ANNEX I:
MODELLING KEY ASSUMPTIONS & METHODOLOGIES

CONTENTS

INTRODUCTION

The *APEC Energy Demand and Supply Outlook, 7th Edition* projections stem from a series of energy models, which are applied to all 21 APEC economies. There are eleven main models, which are connected via an integration module, and run sequentially: macroeconomic, industry, transport, buildings (including residential and services), agriculture and non-specified, hydrogen, electricity, heat, refineries, and production and trade. This annex also describes the methodology for calculating renewables supply potential, investment and security.

The modelling approach of the 7th Edition has built on the 6th Edition by, in part, disaggregating top-down methodologies where data are available. All projections cover the base year (2016) to 2050 (the Outlook period) and all models use consistent assumptions (GDP, population, energy prices). Energy projections are demand-driven and the supply model balances flows. APERC has retained the renewables definition from the 6th Edition (broadly includes technologies such as large hydropower, but does not include pumped-storage), which follows the UN's definition[1].

The Outlook calculates CO_2 emissions from fuel combustion activities and a portion of industrial process emissions as defined by the IPCC. Agricultural and industrial emissions (other than for fuel combustion), other upstream fossil fuel production emissions, fugitive emissions and LULUCF are excluded. Global carbon factors are used for coal, oil and gas, rather than the economy specific factors used in the 6th Edition.

SCENARIO ASSUMPTIONS

The 7th Outlook includes two alternative scenarios in addition to the BAU scenario:

1. The **APEC Target** scenario simultaneously considers the APEC goals to reduce energy intensity and increase the share of renewables in the energy system. This differs from the 6th Edition, where each of these goals was looked at independently.

2. The **2-Degrees Scenario** (2DC) generally follows the carbon emissions reduction pathway included in the International Energy Agency's *Energy Technology Perspectives* publication (IEA, 2017). This pathway provides a 50% chance of limiting average global temperature increases to 2 degrees Celsius.

All of the scenarios include an extended time horizon through 2050. Both of these scenarios are compared to the trajectory implied by the current Intended Nationally Determined Contributions (INDCs) or NDCs.

BUSINESS-AS-USUAL (BAU)

The BAU scenario reflects current policies and trends within the APEC energy sector. In turn, it largely projects past trends into the future.

APEC TARGETS (TGT)

The TGT scenario is driven by APEC's goals of reducing energy intensity while increasing the share of renewables. The energy denominator for these two targets are still under discussion – it could be primary energy, final energy,

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[1] https://unstats.un.org/unsd/energy/ires/

or final energy excluding non-energy use. In order to construct this scenario, APERC has chosen to use final energy excluding non-energy use as the basis for evaluating progress toward these two goals.

In the case of renewables, the definition of "renewables" in the APEC goal was still under discussion during Outlook development and modelling runs. For the purpose of this analysis, APERC has retained the definition from the 6th Edition's High Renewables Scenario, which includes renewables as defined by the UN[2] but excludes biomass in the buildings sector (as this is considered to be traditional).

TWO DEGREES CELSIUS SCENARIO (2DC)

The two-degree Celsius scenario (2DC) is inspired by the COP21[3] declaration: "*Holding the increase in the global average temperature to well below 2DC above pre-industrial levels*" (UNFFFC, 2015). The 2DC generally follows the carbon emissions reduction pathway included in the *Energy Technology Perspectives* (ETP) publication by the International Energy Agency. This pathway provides a 50% chance of limiting average global temperature increases to 2 degrees Celsius.

Sub-targets are set for each energy sub-sector using outputs from the ETP, which utilised an integrated cost-optimised modelling approach to determine the proportion of total carbon reductions by each sub-sector. This integrated approach means that some sectors will achieve greater carbon reduction than others as a proportion of their current emissions levels.

All methodologies described in this document are comprehensive abstracts. APERC is willing to share more details with interested parties. For more information, please visit https://aperc.ieej.or.jp/ and contact us.

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[2] https://unstats.un.org/oslogroup/meetings/og-04/docs/oslo-group-meeting-04-comments-issue-3.2-iaea.pdf

[3] The 21st Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC) in Paris in 2015.

COMMON ASSUMPTIONS

INTRODUCTION

The common assumptions used in almost all APERC models are GDP (Gross Domestic Product), population and energy prices. These three assumptions operate exogenously to the models and come from other organisations where available (Table 1). Like the 6th edition of the Outlook, population projections come from the United Nations Department for Economic and Social Affairs (UN DESA), with some small adjustments based on individual economies' own projections. Likewise, energy price projections come from the Institute of Energy Economics, Japan (IEEJ). However, based on feedback during the 6th Edition Economy Roadshow, 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), where not. Historical GDP data to 2017 comes from the World Bank (2018a). GDP is measured in billion USD at the 2016 currency exchange rate, using purchasing power parity (PPP) to facilitate comparison across economies. These key assumptions are held constant across the three Outlook scenarios.

Table 1 • Key assumptions sources

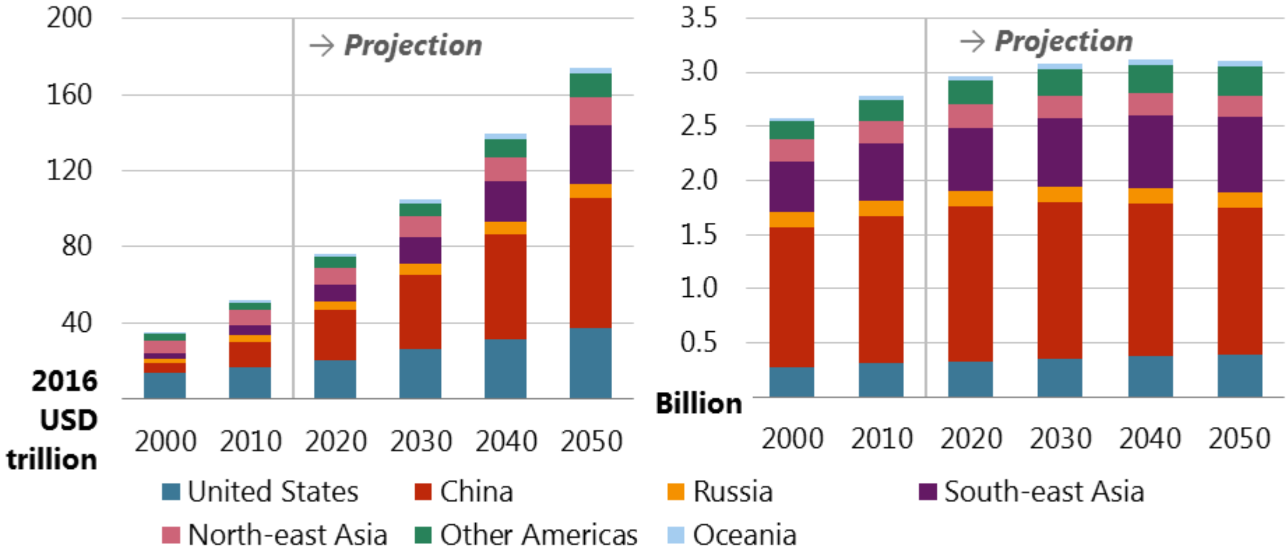
	Abbreviation	GDP Source	Population
Australia	01_AUS	OECD	UNDESA
Brunei Darussalam	02_BD	APERC	UNDESA
Canada	03_CDA	OECD	UNDESA
Chile	04_CHL	OECD	UNDESA
China	05_PRC	OECD	UNDESA
Hong Kong, China	06_HKC	APERC	UNDESA
Indonesia	07_INA	OECD	UNDESA
Japan	08_JPN	OECD	UNDESA
Korea	09_ROK	OECD	UNDESA
Malaysia	10_MAS	APERC	UNDESA
Mexico	11_MEX	OECD	UNDESA
New Zealand	12_NZ	OECD	UNDESA
Papua New Guinea	13_PNG	APERC	UNDESA
Peru	14_PE	APERC	UNDESA
Philippines	15_RP	APERC	UNDESA
Russia	16_RUS	OECD	UNDESA
Singapore	17_SIN	APERC	UNDESA
Chinese Taipei	19_CT	APERC	UNDESA
Thailand	19_THA	APERC	UNDESA
United States	20_USA	OECD	UNDESA
Viet Nam	21_VN	APERC	UNDESA

GDP AND POPULATION

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). The ten economies modelled by APERC accounted for only 9.1% of total APEC GDP in 2016 and 11% in 2050. Population projections are from *World Population Prospects 2017*, published by UN DESA (2018).

APEC-wide GDP grows robustly through the Outlook period, increasing by 167%, from USD 65 trillion in 2016 to USD 174 trillion in 2050. In contrast, population is projected to grow moderately from 2.9 billion in 2016 and peak at 3.1 billion people in 2043 before tailing off towards the end of the Outlook (Figure 1). While China is the main driver of APEC GDP growth, accounting for USD 47 trillion of the USD 109 trillion APEC increase, south-east Asia is the main driver of population growth, accounting for 137 million of the 209 million APEC increase (and exceeding population decreases in China, Russia and north-east Asia, combined).

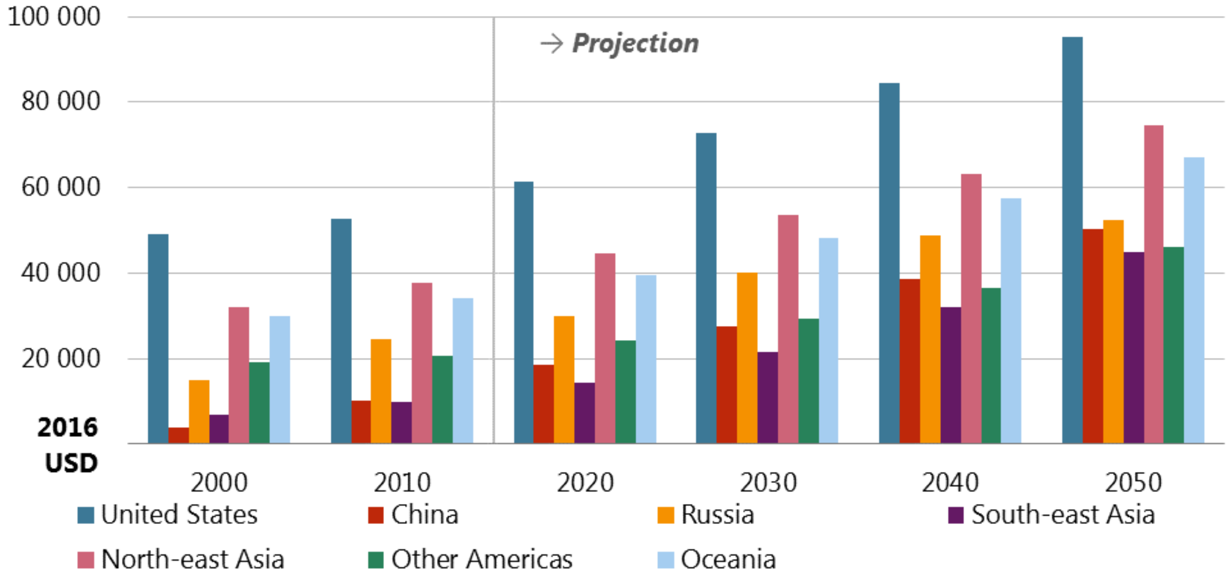
Figure 1 • GDP and population by region in all scenarios, 2000-50



Sources: APERC analysis, OECD (2018), UN DESA (2018) and World Bank (2018a and 2018b).

The effect of strong GDP and modest population growth significantly increases per capita GDP across the APEC region (Figure 2). The United States, north-east Asia and Oceania remain the wealthiest regions in APEC through the Outlook, but the gap to other regions narrows by 2050. China, in particular, grows rapidly from the poorest region in APEC in 2000, to reach a similar level to Russia, south-east Asia and other Americas by 2050. Overall, APEC-wide GDP per capita increases remarkably, from USD 22 536 in 2016 to USD 56 218 in 2050.

Figure 2 • GDP per capita by region in all scenarios, 2000-50



Sources: APERC analysis, OECD (2018), UN DESA (2018) and World Bank (2018a and 2018b).

THE 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, the age-structure of the population, 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, with the exception of 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), with the exception of 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.

ENERGY PRICES

The Institute of Energy and Economics, Japan (IEEJ) provided the key global fuel price assumptions used in this Outlook. Given the different energy and economic positions of each economy, APERC made some adjustments for each energy type accordingly (shown in Table 2).

Table 2 • Fuel price assumptions, 2016-50

	2016	2020	2030	2040	2050
Crude oil (USD per toe)	297	531	620	755	812
Diesel (USD per toe)	356	637	744	906	974
Fuel oil (USD per toe)	312	557	651	793	852
Natural gas					
Net importer Asia (USD per toe)	275	418	434	449	450
Neutral Asia (USD per toe)	248	376	391	404	405
Net exporter Asia (USD per toe)	220	335	347	360	360
Americas and Russia (USD per toe)	98	136	160	192	201
Thermal coal					
Net importer (USD per toe)	105	127	132	148	151
Neutral (USD per toe)	95	114	118	133	136
Net exporter (USD per toe)	84	101	105	118	121

CO_2 EMISSION FACTORS

Based on feedback received during the 6th edition roadshow, APERC decided to standardise the carbon dioxide (CO_2) emission factors used in the Outlook. As such, they are applied universally to all APEC economies over the entire Outlook period and are based on United Nations Intergovernmental Panel on Climate Change guidelines (IPCC, 2006).

Table 3 • Emission factors

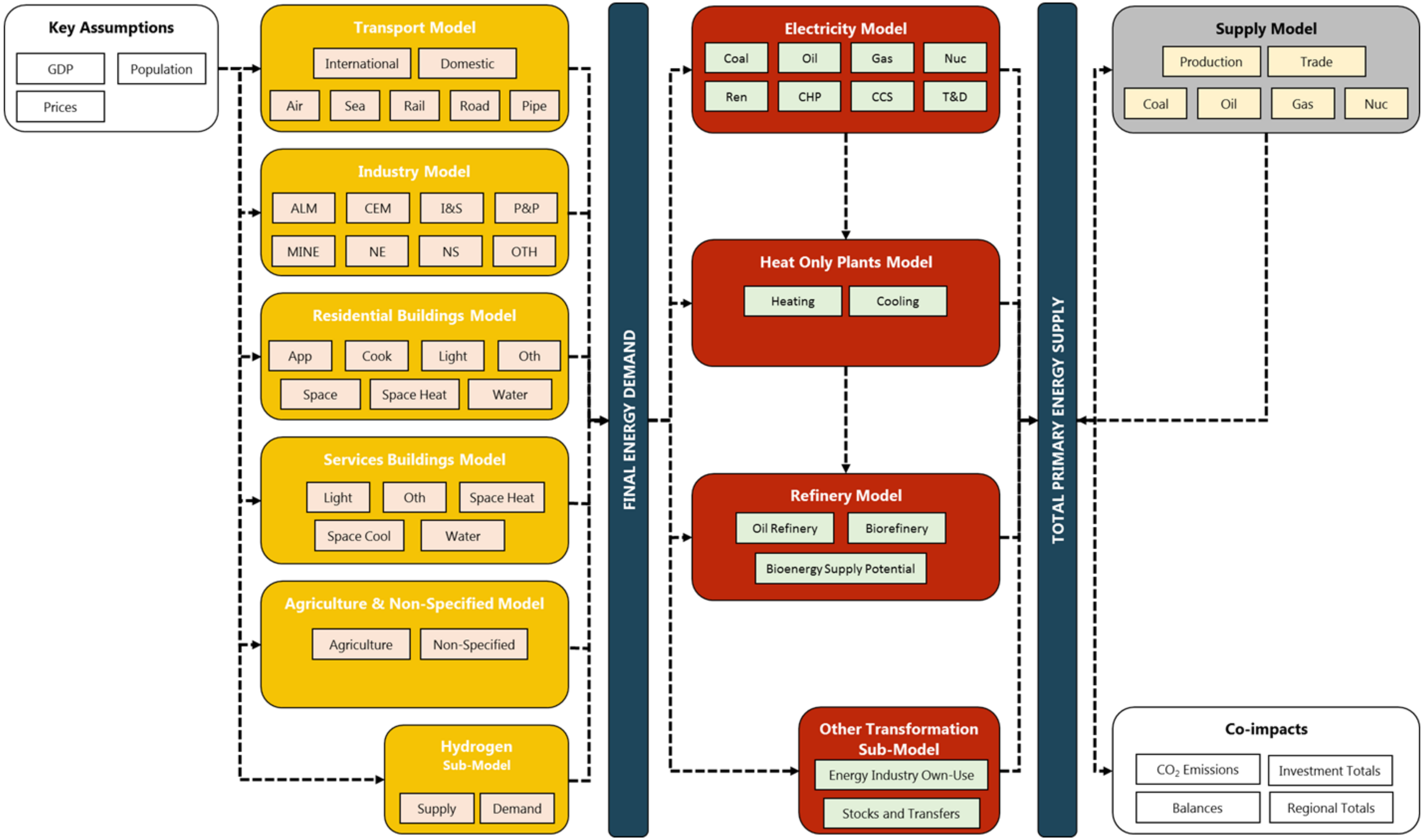
Fuel	
Coal (Mt CO_2 per mtoe)	4
Oil (Mt CO_2 per mtoe)	3
Gas (Mt CO_2 per mtoe)	2.35
Geothermal (Mt CO_2 per mtoe)	0.36

INTEGRATION

The integration module serves to connect all of the other models so that they can communicate with each other. It comprises 21 sub-modules and runs (mostly) sequentially with the outputs of some models forming the inputs of others (Figure 3). It runs in GAMS, a modelling platform, which is better at handling large datasets than Excel and avoids having direct, changeable, links between individual models (which was the case in the 6th edition).

