APEC ENERGY DEMAND AND SUPPLY OUTLOOK 8TH EDITION

METHODOLOGY

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ASIA PACIFIC ENERGY RESEARCH CENTRE

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SECTION 1: INTRODUCTION

1. BACKGROUND

Since 1998, the Asia Pacific Energy Research Centre (APERC) prepares the APEC Energy Demand and Supply Outlook to support the Asia-Pacific Economic Cooperation (APEC) economies by providing an independent and technical analysis of historical and current trends, impacts of energy policies, potential risks, and other factors that might affect the development of the future energy sector in the Asia Pacific region.

The APEC Energy Demand and Supply Outlook 8th Edition provides projections for energy demand, transformation, supply, and energy-related CO_2 emissions for the 21 APEC member economies. These projections stem from a combination of historical data, scenario design, mathematical models, assumptions, and expert judgment, collectively referred to as Knowledge-based Modelling[1].

The methodology to develop the APEC Energy Outlook is constantly updated to incorporate new data and to ensure that the questions raised in each Edition are addressed. In the APEC Energy Demand and Supply Outlook 8th Edition, APERC estimated the level of additional efforts required to achieve carbon neutrality by 2050 in each APEC economy member and detect potential risks to the energy systems.

Substantial effort has been made to update the analysis since the previous the APEC Energy Demand and Supply Outlook 7th Edition, including the utilisation of historical energy balance tables from the Expert Group on Energy Data and Analysis (EGEDA) and the implementation of the open-source linear programming framework OSeMOSYS[2] for some sectors.

Analysis in this Edition spans demand, transformation, and supply in the energy system, as well as macroeconomic trends. CO_2 emissions are calculated from fuel combustion only as defined by the IPCC. Other emissions are excluded. Global carbon factors are used for coal, oil, refined products, and natural gas.

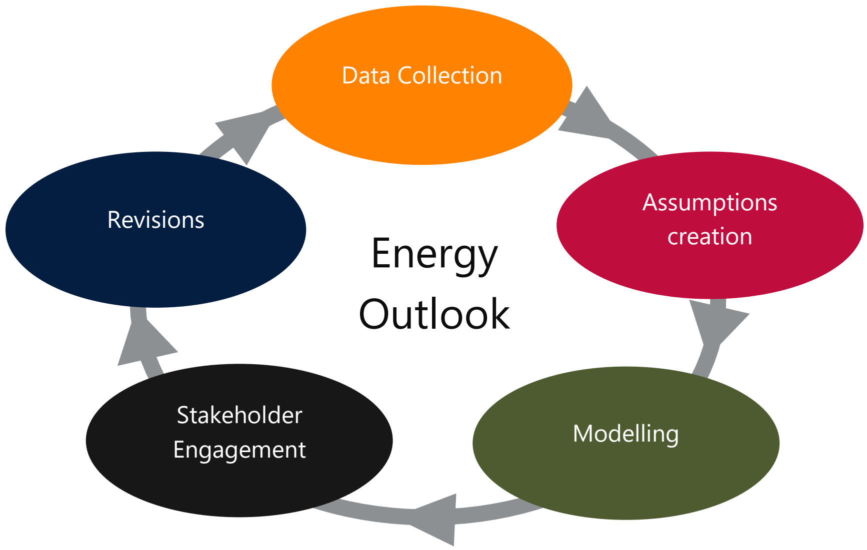
2. ANALYSIS

The analysis is an iterative process involving data collection, assumptions creation, modelling, stakeholder engagement, and revisions (Figure 1). The analysis is done at each individual economy level; regional or subregional analysis is obtained by grouping economies.

[1] David Daniels presentation at APERC 2019 Annual Conference

[2] http://www.osemosys.org/

Figure 1. Analysis Cycle



Many data types are utilised; for example, energy balances are obtained from the Expert Group on Energy Data and Analysis (EGEDA) database that compiles and standardize energy balances from each APEC economy. Other data is obtained from publicly available sources. Specific data requirements for sectors are discussed in the respective chapters. Historical data are used to estimate current trends and a starting point for the projections.

Next, long-term projections are obtained from models that estimate energy demand, transformation, and supply. Detailed explanations of each model are provided in the subsequent chapters.

Stakeholder engagement is an important component of the analysis. Feedback from experts in the APEC Energy Working Group and external reviewers are crucial for making sure that assumptions, modelling methodologies, and policy developments are adequately incorporated into the analysis.

Throughout the course of the analysis, experts provided feedback on scenario definitions, model results, and chapter text.

Finally, feedback from expert reviews is incorporated into the analysis by updating assumptions and data sources.

3. SCENARIOS

Scenario development does not aim to predict future energy demand and supply; on the contrary, this heuristic technique evaluates the robustness of a solution to the problem of energy supply under the uncertainty of several factors such as energy demand and others. Consequently, additional insights are obtained when the results of different scenarios are compared.

The 8th Edition modelled two forward looking scenarios: the Reference scenario (REF) and the Carbon Neutrality scenario (CN).

The base year for both scenarios is 2018 and projections continue to 2070 but the results are reported until 2050. Modelling for years 2017 and 2018 were performed to calibrate the models, but actual reported data are used for these years.

3.1 THE REFERENCE SCENARIO (REF)

The Reference Scenario (REF) is a pathway where existing trends in technology development and deployment, and policy frameworks continue in a similar manner. In previous Editions, this scenario was referred to as the Business as Usual (BAU) scenario, however, in this Edition, the name of this scenario was changed to Reference to reflect the dynamic nature of the energy system and policy environment.

In terms of general assumptions and characteristics, on the demand side, energy efficiency and fuel economy standards continue to improve gradually. The trend towards greater electrification is assumed to continue. Fuel switching away from coal to natural gas also continues.

The following chapters describe the sectoral assumptions in greater detail.

3.2 THE CARBON NEUTRALITY SCENARIO (CN)

The Carbon Neutrality Scenario (CN) outlines a potential pathway where energy efficiency, fuel switching, and technological advancement leads to a significant reduction in CO_2 emissions from fossil fuel combustion through 2050.

CN is performed in a bottom-up manner. Instead of setting a CO_2 emissions cap for APEC, assumptions are applied at the sectoral level in each economy.

Emissions accounting includes CO_2 produced from combustion in the energy sector only, net of any captured CO_2 from CCS.[3] The combination of bottom-up analysis and exclusion of negative emissions means that reported emissions remain positive through 2050. Negative emissions from other non-energy sectors would need to occur to show "true" carbon neutrality.

Technology maturity and commercial availability are key assumptions in CN. Hydrogen supply chains—blue and green—are assumed to be available at scale from 2030 to serve end-use applications in buildings, mainly mixed with natural gas to decarbonize heating, industry, and

[3] There are other emissions sources, such as from land-use, that are not considered.

transport. While technically possible, hydrogen consumption by the power sector is not considered.

There is a small uptake of CCS use in industry and hydrogen production in REF. CCS becomes far more commercially viable in CN and is utilised in greater quantities by industry, power, hydrogen production, and own-use sectors from the 2030s.

4. MACROECONOMIC ASSUMPTIONS

The common assumptions used in almost all APERC models are GDP (Gross Domestic Product) and population. These two assumptions operate exogenously to the models and come from other organisations where available (Table 1). Like the last two editions of the Outlook, population projections come from the United Nations Department for Economic and Social Affairs (UNDESA), with some small adjustments based on individual economies' own projections.

Table 1. GDP and Population Source per APEC Economy

Economy	GDP	Population
Australia	OECD	UNDESA
Brunei Darussalam	APERC	UNDESA
Canada	OECD	UNDESA
Chile	OECD	UNDESA
China	OECD	UNDESA
Hong Kong, China	APERC	UNDESA
Indonesia	OECD	UNDESA
Japan	OECD	UNDESA
Korea	OECD	UNDESA
Malaysia	APERC	UNDESA
Mexico	OECD	UNDESA
New Zealand	OECD	UNDESA
Papua New Guinea	APERC	UNDESA
Peru	APERC	UNDESA
Philippines	APERC	UNDESA

Russia	APERC	UNDESA
Singapore	APERC	UNDESA
Chinese Taipei	APERC	UNDESA
Thailand	APERC	UNDESA
United States	OECD	UNDESA
Viet Nam	APERC	UNDESA

However, based on feedback from earlier releases, APERC decided to use the same source for GDP where possible (OECD), and utilise the APERC macro model (which is based on a Solow-Swan growth model and utilises demographic information from CEPII) in the absence of such external projections. Historical GDP data to 2019 comes from the World Bank (2021). GDP is measured in billion 2018 USD dollars, using purchasing power parity (PPP) to facilitate comparison across economies. These key assumptions are held constant across the two Outlook scenarios.

GDP projections are from the OECD for OECD-member countries and other significant non-OECD member countries modelled by the OECD (2018). Remaining economies are modelled by APERC using a Solow-Swan growth model based on a Cobb-Douglas production function (see the next section for further details).

Global events warrant a revision of the methodology to account for the impacts of the COVID-19 pandemic. Adjustments to the projections to account for the pandemic are taken from the International Monetary Fund (IMF) for 2020 to 2025 (IMF, 2021). A reversion to the growth trends estimated by the OECD and the APERC macro model is assumed to occur in 2026. This implies that the COVID-19 pandemic will have a level effect on GDP throughout APEC through 2050.

4.1 APERC MACRO MODEL

GDP modelled by APERC, as defined below, is a function of labour inputs (population structure and economic activity rates), capital inputs (GDP, depreciation, and savings rates) and total factor productivity (technological progress). Total factor productivity is modelled based on historical trends.

$$GDP = TFP * K^{\alpha} * L^{\beta}$$

Where: GDP is gross domestic product,

TFP is total factor productivity,

K is capital,

L is labour,

α and β are the elasticities of capital and labour (and $\alpha + \beta = 1$)

Capital is accumulated through a permanent-inventory process, where capital for each year is the gross fixed capital formation plus the depreciated historical capital accumulation (real value). The gross fixed capital formation rate is estimated from a savings rate, which is affected by GDP per capita, demographics, and other factors encapsulated by historical savings rates. The historical capital depreciation rate is set at a constant value of 6% for all economies. Historical data is sourced from the World Bank, except for Chinese Taipei, which is based on International Monetary Fund and government data.

