# CARBON NEUTRALITY SCENARIO IN THE 8TH APEC ENERGY DEMAND AND SUPPLY OUTLOOK

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# 1. Overview

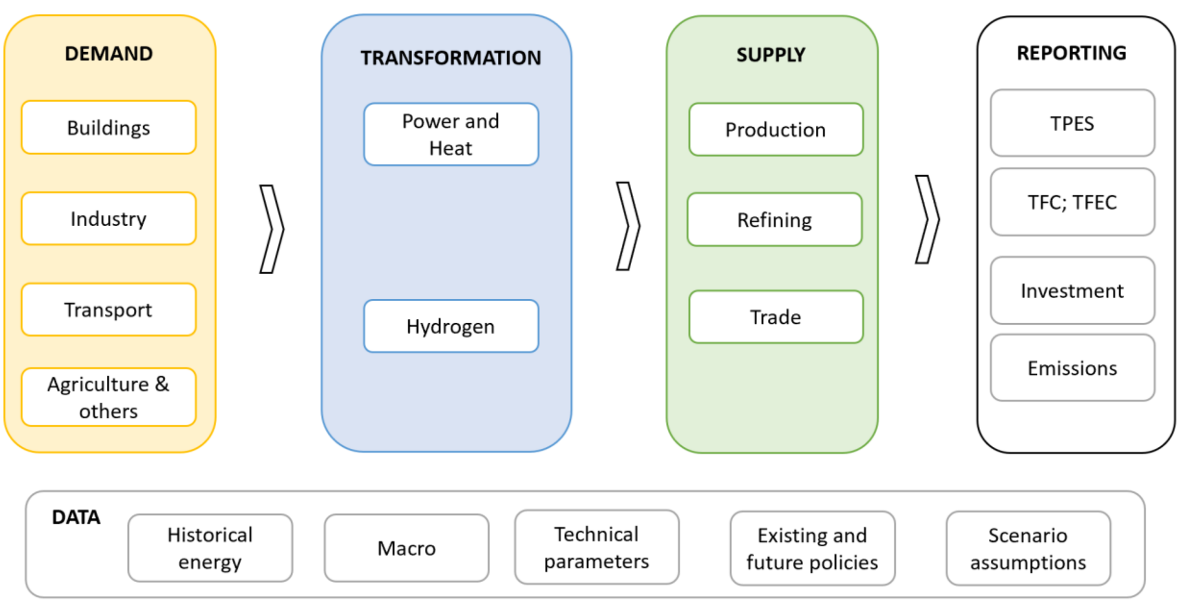
The 21 economies that comprise the Asia Pacific Economic Cooperation (APEC) forum are home to almost three billion people and account for 60% of global GDP. APEC is reliant on immense levels of energy supply, with a large trade component, required to enable continued strong economic growth in the region. The forum's purpose is to promote regional economic integration and trade. Understanding long-term energy market trends is fundamental to achieving this and has become increasingly important in the context of the global push toward decarbonisation.

For the 8th edition of the APEC Energy Demand and Supply Outlook, the Asia Pacific Energy Research Centre has constructed two potential energy futures from 2018 to 2050. The 8th edition contains two scenarios. The Reference scenario (REF) analyses recent trends in APEC energy consumption, production, and trade, to deliver one potential energy future. The Carbon Neutrality scenario (CN) explores hypothetical pathways for each of the 21 APEC member economies to reach carbon neutral energy sectors. CN explores additional energy sector transformations such as increased levels of energy efficiency, behavioural changes, fuel switching, and CCS deployment. The pathways are constructed based on the unique characteristics, policy objectives, and starting points of each economy. CN does not consider $CO_2$ emission sinks, such as land-use or technologies like direct air capture.

# 2. Methods

The 8th edition Outlook modelling involves decomposing the APEC energy system into multiple subcomponents spanning demand sectors (such as industry, transport, and buildings), transformation (power, heat, and refining), and supply (production and trade). Demand sector modelling relies on estimates of output, energy efficiency, fuel switching rates, activity rates, technology diffusion, and multiple other variables.

*Figure 1. Energy system modelling structure.*



Calibration occurs via knowledge-based iteration, particularly with economy-level experts. When demand is finalised, the power, heat, refining and supply, sector models deliver the required energy based on assumptions about fuel cost trajectories, and policy/market intervention.

In the case of the power sector, a least cost optimization model (OSeMOSYS) is deployed. However, cost-based decisions are assumptions are overridden if there is political backing for certain technologies or fuels that enhances their relative economic viability. There is frequent iteration of results, with extensive review and input from economy and energy experts to arrive at final energy demand, transformation, and supply results. Assumed output and activity is close to the same in both 8th Outlook scenarios.

## 2.1 The Carbon Neutrality scenario

CN illustrates a potential pathway where energy efficiency, fuel switching, and technology advance substantially to reduce $CO_2$ emissions from fossil fuel combustion through a projection period starting in 2018 and running through 2050.