The integration module firstly takes the key assumptions (GDP, population and energy prices) and distributes them to all of the demand models. After those models have run, it re-imports the results and totals them (to create final energy demand). This is then sent to the hydrogen sub-model to run, and then re-imported. The results are again summed and then sent to electricity to run. The results are re-imported, sent to heat to run, re-imported and sent to refineries to run, then re-imported. The module then calculates total primary energy supply (TPES) and sends it to the supply model (to calculate production and trade) and re-imports the results. This process has to be looped because energy use by coalmines and oil and gas facilities are a function of production, but are also used to calculate TPES. Looping allows these values to converge. Once that has happened, final TPES is calculated. After this, separate integration modules calculate totals for investment, regional groupings and CO_2 emissions (co-impacts).

Figure 3 • APERC Model layout

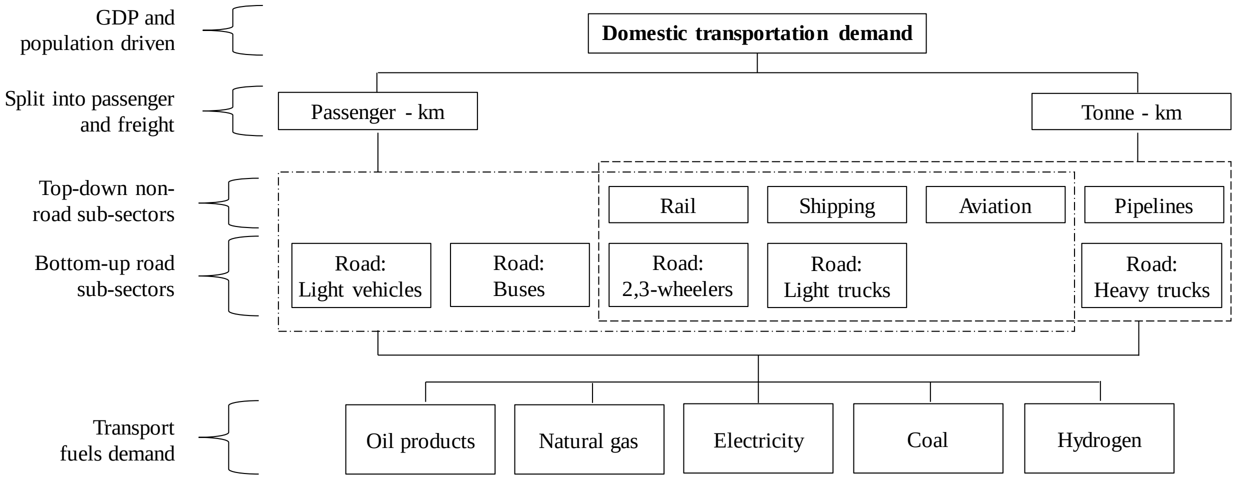


TRANSPORT

INTRODUCTION

The APERC Transport model projects the fuels demand by APEC's transportation sector. It consists of eight sub-sectors, namely: international and domestic aviation, international and domestic shipping, road, rail, pipelines and other transportation demand. International sub-sectors are modelled using top-down econometric approach. Domestic non-road sub-sectors are modelled using top-down approach and activity and intensity indicators. Road demand utilises bottom-up approach and projects vehicle stocks, mileages and other indicators. Vehicle types further break down the road subsector in five groups: 2-wheeleres (2W), light vehicles (LV), light trucks (LT), buses (BUS) and heavy trucks (HT). The model is developed upon a combination of Excel and GAMS software packages. The structure of the domestic transport model is shown on Figure 1 and explanation for all equations are provided in Table 1.

Figure 1 • Domestic transport flow structure



MODEL ENHANCEMENTS FROM 6TH EDITION

For the 6th Edition of APEC's Energy Demand and Supply Outlook a different model is utilised. The most significant differences include:

- A transfer from STELLA (Systems Thinking, Experimental Learning Laboratory with Animation) visual programming language for system dynamics modelling towards more flexible Excel and GAMS (General Algebraic Modelling System),
- Formulation of activity-based (passenger-kilometre (PKM) and tonne-kilometre (TKM)) analysis for non-road sub-sectors, which is not available in the previous edition,
- Extending the list of vehicle types from light vehicles, heavy vehicles and motorcycles (only in selected economies) used in the 6th Edition to 2-wheelers (2W), Light Vehicles (LV), Light Trucks (LT), Buses (BUS) and Heavy Trucks (HT) in all economies, enriching the bottom-up road sub-sector analysis, and

- The modification of the automated road passenger vehicle consumer choice sub-model[4] towards one with more evident manual control based on researchers' and experts' inputs in order to accommodate a low carbon scenario.

DATA SOURCES

Main input data includes GDP and population, annual fuel demands; VKM (vehicle-kilometre), TKM and PKM statistics, vehicle stock and annual sales of all types of road vehicles by powertrains; fuel efficiency information, annual vehicle mileages, 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:

- IEA's annual fuel demand statistics for APEC economies (IEA, 2018), except for Papua New Guinea, which relies on EGEDA data (EGEDA, 2018).
- IEA publications estimating sub-sectoral fuel efficiency indicators, for instance Energy Technology Perspectives 2017 and UIC IEA Railway Handbook.
- Transportation policy information available on respective government or agency websites and publications.
- Vehicle sales and statistics from a variety of sources, including the International Organization of Motor Vehicle Manufacturers (OICA)[5].

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 can use proxies to estimated fuel efficiency, load and occupancy coefficients; use estimated fuel efficiency to split energy demand into freight and passenger, or estimate base-year vehicle stocks using the vehicle ownership function, calibrated to historical trends.

SCENARIO ASSUMPTIONS

Apart from the BAU, transport model assumes the TGT scenario with progressively improving Passenger and Freight transportation activity, accelerated fuel efficiency improvement, and increased share of biofuels. The 2DC further pushes for the decoupling of the transportation activity and economic growth, reduced vehicle

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[4] The vehicle consumer choice sub-model is based on a logit choice approach and modelled the consumer vehicle-buying decision-making process. It is assumed that consumers make decisions to purchase a vehicle based on (1) the consumer rational choice of owning and operating the vehicle and (2) their intrinsic non-rational preference for one vehicle type over another. The latter reflected consumers' factoring of the availability of refuelling infrastructure, vehicle's "green image", and vehicle performance and customer's cultural preferences.

[5] OICA (2015).

ownership and vehicle mileage; but keeping fuel efficiency and energy intensity consistent with the TGT. In addition, transport in the 2DC also better supports advanced fuels and vehicles and mode/technology shifting. Detailed assumptions are described in each sub-model below.

TRANSPORT SUB-MODELS DESCRIPTION

INTERNATIONAL AVIATION AND MARINE

International aviation and international marine sub-models are used to calculate the bunker fuels demand, basically driven by GDP. They identify the relationship (elasticity) between economies' economic growth and fuels demand for international travel, mainly international shipping and passenger aviation. The calibration period is based on the available data (1990-2016 in this case). For BAU, the elasticity remains constant in the projection period, and in the TGT and 2DC respectively adjusted 5-15% and 10-25% below the BAU. The fuel mix for international aviation remains as per the base year in the BAU, and up to 1% of bio-jet fuels is added in the TGT and up to 5% in the 2DC. The fuel mix for international shipping in the BAU follows the historical trend, shifts away from fuel oil to diesel and bio-diesel (up to 5% in the TGT), and consists of diesel and bio-diesel (up to mandatory blend rates applied for road transport in the 2DC). Key equations are summarised below.

Key formulation, and calibration to historical values	$\varepsilon_{ec} = \frac{\Delta FED / FED_0}{\Delta GDP / GDP_0} = \frac{\frac{FED_{ec,y} - FED_{ec,y0}}{FED_{ec,y0}}}{\frac{GDP_{ec,y} - GDP_{ec,yo}}{GDP_{ec,y0}}}$
Adjusting elasticity for TGT and 2DC	$(\varepsilon_{GDP}^{TGT\ or\ 2DS})_{ec,y} = \varepsilon_{GDP} - \theta \times (y - y0)$
Fuel demand projection (all scenarios)	$DEMAND_{ec,fuel,y} = FUELMIX_{ec,fuel,y} \times FED_{ec,2016} \times \left(1 + \varepsilon_{GDP,ec} \times \frac{GDP_{ec,y} - GDP_{ec,y0}}{GDP_{ec,y0}}\right)$

DOMESTIC PASSENGER AND FREIGHT

Domestic passenger and domestic freight activity sub-models are used to project the future demand by each mode of transport. Domestic passenger modes include road (2W, LV, LT and BUS), rail, shipping and aviation. Domestic freight modes include road (2W, LT and HT), rail, shipping, aviation and pipelines.

The sub-models identify the **elasticity of passenger and freight activity** to GDP and GDP per capita. Its projection in the BAU and TGT follows historical trends as per observations that each additional unit of GDP requires less freight activity than in previous periods, and per capita passenger activity increases with GDP per capita growth, but saturates at economy-specific levels. In the 2DC, elasticities are reduced 1-10% per year faster than in other scenarios, reducing freight and passenger demand, due to teleworking, optimised logistics, fleets utilisation, and goods shipments, and increasing share of public transport.

For BAU, the **mode shares** projections follow the historical trend (a cubic spline extrapolation to 2050 is used), the role of private passenger transport and road freight will increase as these become more accessible and provide great flexibility. For TGT and 2DC, shifts towards more efficient transport are assumed to occur as 2W → LT → LV → BUS → RAIL (in passenger transport) and 2W → LT → HT → RAIL/SHIPPING (in freight transport). Aviation and shipping provide some unique services, such as deliveries to remote and isolated areas, or high-speed deliveries, which makes them difficult to substitute. Mode substitution therefore occurs at a much lower rates. The projected per mode activity demand is then used to calculate the respective energy demands. Key equations are summarised below.

Freight activity calibration for historical data	$\left(\frac{TKM_{ec,y}}{GDP_y}\right) = AFRT_{ec} \times \ln GDP_{ec,y} + BFRT_{ec}$
Freight activity as a function of GDP	$TKM_{ec,sc,y} = GDP_{ec,y} \times \left(AFRT_{ec,sc,y} \times \ln GDP_{ec,y} + BFRT_{ec,sc,y}\right)$
Per passenger transport activity calibration	$\left(\frac{PKM_{ec,y}}{POP_{ec,y}}\right) = APASS_{ec} \times \ln \frac{GDP_{ec,y}}{POP_{ec,y}} + BPASS_{ec}$
Passenger transport activity as a function of GDP per capita	$PKM_{ec,sc,y} = POP_{ec,y} \times \left(APASS_{ec,sc,y} \times \ln \frac{GDP_{ec,y}}{POP_{ec,y}} + BPASS_{ec,sc,y}\right)$
Mode-specific freight service	$TKM_{ec,sc,y,mode} = TKM_{ec,sc,y} \times FRTMODES_{ec,sc,y,mode}$
Mode-specific passenger service	$PKM_{ec,sc,y,mode} = PKM_{ec,sc,y} \times PASSMODES_{ec,sc,y,mode}$

DOMESTIC NON-ROAD

Domestic non-road sub-models include: (1) rail sub-model, (2) shipping sub-model, (3) aviation sub-model, and (4) pipeline sub-model. Pipelines are only used for freight services, while other domestic non-road sectors could provide both passenger and freight services. Modellers identify intensity of freight and passenger services by mode, and calibrate it for the period where TKM and PKM data is available (proxy when it is not). The base year historical fuels demand should match the calculated values.

Key fuel demand formulation for non-road transport modes	$DEMAND_{ec,sc,mode,fuel,y} = TKM_{ec,sc,mode,y} \times FRTINTENSITY_{ec,sc,mode,y} \times FRTFUELMIX_{ec,sc,mode,fuel,y} + PKM_{ec,sc,mode,y} \times PASSINTENSITY_{ec,sc,mode,y} \times PASSFUELMIX_{ec,sc,mode,fuel,y}$

Biodiesel blend rate for rail and shipping is in-line with blend rates for road vehicles. Other assumptions for the fuel mix in passenger and freight service include:

- **Rail:** Fuel mix remains as per the base year with adjustments for expected effects of the current policy in the BAU; for TGT, electricity share increases by 5-25% in addition to BAU; and for 2DC, the use of electricity is maximised;
- **Aviation**: the fuel mix is mainly jet-fuels and the shares kept constant for BAU and TGT, for 2DC up to 1% share of electricity (drone deliveries, and short distance passenger flights) and 0-5% of jet bio-fuels is added;
- **Shipping**: the fuel mix for BAU is the same as in the base year, with policy adjustments and reflecting evident historical trends; in the other two scenarios, on average 10% and 25% of fuel oil is substituted with diesel, however varies greatly by economy. No assumptions on natural gas and liquefied natural gas as fuel for shipping has been made; and
- **Pipelines**: the fuel mix in all scenarios the same as in the base year.

Non-fuel-specific assumptions made on modal energy intensity are:

- **Rail:** 0.0-0.5%/yr (BAU), 0.1-0.75%/yr (TGT) and 0.25-1.0%/yr (2DC), where higher values correspond to economies with high shares of diesel switching to electricity; the improvements are driven by powertrain efficiency improvements, advances in logistics and higher occupancy rates for passenger services and load factors for freight services;

- **Aviation**: 0.1-0.25%/yr (BAU), 0.2-0.5%/yr (TGT) and 0.25-1.0%/yr (2DC), the improvement is driven by relatively fast APEC-wide fleet renovations, which follows the fast growing passenger service demand, improving jet-engine technology, flight operations, and improved occupancy rates and load factors;

- **Shipping**: 0.0-0.1%/yr (BAU), 0.05-0.25%/yr (TGT), and 0.05-0.50%/yr (2DC); improvements come from gradual fleet upgrades due to switching to higher standard fuels; and

- **Pipelines**: depending on historical efficiency improvements and announced targets, efficiency improvement reaches up to 1%/yr in the 2DC, driven by optimised (avoiding peak and minimal times through added storage capacity) pipeline operations.

DOMESTIC ROAD

Domestic road sub-model is a bottom-up stock dynamic mode, covering five types of vehicles, where all, except 2W with only three (conventional gasoline ICE, battery electricity and fuel-cell electric), could have ten types of powertrain. It consists of six modules: private vehicle ownership, buses stock, heavy trucks stock, vehicle utilisation, vehicle stock turnover, and vehicle annual mileage modules.

Private vehicle ownership module uses APERC-defined ownership growth model, which originated from Gompetz growth model (Dargay, 2007), but better fits with historical stock data of APEC economies. This models the interactions between the private (2W, LV and LT) vehicle ownership and income per capita. Similar to Gompetz, this is an S-shaped function, where long-run vehicle saturation (maximum ownership) level and necessary scale and curvature coefficients are obtained from historical stocks data. In the 2DC, the vehicle ownership ratio $\gamma_{ec,type}$ is reduced by 10%, meaning fewer private road vehicles.

Stock size (Gompertz vehicle ownership function)	$STOCK_{ec,sc,type,y} = POP_{ec,y} \times \gamma_{ec} \times e^{\left(\alpha_{ec} \times e^{[\beta_{ec} \times GDP_{ec,y}]}\right)}$
The modified formula (only for 2W, LV and LT)	$STOCK_{ec,sc,type,y} = POP_{ec,y} \times \left[\beta^{0}_{ec,type} + \gamma_{ec,type} \times \left(1 - e^{\left(\frac{\frac{GDP_{ec,y}}{POP_{ec,y}}}{\frac{GDP_{ec,y0}}{POP_{ec,y0}}}\right)^{\alpha_{ec,type}}}\right)\right]$

Buses stock module uses per bus productivity expressed in $\left[\frac{passenger\ x\ kilometre}{vehicle\ x\ year}\right]$ units. Based on historical bus stock and bus passenger activity data, the historical productivity and its linear trend is calculated. For BAU, the trend is linearly projected to 2050; for TGT productivity improves by 5-15%, and for 2DC by 10-25%. This is mainly driven by bus routes, schedule and sizing optimisation as well as higher occupancy rates.

Example of bus productivity calibration	$PROD_{ec,BUS,y0} = \frac{PKM_{ec,BUS,y0}}{STOCK_{ec,BUS,y0}}$
Calculating Buses stock using obtained and scenario-adjusted productivity indicators	$STOCK_{ec,sc,BUS,y} = \frac{PKM_{ec,sc,BUS,y}}{PROD_{ec,sc,BUS,y0}}$

Heavy Truck stock module, similarly, uses per Heavy Truck (HT) productivity expressed in $\left[\frac{tonne\ x\ kilometre}{vehicle\ x\ year}\right]$ units. Based on historical HT stock and freight activity data, the historical productivity and its linear trend is calculated. In the BAU, the trend is linear to 2050; in the TGT, productivity improves by 5-15%, and in the 2DC by 10-25%. This is mainly driven by minimizing the trucks running with zero loads, and optimising the load factors.

Vehicle utilisation module is developed to address that 2W and LT vehicles provide both freight and passenger services. A dual-use vehicle is assumed to have the same average annual vehicle mileage regardless of the usage purpose. This module calculates the shares of vehicles used for passenger and bus services based on the occupancy rates, load factors and powertrain-specific mileages. Calculated share of vehicles are used to calculate the freight and passenger energy demand from 2W and LT.

Initial system of equations

$$\begin{cases} TKM_{ec,sc,type,y} = k_{ec,sc,type,y} \times STOCK_{ec,sc,type,y} \times MILE_{ec,sc,type,y} \\ \qquad \times LOADFACTOR_{ec,sc,type,y} \\ PKM_{ec,sc,type,y} = \left(1 - k_{ec,sc,type,y}\right) \times STOCK_{ec,sc,type,y} \times MILE_{ec,sc,type,y} \\ \qquad \times OCCUPANCY_{ec,sc,type,y} \end{cases}$$

After solving this system for k we obtain that

$$k_{ec,sc,type,y} = \frac{TKM_{ec,sc,type,y} \times OCCUPANCY_{ec,sc,type,y}}{PKM_{ec,sc,type,y} \times LOADFACTOR_{ec,sc,type,y} + TKM_{ec,sc,type,y} \times OCCUPANCY_{ec,sc,type,y}}$$

Vehicle stock turnover module determines two important indicators:

(1) *The future market shares* of powertrains for vehicles of a given type define the speed of vehicle powertrain technology replacement. The effects of availability of refuelling infrastructure, vehicle emissions level and performance are taken into account. All shares are normalised to unity (sum of shares equals 1) in every year, and then used for calculations. For BAU scenario the market shares are projected based on historical trends; for TGT scenario the share of advanced energy vehicles increases by 10-50% compared to BAU; for 2DC scenario in most of economies the markets would consist of primarily advanced vehicles. China vehicle market in the 2DC will consist of 100% advanced vehicles from 2040, in order to achieve its emissions and fuel economy targets.