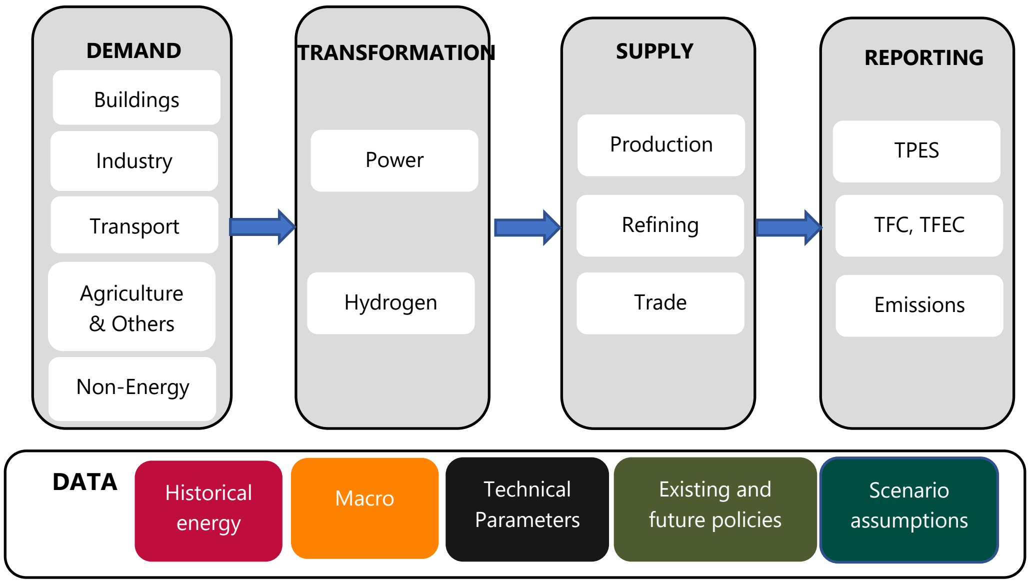
Labour is measured by the total demographic-weighted employed population. Different age groups and education levels are given different weights; for example, the working-age population, ranging from 15 to 60, has a higher activity rate than other groups. Education level is divided into primary, secondary, and tertiary attainment, with more highly educated people having higher weights. Male and female participation rates are also considered separately to account for regional differences in participation between the genders. Most of the data for labour is from the CEPII model (CEPII, 2012), except for data for Chinese Taipei which is based on historical government data and APERC estimations.

TFP is the measure of an economy's long-term technological change or technological dynamism. It accounts for effects in total GDP output not caused by inputs of labour and capital. TFP is projected using a logit model regression based on historical trends.

5. SECTORAL MODEL INTEGRATION

The integration process brings together historical data and model results from each sector. This process maintains consistency of data and results between models. The process begins with the end-use demand in residential, transport, industry, agriculture, and non-energy sectors. Primary and secondary energy consumption from these sectors is used as an input for the transformation and supply sectors. Next, the power and hydrogen sectors are run to satisfy electricity and hydrogen demand. The refining and supply models then calculate the refining, production, and trade activities necessary to satisfy the primary and secondary energy demand from the demand and transformation activities. Finally, results are reported in tabular and chart form. Additionally, CO_2 emissions are estimated and reported.

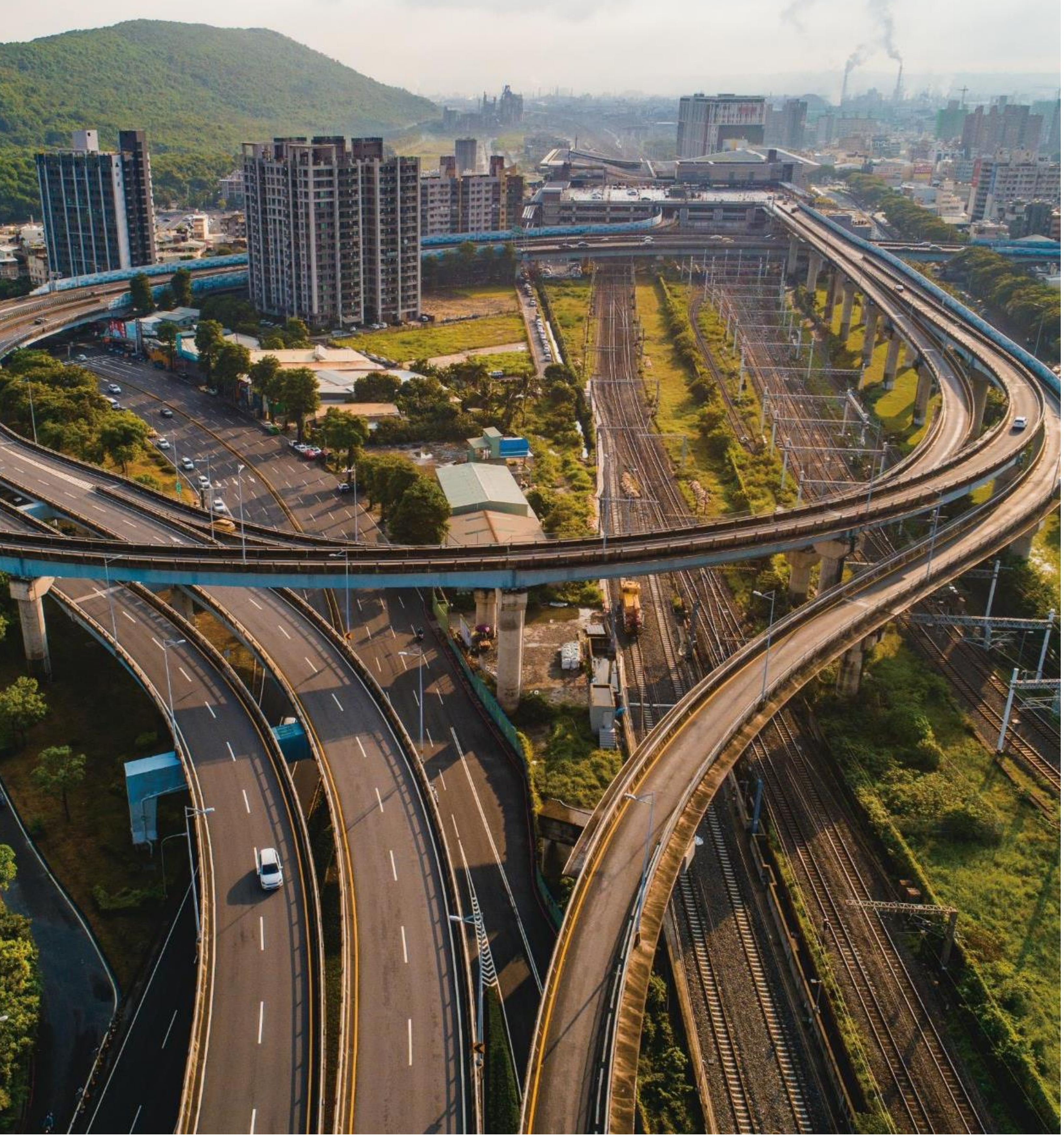
Figure 2. Model Integration Structure



OSeMOSYS data format is used for all sectoral models regardless of being an optimisation or not. The OSeMOSYS data format is convenient for maintaining consistency across all sectors. Later, OSeMOSYS is run using this data file. The output results file can then be utilised as an input for other models (e.g., the power sector model) and for reporting.

A custom Python package is utilised to run the model data files. This package allows data to be formatted in an Excel file for use in OSeMOSYS[4].

[4] https://pypi.org/project/aperc-osemosys/



SECTION 2: DEMAND

6. TRANSPORT MODEL

The APERC Transport model projects the fuels demand in APEC's transportation sector. Demand is for the modes: domestic aviation, shipping, rail and all the different vehicle types within road. There is also a small amount of non-specified transport energy use. Generally, all energy demand is calculated by multiplying forecasts of energy intensity by forecasts of freight and passenger activity.

$$E_{t,f} = Act_{t,tech} \times I_{tech,f}$$

Where: E is energy demand,

Act is activity,

I is energy intensity,

t is time,

$tech$ is technology[5]

f is fuel

To forecast energy intensity, there is a different method for non-road; namely rail, aviation, and shipping versus road transport:

For non-road, energy intensity was forecasted by assuming an annual rate of improvements that depends on the scenario.

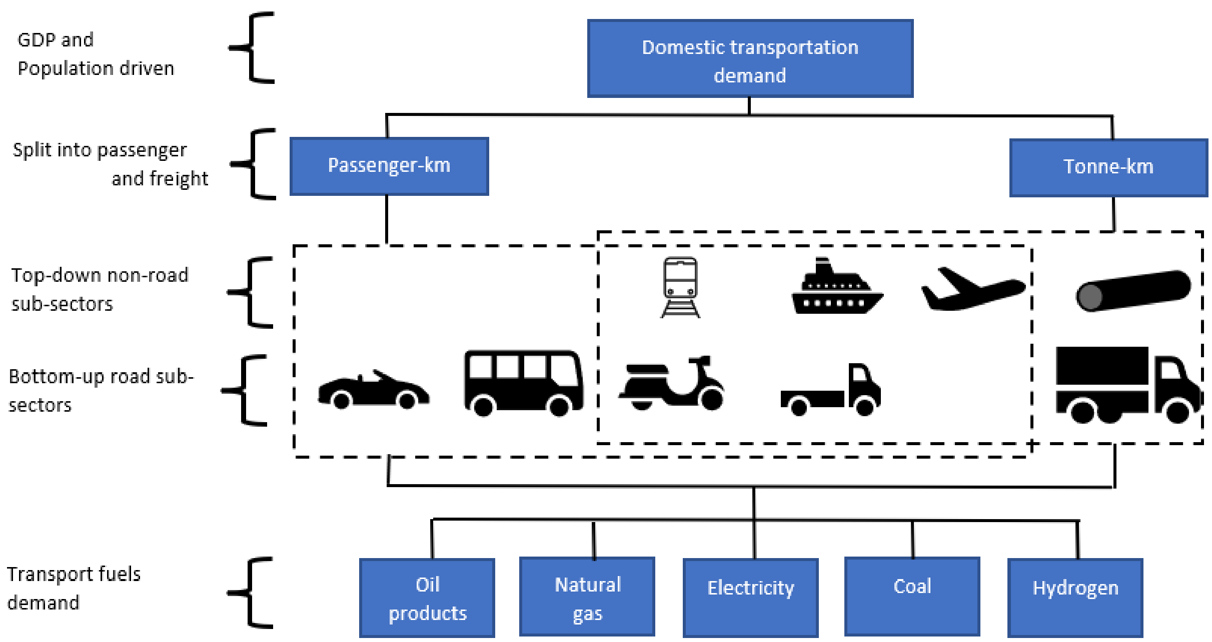
For road, the data is forecasted using a stock model which uses estimates of vehicle stocks, vehicle stock turnover rates, sales and, current and new vehicle efficiencies for the base year up to 2050.

