The 430th Forum on Research Work

IEEJ Outlook 2019

Energy transition and a thorny path for 3E challenges

Energy, Environment and Economy

Tokyo, 15 October 2018

The Institute of Energy Economics, Japan

Structure of IEEJ Outlook 2019

(1) Energy demand / supply and climate change up to 2050

Overviewing world energy market up to 2050 based on the "Reference Scenario" and the "Advanced Technologies Scenario"

Reference Scenario

Reflects past trends with the current energy and environment policies.
Does not reflect any aggressive policies for low-carbon measures.

Advanced Technologies Scenario

Assumes introduction of powerful policies to enhance energy security and address climate change issues.
The utmost penetration of low-carbon technologies is assumed.

(2) Risk and impact of energy supply disruptions

We discuss risks and measures for energy supply disruptions considering the characteristic of two energy sources; oil which has been at the heart of the traditional energy security debate and electricity which is expected to increase the role of energy supply in the future.

(3) No New Coal-fired Power Plant Case

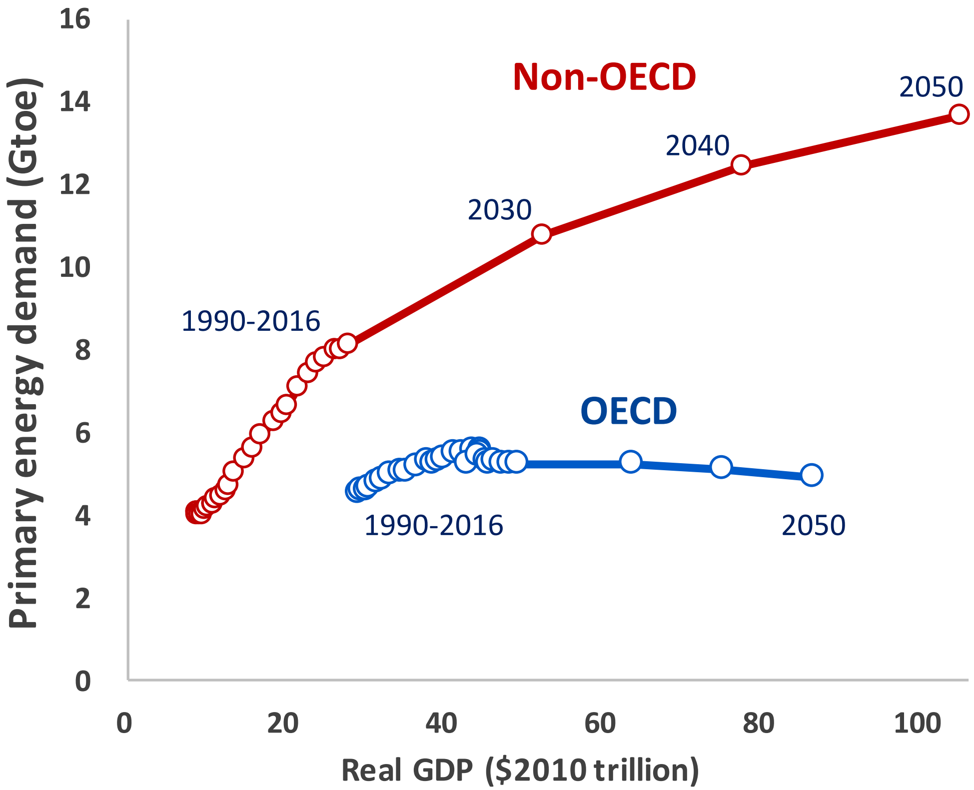
We simulated a hypothetical case in which all new coal-fired power plants would be banned from construction after 2020 without exception assuming two patterns for the substitution; a) natural gas-fired power generation, b) solar PV / wind power generation.

Energy supply / demand and climate change up to 2050

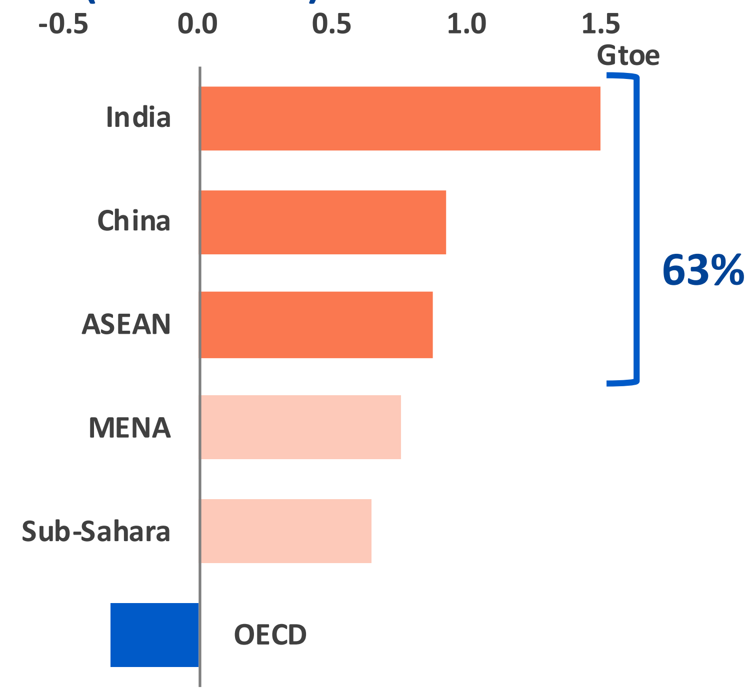
Reference Scenario

Dramatic growth of energy demand in Asia

Primary energy demand vs. real GDP



Change in energy demand (2016-2050)

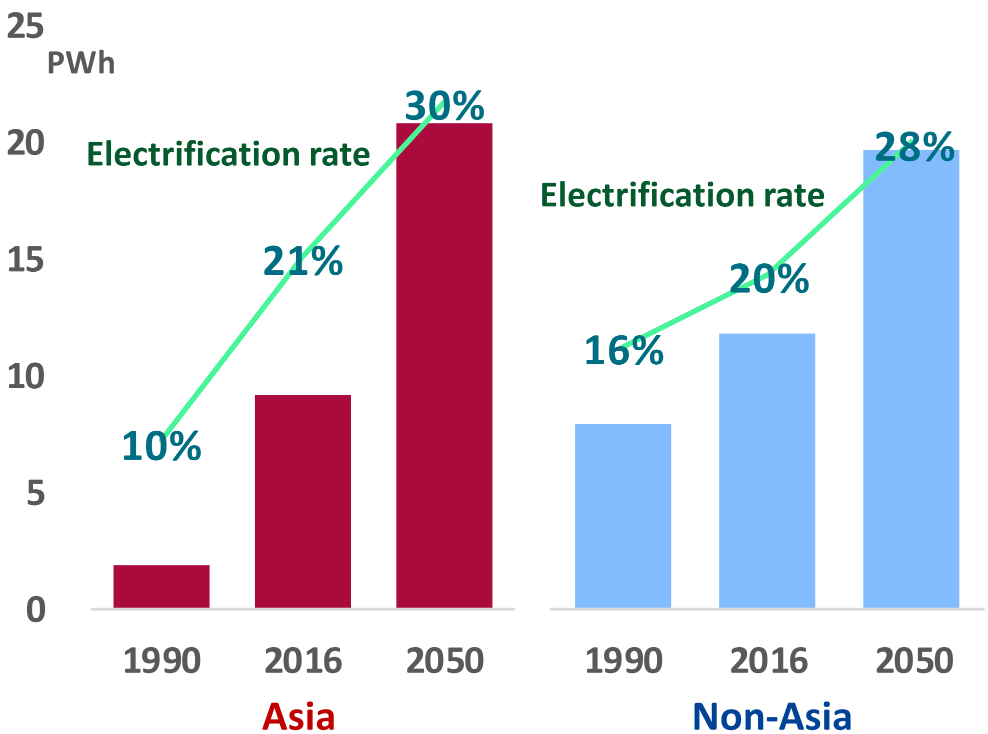


* MENA: The Middle East and North Africa

- The global primary energy demand will increase by 1.4 times in 2050.
- The net increase in energy demand can be entirely attributable to non-OECD.
- In OECD, decoupling between growth of the GDP and energy consumption proceeds.
- 63% of the increment come from China, India and the ASEAN countries.
- Share of Asia in the global primary energy demand will increase from 41% to 48%.

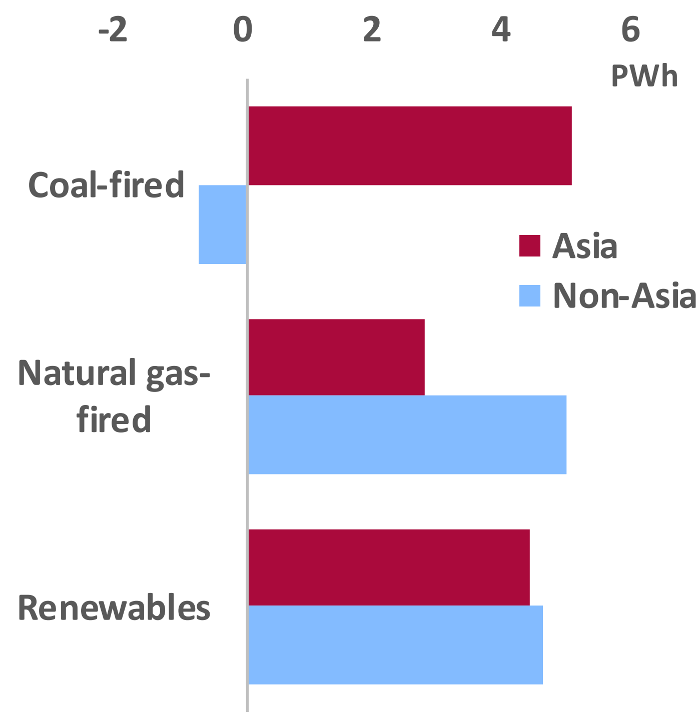
Growth of dependence to electricity

❖ Electricity demand and electrification rate



* Electrification rate: Share of electricity in the final energy consumption

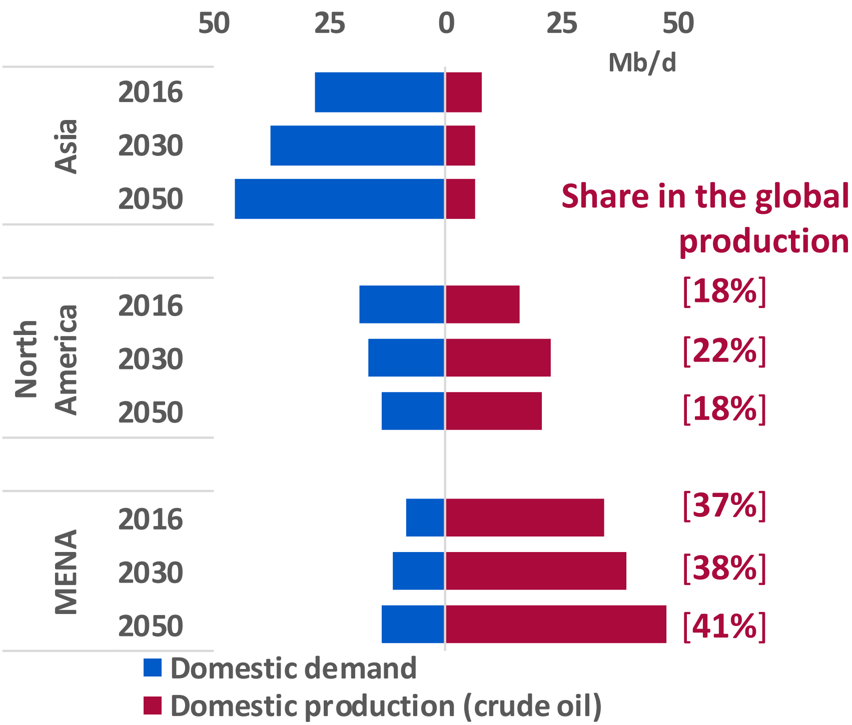
❖ Change in electricity generation (2016-2050)



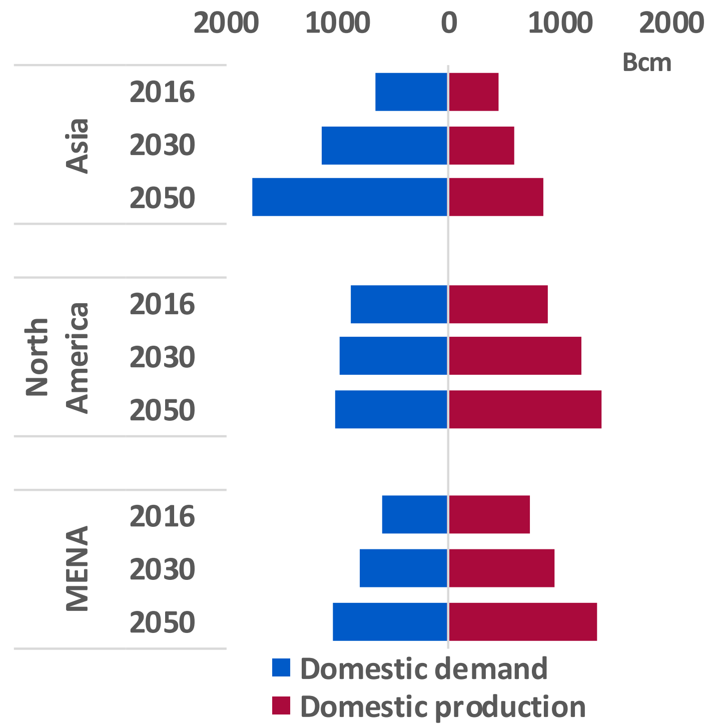
- ◆ 60% of the increment in the primary energy demand will be consumed for power generation.
- ◆ The global electricity demand will double in 2050, and 60% of the increment will occur in Asia.
- ◆ In Asia, electrification rate will increase to 30% in 2050, and 40% of electricity demand will be covered by coal, which can be obtained plentifully and inexpensively.
- ◆ Except for Asia, natural gas-fired power generation will be applied more than the coal-fired.

Expanding gap between supply and demand in Asia

❖ Oil supply / demand



❖ Natural gas supply / demand



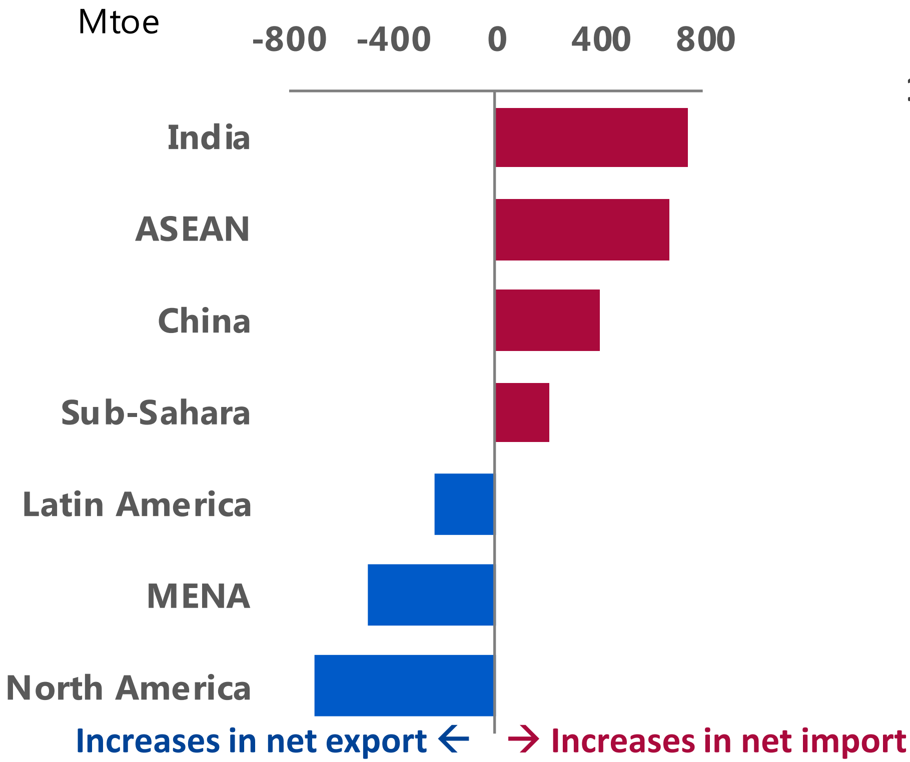
* North America: Canada and United States. MENA: The Middle East and North Africa

- In Asia, supply and demand gap is concerned, as demand for oil and natural gas increases more remarkably than their production.
- The gap will be covered by export from North America and MENA .
- Dependence on the Middle East will increase due to decrease of production of North America after 2030 (the OPEC share in oil production will increase from 42% to 47%).

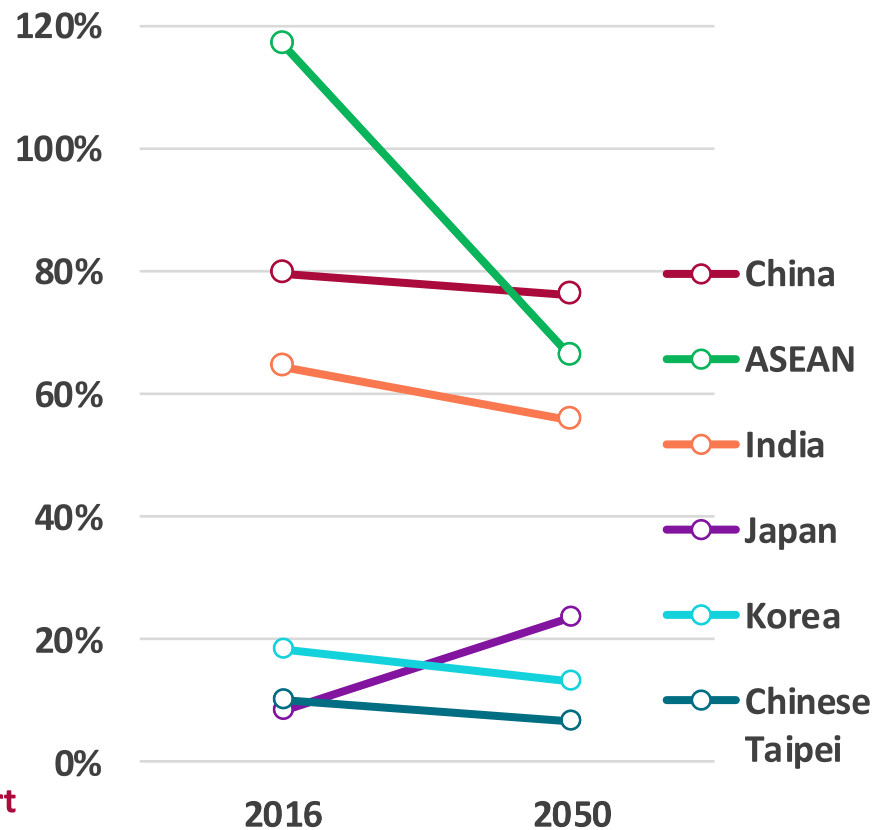
Reference Scenario

Increase of energy imports in Asia

❖ Increase of net import energy (2016-2050)



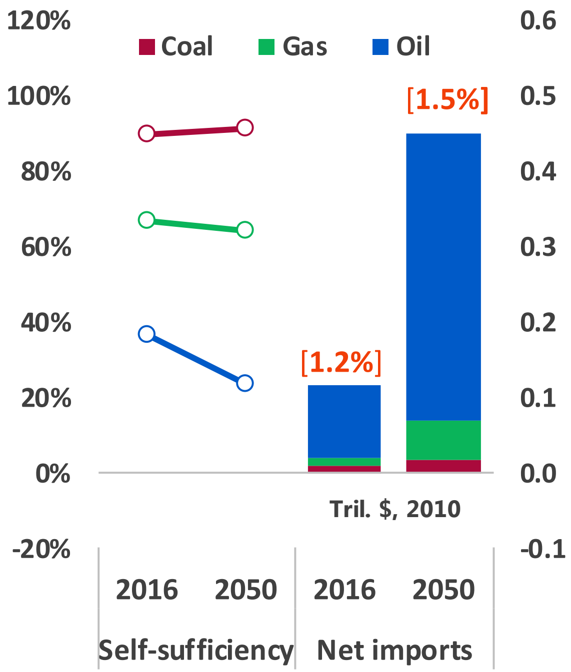
❖ Self-sufficiency rate



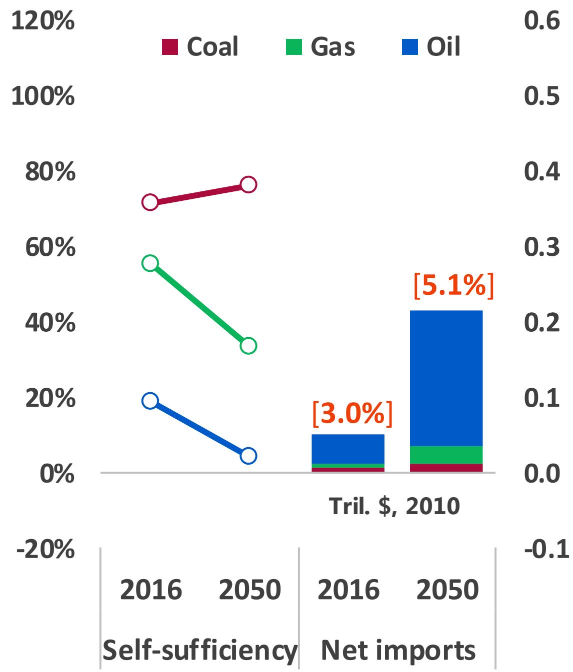
- ◆ Energy imports of Asia will increase dramatically.
- ◆ 80% of energy traded globally will be consumed in Asia.
- ◆ United States will be a net exporter in the middle of the 2020s.
- ◆ Self-sufficiency rate in Asia will decrease from 72% to 63%. This tendency is remarkable for ASEAN, which will be a net importer in the first half of the 2020s.

Increase of oil import spending in Asia

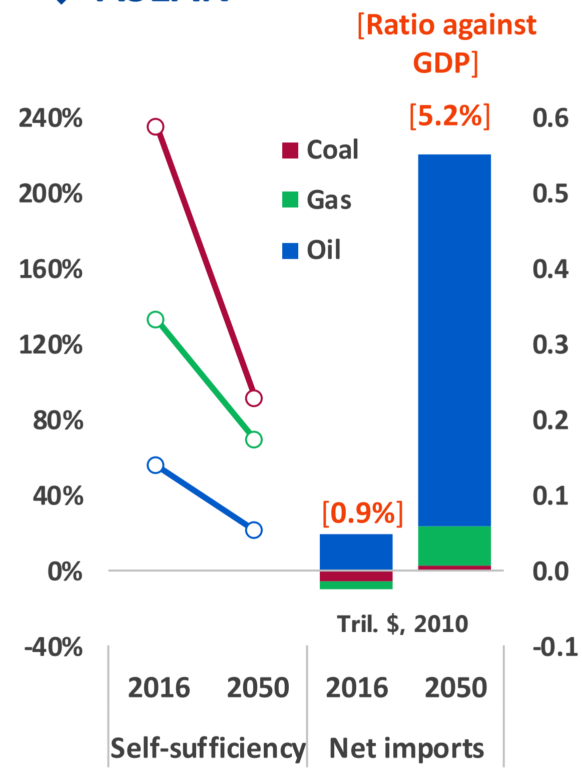
China



India



ASEAN



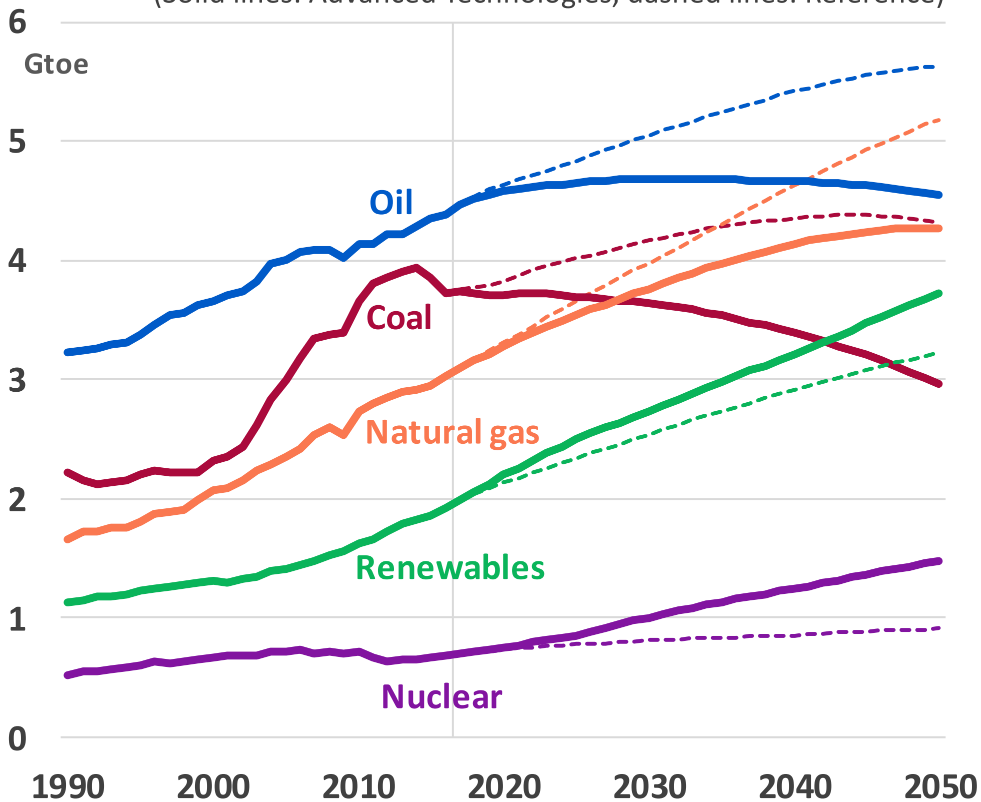
In Asia…

- ◆ Self-sufficiency rate of oil will decrease from 28% to 14%, due to increase of consumption for transportation. Self-sufficiency rate of natural gas will also decrease remarkably.
- ◆ Self-sufficiency rate of coal will be maintained at a level of 80%.
- ◆ The amount of oil import will increase remarkably, and the total amount of energy import will grow from 1.6% to 3.0% against the GDP (from 0.9% to 5.2% in the ASEAN).

Coal declines while oil hits peak in 2030

Primary energy demand

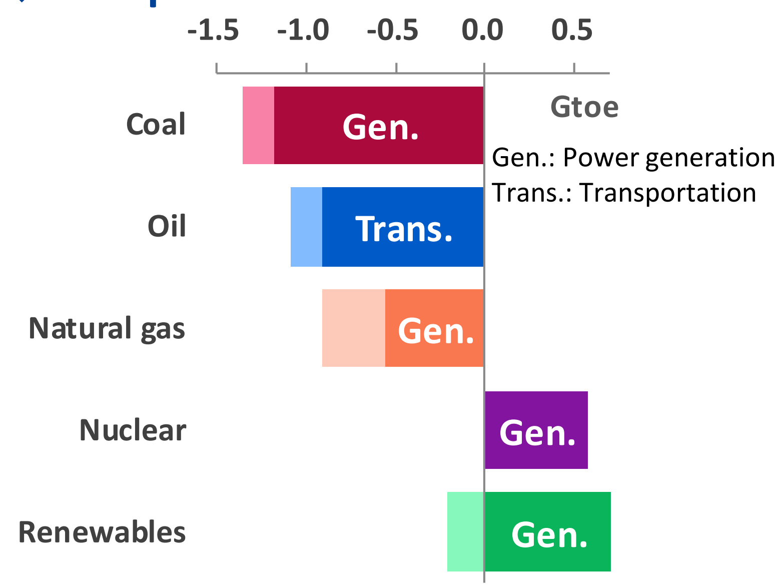
(Solid lines: Advanced Technologies, dashed lines: Reference)



Advanced Technologies Scenario

It is assuming preparation and implementation of more ambitious strategies or programs for energy security, mitigation of climate change and so on.

Comparison with the Reference

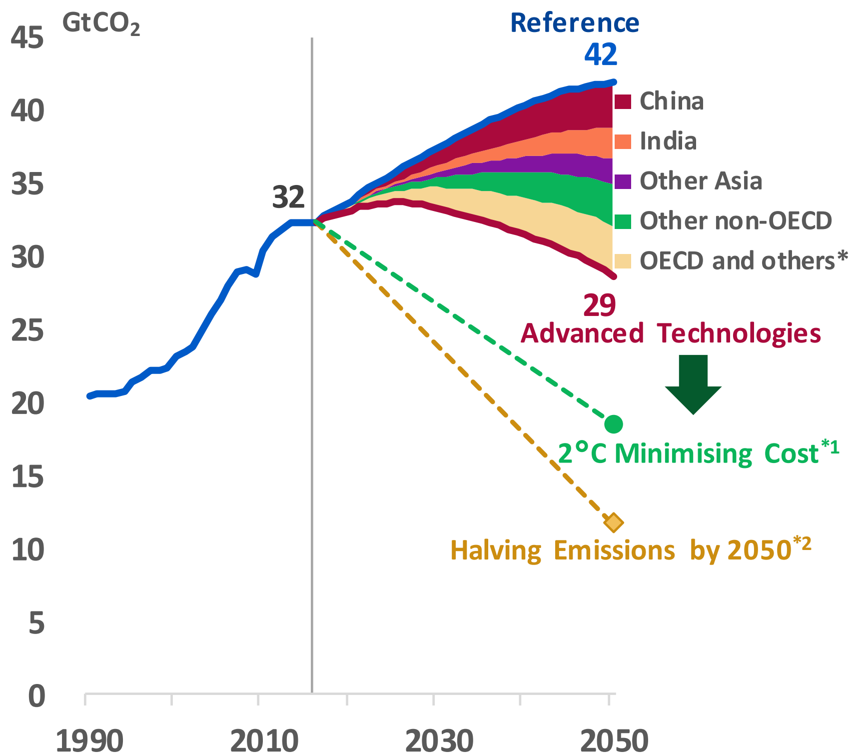


In the Advanced Technologies Scenario…

- Coal consumption will decrease remarkably (especially, for power generation).
- Oil consumption will decrease after peaking in 2030.
- Although share of fossil fuel in energy consumption will decrease from 81% to 69% in 2050 (to 79% in the Reference Scenario), high dependency on fossil fuel continues.

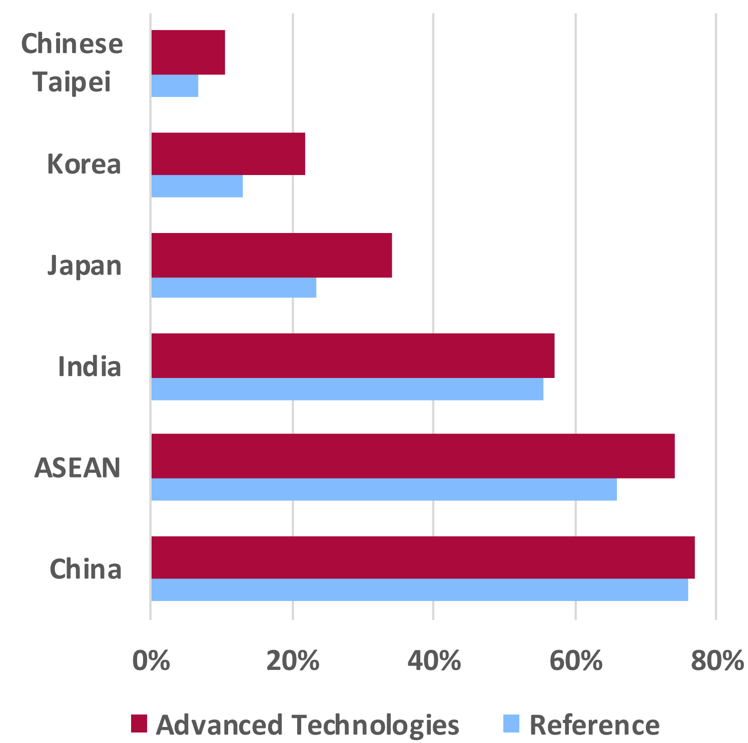
Improve environmental and security issues

❖ Energy-related CO_2 emissions



* Includes international bunkers.
*1 Refer "IEEJ Outlook 2018". *2 This path represents an emission path in the RCP2.6 scenario summarised in the fifth Assessment Report by IPCC.

❖ Self-sufficiency rate in Asia (2050)

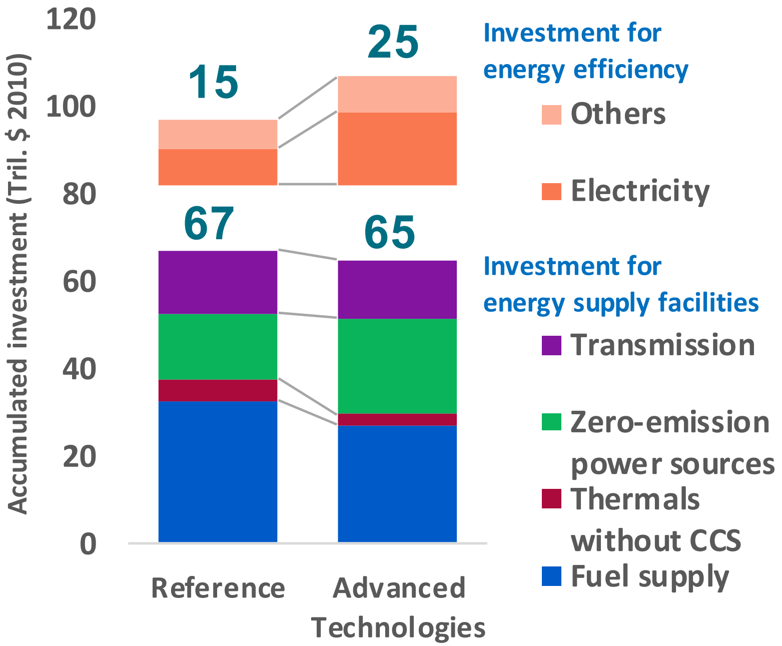


In the Advanced Technologies Scenario…

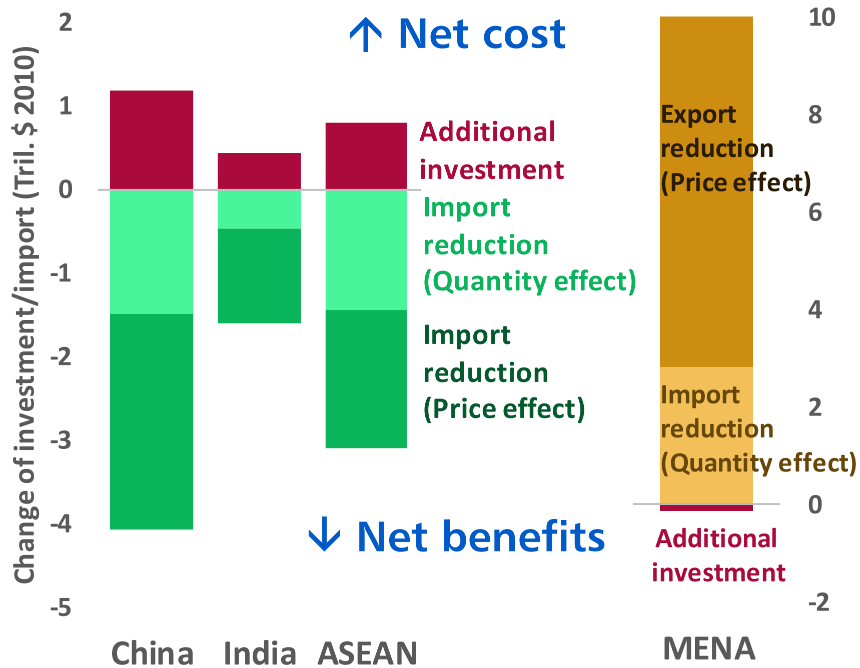
- ◆ CO_2 emissions will peak in the mid-2020s and will decrease by 11% in 2050 from 2016. However, to maintain temperature rise caused by the climate change within 2 degree Celsius, additional programs and innovative technologies are required.
- ◆ Compared with the Reference Scenario, self-sufficiency rate in Asia will improve by 3%p in 2050.

Required investment for energy supply

Required investment (2017-2050)



Difference of benefits and cost between two scenarios (2017-2050)



* "Electricity" includes the saving through electrification.

* MENA: The Middle East and North Africa

- In the Reference Scenario, $67 billion of investment is required for the energy supply facilities (1.5% against GDP).
- In the Advanced Technologies Scenario, $8 billion of investment is additionally required.
- In Asia, additional investment can be covered by the savings through reduction of fuel imports.
- In the Middle East, decreases in revenues from oil and natural gas export will be much more than decreases in the upstream investment.

Addressing climate change issues

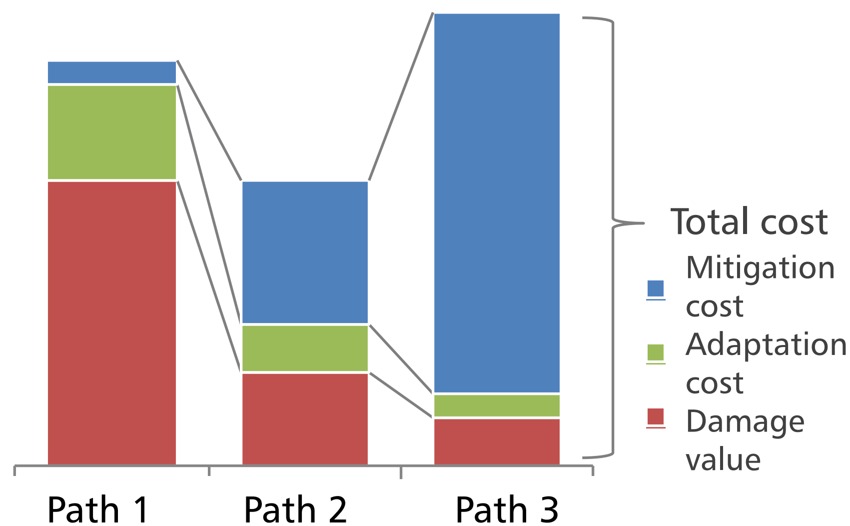
——Republication of IEEJ Outlook 2018——

Rule for ultra long-term: Reduce the total cost

❖ Mitigation + Adaptation + Damage = Total cost

Mitigation	Typical measures are GHG emissions reduction via energy efficiency and non-fossil energy use. Includes reduction of GHG release to the atmosphere via CCS These measures **mitigate** climate change.
Adaptation	Temperature rise may cause sea-level rise, agricultural crop drought, disease pandemic, etc. **Adaptation** includes counter measures such as building banks/reservoir, agricultural research and disease preventive actions.
Damage	If mitigation and adaptation cannot reduce the climate change effects enough to stop sea-level rise, draught and pandemics, **damage** will take place.

❖ Illustration of total cost for each path



	Path 1	Path 2	Path 3
Mitigation	Too small	Reasonable	Too big
Adaptation	Big	Medium	Small
Damage	Big	Medium	Small

Without measures against climate change, the mitigation cost is small, while the adaptation and damage costs become substantial. Aggressive mitigation measures on the other hand, would reduce the adaptation and damage costs but the mitigation costs would be notably colossal.

The climate change issue is a long-term challenge influencing vast activities over many generations. As such, and from a sustainability point of view, the combination (or the mix) of different approaches to reduce the total cost of mitigation, adaptation and damage is important.

Minimising total cost in IAM*

* Integrated Assessment Model

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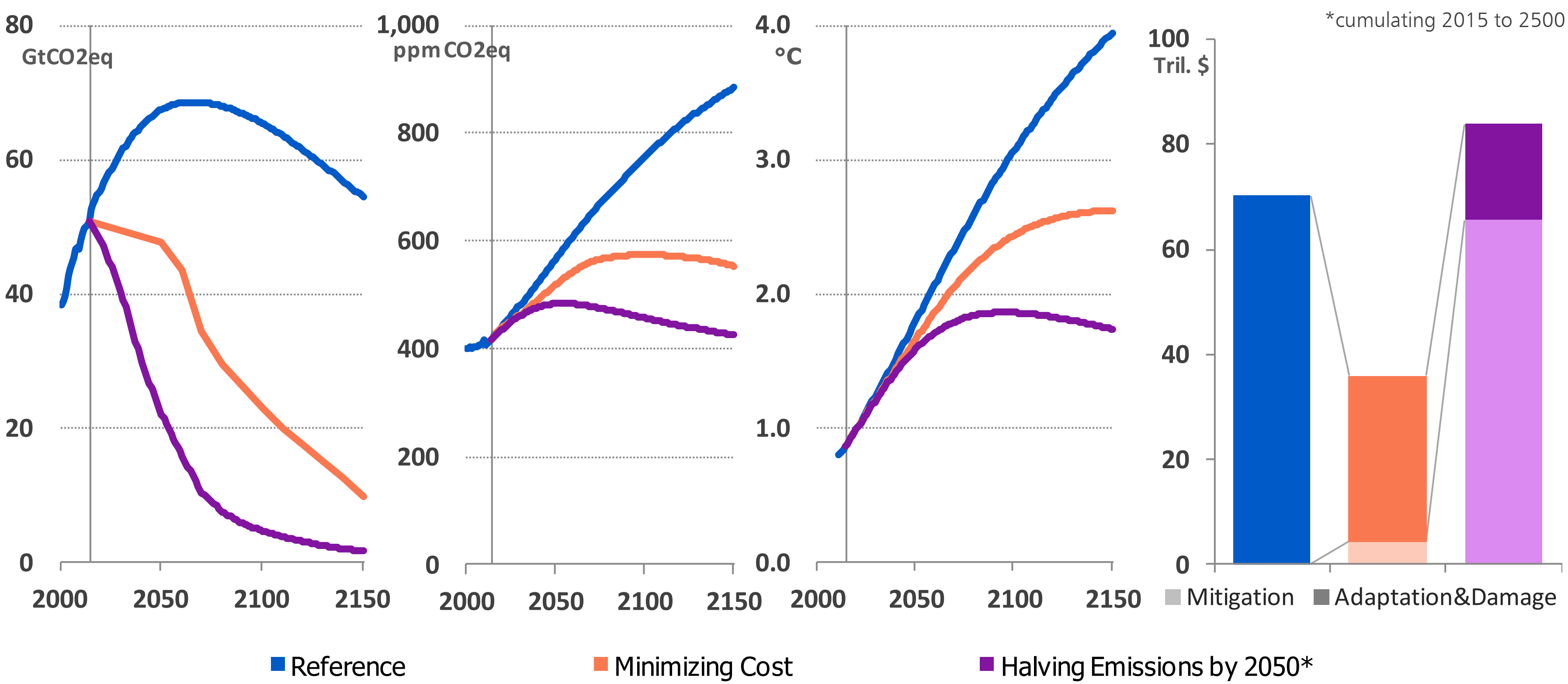
❖ GHG emissions ❖ GHG concentrations (incl. aerosol, etc.) ❖ Temperature rise (vs. 1850-1900) ❖ Total cost (cumulative present value*)

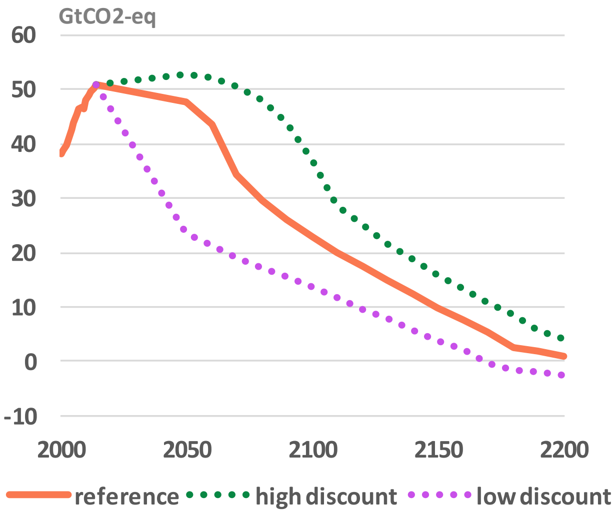


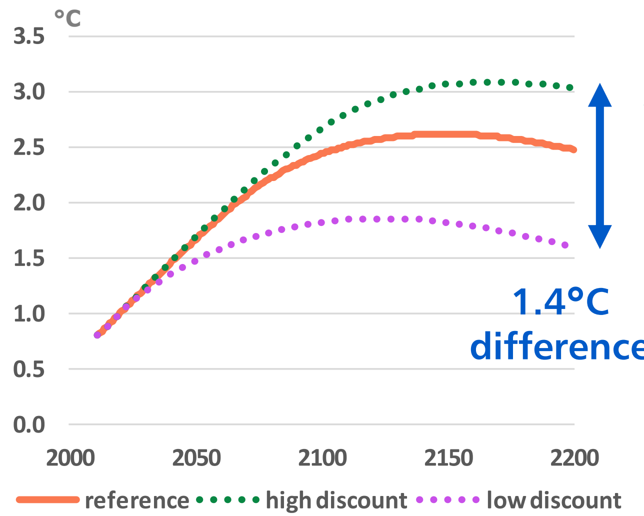
Total cost of the Minimising Cost Path is half of the Reference Path. In 2150, GHG emissions decrease by 80% from now and temperature rises by 2.6 °centigrade from the late 19th century. In the Halving Emissions by 2050 Path, temperature peaks at 2100, resulting in 1.7°C in 2150. However, total cost is 20% higher than the Reference Path and double of the Minimising Cost Path.

* Emissions path reflected "RCP 2.6" in the 5th Assessment Report (AR5) by the Intergovernmental Panel on Climate Change (IPCC).

Still large uncertainties in the climate analysis

❖ GHG emissions and temperature rise using different discount rates (Minimising Cost)





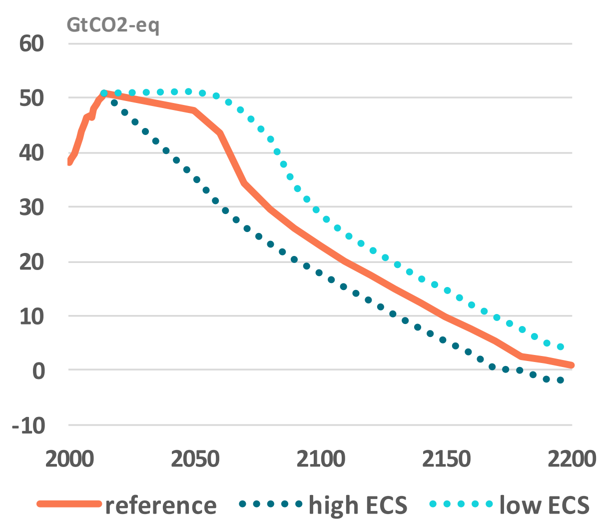
Discount rate
This model uses 2.5%. There are a range of 1.1 to 4.1% summarised by AR5.

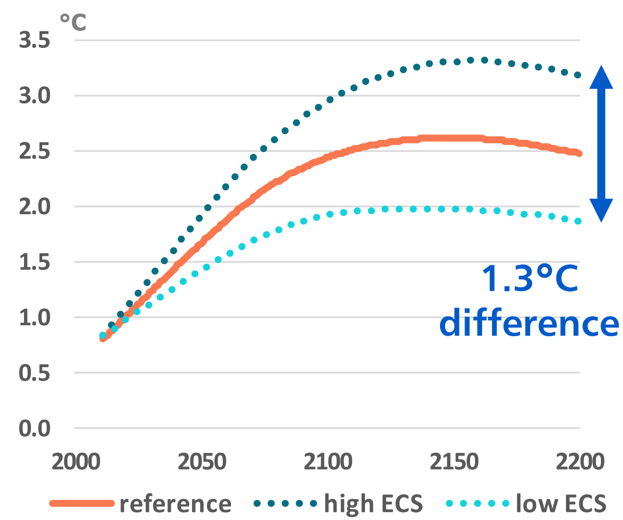
Note: The value used when converting future value (income and expenditure) into the current value. The lower discount rate tends to raise emphasis of adaptation and damage, and strengthen immediate GHG reduction. The higher discount rate raises emphasis of mitigation costs and delays GHG reduction efforts.
Although the rate changes every year in the model analysis, it is represented by the average value in 2015 to 2300 here.

❖ GHG emissions and temperature rise using different ECS (minimising cost)

Equilibrium Climate Sensitivity (ECS)
This model uses 3 degree.
According to AR5, high possibility that ECS is between 1.9 and 4.5 degree.

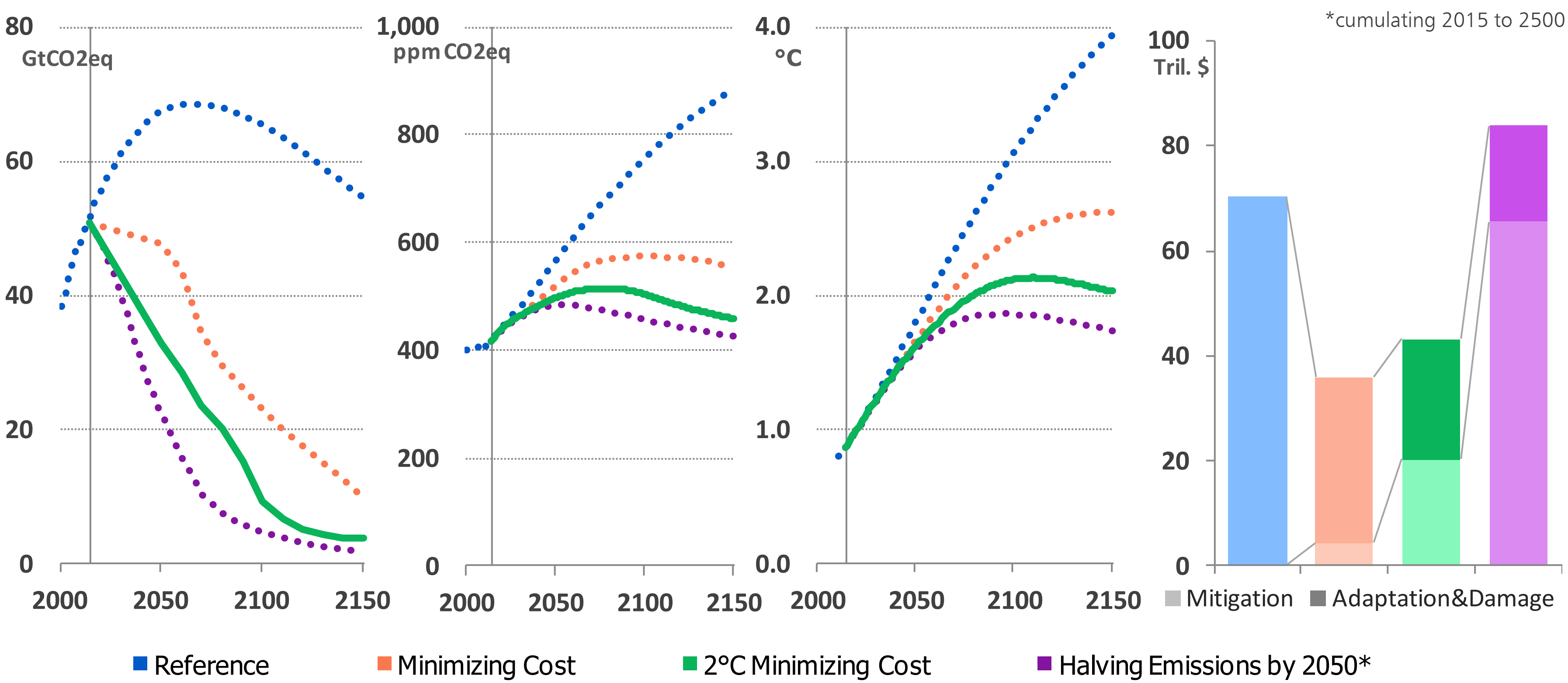
Note: A parameter indicating how much degrees centigrade the temperature will rise when the atmospheric greenhouse gas concentration (CO_2 equivalent concentration) doubles.





Another path to “2°C target”

❖ GHG emissions ❖ GHG concentrations (incl. aerosol, etc.) ❖ Temperature rise (vs. 1850-1900) ❖ Total cost (cumulative present value*)



“2°C Minimising Cost Path,” for example, is a path that minimise total cost under the condition of 2°C temperature rise in 2150. Its total cost is 20% higher than the Minimising Cost Path without the temperature limit. GHG emissions decrease by 30% in 2050 and needs almost zero-emissions after 2100. Temperature rises to just over 2°C in 2100 and then declines to 2°C.

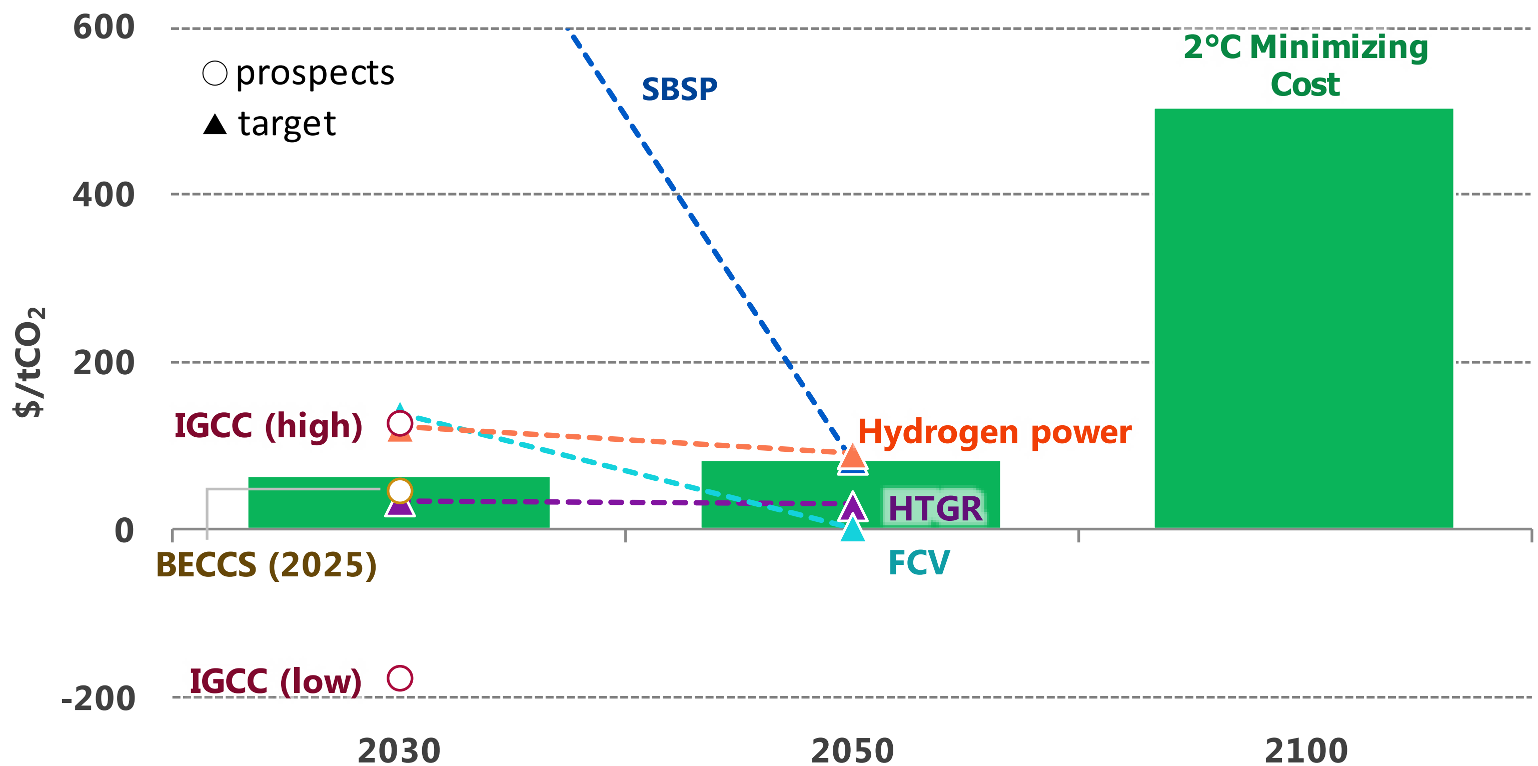
* Emissions path reflected “RCP 2.6” in the 5th Assessment Report (AR5) by the Intergovernmental Panel on Climate Change (IPCC).

Technology development for ultra long-term

Technologies		Description	Challenges
Technologies to reduce CO_2 emissions	Next generation nuclear reactors	Fourth-generation nuclear reactors such as ultra-high-temperature gas-cooled reactors (HTGR) and fast reactors, and small- and medium-sized reactors are now being developed internationally.	Expansion of R&D support for next generation reactors
	Nuclear fusion reactor	Technology to extract energy just like the sun by nuclear fusion of small mass number such as hydrogen. Deuterium as fuel exists abundantly and universally. Spent nuclear fuel as high-level radioactive waste is not produced.	Technologies for continuously nuclear fusion and confining them in a certain space, energy balance, cost reduction, financing for large-scale development and establishment of international cooperation system, etc.
	Space-based solar power (SBSP)	Technologies for solar PV power generation in space where sunlight rings abundantly above than on the ground and transmitting generated electricity to the earth wirelessly via microwave, etc.	Establishment of wireless energy transfer technology, reduction of cost of carrying construction materials to space, etc.
Technologies to sequestrate CO_2 or to remove CO_2 from the atmosphere	Hydrogen production and usage	Production of carbon-free hydrogen by steam reforming of fossil fuels and by CCS implementation of CO_2 generated.	Cost reduction of hydrogen production, efficiency improvement, infrastructure development, etc.
	CO_2 sequestration and usage (CCU)	Produce carbon compounds to be chemical raw materials, etc. using CO_2 as feedstocks by electrochemical method, photochemical method, biochemical method, or thermochemical method. CO_2 can be removed from the atmosphere.	Dramatic improvement in quantity and efficiency, etc.
	Bio-energy with carbon capture and storage (BECCS)	Absorption of carbon from the atmosphere by photosynthesis with biological process and CCS.	It requires large-scale land and may affect land area available for the production of food, etc.

Lower cost is key for innovative technologies

❖ CO_2 reduction cost by innovative technology



Note: Cost (= carbon price) for "2°C Minimising Cost" is the highest cost of the technology adopted at each year. Refer to IEEJ Outlook 2018 for detail.

Implicit carbon price for the 2°C Minimising Cost Path is $85/tCO$_2$ in 2050. The target costs for innovative technologies, such as BECCS, hydrogen-fired power generation, FCV, HTGR, and SBSP are within the range of the carbon price. The 2°C target can be reached with using these technologies. It is important to enhance R&D from the long-term view and international collaboration is dispensable.

