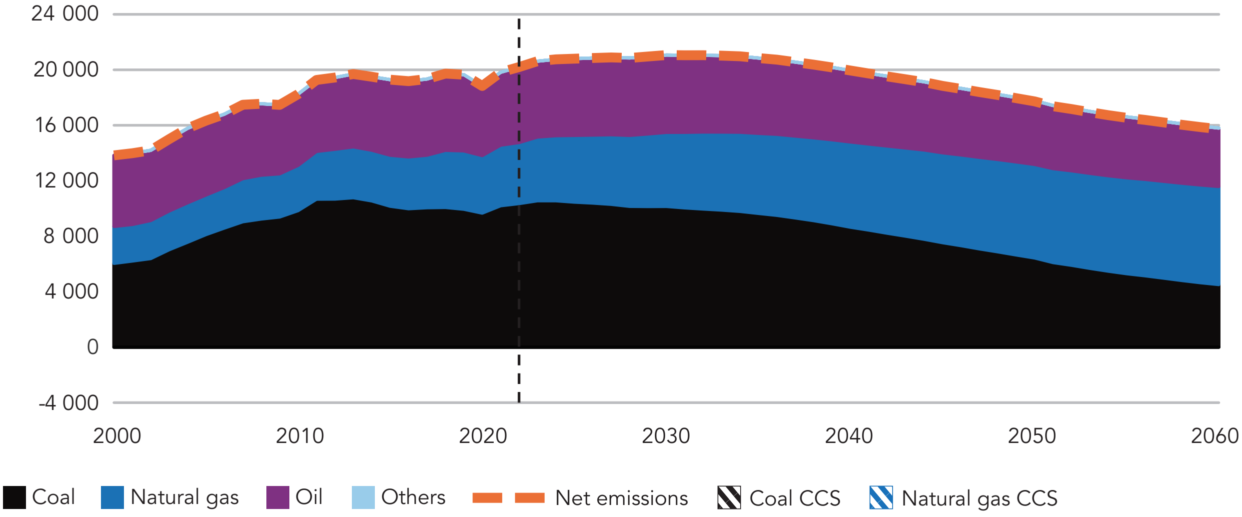
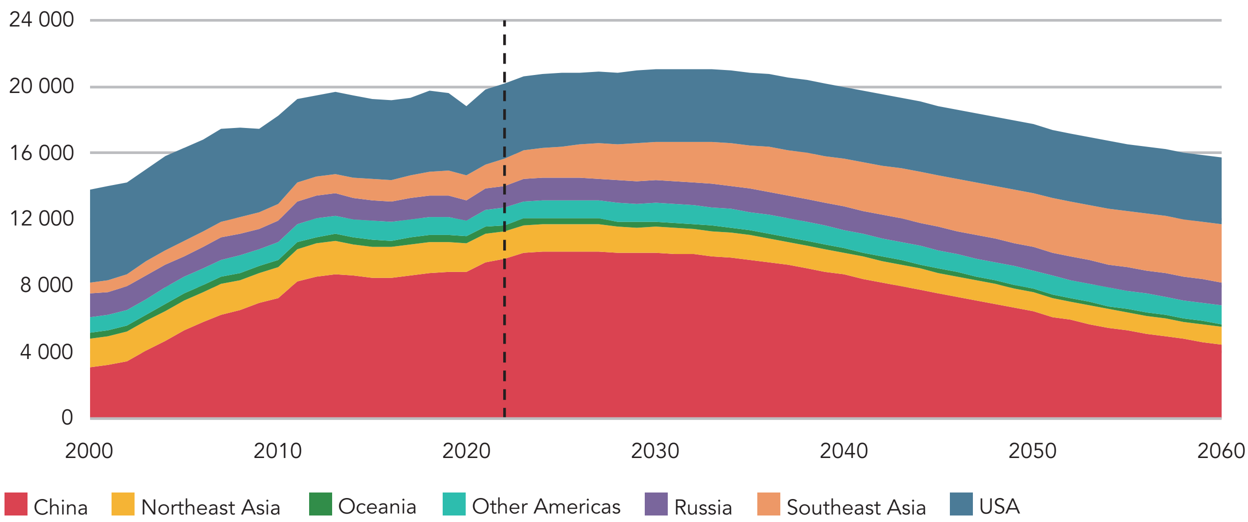


Figure 7.2: APEC CO_2 emissions by fuel, REF (million tonnes)



Approximately 53% of the decline in APEC's net CO_2 emissions by 2060 is expected to occur in China, mainly driven by decreasing emissions in the power, industry, and transport sectors. (The net emissions already take into consideration marginal absorption of CO_2 emissions by carbon capture and storage [CCS].) Notable declines in net emissions are also expected in Oceania (49%) and Northeast Asia (38%), while the United States' net emissions are projected to decline modestly (12%). In contrast, significant increases in emissions are projected to occur in Southeast Asia (117%), given its reliance on coal and natural gas throughout the projection period.

Figure 7.3: APEC CO_2 emissions by subregion, REF (million tonnes)



Target Scenario (TGT)

In TGT, APEC's total net CO_2 emissions are projected decline to 6,700 million tonnes by 2060—about 52% lower than 2000 levels. Enhanced electrification in the transport sector reduces this sector's CO_2 emissions by 80%, while significant declines in coal utilisation and limited growth in natural gas usage reduces power sector emissions by 64% between 2022 and 2060. Carbon capture and storage (CCS) plays a greater role in TGT in the power and industry sectors, collectively removing 800 million tonnes from the atmosphere by 2060.

Figure 7.4: APEC CO_2 emissions by sector, TGT (million tonnes)