To forecast activity, the model first identifies the current and historical rate change of passenger and freight activity to GDP per capita and, finally, multiplies this result by forecasted GDP per capita to project activity. Adjustments were then applied based on qualitative assessment.

The structure of the domestic transport model is shown on Figure 3. Please note that the powertrain is considered for the road vehicle types.

[5] Where technology refers to the specific mode, vehicle type and powertrain combination.

Figure 3. Domestic Transport Model Structure



6.1 TRANSPORT SUB-MODELS

Given the characteristics of different transport modes, the transport model is required to be divided into different sub-models:

6.1.1 DOMESTIC PASSENGER AND FREIGHT ACTIVITY

Domestic passenger and domestic freight activity are used to project the future demand by each mode of transport. Domestic passenger transport modes include road, rail, shipping, and aviation. Road mode can be further divided into 2 or 3 wheelers (2-3W), light vehicle (LV), light truck (LT) and bus. Additionally, domestic freight transport modes include 2-3W, LT, and heavy truck (HT)

The model identifies the rate of change of passenger and freight activity to GDP per capita using linear regression. This is used to project activity growth relative to GDP per capita, as projected for the rest of the Outlook.

6.1.2 DOMESTIC NON-ROAD EFFICIENCY

Domestic non-road includes rail, shipping and aviation for passenger and freight services.

In this model, domestic non-road only uses improvements of energy intensity that are assumed according to the scenario.

$$I_t = I_{t-1} \times (1 - r)$$

Where: I is energy intensity

t is time

r is the rate of improvement of energy intensity

6.1.3 DOMESTIC ROAD EFFICIENCY

Domestic road efficiency is calculated using a stock model, covering five type of road vehicles (LT, HT, LV, 2-3W and buses). All types of road vehicles have various types of powertrains[6] except 2-3W that only use gasoline internal combustion engines or batteries. This model uses information on vehicle stocks, vehicle stock turnover rates, replacement stocks and, current and new vehicle efficiencies to forecast the expected efficiency of the road vehicle fleet in each economy.

6.2 SCENARIO ASSUMPTIONS

Table 2. Key Scenario Assumptions in Transport

Scenario	Assumptions
REF	Transport activities depend on macroeconomic variables. Fuel efficiency in road transport does not improve drastically. Energy efficiency in other transport modes improves moderately. Increase the share of battery based electric vehicle, BEV, in new sales. Around 50% of new sales of light vehicles corresponds to BEV by 2050.
CN	Additional fuel efficiency improvements due to technological breakthrough Increase of shifting away from gasoline and diesel. Increase of shifting to different modes and vehicle types. By 2050, between 70 to 90% of new sales of light vehicles corresponds to BEV. Around 20% of new sales of heavy truck corresponds to fuel cell electric vehicles.

[6] Ranging from internal combustion engines for gas and diesel, to battery electric vehicles, all hybrid combinations of the two, and then fuel cell electric vehicles and, CNG and LPG fuelled engines.

6.3 DATA SOURCES

Main input data includes GDP and population, annual fuel demands, vehicle-kilometre (VKM), tonne-kilometre (TKM), and passenger-kilometre (PKM) statistics, vehicle stock and annual sales of all types of road vehicles by powertrains; fuel efficiency information and fuel mix data for road vehicles. One of the key challenges with APERC's model formulation is to make sure that diverse transportation statistics of APEC economies, or the absence of such, could be incorporated and sufficient to achieve similar level of details for all economies.

The main sources include:

Table 3. Transport Data and Sources

Data	Sources
GDP	Historical: World Bank Development Indicators. Projections: OECD and internal analysis of APERC. COVID-19 impacts from 2020 to 2025 (IMF)
Population	UN DESA projections out to 2050
Energy data	Historical: APEC Expert Group on Energy Data and Analysis (EGEDA) annual economy submissions of energy data.
Efficiency	IEA publications estimating sub-sectoral fuel efficiency indicators, for instance Energy Technology Perspectives 2017 and UIC IEA Railway Handbook.
Vehicle sales and statistics	Vehicle sales and statistics from a variety of sources, including the International Organization of Motor Vehicle Manufacturers (OICA).

Additionally, transport policy information was available on respective government or agency websites and publications.

Data are also sourced from: the Global Fuel Economy Initiative (GFEI); International Air Transport Association (IATA); International Civil Aviation Organization (ICAO); International Council on Clean Transportation (ICCT); International Transport Forum at the OECD (ITF); International union of railways (UIC); International Association of Public Transport (UITP); UN Economic and Social Commission for Asia and the Pacific (ESCAP); and each economy's statistical agencies, transport/highway authorities and domestic studies.

Wherever data gaps exist, modellers have used proxies to estimate this data.

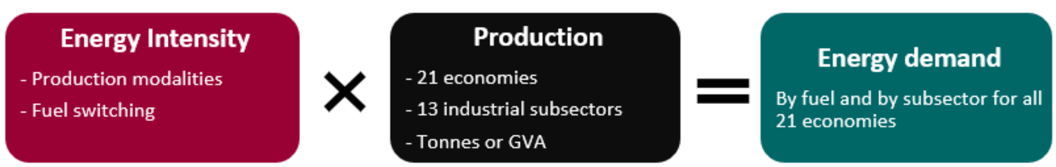
7. INDUSTRY MODEL

The industry model estimates final energy demand for 13 industrial subsectors:

1. Iron and steel
2. Chemicals (including petrochemicals)
3. Non-metallic minerals (primarily cement)
4. Non-ferrous metals
5. Pulp, paper, and printing
6. Mining
7. Construction
8. Transport equipment
9. Machinery
10. Food, beverages, and tobacco
11. Wood and wood products
12. Textiles and leather
13. Non-specified[7]

Modelling final energy demand for these industrial subsectors involves estimating i) production (output) and ii) energy intensity (fuel switching, including transitions to alternative production modalities, is incorporated at this stage). The combination of these two components determines energy consumption.

Figure 4. Industry Model Structure



7.1 INDUSTRY SUB-MODELS (INCLUDING SCENARIO ASSUMPTIONS)

7.1.1 SUB-MODEL 1: INDUSTRIAL SUBSECTOR PRODUCTION ESTIMATES

For certain subsectors, historical production is available at a more disaggregated level than available in the historical energy data from EGEDA. For example, steel production is available for basic oxygen furnace (BOF) and electric arc furnace (EAF) production modalities for most

[7] Non-specified is a catch all for those economies that are unable to disaggregate their industrial data into the other twelve industrial subsectors.

economies. This disaggregation and assumptions about the changing share of these two production modalities improves the energy projections out to 2050.

Estimating subsector production involves a knowledge-based modelling approach, as described earlier. GDP and population projections provide a basis that is assessed in concert with anticipated product intensity (the amount of production per unit of GDP or per person) for each APEC member economy.

The baseline model provides estimates according to the following specification:

$$ln\left(\frac{Production_{e,t}}{Population_{e,t}}\right) = k + c_1 \times ln\left(\frac{GDP_{e,t}}{Population_{e,t}}\right) + c_2 \times ln\left(\frac{Production_{e,t-1}}{Population_{e,t-1}}\right)$$

Where: e is economy,
t is time (annual data),
k, c_1, and c_2 are coefficients obtained by performing an econometric estimation

Because long-term forecasts are more affected by the uncertainty of the variables when projecting far into the future, knowledge-based adjustments are made to the results. Trade trends and assumptions about the extent that each economy supplies international markets are implemented at this knowledge-based adjustment stage.

Production assumptions are documented in Table 4.

Table 4. Key Scenario Assumptions in industrial production

Sectors	Assumptions
All sectors	GDP and population projections that feed into the subsector production model are the same for REF and CN. Production estimates for iron and steel, chemicals (including petrochemicals), non-metallic minerals, non-ferrous metals, and pulp, paper, and printing are measured in physical units. All other production estimates use gross value added (GVA) (real monetary) units. Production estimates for the iron and steel, non-metallic minerals, and chemicals (including petrochemicals) subsectors are assumed to be approximately 10% lower by 2050 in CN than in REF for all economies. The reduced output is due to assumed material efficiency improvements. Mining production in CN is assumed to be higher than in REF for Australia, Canada, Chile, China, Mexico, Russia, and Viet Nam due to increased demand for critical minerals. The production estimates for all other sectors are assumed to be the same for both scenarios.
Iron and steel	Scrap steel recycling rates are assumed to increase in REF, leading to greater penetration of EAF instead of BF-BOF production. Scrap steel recycling rates are assumed to be even greater in CN, leading to a greater proportion of EAF steel production for almost all economies. CCS is incorporated in REF from the late 2030s for some economies. Deployment occurs earlier, at a faster rate, and for more economies in CN.
Chemicals (including petrochemicals)	CCS is incorporated in REF from the late 2030s for some economies. Deployment occurs earlier, at a faster rate, and for more economies in CN.
Non-metallic minerals	The clinker-to-cement ratio is lower in CN, which means less production of clinker is required (or the energy intensity of cement production is reduced). CCS is incorporated in REF from the late 2030s for some economies. Deployment occurs earlier, at a faster rate, and for more economies in CN.