Technology maturity and commercial availability are key assumptions in CN. Hydrogen supply chains – blue and green – are assumed to be available at scale starting in 2030 to serve end-use applications in buildings, industry, and transport sectors. While technically possible, hydrogen consumption by the power sector is not considered. CCS is assumed to be commercially available. CCS is utilized earlier (2030) and in greater quantities in the industry sector. CCS retrofits and new-builds become available in the power sector starting in 2030.

The CN is intended as a guide to show the magnitude of $CO_2$ reductions possible in the context of the assumptions made about technology diffusion, costs, and global trends. CN can be used to quantify the magnitude of remaining $CO_2$ emissions that would require further action from policymakers, industry participants, and researchers.

Characteristics that distinguish the Reference scenario results from the Carbon Neutrality scenario are energy efficiency rates that follow historic trends; gradual rates of fuel switching; and relatively slower diffusion of new technologies in demand and power sectors. Assumed output and activity is close to the same in both 8th Outlook scenarios.

*Table 1. Main assumptions in the Carbon Neutrality scenario.*

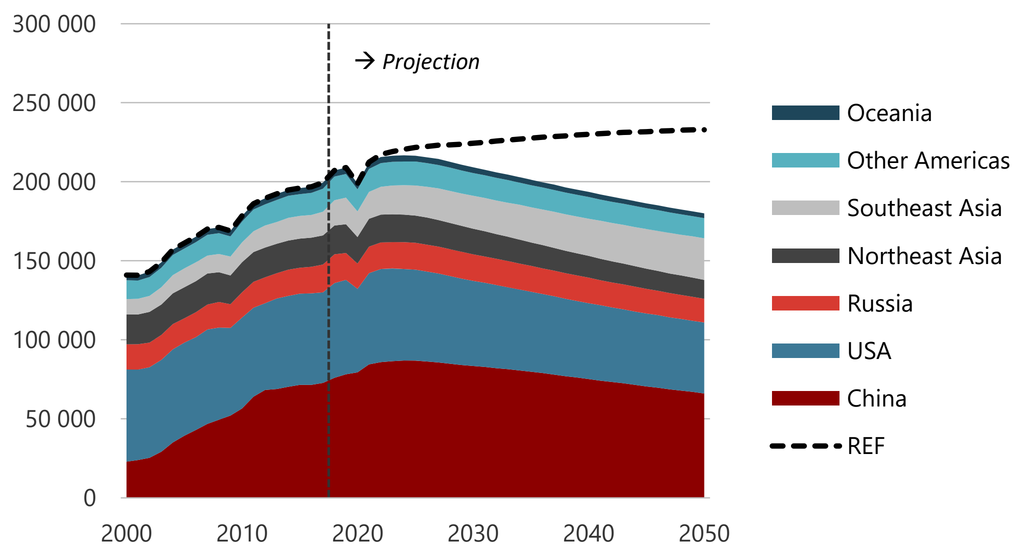
| Item | Assumption |
|---|---|
| **GDP and population** | • Historical GDP data from World Bank WDI.<br>• GDP projections from OECD and internal analysis.<br>• COVID-19 impact on GDP is incorporated in between 2020-2025 (IMF). |
| **Buildings** | • Increased electrification and efficiency measures.<br>• Accelerated reduction in traditional biomass. |
| **Industry** | • Material efficiency improvements for steel, cement, and chemicals subsectors.<br>• Hydrogen for steel production and chemicals introduced in 2030.<br>• Higher fuel switching rates from coal to biomass, electricity, and natural gas in multiple industry subsectors. Energy efficiency more rapid than REF.<br>• Uptake of CCS for steel, cement, and chemicals starting in 2030. |
| **Transport** | • Improved fuel efficiency and hybridization.<br>• New vehicle sales share reach 90% EVs in 2035 and increase to 100% in 2050.<br>• Hydrogen fuel cell vehicles utilised for heavy road transport.<br>• Aviation sector gradually adopts biojet and hydrogen fuels after 2025. |
| **Power and heat** | • CCS for gas-fired plants and some coal-fired plants in select economies.<br>• Near complete coal phase-out by 2050.<br>• Improved competitiveness of utility-scale PV and wind (onshore and offshore). |
| **Supply** | • Global export market for oil, natural gas, and coal is lower assuming carbon neutrality measures outside APEC. |
| **Climate** | • Individual economy targets vary between 2050-2060.<br>• Aggregate APEC emissions observed through 2050.<br>• Fugitive and negative emissions are not considered. |

# 3. Results

## 3.1 End-use demand by APEC sub-region

The APEC region consumed around 250 PJ of energy in 2018, which represents an increase of more than 1.5 times since the 2000s. China accounts for more than 80% of this increase, with the increase in energy consumption fundamental to its growth story. However, China's industrial- and infrastructure-led growth is transitioning to service-oriented growth. Elsewhere in APEC, economies in southeast Asia are expected to grow rapidly. These economies are expected to more than double their relative share of end-use energy demand in the APEC energy mix. Southeast Asia is also the only region to increase its energy consumption in the projection.