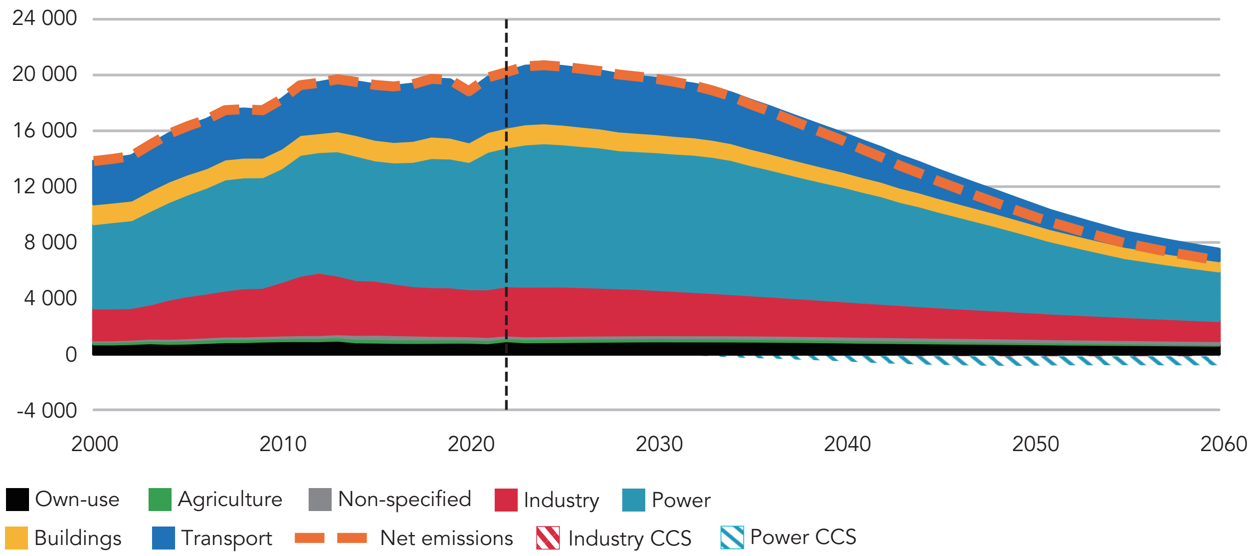
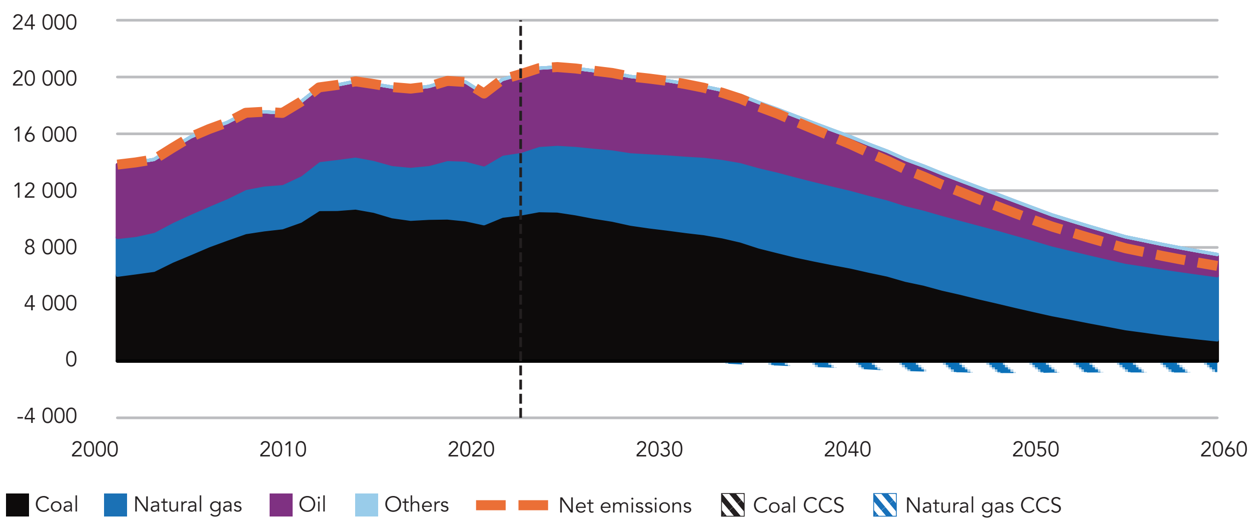
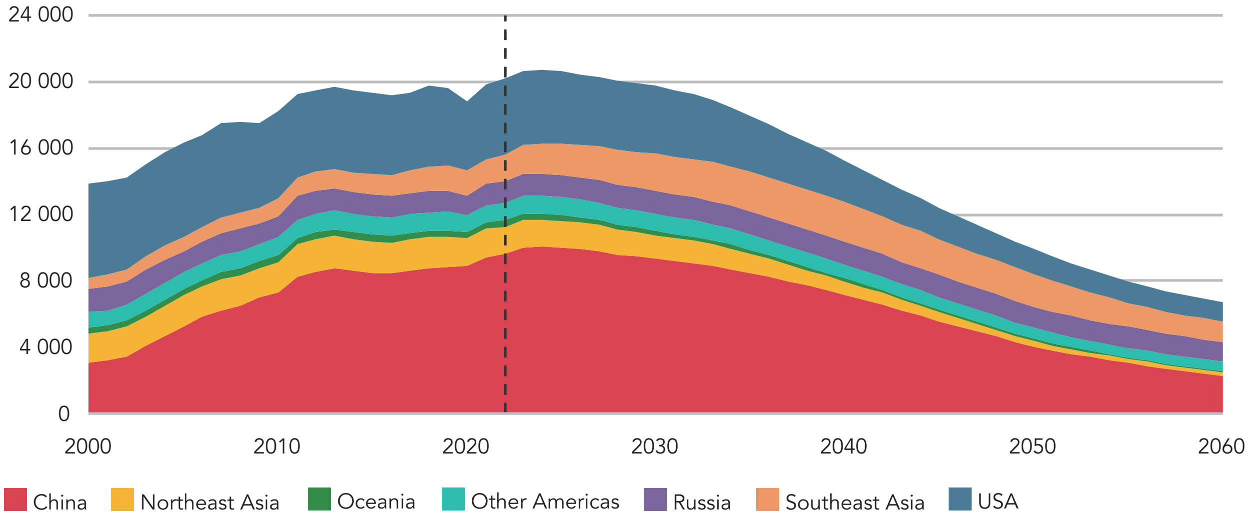


Figure 7.5: APEC CO_2 emissions by fuel, TGT (million tonnes)



In TGT, every subregion is expected to reduce its net CO_2 emissions by 2060 from 2022 levels. The greatest emissions reduction is expected to come from Northeast Asia (88%) followed by Oceania (80%), and China (76%).

Figure 7.6: APEC CO_2 emissions by subregion, TGT (million tonnes)