(2) *The rate of vehicle retirement or scrapping* depends on historical data and determines the annual type- and powertrain-specific retirements in each of the vehicle age group. The input data consists of economies' vehicle stock by type, powertrain and age. Survival rate of a vehicle is a probability that, after entering the market, the vehicle is operable at certain age. The survival rate is defined by an S-shape curve 'Weibull distribution' function depending on vehicle age, scrappage start age, failure rate, and characteristic service life for all vehicle types. Annual vehicle sales are determined by subtracting the surviving stock (i.e. vehicle stock in previous year minus vehicle retirement) from expected vehicle stock in each year. Vehicle sales in the base year are used to validate the sub-model.

Recursive vehicle stock formulation

$$\begin{aligned} STOCK_{ec,sc,type,powertrain,y+1} &= STOCK_{ec,sc,type,powertrain,y} - RETIREMENT_{type,powertrain,y} \\ &\quad + SALES_{ec,sc,type,y+1} \times MARKET_{ec,sc,type,powertrain,y+1} \end{aligned}$$

Vehicle annual mileage module calculates the necessary average annual mileage to satisfy the passenger and freight road demand. As a preliminary step road vehicle parameters such as mileage, occupancy rates and load factors are calibrated to match statistical and modelled fuels demand in the base year. Mileages for the projection period are calculated to satisfy the passenger and freight demand, given occupancy and load factors. Finally, fuels demand is calculated for road subsector.

$$\begin{aligned} PKM_{ec,sc,type,y} &= \sum_{powertrain} \left[STOCK_{ec,sc,type,powertrain,y} \times MILE_{ec,sc,type,powertrain,y} \right. \\ &\quad \left. \times OCCUPANCY_{ec,sc,type,powertrain,y} \right] \\ TKM_{ec,sc,type,y} &= \sum_{powertrain} \left[STOCK_{ec,sc,type,powertrain,y} \times MILE_{ec,sc,type,powertrain,y} \right. \\ &\quad \left. \times LOADFACTOR_{ec,sc,type,powertrain,y} \right] \end{aligned}$$

$$DEMAND_{ec,sc,type,powertrain,fuel,y} = STOCK_{ec,sc,type,powertrain,y} \times MILE_{ec,sc,type,powertrain,y} \times FUELECONOMY_{ec,sc,type,powertrain,y} \times FUELMIX_{ec,sc,type,powertrain,fuel,y}$$

FORMULATION EXPLANATION

Table 1 • Variables used in key formulations

Variables	Explanation
ec	APEC economies
sc	7th Edition scenarios (BAU, TGT and 2DC)
y	projection year (from 2016 to 2050), where *y0* is the base year, i.e. 2016
$POP_{ec,y}$	population of an economy in year y
$GDP_{ec,y}$	GDP of an economy in year y
ε	elasticity of bunker fuels (international aviation and marine) demand to GDP
θ	elasticity adjustment coefficient for different scenarios
mode	mode of transport for road sector (2W, LV, LT, BUS, and HT) and for non-road (Rail, Shipping, Aviation and only for freight Pipeline)
type	road-only modes of transport (2W, LV, LT, BUS, and HT), used for simplicity in road sub-sector formulas
powertrain	road vehicle powertrains (internal combustion (ICE) gasoline, ICE diesel, ICE LPG, ICE natural gas, ICE flex-fuel, hybrid gasoline, hybrid diesel, plug-in hybrid gasoline, battery electric vehicle, and fuel-cell vehicle)
fuel	transport fuels (gasoline, diesel, LPG, other petroleum products, natural gas, jet-fuels, bio-ethanol, biodiesel, other biofuels, electricity and hydrogen)
$PKM_{ec,sc,mode,y}$	passenger activity indicator [passenger-kilometres]
$TKM_{ec,sc,mode,y}$	freight activity indicator [tonne-kilometres]
$PASS_{ec,sc,mode,y}$	passenger service mode split
$FRT_{ec,sc,mode,y}$	freight service mode split
$FRTINTENSITY_{ec,sc,mode,y}$	average energy intensity of freight service per mode
$PASSINTENSITY_{ec,sc,mode,y}$	average energy intensity of passenger service per mode
$FRTFUELMIX_{ec,sc,mode,fuel,y}$	average fuel ratios for modes of freight service
$PASSFUELMIX_{ec,sc,mode,fuel,y}$	average fuel ratios for modes of passenger service
$STOCK_{ec,sc,type,powertrain,y}$	type- and powertrain-specific vehicle stock
$SALES_{ec,sc,type,powertrain,y}$	type- and powertrain-specific new vehicle sales
$MARKET_{ec,sc,type,powertrain,y}$	Type- and powertrain-specific shares of new vehicle sales (market structure)
$RETIREMENT_{ec,sc,type,powertrain,y}$	type- and powertrain-specific vehicle retirements
γ_{ec}	economy-specific vehicle ownership saturation level
α_{ec}	economy-specific vehicle ownership shape coefficient
β_{ec}	economy-specific vehicle ownership rate coefficient

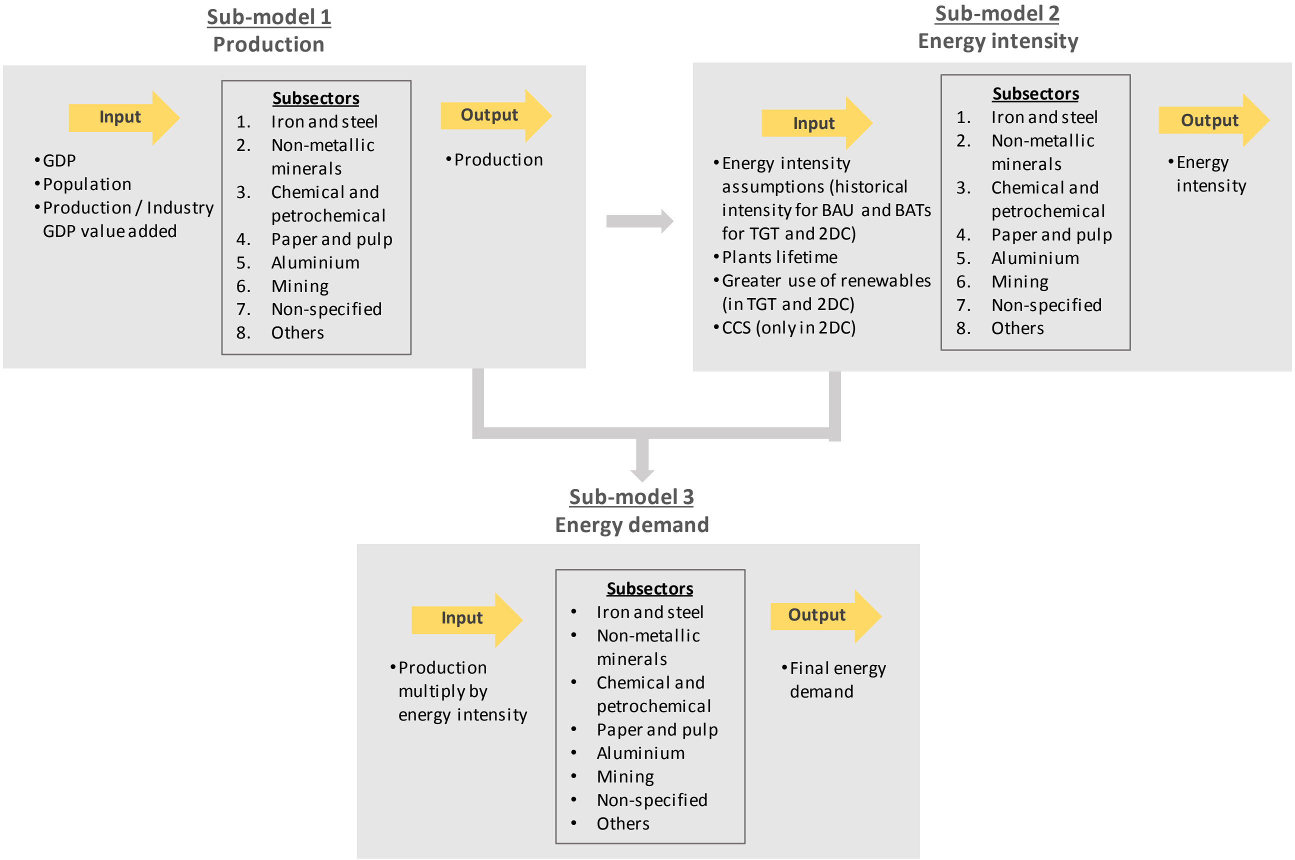
β^0_{ec}	economy-specific vehicle ownership curve vertical adjustment
$OCCUPANCY_{ec,sc,type,y}$	average passenger quantity per vehicle in 2W, LV, LT and BUS modes
$LOADFACTOR_{ec,sc,type,y}$	average tonne quantity per vehicle in 2W, LT and HT modes
$FED_{ec,sc,mode,y}$	Total energy demand by mode
$DEMAND_{ec,sc,mode,fuel,y}$	fuels demand by mode
$FUELECONOMY_{ec,sc,type,powertrain,y}$	average energy consumption of road vehicle per 1 km of travel
$FUELMIX_{ec,sc,type,powertrain,y}$	Road type- and powertrain-specific average fuel mix
$AFRT_{ec,sc,y}$, $BFRT_{ec,sc,y}$	Economy-specific coefficients for total freight activity projections
$APASS_{ec,sc,y}$, $BPASS_{ec,sc,y}$	Economy-specific coefficients for total passenger activity projections
$PROD_{ec,sc,type,y}$	Productivity indicator for buses and HT.
$k_{ec,sc,type,y}$	Share of 2W or LT stock used for freight operations

INDUSTRY

INTRODUCTION

The industry model estimates final energy demand in eight industrial subsectors: iron and steel, non-metallic minerals, chemical and petrochemical, paper and pulp, aluminium, mining, non-specified[6] and others[7]. Each subsector consists of three sub-models: production, energy intensity and energy demand (see Figure 1). Sub-model 1 projects production by each industrial subsector, for example, crude steel production, clinker production etc. Sub-model 2 calculates energy intensity of each fuel used in the subsector. Sub-model 3 estimates the energy demand by multiplying the production projection and energy intensity.

Figure 1 • Industry model structure



Note: The industry model uses industry GDP value added to project energy intensity and energy demand for mining, non-specified and others because the production data of these industrial subsectors are not available.

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[6] Includes all subsectors that are not covered in iron and steel, cement, chemical and petrochemical, paper and pulp, aluminium, mining and others.

[7] Includes non-ferrous metals except for aluminium, transport equipment, machinery, food and tobacco, wood and wood products, construction, textile and leather.

MODEL DESCRIPTION

SUB-MODEL 1: PRODUCTION

Sub-model 1 projects each subsector's production, including crude steel (iron and steel), clinker[8] (non-metallic minerals), basic chemical products[9] (chemical and petrochemical), paper (paper and pulp), primary aluminium production[10] (aluminium). We assume production per capita in the projection year is a function of GDP per capita in the projection year production per capita in the previous year.

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

Where e is economy

y is year

k, c_1 and c_2 are coefficients obtained by performing an econometric estimation

For mining, non-specified and others, these three subsectors are projected with industry GDP value-added instead of production due to data availability, but the calculation is the same.

SUB-MODEL 2: ENERGY INTENSITY

The energy intensity sub-model estimates energy intensity of each fuel used in each subsector, which is the amount of the fuel required to produce one tonne of production. There are two ways to project the energy intensity according to the characteristics of subsectors. For iron and steel, and aluminium, it is more complicated because they have different production processes. Crude steel can be produced using either blast furnace-basic oxygen furnaces (BF-BOF) or electric arc furnaces (EAF). Aluminium can be produced using either pre-baked anodes or Soderberg anodes. Hence, for these two subsectors, we need to first calculate energy demand of each fuel for different process and then estimate the energy intensity of each fuel for different process.

$$FED_{process\ A,fuel,base\ year} = EI_{process\ A} \times production_{process\ A,base\ year} \times \frac{FED_{process\ A\&B,fuel,base\ year}}{FED_{process\ A\&B,total\ fuels,base\ year}}$$

Where FED is final energy demand

EI is energy intensity

process A is one of production process in iron and steel and aluminium

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[8] The industry model uses clinker production as a proxy to project final energy demand of non-metallic minerals because cement is the most energy-intensive industrial activity in the subsector. Furthermore, we use clinker production to project cement energy demand because it is the largest energy consuming process during cement manufacturing. Clinker production is estimated based on each economy's clinker-to-cement ratio.

[9] We use the most basic chemical products as a proxy to project energy demand of chemical and petrochemical subsector. The basic chemical products include ammonia, ethylene, propylene, benzene, toluene and xylene.

[10] Data for secondary aluminium is not available.

After obtaining energy demand of one production process, the demand of the other process can be easily obtained through subtracting from the total energy demand. This allows us to estimate the energy intensity of each fuel in different production process.

$$EI_{process\ A,fuel,y} = \frac{FED_{process\ A,total\ fuels,base\ year}}{production_{A,base\ year}} \times \frac{FED_{process\ A,fuel,base\ year}}{FED_{process\ A,total\ fuels,base\ year}}$$

The energy intensity estimates in the BAU scenario for the other subsectors that do not have different manufacturing processes are obtained from historical data. In the TGT and 2DC scenarios we assume best available technologies (BATs) would be deployed.

SUB-MODEL 3: ENERGY DEMAND

As in sub-model 2, energy demand is estimated two different ways. For iron and steel and aluminium subsectors, the energy demand of each fuel is the product of projected production and energy intensity of the fuel. We arrive at the total final energy demand of the subsector by summing the demand of each fuel.

$$FED_{\ fuel,y} = production_{process\ A,y} \times EI_{process\ A,fuel,y} + production_{process\ B,y} \times EI_{process\ B,fuel,y}$$

Where process B is the other production process in iron and steel and aluminium.

For the other six subsectors, energy demand is estimated as the previous year’s demand multiplied by the change in production by the change in energy intensity. We arrive at the total final energy demand of the subsector by summing the demand of each fuel.

$$FED_{\ fuel,y} = FED_{fuel,y-1} \times \frac{production_{y} \times \frac{EI_{base\ year}}{EI_{BAU}}}{production_{y-1}}$$

Where $EI_{base\ year}$ is the current energy intensity of the subsector.

ASSUMPTIONS AND DATA SOURCES

ASSUMPTIONS

Sectors	Assumptions
All sectors	• Identical GDP and population projections across all subsectors in all three scenarios. • Assume industrial activities of iron and steel, non-metallic minerals, chemical and petrochemical, paper and pulp, and aluminium subsectors remain the same in all three scenarios. Assume industry GDP value added remains the same in mining, non-specified and others subsectors. • Assume plants lifetime of each subsector remain the same in all three scenarios, except in iron and steel. • Assume BATs deployment in iron and steel, non-metallic minerals, chemical and petrochemical, paper and pulp, and aluminium subsectors in the TGT and 2DC Scenarios. Assume energy efficiency improve by 10% in the TGT Scenario and 20% in the 2DC Scenario in mining, non-specified and others subsectors. • Assume greater use of biomass in non-metallic minerals and chemical and petrochemical subsectors in the TGT and 2DC Scenarios. • Assume CCS deployment in iron and steel, non-metallic minerals, chemical and petrochemical subsectors in the 2DC Scenario.
Iron and steel	• Higher scrap steel recycle rate, leading to greater deployment of EAF relative to BF-BOF in the TGT and 2DC Scenarios. • Accelerate the retirement of existing plants in the TGT and 2DC Scenarios, leading to shorter lifetime of plants. • BATs deployment in the TGT and 2DC Scenarios. • CCS deployment in the 2DC Scenario.
Non-metallic minerals	• Lower clinker-to-cement ratio in the TGT and 2DC Scenarios.