Further CO_2 reductions from Advanced Technologies Scenario

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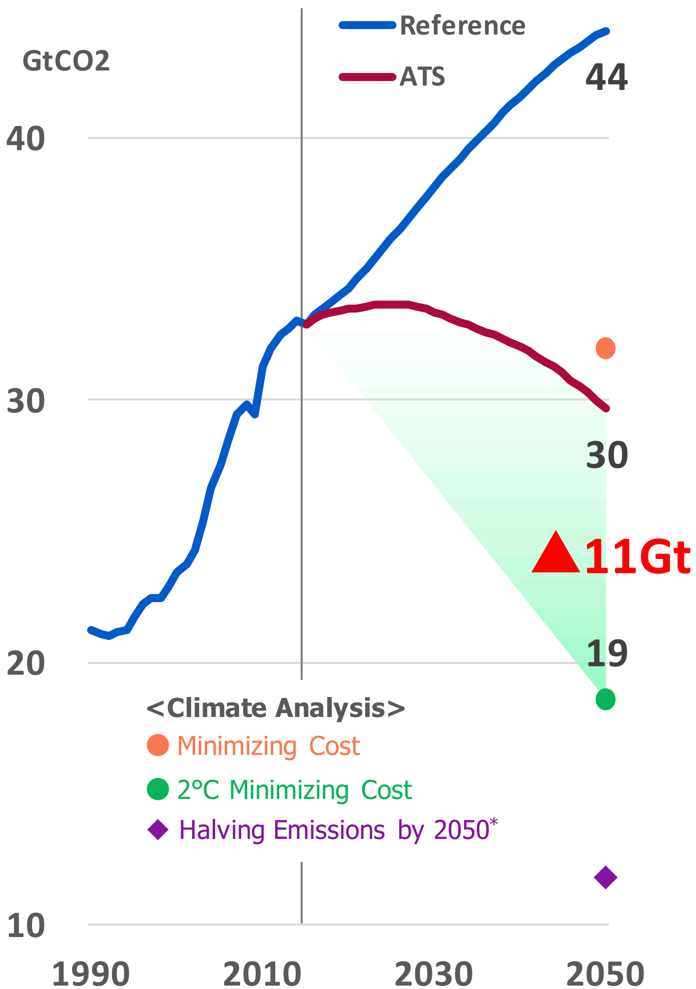
❖ Energy-related CO_2 emissions



❖ Examples of technologies for further reductions

1) CO_2-free hydrogen (refer to Asia/World Energy Outlook 2016)

- **Hydrogen-fired power generation: 1 GW x 3,000 units**
- **Fuel cell vehicles: 1 billion units**

(H_2 demand of 800 Mt/yr corresponds 3 times of today's LNG)

2) Negative-emission technology

- **BECCS (Biomass-fired power generation): 0.5 GW x 2,800 units**

(Fuel supply of 2,000 Mtoe/yr needs land of 2.85 million km^2)

3) Zero-emission power generation and factories with CCS

-10 $GtCO_2$ (Maximum reduction volume by substituting for thermal power generation without CCS)

- **SPS: 1.3 GW x 2,300 units**

or • **HTGR: 0.275 GW x 8,700 units**

or • **Nuclear fusion reactor: 0.5 GW x 4,500 units**

or • **Thermal power generation with CCS: 2,800 GW**

(Estimated CO_2 storage potential is over 7,000 Gt)

\+

-1 $GtCO_2$

- **CCS: Installed in 20% of factories and plants**

(iron & steel, cement, chemicals, pulp & paper, refinery and GTL/CTL)

* Emissions path reflected "RCP 2.6" in the 5th Assessment Report (AR5) by the Intergovernmental Panel on Climate Change (IPCC).

Risk and impact of energy supply disruptions

Causes of oil supply disruptions

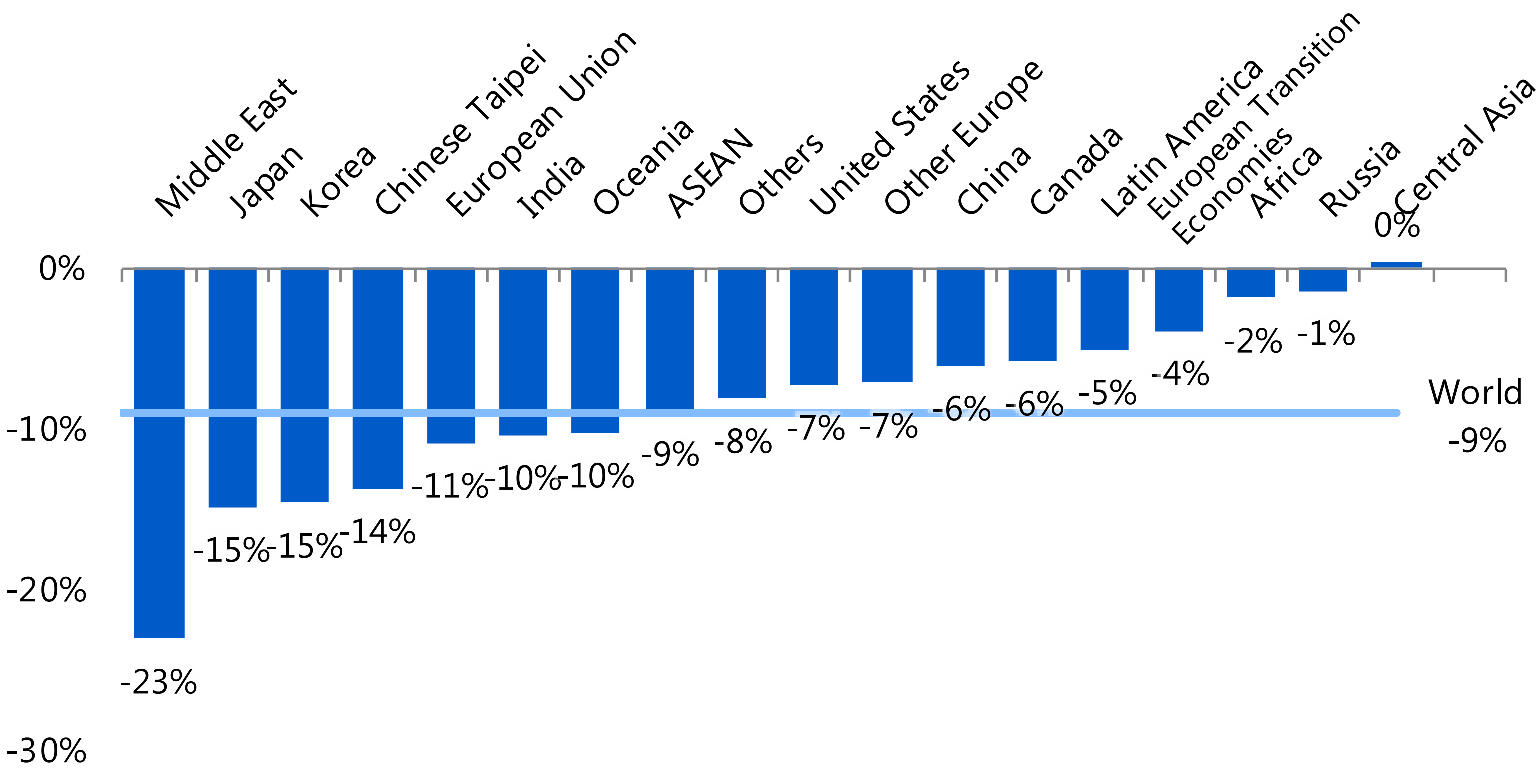
- Oil supply disruptions have been at the heart of the traditional energy security debate.
- Various supply disruptions have occurred at each stage of production, transport, and domestic supply due to accidents, failures, natural disasters, or structural factors affecting society and the economy as a whole. And the risks remain present.

	Risks	Examples
Production	• Destruction or shutdown of production facilities due to unanticipated events such as accidents, failures or natural disasters • Destruction of production facilities and suspension of operations due to political upheavals and terrorism • Halting exports by political will or strategy	1973: OAPEC countries imposed an embargo on exports to the United States and the Netherlands. 2005: Hurricanes shut down oil production facilities in the U.S. Gulf Coast 2018: Exports of crude oil from Libya were partially reduced because of suspension of production and the blockade of ports due to internal strife.
Transportation	• Destruction or shutdown of facilities due to unanticipated events such as accidents, failures or natural disasters • Destruction or suspension of transportation (ships, pipelines, etc.) by terrorism or piracy • Interruption of transport routes by political will, strategy and military action	1984 - 1988: The “tanker war” by Iran and Iraq 2011: Destruction of gas pipelines from Egypt to Israel by terrorist attacks 2018: Attacks on crude oil tankers by Yemeni militants
Domestic Supply	• Destruction or shutdown of supply facilities due to unpredictable events such as accidents, failures or natural disasters • Destruction of supply facilities and suspension of operations due to terrorism	2011: Oil supply suspension due to the damage of oil refineries and oil depots and the destruction of ports, railways and roads caused by the Great East Japan Earthquake

Impacts of the disruption of oil supply on economy

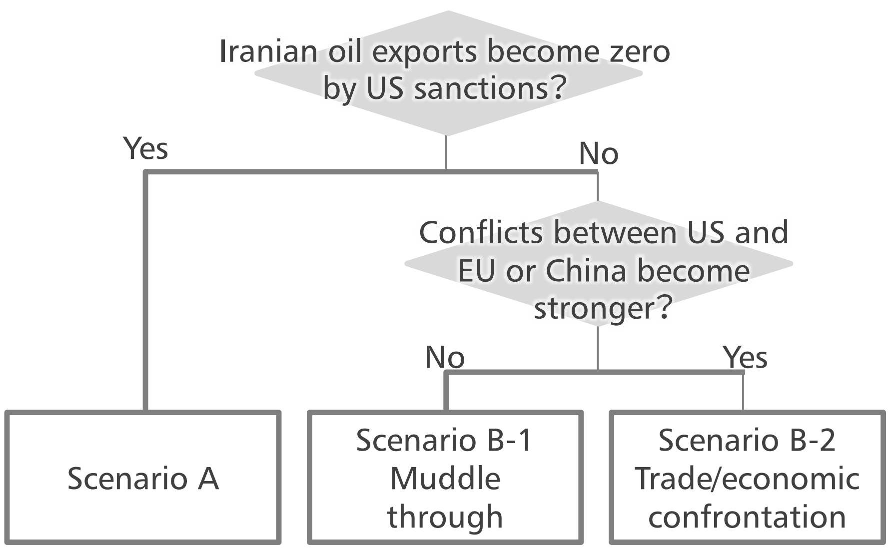
- The disruption of oil supply has major impacts.
- If crude oil production in the Middle East falls by 10 Mb/d and other countries or regions cannot fill in the gap, the global economy would shrink by 9%.
- Except for the Middle East, the epicentre of supply disruptions, Japan, Korea and Chinese Taipei would suffer the most damage.

❖ Impact of a 10 Mb/d decline in crude oil production in the Middle East on real GDP



Impacts of sanctions against Iran on international oil market

- Key result of scenario analysis on the impacts, up around 2020, of US re-imposition of economic sanctions against Iran.
- In the scenario where Iranian crude oil exports (about 2.5 Mb/d) are totally eliminated, oil prices rise due to shortage of OPEC spare capacity.
- In the scenario where trade friction starting from US escalates, world's economic slowdown relaxes oil supply-demand, and eventually pushes down oil prices.



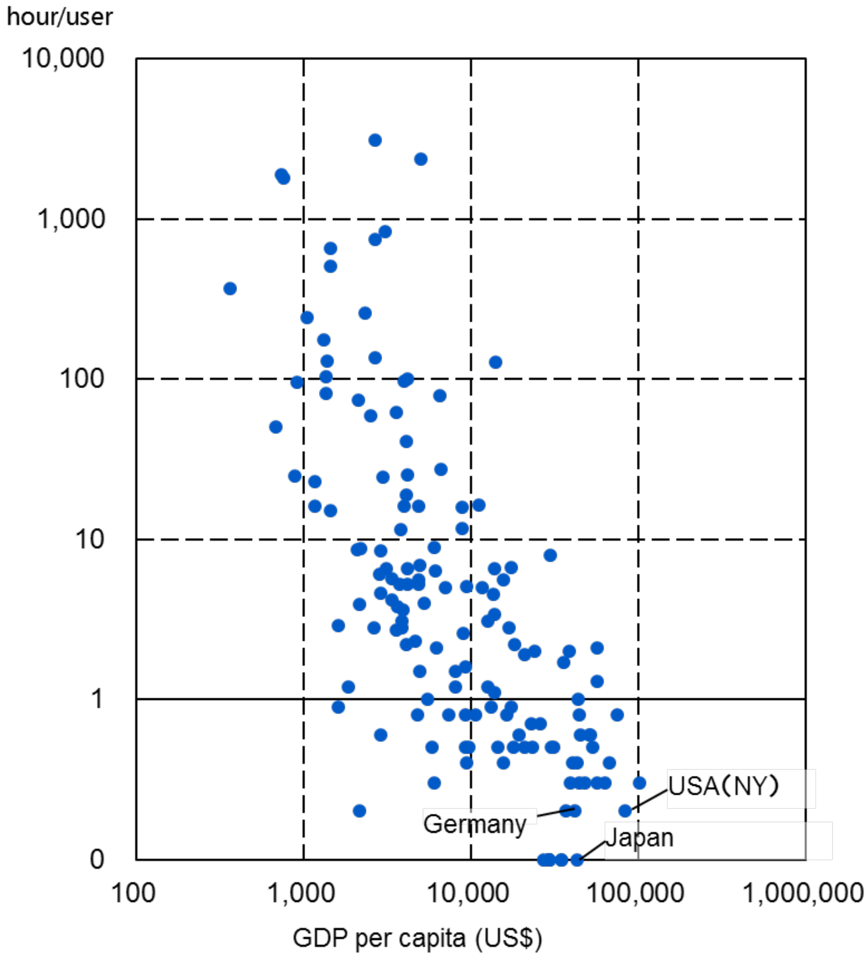
❖ Points of the scenario analysis

	Scenario A	B-1	B-2
Oil market	Tight supply-demand balance and shortage of OPEC spare capacity	Relatively calm market condition thanks to production increase from Saudi Arabia, etc.	Oversupply due to economic slowdown
Oil price	80-100$/bbl or more depending on circumstances	70-80$/bbl	50$/bbl
Other energy	LNG demand decline with the rise of prices. Coal becomes more competitive.	-	Lower LNG price materialise potential demand. FIDs of new liquefaction plans are postponed.

Source: IEEJ, Scenario analysis on the impacts of sanctions against Iran on international oil market, August 2018

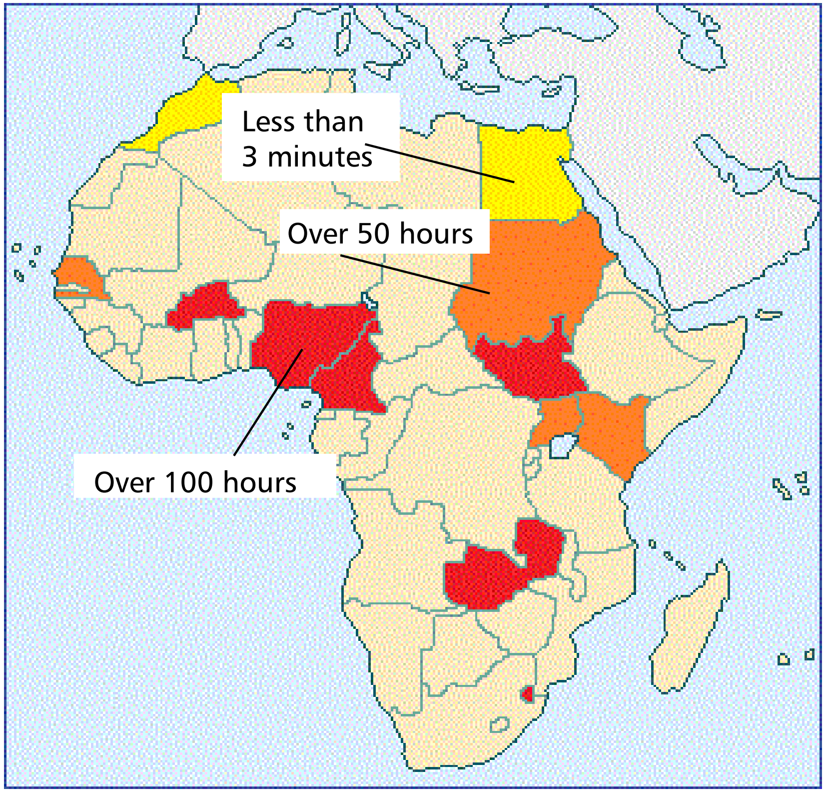
International comparison of power outage

❖ Income level and power outages (2015)



Source: World Bank "Doing Business database", "World Bank Open Data"

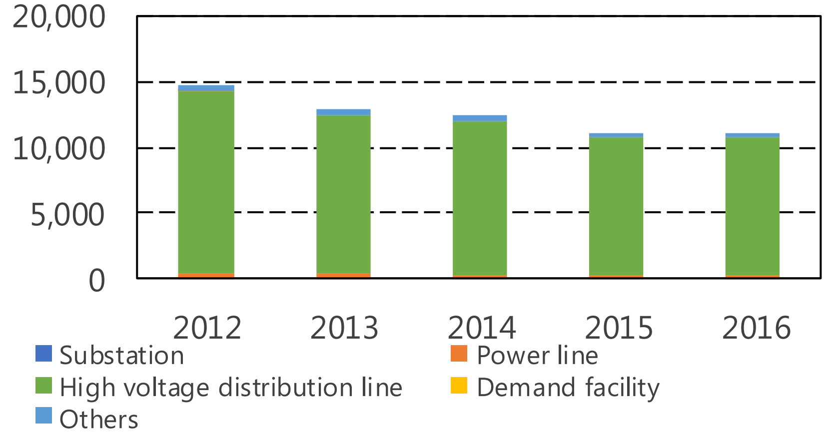
- Power outages vary widely by region. Sub-Saharan, island states, and South Asia tend to be long.
- The countries where power outages exceeded 1,000 hours (11% per year) in 2015 are Iraq, Comoros, Eritrea, Nigeria, Pakistan, South Sudan, and Swaziland.



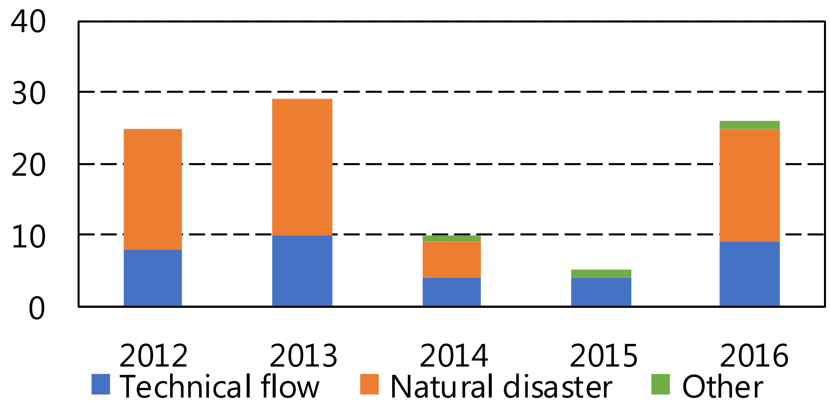
Power outage in Japan

- More than ten thousand power outage has occurred in Japan if including low voltage. The main cause is a distribution system and the extent of the suffered area is limited in the most power outage.
- Large scale power outage sometime increases due to natural disaster (typhoon, heavy rain, etc.).
- In the developed countries, the grid modernisation including automation of transmission and distribution system enables the swift recovery if there is no physical damage.

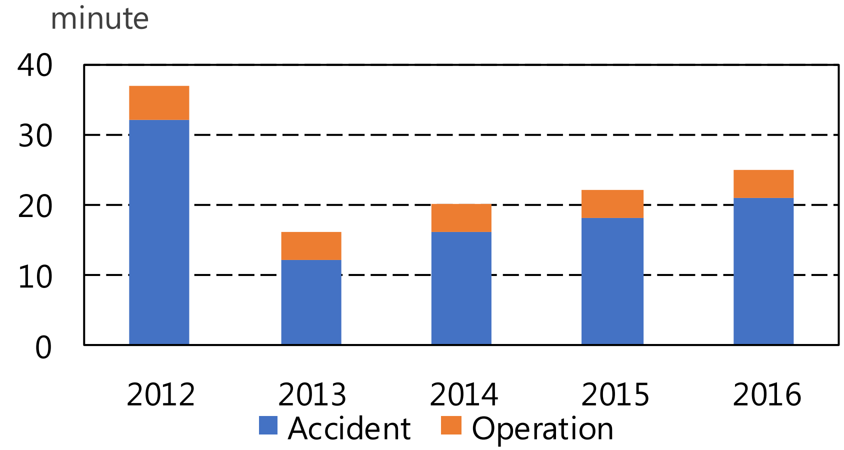
❖ Number of power outage by cause



❖ Number of large-scale power outage



❖ Power outages per low voltage user



Source: Organization for Cross-regional Coordination of Transmission Operators, Japan "Reports about the quality of electricity", Nov. 2017.

New threat for power supply

Structural risk	

Structural risk

● **The increasing dependence on a specific energy source**

✓ While regions which depend on gas-fired power generation have increased in the United States and natural gas is supplied by pipeline, the supply risk caused by natural gas supply disruption becomes more evident.

● **The "duck curve" of net load due to the expansion of solar PV**

✓ In California and Japan where introduction of solar PV power generation is expanding, the duck curve of net load which the peak load comes twice a day is progressing. Requirement for electricity supply capacity is increasing that can follow, particularly, steep rise of electricity demand from daytime to early evening.

● **The shutdown of power plants due to economic feasibility**

✓ There is a risk of unexpected large-scale closure of power generation capacity in the short term due to its economic feasibility. In the United States, during 2012 to 2017, large capacities (coal-fired: 55 GW, gas-fired: 36 GW, nuclear: 5 GW) were closed due to unfavourable market condition. Unbundled power business structure is challenging the transmission system operator or the reliability assessment organisation to capture such plans.

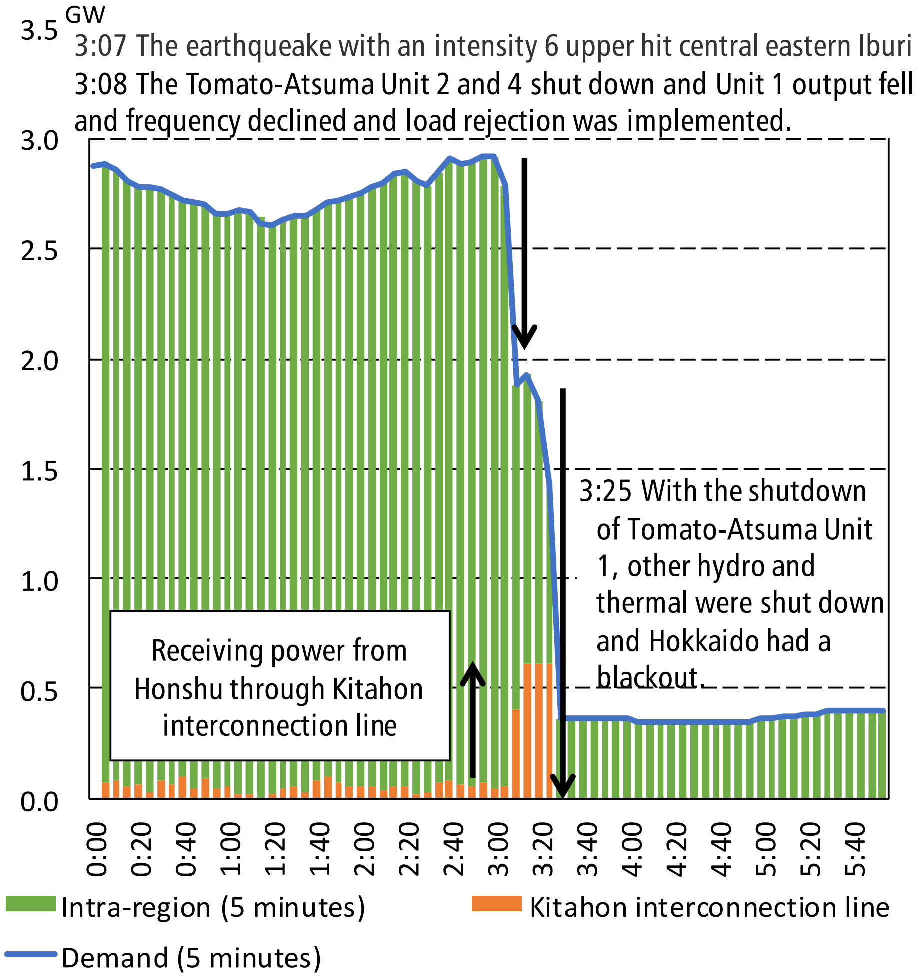
Sudden risk

● **Cyber attacks**

✓ In Ukraine, power outage occurred due to cyber attacks in December 2015 and December 2016. Power system control was hacked and ended up power outage. When capacity of virtual power plants (VPPs), connecting distributed power generators via open network, increases in the future, cyber attacks can possibly risk VPP system.

The massive blackout following the 2018 Hokkaido Eastern Iburi earthquake

❖ Background of the blackout in Hokkaido



Source: Hokkaido Electric Power "Electricity forecast", Organization for Cross-regional Coordination of Transmission Operators, Japan. "System information service", JEPX "Electric information public system"

Background of the blackout

3:07 The earthquake with an intensity 6 upper hit central eastern Iburi.

3:08 Supply -1.8 GW, demand -1.4 GW

	GW
Tomato-Atsuma Unit 2 and 4 shut down	-1.16
Tomato-Atsuma Unit 1 output fall	-0.05
Hydro stopped due to an accident in the transmission line	-0.43
Wind stopped due to low frequency	-0.17
Blackout due to an accident in the transmission line	-0.13
Automatic load shedding with low frequency	-1.3

3:09 The frequency recovered after received electricity from Kitahon interconnection (0.5 GW).

3:20 The frequency dropped again due to output fall of Tomato-Atsuma Unit 1. Hokkaido area became blackout due to run-out of margin to maintain frequency.

The cause of the blackout

The shutdown of power generation capacity larger than the mandate obligation of primary reserve (3% of the demand of relevant time: about 0.09 GW)

The recovery from the blackout

13:35 Sunagawa thermal unit 3 restarted by using power supply from hydroelectric.

Sep 8 2:00 The recovery rate was 99%.

Feature of oil and electricity in supply disruption

	Oil	Electricity
Geographical spread of the impacts	**Wider** • The impact of a crisis in an oil producing country or international transportation route spreads to the world. • Soaring international oil price spreads to every corner of the world economy within a short period of time.	**Limited** • The most of an impact is limited to the country or region
Demand substitutability	**More elastic** • Substitutable in some usage such as boiler and power generation	**Less elastic** • No substitutability in most usages
Response to supply disruptions	• Diversification of import partner countries / routes • Geographical distribution of domestic facilities • Redundancy of domestic supply network • Support for economic stabilisation in oil-producing countries • Stockpiling	• Diversification of power generation fuels • Geographical distribution of power generation facilities • Redundancy of transmission and distribution networks • Reserve power generation capacity

Note: Evaluation on geographical spread and demand substitution show relative relation between oil and electricity.

Preparation for emergency

Oil

- Stockpiles is developed in many countries on their own way and amount.
- Among the IEA member countries, collaborative response mechanism is established.
- Within Japan, collaboration system among oil companies and central service station (SS) / inhabitants SS are being established.
- Japan which has no choice but to depend imports will remain exposed to the supply disruption.

- **Maintenance and enhancement of security system is required.**

Electricity

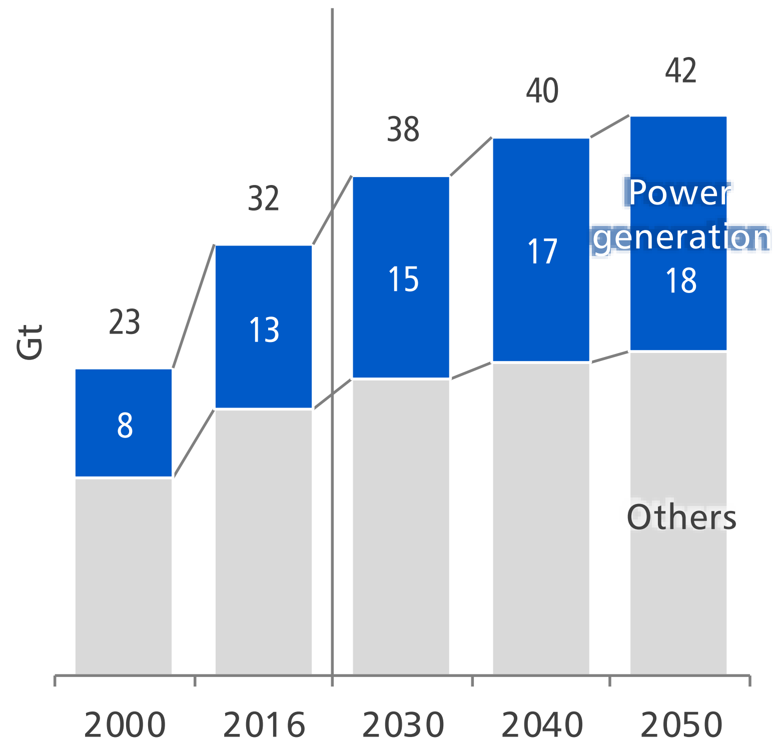
- Before the deregulation of electricity market, the big electric utilities ensured backup power capacity voluntarily more than regulatory requirement.
- In the deregulated market, it becomes impossible to depend on the voluntary effort of the big electric utilities.
- On the other hand, technological innovations enable applying new measures.
  - More accurate supply-demand projection using AI
  - Managing demand using IoT
  - Adjusting supply-demand using storage battery in EVs

- **Establishing appropriate security systems in the electricity market is desired.**

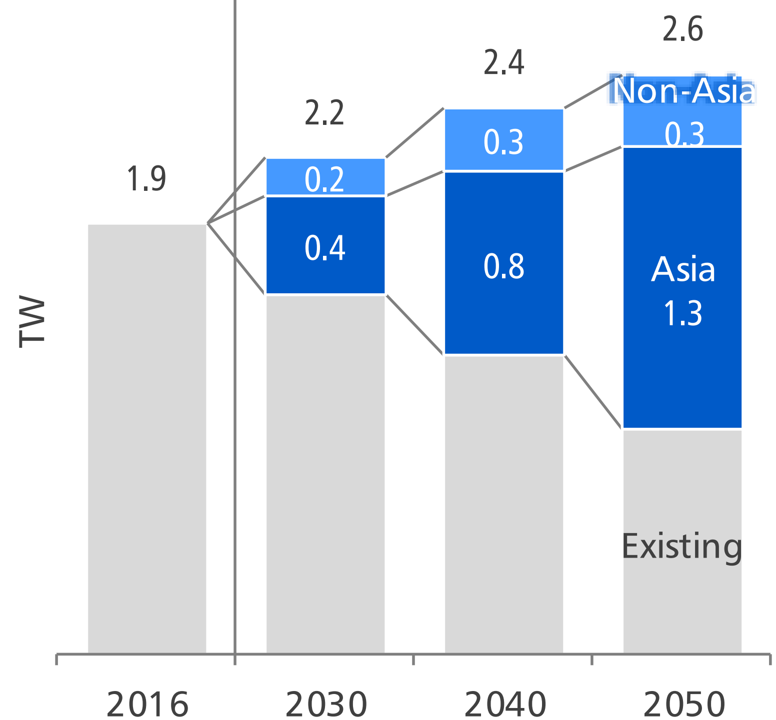
Impact of banning construction of new coal-fired power plants

Decarbonisation in power sector is required

❖ CO_2 direct emissions [Reference Scenario]



❖ New coal-fired power plant capacity [Reference Scenario]



Of additional emissions in 2050 (9.6 Gt), more than half (5.2 Gt) comes from power sector.

ESGs and divestment movements discourage investment for coal-fired power plant.

In the Reference Scenario, coal keeps the largest share in power generation mix.

In 2050, 1.6 TW of new coal-fired power plants were built after 2020 exist. → Without them?

No New Coal-fired Power Plant Case
—— a hypothetical option in the future

There are a lot of problems to be worked on to accomplish the shift from coal.

However, such problems in the real world are set aside in this case study.

No New Coal-fired Power Plant Case

A hypothetical case in which all new coal-fired power plant construction would be banned after 2020.

Two patterns with different substitution options (natural gas; solar PV / wind) for coal-fired power generation are prepared:

No New Coal-fired Power Plant (Natural Gas Substitution) Case

No New Coal-fired Power Plant (Renewables Substitution) Case

Judging from base-load function of coal-fired power generation, nuclear can be supposed as one of the substitution options. However, world-wide nuclear penetration requires challenges on technology transfer, matured regulation, and non-proliferation, which are difficult to overcome in short period. In addition, today's coal phase-out opinions rarely suppose the substitution of nuclear. Therefore, just two patterns (natural gas and renewables) are prepared in this case study.

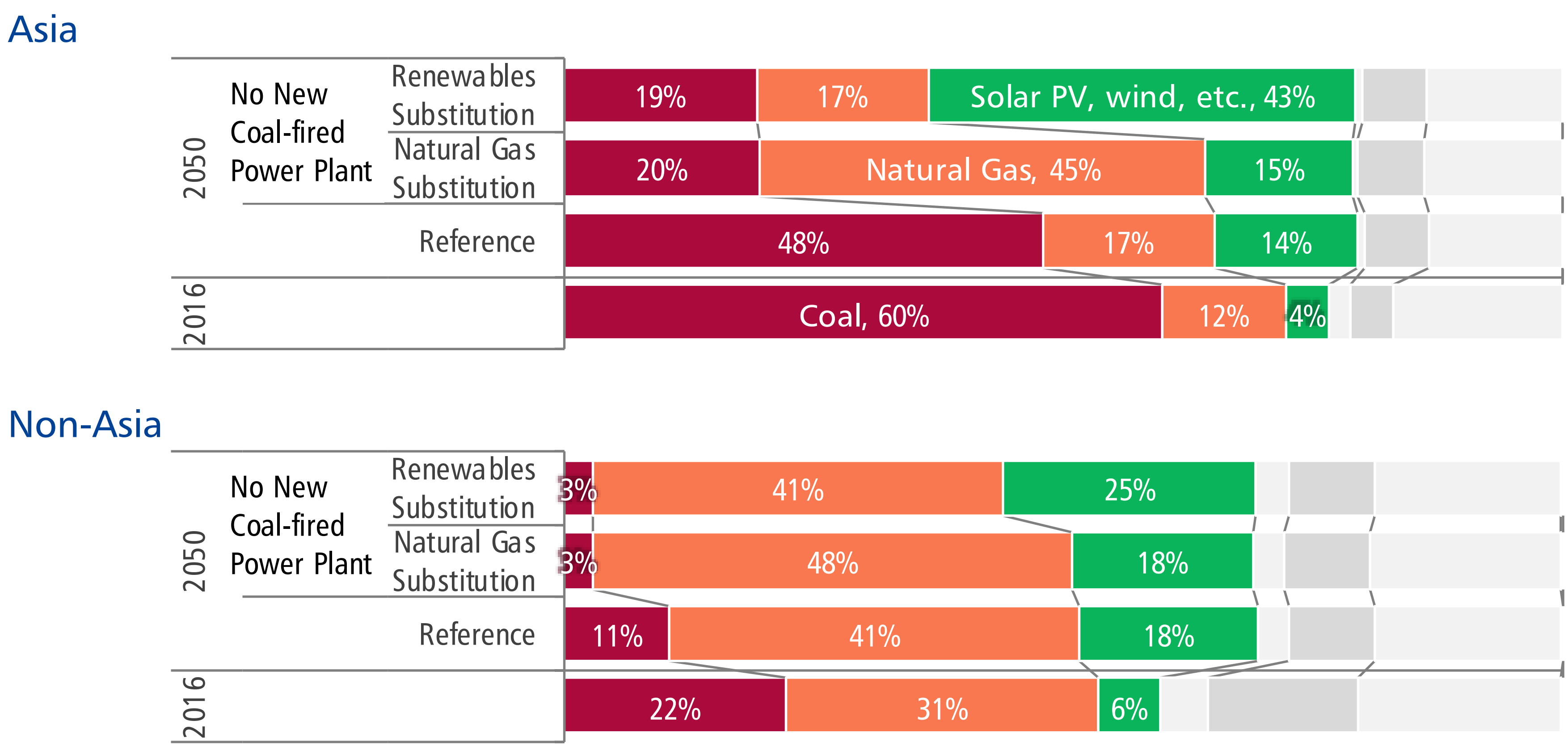
Discuss effects of banning the construction of new coal-fired power plants, in terms of energy supply-demand balances and economics.

No New Coal-fired Power Plant Case does not indicate prospect or feasibility of the coal-fired power plant ban.

Drastic transition of power generation mix! Especially in Asia!!

IEE JAPAN

❖ Power generation mix

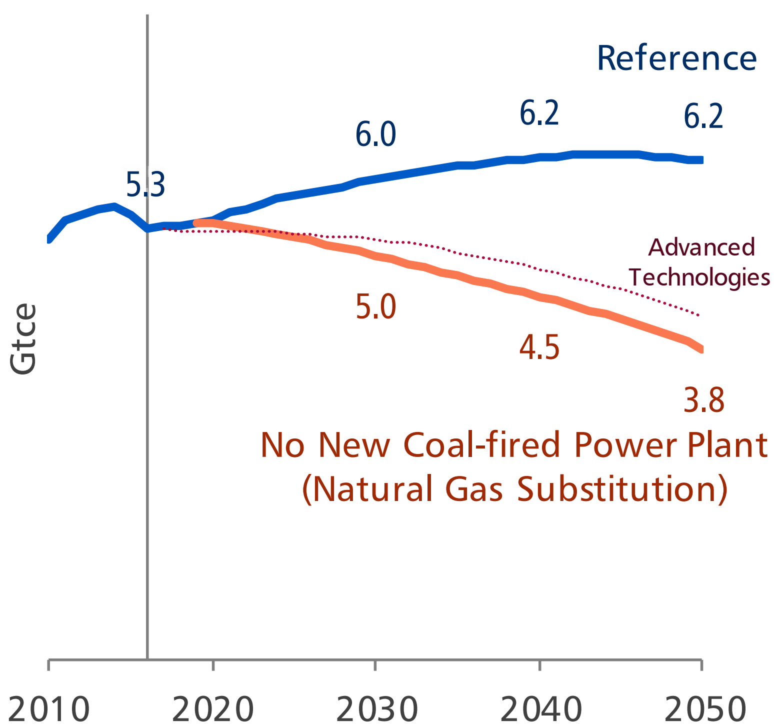


Since Asia largely depends on coal-fired power generation, abolishment of coal-fired power plant construction means drastic transition of power generation mix.

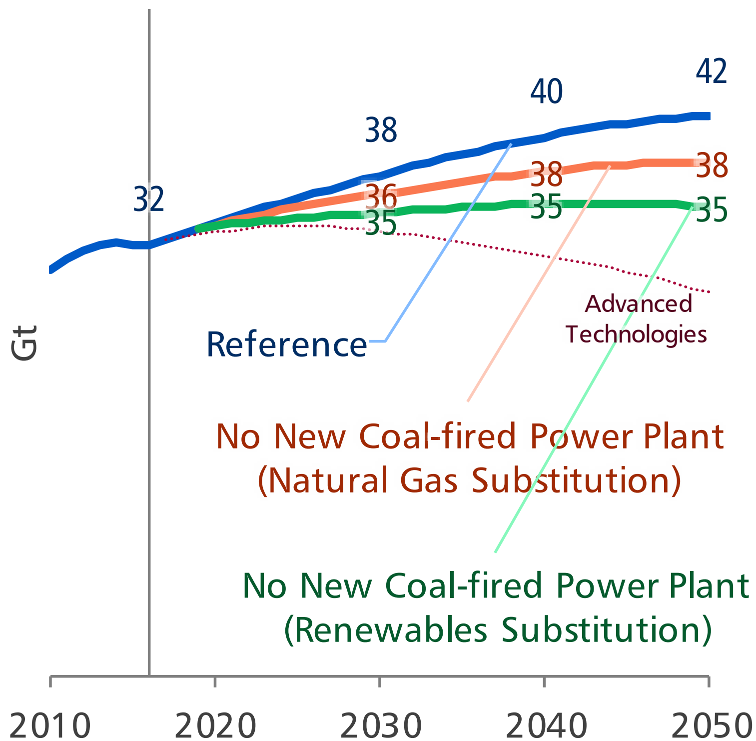
On the other hand, transition is relatively limited in non-Asia. Even if solar PV and wind substitute for coal-fired power generation, natural gas remains the largest share.

Pros of ban on new coal-fired power plant construction

Primary consumption of coal



CO_2 emissions



The reduction of 2.3 Gtce in 2050 is comparable to the current production of China.

It leads to reduction of local pollutants.

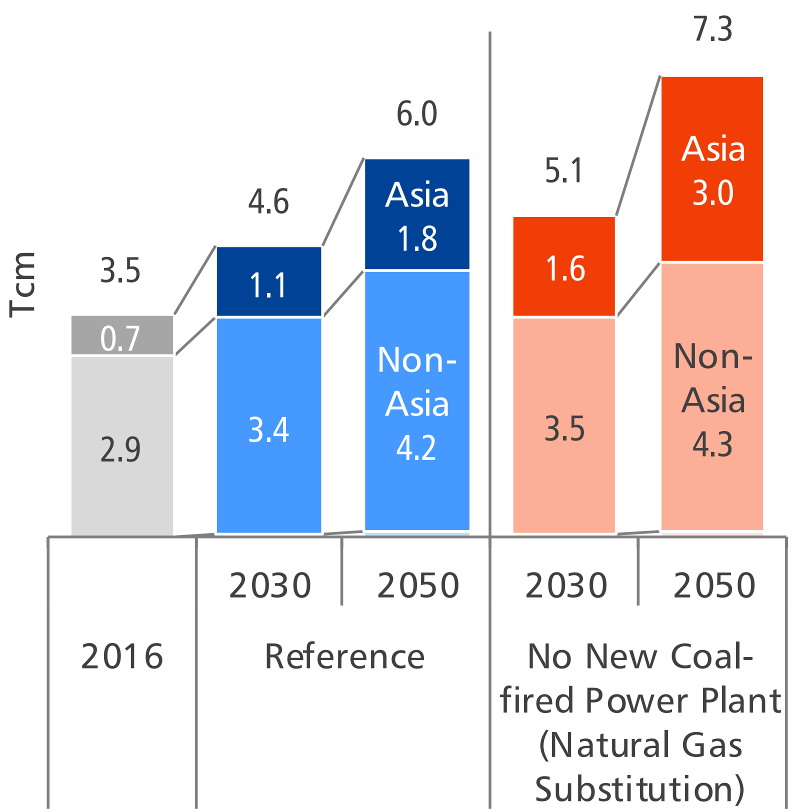
CO_2 reduction in 2050 is 3 Gt (Natural Gas Substitution), or 7 Gt (Renewables Substitution).

However, even in the latter case, CO_2 emissions are not less than the current level.

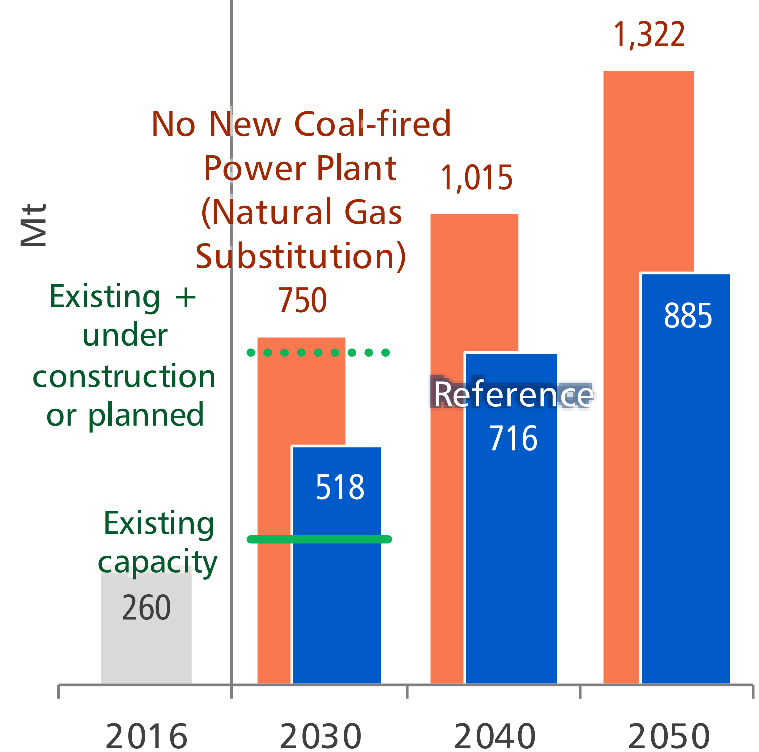
Note: Consumption of coal in the Renewables Substitution is almost same as that of the Natural Gas Substitution.

Substitution of natural gas requires dramatic expansion of supply

❖ Natural gas supply



❖ LNG demand



Natural gas consumption in 2050 reaches twice the current level. Cumulative consumption until 2050 may exceed the proven reserves.

All possible resources need to be developed no matter how difficult.

LNG demand in 2030 is 3 times the current level.

To meet enormous demand, even LNG projects without definite developed plan need to come into operation.

Challenges are not only the supply chains…

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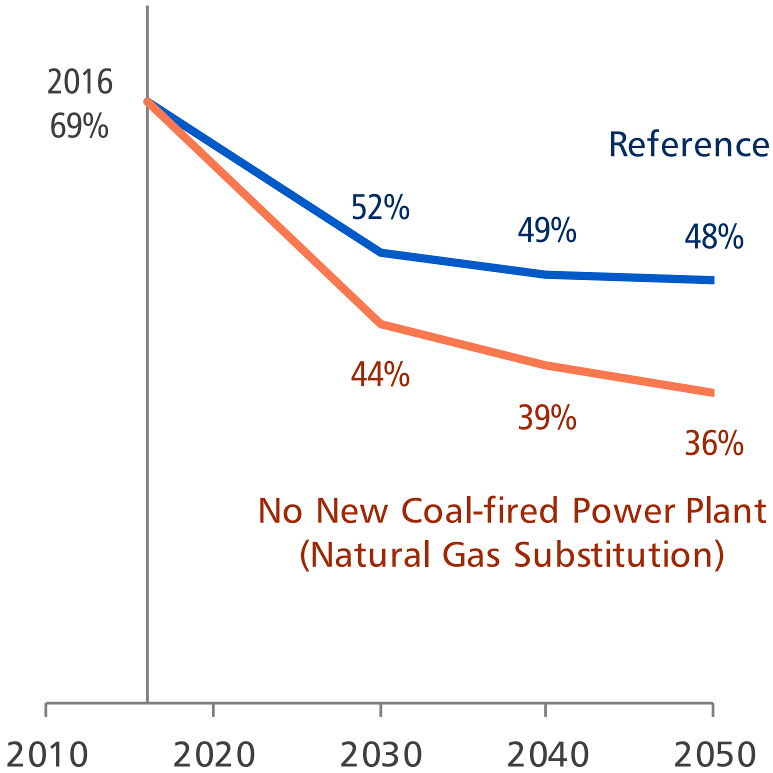
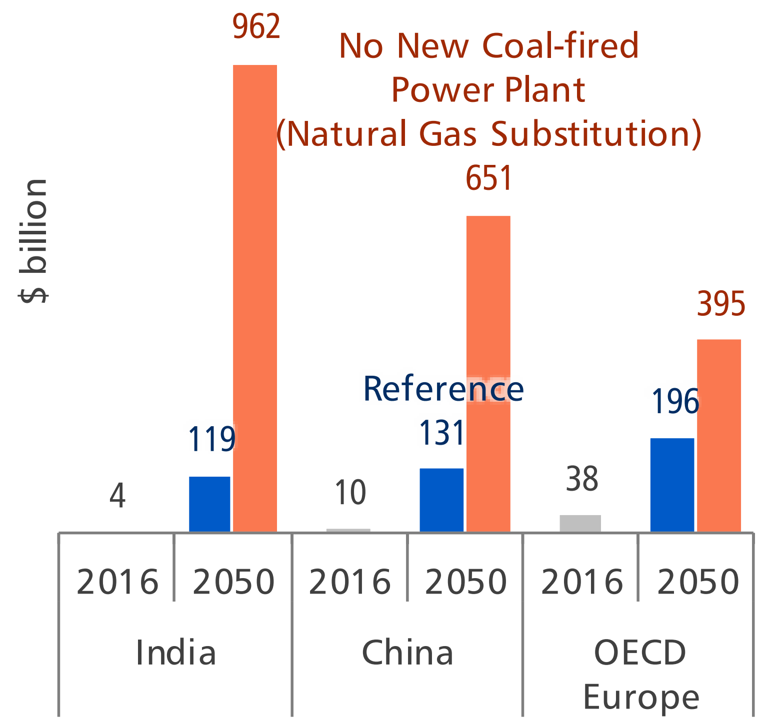
❖ Natural gas self-sufficiency rate (Asia)



❖ Net import spending of natural gas



Even if these rapid increases in production and trade can be realised, Asia will face energy security problems.

Self-sufficiency rates of natural gas fall to half of the current level.

If natural gas prices rise due to drastic increase of demand, undesired effects reach non-Asia such as OECD Europe, in which natural gas demand slightly increases.

Substitution of solar PV / wind requires unprecedented capacity expansion

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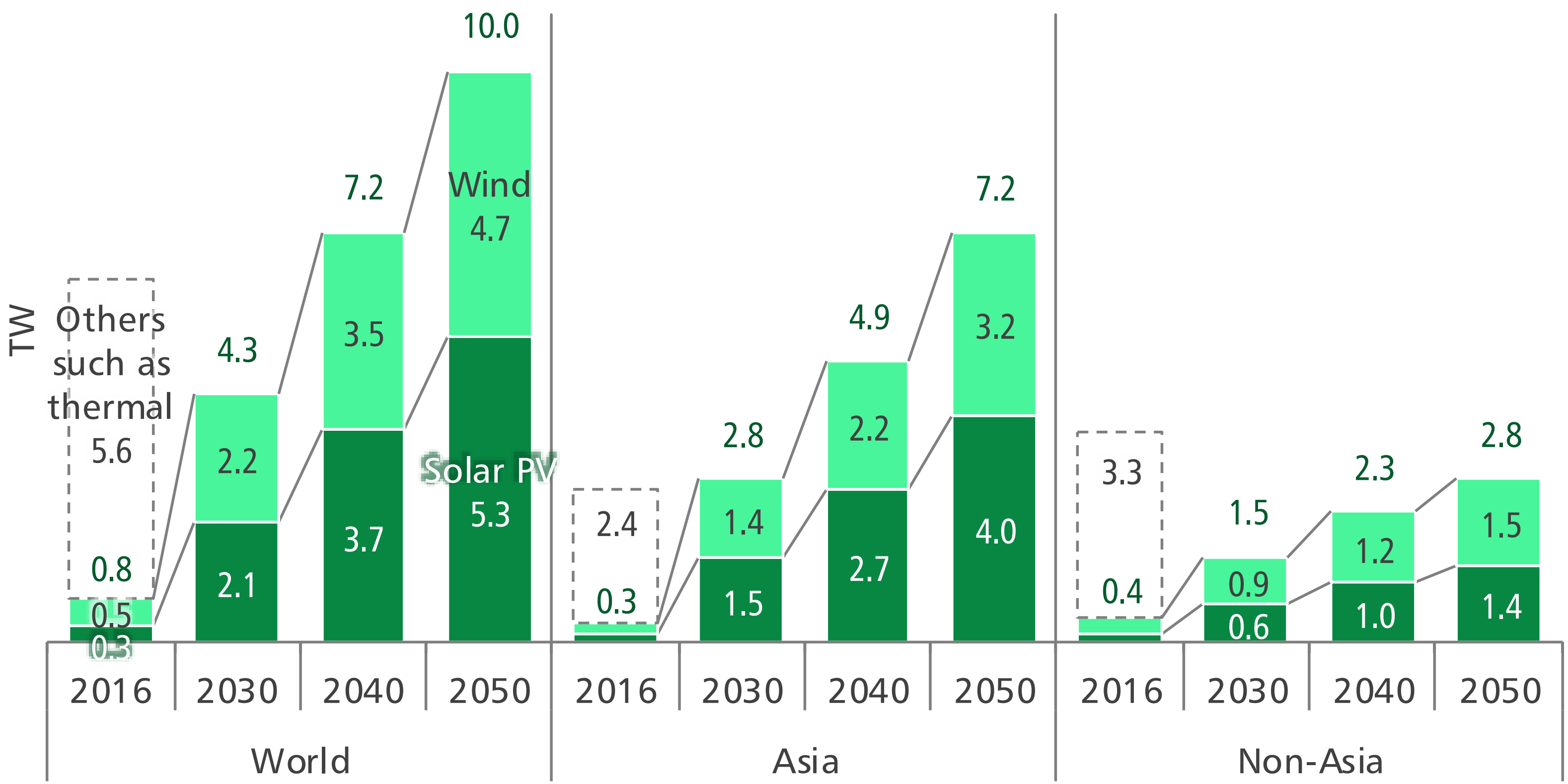
❖ Solar PV and wind power generation capacity
[No New Coal-fired Power Plant (Renewables Substitution) Case]



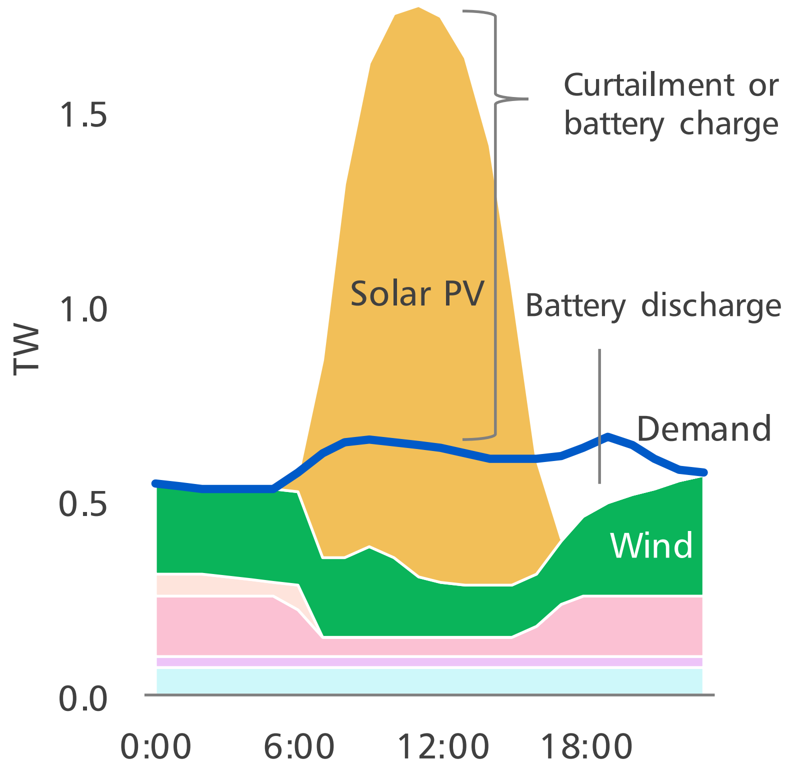
Even if efficient storage and transmission technologies without any loss become available worldwide, 10 TW of solar PV and wind power generation capacity combined is required in 2050.

In Asia, solar PV and wind power generation capacity combined reaches 7.2 TW, 2.7 times the current total generation capacity. Sustainable measures to promote mass adoption are essential.

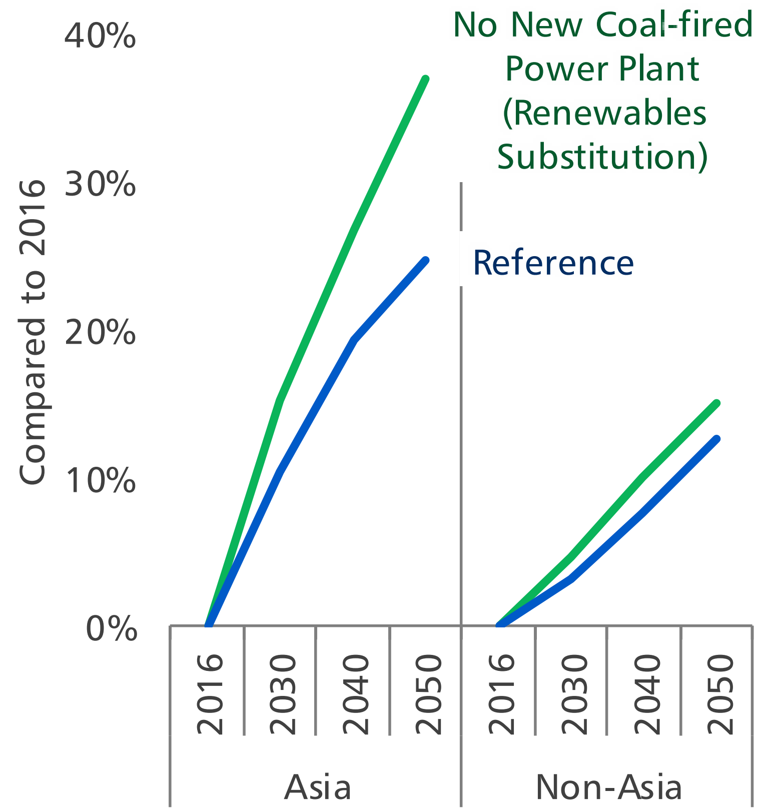
Keep an eye on electricity security

❖ Electricity balance in India «indicative»

[No New Coal-fired Power Plant (Renewables Substitution) Case, 2050]



❖ Electricity cost «indicative»



Electricity supply and demand must always be balanced.

Urgent subjects are technical study on frequency, voltage, transient stability, etc. under massive introduction of variable power sources.

It is necessary to make preparation, such as facility implementation and operation alteration for massive introduction of variable renewables.

In Asia, despite cost increase, avoid energy poverty and a decline in competitiveness.

Note: Shape of demand load curve is based on the current curve.

Note: does not include levies for renewable power source promotion.

Victoria concordia crescit
(Victory comes from harmony)

An entire ban on construction of coal-fired power plants

☺ 3 Gt～7 Gt of CO_2 reduction

☹ Drastic increase of alternative energy demand

Energy security challenges such as natural gas / electricity stable supply, economics, etc.

!

The country should promote to abolish coal-fired power generation that can do so.

If difficult, or with better CO_2 reduction measures, they should assess their priorities, making effort quickly to replace low-efficiency coal-fired power plants with high-efficiency ones and reduce dependency on coal-fired power generation.

Always keep in mind……

Are you prepared to support for the drastic energy transition in developing Asia?

Think it over.

Shift from coal-fired power generation is only one means, and that the end is to address climate change.

On a larger scale,

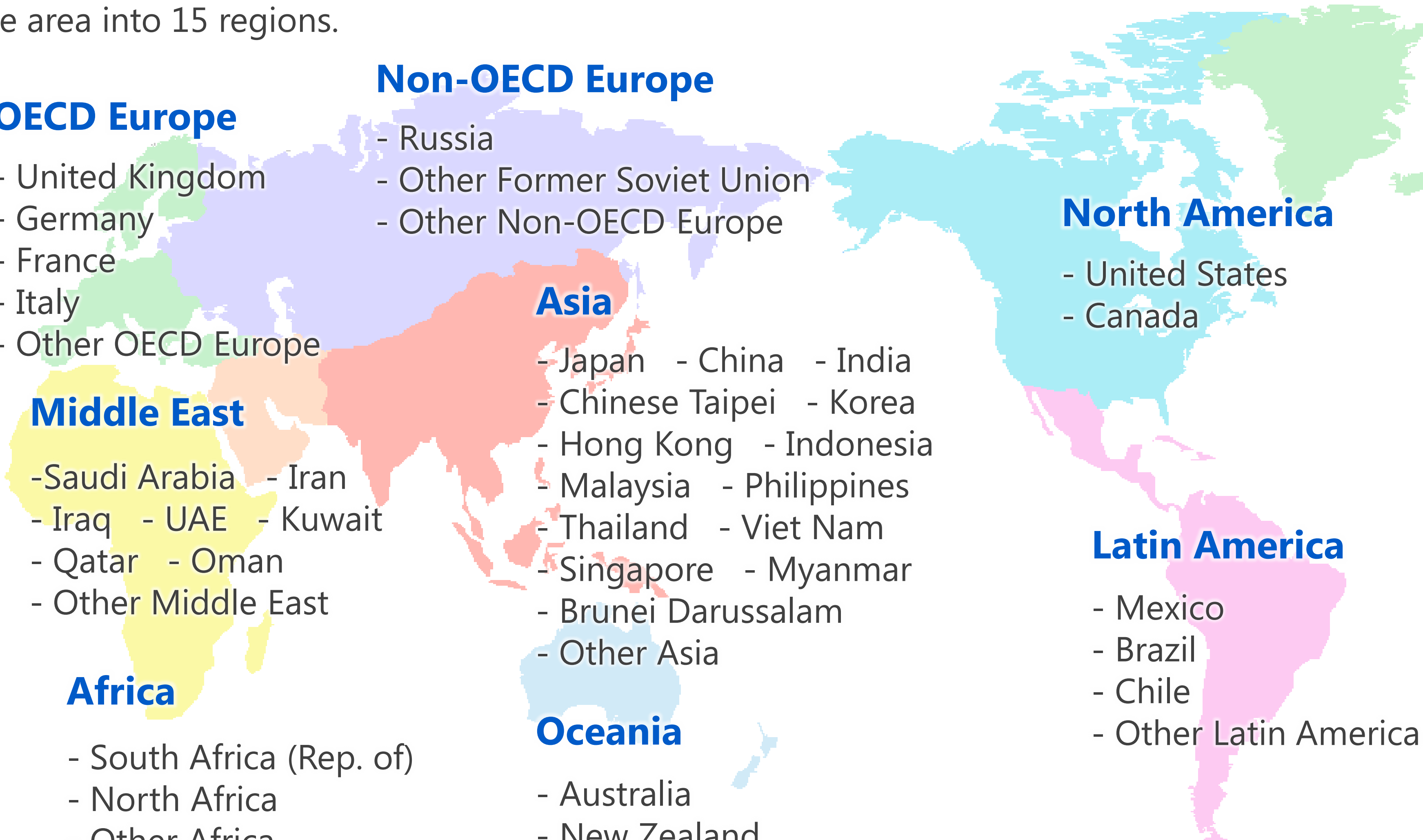
Climate change is one of humanity's great challenges, but not the only one.