Emissions Intensity

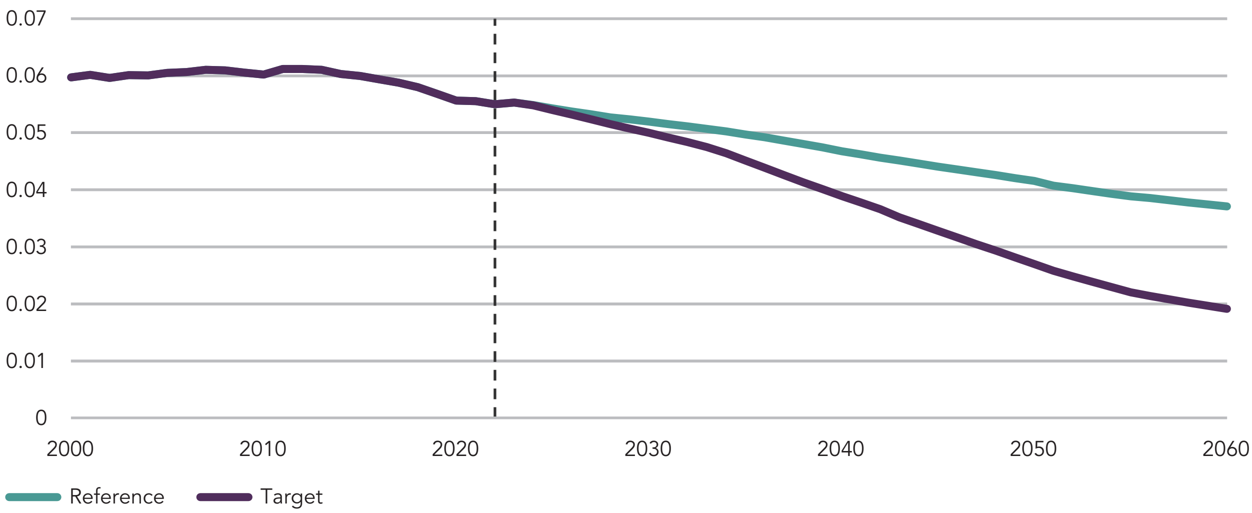
APEC's emissions intensity can be defined as follows:

$$\text{Emissions Intensity} = \frac{\text{Gross } CO_2 \text{ Emissions}}{\text{Energy Supply}}$$

where emissions intensity is expressed in million tonnes per PJ.

As shown in Figure 7.7, APEC's historic emissions intensity has been steadily declining. By 2060, APEC's energy supply mix is expected to shift towards lower-emission sources, and APEC's CO_2 emissions intensity relative to its energy supply is expected to decline by 37% and 65% in REF and TGT, respectively, from 2022 levels. While natural gas is expected to remain dominant in APEC's energy mix, reductions in coal and oil use, together with rising shares of renewables and nuclear, drive the overall decline in emissions intensity across both scenarios.

Figure 7.7: APEC CO_2 emissions intensity, REF and TGT (million tonnes per PJ)

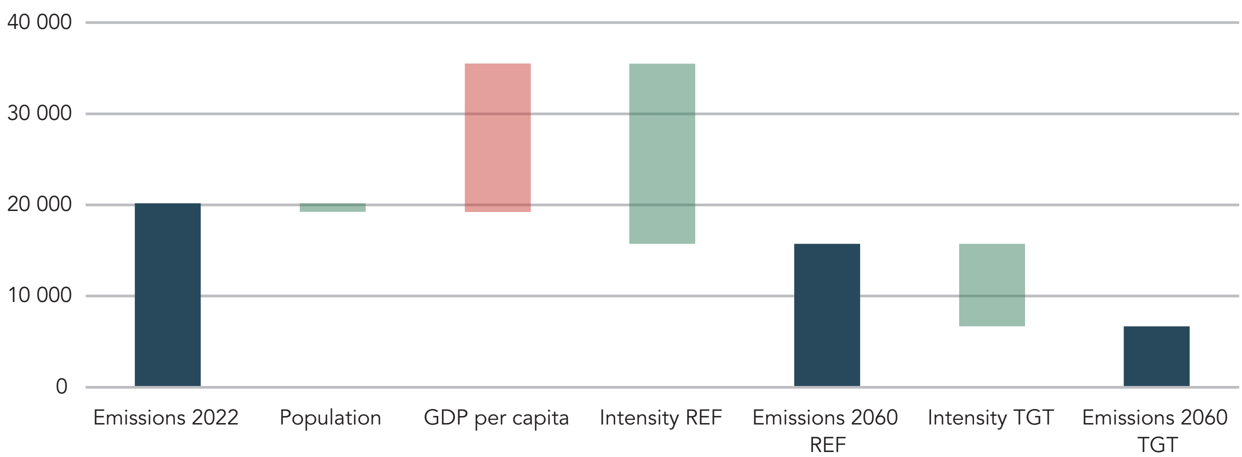


A Kaya identity decomposition was applied to quantify the contribution of key CO_2 emissions drivers in APEC: population, GDP per capita, energy intensity, and emissions intensity:

$$CO_2\ \text{Emissions} = \text{Population} \times \frac{\text{GDP}}{\text{Population}} \times \frac{\text{Energy Supply}}{\text{GDP}} \times \frac{CO_2\ \text{Emissions}}{\text{Energy Supply}}$$

In both scenarios, as the population of APEC declines marginally, per capita GDP growth becomes the strongest driver of emissions growth by 2060. Despite growth in APEC's per capita GDP, improvements in energy and emissions intensities more than offset this increase, resulting in declining emissions in both REF and TGT. Improvements in energy intensity are driven by gains in energy efficiency and increased electrification across demand-side applications, resulting in a substantial decline in energy supply per unit of economic output. Reductions in emissions intensity are primarily attributed to the sharp decline in carbon-intensive fuels, such as coal, within the energy supply mix.

Figure 7.8: APEC CO_2 emissions components, REF and TGT (million tonnes)



Residual CO_2 Emissions

Despite the contribution of CCS to emissions reductions in the TGT scenario, residual CO_2 emissions are projected to remain at 6,700 million tonnes across all APEC subregions by 2060, with the power sector accounting for approximately 43% of these remaining emissions. Although solar and wind are expected to comprise a significant share of APEC's electricity generation by 2060, these energy sources do not fully displace fossil fuels in most subregions, even in TGT. Coal is largely phased out across most APEC subregions, but remains in use in Southeast Asia. In addition, natural gas continues to be crucial in most APEC economies, supporting grid reliability and the integration of variable solar and wind generation. The industry sector is projected to emit an estimated 19% of the residual emissions in 2060 in TGT, despite significant progress in electrification. Several industry subsectors still require high-temperature processes that necessitate significant volumes of fossil fuels, limiting the adoption of low-carbon alternatives like hydrogen and biomass.

APEC's residual emissions in 2060 could be further reduced by other carbon removal strategies, including natural approaches such as reforestation and afforestation, as well as technological initiatives such as direct air capture. While natural removals are generally less expensive than technological approaches, their effectiveness hinges on land availability, as well as their potential impacts on biodiversity and crop production. A balance between natural and technological initiatives is likely necessary to address the residual CO_2 emissions in APEC.

8. APEC Energy Goals

8. APEC Energy Goals

APEC has two official energy goals:

1. Reduce energy intensity of total final energy consumption (TFEC) by 45% in 2035 relative to a 2005 baseline
2. Double the share of modern renewables in the APEC energy mix from 2010 by 2030

Although not an official APEC energy goal, APEC Leaders agreed in 2023 to pursue and encourage efforts to triple renewable energy capacity globally.