7.1.2 SUB-MODEL 2: INDUSTRIAL SUBSECTOR ENERGY INTENSITIES

Once production estimates have been obtained, the next stage is to estimate the energy intensities and shifting energy mix, if applicable. Considerations that feed into industrial energy intensity modelling is provided in Table 4.

Table 5. Industry Energy Intensity Sub-Model

Sectors	Assumptions
All sectors	Historical rates of improvement in physical energy intensity (tonnes) and GVA intensity (real output) are considered as qualitative input to determine plausible energy intensity projections out to 2050 for both scenarios. Energy intensity projections incorporate assumptions about the average production facility age for different subsectors, and available technologies (including best available technologies) that will inevitably replace retiring facilities or add to production capacity. The energy intensity improvements are assumed to be greatest in CN. Electrification potential for production processes and rate of switching from fossil fuels to electricity is considered. Electrification is highest in CN for all subsectors and economies. Other fuel switching, such as from coal-to-gas, or coal-to-biomass is incorporated. Assumptions about energy efficiency policy intervention is incorporated.
Iron and steel	The extent to which hydrogen, biomass, or natural gas can be incorporated into different steel production processes is assessed. Hydrogen plays a small role for a subset of some economies in REF. In CN, this role expands significantly and to additional economies. Coal transformation is not modelled in the 8th Outlook. However, a large portion of the role for hydrogen is assumed to displace the coke that is delivered via blast furnaces (the result of transforming coking coal into coke). Hydrogen displaces coke via the direct reduced iron process. CCS deployment involves parasitic energy losses or additional energy requirements, and these are incorporated within the energy intensity model.
Chemicals (including petrochemicals)	CCS deployment involves parasitic energy losses or additional energy requirements, and these are incorporated within the energy intensity model. The share of ammonia production impacts the extent to which CCS is deployed, given that ammonia production is currently the most viable for CCS implementation.

Non-metallic minerals	The clinker-to-cement ratio is lower in CN, which means less production of clinker is required (or the energy intensity of cement production is reduced). The extent to which biomass or natural gas can be incorporated into cement manufacturing processes in place of coal is considered, with a higher rate assumed for CN. CCS deployment involves parasitic energy losses or additional energy requirements, and these are incorporated within the energy intensity model.

7.2 DATA SOURCES

The main data sources used as inputs for the industry model are available in Table 6.

Table 6. Industry Data and Sources

Data	Sources
GDP	Historical: World Bank Development Indicators. Projections: OECD and internal analysis. COVID-19 impacts from 2020 to 2025 (IMF)
Population	UN DESA projections out to 2050
Industrial energy data	Historical: APEC Expert Group on Energy Data and Analysis (EGEDA) annual economy submissions of energy data. Projected: Final output of the APERC industry model.
Iron and steel	Production: World Steel Association.
Non-metallic mineral	Cement production: USGS Clinker-to-cement ratio: Cement Sustainability Initiative
Chemical and petrochemical	Ammonia: USGS Olefins: METI
Paper and pulp	Paper production: Food and Agriculture Organization of the United Nations
Aluminium	Primary aluminium production: USGS
Mining, non-specified, and others	Industry GDP value added: OECD

8. BUILDINGS MODEL

Energy demand in buildings sector accounts for almost one-third of the total energy demand in APEC; so, several energy policies have been implemented focusing on promoting energy saving strategies and improving the efficiencies of appliances and technologies that are used in this sector. However, buildings energy demand has continued to show an increasing trend. Population growth and rise of income, which are related to the expansion of constructed area and the access to more energy services, have been usually mentioned as main factors that sustain this energy demand growth.

To develop a model that estimate the impact of energy policies in this sector, some simplifications has been adopted, considering data availability for the 21 APEC economies:

Initial energy demand projections are based on historical trends of energy demand and some macro variables. Later, policies are modelled to have effects on initial projections.

Fuel demand is not constrained by fuel availability except when a specific policy is set. Demand of a specific fuel in buildings is determined in this model and the supply model will determine whether the fuel is produced or imported by the economy.

The energy output of the end-use application of a fuel, fuel demand multiplied by the respective technology efficiency, does not vary among scenarios. This consideration implies that, for example, the amount of heat produced for cooking stays constant, but the fuel demand might vary depending on the efficiency of the technology that consumes the fuel.

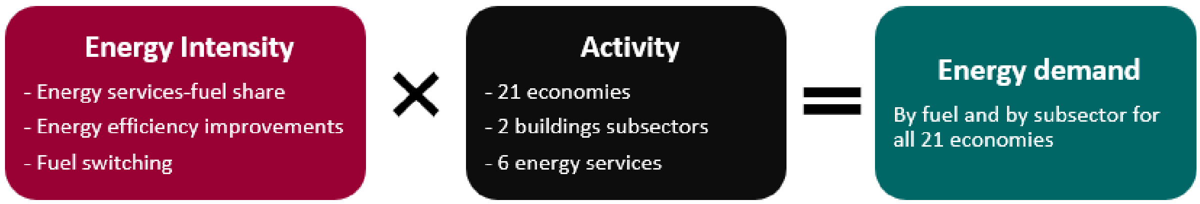
Long-term effects of the COVID-19 crisis that might cause changes in energy consumption patterns in buildings were not considered. Energy demand in buildings return to normal trend after 2021.

8.1 BUILDINGS MODEL DESCRIPTION

The building model projects energy demand by economy. Energy demand in each module follows a top-down approach, primarily driven by macroeconomic variables.

The model is made up of two demand subsectors: residential and commercial/services. Furthermore, energy use is divided into six energy services: space heating, space cooling, water heating, lighting, cooking, and others.

Figure 5. Buildings Model Structure



This methodology uses macro assumptions and historical energy demand to project future energy demand via the following steps:

Carry out regressions using GDP (Gross Domestic Product), population, household size, urbanisation, electrification, and energy demand by economy to estimate energy demand by energy services: space heating, space cooling, lighting, water heating, cooking, and other end-uses. The results of the regressions will indicate a significant variable.

Estimation of fuel demand is obtained by using a fuel share per energy service in every energy service. This fuel share per energy service is calibrated with available data.

Alter the technology efficiency and fuel mix assumptions to 2050 depending on scenario.

$$E_f = \sum_i A_i S_{f,i}$$

Where: E_f is energy demand of fuel *f*;

A_i is energy demand by energy service *i*;

$S_{f,i}$ is share of fuel f in energy service *i*;

The final step consists of internal and external revisions of the results to ensure consistency of the projections.

8.2 SCENARIO ASSUMPTIONS

Building energy consumption is characterized by technical characteristics of buildings and appliances used in them. These assumptions allow to implement the difference between REF and CN scenarios through the alteration of energy efficiency factors and the evolution of the fuel share and do not incorporate user behaviour factors.

Table 7. Key Scenarios Assumptions in Buildings

Scenario	Assumptions
Energy efficiency	Adoption of more stringent building energy codes supports improvements in building energy efficiency. Upgraded envelop elements are assumed to be deployed gradually starting in 2025. In CN, these improvements are assumed to be incorporated in all new and refurbished buildings, representing a decrease of energy consumption per building in space colling and heating. The application rate of building elements would be different in each scenario and depend on whether it is a warm or cool climate.
Fuel switching	Growing urbanisation and policies to improve appliance efficiency and indoor air quality are assumed to drives the shift away from traditional biomass, coal, and oil towards electricity as the preferred choice of energy supply. The use of technologies that consume electricity instead of fuels such as oil, coal, or biomass can improve the overall energy efficiency in an energy service due to better efficiencies of these technologies. For simplicity, fuel switching is assumed to occur at a constant linear rate.

8.3 DATA SOURCES

The main data sources used as inputs for the buildings model are available in the following table.

Table 8. Buildings Data and Sources

Data	Sources
GDP	Historical: World Bank Development Indicators. Projections: OECD and internal analysis. COVID-19 impacts from 2020 to 2025 (IMF)
Population	UN DESA projections out to 2050
Building energy data	Historical: APEC Expert Group on Energy Data and Analysis (EGEDA) annual economy submissions of energy data. Projected: Final output of the APERC building model.

9. OTHER END-USE SECTORS MODEL

The 8th Outlook disaggregates the 'Others' model into two sub-models in agriculture and non-specified.

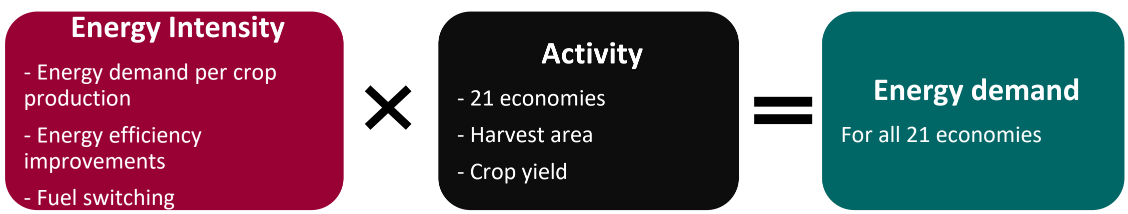
The agriculture sector fundamentally employs energy-intensive machineries (tractors) and water pumping to support various farming activities. Non-specified energy demand follows the IEA definition of "all fuel use not elsewhere specified for which separate figures have not been provided," including military fuel use for mobile and stationary consumption.

9.1 OTHERS MODEL DESCRIPTION

9.1.1 AGRICULTURE MODEL

A simple methodology was adopted to project the agriculture energy demand, using historical sectorial GDP for agriculture, historical fuel consumption dedicated to agriculture, and a sectorial GDP projection for 2016 – 2050. For this Edition, the sector's energy demand is a function of harvest area and crop yield of various crops as defined by the United Nations' Food and Agriculture Organization (FAO).