Reference materials

Geographical coverage

Countries / regions in the world is geographically aggregated into 42 regions.

Especially the Asian energy supply / demand structure is considered in detail, aggregating the area into 15 regions.



OECD Europe

- United Kingdom
- Germany
- France
- Italy
- Other OECD Europe

Non-OECD Europe

- Russia
- Other Former Soviet Union
- Other Non-OECD Europe

North America

- United States
- Canada

Middle East

-Saudi Arabia - Iran
- Iraq - UAE - Kuwait
- Qatar - Oman
- Other Middle East

Asia

- Japan - China - India
- Chinese Taipei - Korea
- Hong Kong - Indonesia
- Malaysia - Philippines
- Thailand - Viet Nam
- Singapore - Myanmar
- Brunei Darussalam
- Other Asia

Latin America

- Mexico
- Brazil
- Chile
- Other Latin America

Africa

- South Africa (Rep. of)
- North Africa
- Other Africa

Oceania

- Australia
- New Zealand

Modelling framework

Major assumptions

GDP, population, energy prices, exchange rates, international trade, etc.

Macroeconomic model

Calculate GDP-related indices, price indices, activity indices including material production, etc. consistently.

Technology assessment model

Use a bottom-up approach to calculate future efficiencies of appliances, vehicles, etc.

Optimal power generation planning model

Calculate the cost-optimal power generation mix to meet the projected future electricity demand.

Energy supply-demand model

Econometric model to project future energy supply and demand by regression analysis of historical trends based on the energy balance tables data of the International Energy Agency.

This model calculates energy demand, supply and transformation as well as related indices including CO_2 emissions, CO_2 intensities and energy self-sufficiency ratios.

Experts' opinions

World trade model

Use the linear programming (LP) method to calculate the future international trade flows of crude oil, petroleum products, etc.

Computable general equilibrium model

Estimate economic impacts induced by changes in energy supply and demand, based on input-output table data.

Climate change model

Calculate future GHG concentration in the atmosphere, temperature rise, damage caused by climate change, etc.

Scenarios and a case in IEEJ Outlook 2019

Reference Scenario	Advanced Technologies Scenario	No New Coal-fired Power Plant Case
Reflects past trends with the current energy and environment policies. Does not reflect any aggressive policies for low-carbon measures.	Assumes introduction of powerful policies to enhance energy security and address climate change issues. The utmost penetration of low-carbon technologies is promoted.	A hypothetical case in which all new coal-fired power plants would be banned from construction after 2020 substituted by natural gas-fired or solar PV / wind power generation

Examples for technology [2050]			2016	Reference	Advanced Technologies	No New Coal-fired Power Plant[*1]
Energy efficiency	Efficient coal-fired power generation[*2]	2030		30%	70%	-
		2050		90%	100%	-
	ZEV[*3] sales share	2030		11%	20%	Same as Reference
		2050		26%	46%	
	Intensity in steel industry[*4]		286	240	215	
	Insulation in the household (vs. 2016)			Improve by 24.4%	By 27.4%	
Fitting CCS to coal- or natural gas-fired power generation[*5]				None	New plants after 2030	
Zero emission power sources	Nuclear (GW)		406	518	859	
	Solar PV		290	2,110	2,922	5,341
	Wind		465	2,254	3,351	4,671

*1 No New Coal-fired Power Plant (Renewables Substitution) Case *2 Share of ultra super critical, advanced-USC and integrated coal gasification combined cycle in newly built coal-fired power plant *3 ZEV: Battery electric vehicles, plug-in hybrid electric vehicles and fuel cell battery vehicles *4 Energy consumption per crude steel production (toe/kt) *5 Only countries and regions with CO_2 storage potential excluding aquifers

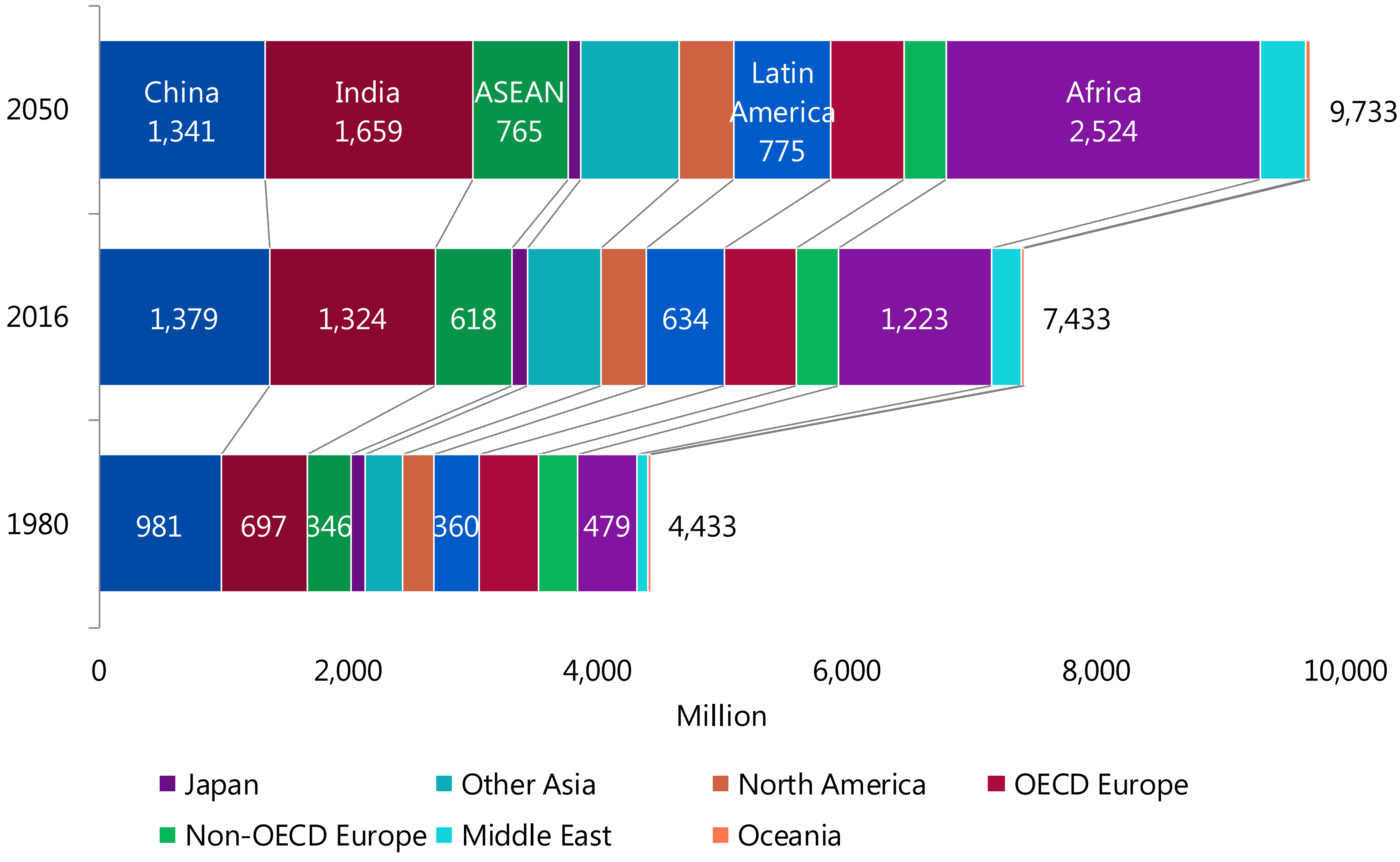
Climate Model Analysis

Reference Path
Emissions path with continuing past trends

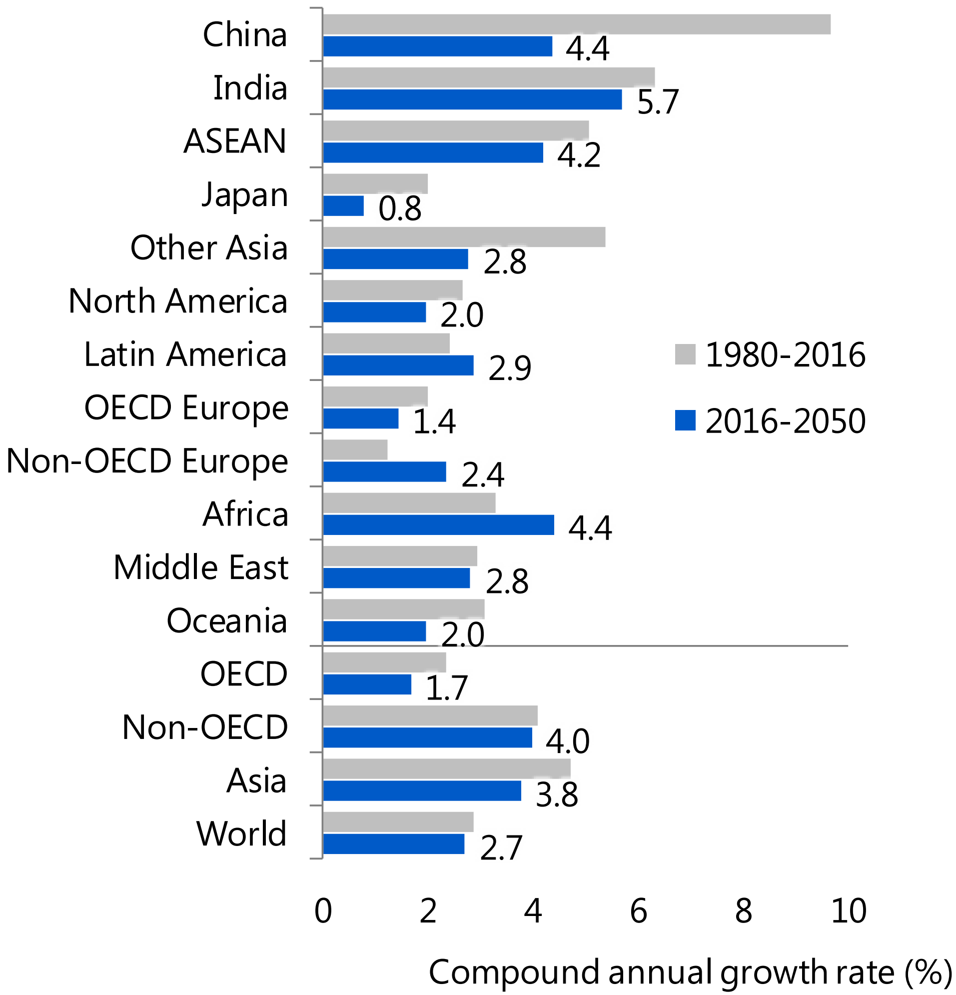
Minimising Cost Path
Emissions path with minimising total cost

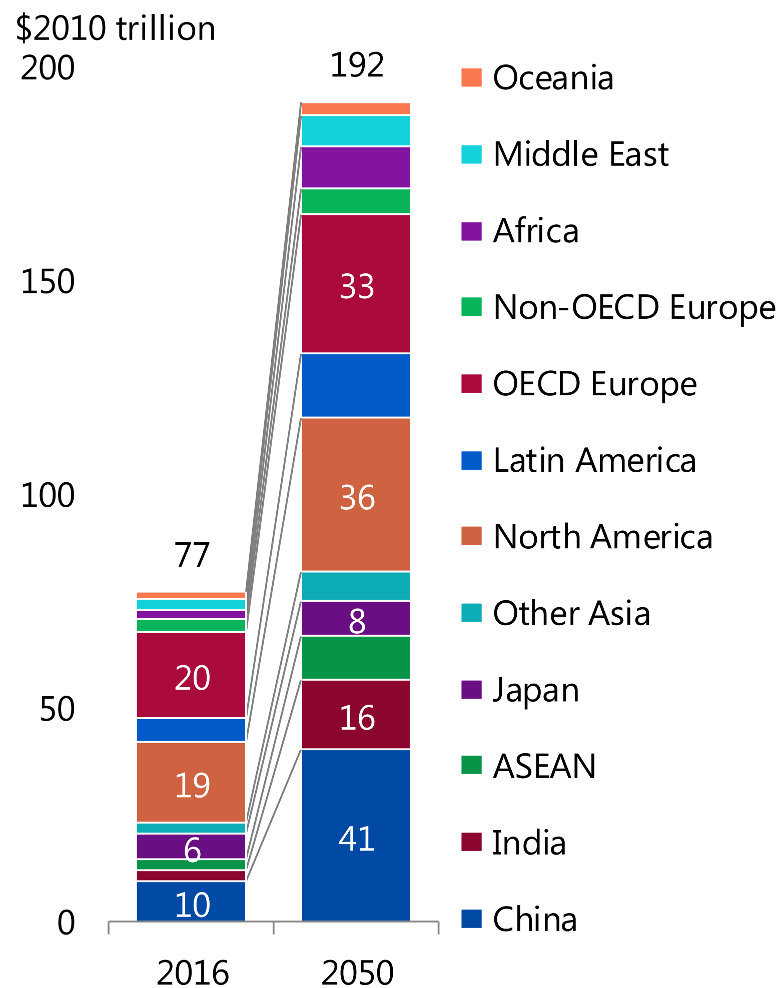
Halving Emissions by 2050 Path
Emissions path reflected RCP2.6 in AR5 by IPCC

Major assumption: Population



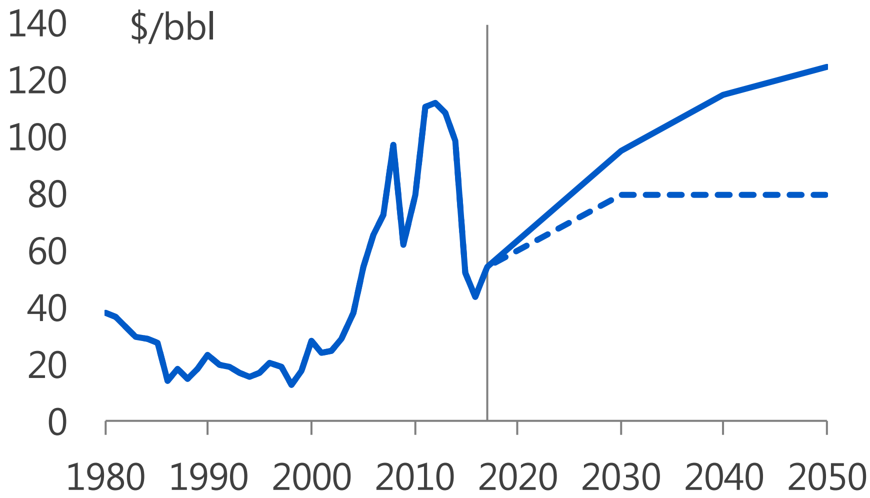
Major assumption: Real GDP



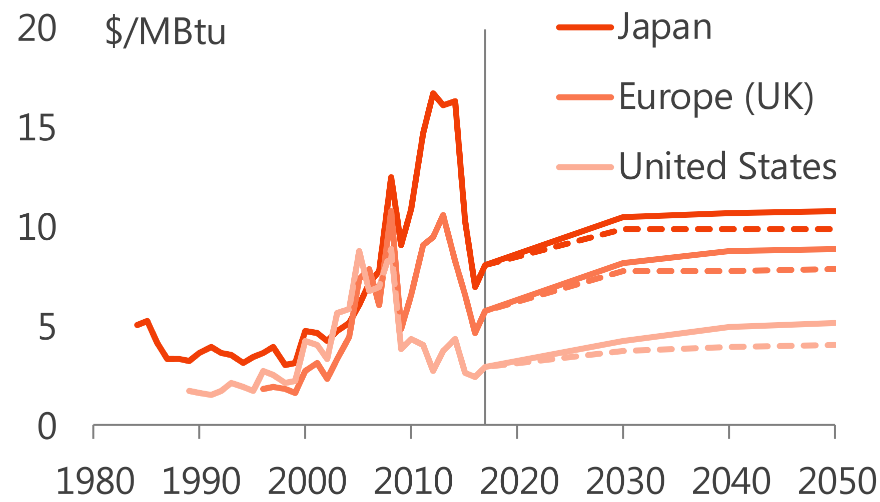


Major assumption: Intl. energy prices

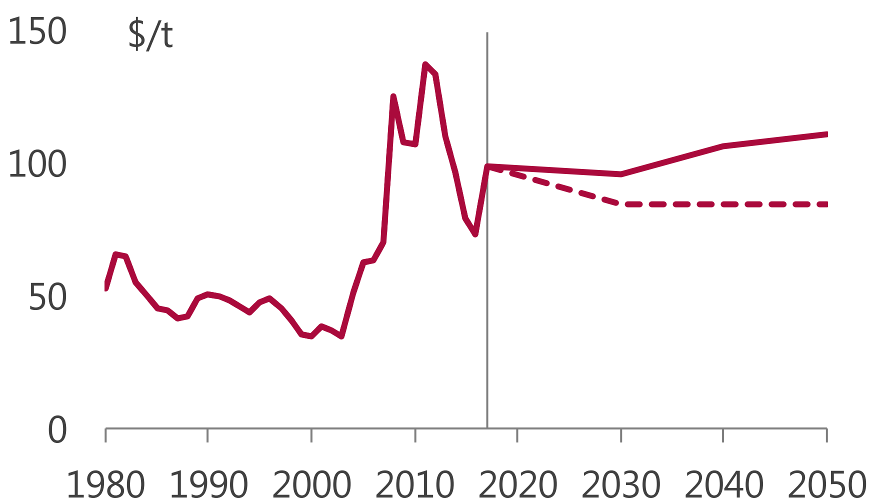
Crude oil



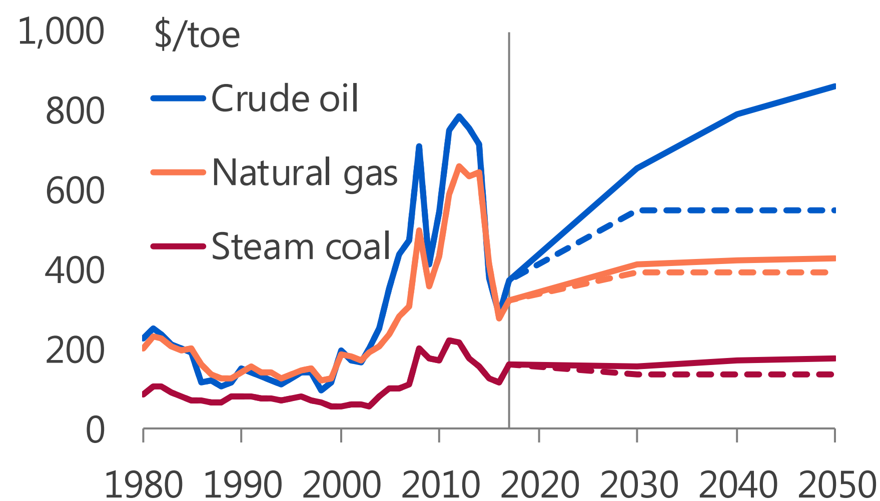
Natural gas



Steam coal



CIF import prices for Japan

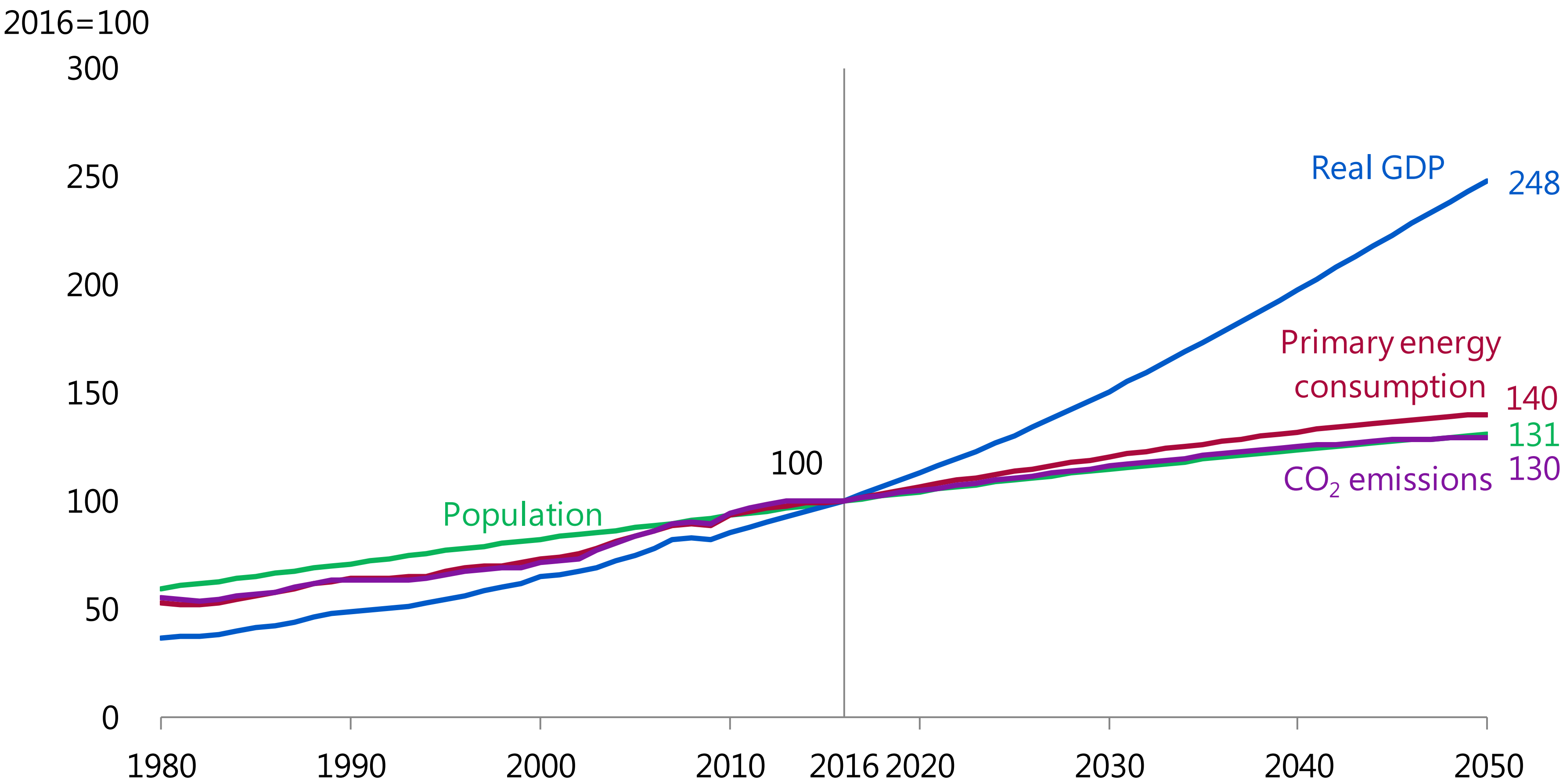


* Historical prices are nominal. Assumed future prices are real in $2017. Solid lines for the Reference Scenario and dotted lines for the Advanced Technologies Scenario.

Energy outlook in the world and Asia, 2016 - 2050

Reference Scenario

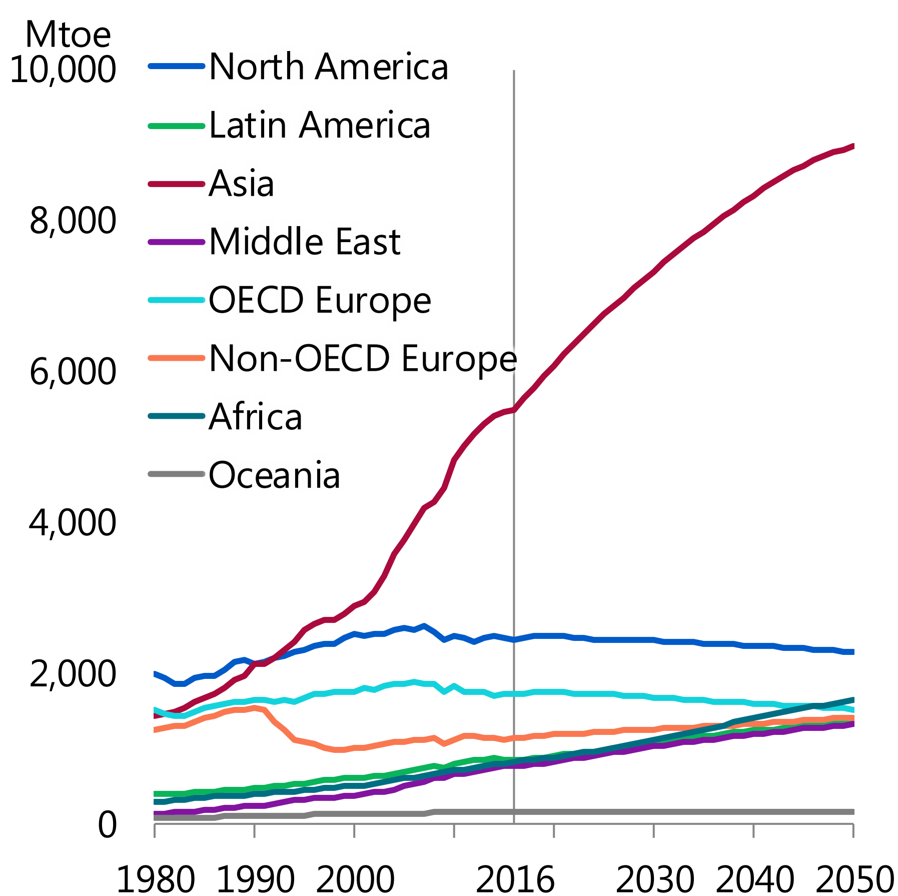
World population, GDP, energy and CO_2



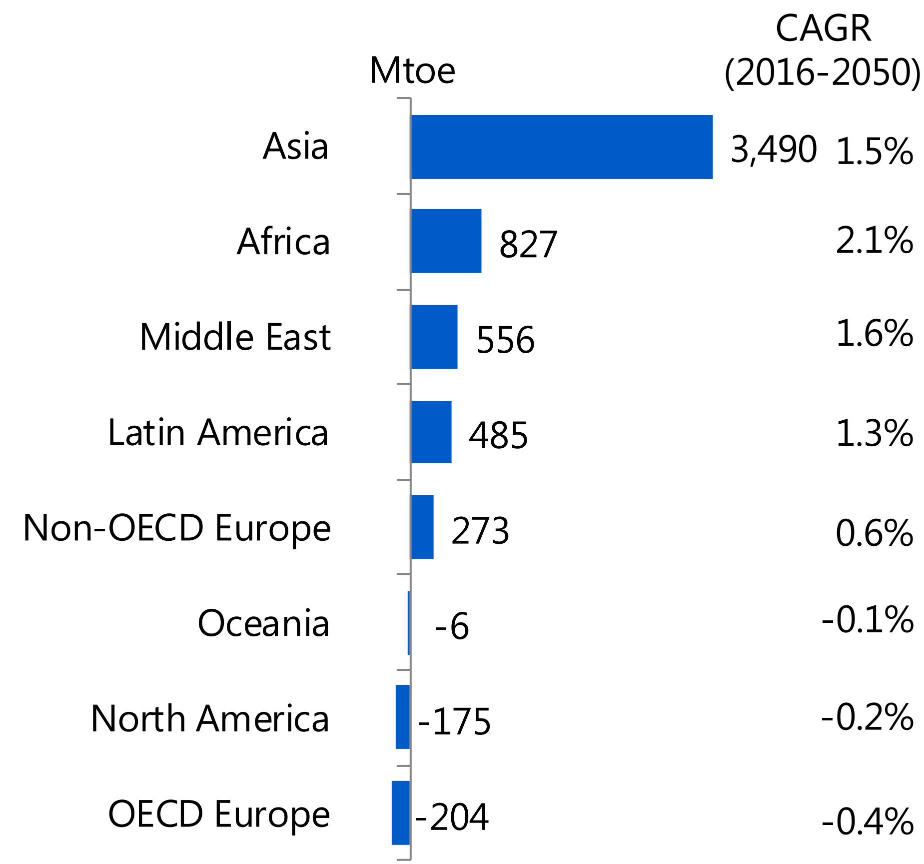
Primary energy consumption (by region)

World

2016 **13.8** Gtoe → (1.4 times) 2050 **19.3** Gtoe



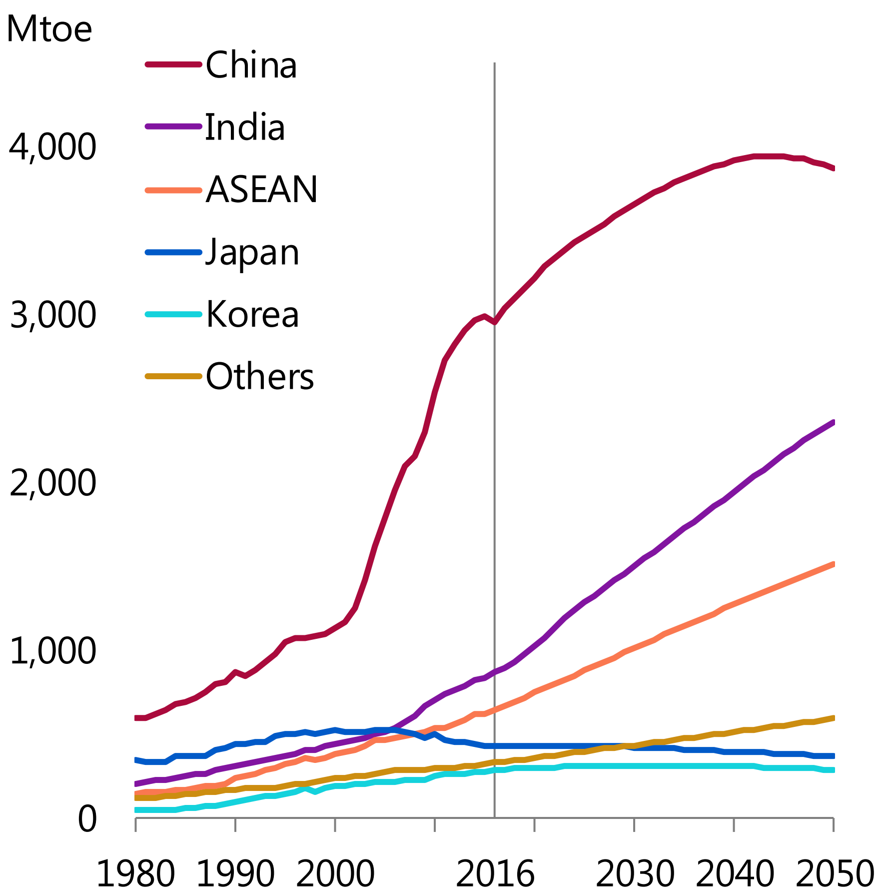
Changes (2016-2050)



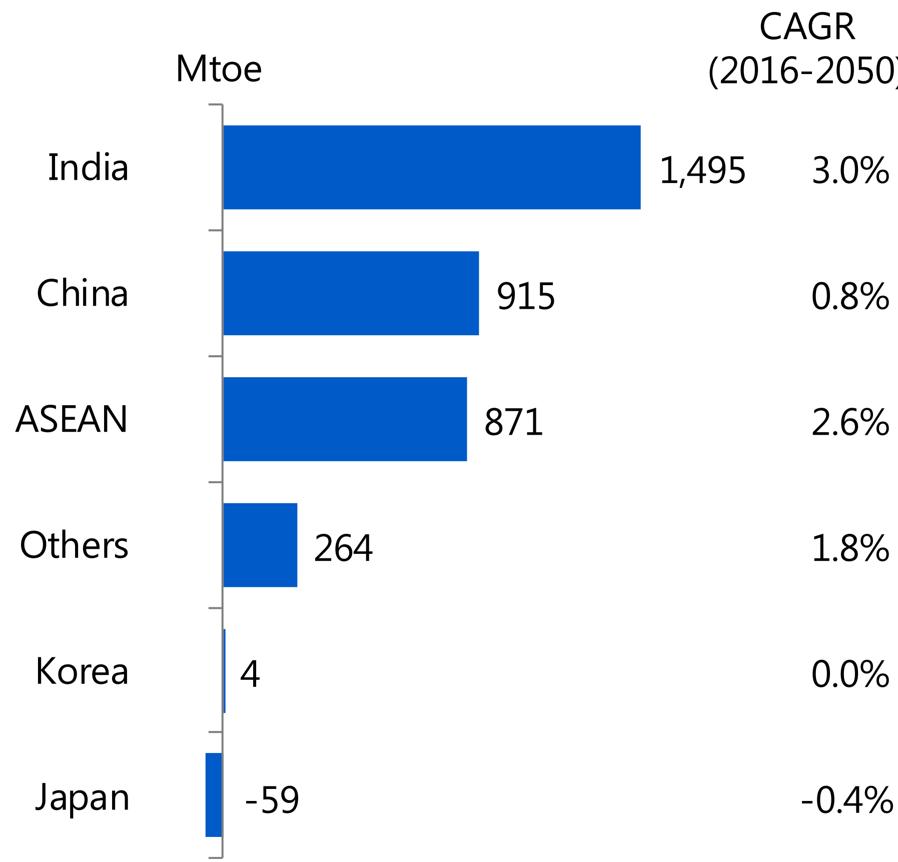
Primary energy consumption (Asia, by region)

Asia

2016	→	2050
5.5 Gtoe	(1.6 times)	**9.0** Gtoe



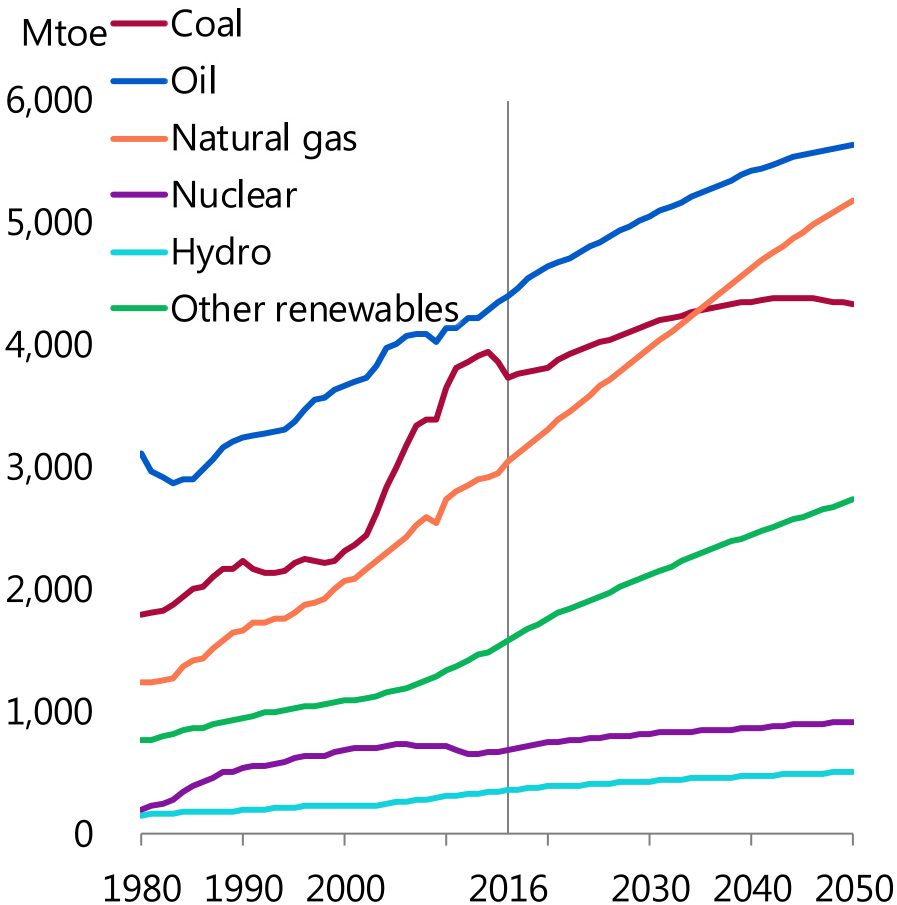
Changes (2016-2050)



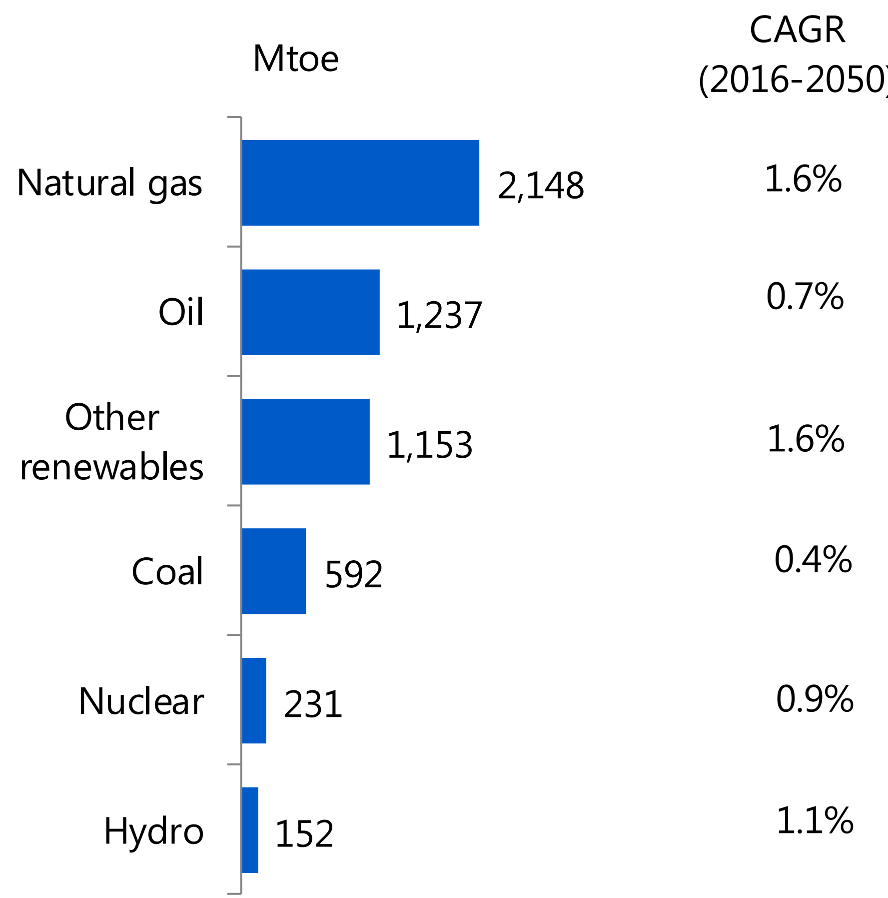
Primary energy consumption (by source)

World

2016 **13.8** Gtoe → (1.4 times) 2050 **19.3** Gtoe



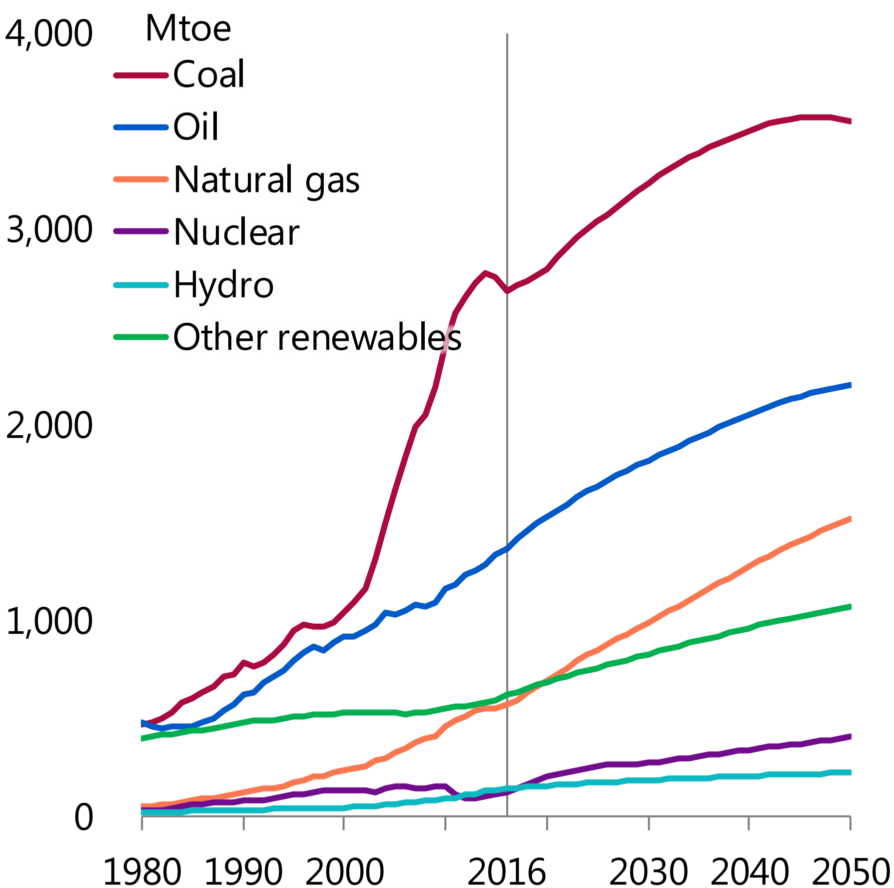
Changes (2016-2050)



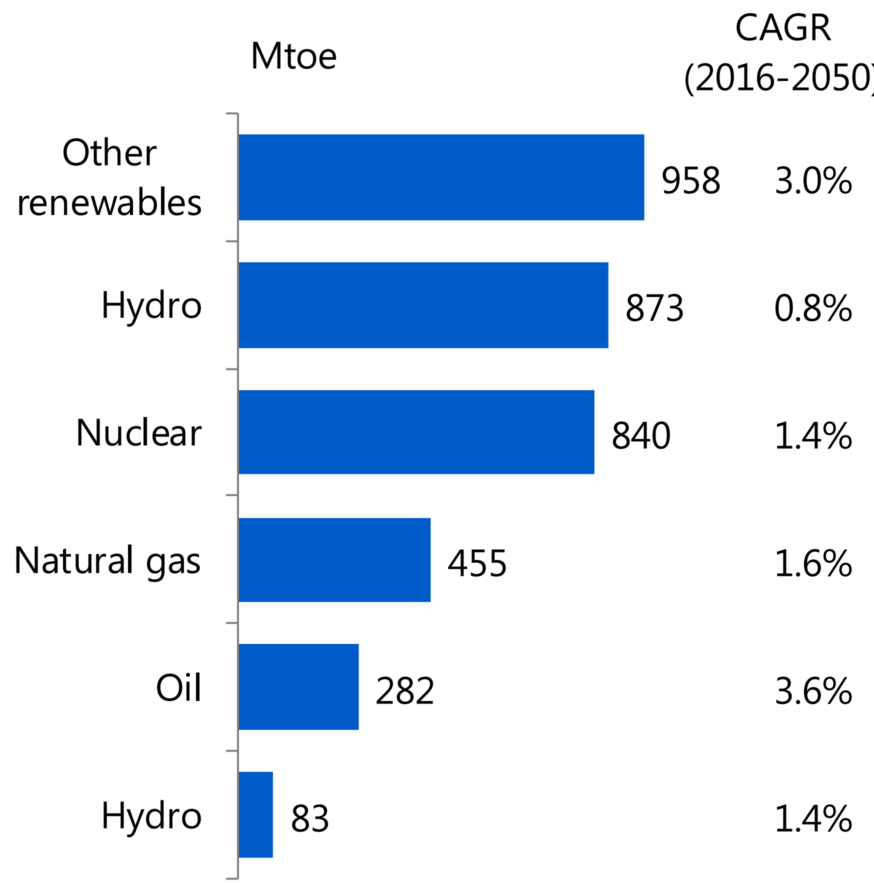
Primary energy consumption (Asia, by source)

Asia

2016 **5.5** Gtoe → (1.6 times) 2050 **9.0** Gtoe



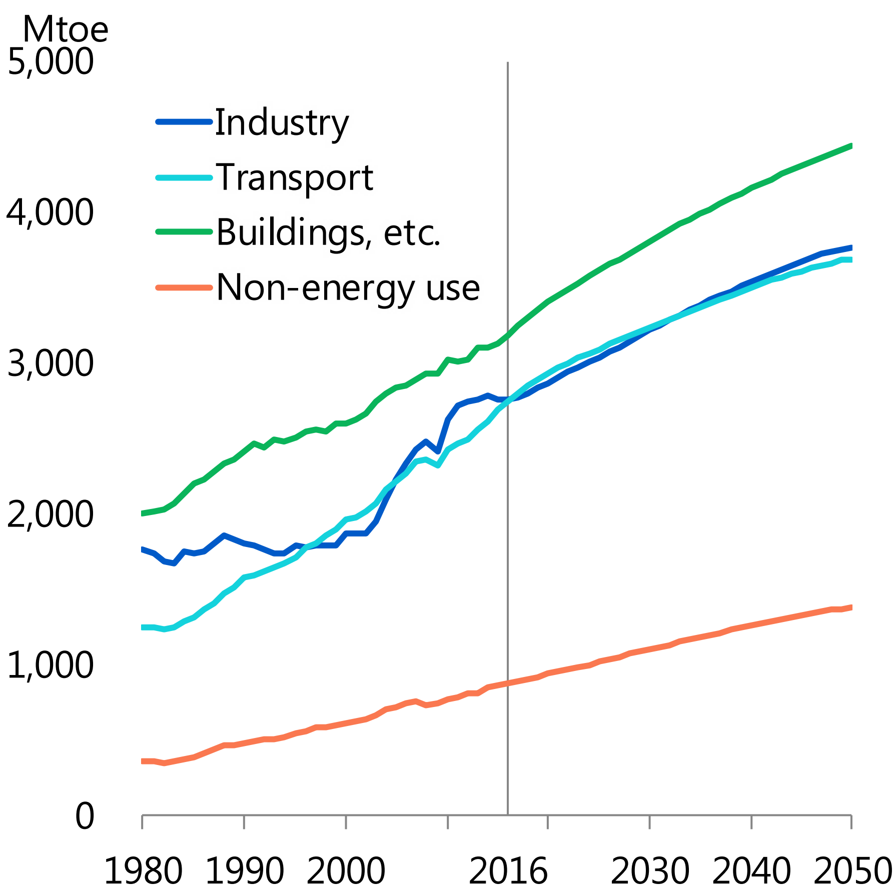
Changes (2016-2050)



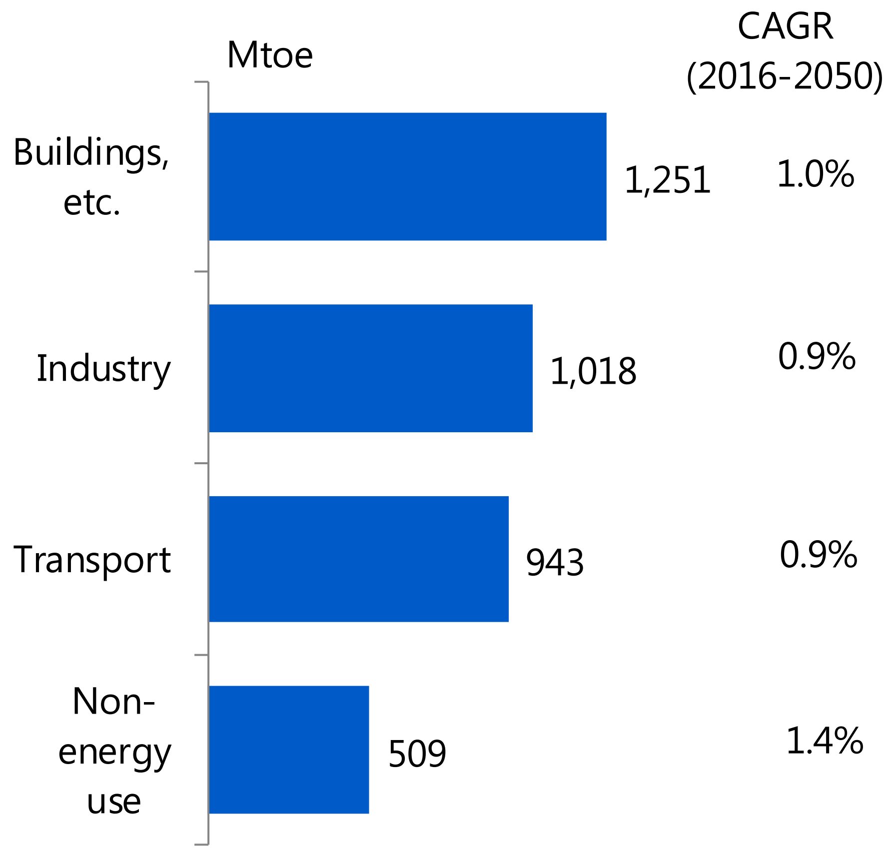
Final energy consumption (by sector)

World

2016 **9.6** Gtoe → (1.4 times) 2050 **13.3** Gtoe



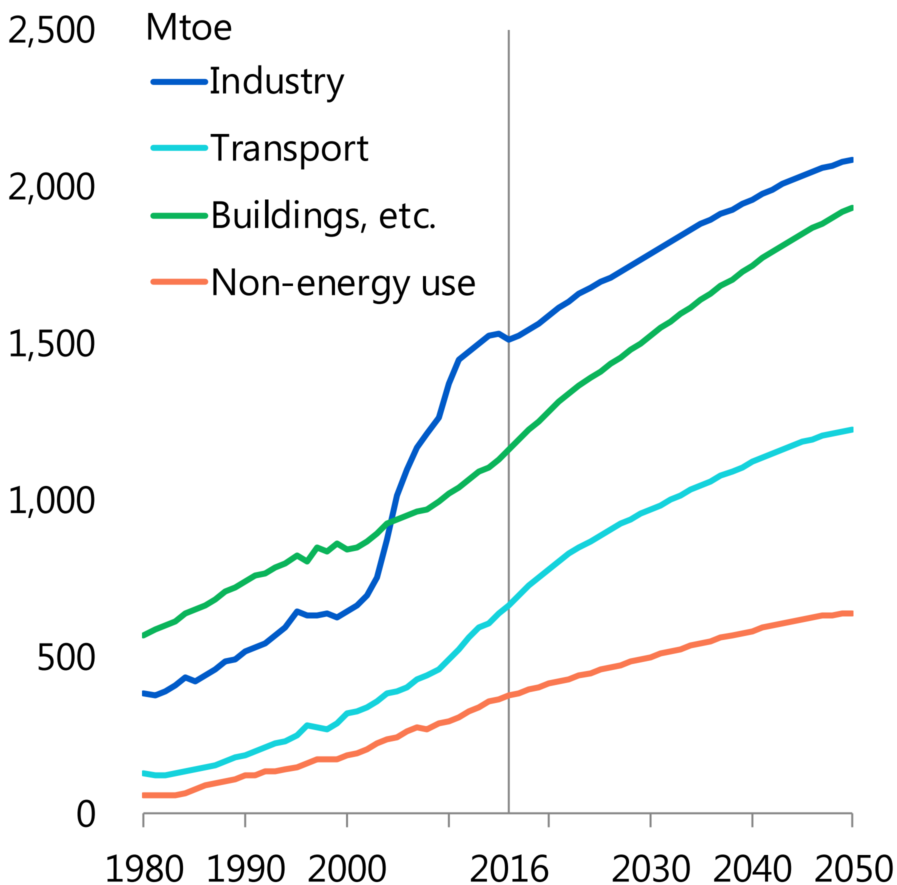
Changes (2016-2050)



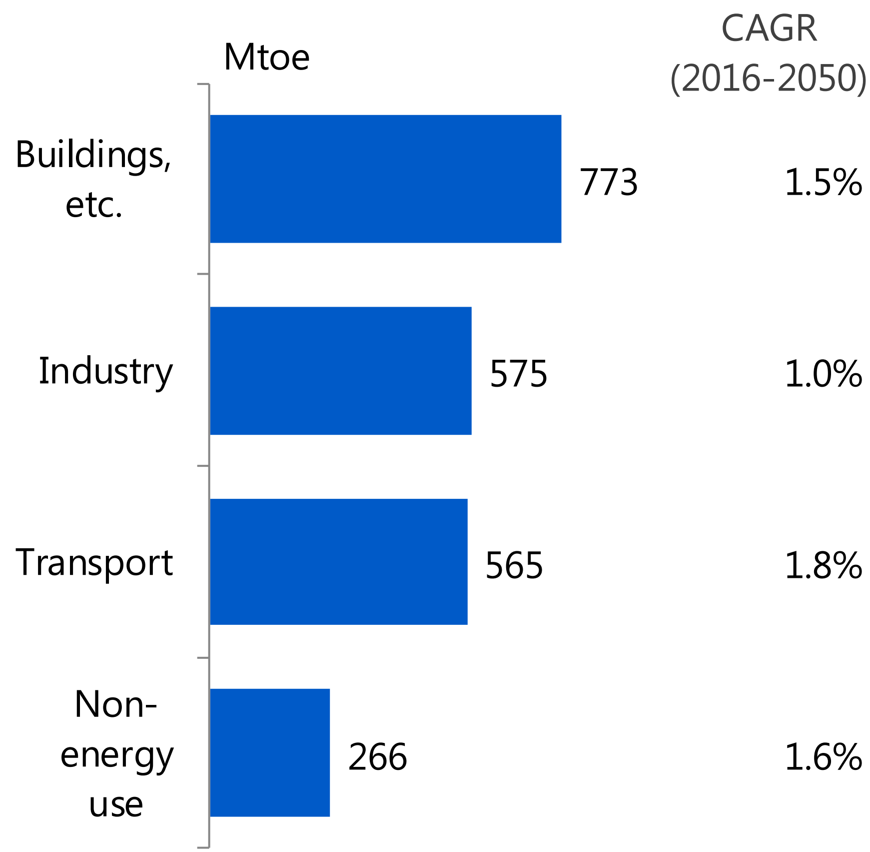
Final energy consumption (Asia, by sector)

Asia

2016 **3.7** Gtoe → (1.6 times) 2050 **5.9** Gtoe



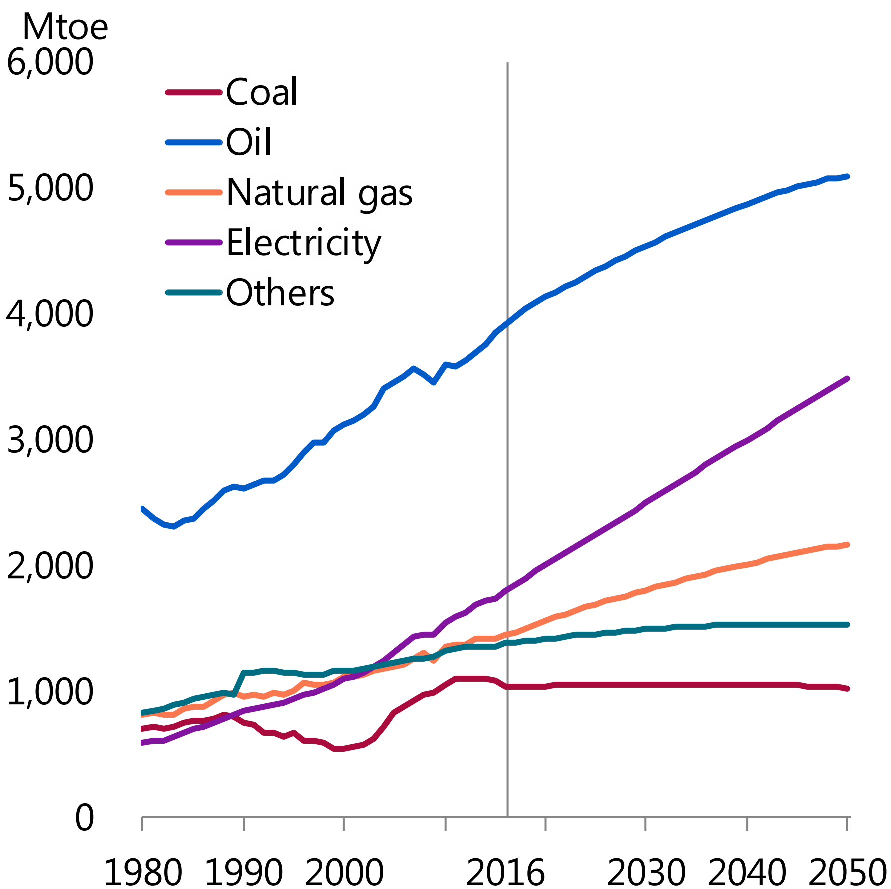
Changes (2016-2050)



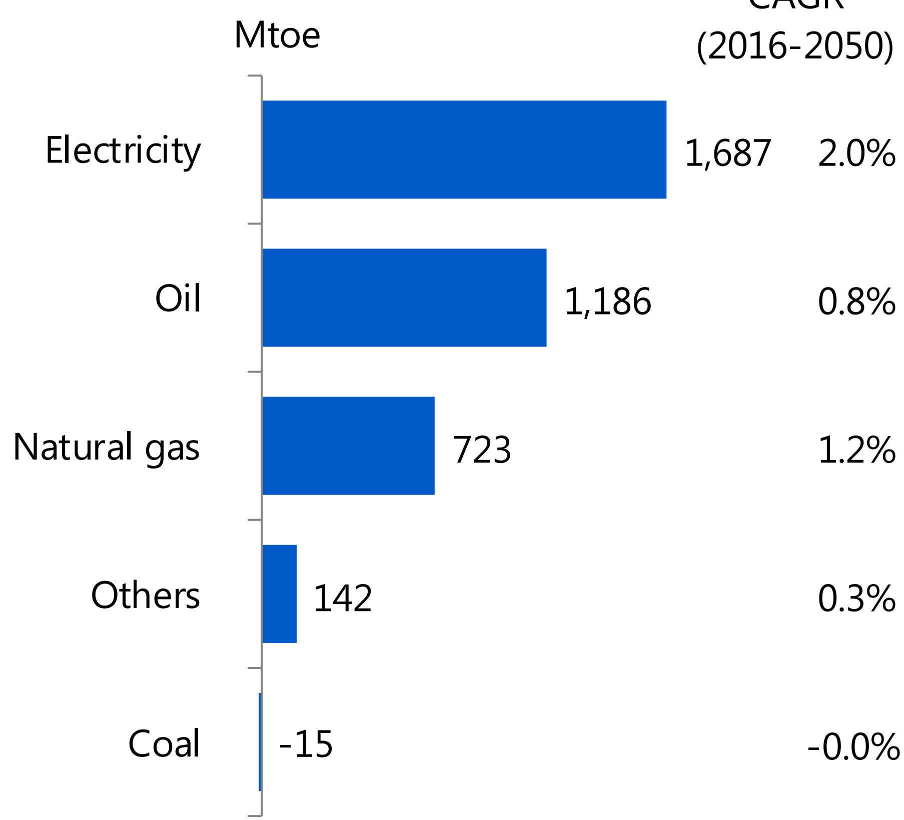
Final energy consumption (by source)