*Figure 2. End-use demand by APEC sub-region[1] (2000-2050) in PJ.*

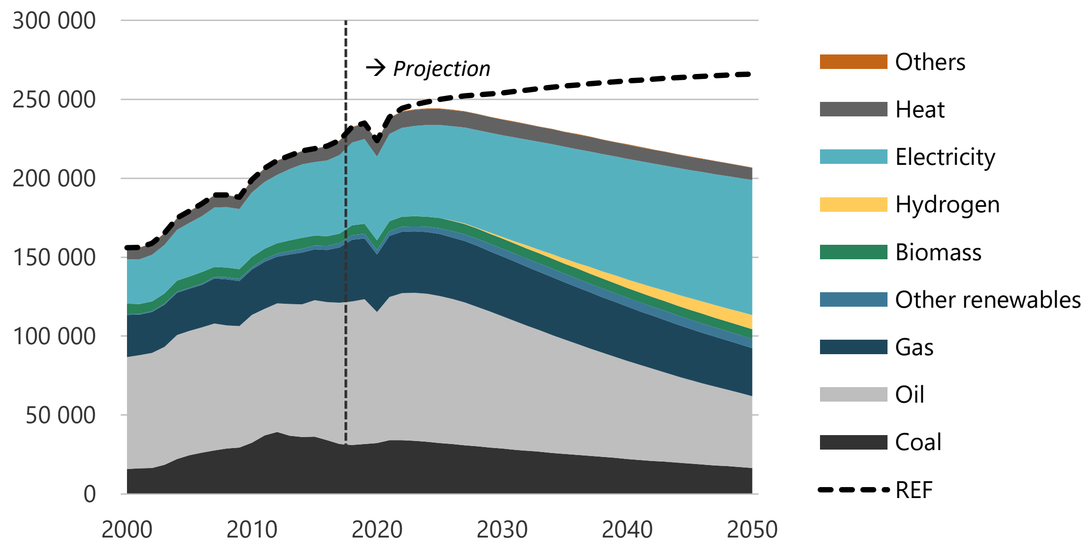



## 3.2 End-use energy demand by energy carrier

In CN, energy demand peaks in the mid-2020s due to a combination of more stringent energy efficiency policies, fuel switching, and electrification. By 2050, energy demand drops below levels seen at the beginning of the projection (2018). While these consumption levels match those of recent years, the composition of energy use is significantly changed and supports much higher levels of economic activity.

*Figure 3. End-use energy demand (2000-2050) in PJ.*

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




Refined products (oil) currently account for almost two-fifths of APEC final energy demand, with its prominence tied to moving things and people within APEC economies. Transport activity is assumed to continue to increase out to 2050, but fuel efficiency improvements and fuel switching to biofuels and electricity reduce refined products consumption to just over one-fifth of the energy mix (2050).

China's industrial sector consumes massive amounts of coal in activities such as cement and steel production. While end-use coal consumption (excluding the power sector) falls by almost half, a substantial portion remains. The remaining coal consumption is subject to carbon capture when feasible.

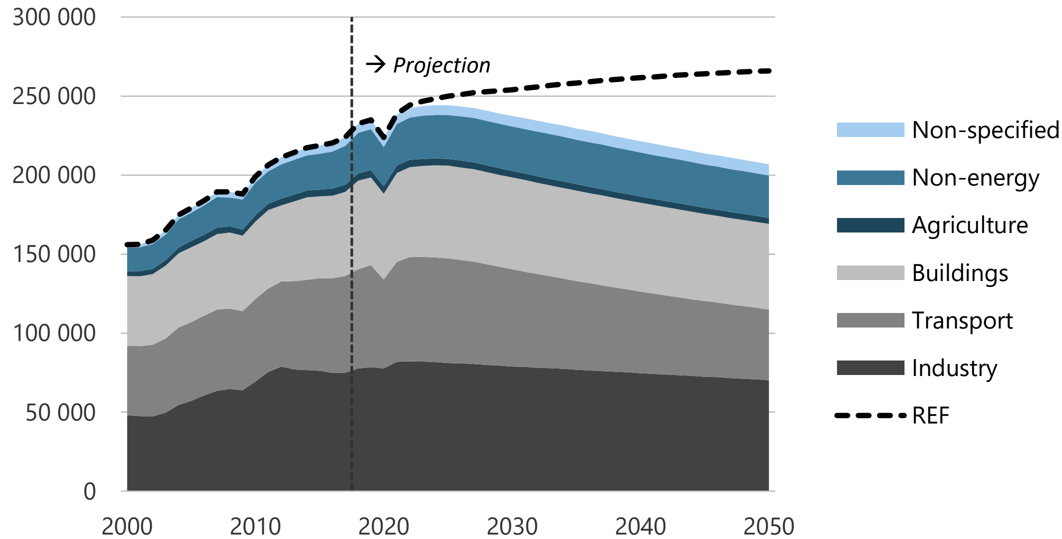
Natural gas consumption does not increase. Instead, electricity and hydrogen supplant natural gas in many end-use energy applications, reducing its consumption by more than one-fifth out to 2050. The share of natural gas in CN end-use energy mix also falls.