Figure 6. Analysis of Agriculture Energy Demand



The FAO recently made its projections[8] to 2050 on harvested area (thousand hectares) and crop yield (tonnes/hectare) of various crops classified under FAO[9] on a global scale. With these two figures, the production of each of the classified crops of type i for APEC economies is calculated via the following equation:

[8] FAO data for Brunei, Papua New Guinea, and Singapore are not available.

[9] Sorghum, sugar beet, sugar cane, barley, cassava, grain maze, paddy rice, wheat, rapeseed, mustard seed, soybean, sunflower seed, other oilseed, coconut, sesame seed, oil palm fruit, banana, citrus fruit, coffee (green), cocoa bean, raw cotton, groundnut, natural rubber, millet, potato, olive, plantain, dried pulse, sweet potato and yam, tea, tobacco, and other cereal.

$$Crop\ production_i = Harvested\ area_i\ x\ Crop\ yield_i$$

The agriculture energy demand of crop i by fuel type j in each economy is calculated via the crop production and its energy intensity during production. The economy-specific energy intensity of fuel type j is the ratio of agriculture energy demand by fuel type j and the crop production by crop type i for the year 2018, as per below:

$$Energy\ intensity_{j,2018} = \frac{Agriculture\ energy\ demand_{j,2018}}{Crop\ production_{i,2018}}$$

The overall agriculture energy demand of each economy is then projected between 2019 and 2050 via the equation below:

$$Agriculture\ energy\ demand_{i,j} = Crop\ production_i\ x\ Energy\ intensity_j$$

9.1.2 NON-SPECIFIED MODEL

The economy-specific non-specified energy demand by fuel type is forecasted using the compound annual growth rate (CAGR) of historical consumption (2010–2018) in EGEDA.

9.2 SCENARIO ASSUMPTION

Table 9. Key Scenario Assumption in Agriculture

Scenario	Assumptions
Reference	When possible, trend follows FAO agriculture FAO agriculture projection through 2050. This scenario assumes business-as-usual fuel mix throughout this period, fuel switching is prominent across the economies, as well as the adjustment of energy intensity in the crop production to reflect improvements in its energy efficiency. Increase of electrification and efficiency follows historical trend.
Carbon Neutrality	Electrification of most machinery and engines, displacing oil products Increase of energy efficiency

10. HYDROGEN MODEL

In the 8th Edition, hydrogen demand is estimated at each end-use sector, according to assumptions of the insertion of hydrogen technologies considering government policies or documents indicating a vision regarding the future of the hydrogen industry.

10.1 HYDROGEN MODEL DESCRIPTION

To project hydrogen production the model considers the following technologies:

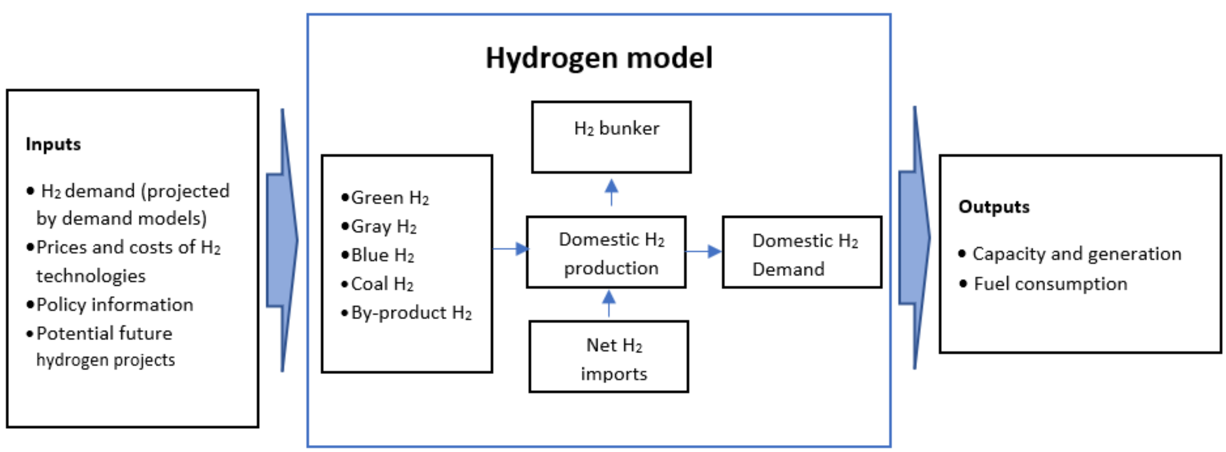
- Electrolysers
- Steam Methane Reforming (SMR) reactors with and without Carbon Capture and Storage (CCS) technologies
- Coal gasification reactors with Carbon Capture and Storage (CCS) technologies
- Other technologies that produce hydrogen as a by-product considering that hydrogen is used for energy services.

The assumed technologies produce the following types of hydrogen:

- Green Hydrogen, that is produced via electrolysis and consumes electricity from renewable energy sources.
- Blue Hydrogen, that is produced via SMR with CCS and consumes natural gas and electricity.
- Gray Hydrogen, that is produced via SMR and consumes natural gas and electricity. This type of hydrogen does not include CCS technologies.
- Coal Hydrogen, that is produced via coal gasification with CCS.
- By-product Hydrogen, that is assumed to be produced as a by-product of industrial activities. This type of hydrogen is relevant only in some economies.

Additionally, depending on the economy and the hydrogen supply and production balances, hydrogen imports are considered. The model structure is described in Figure 7:

Figure 7. Hydrogen Model Structure.



10.2 HYDROGEN MODEL ASSUMPTIONS

To estimate hydrogen supply, economies are classified into different type of hydrogen producers based on fossil fuel reserves and renewable energy potential and on released hydrogen strategies.

- Renewable energy hydrogen potential: economies that has renewable energy potential (China, Chile, Mexico, and New Zealand).
- Low carbon hydrogen and carbon storage potential: economies with potential to produce blue hydrogen: Canada.
- Both renewable and low carbon hydrogen potential: economies with great potential to develop both green and blue hydrogen projects: United States, Peru, Australia.

Next, economies are classified according to their hydrogen exporting potential considering the hydrogen demand projections:

- Hydrogen exports: economies that produce hydrogen for domestic use and export: Australia, Chile, Mexico, and New Zealand.
- Hydrogen imports: economies with limited hydrogen production: Japan, Korea, Chinese Taipei, and Singapore.
- We assume that other APEC economies produce enough hydrogen to meet their own demand and, therefore, are self-sufficient.

We assume that hydrogen will be produced on-site using two production methods—hydrogen produced via electrolysis with 100% renewable energy from solar PV, and steam methane reforming (SMR) of natural gas—according to the following criteria:

The efficiency of hydrogen production using electrolysis ranges between 70%-90% (ITM Power, 2017); an efficiency of 75% is assumed in this model.

For APEC economies, SMR is widely used as it is the least expensive production method of the two options.

Based on assumed evolution of costs for each economy, OSeMOSYS calculates the least cost capacity expansion of the hydrogen production. Finally, the estimated cost of hydrogen is estimated according to the following expression:

$$\mathrm{LC_{H_2}} = \frac{\mathrm{C_{OC}} * \mathrm{f_{CR}} + \mathrm{C_{fix}}}{\mathrm{H_{2\,annual}}} + \frac{\mathrm{C_{fuel}}}{\eta} + \mathrm{C_{var}}$$

Where: LC_{H_2} is levelized cost of hydrogen ($/$Kg_{H2}$);

C_{OC} is overnight capital cost ($);

C_{fix} is fixed cost (\$/year);

C_{fuel} is fuel cost (\$/Kg_{H2});

C_{var} is variable cost (\$/Kg_{H2});

f_{CR} is capital recovery factor;

$H_{2\,annual}$ is H_2 annual;

η is efficiency;

An important assumption in the construction of the CN scenario is the international hydrogen trade and the use of hydrogen in bunkers are restricted to green hydrogen because of its low carbon intensity.

SECTION 3: TRANSFORMATION

11. REFINERY MODEL

The refinery model was developed to investigate the need for new APEC refinery capacities over the projection period (2019-2050) and to analyse the oil demand-supply balance of each APEC economy. It also details the oil products balance based on demand (from the final energy demand sectors) and calculates feedstock requirements and trade opportunities.

11.1 REFINERY MODEL DESCRIPTION

The inputs to the refinery model are the total oil demand results from the demand models (transport, buildings, industry, and non-energy) and economy-level capacity. The refinery model generates the yields of petroleum products using historical data for each scenario.

11.1.1 PRODUCTS YIELDS

The refinery model projects production of refined products such as LPG, jet fuels, gasoline, diesel, and "others". An important assumption used to estimate future production of refineries is that a typical yield can be estimated using five-year average of the past yields.

In the equation below, the yield of economy i is calculated for fuel type f in year j, as:

$$Refinery\ production_{f,i,j} = \sum_{k=2014}^{2018} \frac{Refinery\ Yield_{f,i,k}}{5} \times\ demand_{i,j}$$

The model does not breakdown any of the products into different specifications nor does it individually consider fuel oil, asphalt, lube, chemicals, or different grades of these products within the "others" category, but the model does account for it as an aggregate "others" grouping.

The model is not designed to optimise the raw materials going into the refinery's crude distillation unit (CDU) as crude oil or condensate as well as another feedstock. It assumes that the raw materials are refined according to their specific boiling points into different petroleum products. The crude oil (including condensate and chemicals) feedstock are fractionated according to the required quality specifications of the economies.

The accuracy of the refinery model depends on several variables such as the detailed refinery configurations to be modelled, the complexity of the refinery units of operations, the severity of how the refinery is operated and the operating conditions (such as pressure, temperature, and catalyst severity). The differences in the types of refineries in APEC economies underpins the differences in terms of the quality and quantity of refinery outputs.