DATA SOURCES

Sectors	Sources
Iron and steel	• Crude 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

RESIDENTIAL BUILDINGS

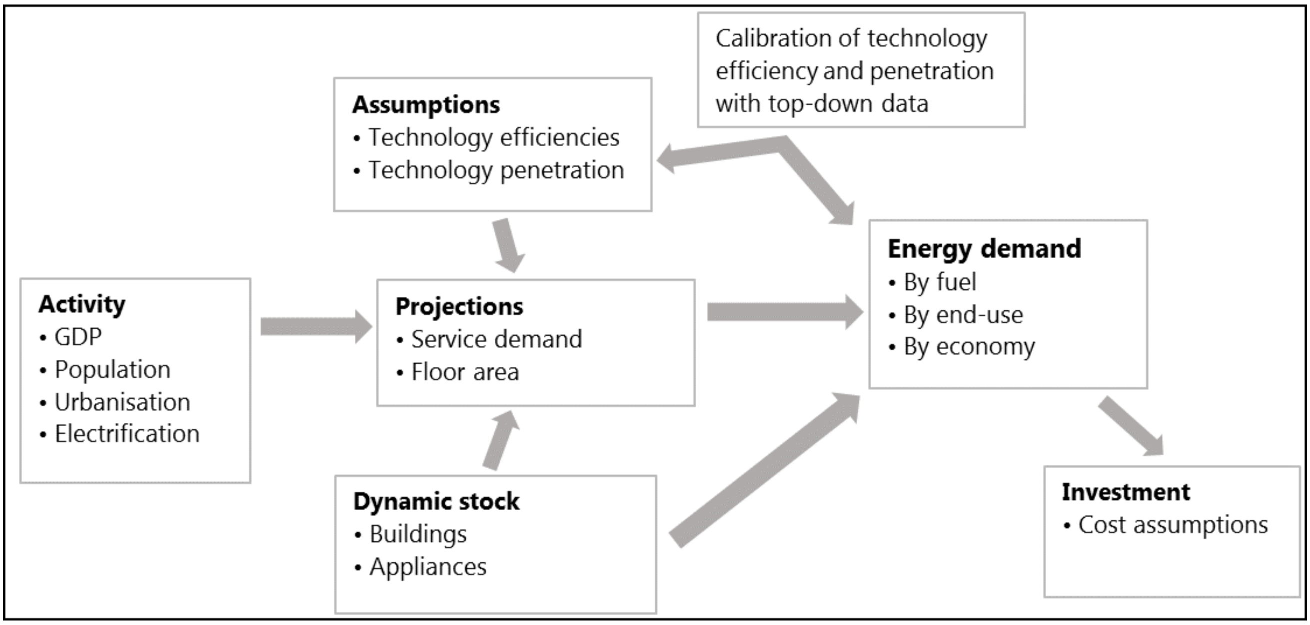
INTRODUCTION

The residential model uses a bottom-up approach to project energy demand at an end-use and household level for each of APEC's 21 member economies. The model runs in excel and is developed using the same methodology as the BUENAS (Bottom-Up Energy Analysis System) Model used by Lawrence Berkley National Labs to analyse energy efficiency opportunities in buildings (Mc Neil, 2008). This methodology (layout shown in Figure 1) uses macro assumptions and historical energy demand to project future energy demand via the following steps:

- Carry out regressions using GDP, population, household size, urbanisation, electrification and energy demand by economy to estimate the level of energy service demand intensity and floor area.
- Apply a dynamic stock approach to track the additions and retirements of appliances and buildings and how their performance changes over time.
- Alter the technology efficiency and penetration assumptions for each economy to 2050 depending on scenario.
- Calibrate energy demand for the base year (2016) against top-down International Energy Agency (IEA) data via efficiency and penetration assumptions.

Investment costs are calculated as the sum of energy demand by end-use and cost assumptions.

Figure 1 • Residential buildings: Model layout



ACTIVITY MODULE

The first stage of the model estimates the level of demand (or activity) for each energy demanding service or end-use predicated on the relationship between economic development (purchasing power) and the demand for such services (McNeil, 2008). In general, energy service demand increases as the population in an economy is more able to afford them. As such, energy activities for basic needs such as cooking and food preservation are met at lower GDP per household, while other uses such as cooling and convenience appliances increase in use with higher GDP per household. A logistic curve is used to capture the effects of saturation (at some point there is no need to continue buying air conditioners or computers) to approximate the S-curve relationship between GDP per household and energy demand.

$$A = \frac{k}{1 + e^{-(B_0 + B_1 GDP + B_2 Urb + B_3 Ele)}}$$

Where: A is energy service demand;

k is the maximum possible penetration (or intensity) rate possible (and $0 \leq k \leq 1$);

GDP is GDP per household;

Urb is the urbanisation rate (and $0 \leq Urb \leq 1$);

Ele is the electrification rate (and $0 \leq Ele \leq 1$);

B_1, B_2, and B_3 are coefficients.

The model used multivariate regressions (with up to three variables: *GDP*, *Urb* and *Ele*) using historical data from APEC economies to determine the coefficients that shape the curve. The resulting coefficients are plugged into the above formula, along with the key variables, to estimate energy activity demand into the future based primarily on GDP, but also on the other influencing variables. The objective of this part of the process is to obtain a projection for energy activity demand rather than actual energy consumption.

In order to carry out the regression on activity demand, energy consumption by end-use for each economy is converted to activity demand by applying an energy efficiency factor. The following data, used in the regression carried out in Equation 1, are exogenous to the model:

- Historical figures for energy demand by end use and appliance (data available on an economy-by-economy basis or estimated where unavailable).
- GPD (from the OECD where available, modelled by APERC otherwise).
- Population (from the UN Department of Economic and Social Affairs).
- Data on household (HH) size or total number of households in order to be able to estimate GDP per HH (data available on an economy-by-economy basis).
- Electrification and urbanisation rates (from the World Bank where available, economy-by-economy basis otherwise).

DYNAMIC STOCK MODULE

Once basic activity levels are determined, it is possible to estimate total appliance stock for the Outlook period (2016-2050). The dynamic stock module keeps track of units as they enter and retire from the market, and the performance of each cohort in order to estimate the performance of the whole stock. The demolition rate, which is applied in all economies and all scenarios, assumes that at the average life expectancy, 50% of the stock for that year will still be in service.

$$D_n = \left\{ \begin{array}{c} 1 \; if \; (n - i - lifetime) < \; -5 \\ 0.5 - \dfrac{n - i - lifetime}{10} \; if \; |n - i - lifetime| \; \leq \; -5 \\ 0 \; if \; (n - i - lifetime) > 5 \end{array} \right\}$$

Where: D_n is the demolition rate;

n is the current year;

i is the year the stock entered service;

Lifetime is the assumed average lifetime for the appliance (and *lifetime* = {10, 12, 15}).

Effectively, this formula means that 100% of a cohort survives after entering the market until 5 years before the average lifetime. At that time, the stock will begin to be retired gradually over 10 years (linearly), such that 5 years after the average lifetime none of the initial stock remains (for example, if the average lifetime is 15 years, a cohort will begin retiring after 10 years and be completely retired after 20 years). The model artificially starts 6 years prior to the first estimated stock year (1990) in order to gradually build an age profile.

The purpose of the dynamic stock model is to allow policy changes to be implemented at a certain time, but only affect stock entering the market after that point. For example, if the minimum energy performance standards of air conditioners are increased in 2020, then the efficiency of all air conditioners sold after that point increases but the existing stock, which slowly retires, is unchanged.

ENERGY DEMAND MODULE

This module brings together the annual stock (for both buildings and appliances) and activity projections from the previous two modules and combines them with technology efficiency and share assumptions to generate projections for energy demand by fuel, end-use and economy from 2017 to 2050. Total energy demand in each year is calculated as the sum of all the individual technologies, which are calculated as the sum of the stock present in each year multiplied by the efficiency and share.

$$E_{tn} = A_{tn} * S_{tn} * \sum_{t,i=1984}^{2050} (Q_{ti} * F_{ti}) + (Q_{ti+1} * F_{ti+1}) + \cdots + (Q_{tn} * F_{tn})$$

Where: E_n is the energy demand for technology t in year n;

A_n is the activity level (or service demand) in year n;

S_n is the share of each technology in year n (and $0 \leq S_n \leq 1$);

Q_i is the quantity of units remaining that entered the market in year *I;*

F_i *is* the efficiency of units that entered the market in year i.

The technology shares and efficiency factors change over time and by economy and are a key driver of changes across scenarios. Data for technology efficiency and shares for the baseline year (and for past years, where available) is based on a wide variety of sources from each economy, including studies and policy documentation, top-down energy demand trends, general development trends, and technology progression trends.

The results are compared with the IEA's energy balances for all APEC economies (except Papua New Guinea, which is not included in IEA statistics so EGEDA statistics are used instead). The technology efficiency and shares are adjusted for the base year (2016) to ensure that the sum of energy demand matches the IEA balance total. Historical numbers are all from the IEA which is why there is no breakdown of end-use before the base year.

Finally, investment numbers are calculated based on cost assumptions for each technology and compared to a baseline scenario in which technology stays the same through the Outlook. This means that only the additional costs related to improved energy performance are captured in the investment numbers. Costs are assumed to be the same in all scenarios.

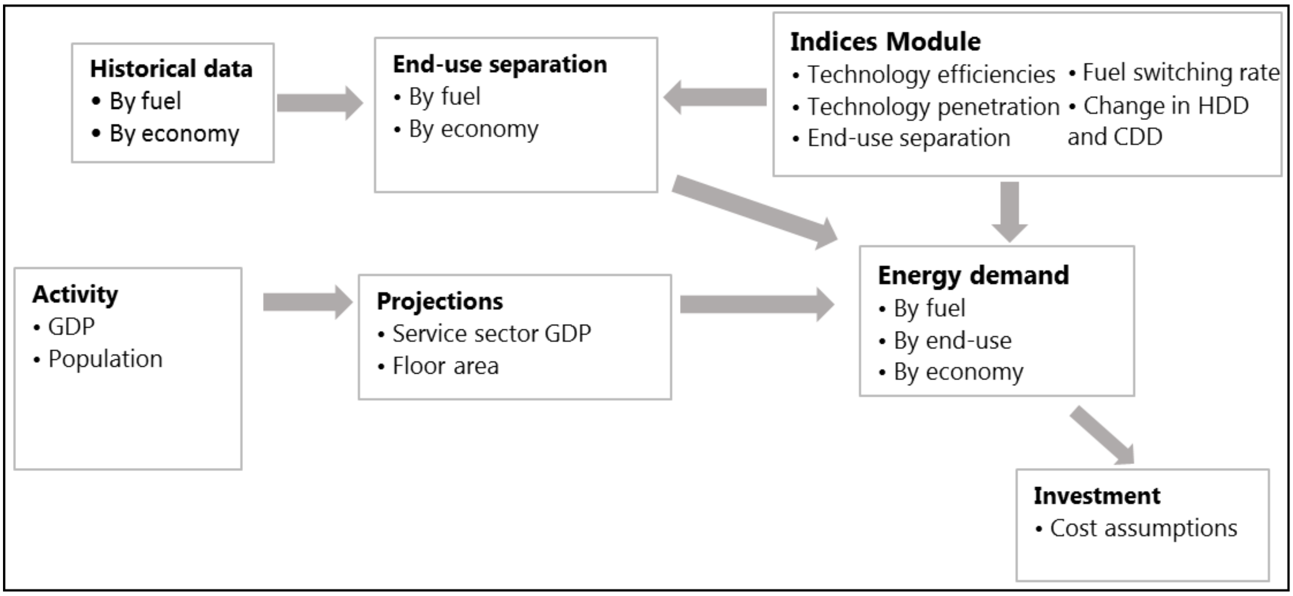
SERVICE BUILDINGS

INTRODUCTION

The services sector is modelled using a top-down approach, primarily driven by per capita GDP (Figure 1). Improvements made since the APEC Energy Demand and Supply Outlook 6th Edition allow for increased levels of detail for each end-use category and fuel types for each of the 21 APEC economies. Macro assumptions, historical energy demand and technology penetration assumptions are the primary mechanisms used to project future energy demand using the following methodology:

- Historical energy demand in service buildings is separated into five end-uses: space heating, space cooling, lighting, water heating and other end-uses.
- Activity (floor area), which is driven by macroeconomic data such as population, GDP per capita, and service sector share of GDP
- Activity projection and for each scenario assumptions on technology (efficiency, building performance and mix), change in heating and cooling demand and shift in the fuel mix.
- Investment costs are derived from the product of energy demand by end-use and cost assumptions.

Figure 1 • Service buildings: Model layout



ACTIVITY MODULE

Floor area in service buildings is the primary activity driver for projecting sectoral final energy demand. Historical data show that as most economies develop, an increase in GDP per capita is accompanied by an increased share of GDP in the service sector and corresponding growth in floor area (IEA, 2016). The floor area is projected from total GDP per capita using two logistic regressions that are manually fit to the historical data sets. Historical service GDP data from the World Bank (2018) is used to project the share of service GDP to 2050 (see the Macro section regarding total GDP). Using the projected service GDP, floor area is derived from data on service building floor area gathered from each economy. When historical data are not available, the floor area projection curves for economies are calibrated using data from similar economies.

ENERGY DEMAND MODULE

The total demand in the base year (2016) for each fuel type is allocated to the end-uses based on historical data, where available, or on proxies where it is not. Demand is projected by multiplying the base year by a series of indices affecting the end use and fuel switching opportunities.

$$ED_{fuel,n} = \left(ED_{fuel,base} * \frac{F_n}{F_{base}} * HCDD_n \; * APP_{fuel,n} * BEI_n\right)\left(1 - \; FS_{fuel,n}\;\right)_{fuel \neq eletriciy}$$
$$OR \; \left(1 + \sum_{fuel \neq eletriciy} FS_{fuel,n} \; * \; RE_{fuel}\right)_{fuel = eletricity}$$

Where: ED_n is energy demand in year n

F_n is total building floor area in year n

F_{base} is the building floor area in the base year

$HCDD_n$ is the heating degree day index, or CDD (cooling degree day index) for space conditioning for year n

APP_n is the appliance efficiency index for the heating/cooling appliances relevant that particular fuel

BEI_n is the Building Envelop Index applicable to space heating or space cooling in year n

FS_n is the fuel switching rate for the fuel towards another fuel

RE_{fuel} is the relative efficiency of a given fuel divided by the efficiency of the same service provided by electricity. This is used to account for fuel switching from other fuels towards electricity

Water heating use in Equation 4 is modified by removing $HCDD_n$ and replacing BEI_n with SWH_n which is an index that accounts for the growth in solar water heating and the resulting reduction in hot water heating demand. Lighting, water heating and Other Use are also based on Equation 4 but modified by removing $HCDD_n$ and BEI_n.

INDICES MODULE

The indices module is used to build indices for the key drivers of energy demand in the service sector. The data sources used to construct each appliance efficiency index is based on EIA (2016), EIA (2018), Energy Alliance (2018), Mc Neil (2008) and Siemens (2018).

BUILDING ENVELOP IMPROVEMENT

The adoption and tightening of building energy codes underpins the ongoing improvement in building energy efficiency. The energy saving effect of each envelop element differs in heating and cooling demand (DOE, 2014). Envelop elements are assumed to be upgraded gradually. New envelop technologies are assumed to be progressively deployed until they reach full penetration. For example, in the 2DC Scenario, new technologies are assumed to be fully deployed by 2025 or 2030 depending on the type of technology. However, it is assumed that only new and refurbished buildings are subject to this envelop improvement. As the application rate of building elements would be different in each scenario and also depend on whether it is a warm or cool climate economy, so different indices are constructed for each case and also for space heating and space cooling purposes.

CHANGE IN HDD AND CDD

The change in climate is assumed to affect energy demand. An increase in Cooling Degree Days (CDD) would increase space cooling demand and vice versa whereas an increase in Heating Degree Day (HDD) would increase space heating demand. This effect is least pronounced in the 2DC, since the global temperature rise is lower than that in the BAU and TGT. Data from the IPCC 2014 is used to estimate temperature changes by 2050.

FUEL SWITCHING

Growing urbanisation and policies to improve appliance efficiency and indoor air quality are assumed to underpin the shift away from biomass, coal, and oil towards electricity as the preferred choice of energy supply. It is assumed that, so long as the level of service is not degraded, users prefer electrical appliances. The difference in the efficiency of the appliances (electricity compared with oil, coal or biomass) therefore results in a reduction in energy demand overall. For simplicity, fuel switching is assumed to occur at a constant linear rate.

AGRICULTURE AND NON SPECIFIED (OTHERS)

INTRODUCTION

The “others model” is composed of two separate sub-models: agriculture and non-specified energy. Energy demand in the agriculture sector comes mainly from machinery (tractors) and water pumping, which are necessary to undertake sowing, irrigating and cropping activities. Non-specified energy consumption follows the IEA definition, “all fuel use not elsewhere specified for which separate figures have not been provided”, including military fuel use for mobile and stationary consumption (IEA, 2018). In the 6th Edition the others sector modelled agriculture, buildings and non-specified together. These sub-sectors have been disaggregated for the 7th Edition using a consistent methodology for agriculture and non-specified energy demand.

MODEL DESCRIPTION

AGRICULTURE MODEL

Agricultural energy demand is a function of three main variables: historical sectorial GDP for agriculture, historical fuel consumption dedicated to agriculture, and a sectorial GDP projection for 2016-2050. Data availability and quality is poor in the agriculture sector, which is why a relatively basic methodology is employed.

The share of agriculture in each economy’s GDP comes from the World Bank for years 1990-2016. The shares of agriculture in GDP for 2017-50 are calculated as a linear trend using ordinary least squares on the 2000-16 historical data. The agriculture sectorial GDP projection is therefore calculated as:

$$Projected\ GDPA_i = GDP_i * Share\ GDPA.$$

Projected energy use in agriculture is calculated by using the ratio of agricultural GDP and total GDP for each economy in conjunction with energy intensity for each fuel type j ($\mathrm{Energy\ intensity_j}$). With i representing a year between 2011 and 2016, it is calculated as:

$$Energy\ intensity_j = \frac{1}{n}\sum_{i=2011}^{n=5} \frac{Energy\ consumption_{\ (i.j)}}{GDP_i}$$

Similarly, an energy intensity indicator called total energy intensity ($\mathrm{TEI_{2016}}$) for all fuels is:

$$TEI_{2016} = \frac{1}{n}\sum_{i=2011}^{n=5} \frac{Total\ energy\ consumption_{\ (i)}}{GDP_i}$$

An annual 1% decrease in energy intensity is assumed for all fuels and economies, called the efficiency gain (EG), is calculated as:

$$\mathrm{EG_{i=2016}} = \mathrm{TEI_{2016}} \text{ and } \mathrm{EG_{i\geq 2017}} = .99 * \mathrm{EG_{i-1}}$$

Energy demand for each fuel, year ($\mathrm{FED_{(i,j)}}$) in each economy in the Outlook period then is:

$$FED_{(i,j)} = \frac{Energy\ intensity_j * Projected\ GDPA_i *\ EG_i}{TEI_{2016}}$$

NON-SPECIFIED MODEL

For non-specified energy use, economy-specific average annual growth rates by fuel type are utilised. First, the compound annual growth rate (CAGR) for 2010-2016 is calculated for each economy and fuel type (i.e. coal, oil, gas, biomass, other renewables, electricity, and heat) using IEA statistics (IEA, 2018).

$$CAGR_i = \left(\frac{GR_{2016}}{GR_{2010}}\right)^{\frac{1}{5}}-1$$

The results of these calculations are a set of economy-specific and fuel-specific CAGRs. Projecting forward, the CAGR is assumed to be equal to:

- 25% of the calculated CAGR for 2017-2025
- 10% of the calculated CAGR for 2026-2035
- 5% of the calculated CAGR for 2036-2050

Upon receiving particular comments from reviewers in the economies in response to sets of preliminary results from the non-specific model, adjustments are made to four economies (Canada, Japan, Korea and Mexico). For these economies, non-specified energy demand projections are manually adjusted to assume an annual 0.01% decrease in energy demand (by fuel), using 2016 as base year.

$$NS_{i\geq 2016} = .99 * NS_{\ i-1}$$

In terms of the results, of the twenty-one APEC economies, seven economies are assumed to have zero energy demand in the non-specified sector: Australia, Malaysia, Papua New Guinea, Peru, the Philippines, Russia and Viet Nam. For all cases, non- specified energy consumption has been historically reported as zero (at least since 1980).