World

2016 **9.6** Gtoe → (1.4 times) 2050 **13.3** Gtoe



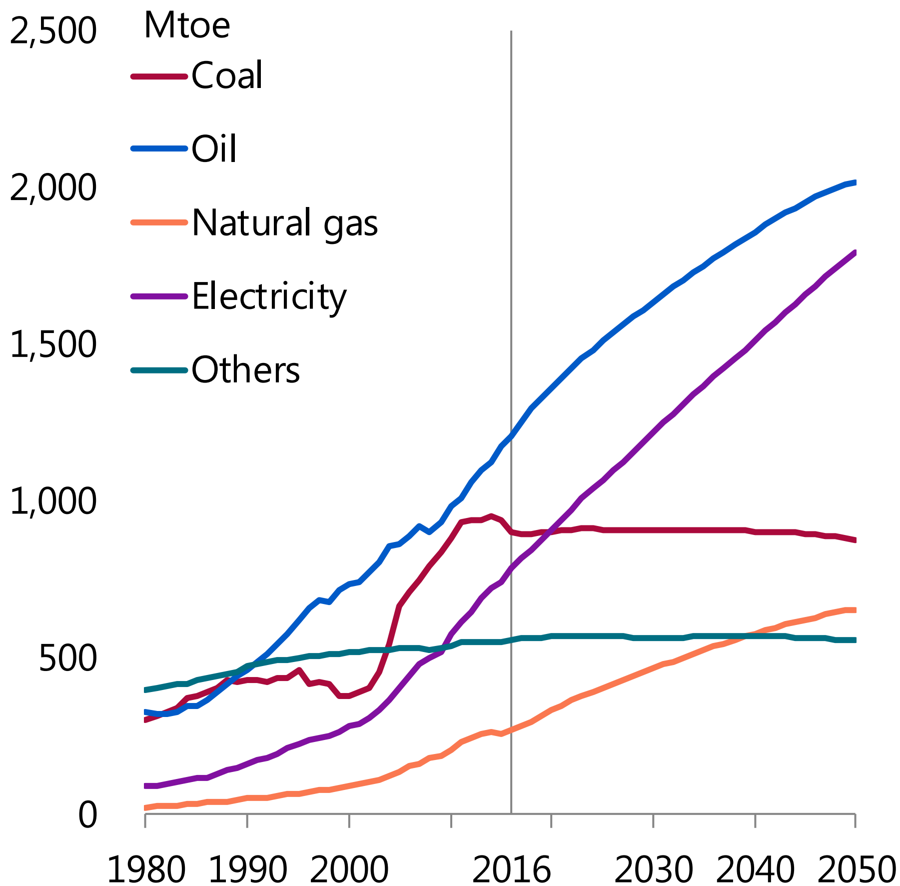
Changes (2016-2050)



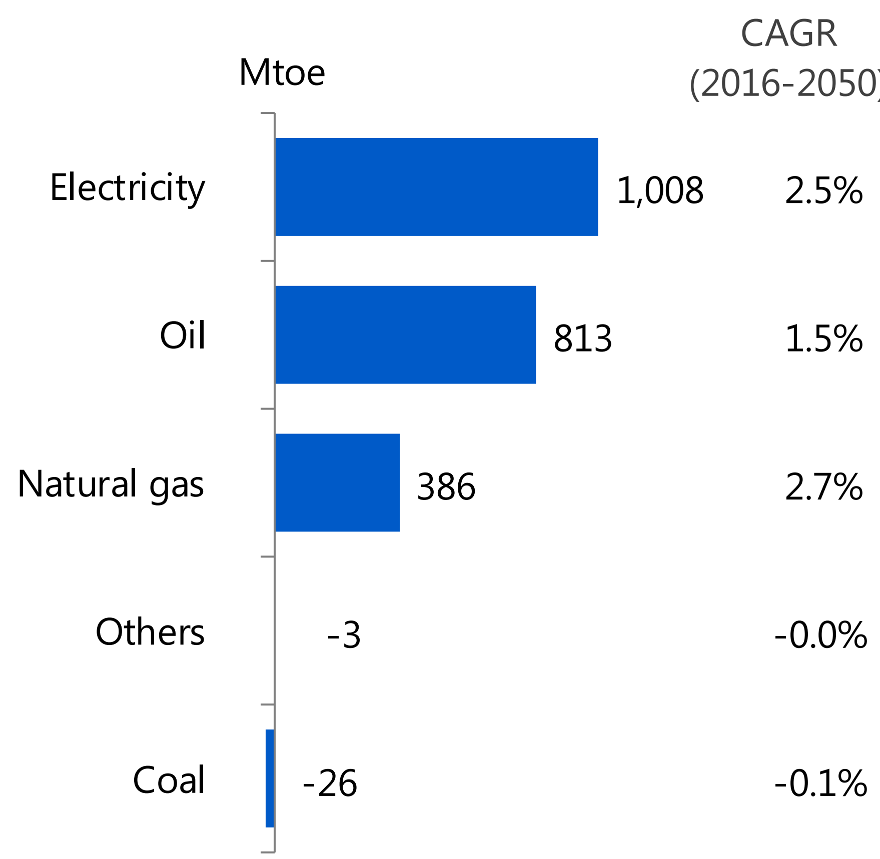
Final energy consumption (Asia, by source)

Asia

2016	→	2050
3.7 Gtoe	(1.6 times)	**5.9** Gtoe

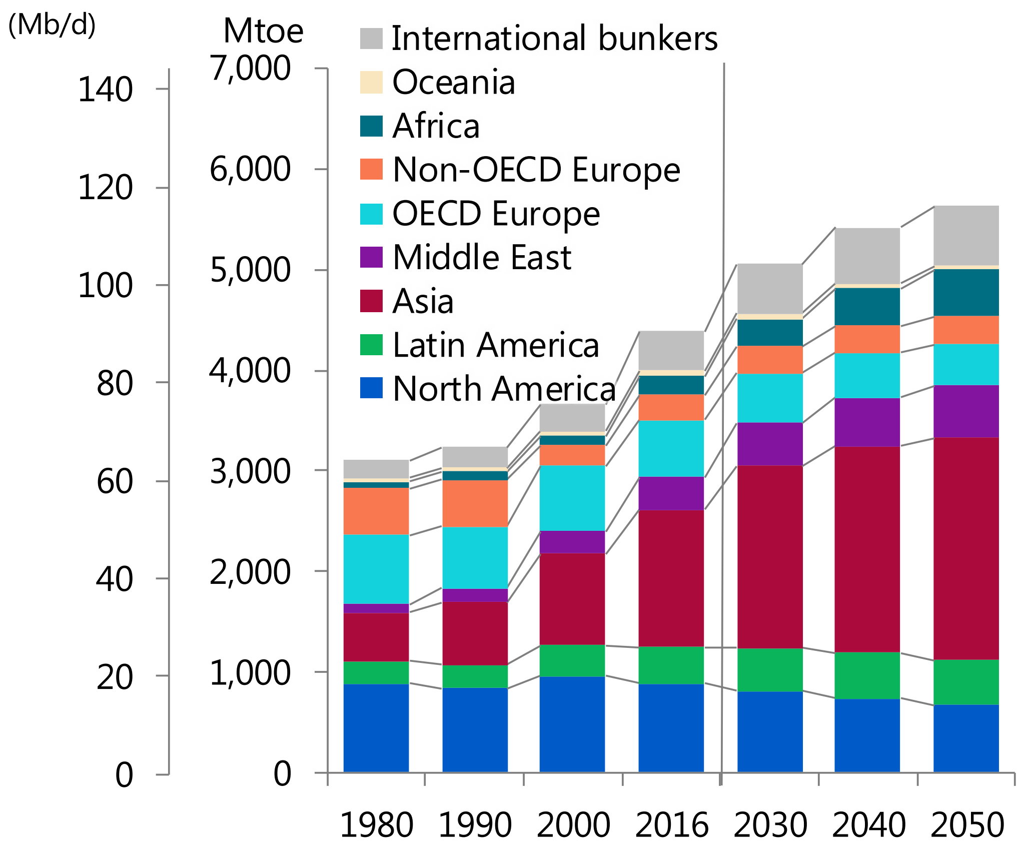


Changes (2016-2050)

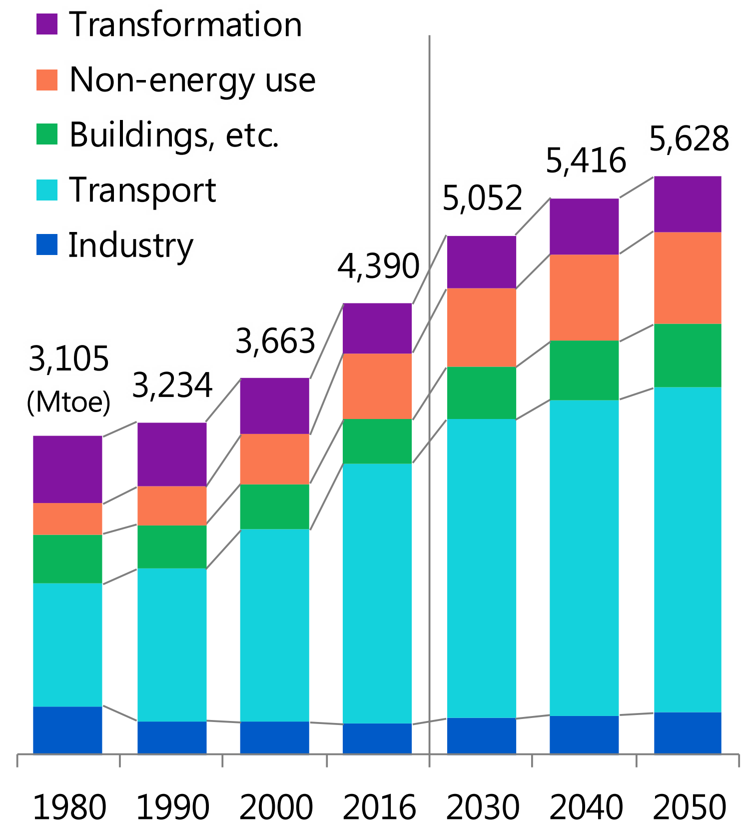


Oil consumption

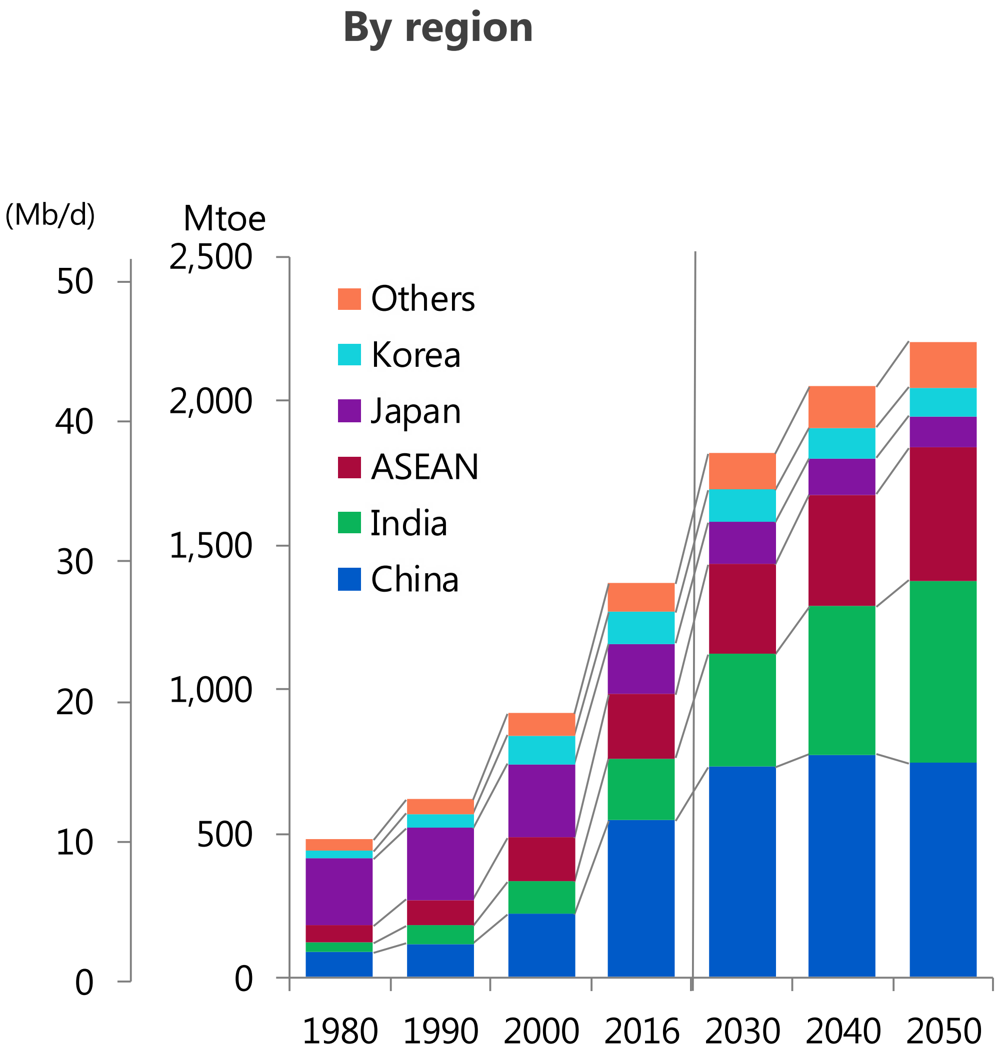
By region

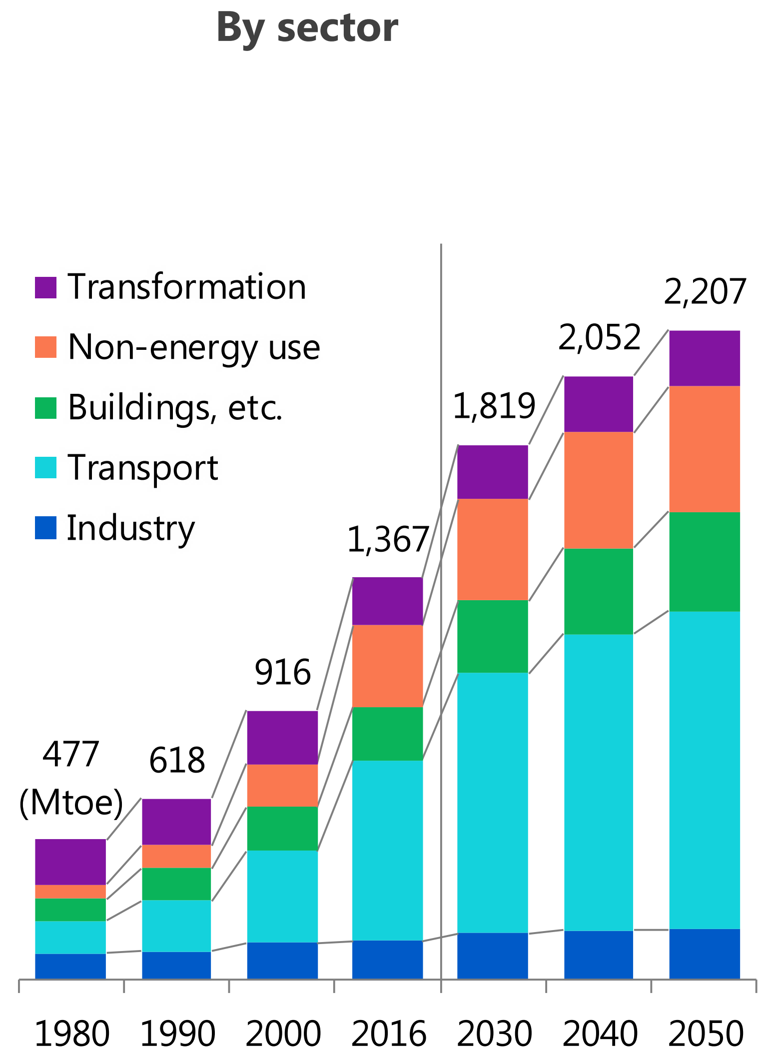


By sector

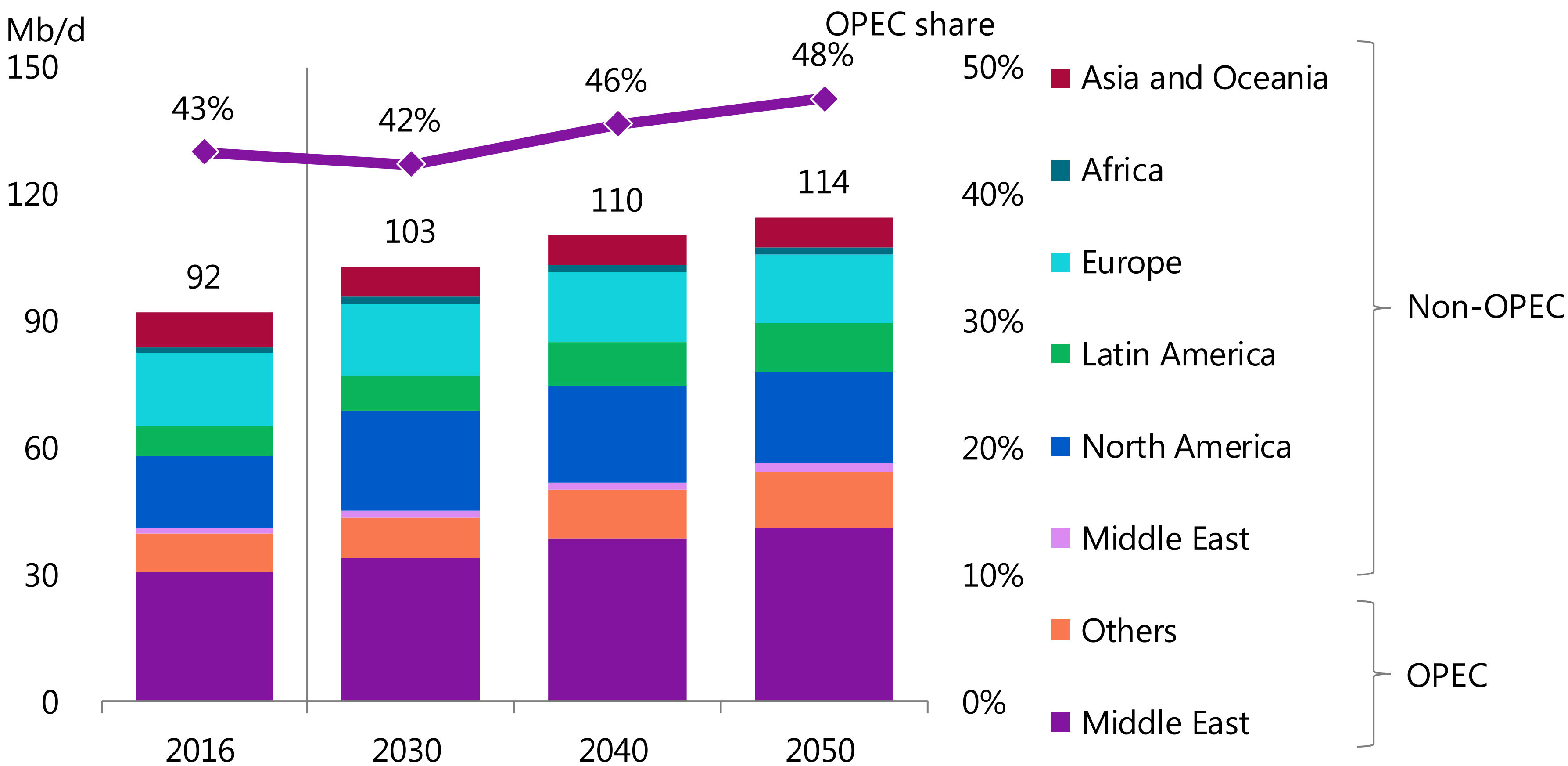


Oil consumption (Asia)

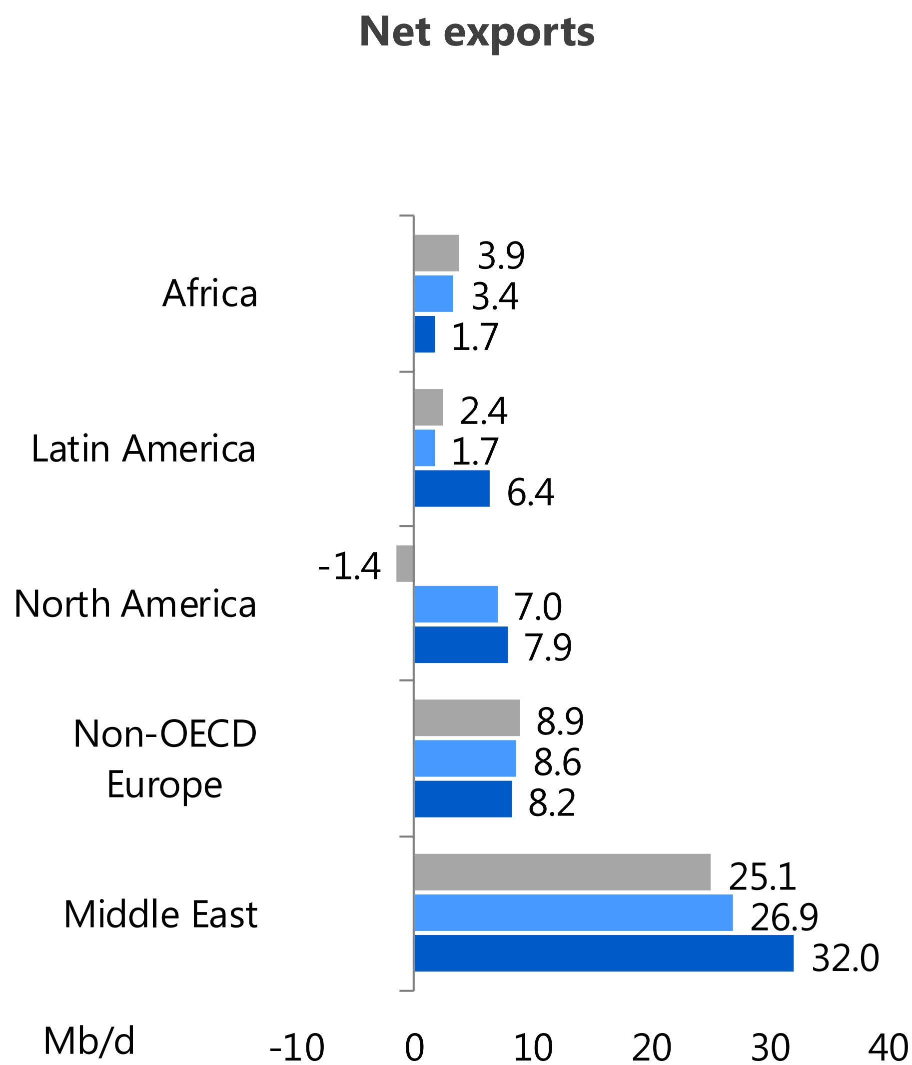


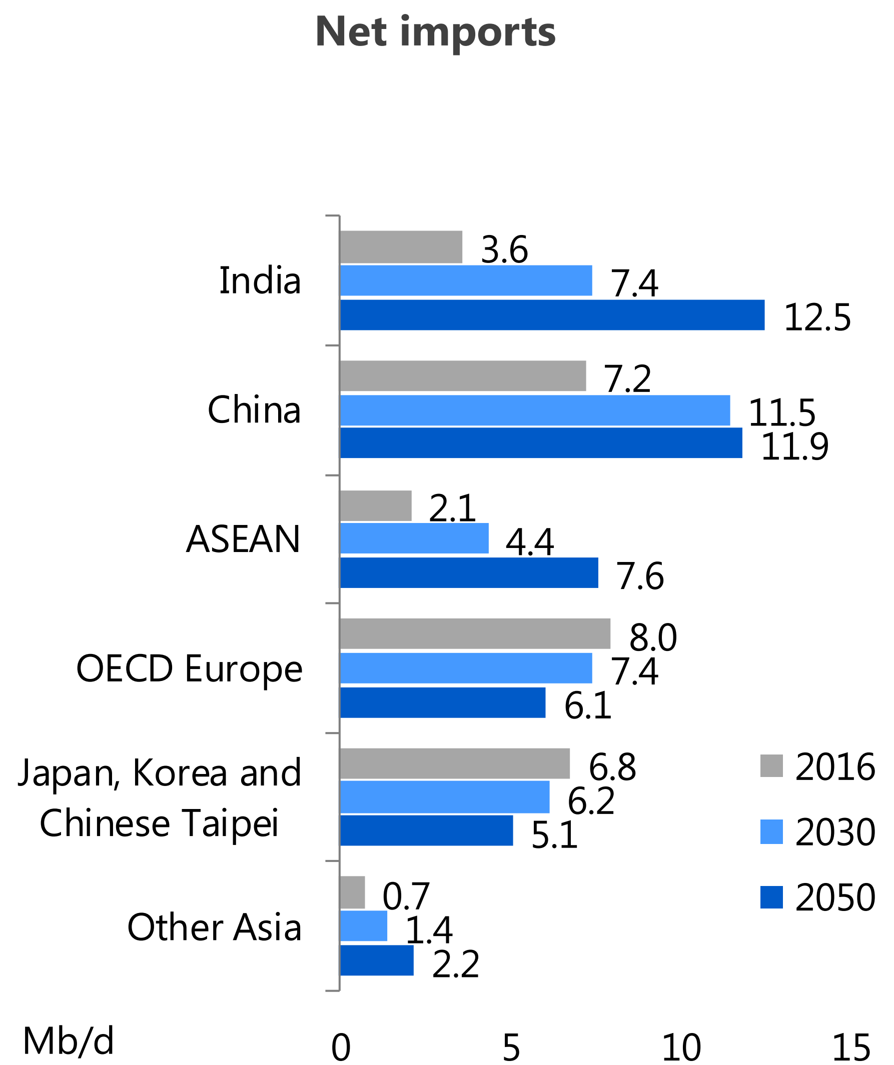


Crude oil production

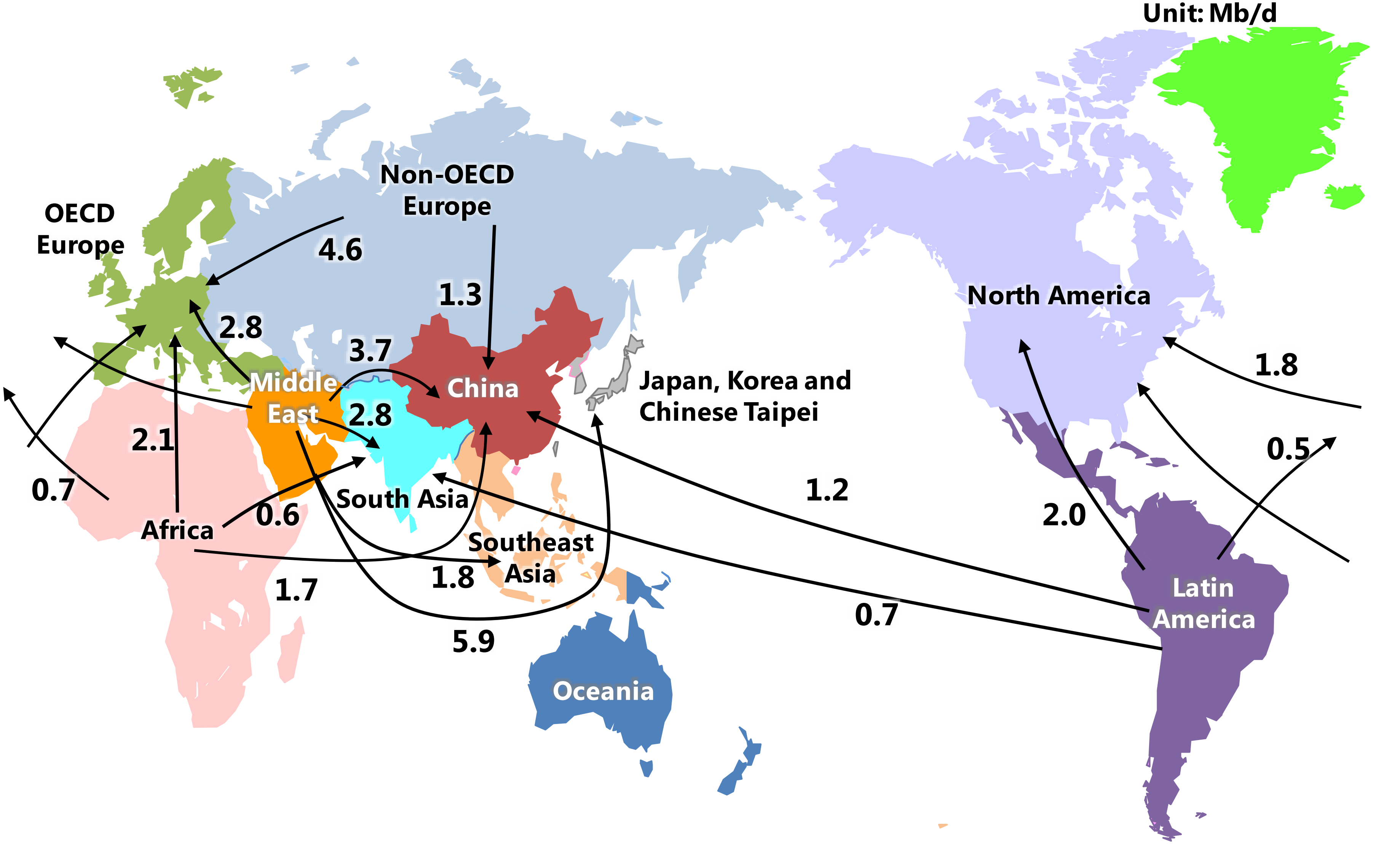


Oil net exports / imports

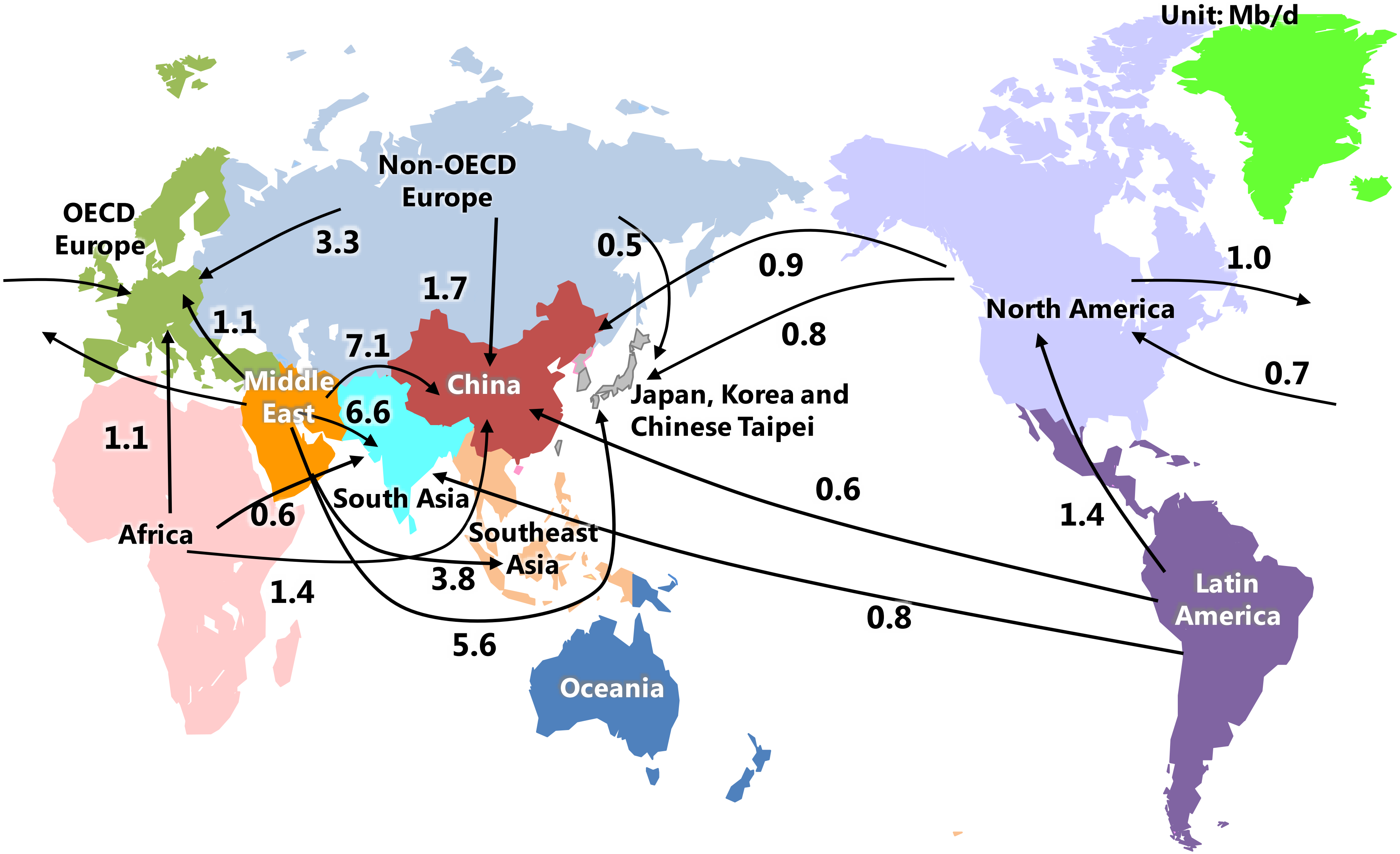




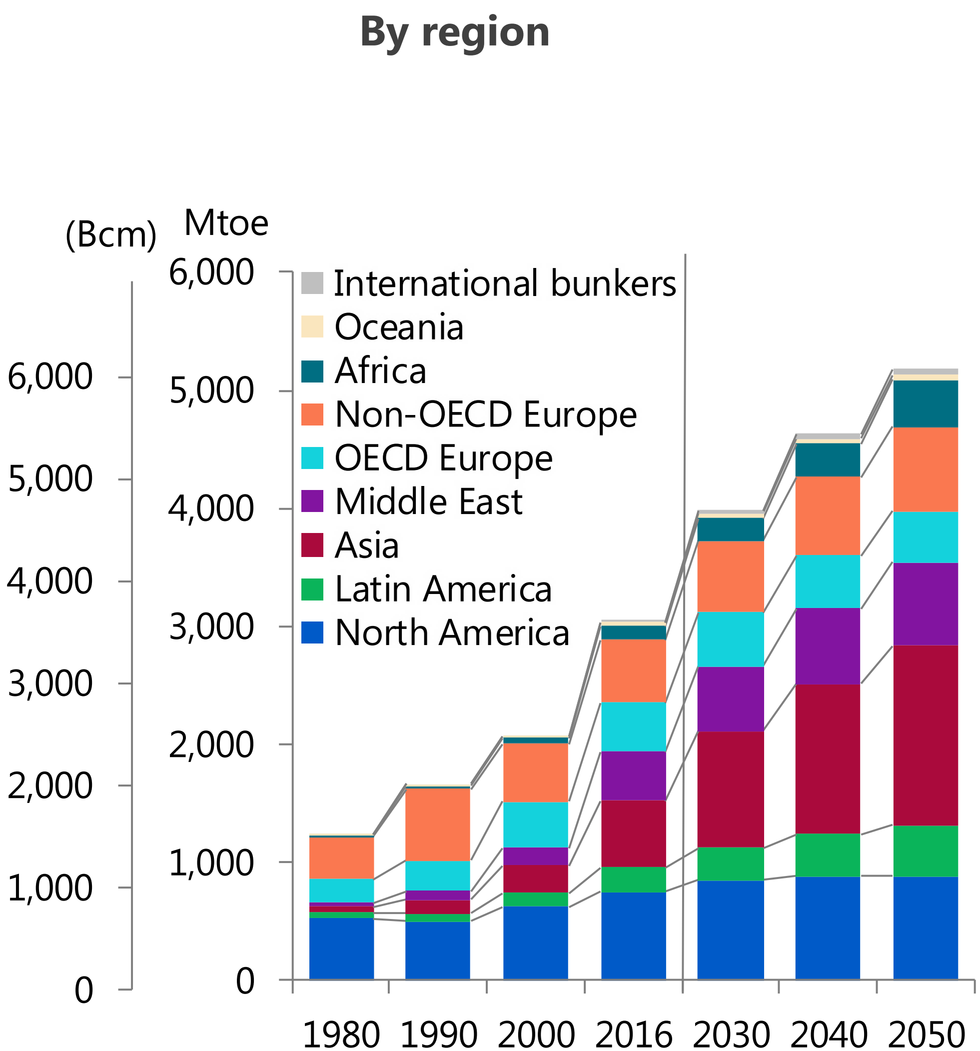
Major crude oil trade flows (2017)

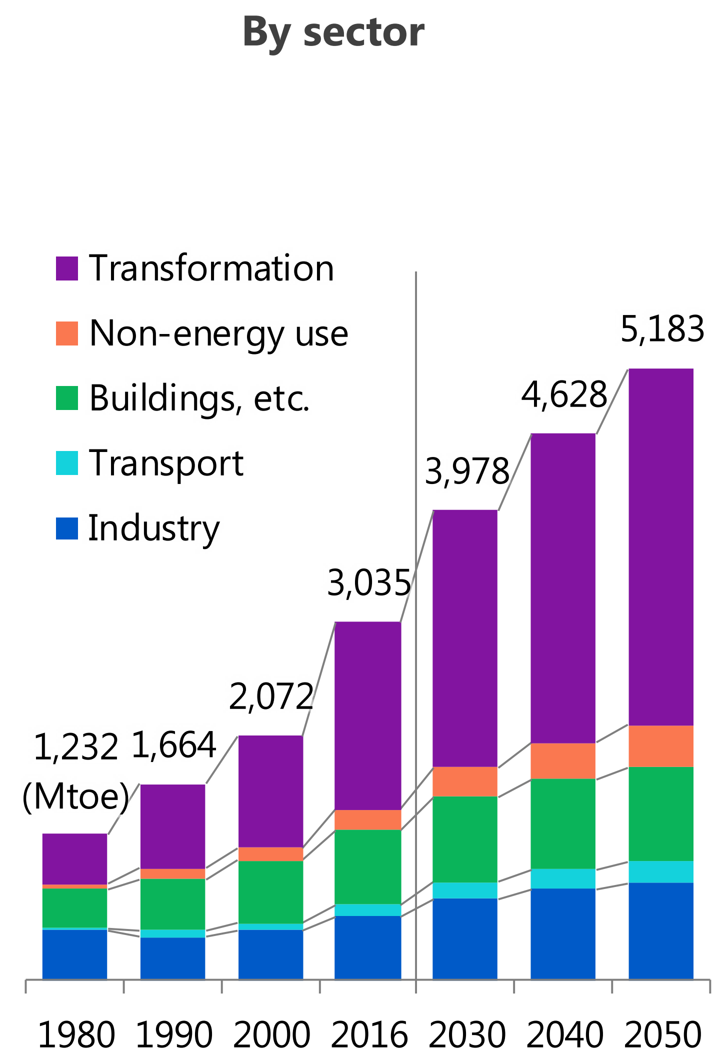


Major crude oil trade flows (2030)



Natural gas consumption

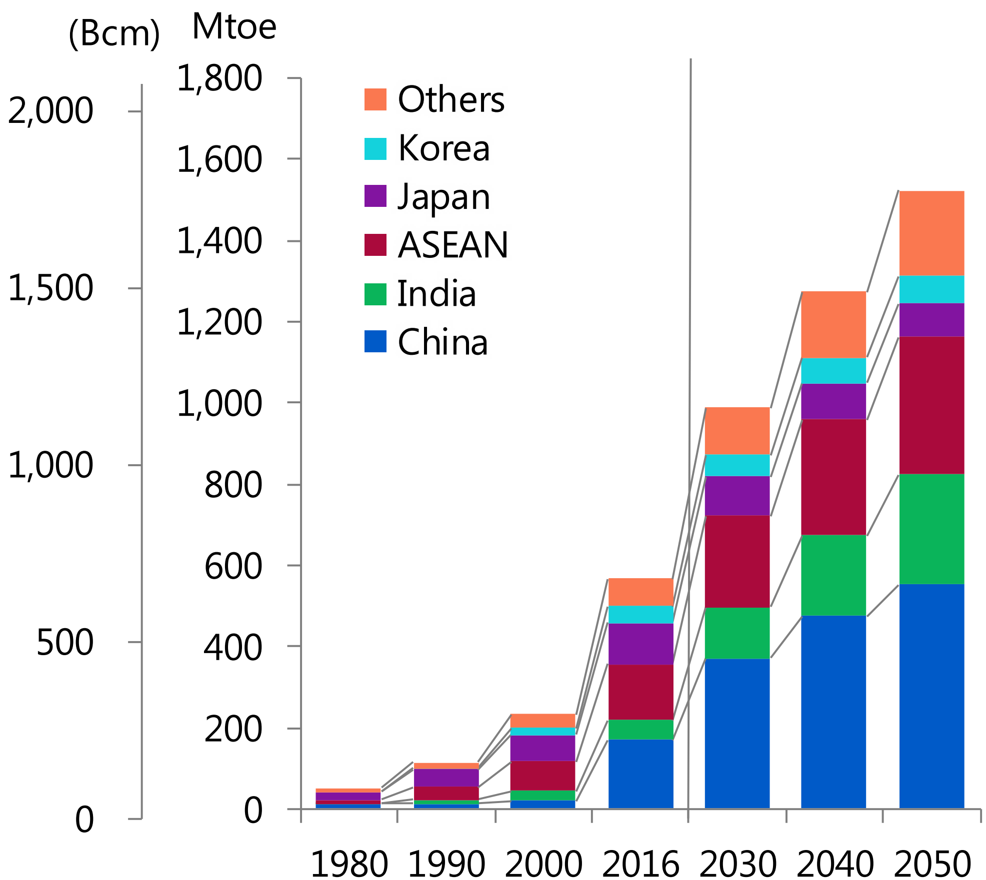




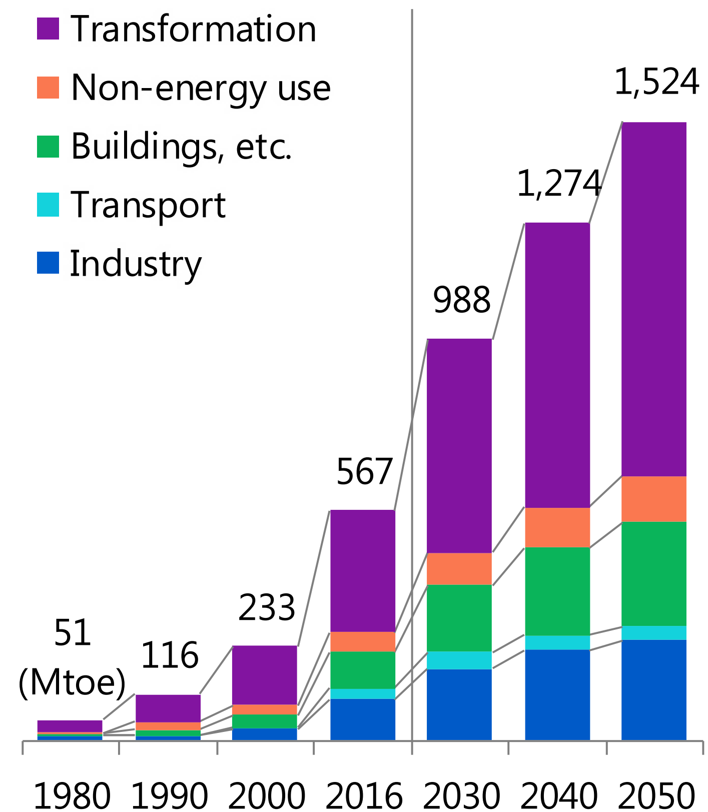
Reference Scenario

Natural gas consumption (Asia)

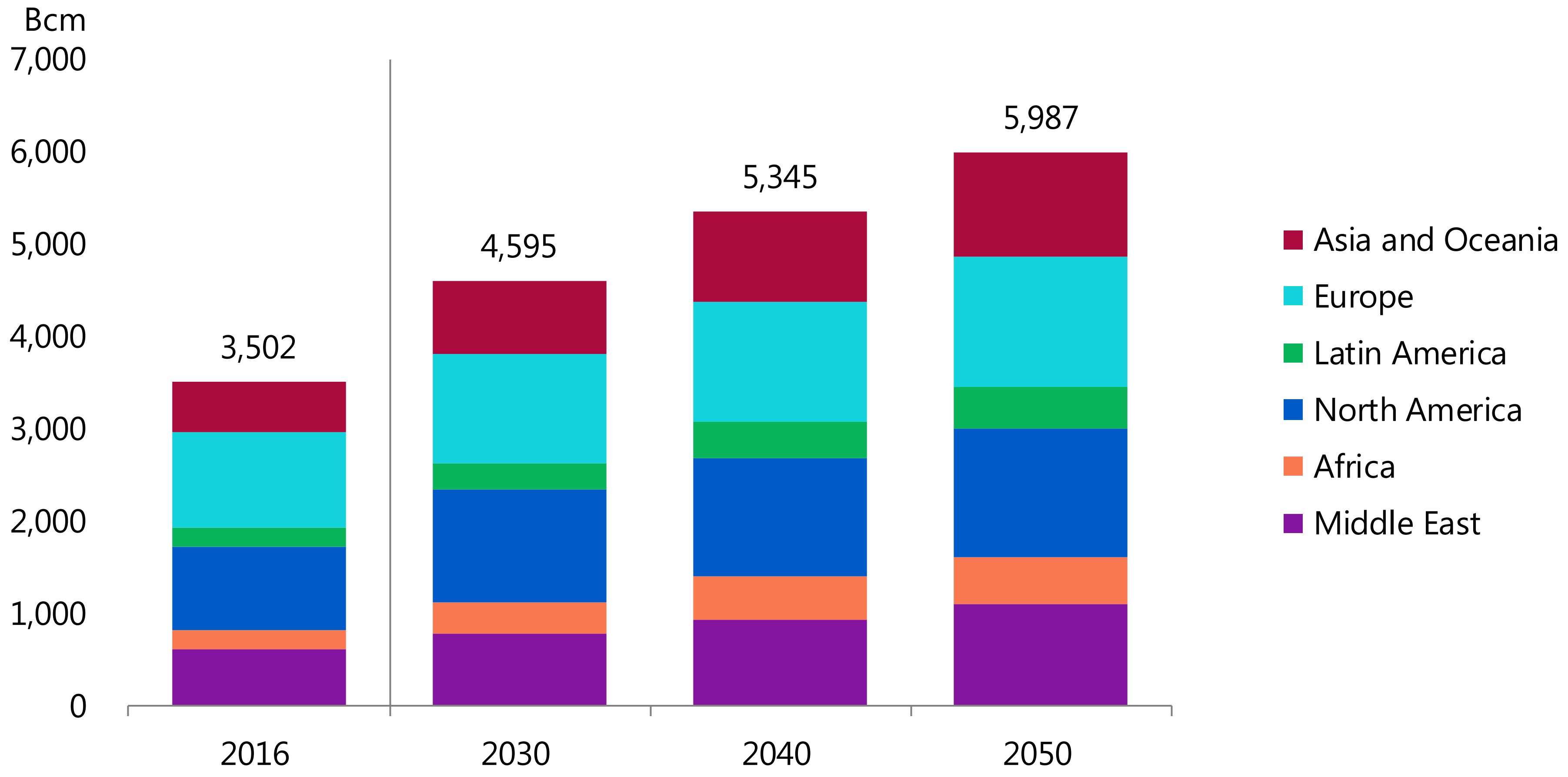
By region



By sector

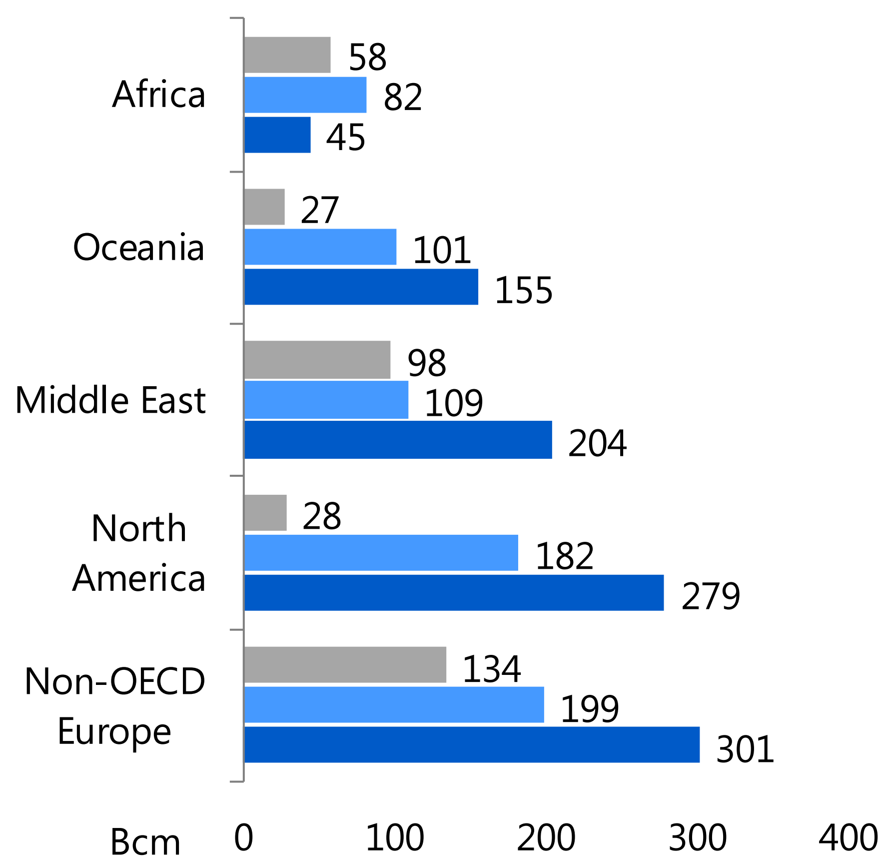


Natural gas production

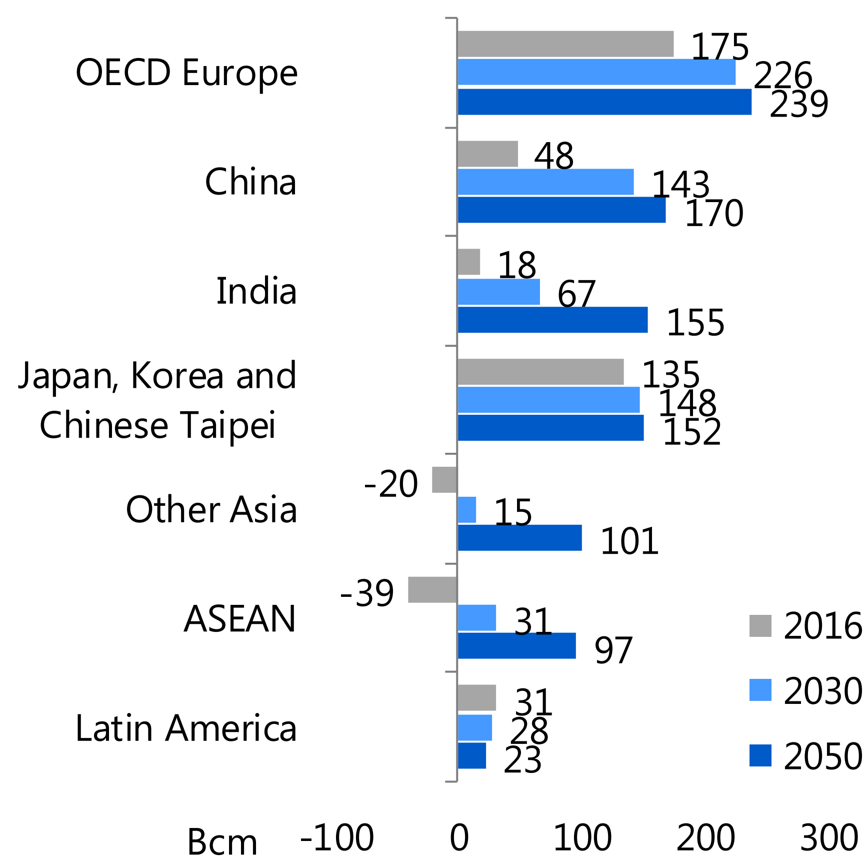


Natural gas net exports / imports

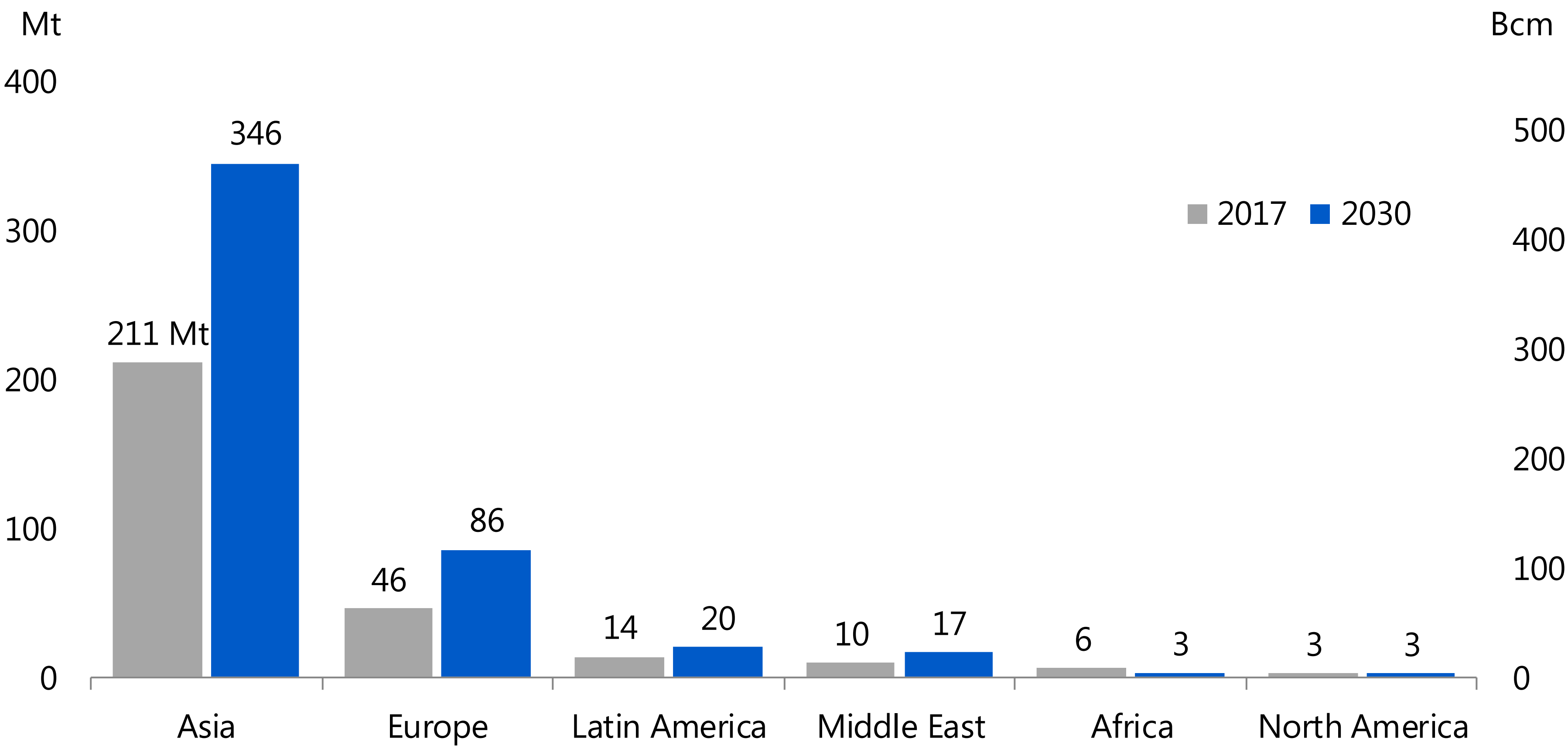
Net exports



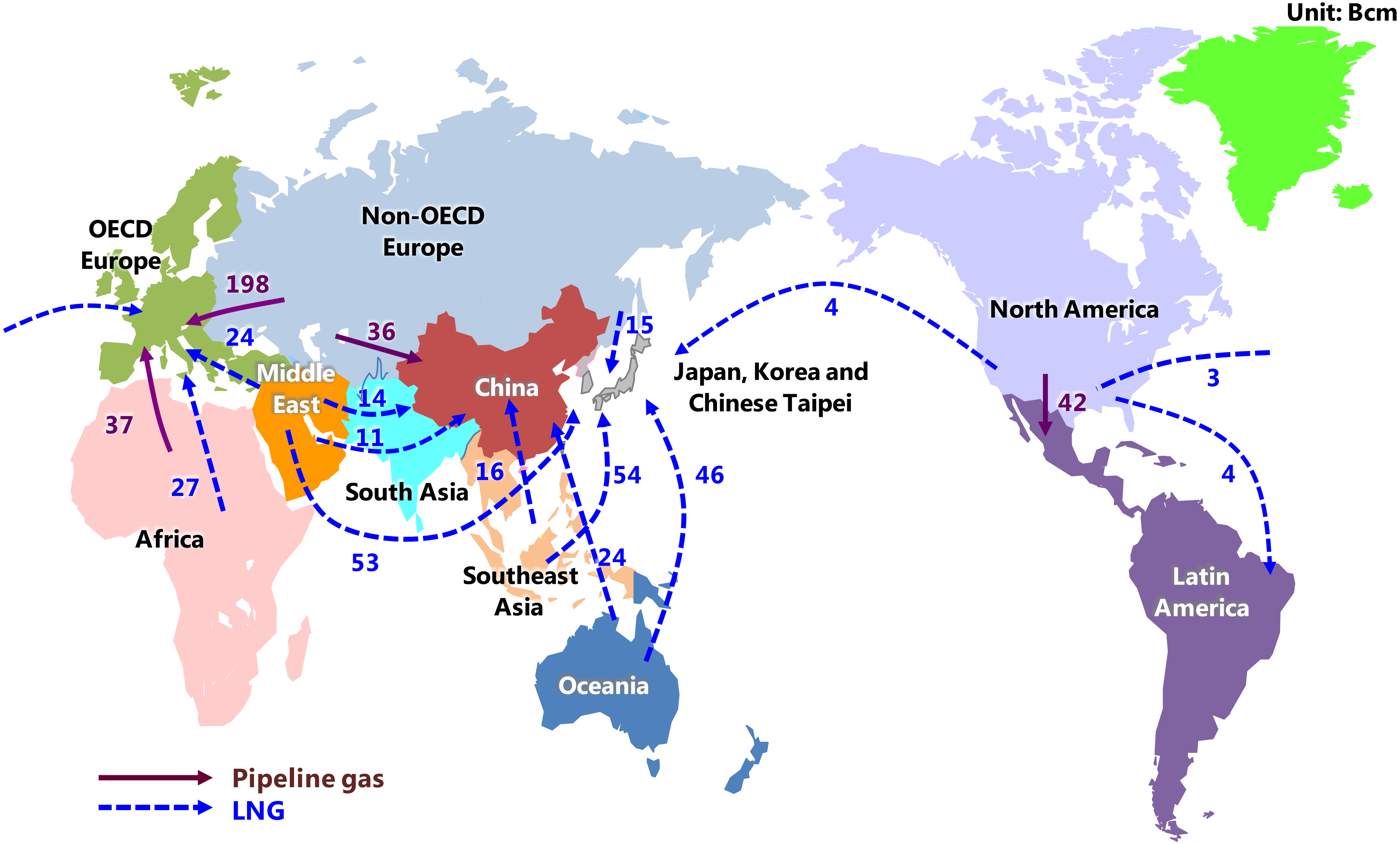
Net imports



LNG imports

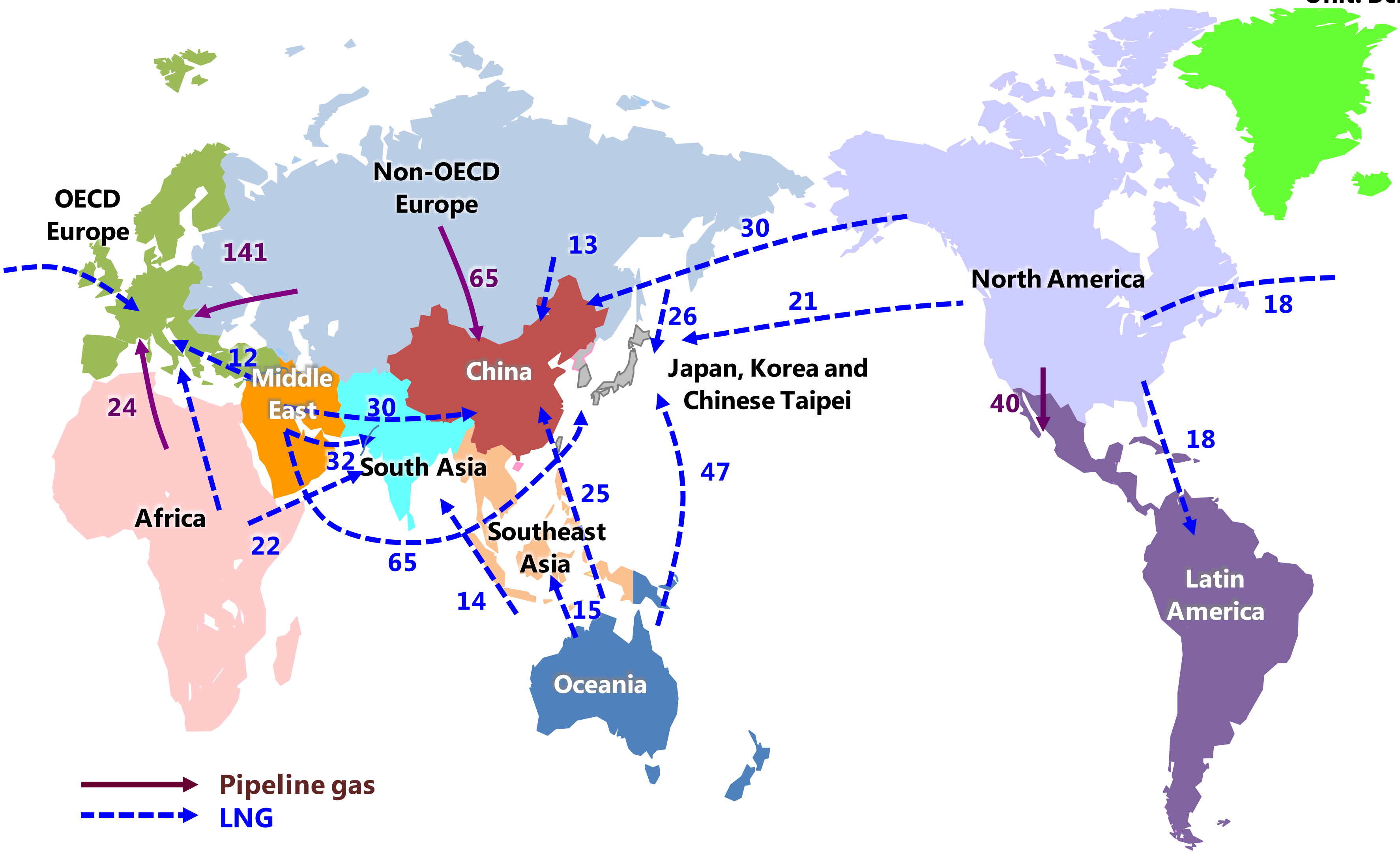

Mt
Bcm
400
300
200
100
0
500
400
300
200
100
0
2017
2030
211 Mt
346
46
86
14
20
10
17
6
3
3
3
Asia
Europe
Latin America
Middle East
Africa
North America