The refinery model is not simulating the complexity of the unit operations of the refineries in the economy and thus, the model is not optimising the products from the refining process of the refineries. Instead, the model used the past historical yields of the refineries of the economies to estimate the yields of the refineries of the economy. The proportions of the products are then determined from the calculated yields and projected into 2050.

11.1.2 REFINERY OIL LOSS AND OWN USE

The refinery oil loss and refinery own use can be calculated by the five-year average as:

$$Oil\ loss\ from\ refinery_{i,j} = \sum_{k=2014}^{2018} \frac{Refinery\ Oil\ loss_{i,k}}{5} \times Refinery\ throughput_{i,j}$$

$$Own\ Use\ of\ refinery_{i,j} = \sum_{k=2014}^{2018} \frac{Refinery\ Own\ Use_{i,k}}{5} \times Refinery\ throughput_{i,j}$$

The refinery output is calculated as the net petroleum product excluding the refinery own use and oil loss. Refinery own use and oil loss are calculated and deducted from the refinery input to obtain net refinery products.

11.1.3 UNDER-UTILISATION OF APEC REFINERY CAPACITY

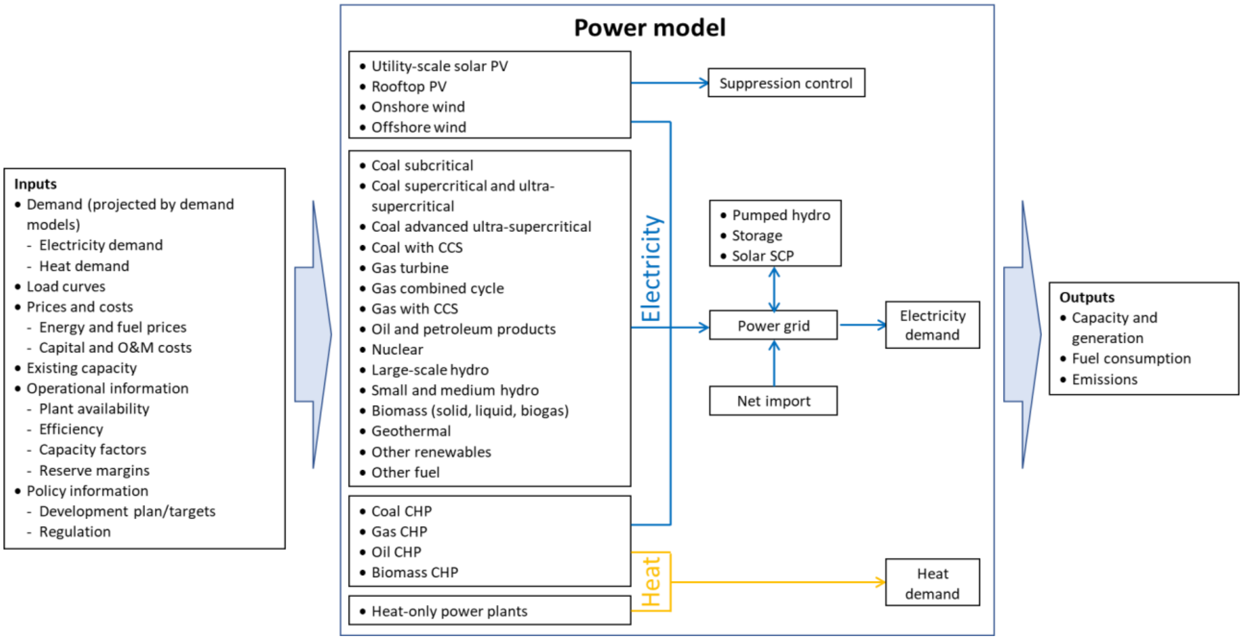
APEC refinery capacity projections are based on five-year historical utilisation rates. Some APEC economies have actively developed refining capacity not only to cope with domestic refined products demand but to also capture export market opportunities.

The refinery model evaluated the APEC utilisation rate by calculating the excess refining capacity in the APEC region in 2018 implying that refineries operated at approximately 93% utilisation rate. This rate is assumed to decline gently to 2050, when it reaches 90%.

12. POWER MODEL

The power model calculates electricity and heat generation from power plants, including combined heat and power (CHP) and heat-only plants, to optimally meet demand determined in the demand models. The power model assumes that annual electricity and heat demand is met, and enough capacity is installed to meet the peak load plus reserve margin criteria. This is a bottom-up model formulated as a linear programming problem, which determines capacity expansion and operation of each technology option based on cost-minimisation.

Figure 8. Power Model Structure



Note: PV=photovoltaics; CCS=carbon capture and storage; CHP=combined heat and power; SCP=concentrated solar power

12.1 POWER MODEL DESCRIPTION

The model includes 33 technologies: 30 types of power generation and 3 types of storage. One calendar year is divided into 12-time segments (2 representative days × 2 time slots per day × 3 seasons). Power systems in each economy are modelled as a single node system for simplicity in data gathering and solution times. The model projects electricity and heat supply in a single economy, and the objective function is the discounted total system cost over the projection period (denoted as z in the equation below) in each economy. The system cost consists of capital costs, fuel costs, operation, and maintenance (O&M) costs. We assume a discount rate of 5% for all economies.

$$z = min\left(\sum_{y} \frac{1}{\gamma_y}(cc_y + fc_y + oc_y)\right)$$

Where: z is minimized total cost of the electric system;

γ_y is discount rate (5%);

cc_y is total annualised capital costs (USD) for power generation and storage technologies in year y;

fc_y is total fuel costs (USD) for power generation technologies in year y;

oc_y is total O&M costs (USD) for power generation and storage technologies in year y.

The cost minimization problem is solved using OSeMOSYS for each economy. Constraints are formulated to ensure material balances, describe the technical characteristics of modelled technologies, and include policy directions. Key constraints include electricity supply-demand balance, power plant availability constraints, ramping constraints for thermal plants, storage availability constraints, reserve margin constraints.

Electricity exports and imports were assumed constant throughout the forecast period in line with the base year. Additionally, the renewable solar power export project from Australia to Singapore (Australia-Asia PowerLink project) was included in the model.

CHP plants and heat-only power plants, which are essential in some APEC economies in terms of providing acceptable living conditions and providing heat for industrial consumers, are included in the current version of the power sector model. The assumptions are based on CHP market penetration, policy assessment, and CHP potential.

It is important to note that the development of nuclear and renewable energy in the context of the goals declared by almost all APEC economies to achieve carbon neutrality by the middle or beginning of the second half of the 21st century is critically important. Moreover, the development of nuclear power (operational safety issues, long investment cycle, nuclear fuel handling issues) and renewable energy, which in the future can become the basis of power supply systems, is largely determined by the policies of governments and the latest trends in technology development. Therefore, a thorough analysis of national strategic development documents was carried out. All key development trends, especially in terms of nuclear and renewable energy development, were included in the model.

12.2 SCENARIO ASSUMPTIONS

To make the long-term projections, APERC conducted a thorough survey on each economy's electricity policies and plants, as well as techno-economic data. General assumptions for each scenario are shown in Table 10. Techno-economic assumptions for selected power generation technologies are shown in Table 11.

In the Carbon Neutrality scenario, as an additional measure to reduce CO_2 emissions, it was assumed that 60% of CO_2 emissions from coal-fired power plants in Indonesia and Viet Nam and 80% of emissions from gas-fired plants in APEC would be captured using CCS technologies.

Table 10. Key Scenario Assumption in the Power sector

	Key Assumptions
Australia	In REF, thermal coal/lignite capacity is slowly retired out to 2050 and there are no new coal-fired power plants. Snowy Hydro 2.0 begins operating with 2 GW of capacity in 2025. Offshore wind development is relatively conservative. In CN, Sun Cable electricity exports begin in 2028, though development is driven by Singapore's climate ambitions, rather than Australia's. Natural gas with CCS technology is adopted so that natural gas still plays a transition role while Australia meets ambitious emissions reduction goals. Slightly faster coal phase-out in the latter half of the projection than in REF.
Brunei Darussalam	In REF, natural gas power plants to be maintained throughout. Diesel power plant ceases its operation from 2023 onwards. Coal power plant to enter the electricity generation mix beginning 2020. Cumulative renewable energy installed capacity reaches 1 100 MW (41% of the total installed capacity) in 2050. In CN, existing natural gas power plants to be fitted with CCS units. Diesel power plant ceases its operation from 2023 onwards. Cumulative renewable energy installed capacity reaches 1 500 MW (59% of the total installed capacity) in 2050.
Canada	In REF, unbated coal phase-out drives coal out of the fuel mix by 2050. Low costs of wind, solar lead to two-third share of capacity additions; natural gas nearly a third of capacity additions. Nuclear fleet remains after refurbishment. In CN, do not hit net-zero by 2035 but approach a carbon-neutral power sector by 2050. Retain existing nuclear fleet, with no utilisation of SMRs. Utility storage adoption from 2025; CCUS-equipped natural gas adoption from 2030.
Chile	In REF, close all coal power plants by 2040. In CN, close all coal power plants by 2030.
China	In REF, China will strictly control coal-fired power generation projects, and strictly limit the increase in coal consumption over the 14th FYP period and phase it down in the 15th FYP period. At least 1 200 GW of renewables (solar and wind). Traditional hydro and conventional storage technologies are adopted. Increasing role of natural gas. In CN, coal phasing out by 2050. CCUS-equipped natural gas adoption from 2030. Large scale adoption of renewables including offshore wind projects. Large scale deployment of nuclear reactors. No hydrogen consumption to produce electricity as other technologies expected to be more cost competitive.
Hong Kong, China	In REF, reduction of coal and replace it with natural gas for electricity generation.