Hydrogen is assumed to receive significant policy, enabling adoption in end-use applications such as heavy trucking, and steel and chemicals manufacturing. These uses are supported by hydrogen supply infrastructure that spurs end-use development through improved economics. Hydrogen consumption reaches almost 9 000 PJ in CN, or 4.0% of the end-use energy mix.

## 3.3 End-use energy demand by sector

The APEC industry sector remains the largest consumer of energy through 2050. Industrial energy use declines by 9.0% due to greater levels of energy efficiency, material efficiency (achieving the same final output with less inputs), and fuel switching to more efficient energy carriers (e.g., electricity). There is a projected large decline in output from China's steel and cement sectors, due to ongoing structural changes. These declines are offset by the rise in industrial output for many other economies, such as in southeast Asia.

*Figure 4. End-use energy demand by sector (2000-2050) in PJ.*




The transport sector is currently the second-largest energy consuming sector but drops to third as greater levels of energy efficiency, mostly due to widespread electrification, see demand peak by the mid-2020s. By 2050, transport energy use in 2050 is almost 30% lower than current levels.

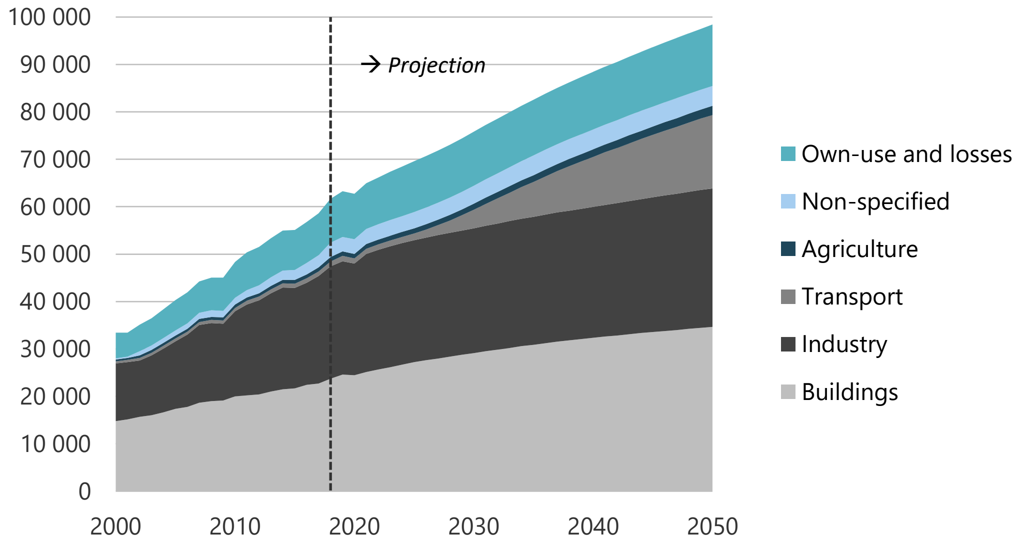
Energy consumption by the buildings sector is expected to fall slightly. This large difference between the two scenarios means that the buildings sector accounts for the second. Appliance energy efficiency improvements and implementation of stricter building codes, suggest that living standards increase without a runaway increase in energy consumption.

The APEC non-energy sector, which mostly relates to chemicals enterprises that use fossil fuels as a feedstock, becomes slightly more prominent, accounting for about one-eighth of the energy mix. The inputs required by these enterprises decreases due to improved efficiencies.

## 3.4 Electricity in end-use energy applications

Electricity in end-use energy applications has increased from 18% in 2000 to 23% just prior to COVID-19. After the pandemic, electrification continues to increase. By 2050, electricity demand increases over 60%, reaching 40% of total energy demand in 2050. In some APEC economies, electrification goals are achieved adding to electricity demand. However, the largest source of electricity demand is in the transport sector as electric vehicles become cost competitive and policy support increases. Sales shares of electric vehicles accelerate rapidly through the 2030s. Electrification of the transport sector has an added benefit of increasing energy efficiency because electric motors are more efficient than internal combustion engines.