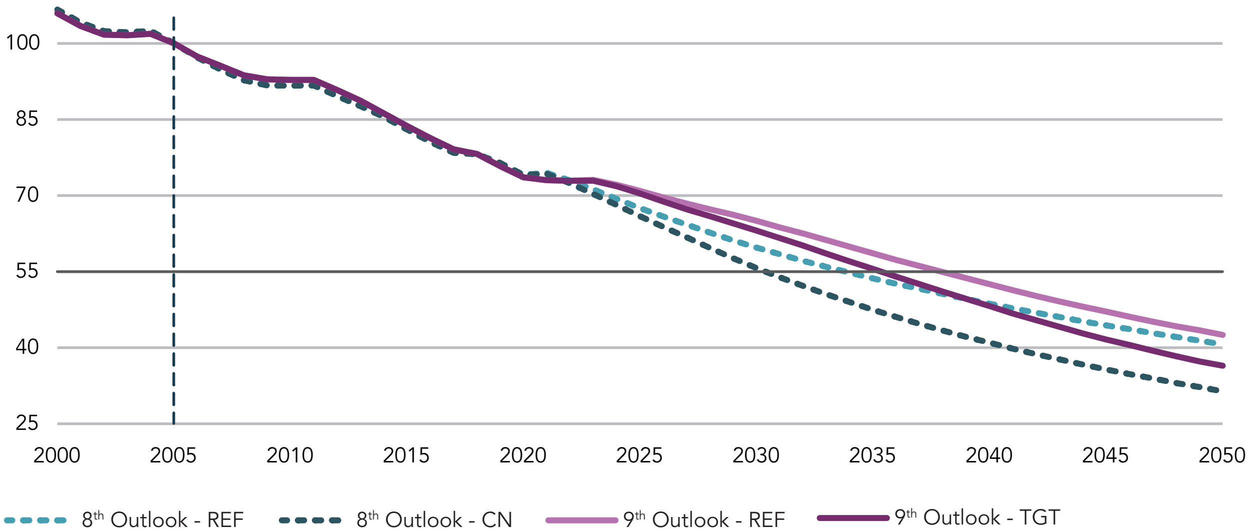
- In the Reference scenario (REF), APEC is unlikely to meet its final energy intensity reduction goal by 2035. In the Target scenario (TGT), however, our projection is that APEC will achieve this milestone.
- Based on recent trends, APEC likely achieved its goal of doubling its share of modern renewable energy six years early in 2024, although final confirmation is pending official data from the Expert Group on Energy Data and Analysis (EGEDA).
- APEC accounted for approximately 56% of global renewable generation capacity in 2022. However, in both the REF and TGT scenarios, APEC falls short of tripling its renewable energy capacity by 2030.

Energy Intensity

At the 2007 APEC Leaders' Meeting in Sydney, Australia, APEC member economies committed to reducing energy intensity by at least 25% by 2030 relative to 2005 levels. This target was subsequently raised to a 45% reduction by 2035 through the 2011 Honolulu Leaders' Declaration, based on recommendations from the APEC Energy Working Group (EWG). At EWG53, members further agreed to monitor progress by analysing final energy consumption intensity (excluding non-energy use) using EGEDA data.

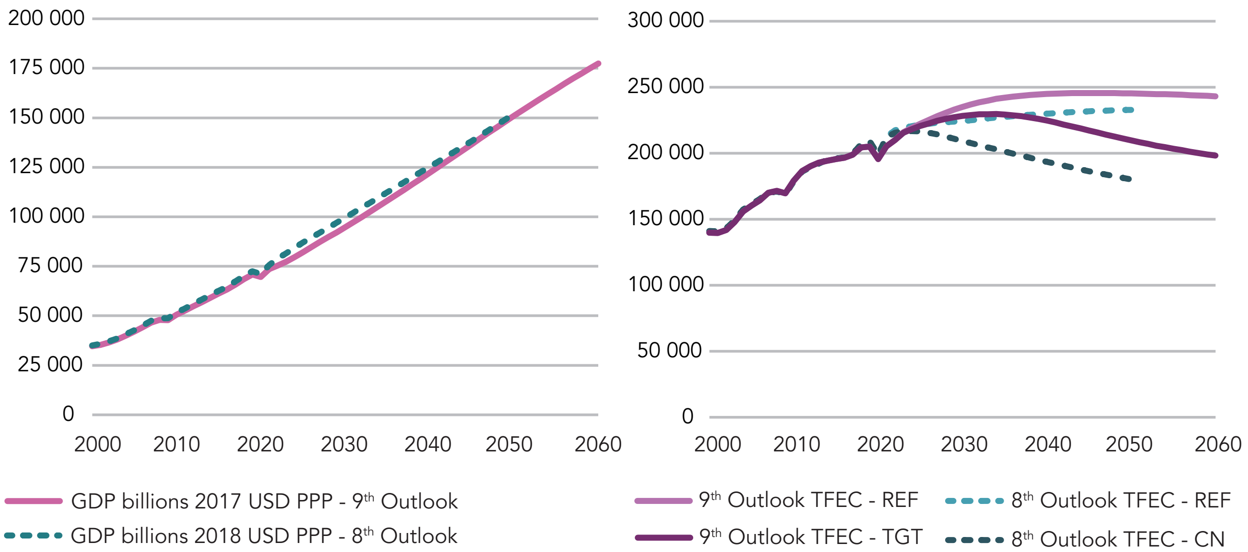
Although final energy intensity has steadily declined for many years, the pace of improvement has slowed, with 2022 recording the smallest reduction in a decade. The 9th edition of the *Outlook* projects a four-year delay in meeting the energy intensity target in REF relative to the Reference Scenario in the 8th edition of the *Outlook*. In REF, APEC is expected to achieve a 45% reduction in TFEC energy intensity by 2038. In TGT, the goal is met in 2035.

Figure 8.1: Comparison of 8th and 9th energy intensity trajectories (PJ/GDP, billion USD), indexed to 100 at 2005



In 2035, APEC's GDP is projected to be 3.8% lower in the 9th edition than in the 8th edition in both scenarios. APEC's TFEC in 2035 is 6.4% higher in REF and 13.9% higher in TGT in the 9th edition relative to the comparable scenarios in the 8th. While the change in TFEC is larger, the combined effect of changes in both metrics contributes to a four year delay between the 8th and the 9th editions in achieving the 45% reduction in energy intensity.