ASSUMPTIONS AND DATA

The projections are based on IEA statistics (2018) for historical data for fuel consumption in the agriculture sector and World Bank data for sectoral GDP (World Bank, 2018c). If data was available from the APEC Expert Group on Energy Data and Analysis (EGEDA, 2018) but no the IEA, that was used instead. Some economies, such as Brunei Darussalam; Hong Kong, China; Papua New Guinea; and Singapore, are assumed to have zero energy demand in the agriculture sector due to lack of data availability from both sources. For economies without GDP data for the base year (2016), the average is adjusted for years 2010-2015. Where agriculture's contribution to GDP is not available in World Bank data, official domestic information was used (often in combination with the 2016 deflator and GDP projections used by the APERC Macroeconomic model).

For all economies, projections of energy use in the agriculture sector are held constant across the BAU and TGT Scenarios. However, in the 2DC scenario, it is assumed that biofuels substitute coal, natural gas and oil products (mostly diesel) at a faster speed compared to the others scenarios and varying on a case by case basis.

HYDROGEN

INTRODUCTION

The hydrogen model is new to the 7th Edition of the Outlook, having been added in order to reflect existing hydrogen consumption or activities in fuel cell technologies in APEC economies. Hydrogen fuel usage or demand (e.g. in industrial applications including oil refineries, ammonia production plants or methanol production plants) are not considered, rather, this model captures hydrogen used as a source of zero-emission fuels for vehicles and electricity production.

The model estimates possible future demand and supply of hydrogen as a fuel while considering current hydrogen activities, existing economy frameworks that could potentially affect the demand of hydrogen, and government policies. The methodology is developed using statistical data based on relevant literature and expert judgement since IEA energy data does not currently include hydrogen.

HYDROGEN DEMAND

In order to project hydrogen demand, this model considers the following potential impacts:

1. Replacing electricity demand with hydrogen for the industry and services sectors by integrating fuel cells at higher rates to end-users.
2. Using fuel cell batteries in residential buildings to supply electricity as power backup.
3. Adopting fuel cell electric vehicles (FCEV) in the transport sector, specifically by substituting a share of future vehicle sales with FCEVs.

As a base, the estimated hydrogen share for each sector are calculated based on its consumption in each sector, each year over the total energy demand respectively for the industry and buildings (cases 1 and 2 above). Hydrogen consumption is derived from historical data and demand model results (for projection), supplemented by various other sources. Total energy demand is also based on projected total energy demand from the industry and services (demand) models.

This share is then applied exogenously to the demand models. We assume that the calculated hydrogen share directly replaces demand for grid-supplied electricity for the indicated sector in each year. Subsequently, the growth curve for hydrogen demand in the sector is back-cast linearly, with a maximum growth rate of 0.1-0.3% per year.

In the industrial sector, hydrogen substitution applies to only manufacturing, where it is already used as a fuel. Assumptions are made for China, Japan, Korea, Russia and the United States in the TGT and 2DC.

In commercial buildings, hydrogen fuel cells are considered a backup power option, with particularly strong opportunities for telecommunications. In this sector, hydrogen is assumed to replace between 0.01-0.3% of electricity demand, with its overall share increasing by 0.05-0.1% per year. Assumptions are made for Australia, China, Japan, Korea, and the United States in the TGT and 2DC.

For residential buildings, we assume that the deployment of fuel cell technologies, except from Japan, Korea and Thailand, follows the same energy consumption structure as Japan's successful fuel cell commercialisation program Ene-farm. A similar concept (e.g. initial introduction of fuel cell batteries (FCB) and energy (GJ) per unit of FCB) is applied to other economies that have potential to use these technologies. Deployment of FCBs for these economies starts from 2025.

Finally, in the transport sector, substitution rates are set for vehicle sales (i.e. sales share) for light duty, two wheelers, buses and trucks and replace them with fuel cell electric vehicles (FCEV). Substitution rates are economy specific (applied for Canada, China, Japan, Korea and the United States). The sales share is defined as the percentage of car sales in a given year that are FCEVs. For example, in Japan and Korea, for every 10 000 new cars sold over one year, one would be a FCEV (i.e. 0.01% out of total amount of cars sold). The number of FCEV for each vehicle type is then calculated by multiplying this share with total vehicle sales of that vehicle type in that year. Projections of hydrogen consumption are calculated based on the size of the vehicle fleet, and assuming an efficiency of 0.9. This calculation is completed using the equation below:

$$Hydrogen\ consumption = \frac{No.of\ FCEV * Mileage\ (km)}{Efficiency * Fuel\ economy\ (\frac{km}{kg\ of\ H2})}$$

HYDROGEN SUPPLY

To estimate hydrogen supply, we first identify economies that are more likely to be hydrogen producers based on fossil fuel reserves and renewable energy potential. Next, we identify hydrogen exporting and importing economies considering the hydrogen demand projections (described earlier):

1. Domestic consumption: We assume that Malaysia, Russia, Chinese Taipei, Thailand and the United States produce enough hydrogen domestically to meet their own demand.
2. Hydrogen exports: economies that produce hydrogen exclusively for export (Australia, Brunei Darussalam and Chile); and economies that produce hydrogen for domestic use as and export (Canada).
3. Hydrogen imports: economies with limited hydrogen production domestically: China; Japan and Korea.

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 (Strategic Analysis Inc., 2016).

For economies that are listed in category (i), projections of hydrogen production are assumed to be equalled to the volume of hydrogen required for demand (production levels are assumed to start with 50 tons and increase at rate 10% per year). For category (ii), in addition to domestic hydrogen demand, the export volumes are also added. For category (iii), the production levels are assumed to start with 50 tons and increase at rate 10% per year. Remaining demand is assumed to be met with imported hydrogen.

The amount of hydrogen produced from solar PV and gas is defined using hydrogen production shares. The amount of electricity needed for production of hydrogen using solar PV and electrolysis is then calculated as shown in the following equations:

$$\boldsymbol{Electricity\ required\ for\ H2\ (TWh) = \frac{H2\ production\ from\ solar\ PV\ (kg) * 50.2\ \frac{kWh}{kg\ of\ H2}}{1\ \mathrm{x}\ 10^{9}}}$$

Assuming electrolyser produces 50.2 kWh per kg of H_2 (Strategic Analysis Inc. and NREL, 2014).

$$\boldsymbol{Hydrogen\ installed\ capacity\ = \frac{Total\ hydrogen\ demand\ (TWh) *\ 1000000}{365 * 24 * H2\ conversion\ factor\ * H2\ utilization\ rate)}}$$

Assuming hydrogen conversion factor is 80% and hydrogen utilization rate is 3 hours per day

$$\boldsymbol{RE\ capacity\ (MW)\ required\ to\ meet\ demand = \frac{Hydrogen\ installed\ capacity\ (MW) *\ RE\ shares\ (\%)}{RE\ to\ H2\ conversion\ factor\ (PV)}}$$

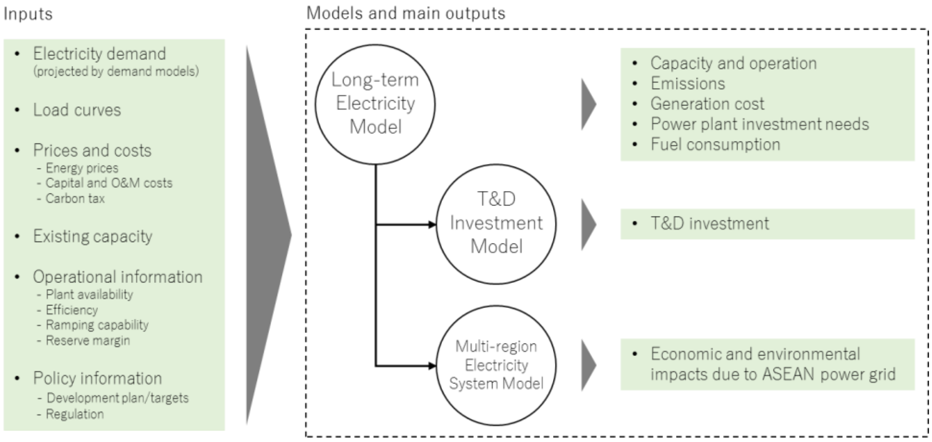
Assuming solar PV conversion factor to hydrogen is 11% (15%*75%).

ELECTRICITY

INTRODUCTION

The electricity projection system aims to calculate electricity and heat supply from power plants, including combined heat and power (CHP) plants, to meet demand. The system consists of three models: long-term electricity model, transmission and distribution (T&D) investment model, and international power grid analysis model (Figure 1). The long-term electricity model, which is designed to project electricity supply until 2050, works as the main module in the system; whereas the latter two models are for supplemental analyses.

Figure 1 • Electricity projection system



MODEL ENHANCEMENTS FROM 6TH EDITION

Key model enhancements are listed as follows:

- Improved technology breakdown in the long-term electricity model. For supply side, carbon capture and storage (CCS) is considered not only for coal-fired power plants (as in the previous edition) but also for natural gas-fired and biomass-fired power generation. CHP plants, which are crucial for some economies with commercial heat demand, such as Russia, are explicitly modelled. On the demand side, the impact of electric vehicle penetration on daily load curves are modelled.

- Improved temporal resolution in the long-term electricity model to incorporate seasonal and diurnal generation profiles of variable renewable energy (VRE) – solar photovoltaics and wind power – and to consider system integration measures, including ramping operation of flexible generators, energy storage, demand response (such as EV charging to absorb excess electricity) and curtailment.

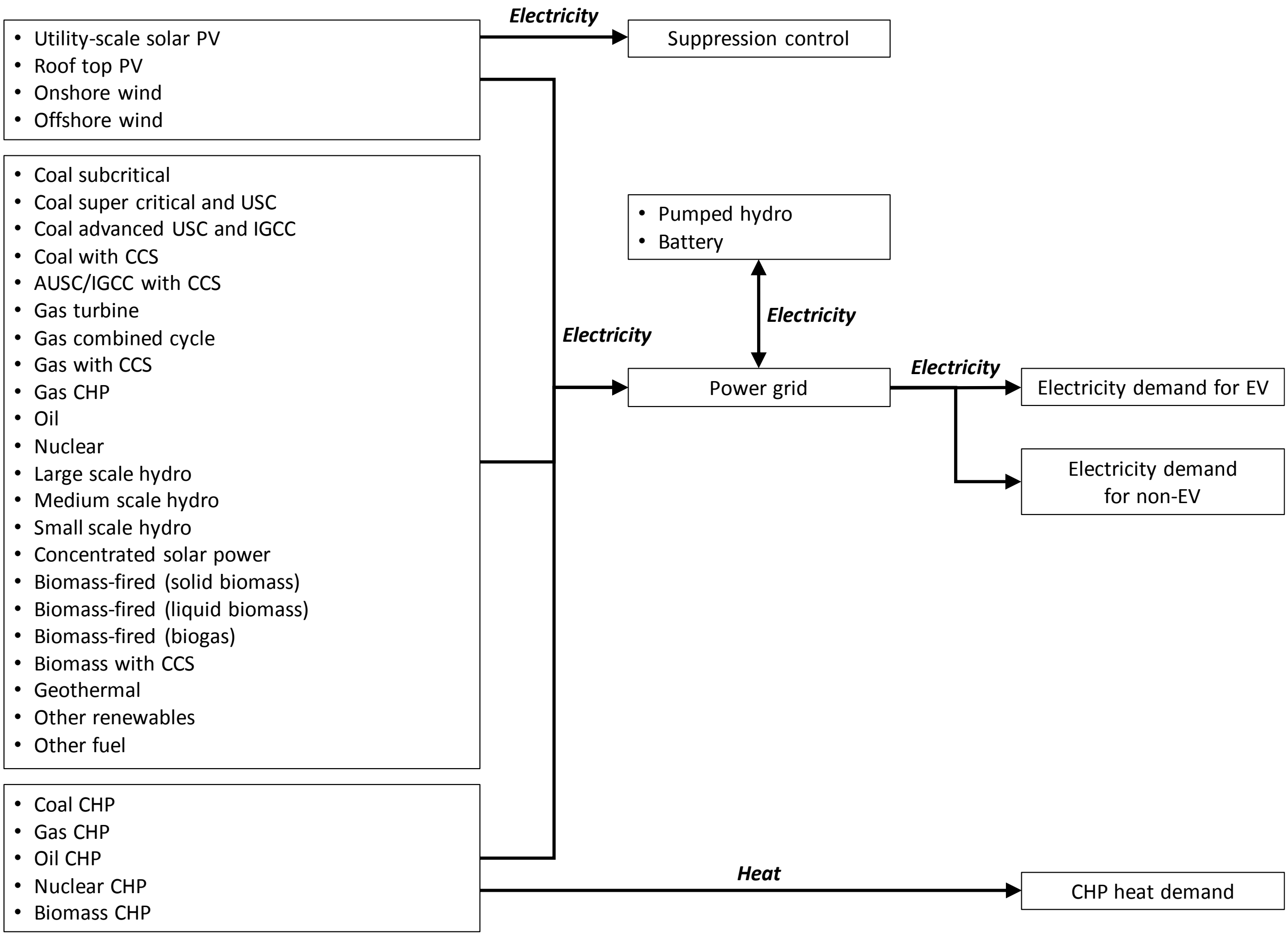
- Development of a sub model for analysing the costs and benefits of international power grid interconnection in Southeast Asia.

MODEL DESCRIPTION

LONG-TERM ELECTRICITY MODEL

This model calculates the capacity and operation of power plants necessary to satisfy both electricity and heat demand as projected by the energy demand models. It is a bottom-up model, formulated as a linear programming problem, and includes 33 technologies: 31 types of power generation and 2 types of storage. One calendar year is divided into 72 time segments (6 representative days per year × 6 time slots per day × 2 weather patterns). Weather patterns in the model consist of sunny and cloudy. Power markets in each economy are modelled as a single grid for simplicity in data gathering and solution times. Improving spatial resolution will be a key priority during the 8th edition of the Outlook.

Figure 2 • Electricity model structure and modelled technologies



Note: PV=photovoltaics; USC=ultra-super critical; AUSC=advanced USC; IGCC=integrated coal gasification combined cycle; CCS=carbon capture and storage; CHP=combined heat and power; EV=electric vehicle.

This model projects electricity 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). The system cost consists of capital costs, fuel costs, operation and maintenance (O&M) costs and carbon penalties. Carbon penalties are included in economies where explicit carbon tax is implemented or highly likely to be implemented. We assume a discount rate of 7% for OECD economies and 10% for the rest of the economies, reflecting different investment risks in matured and emerging markets.

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

Note: γ_y: discount rate (7-10%), cc_y: total annualised capital costs (USD) for power generation and storage technologies in year y, fc_y: total fuel costs (USD) for power generation technologies in year y, oc_y: total O&M costs (USD) for power generation and storage technologies in year y, ec_y: total carbon penalties (USD) in year y.

Constraints are formulated to ensure material balances, to describe technical characteristics of modelled technologies, and to 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 and CO_2 emission constraints.

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 as follows. The BAU includes existing policies and plans that are highly likely to be implemented, while "targets" or "goals" are not included. 1 summarizes key assumptions for the BAU Scenario. The TGT assumes T&D efficiency improvements of 10% from 2016 to 2050 (while current efficiency continues in the BAU) and accelerated renewable deployments; this scenario also includes renewable energy targets, where applicable. The 2DC imposes significant CO_2 emissions reduction constraints, by more than 90% from 2016 to 2050, in the electricity sector in each economy (except for Singapore where the technology options modelled in this Outlook, such as renewables, CCS and nuclear, may be insufficient to achieve the significant reductions due to domestic resource potential and feasibility challenges). The 2DC also includes T&D efficiency improvements (by 10% from 2016 to 2050, the same assumption as in the TGT), accelerated retirements of fossil fuel-fired power plants, and accelerated installation and lifetime extension of nuclear reactors in some economies. Large-scale CCS technologies become available after 2030 in the 2DC. Techno-economic assumptions for selected power generation technologies are shown in Table 2.