	Key Assumptions
	In CN, phasing out coal by 2037, replacing it with natural gas for electricity generation. Adoption of CCUS-equipped natural gas from 2036. Higher solar capacity by 2050, double compared to REF.
Indonesia	In REF, coal and gas-fired units are used to meet rapidly increasing electricity demand. Lower scale adoption of solar and wind projects. In CN, CCS-equipped natural gas and coal adoption from 2035. Higher scale adoption of solar and wind projects. Nuclear reactors adoption from 2040.
Japan	In REF, partial adoption of offshore wind projects. The 30 nuclear units under operation by 2030 with plant lifetime extensions of up to 60-years. Renewable energy share reaches 40% by 2040. In CN, unabated coal phased out by the 2040s and CCUS-equipped natural gas adoption from the 2030s. Large scale adoption of offshore wind projects. The 30 nuclear units under operation by 2030 with plant lifetime extensions of up to 60-years. Renewable energy share reaches 50% by 2040.
Korea	In REF, decrease of coal power generation and expansion of renewable and LPG power generation. 20% of total power generation from renewable sources by 2030. In CN, phase-out of coal power generation and acceleration of wind and solar. Application of CCS technology to gas-fired power plants.
Malaysia	In REF, peninsular Malaysia Generation Development Plan 2021-2039. Moderate adoption of solar projects beyond 2030. Natural gas and renewables power plants to replace retired coal plants. Oil generating capacity remains for energy security and severe peaking purposes. In CN, more renewables in electricity generation, particularly solar, with 18 GW of renewables capacity target achieved by 2035. CCUS-equipped natural gas adoption from 2029. No hydrogen consumption or co-firing (coal and biomass) fuel blends.
Mexico	In REF, no inclusion of new coal plants. Economic dispatch is assumed. In CN, no inclusion of new nuclear plants. CCS for gas-fired plants.
New Zealand	In REF, assumed an optimal transmission system operation in the event of the future closure of New Zealand's aluminium smelter at Tiwai. After 2023, hydroelectricity will reduce the role of natural gas. Coal is phased out by 2030; natural gas stays for backup but is also phased out by 2044.

	Key Assumptions
	In CN, natural gas is replaced with pumped storage in the 2030s. Coal is phased out before 2030. No hydrogen consumption due to other technologies being more cost competitive. Large-scale adoption of renewables, particularly onshore wind projects.
Papua New Guinea	In REF, access to electricity increases to 70% by 2030 and 100% by 2050. Gas-fired units are used to meet rapidly increasing electricity demand and reduce generation from oil products. Small adoption of new geothermal projects. In CN, moderate adoption of solar projects. Hydroelectricity becomes the leading technology to meet incremental capacity requirements. Moderate adoption of new geothermal projects.
Peru	In REF, moderate scale adoption of renewables. Coal phased out by 2023. However, some coal-fired units used by auto-producers in the industry sector remain. In CN, gas-fired units begin to decommission in 2040, with a combination of renewables set to replace them. No hydrogen consumption or co-firing natural gas units as we expect other technologies to be more cost competitive. CCS in power was not assumed.
Philippines	In REF, coal and gas-fired units are used to meet rapidly increasing electricity demand . In CN, CCS-equipped natural gas power plants adoption from 2035. Increased adoption of renewables technologies . No hydrogen consumption or co-firing coal units as we expect other technologies to be more cost competitive.
Russia	In REF, maintaining the existing structure of installed capacity of power plants. Gradual replacement of coal. In CN, significant increase in the capacity of nuclear power plants. Gradual decommissioning of coal-fired power plants. Use of CCS in 60% of gas-fired power plants. Slight increase in the capacity of the solar and wind power plants.
Singapore	In REF, solar targets: 1.5 GWp in 2025; 2.0 GWp in 2030. 100 MW electricity import trial with Malaysia starts in 2025. Coal phased out by 2027. In CN, gas-fired CCS introduced in 2031, makes up 100% of active natural gas capacity by 2050. Sun Cable with Australia online in 2028, ramping imports up to 17 TWh per annum from 2029 to 2050. Solar deployment increases further, but still under its full potential.
Chinese Taipei	In REF, nuclear phaseout by 2025. Renewable energy share reaches 20% of electricity generation by 2025. 12GW of new gas-fired units by 2025, replacing coal-fired units.

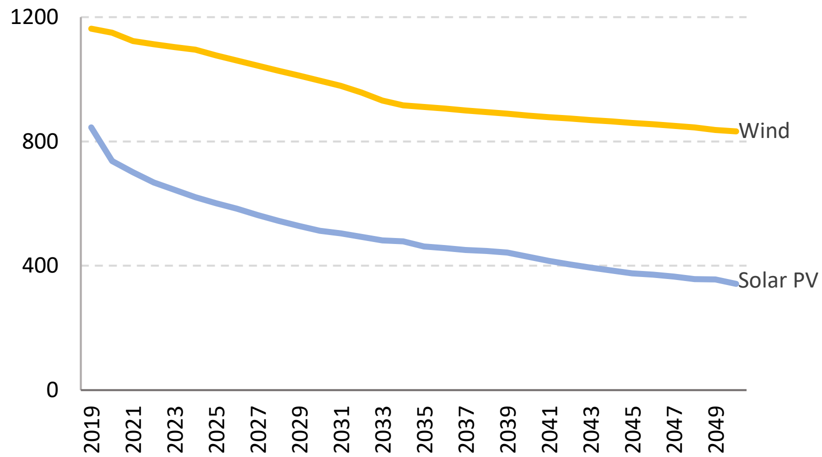
	Key Assumptions
	In CN, nuclear phaseout by 2025. CCS technology starts to be applied to natural gas power plants by 2030. No new coal-fired units will be commissioned after 2025. Large scale deployment of offshore wind projects
Thailand	In REF, electricity generation based on revised PDP 2018. Gas-fired units are used to meet rapidly increasing electricity demand. Moderate adoption of Solar and Biofuels projects (Biomass, MSW and Biogas). Wind Power projects aligned with AEDP 2018 targets. In CN, CCS-equipped natural gas adoption from 2029. Moderate scale adoption of Solar and Wind projects. No hydrogen consumption or co-firing coal units as we expect other technologies to be more cost competitive.
United States	In REF, minimal production of electricity using coal-fired power plants. Only units under a technical minimum operation basis will remain after 2035 in some US regions. A small deployment of offshore wind. No CCS is deployed. In CN, approaching carbon neutral power sector by 2035. Retain existing nuclear fleet, with expansion only using small modular reactors. Large-scale adoption of offshore wind projects. CCS adoption for natural gas plants starting in 2030.
Viet Nam	In REF, the draft of Vietnam's Power Development Plan 8 Update (PDP8) is used as a guideline. Coal and gas-fired units are used to meet rapidly increasing electricity demand. Moderate scale adoption of wind and solar projects. In CN, CCUS-equipped natural gas and coal adoption from 2035. Moderate scale adoption of solar and wind projects. No hydrogen consumption or co-firing coal units due to other technologies being more cost competitive.

Table 11. Key Assumptions for Selected Power Generation Technologies (All Scenarios)

	Coal SC/USC	Gas CCGT	Nuclear	Solar PV	Onshore wind
Capital cost [USD/kW]	1900 -3700	740 –1200	1500-6600	Figure 9	Figure 9
Lifetime [year]	40	40-50	40-80	20-40	30-40
Average CF [%]	73%	78%	90%	17%	30%
CO_2 Emission [million tonne/PJ]	0.0961	0.0561	-	-	-

Source: APERC analysis, IEA (2016; 2018) and Komiyama, et al. (2015).

Figure 9. Average Capital Cost of Wind and Solar PV Power Plants (USD/kW)



SECTION 4: SUPPLY

13. SUPPLY MODEL

The supply model is mainly an accounting framework for ensuring the supply requirements of each economy are satisfied based on their demand projections. The model takes a bottom-up approach where inputs from domestic demand, power and refinery projections produced in other models determine the supply requirement, which in turn determines the production or import requirement levels. For producer-exporters, the model allows for trading influence the production level.

The energy supply requirements is provided by the inputs of the demand, power and refinery models. The total primary energy supply (TPES) is defined as balance of domestic energy production, net energy trade -difference between imports and exports-, and stock changes, calculating the total amount of primary energy that is available to the economy for its use.

Stock changes, which can be stock builds or stock draws, are used to balance fossil fuel supply with the supply requirements determined by the demand module. Generally, these are only used to square imbalances between the last historical year of the EGEDA dataset (2018) and recent history of publicly available data (2019 to 2021). The storage function is particularly active over the past two years due to the significant imbalances in supply and demand brough about by COVID-19. The storage function generally dissipates after 2025; however, it is sometimes used in future years. For example, some economies use storage builds in both scenarios as they drill for natural gas ahead of the commissioning of LNG export facilities.

13.1 Production

Fossil fuel production is the balance of domestic and global demand and net imports, therefore production can be estimated as follows:

$$Production_{e,f,y} = Total\ Primary\ Energy\ Supply_{\ e,f,y} - Total\ Import_{e,f,y} + Total\ Export_{e,f,y} \pm Stock\ Changes_{e,f,y}$$

Where: e is economy;

y is year;

f is fuel.

Production can be affected by production capacity of fuel accordinly to specific considerations that are discussed below.

13.1.1 COAL, CRUDE OIL AND NATURAL GAS

Crude oil and natural gas production in REF is generally guided by the best-available projection estimates of an economy, if they exist, or any production targets or goals set by the economy. These projections are further guided using qualitative input from APERC researchers and other experts. For producer-exporters, it is assumed that excess production is exported to global markets (see the trade section below).

In CN, production of crude oil and natural gas is generally lower due to lower domestic supply requirements and the assumed global decline in exports markets for both fossil fuels. See the export and table below for these details.

Natural gas liquids (NGLs) production is a byproduct of crude oil or natural gas production, depending on the resource base of the economy. A ratio of NGL to crude oil or natural gas production is calculated in the last year of the historical period, and NGL production is calculated by multiplying the annual production of crude oil or natural gas by this ratio.

Coal production is generally the sum of supply requirements, net trade, and stock changes, but in some instances, it is guided by the targets of particular economies.

To accurately estimate TPES, the model estimates the demand for coal by coal tranformation processes using the demand for coal products from the demand models.