Major natural gas trade flows (2017)

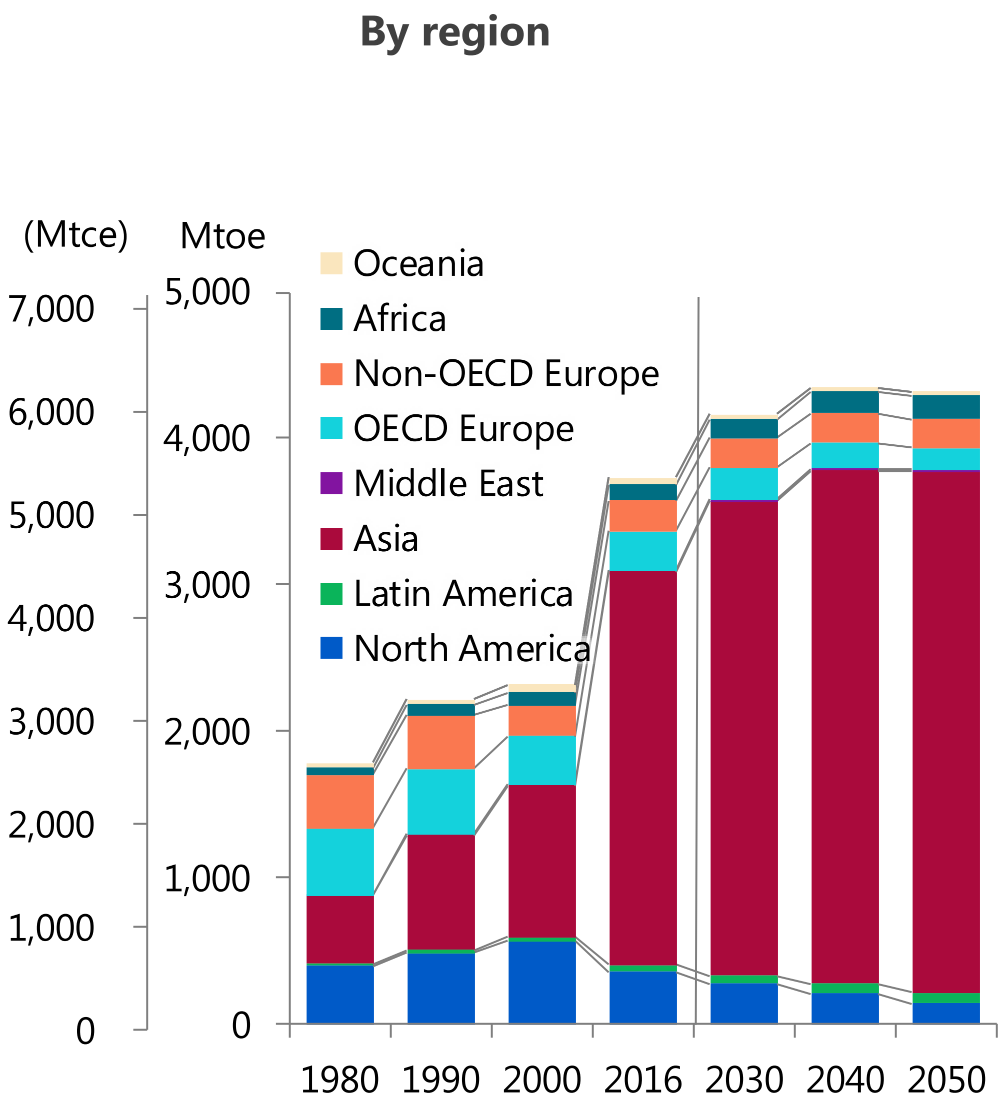


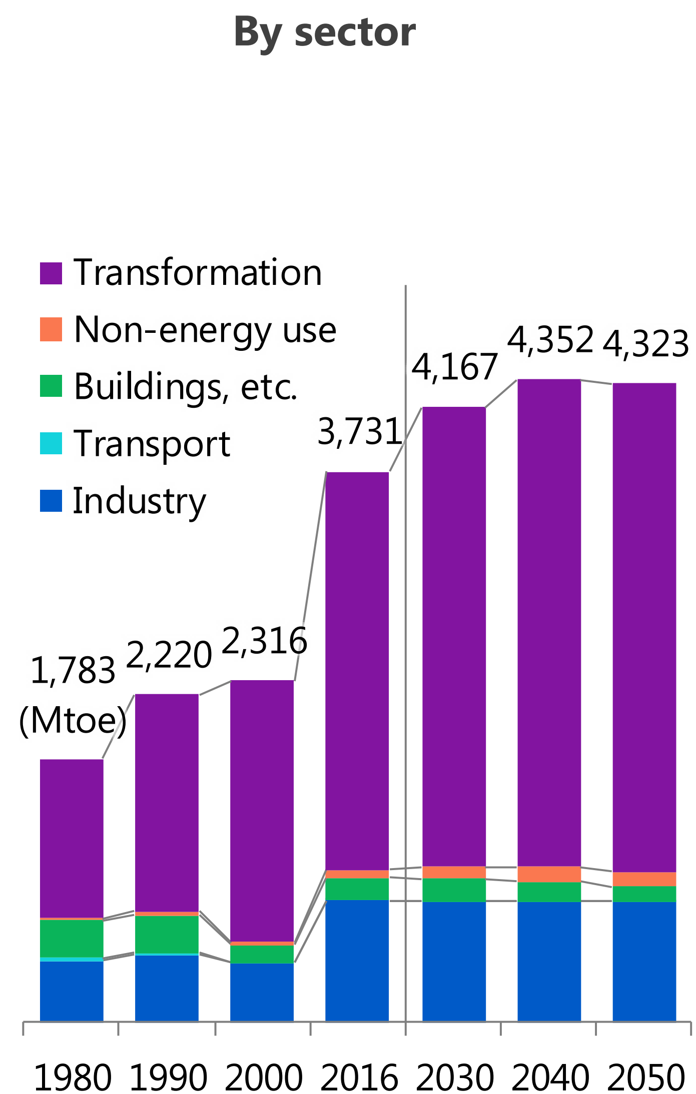
Major natural gas trade flows (2030)

Unit: Bcm



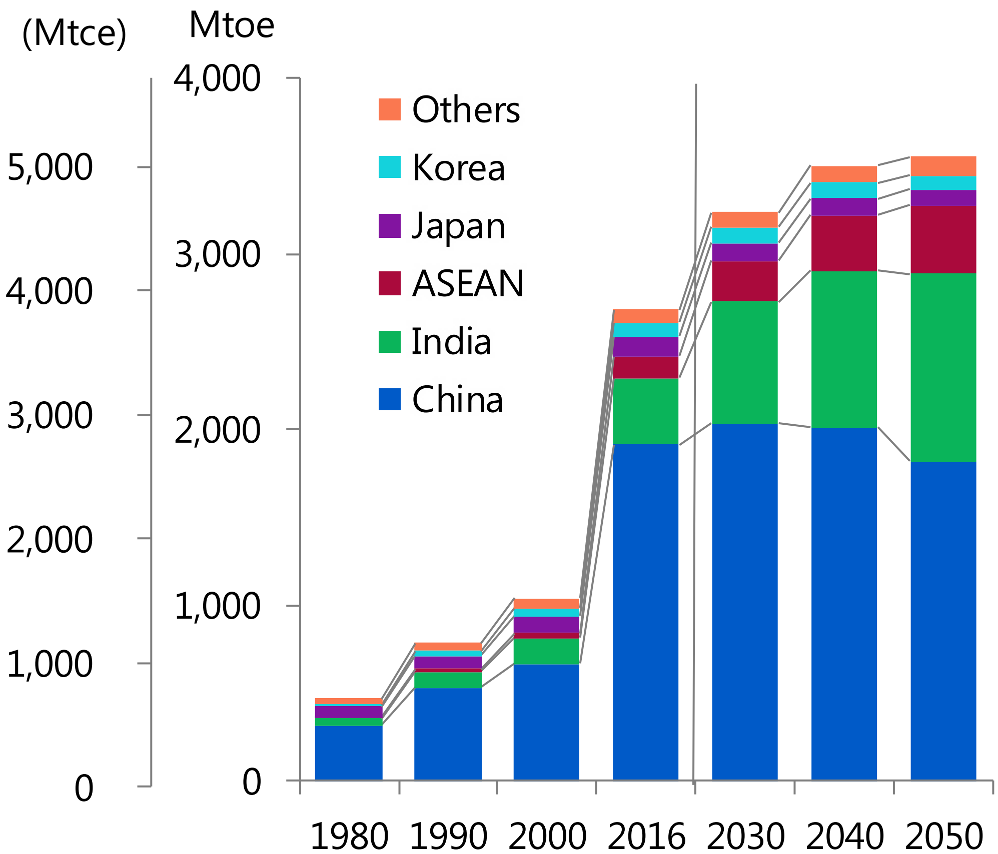
Coal consumption



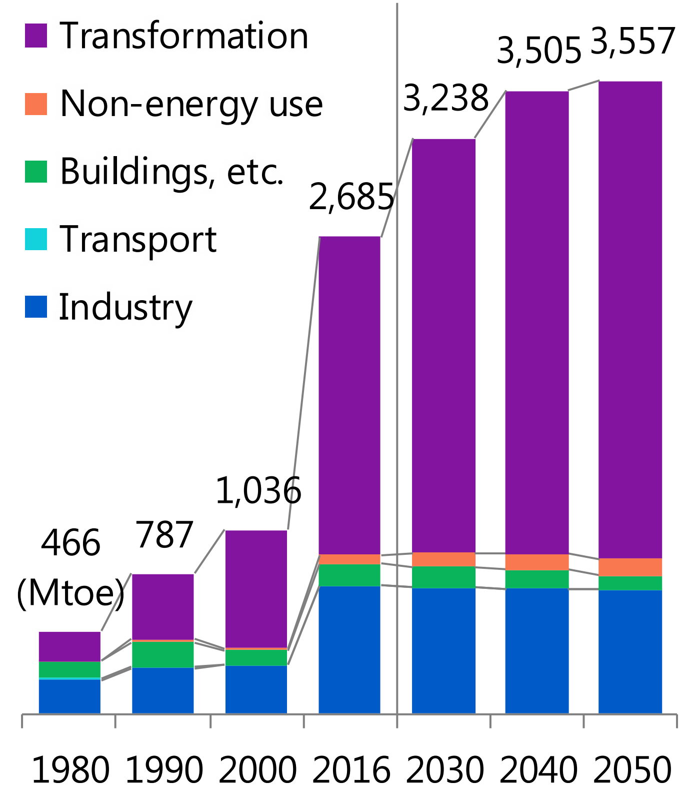


Coal consumption (Asia)

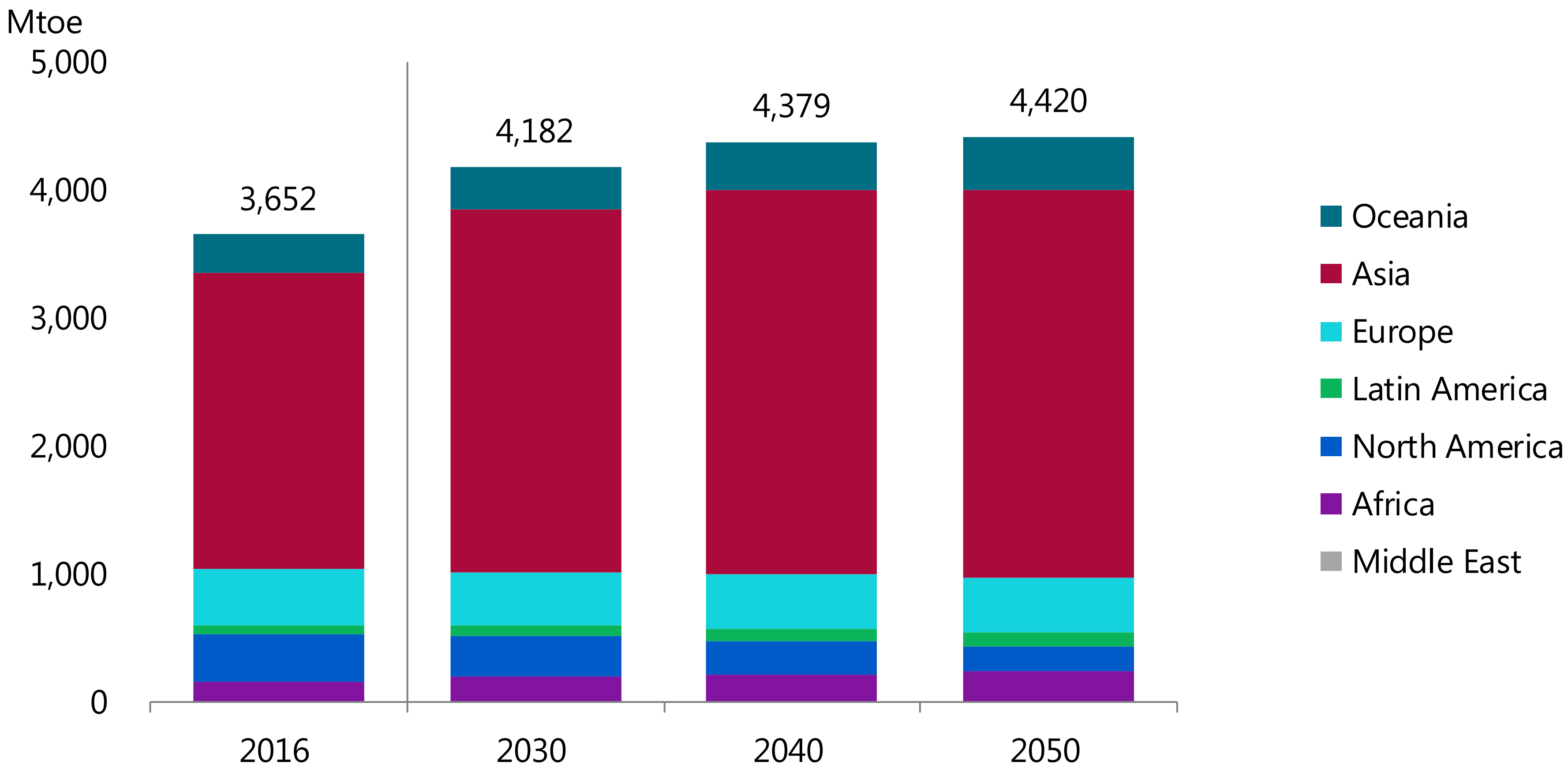
By region



By sector

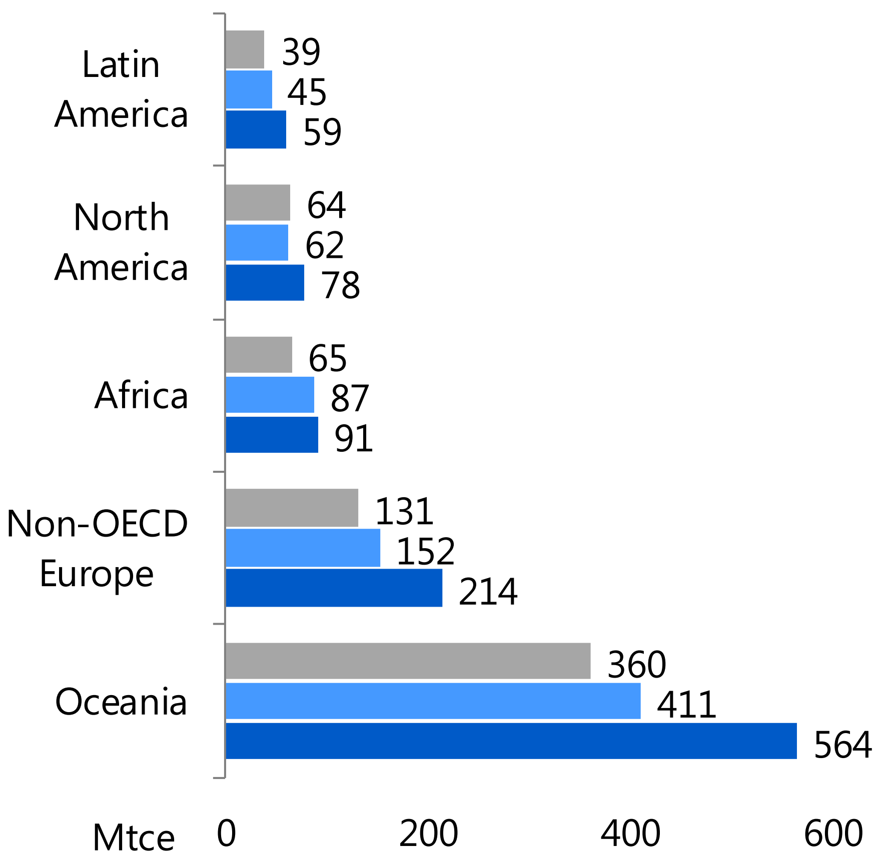


Coal production

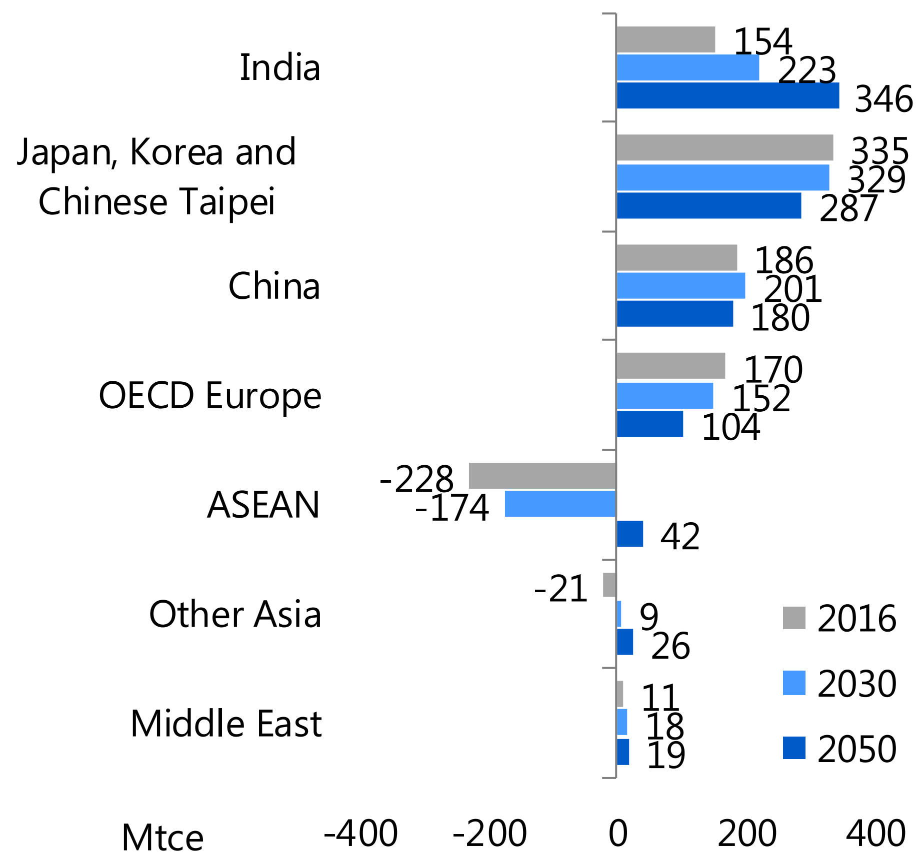


Coal net exports / imports

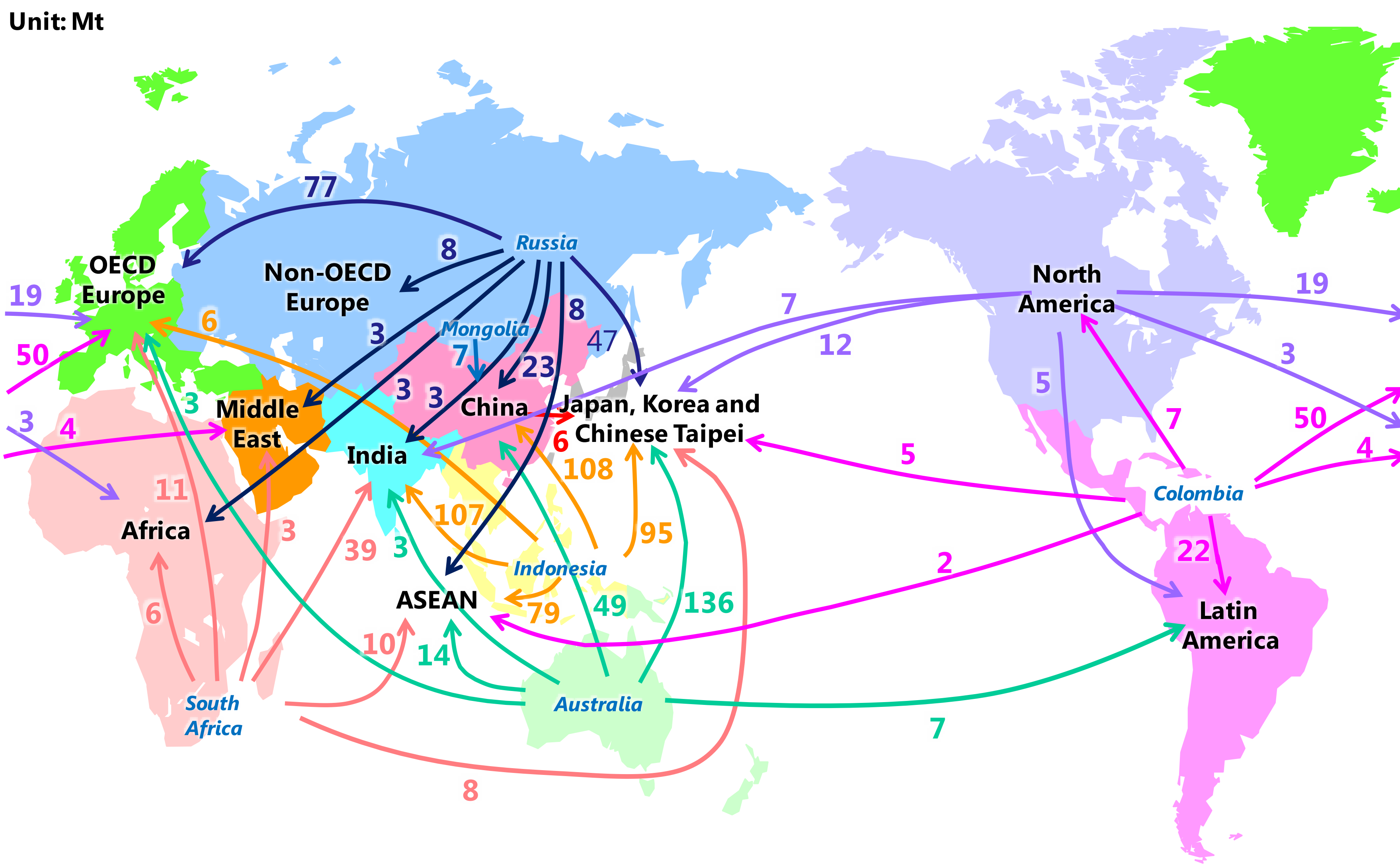
Net exports



Net imports

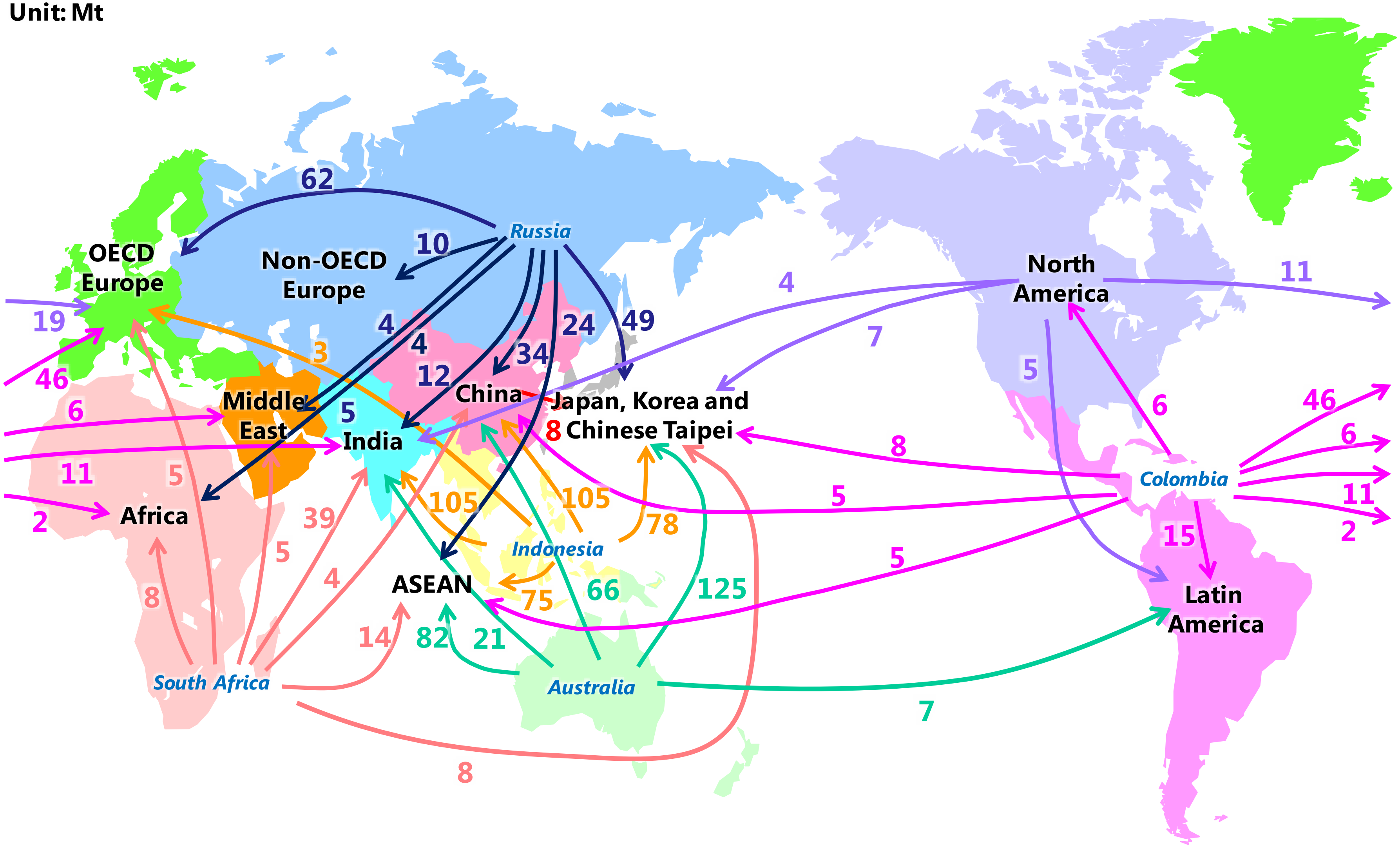


Major steam coal trade flows (2017)

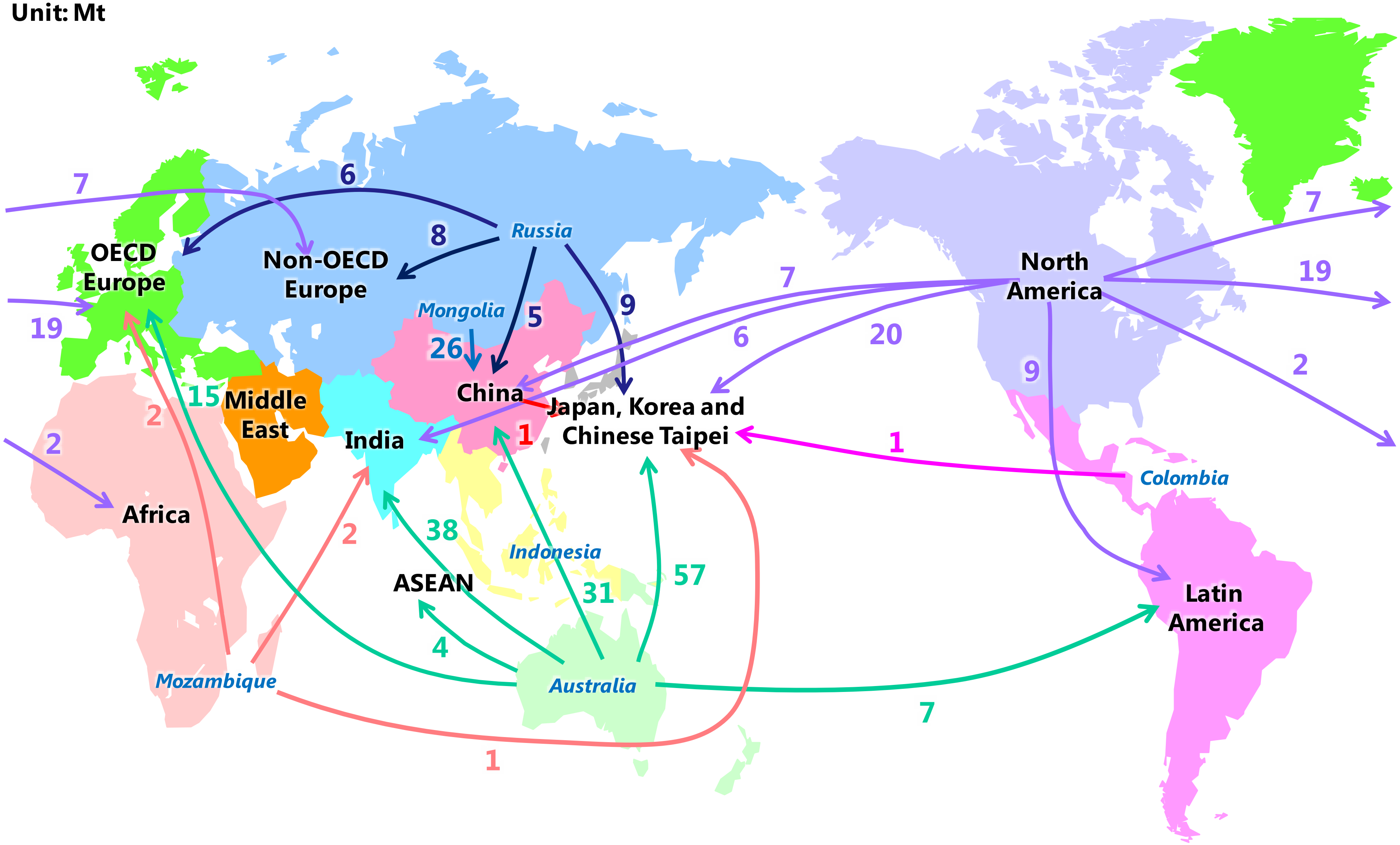


Major steam coal trade flows (2030)

Unit: Mt

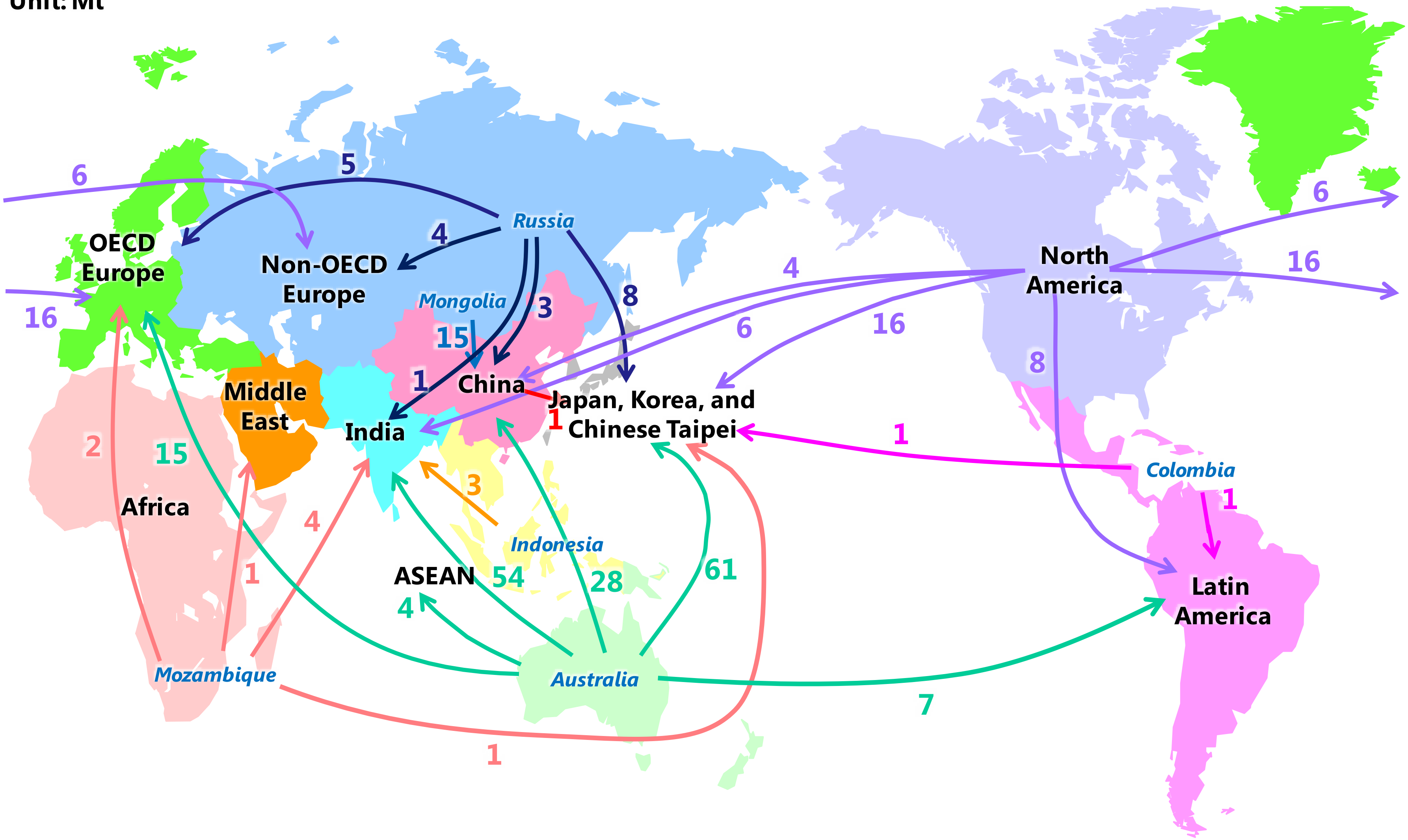


Major coking coal trade flows (2017)

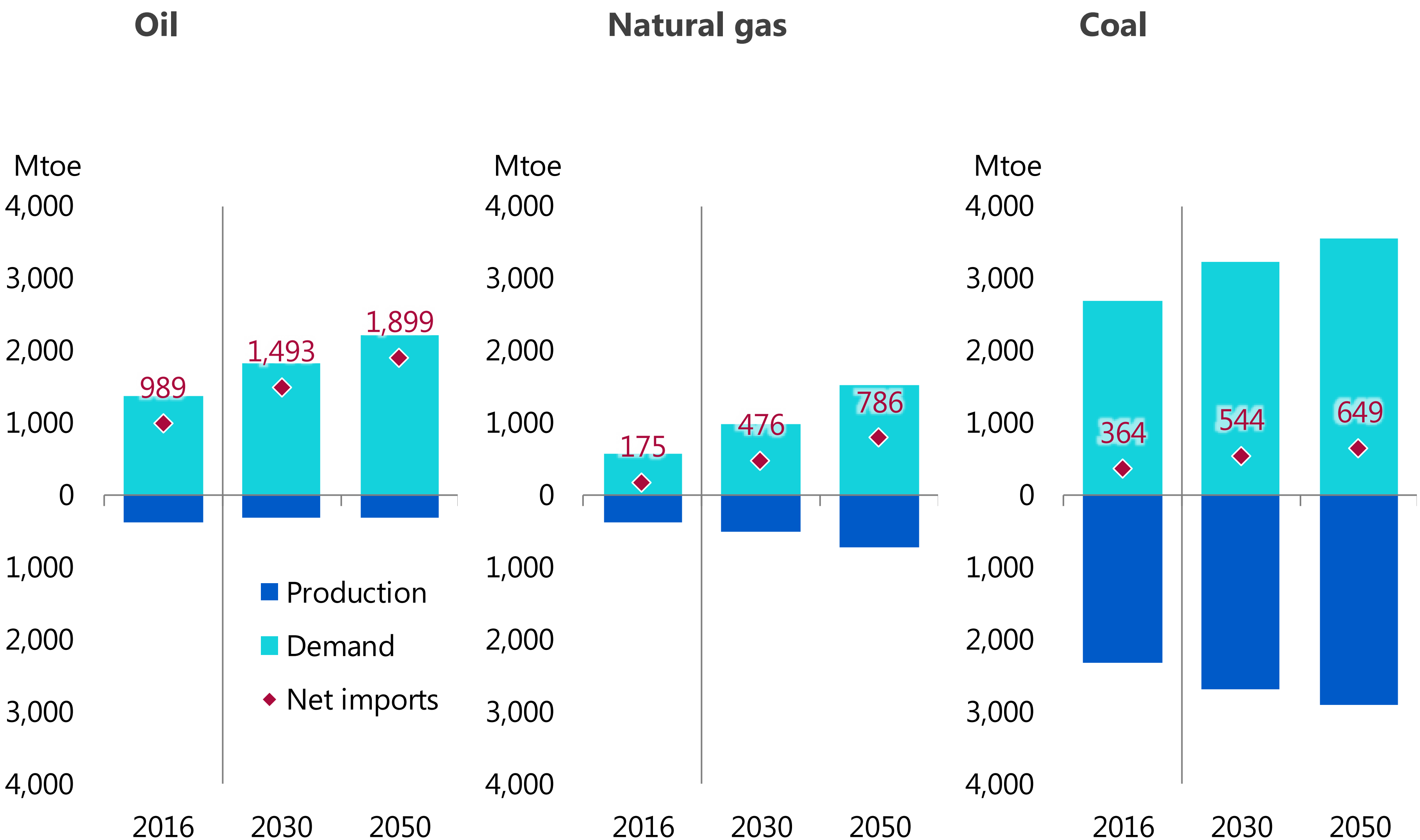


Major coking coal trade flows (2030)

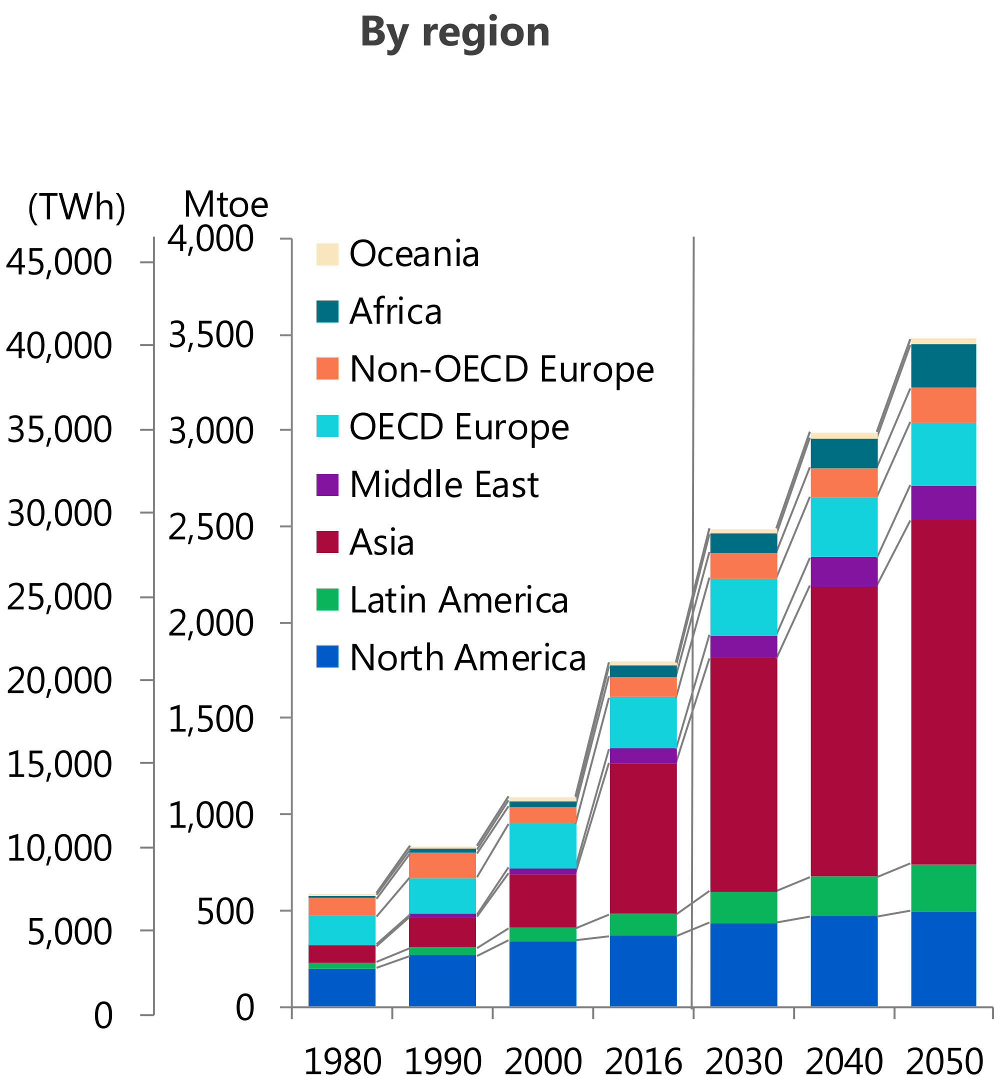
Unit: Mt

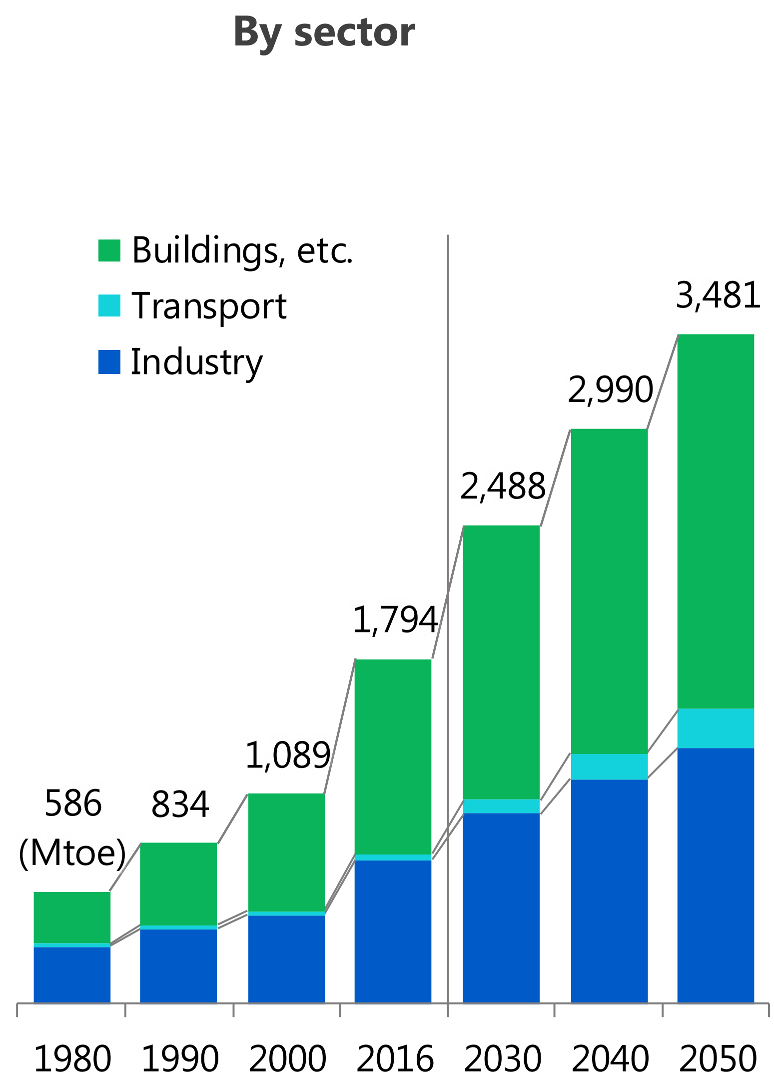


Fossil fuel supply / demand balances (Asia)



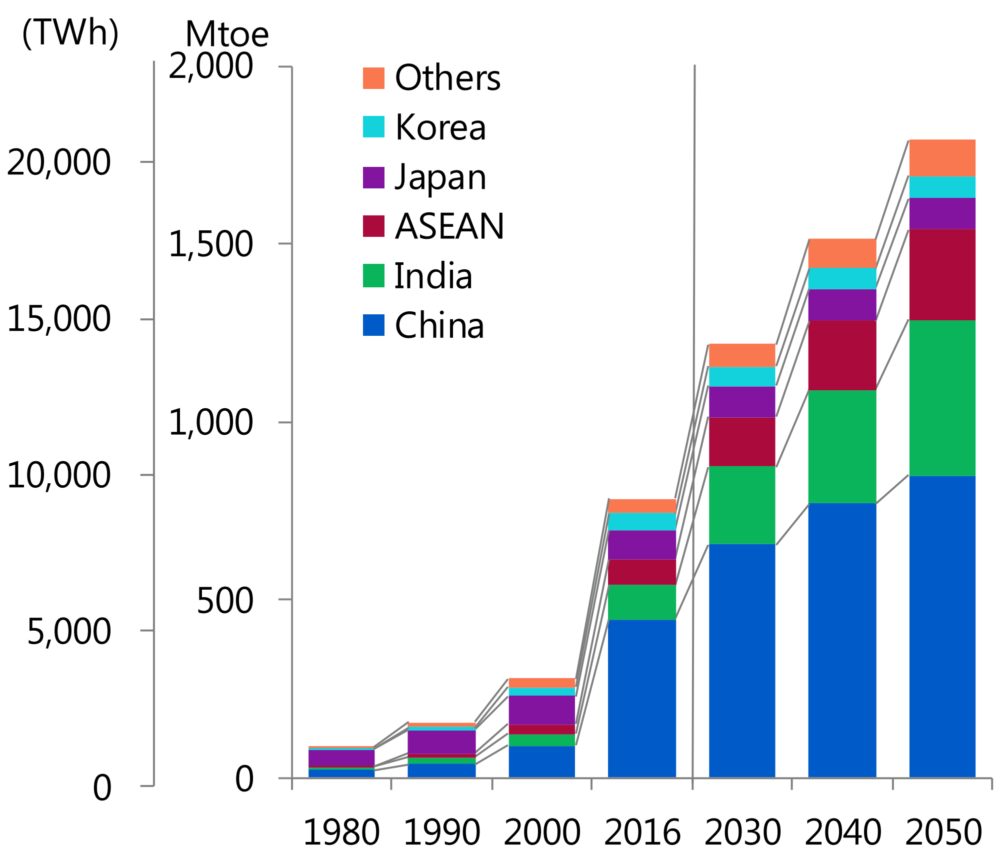
Electricity final consumption



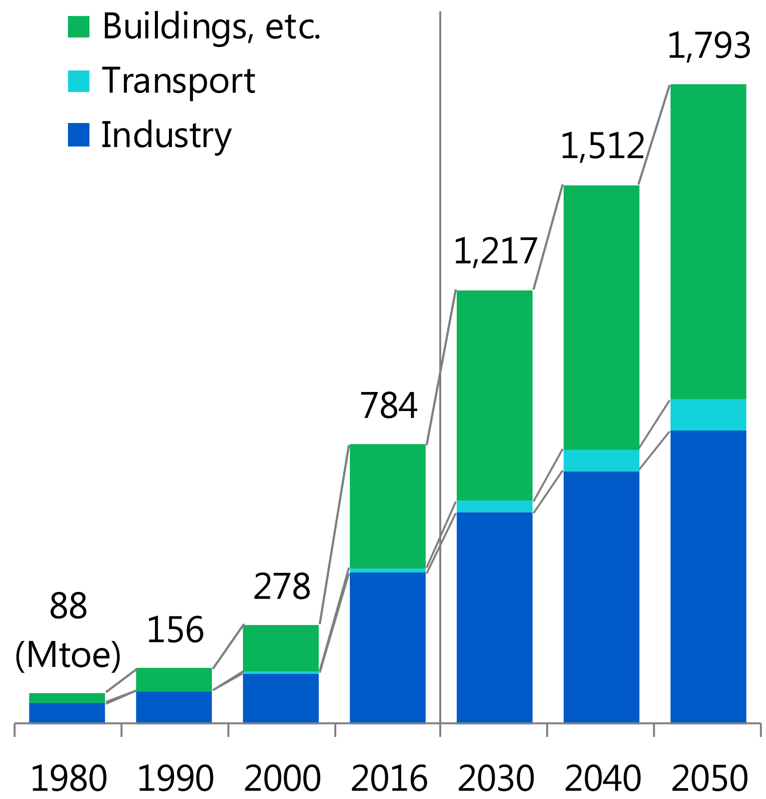


Electricity final consumption (Asia)

By region



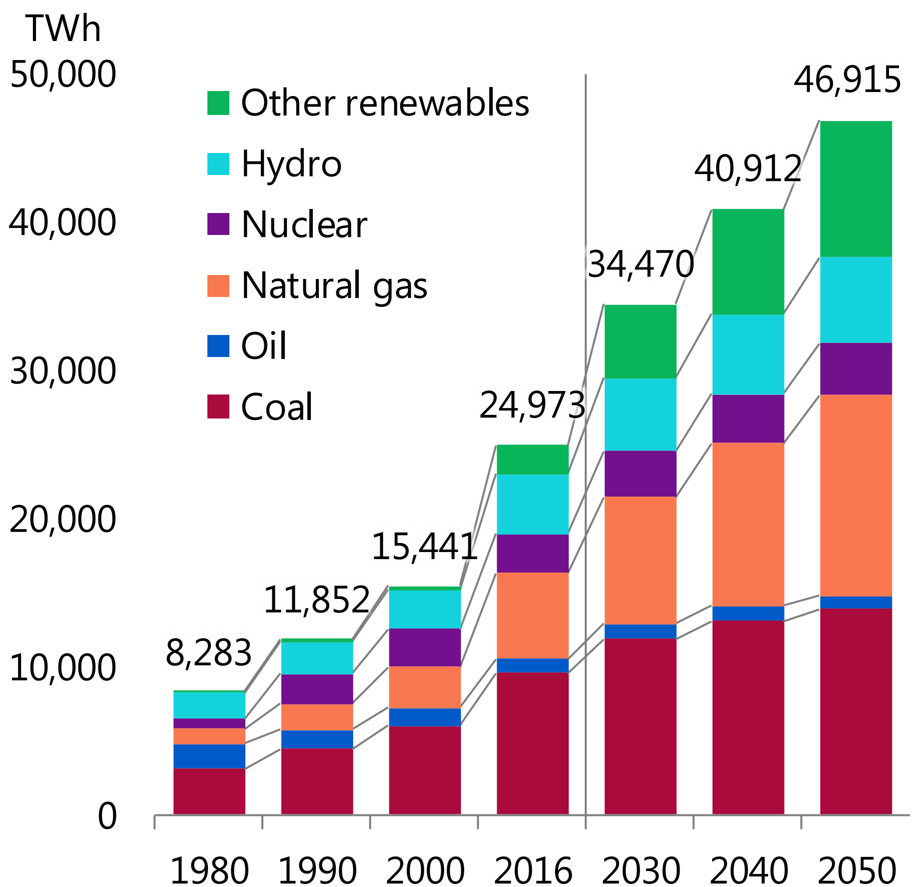
By sector



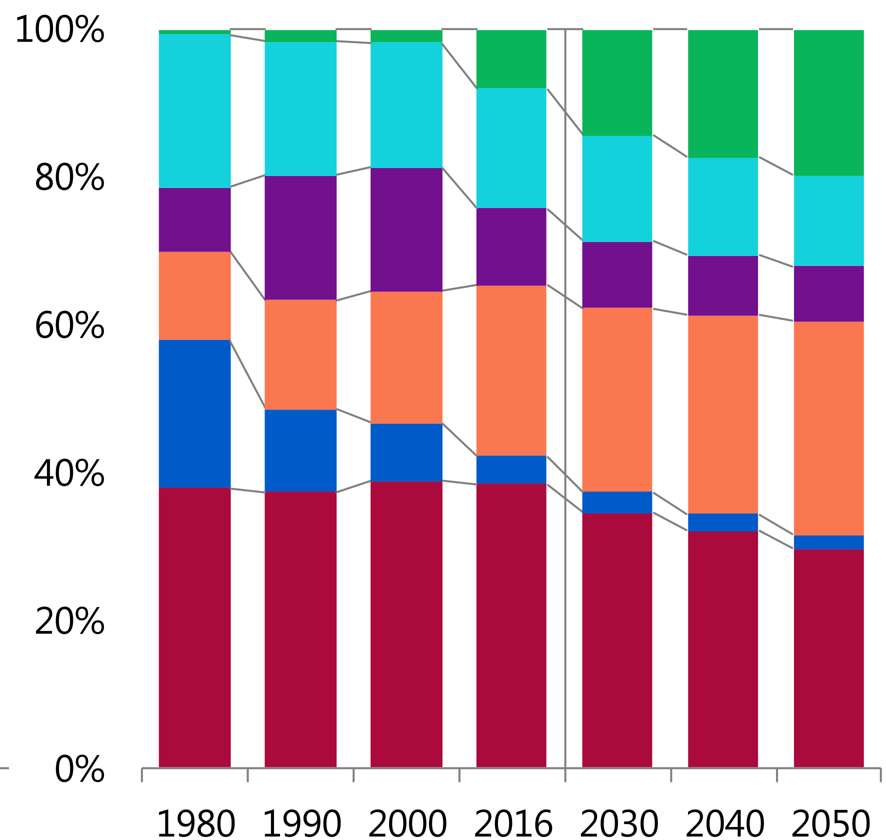
Reference Scenario

Power generation mix

Electricity generated

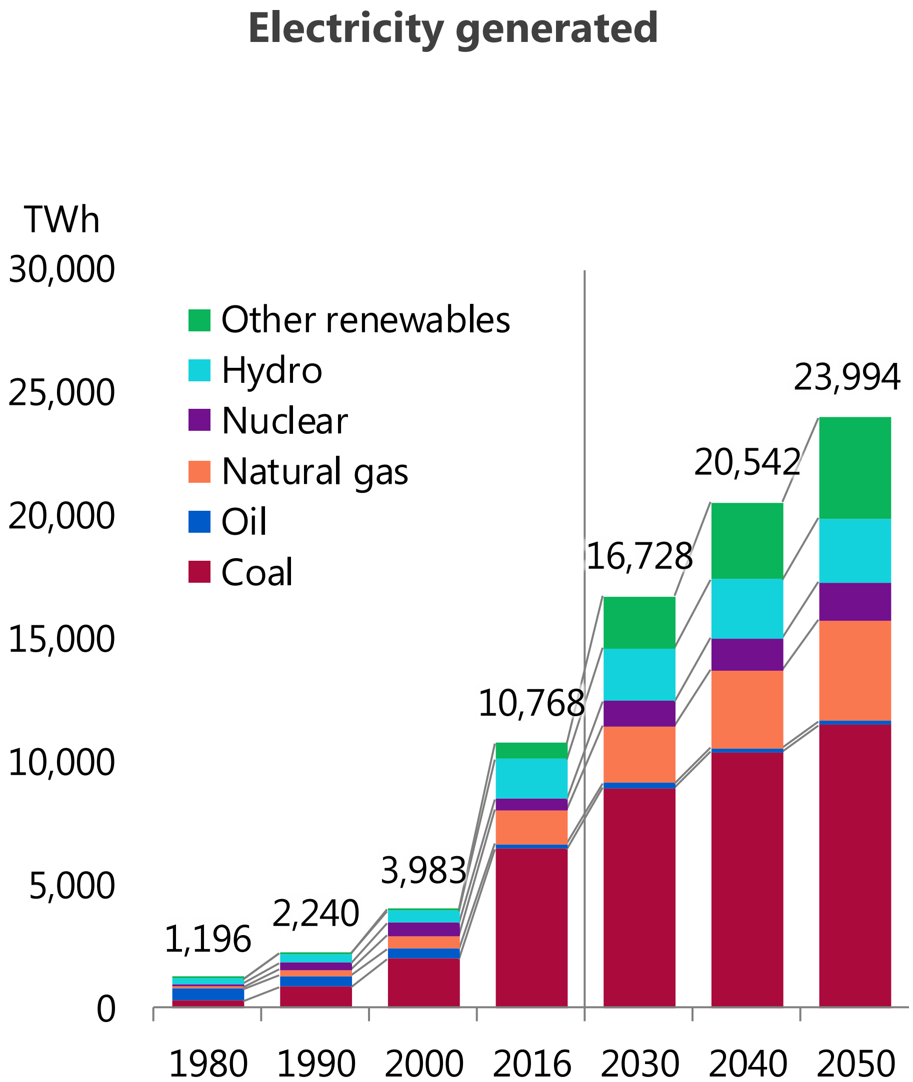


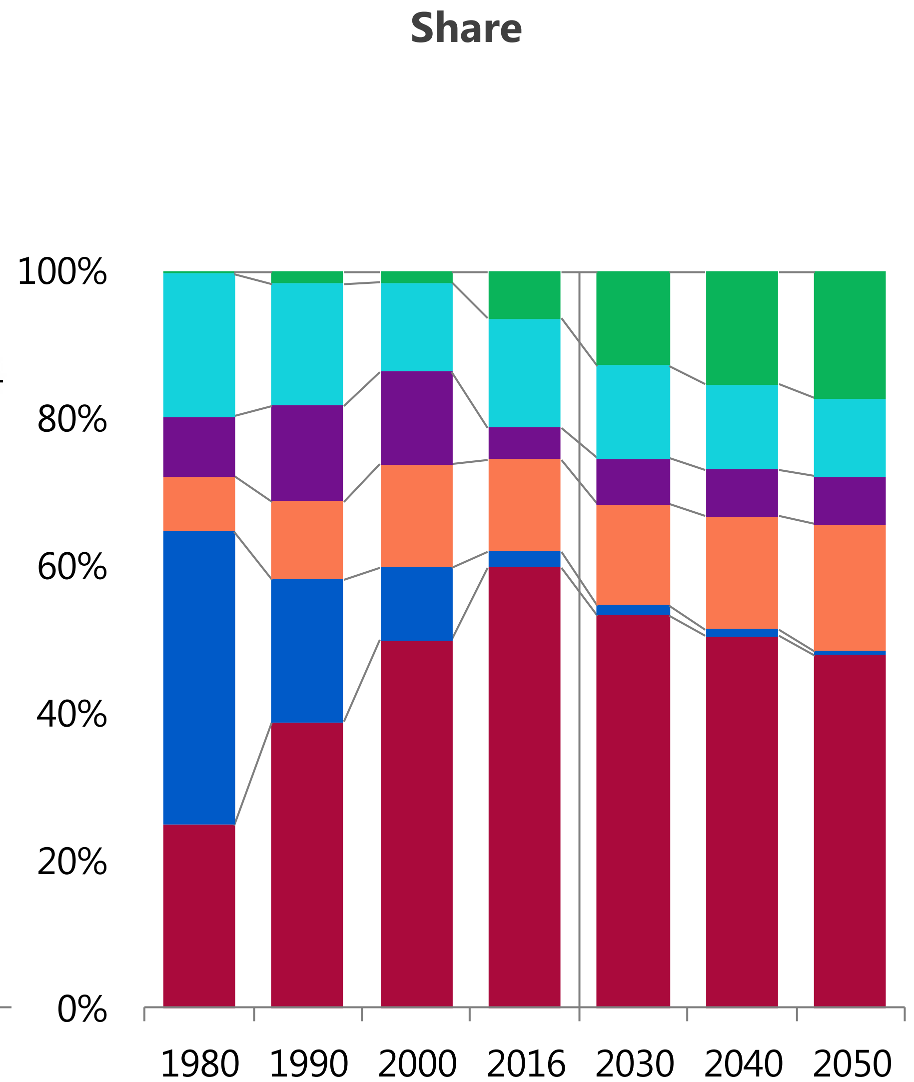
Share



Reference Scenario

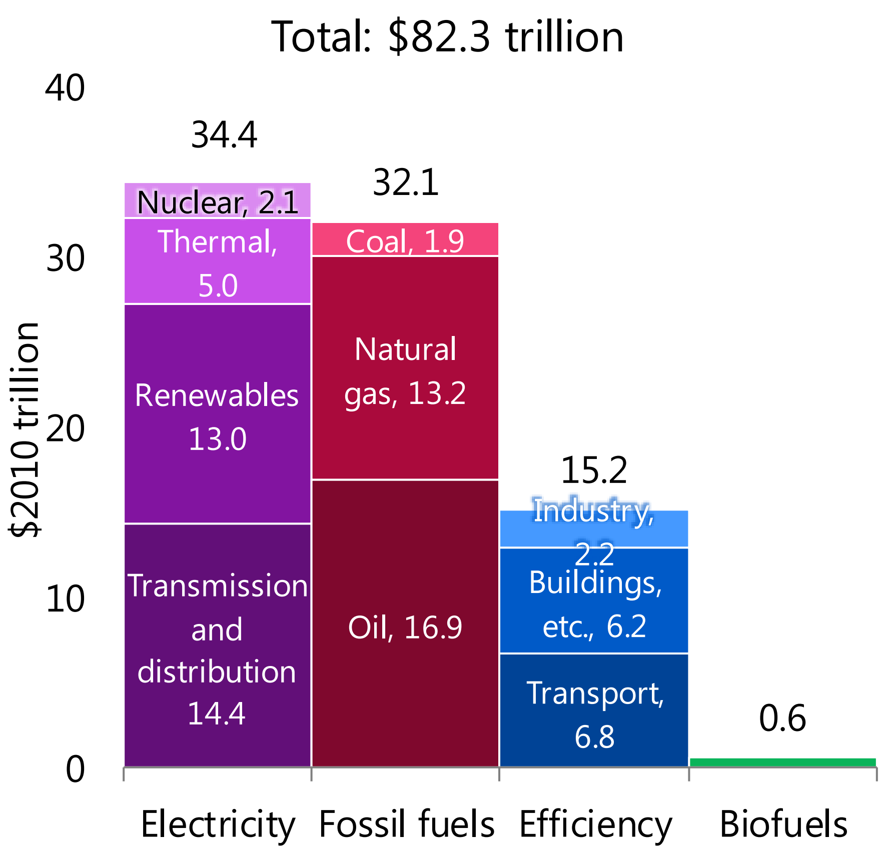
Power generation mix (Asia)