Table 1 • Key policy assumptions for the long-term electricity model in the BAU Scenario

	Key assumptions
Australia	Approximately half of existing coal-fired plants retire due to reaching end of life. East coast natural gas reserves are sufficient to support new generation beyond 2025. No nuclear or new coal-fired power plants are built. Snowy Hydro 2.0 not built under the BAU.
Brunei Darussalam	Natural gas remains the dominant fuel source, while a new coal CHP plant dedicated to new refinery is installed in mid-2019.
Canada	Carbon tax, phase-out of "traditional" coal, and emissions standard for natural gas plans are included (Government of Canada, 2018a; 2018b). Utilities' refurbishment schedule for existing nuclear reactors are considered (Bruce Power, 2015; WNN, 2016).
Chile	Renewable power, such as hydro, wind, solar PV and CSP, dominates new capacity additions based on the economy's long-term plan (Ministry of Energy, 2017).
China	Coal-fired power declines, driven by aggressive policy to mitigate air-pollution issues. Among renewables, solar PV and wind expand due to cost reductions and strong policy

	support (e.g. feed-in tariffs for solar PV). Nuclear capacity target of 58GW by 2020 (NDRC, 2016) is included.
Hong Kong, China	Existing coal-fired plants retire following the economy's climate change action plan; natural gas becomes the dominant fuel source (Environment Bureau of Hong Kong, 2017). Share of electricity imported from China remains at the current level.
Indonesia	Capacity additions and retirements from 2017 to 2026 are based on the utility's plan (PLN, 2018). New renewable capacity additions beyond 2027 follow government policy (Government of Indonesia, 2017). General Plan of Electricity, which outlines electricity generation mix in 2025, is also included (Government of Indonesia, 2017).
Japan	Power producers' long-term plans are included (OCCTO, 2018). Renewables expansion is driven by solar PV. Existing nuclear reactors, except for those where lifetime extension has already been approved as of December 2018, retire after 40 years of operation. The government's long-term energy outlook is not achieved due to retirements of nuclear reactors (METI, 2015).
Korea	The 8th Long-term Basic Electricity Supply Plan is partially included (MOTIE, 2017). No new coal-fired capacity, except for the plants currently under construction. Existing nuclear reactors retire after designed lifetime. Whereas, growth of renewable energy is slower than the plan based on the historical trend.
Malaysia	Renewables and coal expand as outlined in the economy's outlook (Energy Commission of Malaysia, 2017). Hydropower projects in Sabah and Sarawak are completed.
Mexico	Capacity additions and retirements follow the government's power development plan (Secretary of Energy, 2017). Whereas, the minimum share for clean generation, mandated by the Energy Transition Law, is not included in the BAU; the share mandate is achieved in the alternative scenarios in this Outlook (National Commission for Efficient Use of Energy, 2016).
New Zealand	Wind and geothermal power generation expand significantly given the abundant resource available. Share of renewables in power generation reaches 90% by 2050. Capacity additions and retirements in the government's outlook is partially included (MBIE, 2015).
Papua New Guinea	Renewable sources, particularly hydro and geothermal, expands in response to Vision 2050 (PNG, 2011).
Peru	Natural gas and hydro power continues to be dominant source as outlined in the economy's plan (Ministry of Energy and Mines of Chile, 2014).
Philippines	Low-cost power generation options, especially coal-fired, dominate the mix. Private power producers' committed projects are included (DOE, 2019).
Russia	Gas CHP plants dominate to satisfy growing electricity and commercial heat demand. The government's support for renewable energy, totalling 5.5GW by 2024 (excluding large-scale hydro) is included. Nuclear capacity additions and retirements are based on ROSATOM's plan (WNA, 2019)
Singapore	Solar PV grows, although the economy continues to rely on natural gas for majority of the electricity supply due to limited domestic resource availability. The carbon tax introduced in 2019 is included.
Chinese Taipei	The government's and Taipower's long-term development plan are included (Bureau of Energy, 2017; Taipower, 2017). All existing nuclear reactors retire by 2025 in line with the Electricity Act (Chinese Taipei Government, 2017). Renewable energy target is modelled in the alternative scenarios, not in the BAU.

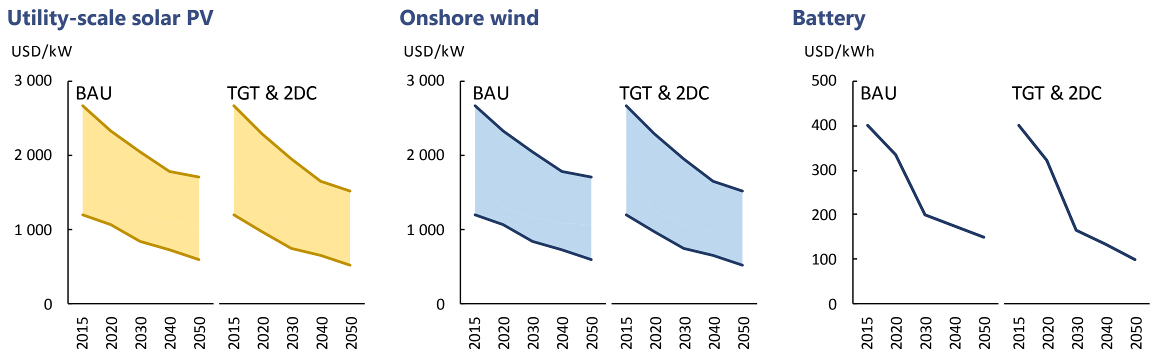
Thailand	The Power Development Plan (PDP2015) is partially included (Ministry of Energy of Thailand, 2015). The economy reduces dependency on natural gas and increases electricity imports from neighbouring economies; whereas, the nuclear capacity additions in the plan are not included.
United States	Low-efficient ageing coal-fired plants retires, and gas-fired power generation expands due to low-cost gas price over the period. Improved economics of solar panels pushes up its installation in the long-term. Lifetime extensions to 80 years for existing nuclear reactors, the additions of Vogtle units 3-4, and the planned retirements of seven reactors during the period of 2018-2025 are included.
Viet Nam	New capacity additions and power imports are based on the economy's power development plan (Viet Nam, 2016). Nuclear projects are not included as the economy decided to halt the projects in 2016.

Table 2 • Key assumptions for selected power generation technologies (all scenarios)

	Coal SC/USC	Coal CCS	Gas CCGT	Gas CCGT CCS	Nuclear	Solar PV	Onshore wind
Capital cost [USD/kW]	750 -3 500	2 450 -7 800	550 -1 500	1 110 -5 000	1 900 -5 300	Figure 3	Figure 3
Annual O&M cost rate	0.035	0.045	0.020	0.030	0.045	0.020	0.035
Lifetime [year]	35-50	35-50	30-50	30-50	30-80	20	20
Max. availability [%]	60-90	60-90	30-95	30-95	2.5-96		
Avg. availability [%]	60-90	60-90	30-90	30-80	2.5-96		
Efficiency [%]	39-42	32-35	46-61	40-49	33		
Max. ramp rate [%/hour]	0.22-0.5	0.22-0.5	0.22-0.5	0.22-0.5	0		
Minimum output level [%]	20-30	20-30	0-15	15	100		

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

Figure 3 • Capital cost assumptions for utility-scale PV, onshore wind and battery technologies, all economies



Source: APERC analysis and IEA (2018).

TRANSMISSION AND DISTRIBUTION INVESTMENT MODEL

The long-term electricity model assumes sufficient transmission and distribution (T&D) capacity exists or will be built; therefore, APERC employs a separate model, which was developed in the last edition (APERC, 2016), for estimating T&D investments for the three Scenarios. This is a top-down model, based on historical T&D infrastructure and electricity demand growth. The inputs and outputs of the transmission and distribution investment model are shown in 3.

Table 3 • Inputs and outputs of the transmission and distribution investment model

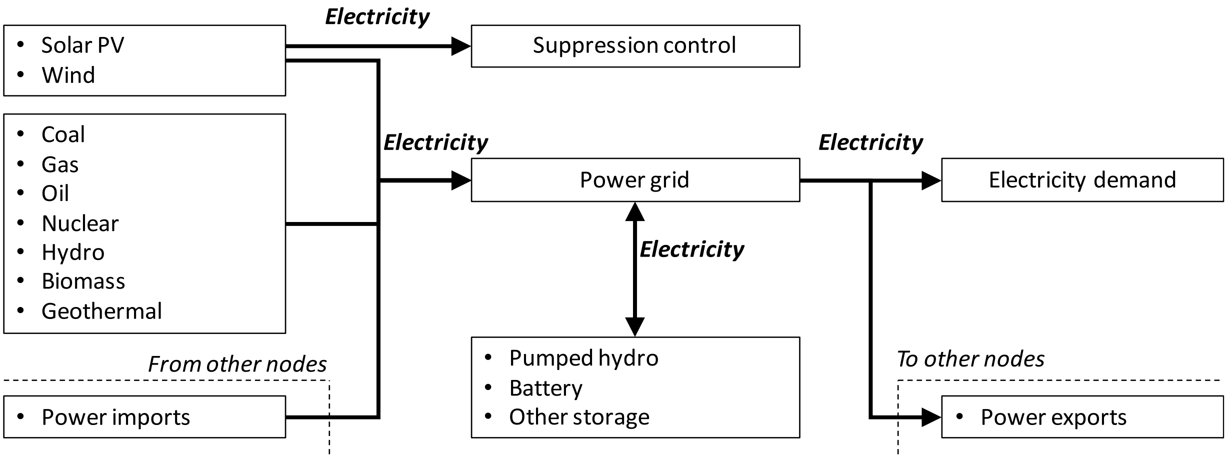
Inputs	Outputs
• Historical transmission & distribution line length • Historical and projected electricity generation • Transmission & distribution line cost	• Investments for transmission & distribution network

We use two sets of equations in the model; one for developing economies that have yet to reach a 100% electrification rate as of 2009, the other for economies with a 100% electrification rate. The former group includes 10 economies (Brunei Darussalam, Chile, China, Indonesia, Malaysia, Papua New Guinea, Peru, Philippines, Thailand and Viet Nam).

MULTI-REGION ELECTRICITY SYSTEM MODEL FOR ASEAN POWER GRID STUDY

APERC developed a multi-region electricity system model for Southeast Asia (ASEAN), referring to the formulation described in Otsuki, et al. (2016). This is a linear programming model, which aims to minimize a single-year total system cost, consisting of the annualized capital cost, operation and maintenance cost and fuel cost and carbon cost for the whole of Southeast Asia, including economies outside of APEC. Figure 4 is a schematic diagram of the model. The model considers a simplified set of technologies compared to the long-term electricity model; to ensure consistency with the long-term analysis, we harmonised techno-economic assumptions and calibrated parameters.

Figure 4 • Schematic diagram of a multi-region power system model



We divide the ASEAN region into 12 nodes (Brunei Darussalam, Cambodia, Indonesia Sumatra-Java, Indonesia Kalimantan, Lao PDR, Peninsula Malaysia, Malaysia Sarawak, Myanmar, Singapore, Thailand north, Thailand south and Viet Nam). This analysis incorporates Laos and Myanmar, which are not APEC economies, to quantify the impacts of power grid integration in the region. The model represents the hourly load curves of two typical seasons in Southeast Asia (dry and wet season) to model load curve characteristics at each modelled node. One calendar year is decomposed into 48 time segments (2 representative days per year × 24 hours per day). Electricity demand data is obtained from the Outlook projection, and typical hourly load curves are from Matsuo, et al. (2015). Techno-economic assumptions for power generation technologies are harmonised with the long-term electricity model.

HEAT

INTRODUCTION

The APERC Heat model projects commercial heat supply, fuel demand and investments by APEC's heating- and cooling-only plants. It consists of two sub-sectors: heating (fossil fuels combustion, direct use of renewables and electricity) and cooling (natural gas, solar heat, electric heat pumps and ocean thermal exchange). The Heat model exogenously receives heating demand, which is calculated as service for demand sectors (residential and commercial buildings and industry) minus their own production, minus combined heat and power (CHP) production. The model utilises a combination of Excel and GAMS software packages.

MODELLING STEPS

1. Prepare latest IEA World Energy Balances;
2. Run GAMS code to read the data, provide initial calibrations for technologies shares and efficiencies as per 'Key formulations' section;
3. End of projection period (2050) shares and efficiencies of technologies for three scenarios are exogenously set by the modeller;
4. Re-run GAMS code to produce quality Layout file.

KEY FORMULATIONS

The relationship between heat production and fuel demand is modelled with a formula below:

$$SHARE_{ec,sc,y,tech} = \frac{\sum_{fuel} HEAT_{ec,sc,y,tech,fuel}}{\sum_{tech,fuel} HEAT_{ec,sc,y,tech,fuel}}$$

$$EFFICIENCY_{ec,sc,y,tech} = \frac{\sum_{fuel} HEAT_{ec,sc,y,tech,fuel}}{\sum_{fuel} DEMAND_{ec,sc,y,tech,fuel}}$$

$$HEAT_{ec,sc,y,tech,fuel} \times SHARE_{ec,sc,y,tech} = DEMAND_{ec,sc,y,tech,fuel} \times EFFICIENCY_{ec,sc,y,tech}$$

Where *ec* represents APEC economy;
sc as scenario (BAU, TGT and 2DC);
y as base year and projection years from 2016 to 2050;
tech as heating technologies;
fuel as fuels used by heat sector;
HEAT as heat supply from heat-only plants;
DEMAND as fuel demand by heat-only plants;
EFFICIENCY as efficiency of heating technologies, and
SHARE as shares of heating technologies.

Efficiency of technologies, if below maximum for a given scenario, improves following an exponential smoothing method. The recursive formulation is as follows:

$$EFFICIENCY_{t+1} = (1-\alpha) \times EFFICIENCY_t + \alpha \times EFFICIENCY_{max}$$

The required capacity (for investment purposes) is calculated as follows:

$$CAPACITY_{ec,sc,y,tech} = \frac{DEMAND_{ec,sc,y,tech}}{8{,}760 \times UTILISATION_{ec,sc,y,tech}}$$

Where *CAPACITY* represents installed capacity for a heating technology, and

UTILISATION as average annual utilisation of installed capacity.

Installed capacity gradually retires after 20-30 years lifetime.

AVAILABLE TECHNOLOGIES

Heating technologies include combustion of fossil fuels (coal, natural gas, other fuels, gasoline, diesel, LPG, jet fuels and other petroleum products); combustion of renewable fuels (solid biomass, biogas, and liquid biofuels such as bio-ethanol, biodiesel and other biofuels); ground-to-air (ground source) and air-to-air heat pumps fuelled by electricity; solar heating, and resistive electrical heating. Cooling technologies include chillers fuelled by natural gas; chillers fuelled by solar heat; ground-to-air (ground source) and air-to-air heat pumps fuelled by electricity; and ocean thermal exchange. Based on IEA's World Energy Balance data, every technology is assigned a share and efficiency for the projection period (2016-2050) which differ among scenarios (BAU, TGT and 2DC).

DATA SOURCE AND ASSUMPTIONS

Two types of data is used:

1. **Fuels demand and heat output is from IEA's Energy Balances:** The Heat model utilises the data provided in IEA's World Energy Balance 2018 edition, with data up to 2016. The GAMS code reads IEA's energy tables and uses "MAINHEAT" and "AUTOHEAT" flows for input fuels for heat-dedicated plants. Produced heat is calculated as a sum of "HEMAINH" and "HEAUTOH" flows. Additionally, regarding electricity for heating, "THEAT" flow is used; and for Heat pump technology, only "THEAT" flow is used. Maximum feasible technology efficiency is set exogenously and varies by scenario.

2. **Cost data is from RE assumptions**: To calculate necessary heating and cooling plant capacity additions for investment, renewable energy costs assumptions (technology CAPEX) collected by APERC in 2017 are used.

3. **Average capacity utilisation factors** reflect the utilisation of installed heating capacity. Heating capacity is assumed to be utilised at 25%, excluding solar heating (100%, i.e. all heat is used), and air-to-air heat pumps (50%); and for cooling by gas and solar is 10%, and air-to-air heat pumps and ocean thermal exchange is at 25%. Relatively low capacity factors (compared to power generation) reflect higher redundancy of heating and cooling capacity.

The Heat model assumes the share of renewables follows the historical trend in the BAU. In the TGT, it doubles if the BAU 2050 share is below 25%, otherwise reaches 50-75%; and in the 2DC, the share exceeds 50% based on maximising the use of renewables and best available technologies for fuel combustion, heat pumps, and solar heating and chillers in economies.

REFINERIES

INTRODUCTION

The refinery model was developed to investigate the investment needed for new APEC refinery capacities over the projection period (2016-2050) 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.

REFINERY MODEL

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 breakdown of petroleum products using historical data for each scenario.

PRODUCT YIELDS

The refinery model projects production of oil products such as LPG, jet fuels, gasoline, diesel, and "others". Using a five-year average of the past yields as a typical yield is a key assumption in generating future production from the refineries. In the equation below, the yield of economy i is calculated for fuel type f in year j, as:

$$f\ from\ refinery\ i\ = (five - year\ average\ f\ yield\ from\ 2012 - 2016)\ x\ demand\ j$$

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.

REFINERY OIL LOSS AND OWN USE

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

$$Oil\ loss\ from\ refinery\ i\ = (five - year\ average\ oil\ loss\ from\ 2012 - 2016)\ x\ refinery\ throughput\ i$$

$$\begin{aligned} &Refinery\ own\ use\ of\ refinery\ i \\ &\qquad = (five - year\ average\ refinery\ own\ use\ from\ 2012 - 2016)\ x\ refinery\ throughput\ i \end{aligned}$$

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

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 other 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.

UNDER-UTILISATION OF APEC REFINERY CAPACITY

APEC refinery capacity projections are based on 5-year historical utilisation rates. Some APEC economies have actively developed refining capacity not only to cope with domestic oil 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 2016 (which is 7%), implying that refineries operated at approximately 93% utilisation rate. This rate is assumed to decline gently to 2050, when it reaches 90%.

SCENARIO ASSUMPTIONS

Additional refinery expansion is required in the BAU Scenario for some economies in order to meet rising demand for oil products. However, in the APEC Target and 2DC Scenarios, the utilisation of existing refineries is lower due to the decreasing demand for oil products across the region. In these two alternative scenarios, APEC liquid fuel demand in most economies is lower than existing refining capacity for the whole projection period, indicating that refineries either reduce their outputs or retire some capacity. In the APEC Target Scenario, some economies may decide to maintain production levels in order to capture the export market opportunities if gross refining margins (GRMs) are positive. However, as the 2DC is designed in the context of a broader global reduction in carbon emissions, it is likely that global liquid fuel demand would decrease. In turn, export opportunities are projected to be much lower, as discussed in Chapter 7 (Energy Trade) of this Outlook, and hence refinery capacity falls significantly.

REFINERY CCS

The 2DC Scenario assumes that carbon capture and storage (CCS) is implemented in the refinery sector from 2030 to help reduce CO_2 emissions. This is assumed to increase refinery energy own-use by an additional 50% in each year it is implemented (British Geological Survey, 2019).As a result, the refinery run increased from the CCS execution year to accommodate for the additional requirement of refinery fuels to compensate for lower refinery output. This is achievable by adjusting the total refinery run (or re-inputting a higher utilisation rate) from the CCS implementation year onwards. The total APEC CO_2 reduction is distributed to each designated economy on annual tonnes over the projection period. Five economies did not have the CCS potential and are excluded from the CCS calculation.