13.2 TRADE

In CN, lower domestic demand for fossil fuels reduces TPES and imports. Furthermore, as the world embraces carbon neutrality, the global export market for fossil fuels starts to decline. This decline is assumed to start in 2023 and increases linearly to 2050. Production in the Carbon Neutrality Scenario is calculated as the sum of both these lower domestic supply and global export market requirements for all fossil fuels.

13.2.1 CRUDE OIL

The projection for crude oil and NGL trade is based on inputs from the refinery model, including the level of crude oil and NGL needed to produce oil products.

In REF, crude oil exports depend on the refining capacity of the domestic economy and a qualitative assessment of the ability of the domestic refinery fleet to process domestically produced crude oil.

CN assumes that crude oil exports begin to decline in 2023, falling at a linear rate as the world embraces carbon neutrality. Exports are 52% below the REF by 2050.

Crude oil imports are generally calculated as the balance of supply, production, and exports.

The source and destination of crude oil trade are not traced at the economy level.

13.2.2 NATURAL GAS

Natural gas is traded as piped gas or LNG. The projection for natural gas trade depends on the supply requirements for the demand and power models, historical data, gas production, LNG import capacity, LNG export capacity and (effective) pipeline capacity.

Changes in pipeline capacity can result from newbuild pipelines, brownfield expansion or retirement of existing facilities. Changes in effective pipeline capacity can result from government policy that restricts trade. An assessment of pipeline infrastructure and policy plans forms a capacity constraint schedule that guides natural gas pipeline trade during the projection. Further work is done to ensure that the results are consistent across APEC members that engage in pipeline trade, and to align non-APEC pipeline trade with future flow expectations at the time of analysis.

A schedule for LNG import and export capacity is made by assessing the proposed project schedule to risk projects and their commissioning dates. This forms a capacity constraint schedule that guides LNG trade during the projection. However, because proposed project schedules do not typically extend to 2050, LNG import capacity is assumed to rise to meet supply requirements if the call of LNG imports exceeds LNG import capacity. The source and destination of LNG trade is not traced at the economy level.

In REF, LNG exports are driven by export capacity and gas production trends. LNG and pipeline imports are calculated to balance the difference between domestic production, exports, and supply requirements.

CN assumes that gas exports begin to decline in 2023, falling at a linear rate as the world embraces carbon neutrality. LNG exports are 25% below REF by 2050. Pipeline exports with non-APEC members also follows this trajectory, while exports to APEC members is guided by the import requirements of those APEC members.

13.2.3 COAL

Coal imports are guided by the historical data of import share over demand.

Most APEC coal exports flow into the APEC region, therefore the demand and power results for both thermal and metallurgical coal in the APEC region are used to guide exports in both scenarios. An assessment of restrictive coal trade policy also informs this process by placing trade constraints on affected member economies.

Coal imports are calculated as the balance between domestic production and exports plus supply requirements.

13.3 ASSUMPTIONS AND DATA SOURCES

13.3.1 ASSUMPTIONS

In projecting production and trade, a few assumptions are applied to all economies. However, given that each economy has their own unique characteristic, specific assumptions are sometimes applied.

Table 12. Key Assumptions for Fossil Fuel Production and Trade

	Reference	Carbon Neutrality
Reserves Replacement Ratio	Default RRR at 50%, with some variation to support the goals, targets, and policy, or to ensure that sufficient supply exists to meet demand.	
2019 to 2021 production and trade data	Align recent-historical years with best-available government, public or consultant data that is available at the time of analysis	
Stock changes	A storage mechanism exists to balance out supply (production and net imports) with supply requirements (demand and transformation) in initial period of the projection (2019 to 2025).	
Crude oil and natural gas production	Guide production trajectory using economy-specific projections or targets, if available, and augmented with qualitative input from APERC analysts and EWG members.	Production equals the sum of demand plus exports less imports, with exports assumed to be lower than REF levels as specified in this table below.
Coal production	Production equals the sum of demand plus exports less imports, with exports guided by the demand and power results of the model as indicated in this table below.	
NGL production	Assume NGL production is equal to the multiplication of crude oil or natural gas production and the ratio of the last historical year of NGL production to crude oil or natural gas production, depending on the resource type of the economy.	
Crude oil and NGL exports	Production in addition to refinery requirements is exported to the global market.	Assuming a decline in the global oil export market in CN as the world embraces carbon neutrality. This decline starts in 2023 and by 2050, global markets are 52% below REF levels, around the same as the reduction in APEC oil requirements.

Crude oil and NGL imports	Assuming crude oil import is determined by refinery input projection.	
Pipeline trade	Post-2019 pipeline infrastructure is commissioned on time. Pipeline trade is proportion to historical demand and production, subject to capacity constraints and any policy to alter pipeline trade flows.	
LNG import capacity	All proposed post-2019 projects come online. Timing may vary depending on the project status at the time of analysis.	
	Further capacity increases occur to meet demand throughout the projection period. This can result in higher or lower import capacity in CN relative to REF, depending on the demand and power trajectory.	
LNG imports	LNG terminal capacity schedule and supply requirements drive LNG imports in both scenarios.	
LNG export capacity	All proposed post-2019 projects come online. Timing may vary depending on the project status at the time of analysis.	
LNG exports	LNG export capacity and production trends of producer-exporters drive LNG exports in REF.	Decline in global LNG export markets in CN as the world embraces carbon neutrality. This decline starts in 2023 and by 2050, global markets are 25% below REF levels, around the same as the reduction in APEC gas requirements.
Coal transformation	Assuming that transformation inputs are proportional to the historical coal use by transformation in the last year of the projection.	
	Coal product requirements guide coal transformation activity.	
Coal imports	Assuming that coal and coal product requirements more than domestic sources are imported from the global market.	

Coal exports	The share of coal exports destined for APEC markets is determined by APEC demand and power results in REF.	The share of coal exports destined for APEC markets is determined by APEC demand and power results in CN.
	The share of coal exports destined for non-APEC global markets is held constant at current levels.	The share of coal exports destined for non-APEC global markets declines in line with APEC coal demand trends. By 2050, the thermal coal market falls about two-thirds below REF levels and the metallurgical market falls by about a third.

13.3.2 DATA SOURCES

Several databases are used to obtain and estimate fossil fuel production. These databases are also used to align the initial years (for example, from 2019 to 2021) of the projection with recent observed history for both the production and trade of all fossil fuels.

In contrast, the 8th Edition generally does not track or estimate trade flows between economies, neither APEC members nor non-APEC members. However, it does track flows between economies that partake in the trade of natural gas via pipelines and ensures that the resulting trade flows between economies are consistent.

Table 13. Production Data and Sources

Data	Sources
Historical data of crude oil, coal, and natural gas production	EGEDA
Gas Trade	EGEDA BP's Statistical Review of World Energy International Group of Liquefied Natural Gas Importers International Gas Union Cedigaz Economy-specific energy statistics.

SECTION 5: CO_2 EMISSIONS

14. CO_2 EMISSION FACTORS

Energy-related CO_2 emissions from fuel combustion activities using emission factors based on the United Nations Intergovernmental Panel on Climate Change guidelines (IPCC, 2006), considering the net calorific values of the carbon content of the fuels.

Table 144. Default net calorific values (NCVs) and lower and upper limits of the 95% confidence interval)

Fuel type	Default NCV (TJ/Gg)	Lower	Upper
Crude Oil	42.3	40.1	44.8
Natural gas liquids	44.2	40.9	46.9
Motor gasoline	44.3	42.5	44.8
Aviation gasoline	44.3	42.5	44.8
Jet kerosene	44.1	42.0	45.0
Other kerosene	43.8	42.4	45.2
Gas/Diesel oil	43.0	41.4	43.3
Residual fuel oil	40.4	39.8	41.7
Liquefied petroleum gases	47.3	44.8	52.2
Ethane	46.4	44.9	48.8
Naphtha	44.5	41.8	46.5
Petroleum coke	32.5	29.7	41.9
Refinery feedstocks	43.0	36.3	46.4
Refinery gas[2]	49.5	47.5	50.6
Coking coal	28.2	24.0	31.0
Sub-bituminous coal	18.9	11.5	26.0
Coke oven coke and lignite coke	28.2	25.1	30.2
Gas coke	28.2	25.1	30.2
Coal tar	28.0	14.1	55.0
Natural gas	48.0	46.5	50.4
Municipal wastes (non-biomass fraction)	10.0	7.0	18.0
Wood/wood waste	15.6	7.9	31.0
Sulphite lyes (black liquor)	11.8	5.9	23.0
Other primary solid biomass	11.6	5.9	23.0
Charcoal	29.5	14.9	58.0

Biogasoline	27.0	13.6	54.0
Biodiesels	27.0	13.6	54.0
Other liquid biofuels	27.4	13.8	54.0
Landfill gas	50.4	25.4	100.0

Table 155. Default Values of Carbon Content (2006 IPCC Guidelines)

Fuel type	Default Carbon content (kg/GJ)
Crude Oil	20
Natural gas liquids	17.2
Motor gasoline	18.9
Aviation gasoline	19.1
Jet kerosene	19.5
Other kerosene	19.6
Gas/Diesel oil	20.2
Residual fuel oil	21.1
Liquefied petroleum gases	17.2
Ethane	16.8
Naphtha	20
Petroleum coke	27.5
Refinery feedstocks	20
Refinery gas[2]	15.7
Coking coal	25.8
Sub-bituminous coal	26.2
Coke oven coke and lignite coke	29.5
Gas coke	29.5
Coal tar	22
Natural gas	15.3
Municipal wastes (non-biomass fraction)	25
Industrial wastes	39
Wood/wood waste	30.5
Sulphite lyes (black liquor)	26

Other primary solid biomass	29.9
Charcoal	30.5
Biogasoline	20
Biodiesels	20
Other liquid biofuels	20
Landfill gas	14.9

Additionally, to evaluate the effect of implementing of carbon capture and storage technologies and average effectiveness of 80% was assumed throughout the projection.

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