*Figure 5. Electricity consumption (2000-2050) in PJ.*

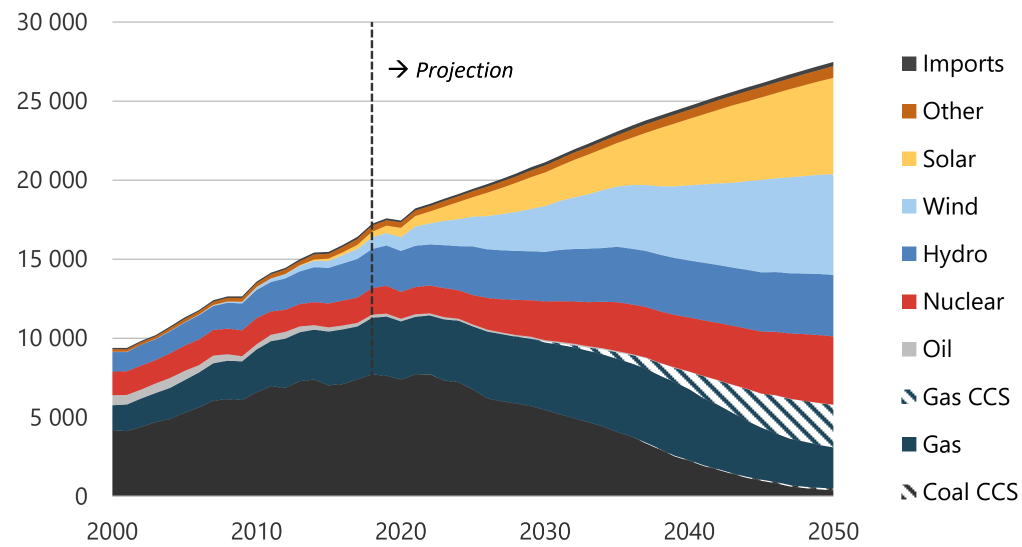



## 3.5 Power generation

Between 2000 and 2018, China led growth in electricity generation (growing 600%). During the same period, southeast Asia's electricity generation nearly tripled. Despite the increase in wind and solar power generation, about two-thirds of the additional generation comes from fossil fuels and nuclear power plants.

In CN, the requirement for more electricity and lower $CO_2$ emissions results in a much different electricity system in 2050 compared to 2018. Over 75% of electricity is generated by wind, solar, and to a lesser extent nuclear, technologies. Natural gas plants equipped with carbon capture and storage (CCS) starting in the 2030s reduce unabated $CO_2$ emissions. By 2050, power plants with CCS technologies will account for 20% of coal-fired generation (all coal CCS units are in southeast Asia) and nearly half of gas-fired generation.

*Figure 6. Electricity generation (2000-2050) in TWh.*




Additional capacity is required to meet the increased demand for electricity. The installed capacity of power plants in CN more than doubles the 2018 total level by 2050. Against the background of an increase in total installed capacity, the share of thermal power plants will almost halve, dropping to 20% of installed capacity. The reduction of thermal power plant capacity occurs due to the almost complete decommissioning of coal-fired plants that were reaching their peak capacity in APEC in 2024. Some gas-fired thermal power plants are commissioned but not enough to offset the decline from coal plants.

Gas-fired and remaining coal power plants in operation will be partially equipped with CCS technologies to decarbonise the power sector. In 2050, more than half the gas power generation capacity will be equipped with CCS.

Wind and solar will dominate the renewable power generation in CN. Nearly two-thirds of total installed capacity in 2050 is solar and wind, which reflects lower capacity factors. The non-dispatchable nature of wind and solar means that improving grid flexibility by the deployment of storage, among other measures, is necessary to allow substantial penetration of non-dispatchable energy to the grid. Overall, this will significantly increase the reliance on critical minerals used in the construction of both wind and solar power plants and storage batteries.

## 3.6 Energy supply

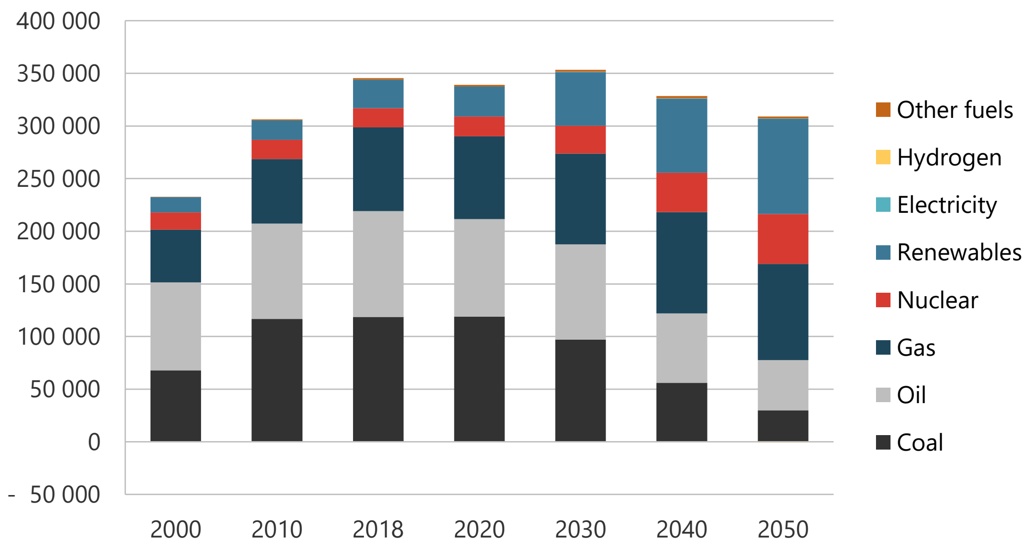
The supply of energy in APEC follows demand. APEC energy supply falls by 10% through 2050, with China and the United States accounting for most of the reduction, falling a seventh and a fifth, respectively. Supply also falls over a third in northeast Asia, a fifth in other Americas, and a third in Oceania. Supply is flat in Russia and grows by three-quarters in southeast Asia.