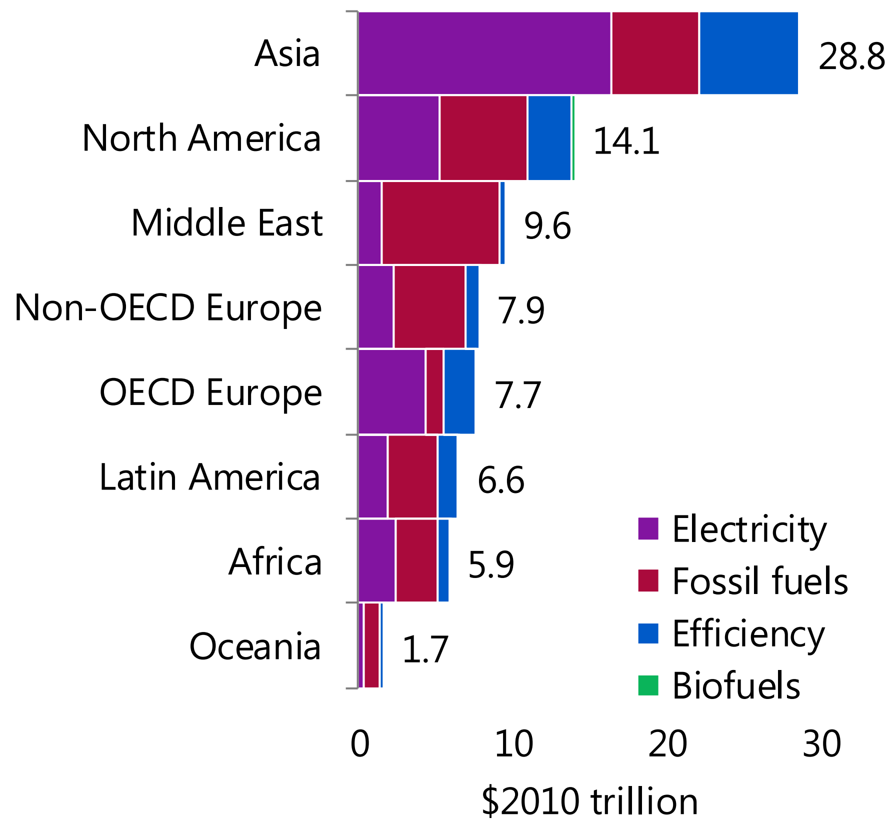


Energy-related investments (2017 - 2050)

By sector

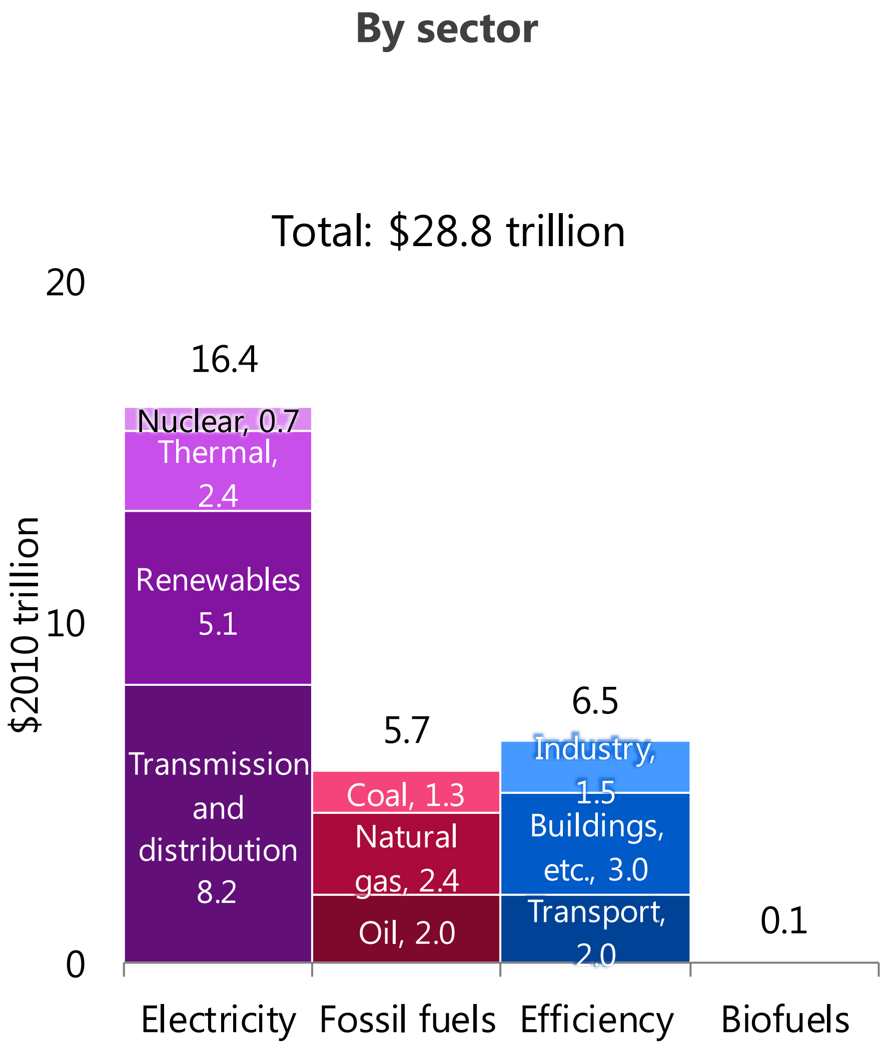


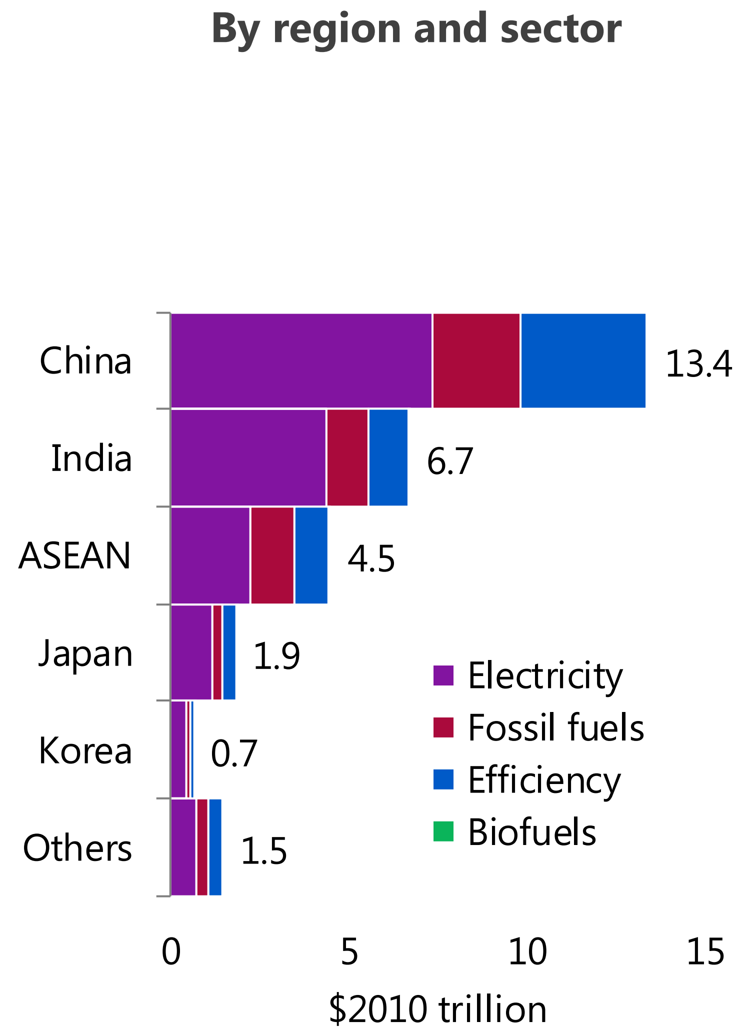
By region and sector



Reference Scenario

Energy-related investments (Asia, 2017 - 2050)

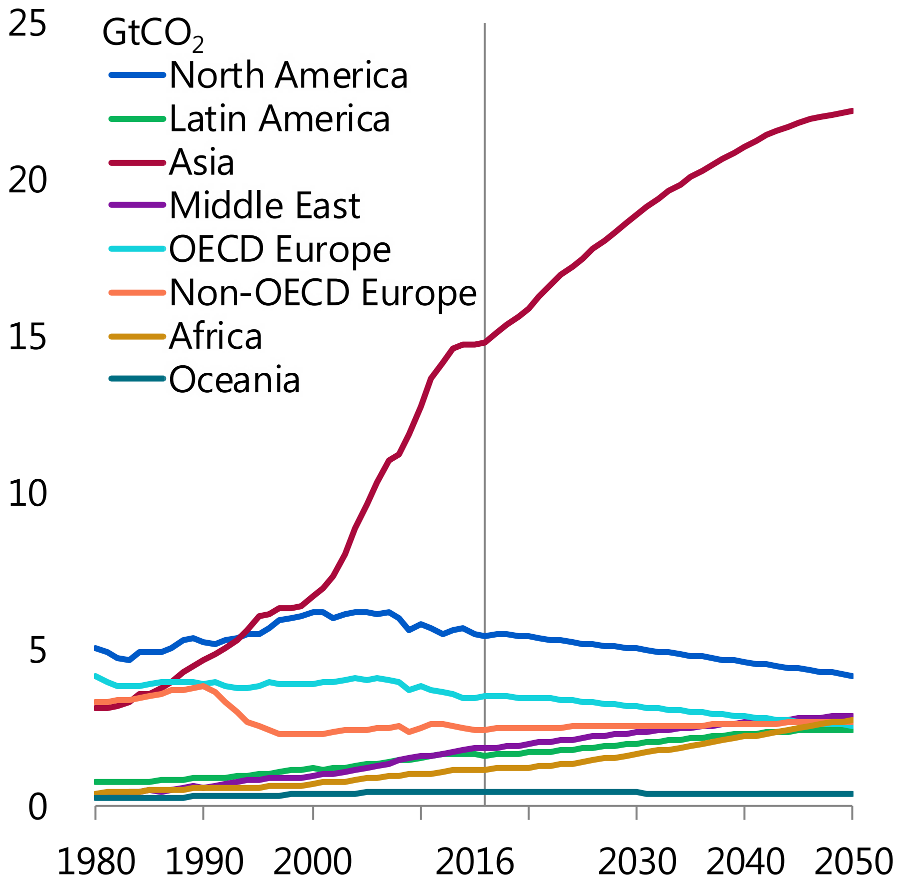




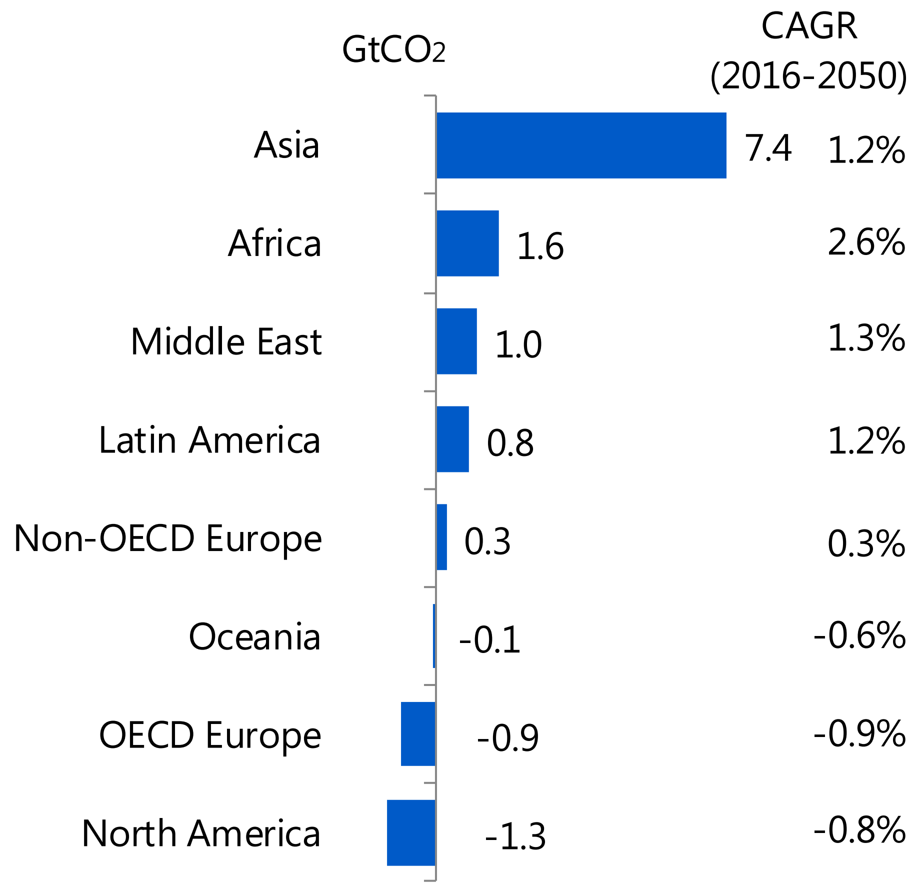
CO_2 emissions

World

2016	→	2050
32.4 Gt	(×1.3)	**41.9** Gt



Changes (2016-2050)

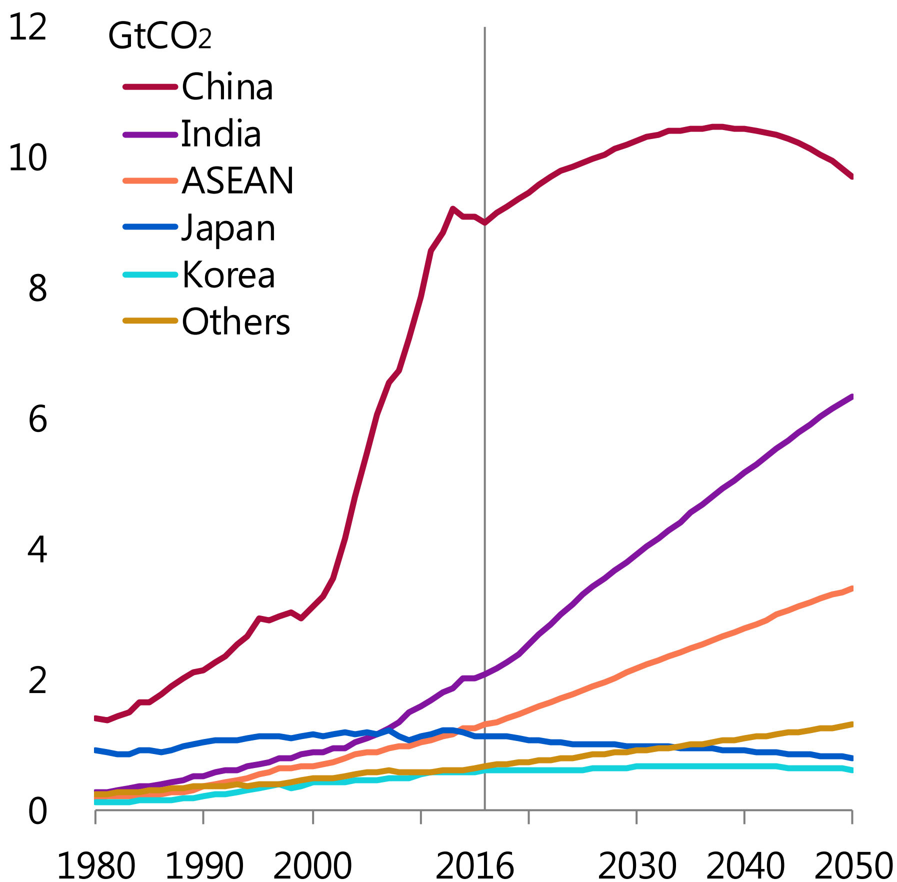


Reference Scenario

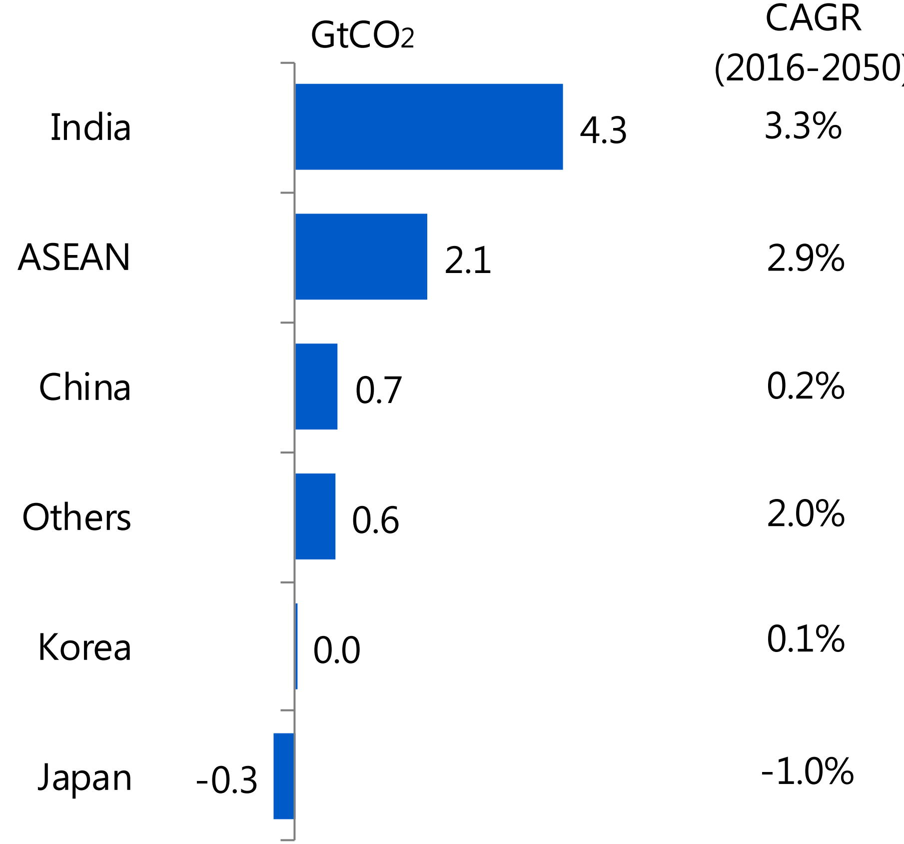
CO_2 emissions (Asia)

Asia

2016	→	2050
14.8 Gt	(×1.5)	**22.4** Gt



Changes (2016-2050)



Advanced Technologies Scenario

Major technological assumptions

In the Advanced Technologies Scenario, each country further enhances policies on energy security and address climate change. Technology developments and international technology transfers are promoted to further penetration of advanced technologies.

Introducing and enhancing environmental regulations and national targets

Environment tax, emissions trading, RPS, subsidy, FIT, efficiency standards, automobile fuel efficiency standard, low carbon fuel standard, energy efficiency labelling, national targets, etc.

Promoting technology development and international technology cooperation

R&D investment expansion, international cooperation on energy efficient technology (steelmaking, cement and other areas), support for establishing energy efficiency standards, etc.

Demand side technologies

■ Industry

Under sectoral and other approaches, best available technologies on industrial processes (for steelmaking, cement, paper-pulp and oil refining) will be deployed globally.

■ Transport

Clean energy vehicles (highly fuel efficient vehicles, hybrid vehicles, plug-in hybrid vehicles, electric vehicles, fuel cell vehicles) will diffuse further.

■ Buildings

Efficient electric appliances (refrigerators, TVs, etc.), highly efficient water-heating systems (heat pumps, etc.), efficient air conditioning systems and efficient lighting will diffuse further, with heat insulation enhanced.

Supply side technologies

■ Renewable energies

Wind power generation, solar photovoltaic power generation, concentrated solar power (CSP) generation, biomass-fired power generation and biofuels will penetrate further.

■ Nuclear

Nuclear power plant construction will be accelerated with capacity factor improved.

■ Highly efficient fossil fuel-fired power generation technologies

Coal-fired power plants (SC, USC, A-USC, IGCC) and natural gas–fired more advanced combined cycle (MACC) plants will penetrate further.

■ Technologies for next-generation transmission and distribution networks

Lower loss type of transformation and voltage regulator will penetrate further.

■ Carbon capture and storage

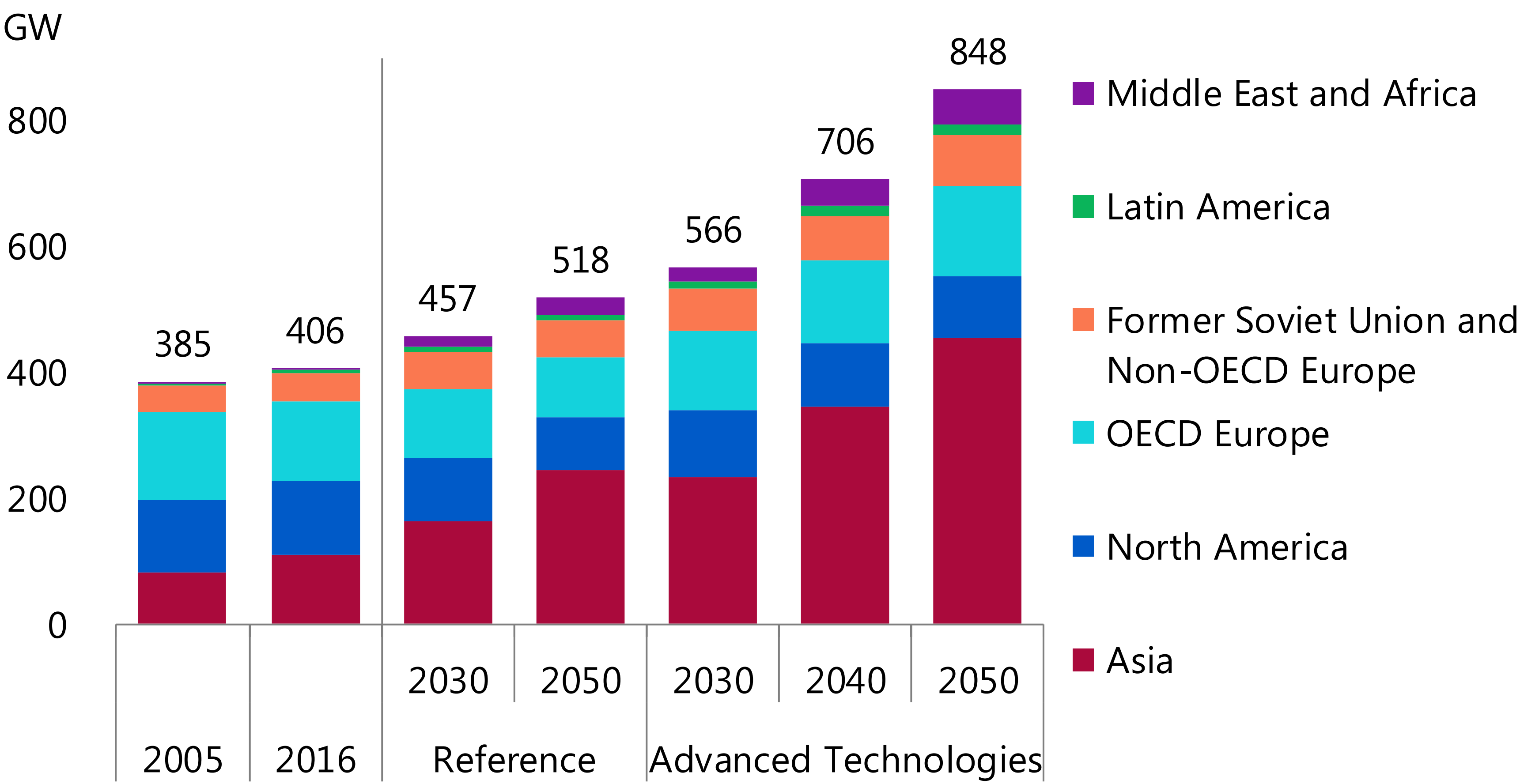
*SC: Super Critical, USC: Ultra Super Critical, A-USC: Advanced Ultra Super Critical

Penetration of low-carbon technologies

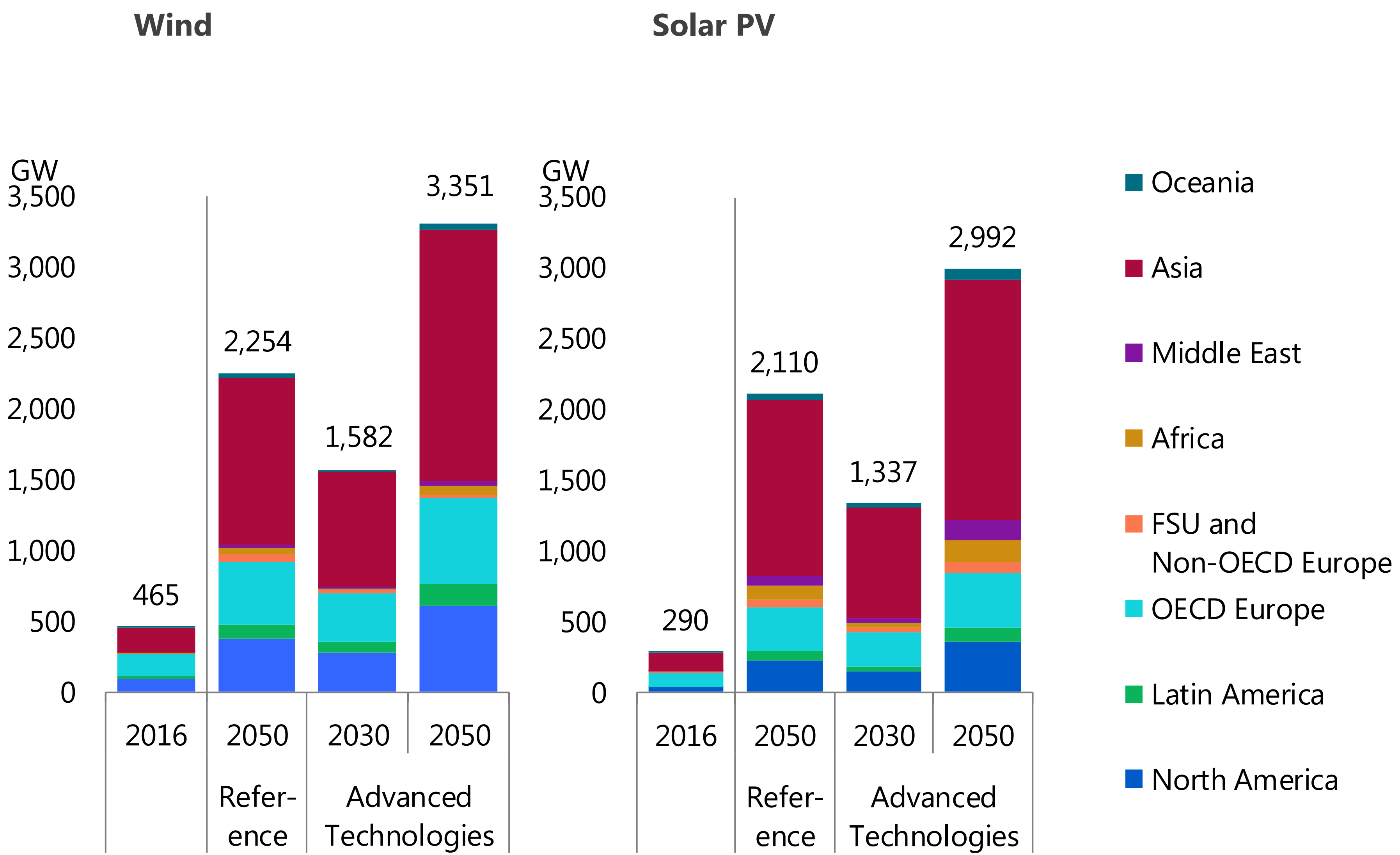
2016 → 2050 (Reference 2050)

	OECD	Non-OECD
Thermal power plant	Maintenance of financial scheme for initial investment. Share of IGCC in install 0→ 60% (20%) Installing CCS after 2030 (Countries which have storage potential except for aquifer)	
[Thermal efficiency (stock basis)]	Natural gas: 48.4% → 56.8% (57.0%) Coal: 37.2% → 43.5% (44.3%)	Natural gas: 37.1% → 49.1% (45.9%) Coal: 35.4% → 39.3% (40.6%)
Nuclear	Maintenance of appropriate price in wholesale electricity market	Maintenance of framework for financing initial investment
[Capacity]	2016: 311 GW → 298 (217)	2016: 96 GW → 550 (302)
Renewables [Capacity]	System cost reduction Cost reduction of power system Efficient operation of power system Wind: 237 GW → 1,091 (718) Solar: 165 GW → 909 (573)	System cost reduction Low cost investment Improvement of power system Wind: 178 GW → 1,912 (1,152) Solar : 60 GW → 1,588 (946)
Biofuels	Development of next generation biofuel Higher diffusion of FFV	Cost reduction of biofuel Relating to agricultural policy
[Consumption]	55 Mtoe → 106 (69)	27 Mtoe → 81 (54)
Industry	Best available technology diffuses 100% in 2050	
Transportation	Cost reduction of high fuel efficiency of vehicles. Twice of travel distance of ZEV	
[[Average fuel efficiency of new vehicle sales]]	14.5 km/L → 39.3 (28.6)	12.9 km/L → 30.5 (21.7)
[Share in annual vehicle sales of ZEV]	0.8% → 64% (40%)	0.6% → 48% (25%)
Buildings	The pace of improvement of efficiency of newly installed appliance, equipment and insulation is twice. 15% improvement in 2050 in ratio of the Reference Scenario Electrification and clean cooking in space heating, water heater and cooking	

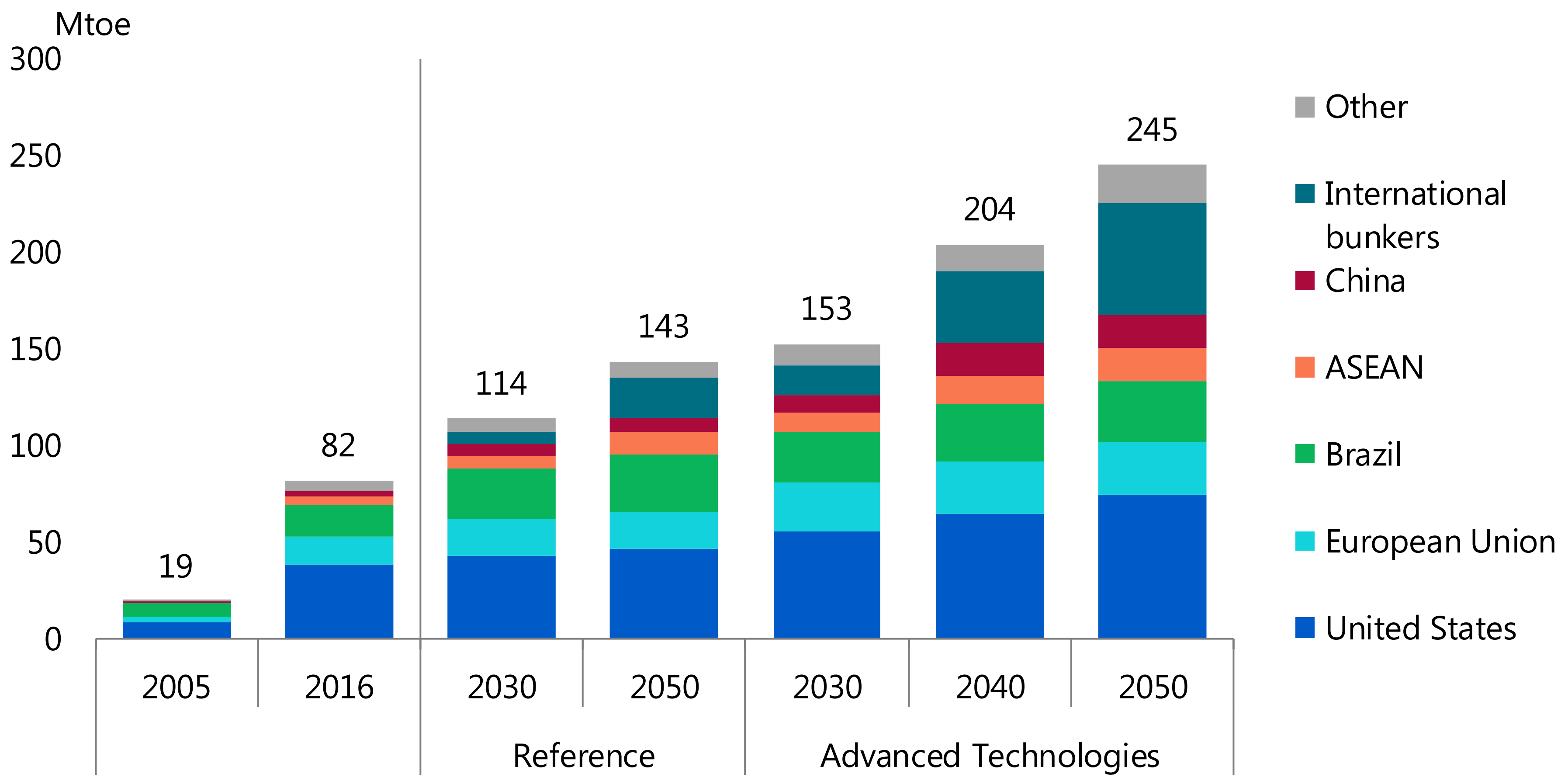
Nuclear power generation capacity



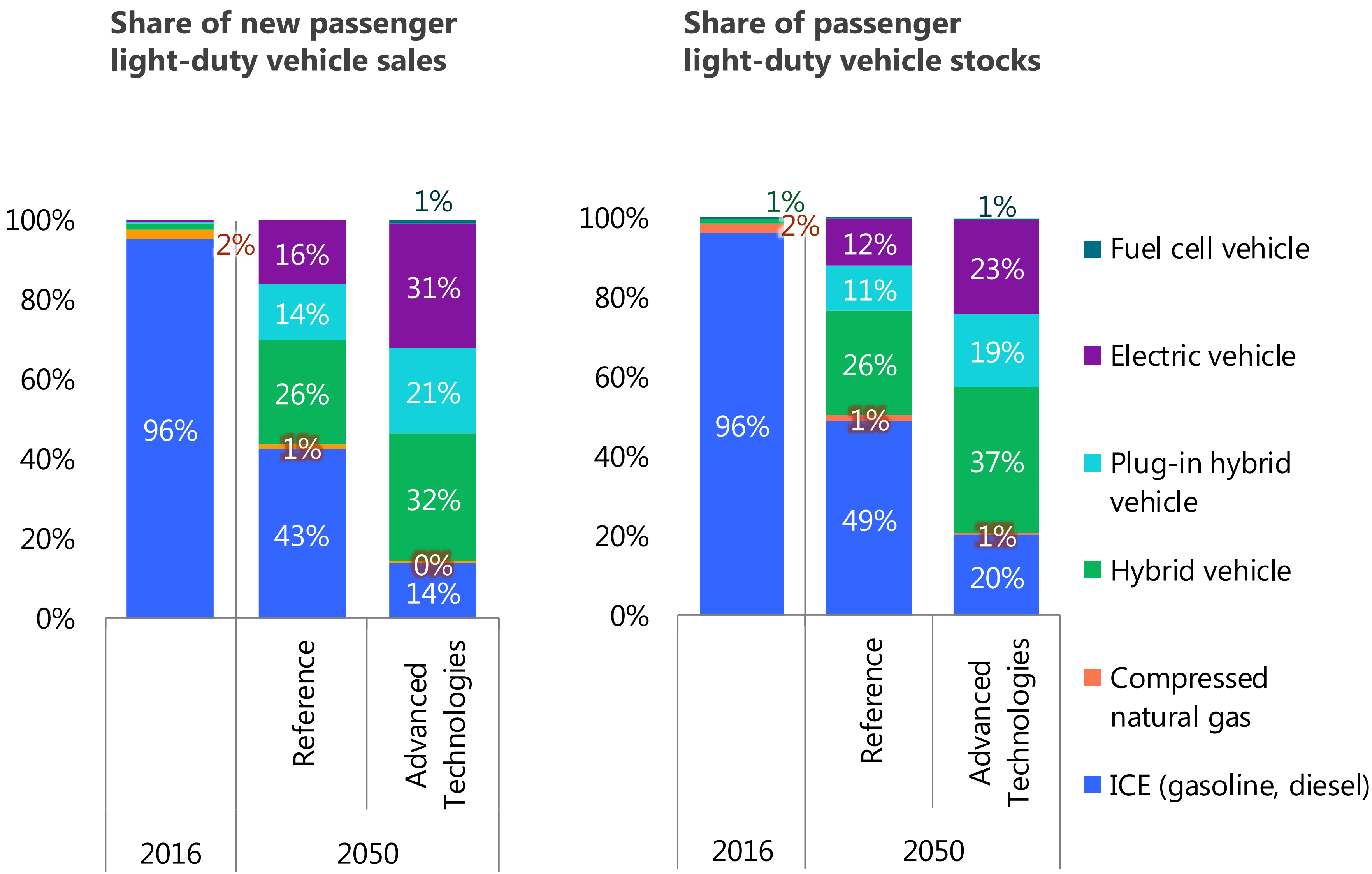
Renewable power generation capacity



Biofuels consumption for transport

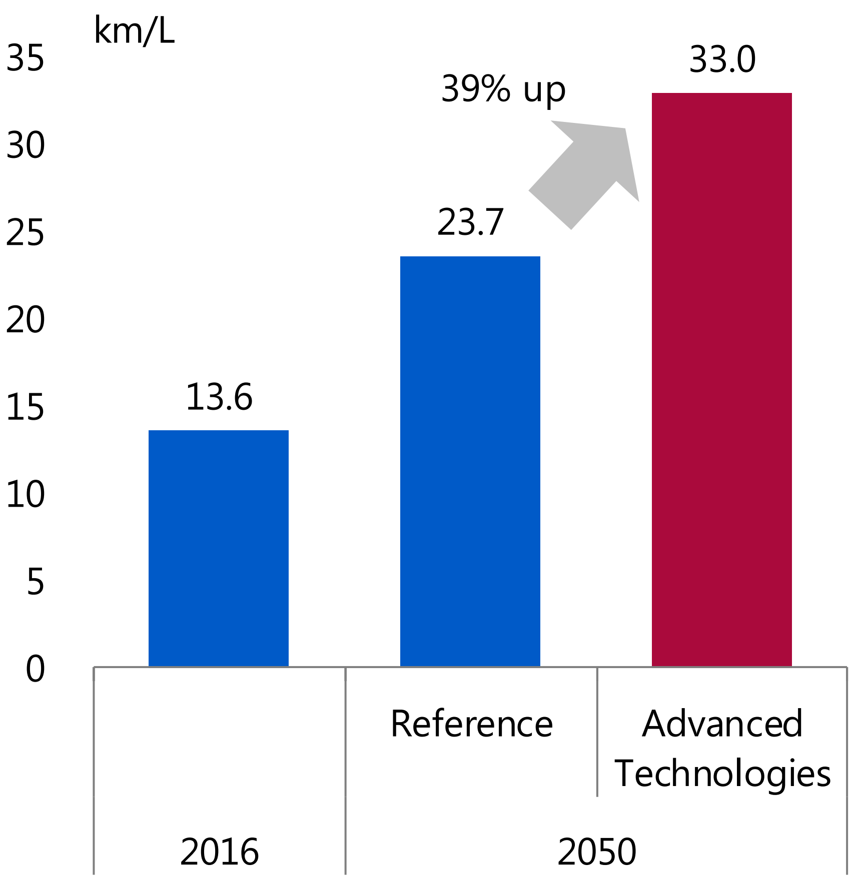


Vehicle stock and sales (by type)

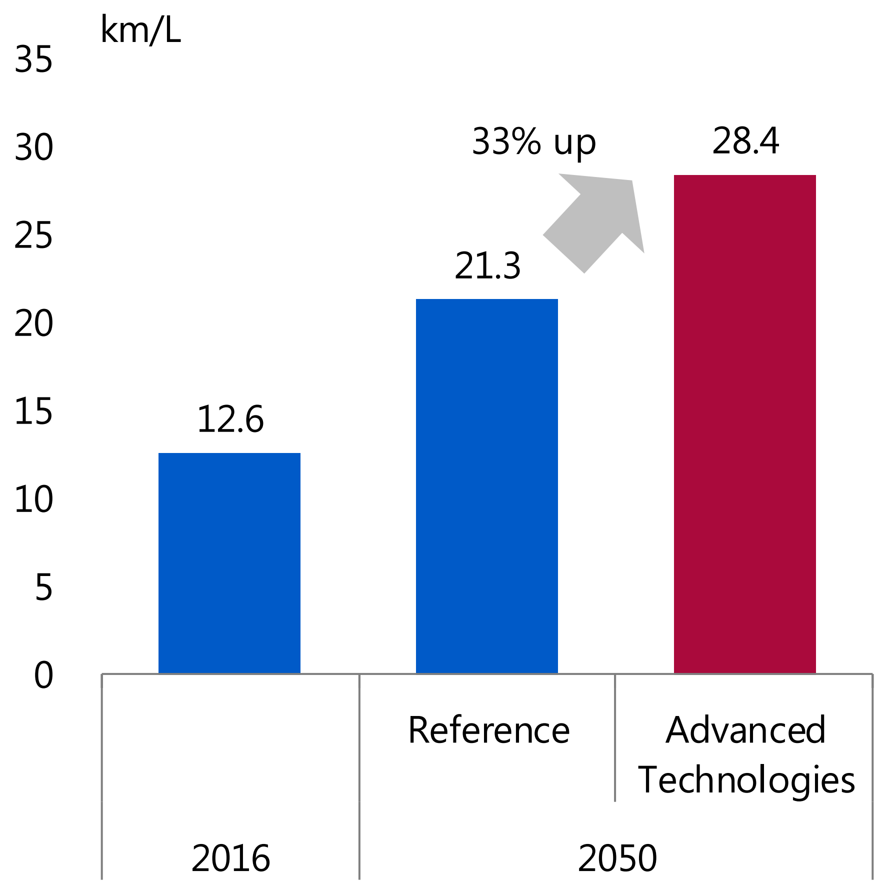


Fuel efficiency of passenger cars

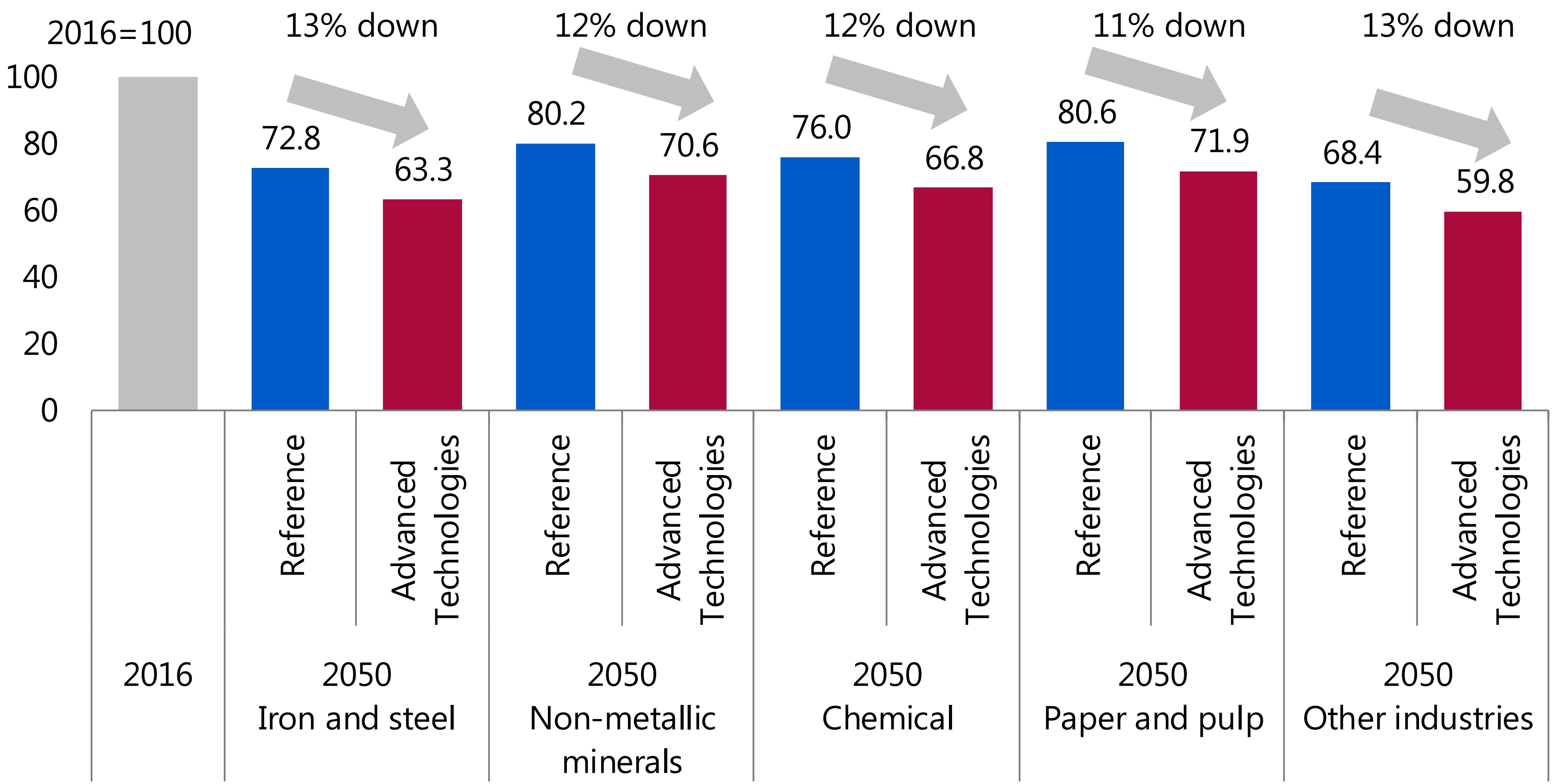
Fuel efficiency (New sales basis)



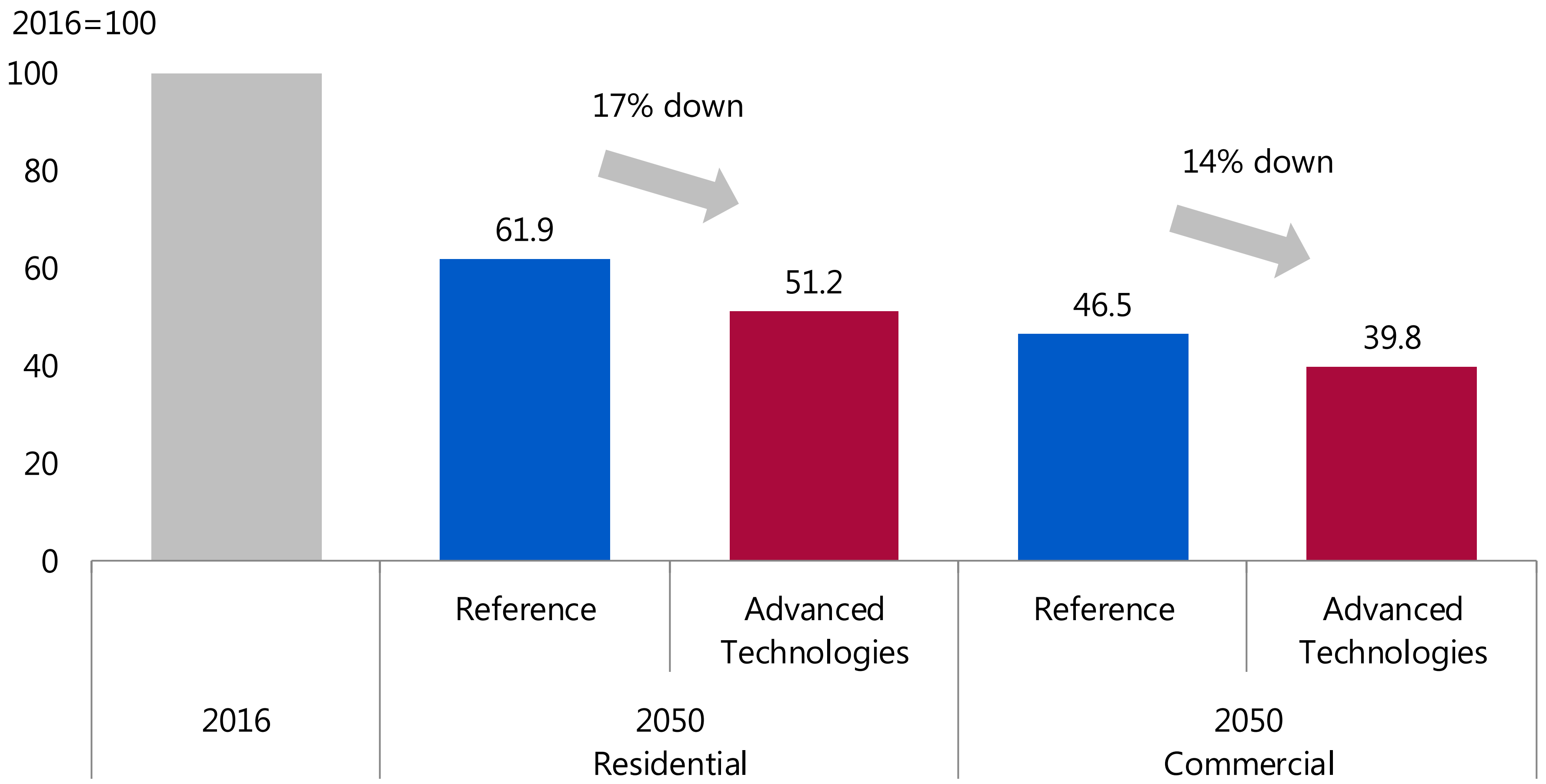
Fuel efficiency (Stock basis)