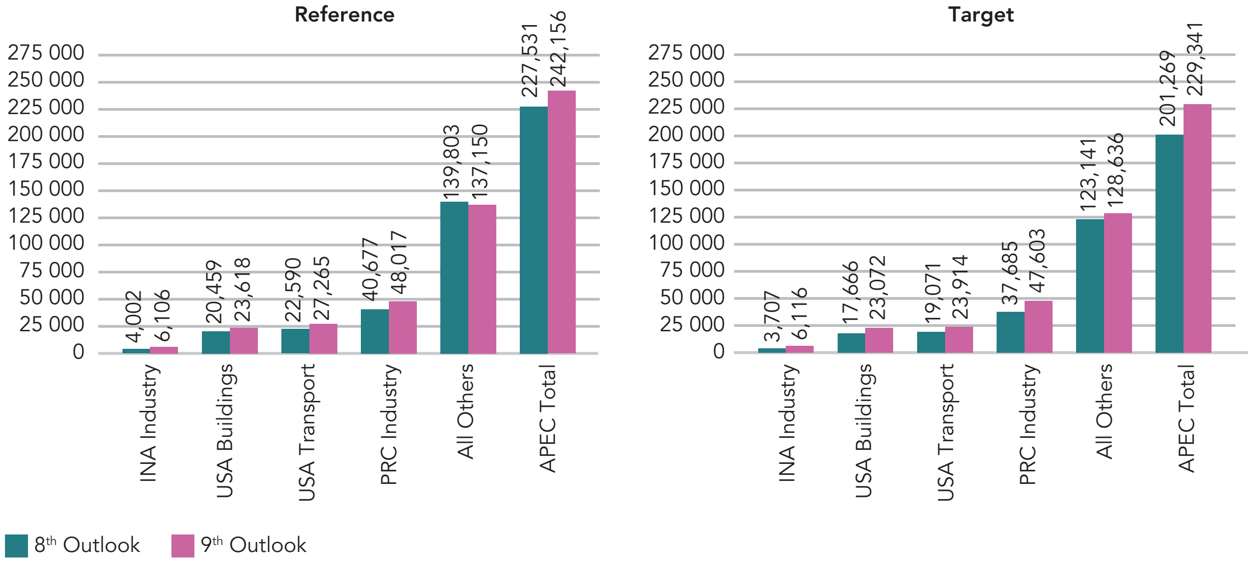
Figure 8.2: Comparison of 8th and 9th GDP and TFEC (PJ) projections



In REF, the increase in projected TFEC is largely driven by higher energy demand in the industry sector in China, the transport and buildings sectors in the United States, and the industry sector in Indonesia. In this scenario, the peak in China's industry energy use shifts from 2022 in the 8th edition to 2030 in the 9th, with demand by 2035 projected to be 18% higher than previously estimated. In the United States, transport energy use rises by 21% in the 9th edition compared to the 8th, and buildings energy demand also increases, largely due to greater data centre and AI adoption by 2035, which was not anticipated in the previous edition of the *Outlook*. In Indonesia, industrial energy use expands sharply, led by growth in nickel production, resulting in a 53% increase relative to the 8th edition.

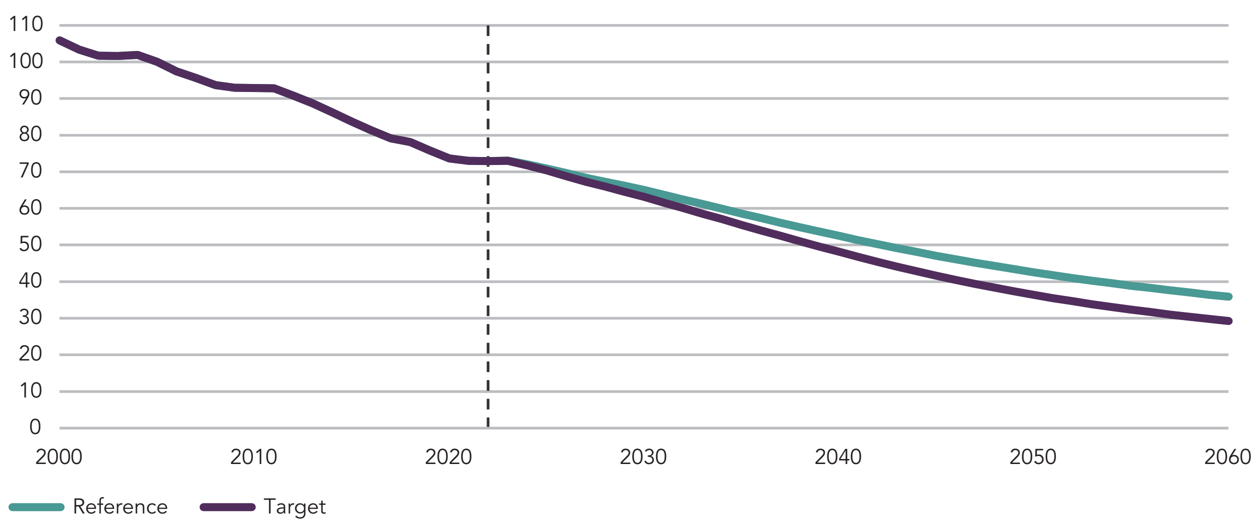
In TGT, the four major drivers of change remain the same though percentage differences in energy differ. In TGT, the goal is achieved by 2035.

Figure 8.3: Drivers of change in TFEC in REF & TGT in 2035 showing differences over 1000 PJ between the 9th and 8th Outlooks' 2035 final energy consumption comparison by economy-sector, and the APEC total (PJ)



In this *Outlook*, final energy intensity is projected to continue improving beyond 2035, reaching a 63% reduction by 2060 relative to 2005 levels in the Reference scenario and a 66% reduction in the Target scenario.

Figure 8.4: Energy intensity of APEC total final energy consumption (PJ/GDP, million 2017 USD, PPP), indexed to 100 at 2005