The role of fossil fuels is diminished, but they still account for more than half of APEC supply in 2050. Declining coal-fired generation drives coal to a tenth of the supply mix, while transport electrification and modal shifting reduce oil to a sixth. The share of gas rises to 30%, mostly on higher use in China and southeast Asia.

Lower-emitting fuels play a larger role in APEC's energy system. Higher variable renewable deployment increases renewable supply by over three-times in terms of both value and share, and nuclear triples to 15%.

Lower domestic supply requirements and a declining global market for fossil fuels drives energy production down a sixth. Natural gas production grows to meet rising demand, but peaks in 2032, and falls to 2018 levels by 2050. Coal and oil production begin to decline in 2023, with coal falling three-quarters and oil by almost half.

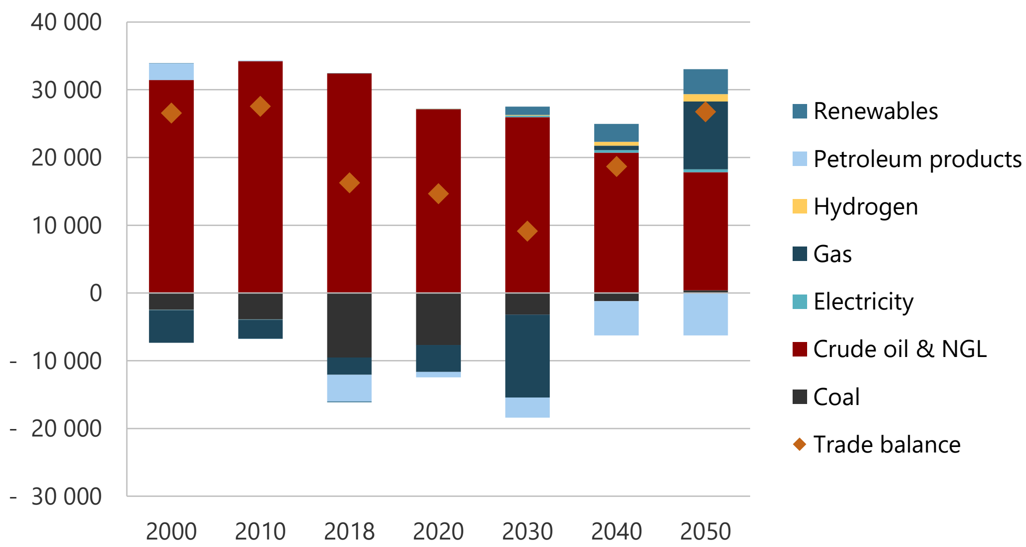
*Figure 7. Energy supply (2000-2050) in PJ.*




A declining global market for fossil fuels reduces APEC's role as a producer-exporter, but robust demand in southeast Asia for coal and natural gas buoys import requirements. APEC net coal imports approach zero by 2050. Whereas APEC gas imports increase as producer-exporters lose market share to non-APEC suppliers. Security of gas supply remains a concern in CN.

Crude oil continues to dominate net energy imports, but lower refinery runs reduce crude oil imports by over a half. APEC becomes a net refinery products exporter, as refineries strive to capture global market share while oil demand falls within the APEC region.

*Figure 8. Net energy trade (2000-2050) in PJ. Exports appear as negative.*




Electricity trade increases by over half, while net hydrogen imports increase, as both energy carriers provide lower-emitting solutions to multiple APEC economies. Further trade of both carriers could reduce the role of fossil fuels in APEC even further than shown here.