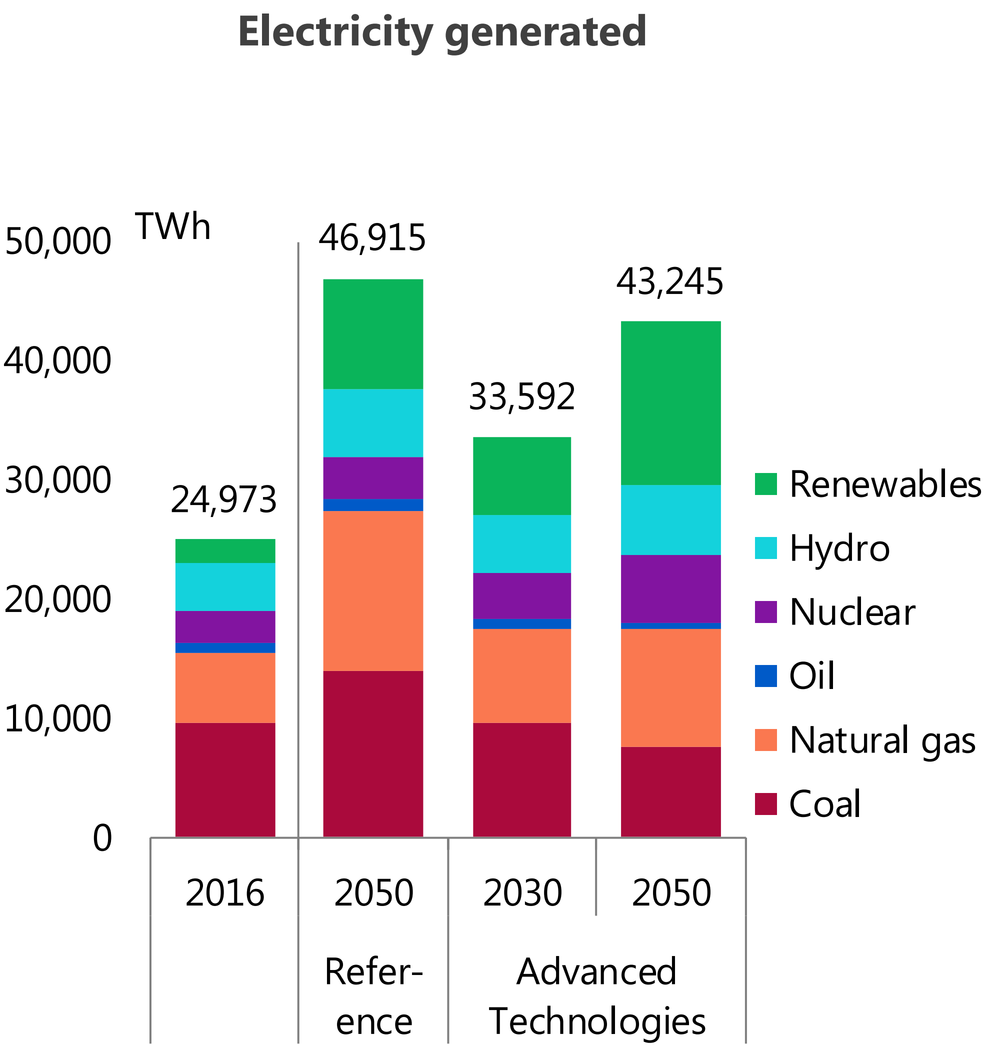
Energy intensity in industry

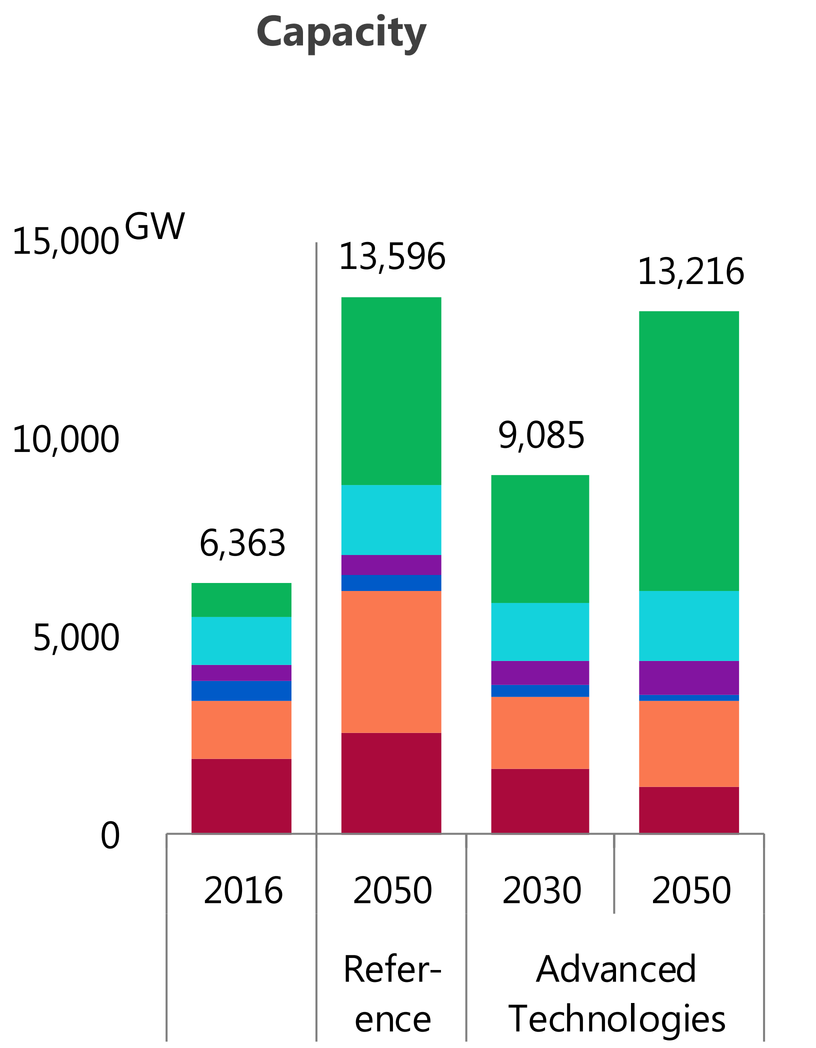


Total efficiency in the buildings sector

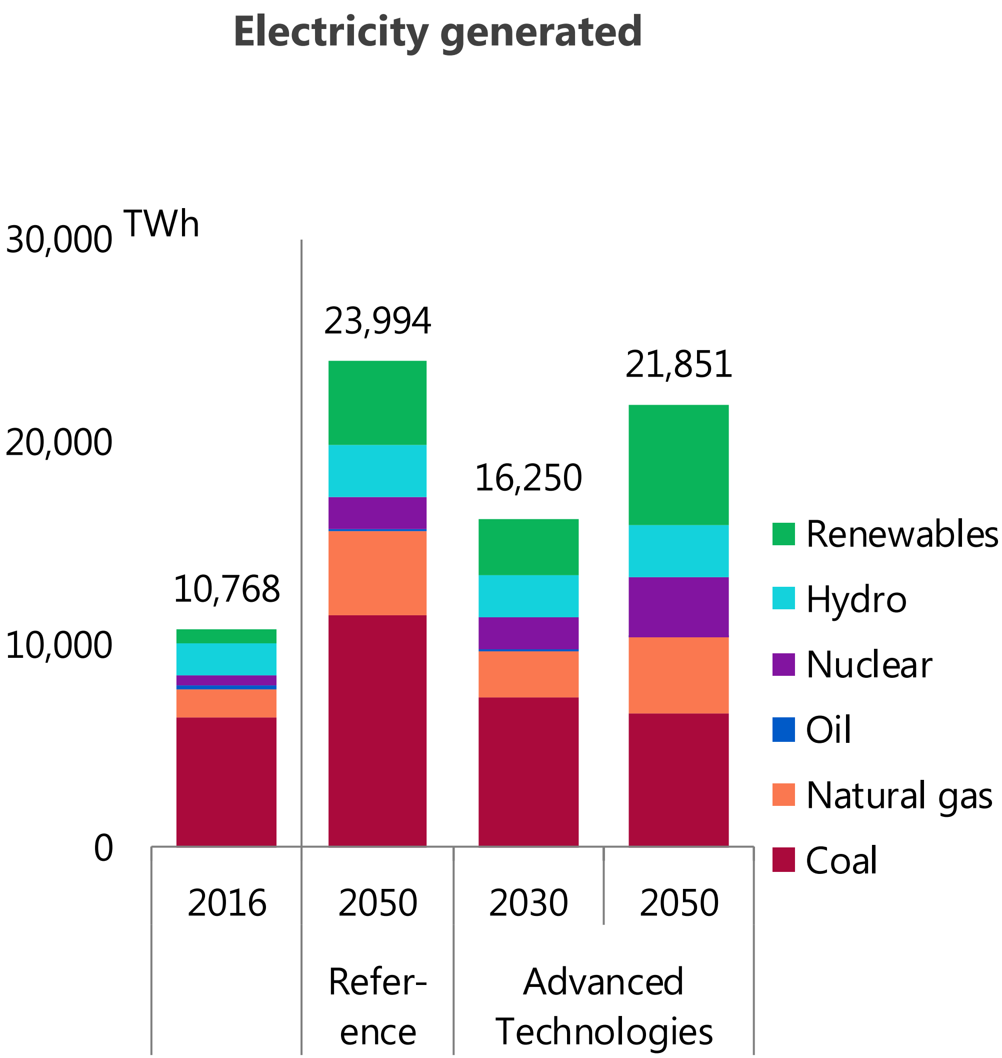


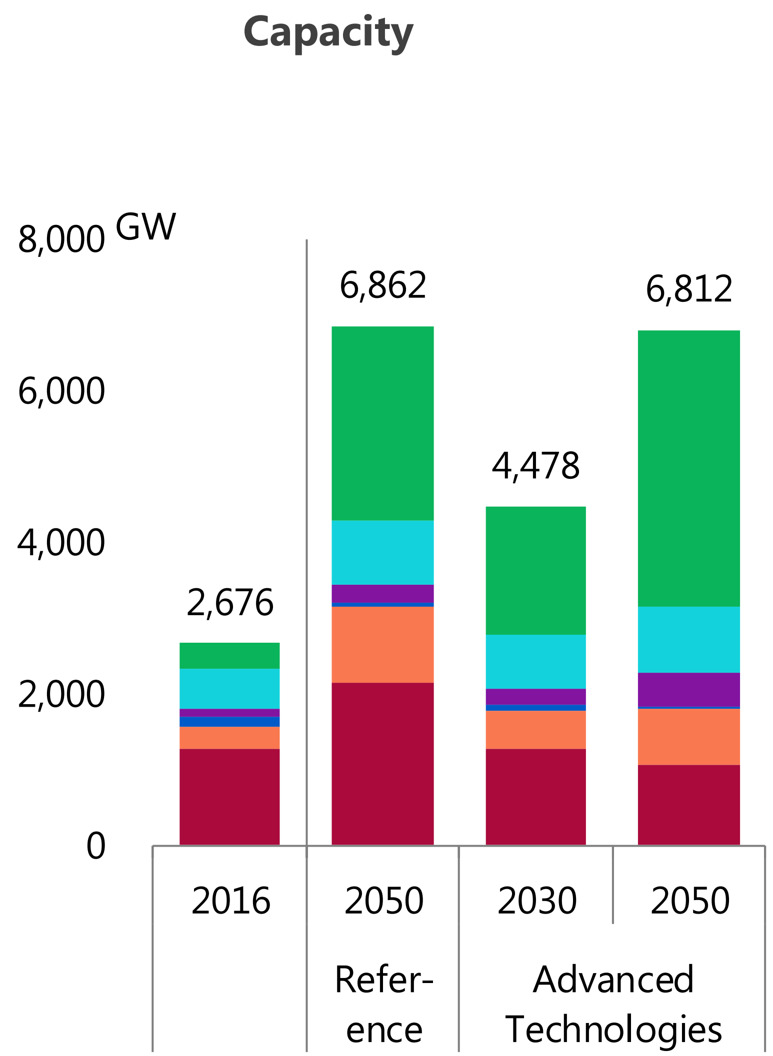
Power generation mix



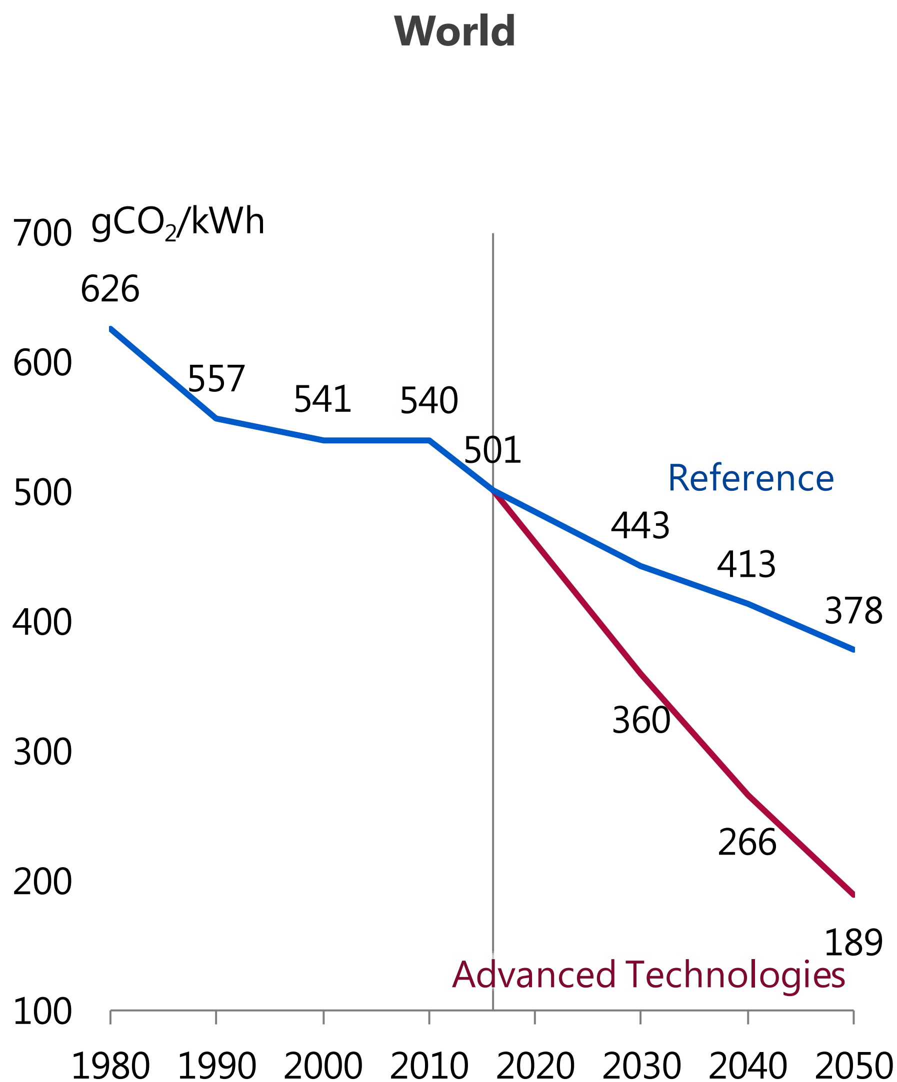


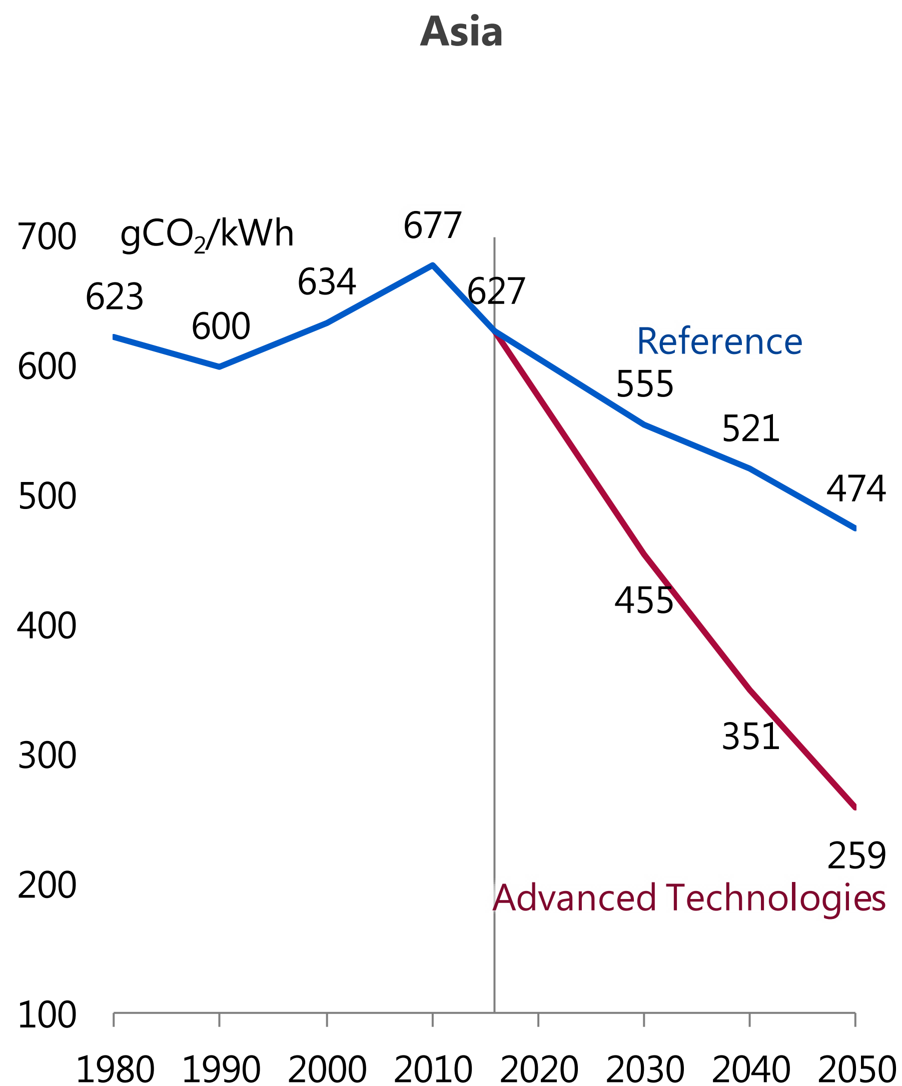
Power generation mix (Asia)





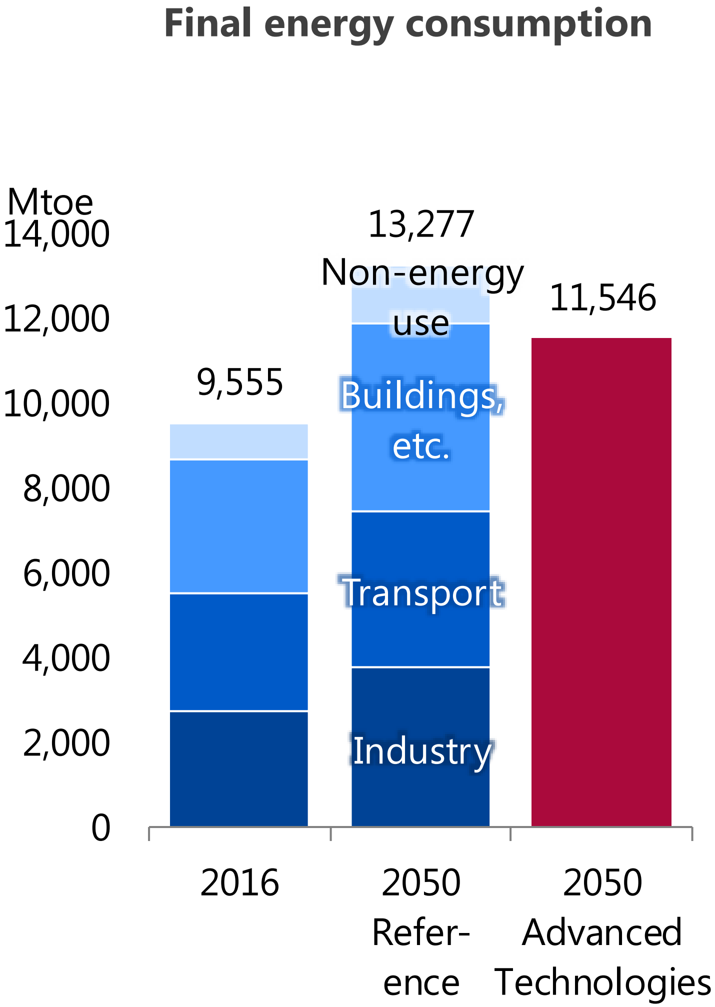
Carbon intensity of electricity

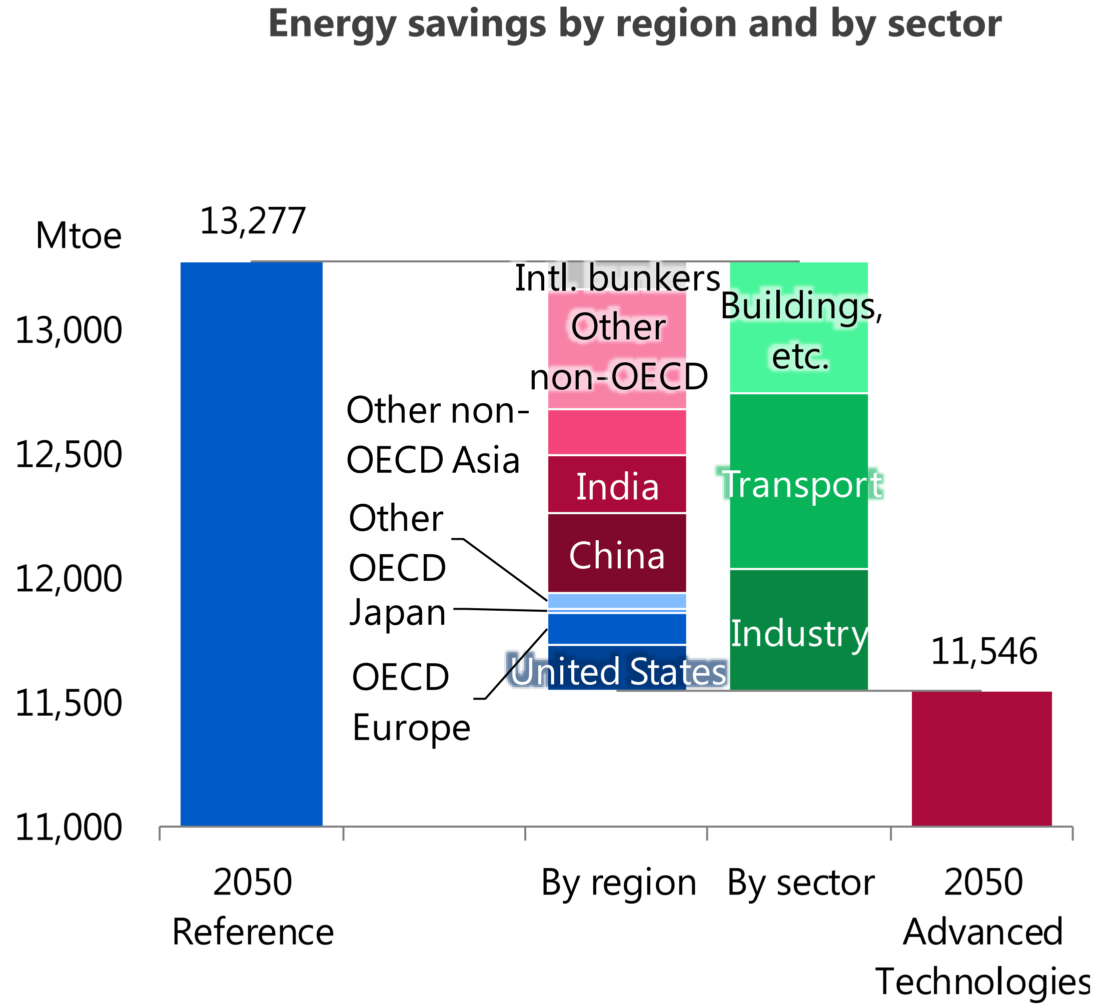




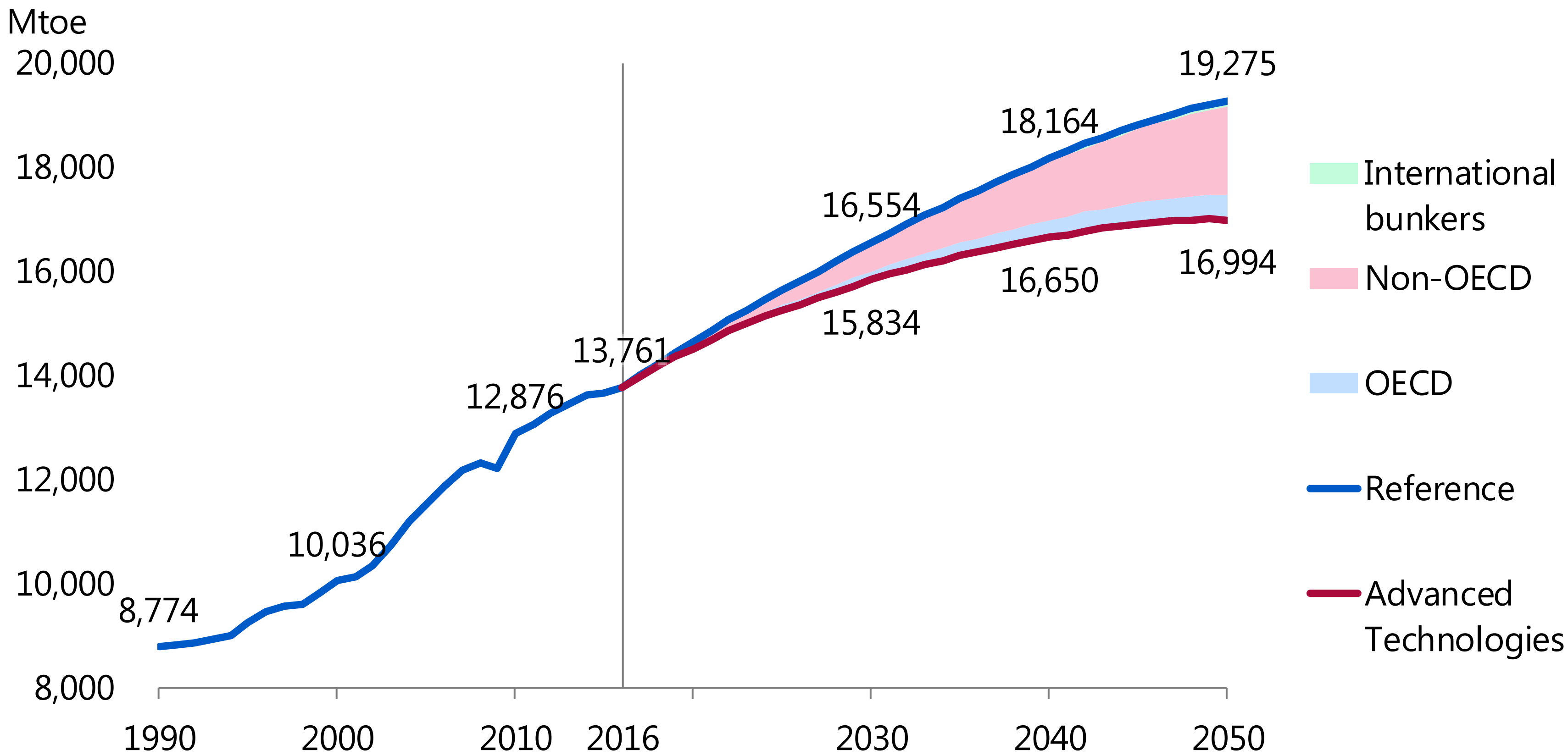
* CO_2 emissions per kWh at generation end

Energy savings (by region and by sector)

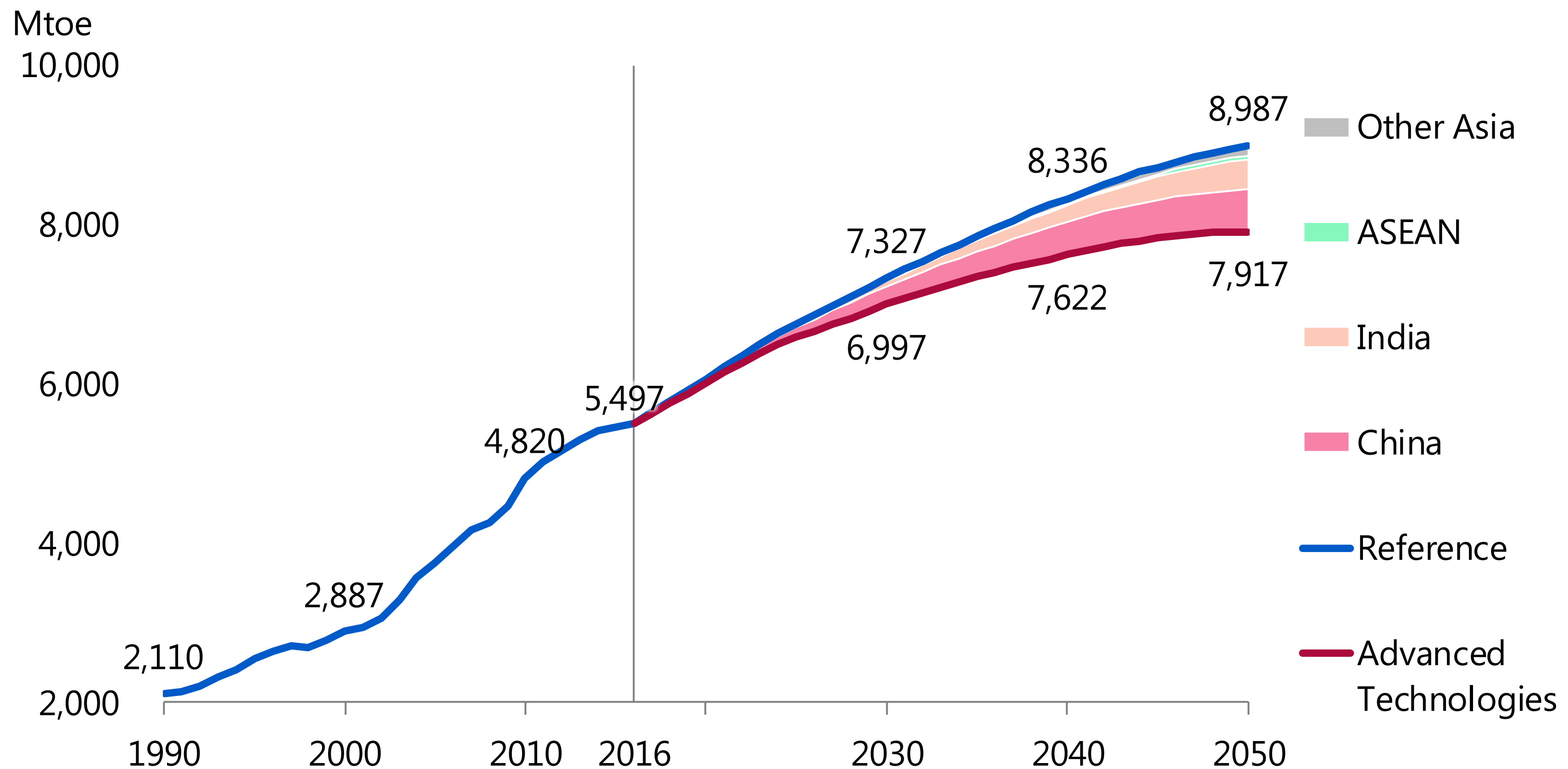




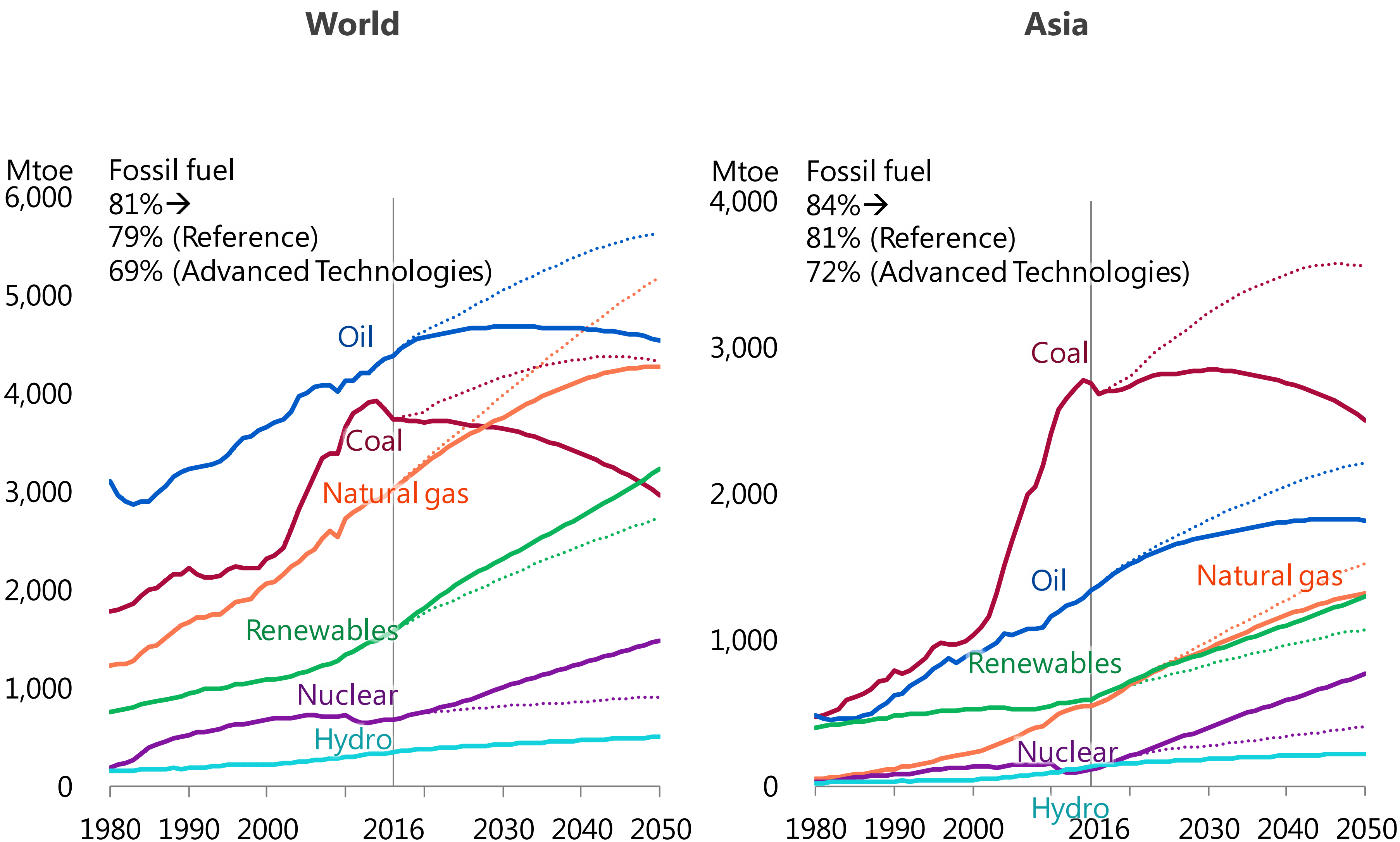
Primary energy consumption reduction



Primary energy consumption reduction (Asia)

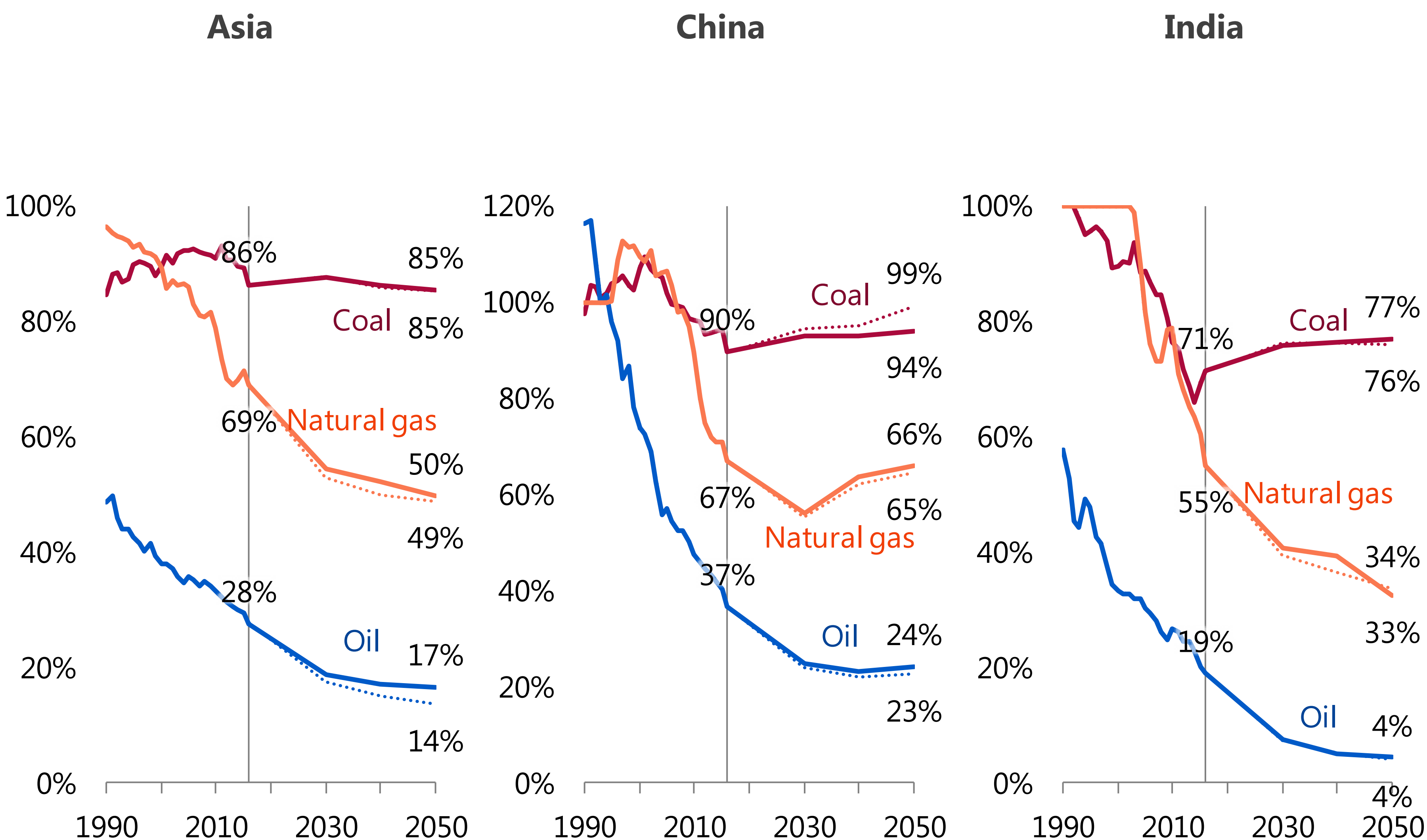


Primary energy consumption (by source)



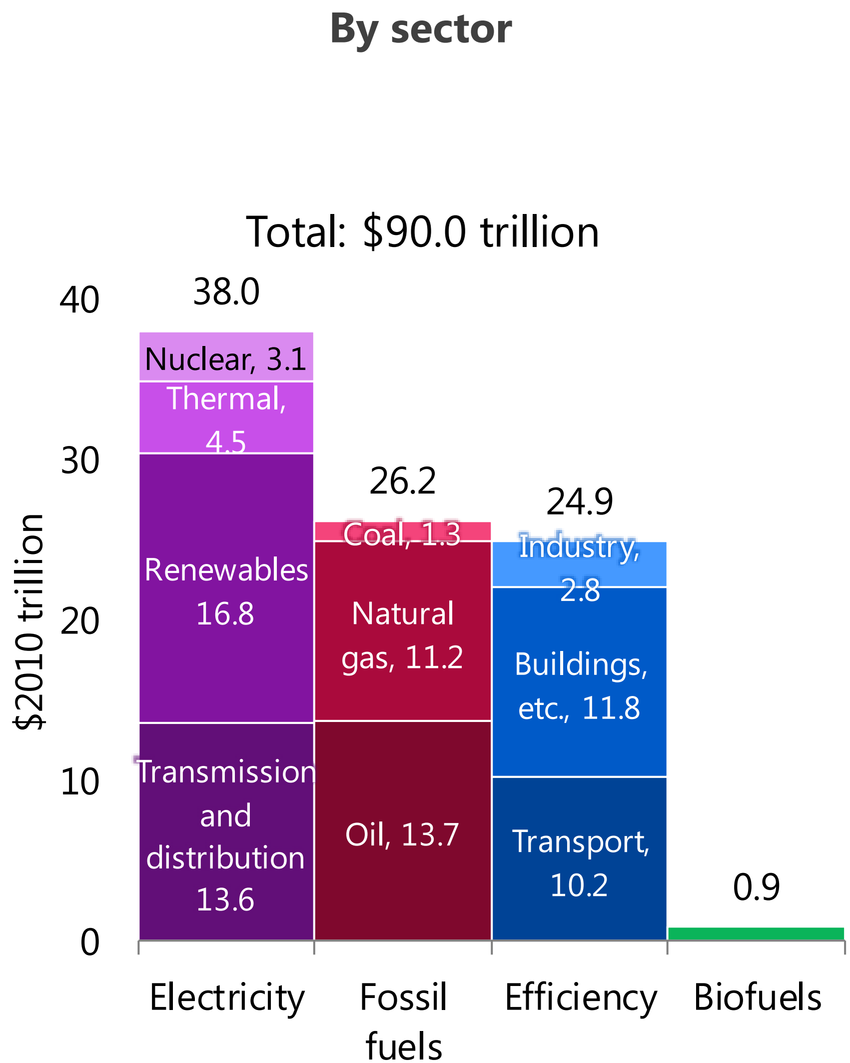
Reference Scenario (dotted), Advanced Technologies Scenario (solid)

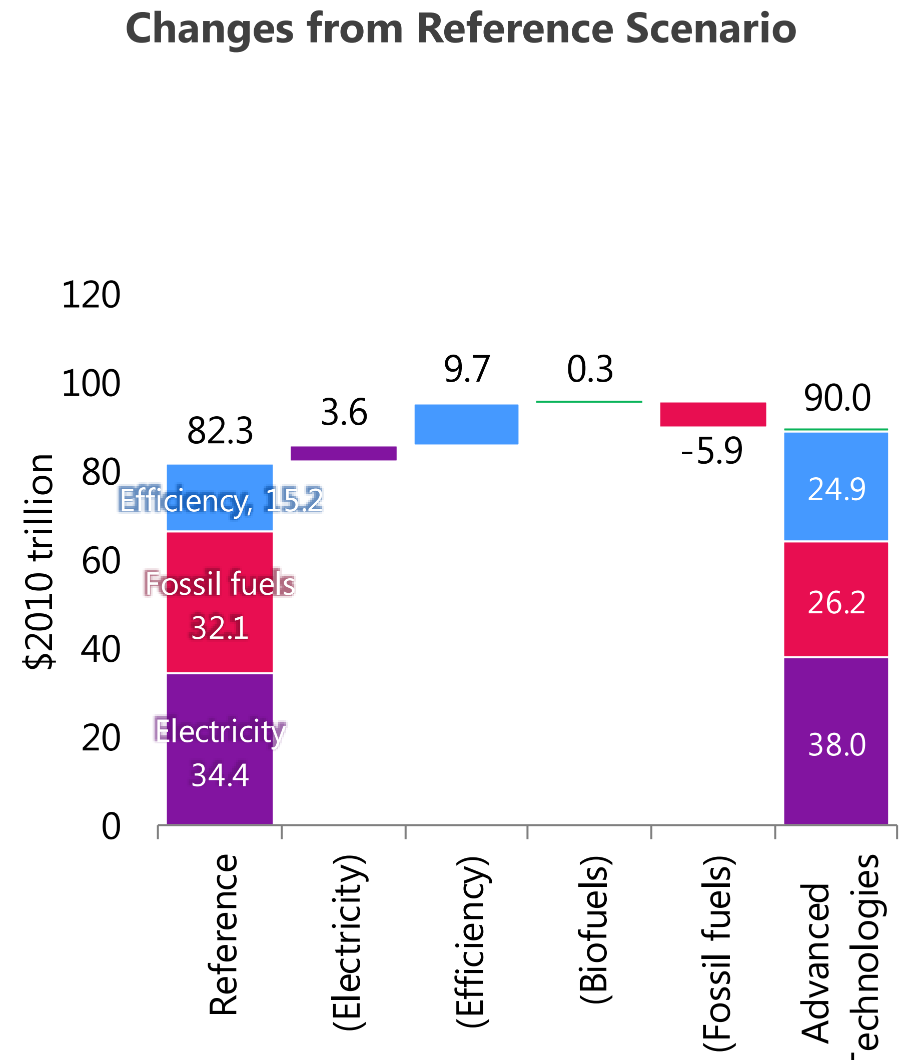
Energy self-sufficiency ratio



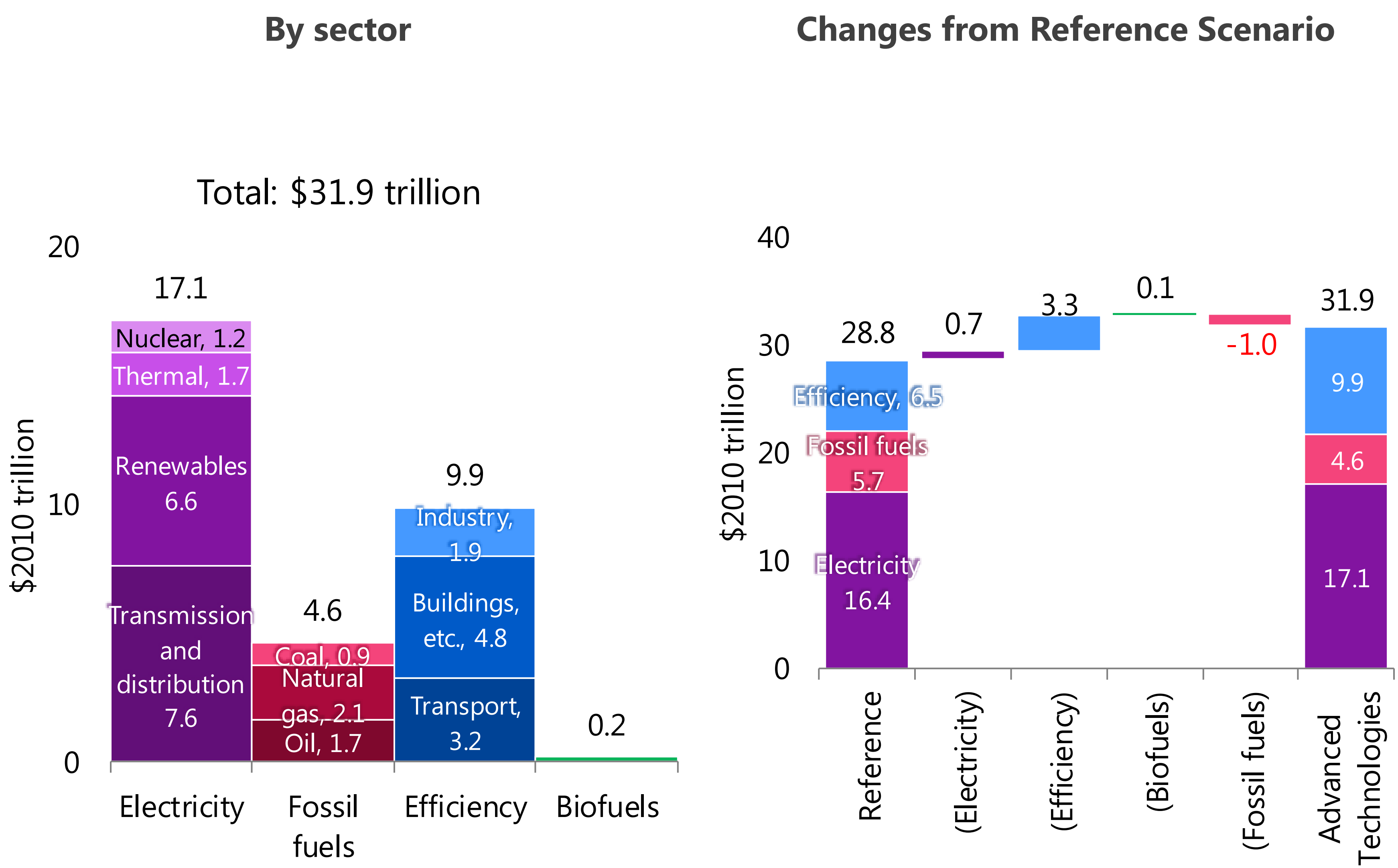
Reference Scenario (dotted), Advanced Technologies Scenario (solid)

Energy-related investments (2017 - 2050)

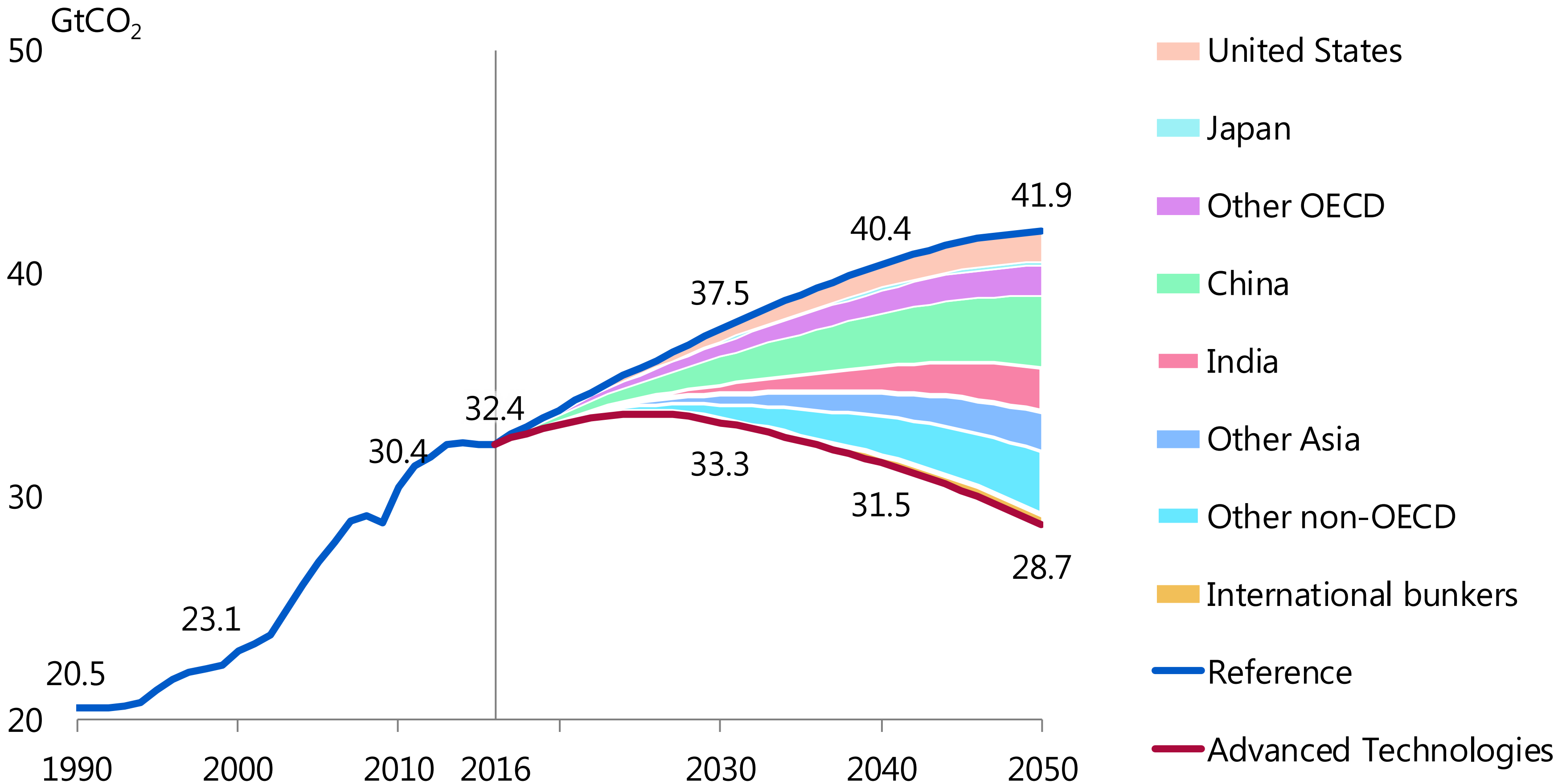




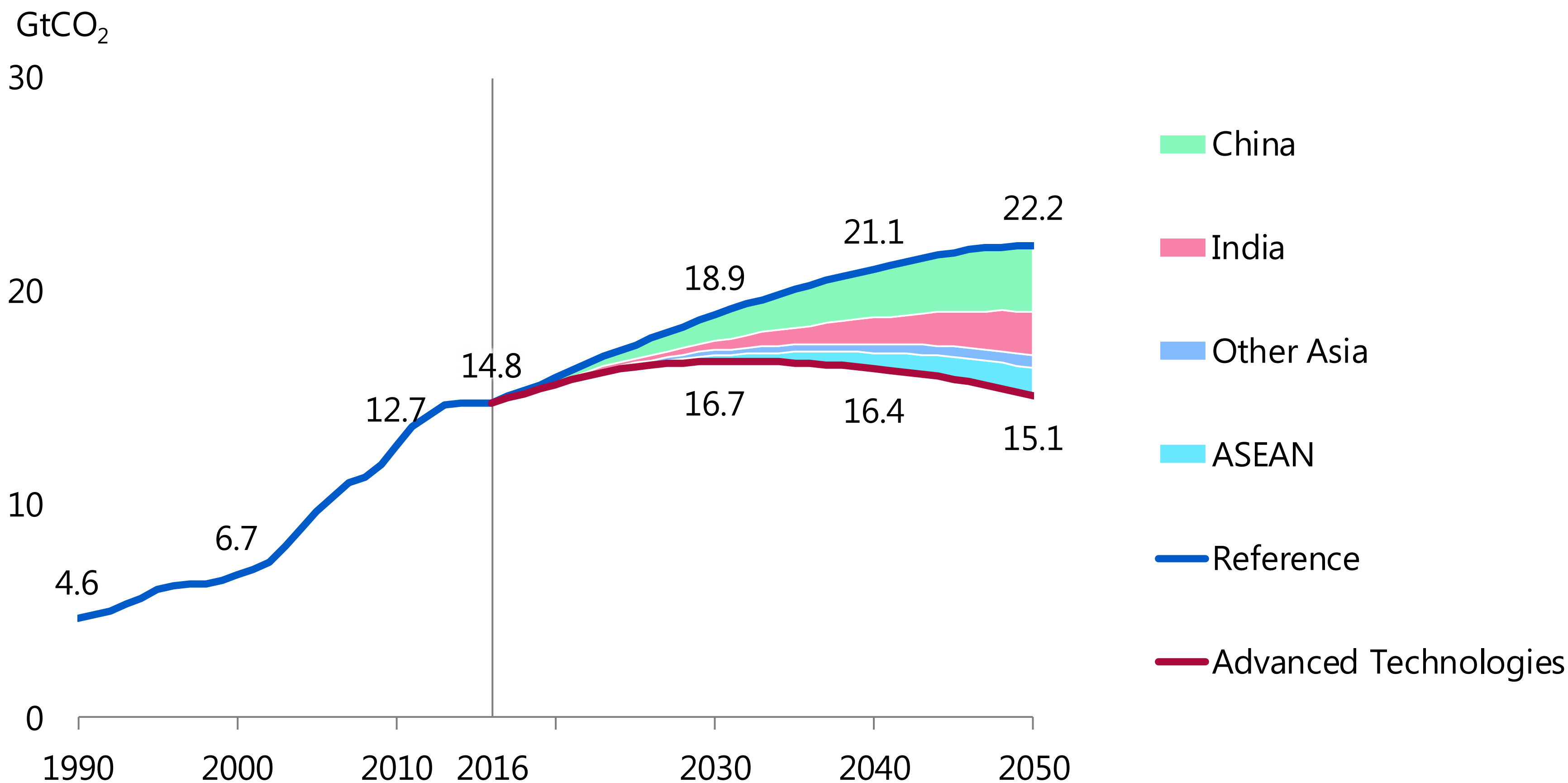
Energy-related investments (Asia, 2017 - 2050)



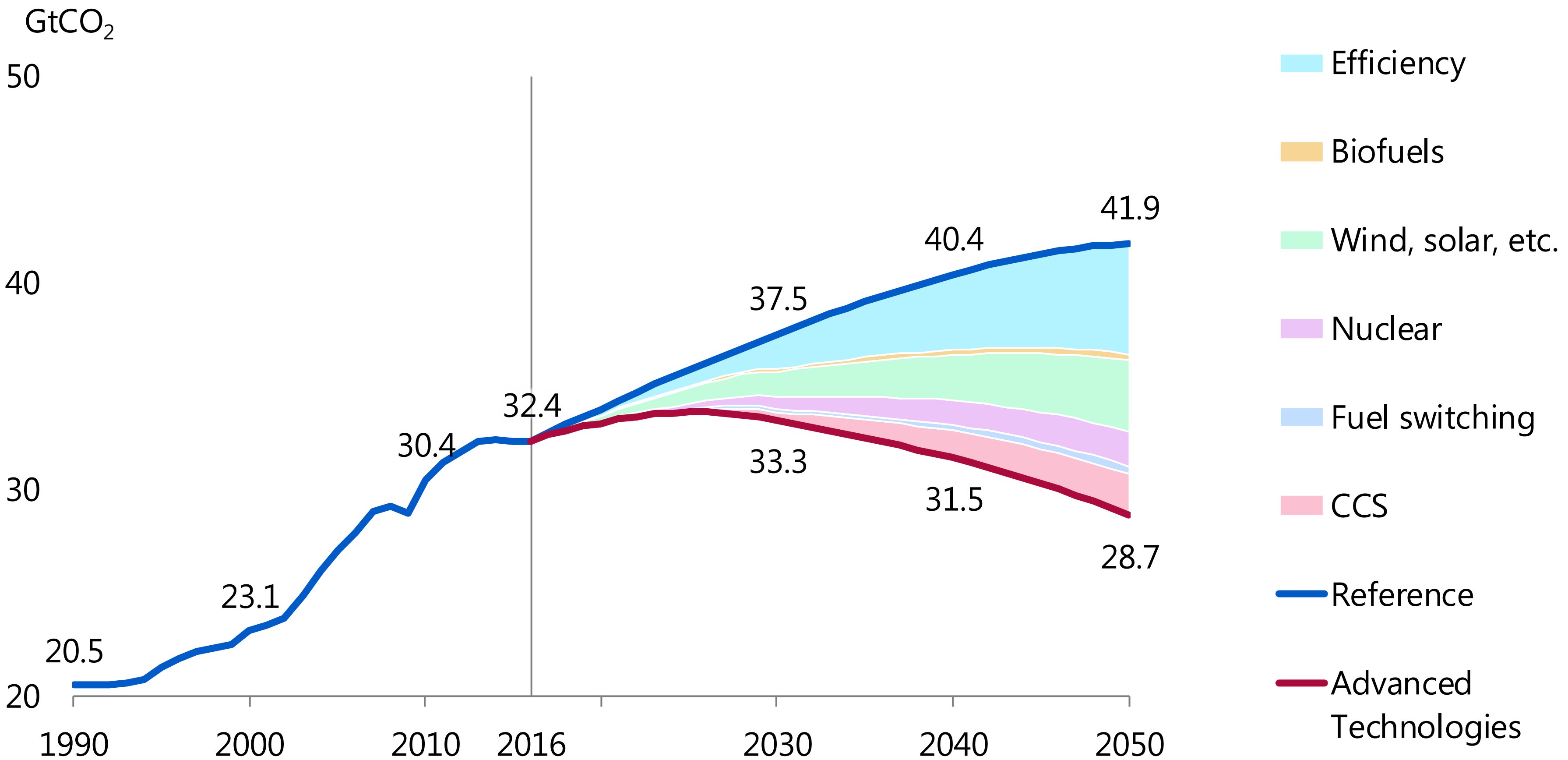
CO_2 emission reduction (by region)



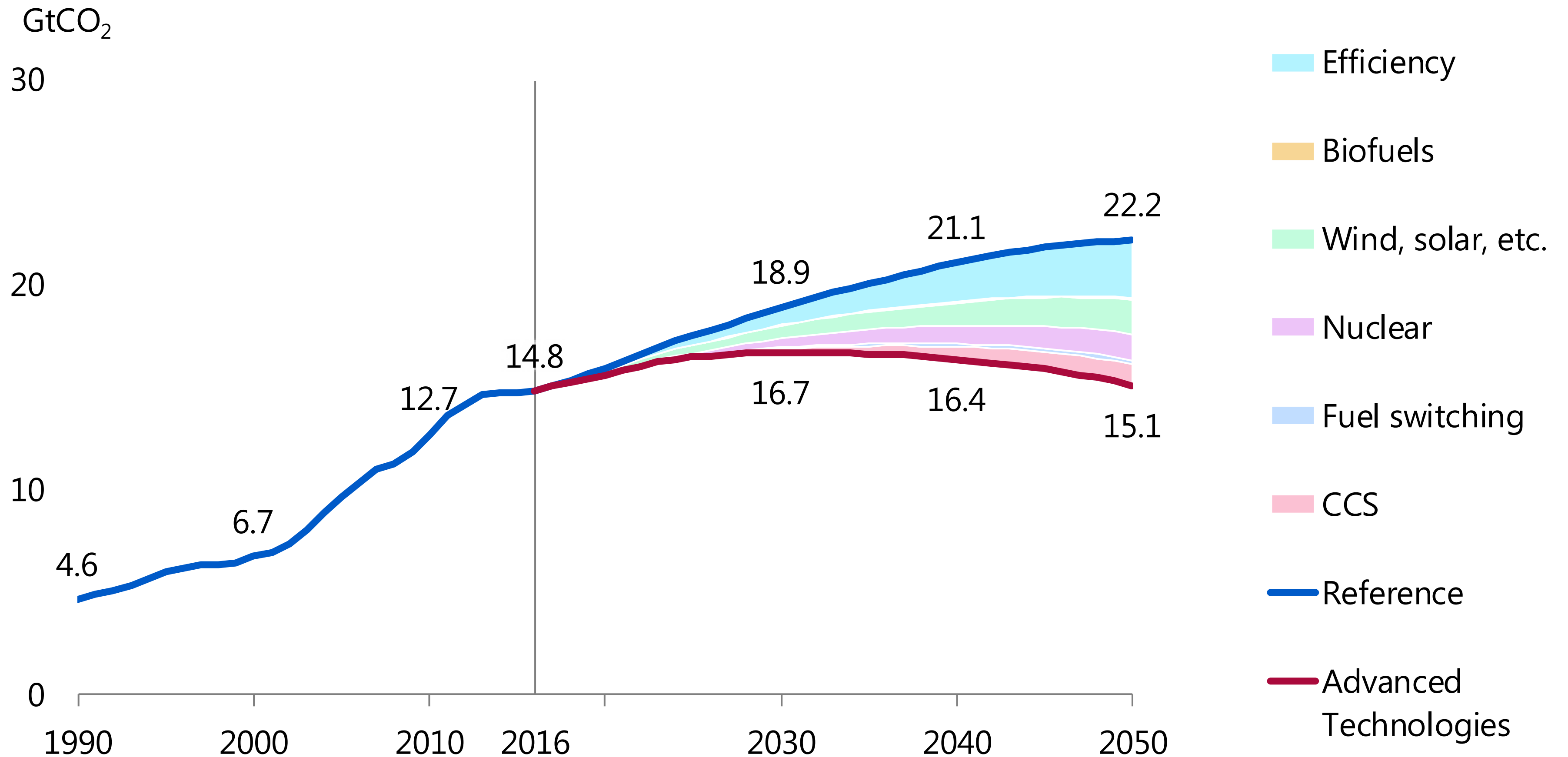
CO_2 emission reduction (Asia, by region)