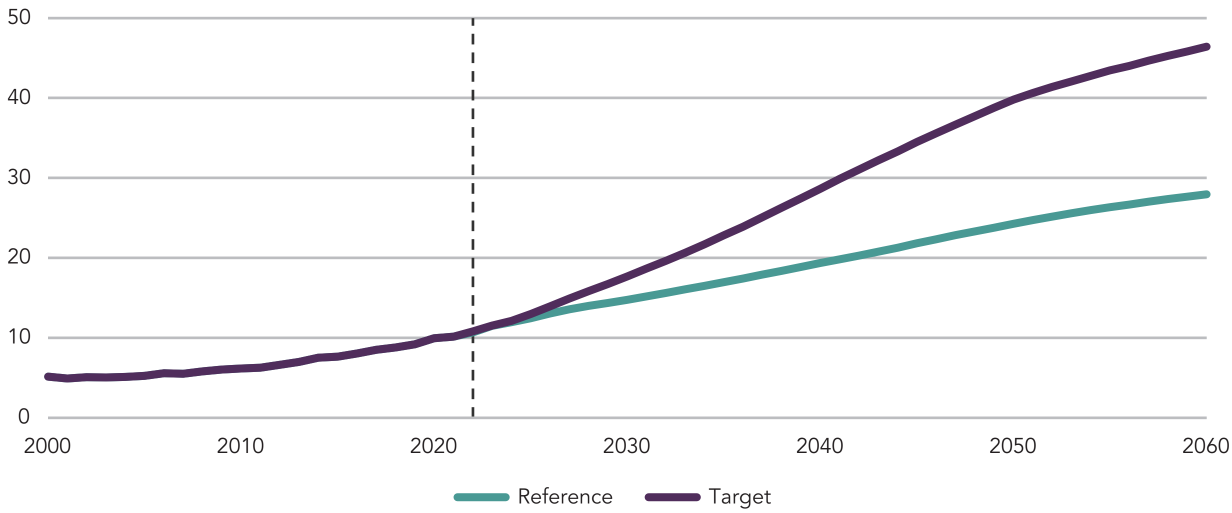
Projected primary energy supply intensity improvements are similar to projected final energy consumption intensity improvements. In both scenarios, a 45% reduction is reached at nearly the same time, whether measured relative to primary energy supply or final energy consumption.

Modern Renewables Share

The second APEC energy goal, announced at the 2014 APEC Energy Ministers Meeting, is to double the share of modern renewables by 2030 compared to 2010 levels. Modern renewable energy demand refers to renewable consumption in end-use sectors (excluding traditional biomass) and includes the share of electricity and heat derived from renewable sources.

Progress has been made towards doubling the share of modern renewables in the energy mix to 12% by 2030 from 6% in 2010. By 2022, the share of modern renewables in final energy consumption had already increased by 75%. Although official 2024 data from EGEDA is not yet available, current trends suggest that the APEC region has likely already achieved this doubling target.

Figure 8.5: Modern renewables share in total final energy consumption, APEC aggregate (%)



Note: Biomass used in the residential and commercial sectors is assumed to be traditional biomass and is not included in the definition of modern renewables. All other renewables (biomass used by industry, hydro, geothermal, etc.) are considered modern renewables. Modern renewables also include the share of electricity that is generated from renewable sources.

The share of modern renewables in total electricity generation is increasing alongside its growing share in total final energy consumption. By 2060, modern renewables could account for 64% of total electricity generation in the Target scenario and 55% in the Reference scenario, up from 26% in 2022.

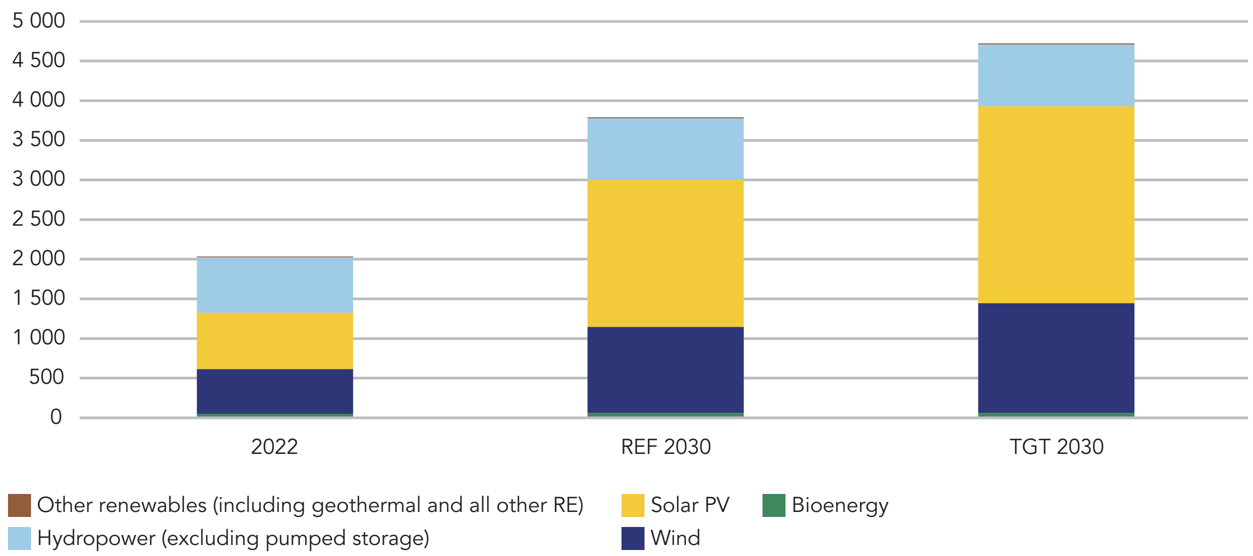
Figure 8.6: Modern renewables share in total electricity generation, APEC aggregate (%)

Tripling Global Renewable Energy Capacity

In 2023, APEC Leaders adopted the Golden Gate Declaration, committing to pursue and encourage efforts to triple renewable energy capacity globally by 2030 through existing targets and policies. The declaration also expressed a commitment to demonstrate similar ambition for other zero- and low-emissions technologies, including abatement and removal technologies, in line with domestic circumstances.

In 2022, APEC accounted for approximately 56% of the global renewable electricity generation capacity of 3,655 GW. By 2030, renewable capacity in APEC is projected to increase by 1.9 times in REF and by 2.3 times in TGT, falling short of a full tripling in both cases. Based on projections in this *Outlook*, APEC is expected to triple its renewable capacity relative to 2022 by 2040 in REF and by 2034 in TGT.

Figure 8.7: APEC renewable electricity capacity in 2022 and in REF & TGT in 2030 (GW)



9. Annex

Conversion Factors

From Petajoule (PJ) to		Multiply by:
Trillion British thermal units	TBTU	0.948
Million tonnes of oil equivalent	MTOE	0.024
Million barrels of oil equivalent	MMBOE	0.164
Million tonnes of coal equivalent	MTCE	0.017
Million tonnes per annum of LNG	Mtpa	0.020
Billion cubic meters of natural gas	bcm	0.028
Billion cubic feet of natural gas	bcf	0.981
Terawatt-hour	TWh	0.028
Million gigacalorie	Million GCal	0.239
Million tonnes of hydrogen	MM tonne H_2	0.008

Regional Groupings

China	
Northeast Asia	Hong Kong, China; Japan; Korea; Chinese Taipei
Oceania	Australia; New Zealand; Papua New Guinea
Other Americas	Canada; Chile; Mexico; Peru
Russia	
Southeast Asia	Brunei Darussalam; Indonesia; Malaysia; the Philippines; Singapore; Thailand; Viet Nam
United States	