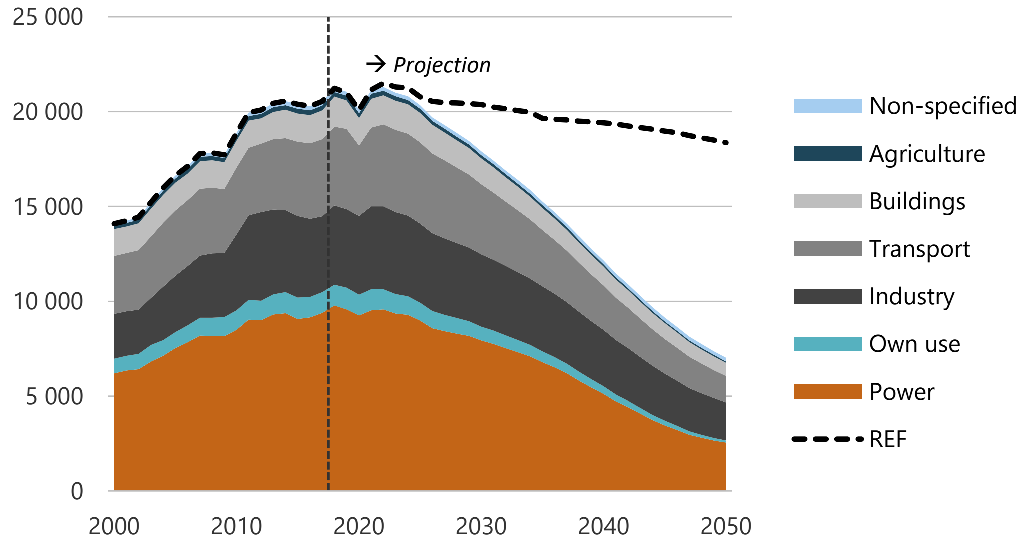
## 3.7 $CO_2$ emissions

The power sector has been the largest source of energy-related $CO_2$ emissions in the APEC region (46% in 2018). The industry and transport sectors each emitted about 20%, while buildings emitted 8%. Coal contributed more than half of the emissions in 2018, with oil and gas contributing 27% and 20%, respectively.

China and the United States are the largest $CO_2$ emitters in APEC and the world, contributing 45% and 23% of APEC-wide $CO_2$ emissions in 2018. China's emissions tripled from 2000 to 2018, with a very large increase in industrial output.

$CO_2$ emissions in southeast Asia doubled between 2000-2018, due to rapid economic development and increasing energy demand, that has been reliant on fossil fuels.

*Figure 9. CO2 emissions (2000-2050) in million tonnes.*

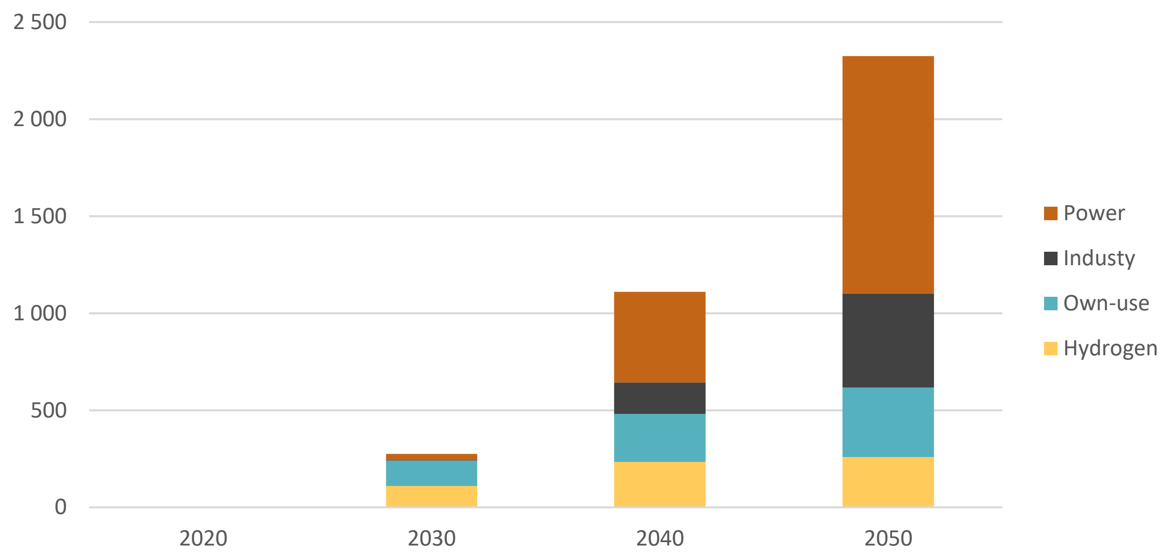



All sectors make significant reductions in their $CO_2$ emissions between 2018 and 2050. Key drivers include phase-out of coal in the power sector; widespread electrification, particularly in the transport sector; successful development of hydrogen applications in transport and industry sectors; and extensive CCS deployment in power (mostly gas-fired units), own-use, and industry sectors.

China and the United States contribute to over 60% of the $CO_2$ reduction in CN relative to REF. Southeast Asia is expected to contribute a further 13%, driven by the region's transition away from coal, and the $CO_2$ of electrification, amongst other reasons.