BIOREFINERY MODEL

Similar to the refinery model, the biorefinery model is a new addition to the 7th edition of the Outlook. By incorporating the demand for biofuels products (bioethanol and biodiesel) in APEC economies, each individual economy model simulates yields based on the raw materials potential of each economy. The biorefinery capacity is then defined and the investment required for installing these facilities is evaluated. Since there is no historical record of biorefinery own use from the IEA database or APERC, it is assumed to be a percentage of input ranging between 1-5% of feedstock.

ASSUMPTIONS AND DATA

The oil demand-supply balance provides the basis to evaluate if future capacity is sufficient to meet domestic demand and if so, if there is excess capacity left for export markets. Since information on refinery yields in APEC economies is not readily available, it is assumed that the past historical yields are representative of the future. Refinery product yields do change over time due to factors such as crude types and refinery unit modifications, but capturing this dynamic is beyond the scope of the model. This can lead to some small discrepancies in terms of the proportions of different products from refinery units. The degree of discrepancies depends on the differences between newly installed capacities as well as the size of the new capacities when compared with the existing refining capacities. However, if newly built capacity consists of expansions or duplicated refinery trains, it is likely that the projected yields will be very close to the historical ratio.

The refinery model utilised refinery capacity data of APEC economies from the IEA as well as from journals, literature, and publications such as Oil and Gas Journal and BP (BP, 2018) as a starting point to construct the model base. The information on policies from APEC economies is also used to investigate the potential plan to add refining capacities into their economies.

PRODUCTION AND TRADE

INTRODUCTION

The production and trade models are new models established by APERC, which are mainly based on demand projections. The model takes a bottom-up approach where inputs from domestic demand projection produced in other models determine the production level or import requirement. For big fossil fuel producers, APERC added world demand factor that may influence the production level.

PRODUCTION

Fossil fuel production is the balance of domestic and global demand and net of imports. With e represents economy, y as year (yb as base year, $y-1$ as previous year) and f as fuel, production is commonly calculated as

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

COAL, OIL AND GAS BY TYPE

Oil (crude oil) and gas production is the total domestic production of oil and gas from both conventional and unconventional sources. Oil and gas production of the next year depends on this year's and its growth rate calculated as following.

$$GR(e,y) = \frac{\sum_{y=1}^{n} P_{(e,y)}}{n}$$

Where n represents the number of a period for moving average, which assumed to be 5 years; $P_{(e,y)}$ represents production growth rate in year y for economy e unless specified

Coal production is the total domestic production of coal from both thermal and metallurgical processes, with the growth rate calculated.

Fossil fuel reserves replacement correlation is used to evaluate the remaining coal reserve based on the assumption that the reserve replacement ratio of coal is 50% (unless specified) as:

$$\begin{aligned} &Coal\ reserves\ (e,y) \\ &\qquad = (Coal\ reserves\ (e,y-1)\ -\ total\ coal\ \ production\ (e,y-1)) \\ &\qquad +\ (total\ coal\ \ production\ (e,y-1)\ \times\ Reserves\ Replacement\ Ratio\ (e,y) \end{aligned}$$

URANIUM

Uranium production follows IAEA/NEA's forecast of for several economies up to 2035, including five APEC members – Australia, Canada, China, Russia and USA. For consistencies purposes, APERC used the A-II class data, which defined as production capability of existing and committed centres supported by RAR and inferred resources recoverable at <USD 130/kgU.

As for uranium demand, the APERC projection of power generated from nuclear source will determine the amount uranium needed. In order to simplify the projection calculation, APERC assumed all uranium needed are in the form of Uranium Oxide (U_3O_8).

TRADE

CRUDE OIL

APERC projection for crude oil import and export is based on inputs from the refinery model, including the level of crude oil needed to produce oil products. For major crude oil exporters, APERC considers the potential export to the existing destination. Crude oil export depends on ratio of crude oil export and production in the base year while crude oil import is the balance of supply, production and export. The crude oil trade flows forecast is determined based on 3 years moving average of shares for each exporter, shown by the following equations:

$$\begin{aligned}
&Total\ crude\ export\ (e,y)\\
&\qquad = \frac{Total\ crude\ export\ (e,yb)}{Total\ crude\ production\ (e,yb)} \times Total\ crude\ production\ (e,y)\\
&Total\ crude\ import\ (e,y)\\
&\qquad = Total\ crude\ supply\ (e,y) - \ total\ crude\ production\ (e,y)\\
&\qquad + \ Total\ crude\ export\ (e,y)\\
&Crude\ import\ flow\ (e,y)\\
&\qquad = \sum_{y}^{s} \frac{Crude\ import_{s1,y1}}{Total\ crude\ import\ (e,y)} + \frac{Crude\ import_{s2,y1}}{Total\ crude\ import\ (e,y)}\\
&\qquad + \frac{Crude\ import_{sn+1,y1}}{Total\ crude\ import\ (e,y)}
\end{aligned}$$

Where e represents economy, y as year (yb as base year, $y-1$ as previous year)
$Crude\ import_{s1,y1}$ is the import source from economy 1 in year $y1$

NATURAL GAS

Natural gas is exported as piped gas or LNG. The natural gas export through pipeline is calculated using the past historical data or the base year data of piped gas export share while LNG export is calculated using the past historical data or the base year data of LNG export share.

For calculation, natural gas export is the total production and import after demand deduction. Natural gas import is the total volume of import through pipelines and LNG import. Natural gas export/import through pipelines of year y is calculated by multiplying the export/import volume of the base year with the pipeline's share in year y. The same manner is done with LNG export/import.

If the current regasification/liquefaction capacity is higher than 70% of the LNG import/export, the additional regasification/liquefaction capacity for the next year should be at least 30% of the current capacity. In the event of no historical capacity, capacity built is 100% higher than LNG import.

COAL

Coal export is the total production and import after demand deduction. Coal import is calculated using the past historical data of import share over the demand.

Export or import is also calculated by the total of coal types (i.e. thermal, lignite, met, coking and others export/import) by volume. Coal trade flows follows the same manner.

ASSUMPTIONS AND DATA SOURCES

ASSUMPTIONS

In projecting crude oil production, a few assumptions are applied to all economies. However, given that each economy has their own unique characteristic, specific assumptions sometimes applied as listed below.

Table 3 • General Assumptions For Fossil Fuel Production And Trade

	BAU	TGT	2DC
World crude oil/gas and coal demand	Derived from World Energy Outlook 2016 Current Policy Scenario	Derived from World Energy Outlook 2016 New Policy Scenario	Derived from World Energy Outlook 2016 450 Scenario
Reserves Replacement Ratio	Default RRR at 50%		
	Assuming Very aggressive exploration (RRR>100%), aggressive exploration (RRR>60%), moderate exploration (RRR = 30%-59%), low exploration (RRR<29%) for oil and gas		
Crude oil production	Assuming growth rate for world demand in each scenario post-2040 to be flat		
	Assuming historical production as conventional, unless specified otherwise		
	Assuming all production are conventional unless specified otherwise		
	Assuming all offshore as conventional production and onshore as unconventional unless specified otherwise in the table below		
Unconventional crude oil production	Assuming unconventional production starts with 5 kbbl/d.		
	Assuming unconventional production starts in 2030 when oil price reaches USD100/bbl.		
	Production growth rate is based on half of the US production in unconventional oil growth rate from 2008-2013 (five years) for the first 5 years and 3%/year after that		
NGL production	Assuming growth rate of past 5 years continues until 2050 (simple average) unless specified otherwise in the table below		
Energy use per unit production	Assuming the ratio of energy use per unit of a barrel of oil production of base year maintain until 2050		
Crude oil export	Assuming the average of the export ratio and production, based on 5 years historical trend, maintained until 2050		
Crude oil import	Assuming crude oil import is only based on refinery input projection		
Total gas production	Assuming growth rate of past 5 years continues until 2050 (simple average)		
Onshore and offshore gas production	Assuming all conventional as offshore and unconventional as onshore (for investment calculation purposes)		
LNG import capacity	Assuming all proposed project post-2017 comes online on time unless specified otherwise in the table below		
	Assuming all economies will add 50% of capacity once the capacity utilization reached 70%.		

LNG export capacity	Assuming all proposed projects post-2017 come online on time unless specified otherwise in the table below
	Assuming all economies with LNG export facilities will add 10% of liquefaction capacity once the ratio of capacity and production reaches 1 unless specified otherwise in the table below
Coal port capacity (export and import)	No new capacity build as current capacity enough to cater coal export/import until 2050
Thermal coal demand	Assuming coal used in transformation to be thermal coal
Lignite coal demand	Assuming lignite demand = production
Metallurgical, coking and other coal demand	Assuming some of the projection of coal use in industry sector to be metallurgical coal

DATA SOURCES

Historical data of oil, coal and gas production is derived from IEA Energy Statistics 2018 (in Mtoe), and then converted to the unit used by official projection of economies (using BP and EGEDA conversion factors). In order to determine the production of uranium, APERC utilised data from Uranium 2016: Resources, Production and Demand, published by International Atomic Energy Agency and Nuclear Energy Agency of OECD (IAEA/NEA, 2017).

The IEA World Energy Statistics does not provide a breakdown of LNG and pipelines import/export. For that, APERC utilised data acquired from publicly available databases such as the International Group of Liquefied Natural Gas Importers (GIINGL) and International Gas Union (IGU), as well as data from a subscriber database, Cedigaz.

Oil and coal trade flows are derived from historical data, based on exporters and importers share. The historical data is retrieved from UN Comtrade database for commodity code of HS 2709 (petroleum oils, crude), HS 2701 to HS 2708 (for coal). The crude oil trade flows forecast is determined based on 3 years moving average of shares for each exporter.

Coal, oil and gas demand are derived from APERC's demand models.

BIOENERGY POTENTIAL

INTRODUCTION

The bioenergy potential model estimates the volume of bioenergy that APEC economies can utilise, provided that all unused feedstock or waste materials are taken into consideration. In the 6th edition of the Outlook, only potential for first-generation biofuel is calculated from the food crop surplus. In the 7th edition, this model also aims to estimate the potential for second-generation biofuels as part of total bioenergy from waste/residues.

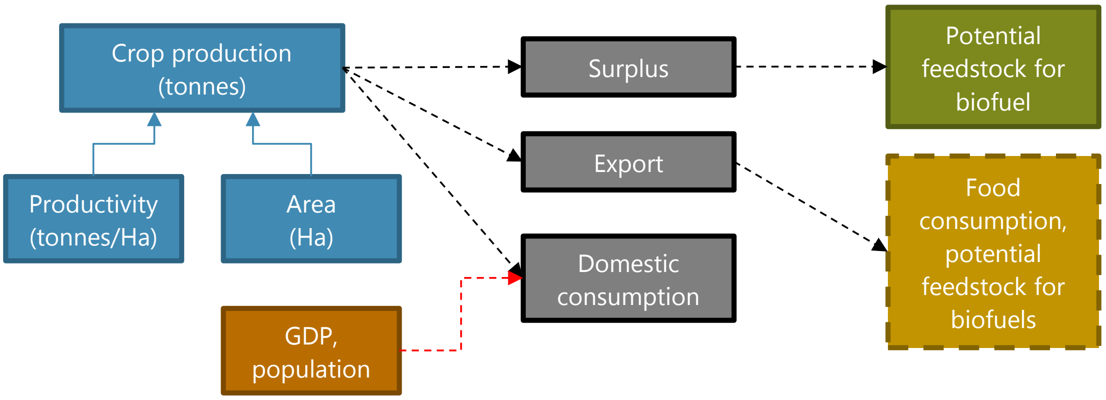
Projection of supply potential is conducted through Simple E (Simple Econometric Simulation System), an add-in application of Microsoft Excel developed by the Institute of Energy Economics Japan (IEEJ) to assist modellers with regression, simulation, and forecasting.

MODEL DESCRIPTION

ESTIMATING FIRST GENERATION BIOFUEL POTENTIAL

In the first stage, energy crop production for each economy is estimated based on the Food and Agriculture Organization of the United Nations (FAO) database. In the second stage, crop production in each economy is divided into domestic consumption, exports and surplus. The domestic consumption is estimated according to GDP and population, while exports are influenced by crop prices. GDP and population are taken from the macroeconomic model, while crop prices are forecast based on historical data obtained from The United Nations Statistics Division (UNSD) for the corresponding economy. In the third stage, food consumption is excluded from surplus and exports. The model then assumes that all the remaining energy crops could be used as potential feedstock for biofuels supply potential.

Figure 1 • Supply potential estimation of first generation biofuels



ESTIMATING ENERGY FROM BIOMASS (AND SECOND GENERATION BIOFUELS)

In order to estimate the supply potential of bioenergy from waste, four sets of data are collected: (1) Agriculture: area harvested and production, (2) Animals: the quantity of buffaloes, camels, cattle, poultry (chickens, ducks), goats, horses, pigs, rabbits/hares, and sheep, (3) Forestry: production of wood fuel and wood chips/particles, (4) Municipal solid waste per capita. Time span is from year 1980 to 2014, or the most updated year in the database, which at the time of publication is December 2017.

For agriculture, forestry production and animal stock,

(1) Agriculture residues include: Barley Straw, Cacao pod, Cassava Stalk, Coconut Frond, Coconut Husk, Coconut Shell, Coffee Husk, Cotton Hull, Cotton Stalk, Groundnut Husk, Maize Cob, Maize Stover, Maize Husk, Millet Straw, Oats Straw, Palm Oil, Empty Bunches, Palm Oil Fronds, Palm Oil Shells, Rice Straw, Rice Husk, Rye Straw, Sorghum straw and stalk, Soybean Straw, Soybean Pods, Sugar Cane Trash, Sugar Cane Bagasse, and Wheat Straw.

(2) Based on the waste emission rate (ton per ton of total waste), high heating value of dry versions (GJ per ton) and the collectible rate of about 25%, from the production of FAO, we calculate the volume of waste that can be used for producing energy and convert them to joule unit. The difference between high and low heating value is about 5-6%.

ASSUMPTIONS AND DATA

FIRST GENERATION BIOFUELS

First generation energy crops are assumed to include maize, rice, wheat, molasses, cassava, sorghum, sugar cane, coconut, soy bean, palm, rapeseed, sunflower and animal fat. The modelling approach prioritises avoiding food versus fuel competition so that the potential for biofuel is based on the surplus of production, after deducting domestic consumption, food exports and other transaction.

SECOND GENERATION BIOFUELS

Second generation biofuels are calculated from total waste biomass potential. These include agricultural residues (barley straw, maize stover and husks, rice straw and husks, sorghum, sugarcane bagasse, and wheat straw) and wood residues (industrial roundwood, wood fuel, wood chip and particles). The model assumes that 20% of feedstock could be used for producing ethanol.

BIOENERGY ALLOCATION TO SECTORS

Biofuel is consumed by transport.

Biogas is consumed by households. Biogas is often produced by animal waste (manure) and organic component from municipal solid waste (MSW). However, as we assume that all MSW will go to the energy plant for electricity purposes, we will not consider the biogas production from MSW. Therefore, animal waste is the only one source that makes up biogas potential in all economies, except clearly identified by economy experts.

Solid biomass is distributed to the power, residential, services, industry and other sectors. We assume that 20% of the bio-potential is used to produce second-generation biofuel and biogas.

SCENARIOS AND DATA

Estimation is based on the current condition of each economy and their historical production. Results of supply potential reflect no extra effort of the government on enhancing the production of energy crop. It could be a reference case for all scenarios of calculating maximum potential supply of renewable energy.

Most data is from FAOSTAT, which is updated annually. Municipal solid waste volume is from World Bank data.

ROOFTOP ENERGY POTENTIAL

INTRODUCTION

The model estimates the total energy potential that can be utilised by installing solar water heaters (SWHs) or photovoltaic (PV) panels on rooftops of buildings in APEC region. There are two sub-models for estimating solar energy potential in residential and services buildings.

MODEL DESCRIPTION

RESIDENTIAL BUILDLINGS

In each economy, each year, we estimated the installation of SWHs and PV panels as follows.

The stock of SWHs is calculated by multiplying the household quantity and the penetration rate of SWHs. The total installed area of SWHs per square meter (m^2) in all detached residential buildings is calculated by multiplying this quantity with the average area of a SWH unit, which is adjusted by solar fraction, efficiency, irradiation, seasonality and lifetime indexes in addition to water heating service demand:

$$SWH\_absorber\_area = \frac{Water\_heating\_service\_demand * solar\_fraction * seasonality}{solar\_irradiation * SWH\_efficiency * 365}$$

The area for PV panels is the remaining available rooftop. Installed capacity and energy potential of PV panels (in GW and GWh) varies by technology (efficiency) and size. Key assumptions about population, number of households, urbanisation rate, total residential area, water heating service demand are retrieved from the Residential model. Other information are studied based on various researches. Urban and rural settings are divided where needed (for example, in China).

SERVICE BUILDLINGS

Among service buildings, we assume that there are only two types of rooftops: multi-storey buildings (offices) and one-storey buildings (all non-office buildings, including hospitals, warehouses, educational institutions and the like). Like residential buildings, we first allocate the space for heating demand and the remainder for PV panels. The total area (in m^2) that could be used for installing solar heating devices is calculated as:

$$Area\_for\_solar\_heating\_devices = \frac{Heating\_demand\_by\_renewables * seasonality * 60\%}{solar\_irradiation * SWH\_efficiency * 365}$$

Heating demand in services includes space heating and water heating demand, varying in each economy.

SCENARIO SET-UP

BAU, TGT and 2DC: Estimation is based on the key assumptions in each scenario (mostly following the buildings models), where total installed area of SWH is limited by the total roof space of all detached houses.