Commonly Used Abbreviations

AI	Artificial intelligence
AFOLU	Agriculture, forestry, and other land use
APEC	Asia-Pacific Economic Cooperation
APERC	Asia Pacific Energy Research Centre
ASEAN	Association of Southeast Asian Nations
bcm	Billion cubic metres
B20/B30	Diesel fuel with 20%/30% biodiesel blending
BEV	Battery electric vehicle
CAPEX	Capital expenditure
CC	Carbon capture
CAGR	Compound annual growth rate
CCS	Carbon capture and storage
CCUS	Carbon capture, utilisation, and storage
CHP	Combine heat and power
$CLCH_2$	Clean and low-carbon hydrogen
CNG	Compressed natural gas
CO_2	Carbon dioxide
COP	Conference of the Parties
COVID-19	Coronavirus disease 2019
EE	Energy efficiency
EGEDA	Expert Group on Energy Data and Analysis
EV	Electric vehicle
EWG	APEC Energy Working Group
FCEV	Fuel cell electric vehicle
FIT	Feed in tariff
GDP	Gross domestic product
GHG	Greenhouse gas
GW	Gigawatt
HVDC	High voltage direct current
ICE	Internal combustion engine
IEA	International Energy Agency
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
IPPU	Industrial processes and product use
kV	Kilovolt
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas
Mtpa	Million tonnes per annum
MW	Megawatt
MTOE	Million tonnes of oil equivalent
MEPS	Minimum energy performance standards
NDC	Nationally determined contribution
NGL	Natural gas liquids
OECD	Organisation for Economic Co-operation and Development
OPEC+	Organisation of the Petroleum Exporting Countries Plus
PHEV	Plug-in hybrid electric vehicle
PJ	Petajoule
PPP	Purchasing power parity
PV	Photovoltaic
REF	The Reference scenario
SAF	Sustainable aviation fuel
SMR	Small modular reactor (nuclear)
SMR	Steam methane reforming (blue hydrogen production)
TGT	The Target scenario
TFEC	Total final energy consumption
TPES	Total primary energy supply
TWh	Terawatt-hour
Tx for VRE	Transmission for variable renewable energy
VPP	Virtual power plant
VRE	Variable renewable energy
UNFCCC	United Nations Framework Convention on Climate Change
ZEB	Zero energy building

Commonly Used Terms

Ammonia/hydrogen co-firing	Combusting ammonia and hydrogen with another fuel (e.g., coal or gas) in the same boiler/turbine to displace part of the fossil fuel and reduce overall emissions.
Amortised CAPEX	The upfront capital expenditure (CAPEX) for constructing an energy asset, expressed as an equivalent annual cost over the asset's expected lifetime (using a discount rate). This annualised figure enables direct comparison with other yearly costs, such as fixed O&M, variable O&M, and fuel costs.
Biofuels	Fuels (liquid, gas, or solid) derived from biological materials instead of fossil fuels.
Biodiesel	In this publication, this is diesel-range fuel derived from biogenic oils and fats (e.g., used cooking oil, animal fats, palm-derived by-products). For modelling purposes, use is represented based on the projected share in total diesel: either as a drop-in blendstock or as a fully drop-in fuel that can be used neat or blended when the projected share exceeds blend limits.
Biogasoline	In this publication, this is gasoline-range fuel derived from biomass (e.g., ethanol and other oxygenates, and renewable hydrocarbon gasoline from upgraded bio-oils or co-processing). For modelling purposes, use is represented based on the projected share in total gasoline: either as a drop-in blendstock or as a fully drop-in fuel that can be used neat or blended when the projected share exceeds blend limits.
Biojet-kerosene	In this publication, this is aviation turbine fuel derived from renewable or waste feedstocks. For modelling purposes, use is represented based on the projected share in total aviation fuel: either as a drop-in blendstock or as a fully drop-in fuel that can be used neat or blended when the projected share exceeds blend limits.
Biomass	Organic material from plants, animals, or microbes (including residues and waste) used for energy or materials.
Bunkers	Fuels supplied to international aviation and maritime navigation. These are reported separately from domestic consumption in energy statistics.
Capital expenditure (CAPEX)	Investment outlays to build new capacity or replace existing long-lived energy assets that have been retired. CAPEX is presented as overnight costs (total upfront build cost, excluding financing) or amortised costs (annualised over the asset's lifetime).
Capacity factor	Actual generation over a period divided by generation at continuous rated output for the same period (%).
Carbon intensity	Greenhouse-gas emissions per unit of energy supply, demand, or economic activity (e.g., gCO_2/kWh, gCO_2/PJ, $MtCO_2$/USD GDP), as the context specifies.
Carbon neutrality	Residual greenhouse-gas emissions balanced by removals over a stated period.
Carbon capture	Separation of CO_2 from point sources or air.
Dispatchable capacity/ generators/power	Generation that can be scheduled and adjusted on request to meet demand.
E-fuels (synthetic fuels)	Fuels made with renewable electricity, water and captured CO_2—including e-diesel, e-gasoline and e-kerosene—treated in this publication as drop-in and blendable with their conventional equivalents.

Electrification	Substituting electricity for direct fuel combustion in end-uses (e.g., heat pumps, electric vehicles, electric arc furnaces).
Energy intensity	Final (or primary) energy use (or supply) per unit of economic output (e.g., PJ/USD, GDP).
Fuel switching	Process of replacing one fuel with another. Often used in the context of replacing a carbon-intensive fuel with a lower-carbon or zero-carbon alternative fuel.
Fixed costs	Expenses that remain constant in the use of an energy asset and do not vary based on electricity generation. Common examples include staff salaries, insurance, and routine inspections.
Low-carbon & waste energy	Low-carbon & waste energy includes all bioenergy, waste-derived energy, renewables, nuclear, and hydrogen-based fuels.
Low-emission technologies	Technologies that significantly reduce emissions relative to incumbent options (especially greenhouse gases).
Hydrogen-based fuels	In this publication, this term includes hydrogen, ammonia, and e-fuels used as energy carriers.
Clean hydrogen	Hydrogen produced through processes that generate minimal direct carbon emissions during production. This primarily refers to hydrogen produced via electrolysis using electricity from renewable energy sources (solar, wind, hydroelectric, etc.), commonly known as green or renewable hydrogen. Clean hydrogen may also include hydrogen produced using nuclear-powered electrolysis (pink hydrogen) and other carbon-free production methods. For classification purposes clean hydrogen is a subset of low-carbon hydrogen.
Low-carbon hydrogen	In the context of the *Outlook*, low-carbon hydrogen is used as a catch-all term for clean hydrogen that was exported and blue hydrogen that was produced or imported. Low-carbon hydrogen refers to clean hydrogen produced and exported to hydrogen importing economies as emissions would be incurred during transportation and distribution. It was assumed that most hydrogen traded amongst APEC economies would be of this form (specifically green hydrogen) with a small proportion being blue hydrogen. Additionally, in the context of hydrogen-producing economies, low-carbon hydrogen specifically refers to hydrogen being produced using fossil fuels with technologies such as CCS or methane pyrolysis that cut lifecycle emissions by at least 90% compared to unabated production. A key example is blue hydrogen made from natural gas via SMR or ATR with CCS.
Unabated hydrogen	This term includes hydrogen produced from natural gas via steam methane reforming (SMR) or auto thermal reforming (ATR) without CCS, also known as grey hydrogen, hydrogen from coal gasification without CCS, also known as black or brown hydrogen, and hydrogen produced via electrolysis using electricity from fossil fuel-dominated power grids, also known as yellow hydrogen.
Grid modernisation	Upgrades that enhance electricity networks' efficiency, resilience, and flexibility (e.g., digitalisation, advanced controls, storage integration).
Modern renewables	In this publication, "modern renewables" includes all renewable energy sources except solid biomass in the buildings sector.