By 2050, $CO_2$ emissions in CN are 62% below REF levels, with power and transport sectors contributing to most of the reduction. These estimates consider only $CO_2$ emissions from combustion of fossil fuels in the energy sector. Fugitive emissions, such as flaring and methane leakage, and non-energy sectors are not considered.

*Figure 10. C02 captured by CCS units in million tonnes.*




Mitigating the remaining 7 000 million tonnes of $CO_2$ emissions in 2050 in CN could require natural removals (for example, forest rehabilitation and preservation) and/or technological (for example, direct air capture). There might be an opportunity for future collaboration between APEC economies.

## 3.8 Components of $CO_2$ emissions

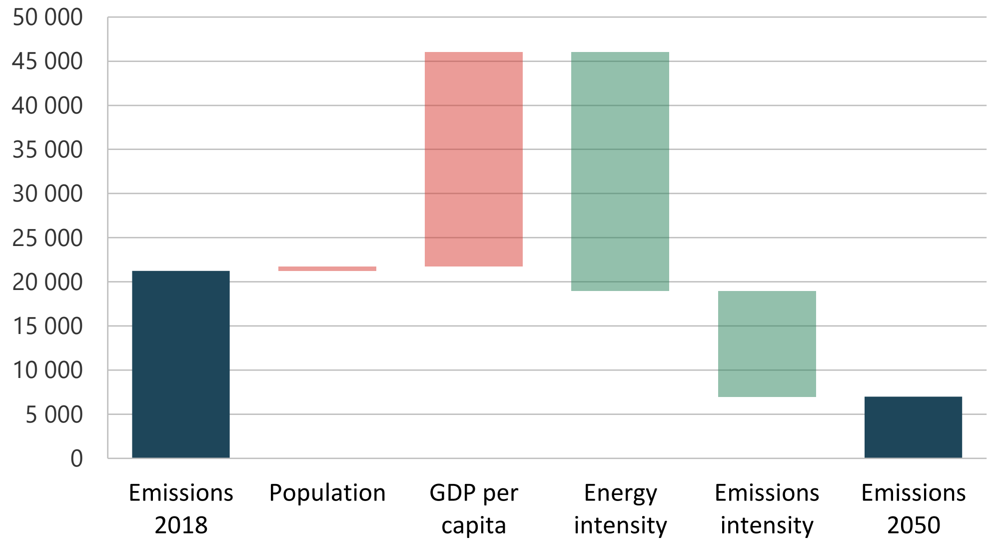
The Kaya identity affords a way to decompose $CO_2$ emissions into four components: population, GDP per capita, energy intensity, and emissions intensity.

*Equation 1. Kaya identity.*

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

At an aggregate level, increasing population and economic activity contribute to CO2 emissions. APEC population is expected to grow by 2.0% to 2050, despite population declines in China and northeast Asia. Population peaks by the 2040s, and the resulting contribution to $CO_2$ emissions (2.1%) is small relative to economic activity. Assuming no improvements to energy or emissions intensity would see $CO_2$ emissions in APEC around 48 gigatonnes by 2050.

*Figure 11. Kaya identity (million tonnes).*




Energy intensity improvements fully offset emissions increases from population and economic activity, a decrease of around 27 gigatonnes. The offset from energy intensity illustrates the potential that energy demand, and subsequently, energy supply to reduce $CO_2$ emissions.

Emissions intensity of the energy supply also contributes to additional emissions reductions (12 gigatonnes), although at a smaller level than energy intensity. Emissions intensity measures the amount of $CO_2$ in the energy supply, meaning that decarbonisation the energy carriers consumed in end-use and transformation sectors, particular power generation, contribute to emissions reductions.

Taken together, energy and emissions intensity illustrate the magnitude of emissions reductions from technological and behavioral changes, driven and supported by economics and policies.

## 4. Conclusion

The APEC region represents nearly 60% of global energy demand and energy-related $CO_2$ emissions. The hypothetical carbon neutrality pathway analysed in this paper highlights the substantial transformation to the trajectory of APEC energy demand and $CO_2$ emissions.

Transformations would be seen in the demand, transformation, and supply components of the energy system. In end-use sectors, combining energy demand reductions with fuel switching, particularly electrification, are effective measures. The addition of wind and solar technologies, decommissioning coal plants, and CCS technologies for natural gas power plants shows substantial potential for decarbonising the power sector.

While population growth, and to a larger extent, economic activity contribute to $CO_2$ emissions, improving energy and emissions intensity can more than offset the increases. These broad measures can inform policymakers about how to measure decarbonisation progress using the Kaya identity and the scale and magnitude expected from the CN pathway.

There is opportunity for additional studies that investigate the role of negative emissions technologies, such as natural carbon sinks and direct air capture technology.

## 5. References

Asia Pacific Energy Research Centre, APEC Energy Demand and Supply Outlook 8th Edition [scheduled for publication in June 2022]