MAX scenario: this scenario is developed to assess the maximum potential of SWH (direct heat). Assuming that all detached houses' rooftop are first covered by SWH, regardless of heating demand at that period, then the rest of the roof space will be filled by solar panels.

KEY ASSUMPTIONS AND DATA

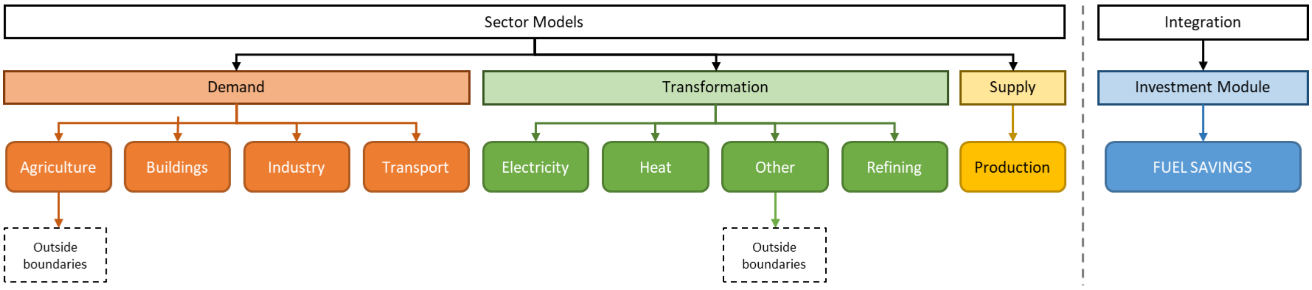
FACTORS	SOURCES	ASSUMPTIONS
Population	Macroeconomic model	
Household quantity	Residential model	
Urbanisation rate	Residential model	
Total residential area	Residential model	
Share of detached houses	Estimated from various sources	
Average floor height of detached house	Estimated from various sources	
Ultilisable area for SWHs and PV panels		25% of the available roof area (facing the sun at noon)
Water heating service demand	Residential model	
Lifetime of SWHs		20 years (adjusted economy by economy)
Irradiation	NREL	$kWh/m^2/day$
Seasonality		Unitless (The ratio of maximum and average level of isolation, insolation versus irradiation)
SWH absorber area average for the base year	Solar Heat Worldwide, IEA	
SWH efficiency	Renewable model assumptions	converted from solar factor in some economies
PV panel efficiency	Renewable model assumptions	Converted from capacity factor
Service building floor area	Service model	
Share of office in all services buildings	Service model and other sources	
Roof share for solar energy in office buildings	Estimated from various sources	
Roof share for solar energy in non-office buildings	Estimated from various sources	
Average energy intensity for water and space heating in service	Service model	kWh/m^2
Final energy demand for water and space heating in service	Service model	GWh
Final energy demand for renewable water and space heating in service	Service model	GWh

INVESTMENT

INTRODUCTION

The investment module aggregates the level of capital investment and fuel expenditures as calculated in each sector model over the projection period. For the 7th Edition, energy investment estimates are calculated in each sector model with the corresponding structure, components, level of aggregation and cost data. The investment methodologies and system boundaries of each sector are outlined below and shown in Figure 2. Fuel savings are calculated directly in the module using the sectoral investments and fuel expenditures.

Figure 2 • 7th Edition Energy Investment Model Layout



Unless otherwise specified, all energy investment projections are presented in 2016 USD. Assumptions from historical data sources already in USD are inflated to 2016 using the US Bureau of Labor Statistics annual statistics (BLS, 2018). Assumptions based on nominal values of future projects are adjusted to 2016 USD using the US Energy Information Agency GDP Chain-type Price Index from the Annual Energy Outlook 2017 (EIA, 2018). Currency conversion factors are extracted from the OECD Statistical Database's PPPs and exchange rates table (OECD, 2017).

On the demand-side, incremental capital spending for efficiency measures are counted as capital expenditures net of the offsetting reduction in energy demand. Capital investments in the transformation and supply sectors are determined counted in their entirety. For the purposes of this analysis, unless otherwise noted, operating and maintenance expenditures, research and development, and financing costs are not included in these estimates.

Where data is available, a high- and low-estimate of energy investment are calculated. All figures and tables are displayed as an average of these two values. Significant capital expenditures for large projects are spread across an assumed construction period, which differs based on the type of project or technology.

MODULE STRUCTURE

Energy investment requirements are calculated ex-post and are not considered when determining energy demand or supply.

Demand: The 7th Edition APEC Energy Demand and Supply Outlook is the first edition that projects demand-side energy investment requirements. Demand-side energy investments are narrowly defined using the existing design of the sector models and available cost data, and the incremental spending by consumers or businesses necessary to improve energy efficiency. This definition is similar to the one used in calculating demand-side energy investments in the IEA's World Energy Outlook (IEA, 2017).

In commercial buildings and transport, lifestyle behavioral changes are assumed to occur in the 2-Degrees Celsius Scenario (2DC) and are thus included in this definition of "incremental" spending to achieve higher energy efficiency. A reduction in energy demand arising from lifestyle changes in these sectors is therefore captured as a reduction in overall energy investment.

In order to project demand-side energy investment in the Business-As-Usual Scenario (BAU), an artificial Baseline Scenario (BASE) is created. This BASE Scenario assumes the current share of technologies deployed in 2016 remains fixed across the projection horizon. The value of this energy investment is then set equal to zero. Any incremental spending undertaken in the BAU Scenario (current legislated policies committed into the future), which changes the deployment of new and existing technologies from the 2015 mix, is included in the BAU energy investment estimate. The APEC Target (TGT) and 2DC Scenarios are also calculated against this BASE Scenario.

Transformation: Investments in the transformation processes include capital expansion of power plants, transmission and distribution capacity, oil refineries, biorefineries, combined heat and power (CHP) and heat only plants.

Supply: Supply investments include coal resources (open-pit and underground); oil and gas (onshore and offshore) production; uranium production; LNG terminals; oil and gas pipelines; oil and coal trains; and coal ports.

INVESTMENT INTEGRATION

The Integration module is used primarily to facilitate exchange of inputs and outputs from sector models. It is also used to estimate the value of fuel savings that can be associated with energy investments in efficiency and lifestyle changes across the scenarios. To quantify the value of the reduction in energy demand between scenarios resulting from expenditures on energy efficiency and behavioural change, estimates of fuel savings between scenarios are calculated. Only sectors (or sub-sectors) included within the aforementioned capital investment boundaries are included in the projections. Exclusions are as follows:

- **Residential buildings**: Other end-uses are excluded.
- **Transport**: International transport, domestic pipelines, domestic navigation and domestic aviation are excluded.
- **Industry:** Chemicals and petrochemicals, mining, non-energy, non-specified industry and other sub-sectors are excluded.
- **Agriculture**: There is no difference in energy demand between the three scenarios.
- **Other**: Outside the energy investment boundaries.

Fuel prices are either exogenous (coal, oil, gas, bioenergy), endogenous (electricity, heat) to the modelling structure or calculated within another model (macro, electricity or heat model). Coal, oil and gas prices are based on assumptions from IEEJ price projections, which are detailed in the Common Assumptions methodology. Bioenergy and nuclear fuel prices are extracted from the electricity model assumptions. Economy-specific electricity prices are assumed to be the average annual cost of generation, projected by the electricity model. Economy-specific heat prices are calculated based on whether there is demand for heat met by heat-only plants in the economy. Heat price is a weighted-average cost based on the price and share of input fuels used in CHP and heat-only plants.

$$\boldsymbol{Price_{Heat} = Share_{CHP} * \sum (Share_i * Price_i) + Share_{HP} \sum (Share_i + Price_i)}$$

$$\boldsymbol{Price_{Elec} = \sum (Share_i * Price_i)}$$

where *i* represents *coal, oil, gas, bioenergy, nuclear* used to produce heat/electricity

For each sector and sub-sector, energy demand by fuel is then multiplied by these fuel prices.

$$SEC_A = \sum (SB_x * Price_i)$$

where, *i* represents coal, oil, gas, bioenergy, electricity, or heat;

SECA as BLD_RES, BLD_SRV, IND, TRN, ELEC, REF, HEAT, SUP;

SBX as sub-sectors,

This calculates the cost of fuel in the BAU Scenario. The TGT Scenario fuel savings are calculated as the difference between the value of energy demand in the TGT Scenario and the BAU Scenario. Similarly, the 2DC Scenario fuel savings are calculated as the difference between the value of energy demand in the 2DC Scenario and the BAU Scenario.

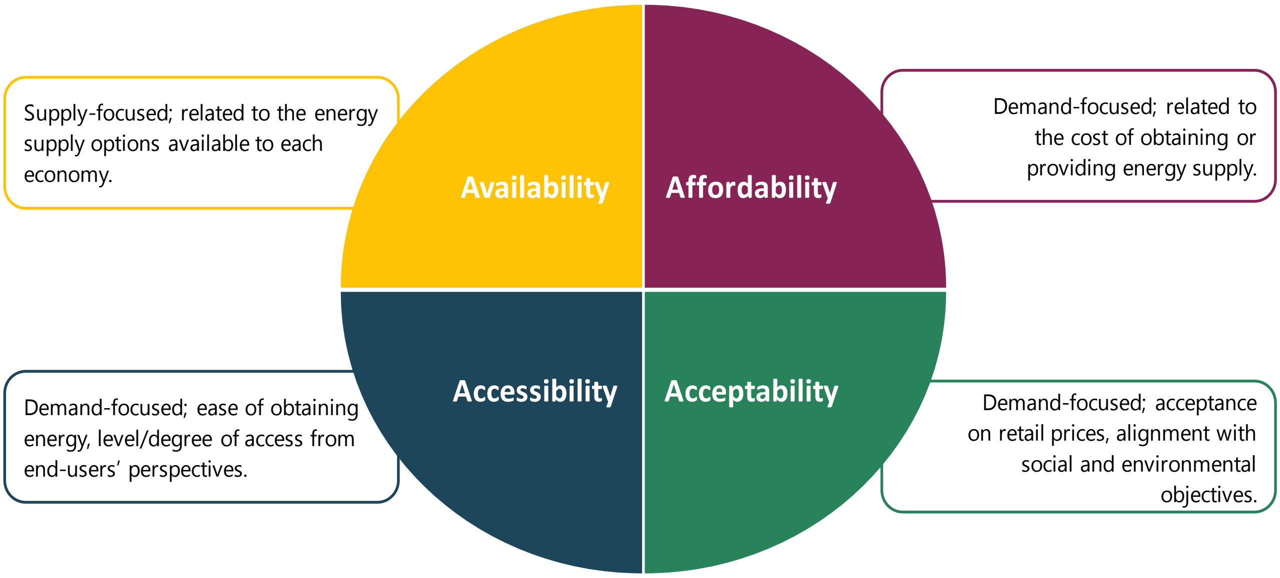
Fuel savings calculated in transformation sectors are captured in demand sectors through demand for electricity, heat, or oil products.

ENERGY SECURITY

INTRODUCTION

The Outlook analysis energy security across four aspects as shown in Figure 3: availability (physical supply), affordability (cost), accessibility (ease of access) and acceptability (social perspectives).

Figure 3 • The 4A’s of energy security



Supply-focused; related to the energy supply options available to each economy.

Demand-focused; related to the cost of obtaining or providing energy supply.

Demand-focused; ease of obtaining energy, level/degree of access from end-users’ perspectives.

Demand-focused; acceptance on retail prices, alignment with social and environmental objectives.

Seven indicators are used to quantify the status of each economy for each of the four aspects as well as how these results would vary in the alternate scenarios. With varying types and levels of domestic resources, some indicators have also been applied at both the individual fuel-level and overall economy-level to provide more meaningful insights and discussion. Indicators include the self-sufficiency ratio, reserves gap, Herfindahl-Hirschman Index (HHI) for availability; percentage of household income spent on electricity (PISE) for affordability, accessibility and acceptability; electrification rate and System Average Interruption Duration Index (SAIDI) for accessibility and acceptability; and CO_2 per capita for acceptability.

The 7th Edition builds on the previous discussion in the 6th Edition, which provided simple and straightforward measurements of security by studying APEC’s fossil fuel diversity, by expanding the scope to include four different aspects of energy security, with at least one indicator for each of these four aspects of energy security.

AVAILABILITY

Availability of supply, which relates to a reliable and uninterrupted flow of energy supply, is analysed across three indicators, calculated at the fuel-level. The self-sufficiency ratio measures the proportion of an economy’s energy supply met using its own resources. This ratio provides a snapshot of reliance on domestic resources in a particular year. A second measure, the reserves gap (RG), quantifies the projected total additional fossil fuel reserves that would need to be discovered over the Outlook period in order to maintain the current reserves-to-production ratio (R2P) for each type of fossil fuel (i.e. coal, natural gas and oil). A third measure, the

Herfindahl-Hirschman Index (HHI), assesses market concentration and diversity, and quantifies the dependence of a given economy on one fuel.

SELF-SUFFICIENCY RATIO

The self-sufficiency ratio, expressed as a percentage, measures the proportion of an economy's energy requirements (expressed as the equivalent to the Total Primary Energy Supply, or TPES) supplied with domestic energy production. The self-sufficiency ratio takes on a minimum value of 0% (when domestic production is zero) and is capped at a maximum of 100% (when an economy is fully self-sufficient). This ratio is computed at the TPES level (all resources are considered), as well as the individual fuel level for crude oil, natural gas and coal.

Self-sufficiency at individual fuel level, mainly for coal, natural gas and crude oil is calculated as

$$S_{s,x,t} = \frac{P_{s,x,t}}{TPES_{s,x,t}}$$

and self-sufficiency at TPES level as

$$TotSub_{s,t} = \sum SOShare_{s,x,t} \times S_{s,x,t}$$

where $S_{x,t}$ *represents self-sufficiency for source x in year t, expressed as a percentage*

$P_{x,t}$ *as production of source x* in year t

$TPES_{x,t}$ *as primary energy supply of fuel x* in year t

$TotSub$ *as self-sufficiency for total primary energy, expressed as a percentage*

$SOShare_{x,t}$ *as share of the source x in year t, expressed as a percentage*

s is the scenario.

RESERVES GAP (RG)

In order to measure the robustness of current reserves, the RG quantifies the projected total additional fossil fuel reserves that would need to be discovered over the Outlook period in order to maintain the current R2P ratio for each type of fossil fuel. The RG shows cumulative production over the Outlook as a percentage of the base year's reserves.

The RG ratio is calculated at the individual fuel level for crude oil, natural gas and coal as:

$$RG_{s,x,t} = \frac{\sum_{t=2016}^{2050} P_{s,x,t}}{R_{s,x,2016}}$$

where $RG_{x,t}$ *represents reserves gap ratio for a fuel x, expressed in percentage, by each year t,*

$R_{x,t}$ *is the remaining proven reserves of fuel x* in year 2016,

$\sum_{t=2016}^{2050} P_{x,t}$ *is the accumulated production of fuel by year t and fuel x.*

HERFINDAHL–HIRSCHMAN INDEX

The Outlook measures fuel diversity by applying the HHI to assess whether a given economy is particularly dependent on one fuel. The HHI is widely used in the industry to track monopolies, to assess market share or to measure market concentration. HHI is the sum of the squares of the individual fuel shares of every fuel in the TPES.

AFFORDABILITY

The definition of affordability is highly subjective, both from an end-user point of view as well as from the viewpoint of an import-dependent economy versus a major exporter.

PERCENTAGE OF HOUSEHOLD INCOME SPENT ON ELECTRICITY

At the end-user level, the percentage of household income spent on electricity (PISE) serves as an indicator of energy services affordability; for each economy, it captures the proportion of annual household income a residential consumer directs towards paying for electricity.

Percentage of household income spent on electricity is the ratio of Abill, average household electricity bill and AIncome, the average household income (GDP over household quantity).

The average household electricity bill (USD) is calculated as

$$Abill_{s,t} = \frac{Consumption_{s,t} \times Tariff_{s,t}}{HH_t}$$

where $Consumption_{s,t}$ *as electricity consumption in the residential sector (kWh),*

$Tariff_{s,t}$ *as electricity tariff (USD per kWh).*

Electricity tariff for the base year is taken from World Bank database ($Tariff_{s,2016}$), and then annual growth of the average electricity cost (from electricity model) is applied calculate electricity tariff (USD per kWh) for year 2016 to 2050.

ACCESSIBILITY

Energy accessibility is examined from the demand perspective, focusing on the ease with which end-users can access reliable electricity supplies. Two indicators are used for this purpose: the electrification rate quantifies the number of people with electricity access as a percentage of the total population while a tool known as a system average interruption duration index (SAIDI) tracks average electricity outage duration for each end-user over the course of a year.

ELECTRIFICATION RATE

Projected electrification rates have been obtained from government targets and policies. Economies that have already achieved full electrification, or achieve it in the near term, are assumed to remain at 100% throughout the Outlook period.

SYSTEM AVERAGE INTERRUPTION DURATION INDEX (SAIDI)

SAIDI measures the annual average outage duration for each customer served, to provide information on the reliability and continuity of energy supply in an economy. Due to data limitations, this indicator is only available as an average from 2013 to 2015.

ACCEPTABILITY

Acceptability broadly refers to social acceptance of the energy supply, with specific definitions varying among economies given the priorities of each population group.

CO_2 PER CAPITA

This investigation includes total CO_2 emissions per capita ($MtCO_2$/Million) to capture the social and environmental acceptability of future APEC energy scenarios.

ASSUMPTIONS AND DATA SOURCES

Historic data are largely gathered from official datasets from the individual economies as well as independent databases such as those provided by the International Energy Agency (IEA) and World Bank. Key assumptions for projections are based on economies' policy targets and/or APERC internal analysis.

Energy data up to the base year are sourced from the IEA Energy Statistics 2018 (IEA, 2018) for all economies except for Papua New Guinea (PNG), which uses APEC Energy Statistics 2016 and the APEC EGEDA Database (EGEDA, 2018).

Electrification rate, SAIDI indicator, electricity tariffs (main cities' data) refer to World Bank database (World Bank, 2017). The number of households is sourced from APERC's residential buildings model.

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