Modal share	Also called modal split, it is the percentage distribution of travel or trips made using different modes of transportation (e.g., bus, car, boat, plane) within an economy or area.
Non-energy demand	Refers to the use of energy resources, primarily fossil fuels, as raw materials or feedstocks for producing goods, rather than for combustion or power generation (e.g., oil used in petrochemicals).
Net-zero emissions	Economy-wide balance between anthropogenic emissions and removals of greenhouse gases by a target date.
Sustainable aviation fuels (SAF)	Alternative aviation fuel derived from liquid biofuels or e-fuels, instead of fossil petroleum.
System flexibility	Refers to the ability of an energy system, such as an electrical grid, to dynamically adjust both power generation and consumption to maintain a stable and balanced supply-demand relationship under varying conditions.
Petroleum liquids	All fuels within the categories of refined petroleum products, crude oil, natural gas liquids, and other hydrocarbons.
Variable cost	Costs that fluctuate in direct proportion to the electricity produced by the asset. Common examples include fuel costs, maintenance, and cleaning that scale with operation.

Guidance on Figures

This report follows a standard layout to support comparison between scenarios. All charts are arranged so that, when two appear side by side, the left chart always represents REF, and the right chart always represents TGT.

Drivers in the transport energy decomposition chart:

This chart is a log mean divisia index (LMDI) decomposition showing the drivers of changes in energy use in the road sector.

- Activity: The change in energy use caused by growth in passenger-km and freight tonne-km, with all other effects held constant.
- Vehicle size/type: The change in energy use caused by changes in the type of vehicle used (such as from car to bus, car to SUV, etc.).
- Engine Type: The change in energy use caused by changes in the type of engine used in vehicles. Most of this effect is caused by shifts from ICE (internal combustion engines) to BEVs (battery electric vehicles).
- Other Factors: The change in energy use caused by all other modelled factors, which include the degradation of pre-existing vehicle efficiency due to age and improvements in overall ICE vehicle efficiency, which is not captured by the engine type effect since that captures changes in the engine type distribution compared to the base year.

CO_2 emissions components:

This chart also uses the LMDI decomposition method to represent the Kaya identity, which employs the following formula:

$$CO_2 \text{ emissions} = \text{Population} \times \frac{\text{GDP}}{\text{Population}} \times \frac{\text{Energy supply}}{\text{GDP}} \times \frac{CO_2 \text{ emissions}}{\text{Energy supply}}$$

- Population: The change in emissions caused by population growth or decline.
- GDP per capita: The change in emissions caused by an increase or decrease in GDP per capita $\left(\frac{\text{GDP}}{\text{Population}}\right)$.
- Intensity REF: The change in emissions caused by improvements or decreases in energy and carbon intensity $\left(\frac{\text{Energy supply}}{\text{GDP}} \times \frac{CO_2 \text{ emissions}}{\text{Energy supply)}}\right)$ in REF.
- Intensity TGT: The change in emissions caused by further change in intensity in TGT compared to REF.

Useful Links

General

Asia-Pacific Economic Cooperation – About APEC

Asia-Pacific Energy Research Centre – APERC

Expert Group on Energy Data and Analysis (EGEDA) – EGEDA

United Nations Framework Convention on Climate Change (UNFCCC) – UNFCC emissions factors

Publicly available models used in the *Outlook* – APERC GitHub

Demographic and Macroeconomic Assumptions

IMF's Global Economic Data – IMF Data

United Nations Department of Economic and Social Affairs (UN DESA) – World Population Prospects

World Bank Group – GDP Data

Agriculture

Food and Agriculture Organization of the United Nations – The future of food and agriculture – Alternative pathways to 2050

Transport

Asian Transport Observatory – ATO

International Energy Agency – EV Life Cycle Assessment Calculator

Power

OSeMOSYS – Open Source Energy Modelling System – OSeMOSYS

Nuclear

International Energy Agency – Energy Statistics Data

International Atomic Energy Agency – Power Reactor Information System

International Atomic Energy Agency – Nuclear Power Reactors in the World 2023 Edition

Nuclear Energy Agency – NEA Small Modular Reactor Dashboard

Nuclear Energy Agency – Uranium 2024: Resources, Production and Demand

World Nuclear Association – Nuclear Fuel Report: Global Scenarios for Demand and Supply Availability 2023-2040

World Nuclear Association – Declaration to Triple Nuclear Energy

Crude Oil

APERC – Oil Report 2024

IEA – Oil Report 2025

OPEC – World Oil Outlook 2050

Natural Gas

CEDIGAZ – Natural Gas Statistical Databases

Bioenergy and Waste

ASEAN Centre for Energy – Fuelling National and Regional Ambitions with Shared Biofuel Strength within ASEAN Countries

Green Air – Commentary: China's SAF industry poised to be a transformative force in aviation's low-carbon future

U.S. Energy Information Administration – U.S. Sustainable aviation fuel production takes off as new capacity comes online

Hydrogen

APERC – APERC Hydrogen Report 2024

IEA – Global Hydrogen Review 2024

International Journal of Hydrogen Energy – Technological aspects of Russian hydrogen energy development

Costs

CSIRO – GenCost: cost of building Australia's future electricity needs

IRENA – Renewable Power Generation Costs in 2023

NREL – Annual Technology Baseline

To access a digital version of the *APEC Energy Demand and Supply Outlook* **Volume 1**, please scan the QR code or visit the following website:

https://aperc.or.jp/reports/APEC_Outlook_9th_Edition-Volume_1.pdf

For the energy demand and supply outlooks for each of the 21 APEC economies, please scan the QR code or visit the following website to read **Volume 2** of the 9th edition of the *APEC Energy Demand and Supply Outlook*:

https://aperc.or.jp/reports/APEC_Outlook_9th_Edition-Volume_2.pdf

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