CO_2 emission reduction (by technology)

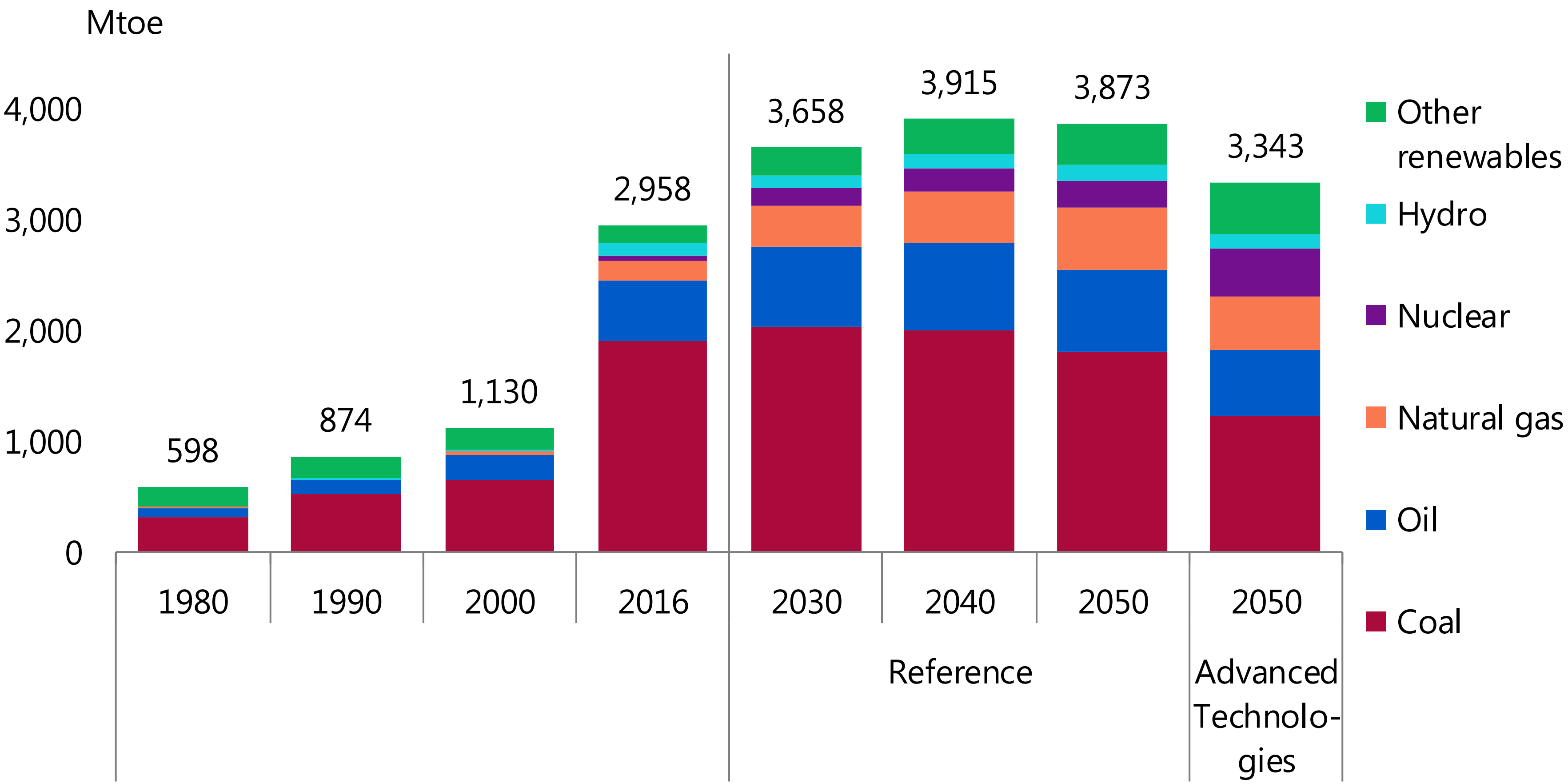


CO_2 emission reduction (Asia, by technology)

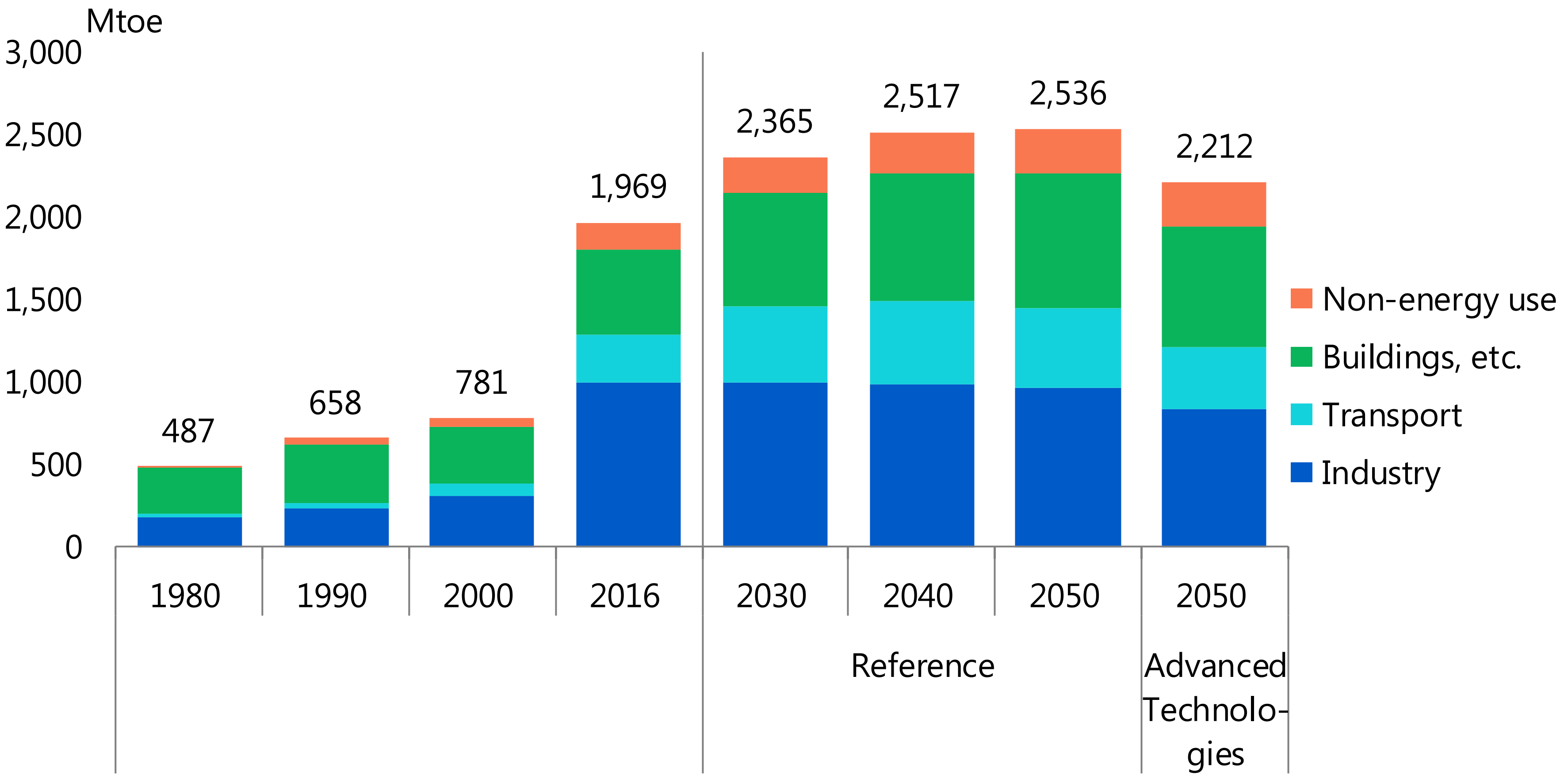


Energy outlook in China, India and ASEAN

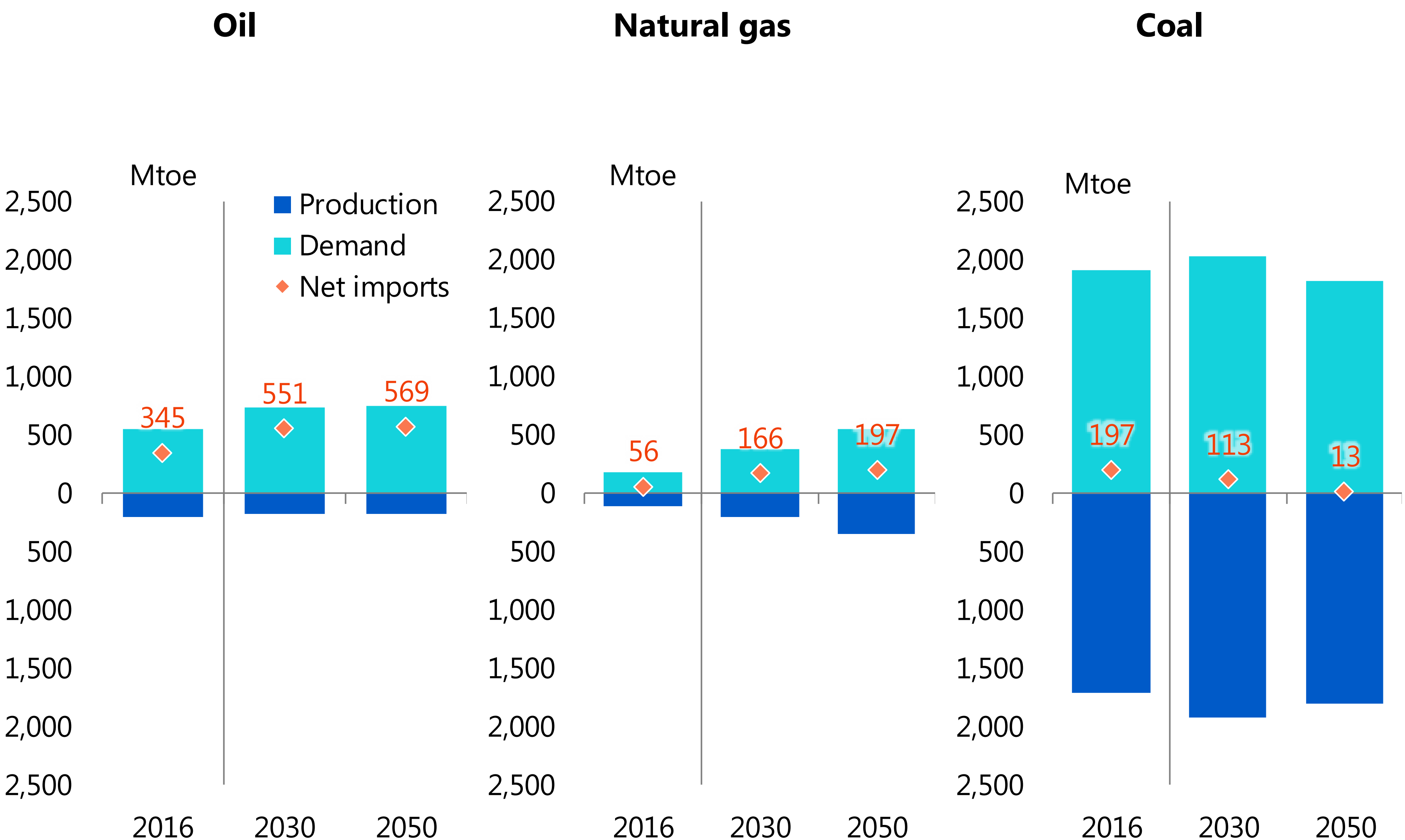
Primary energy consumption (China)



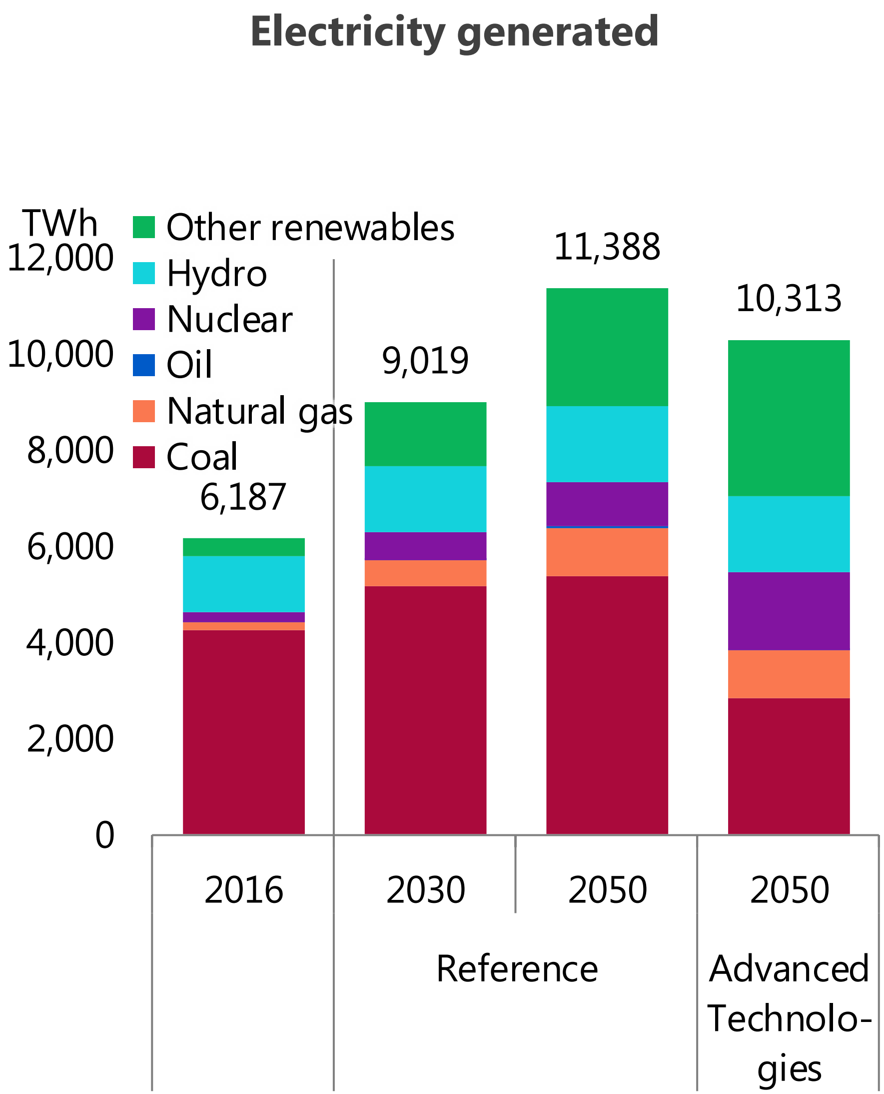
Final energy consumption (China)

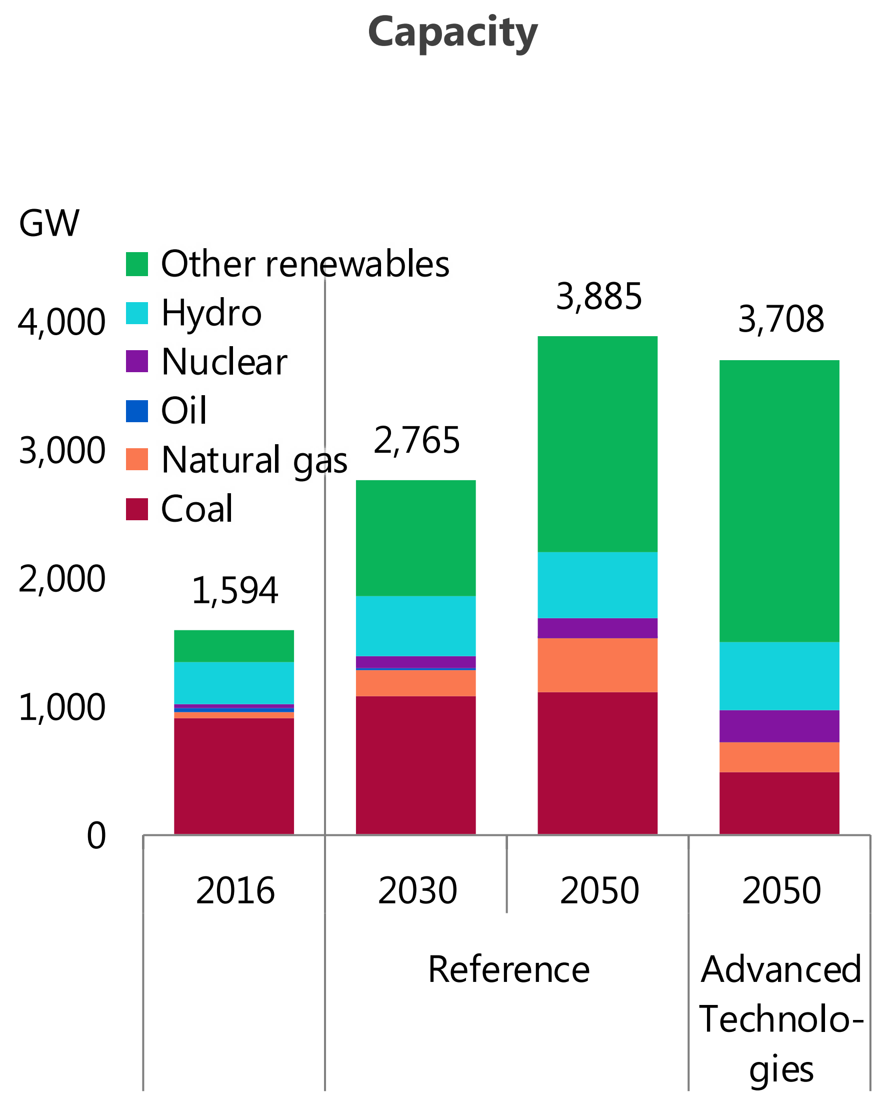


Fossil fuel supply / demand balances (China)

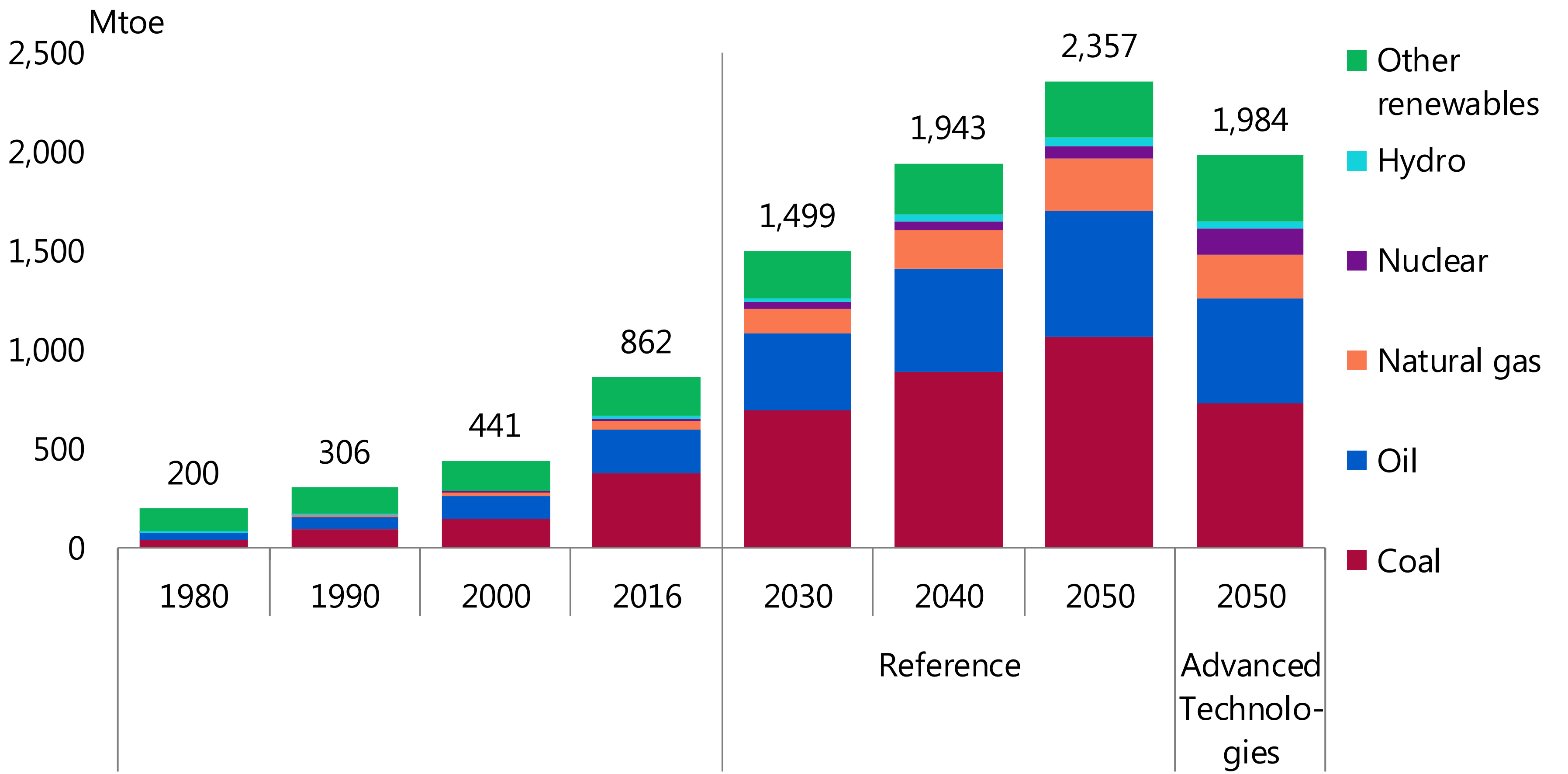


Power generation mix (China)

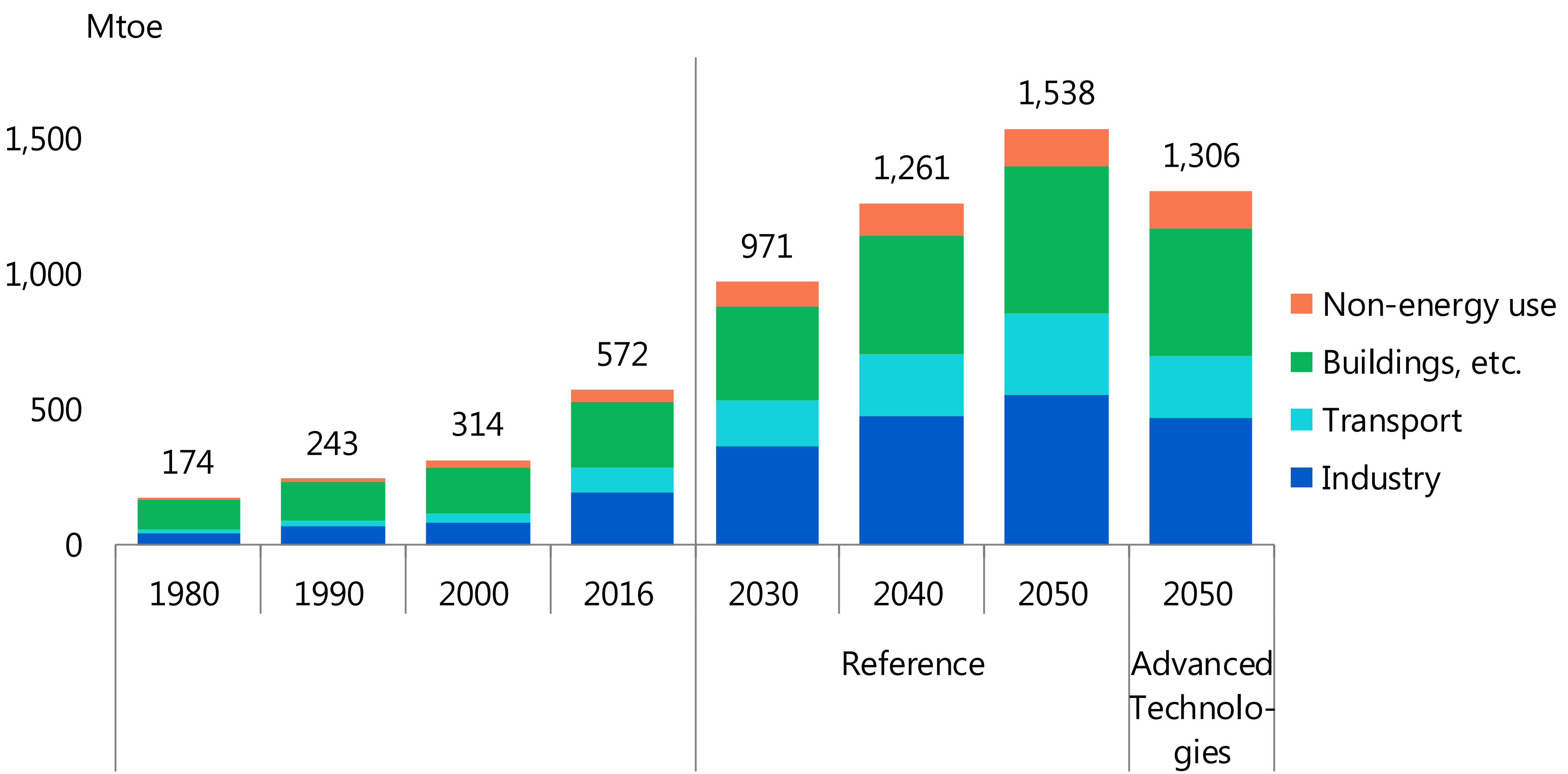




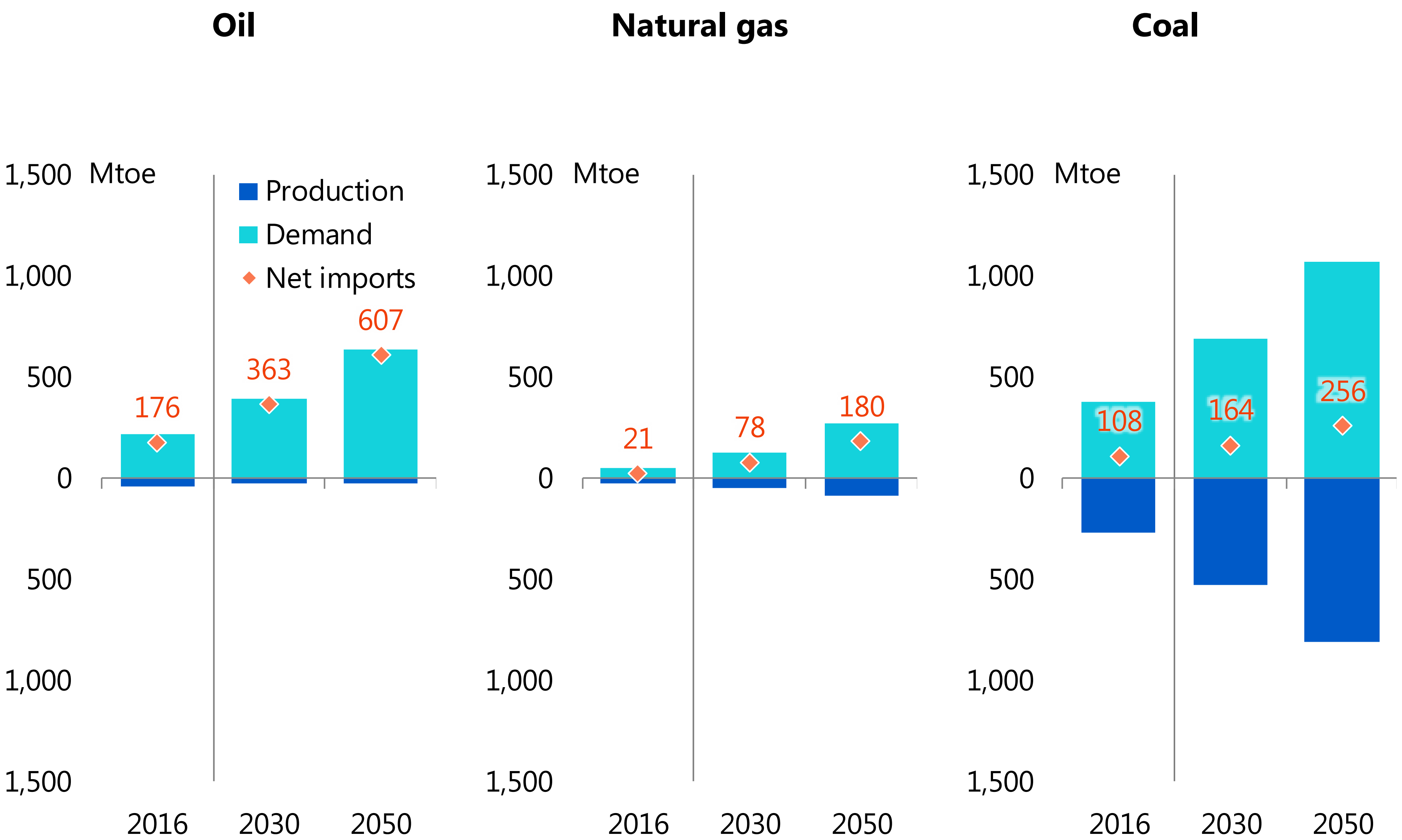
Primary energy consumption (India)



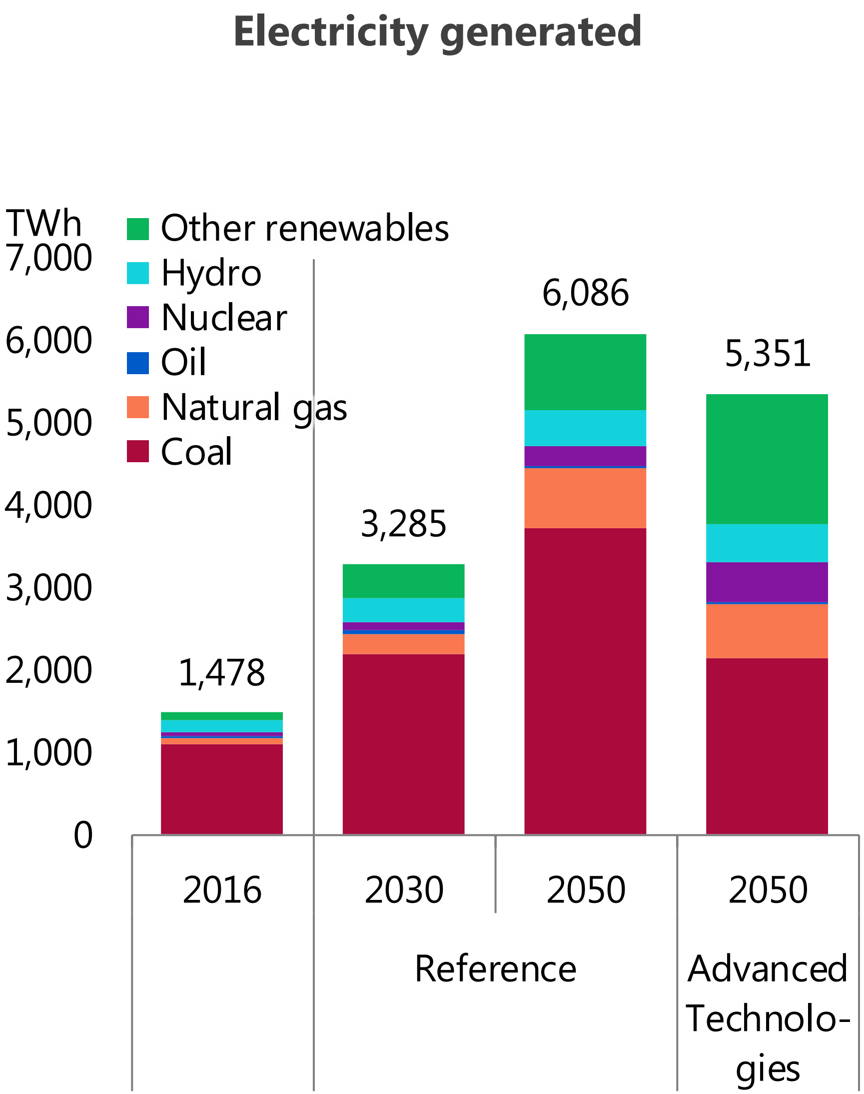
Final energy consumption (India)

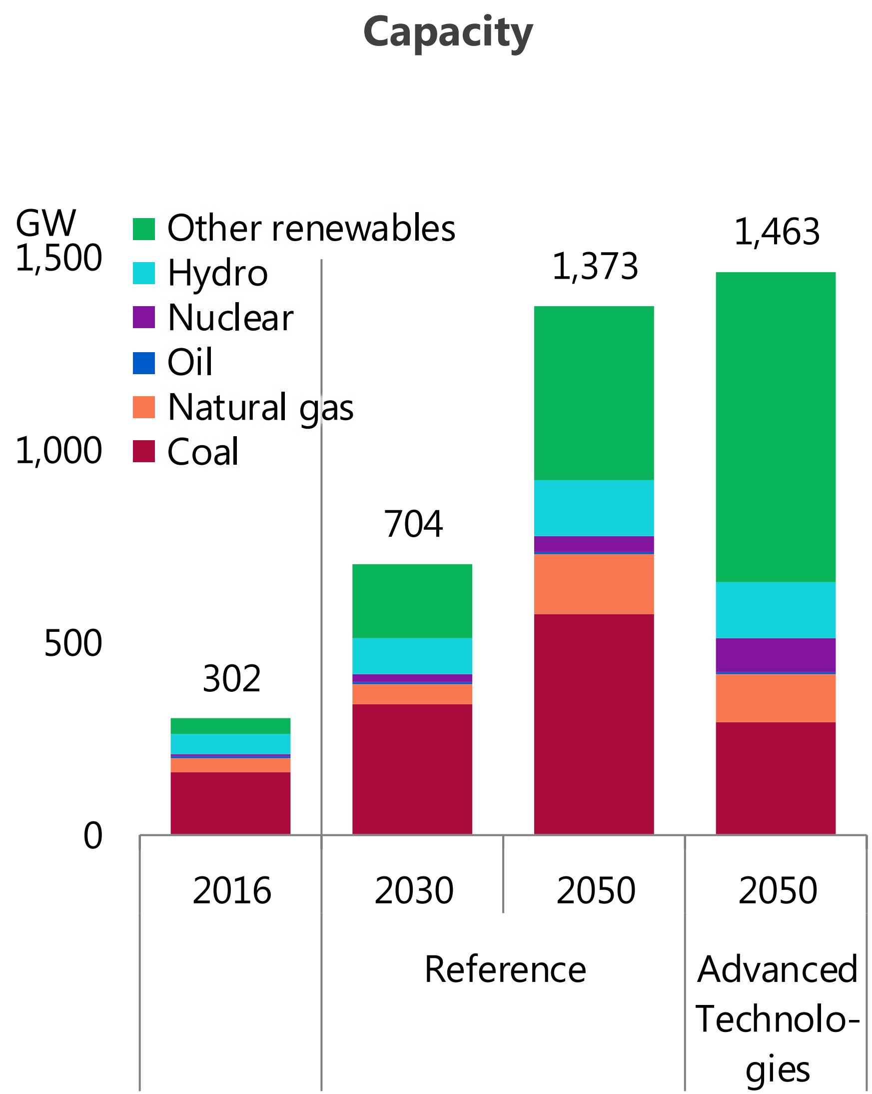


Fossil fuel supply / demand balances (India)

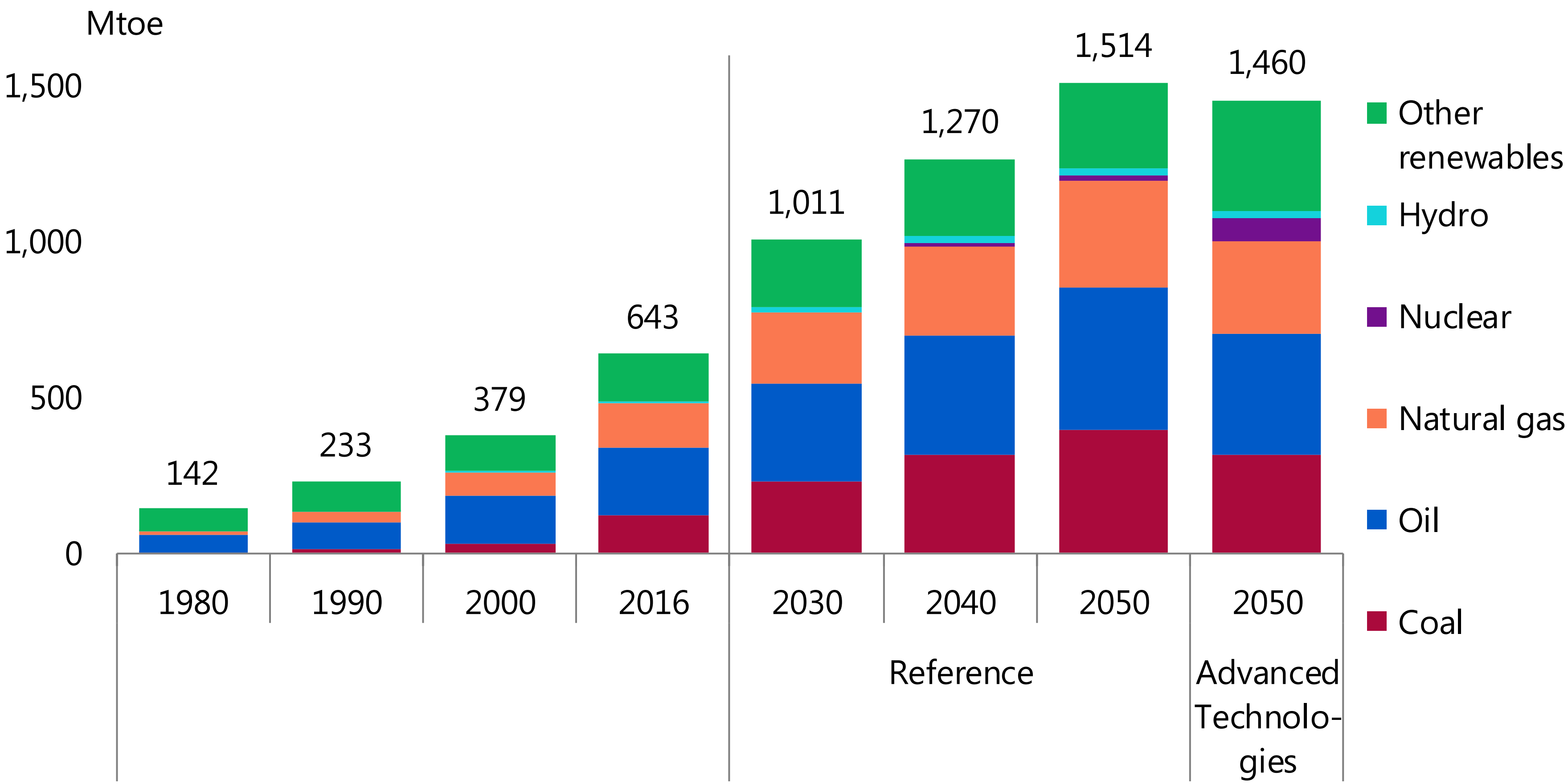


Power generation mix (India)

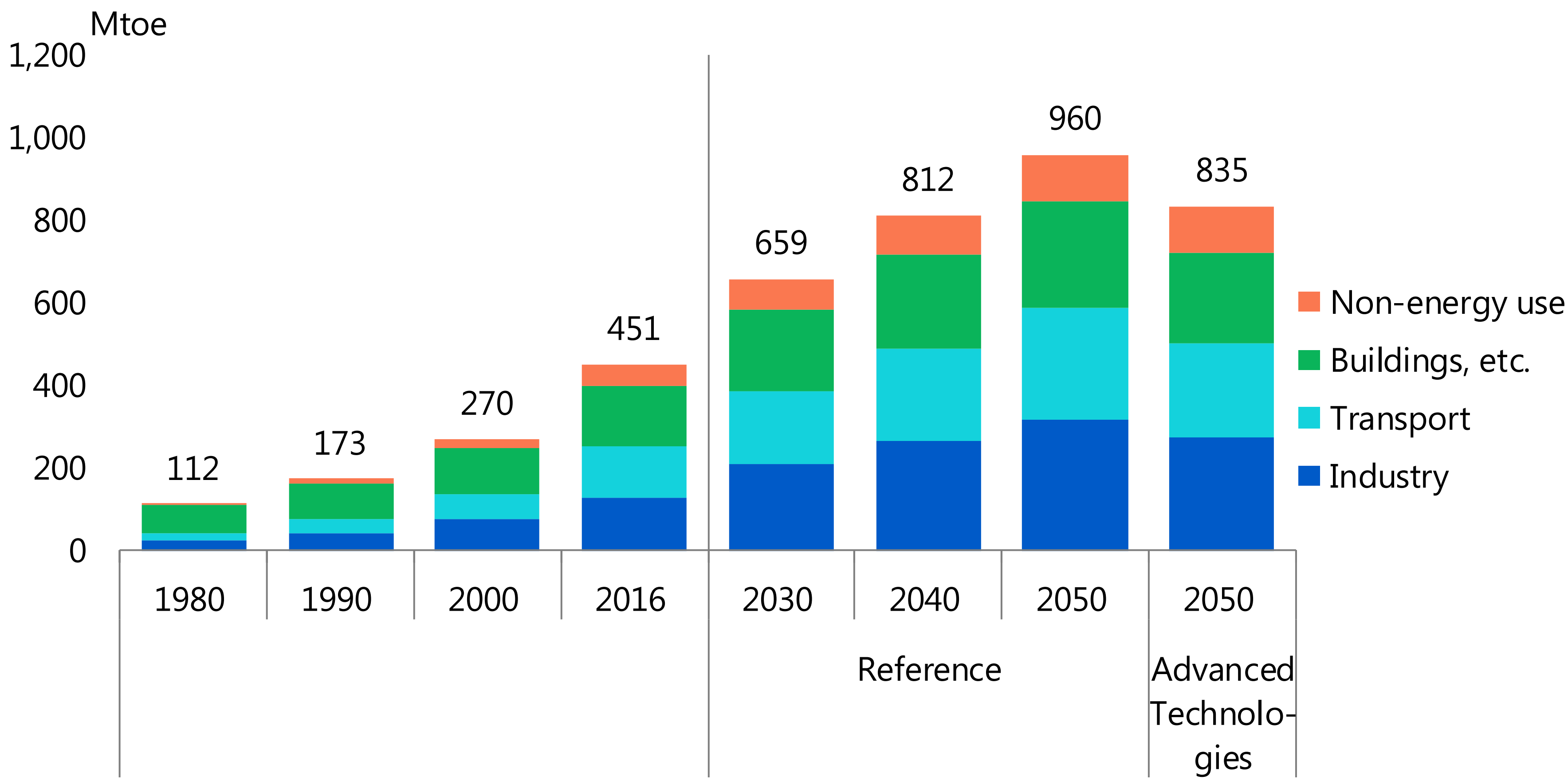




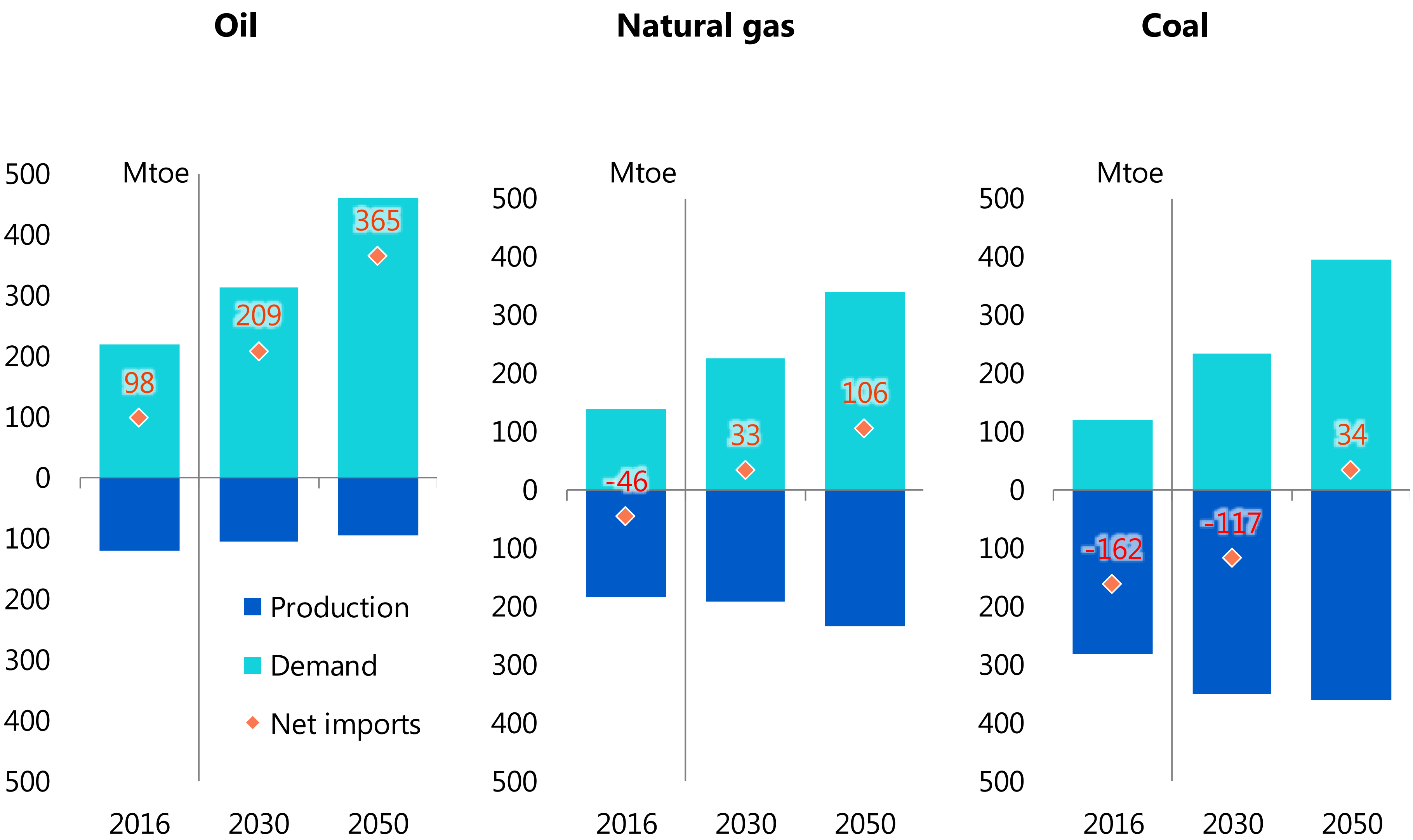
Primary energy consumption (ASEAN)



Final energy consumption (ASEAN)



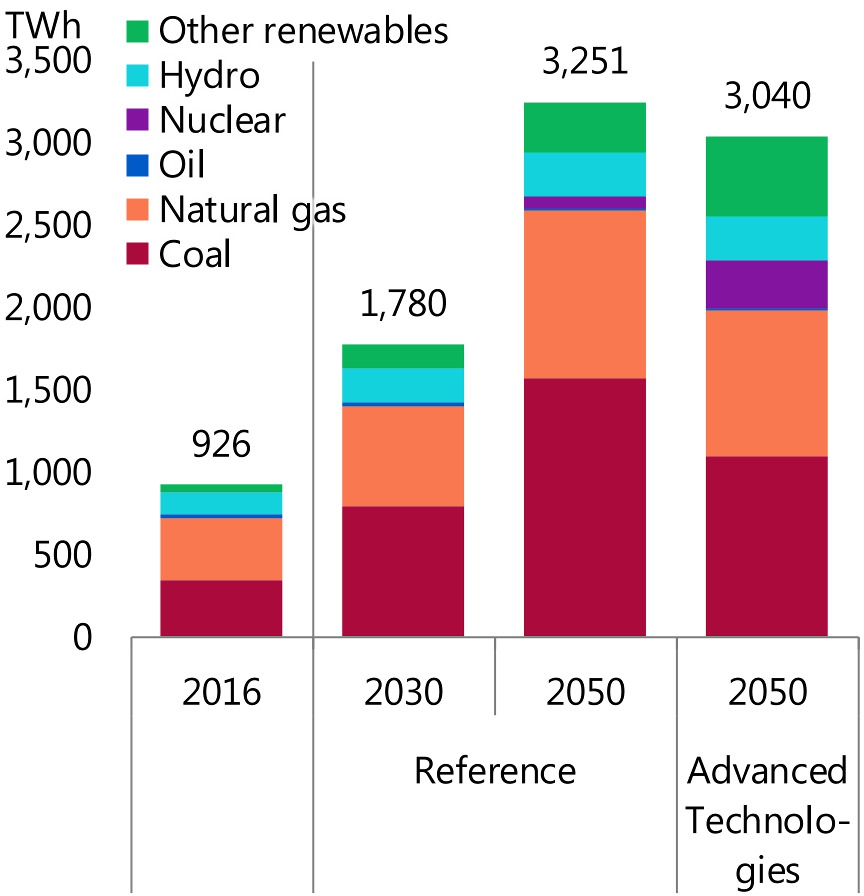
Fossil fuel supply / demand balances (ASEAN)



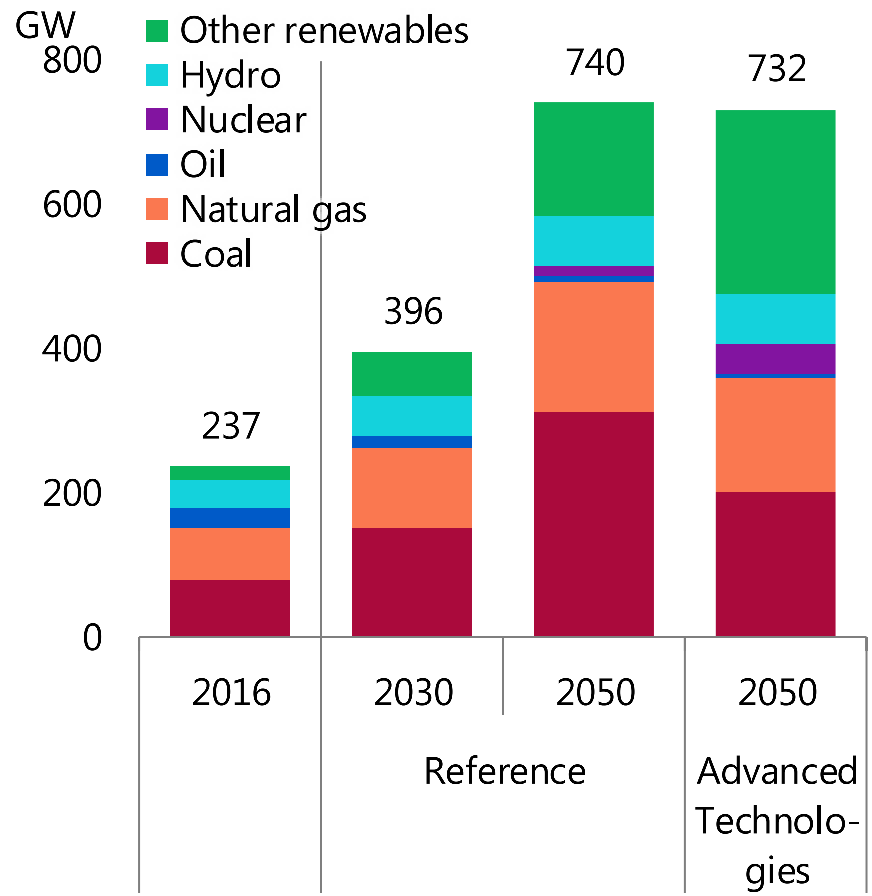
Power generation mix (ASEAN)

JAPAN

Electricity generated



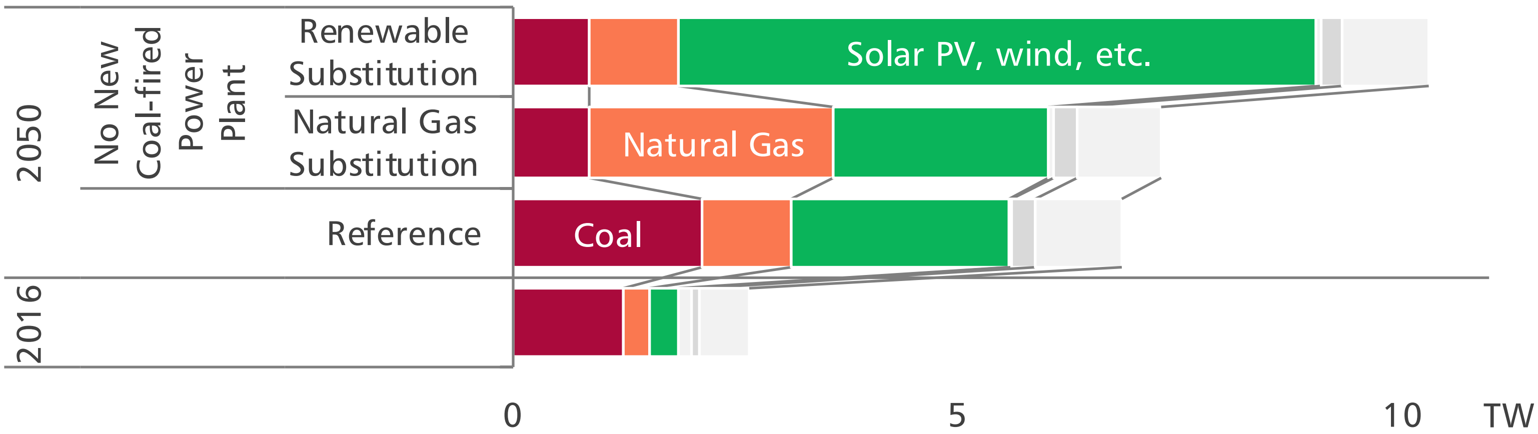
Capacity



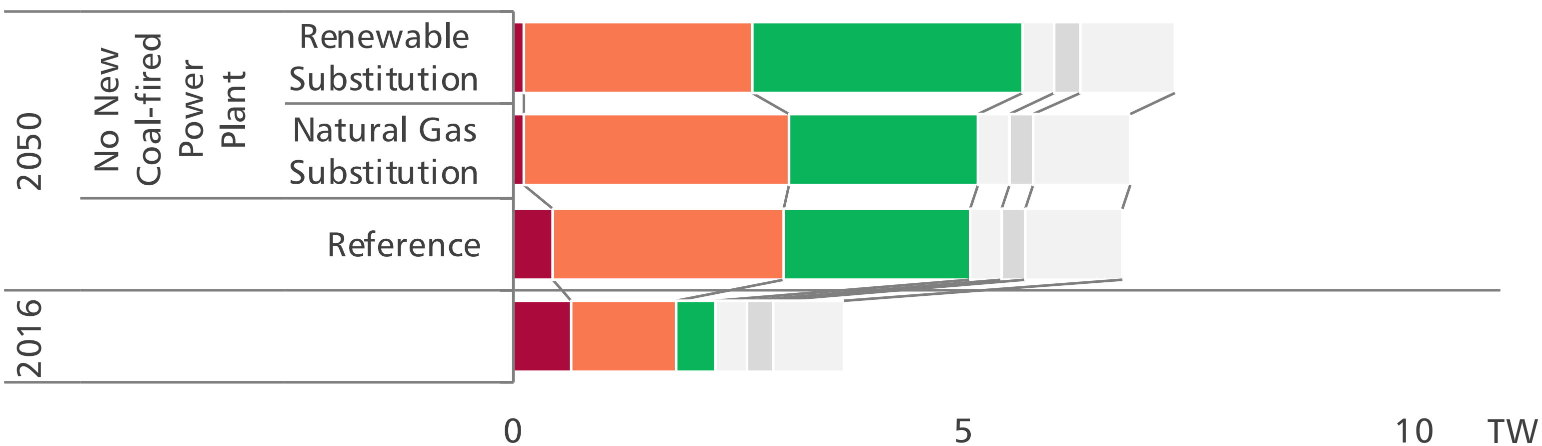
No New Coal-fired Power Plant Case

Power generation capacity «indicative»

Asia



Non-Asia



Note: No New Coal-fired Power Plant (Renewable Substitution) Case is based on approximation that curtailment of solar PV / wind power generation and battery charge are small enough to ignore. Since capacity factor of natural gas-fired power plants is same as in the Reference Scenario, the capacity is possibly overestimated.

Electricity cost estimation

Definition

Includes capital costs of power plants, fuel costs, and system costs.

It does not include financial resource of incentive for renewable energy, which has become an issue in many countries because of its amount.

2010 real price

Assumption

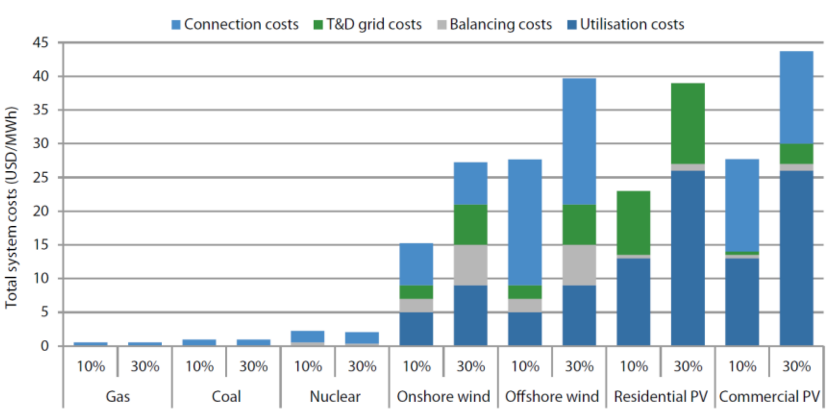
Capital costs of renewable power plants are assumed to continue to decrease until 2050. The decrease rates (solar PV: by 30%, wind: by 10% to 2050) are based on IEA "World Energy Outlook 2016."

No assumption of additional learning effect of additional capacity from the Reference Scenario

Grid and connection costs are set with reference to NEA "The Full Costs of Electricity Provision" (2018).

As for grid / connection costs, no regional specification

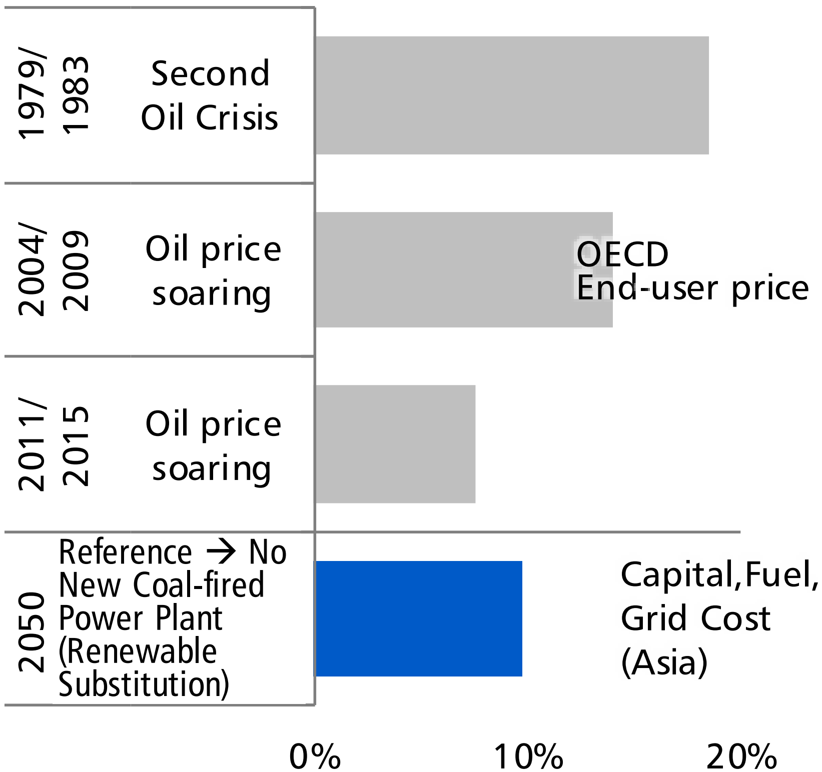
Figure 3.3: **System cost of different generation technologies**



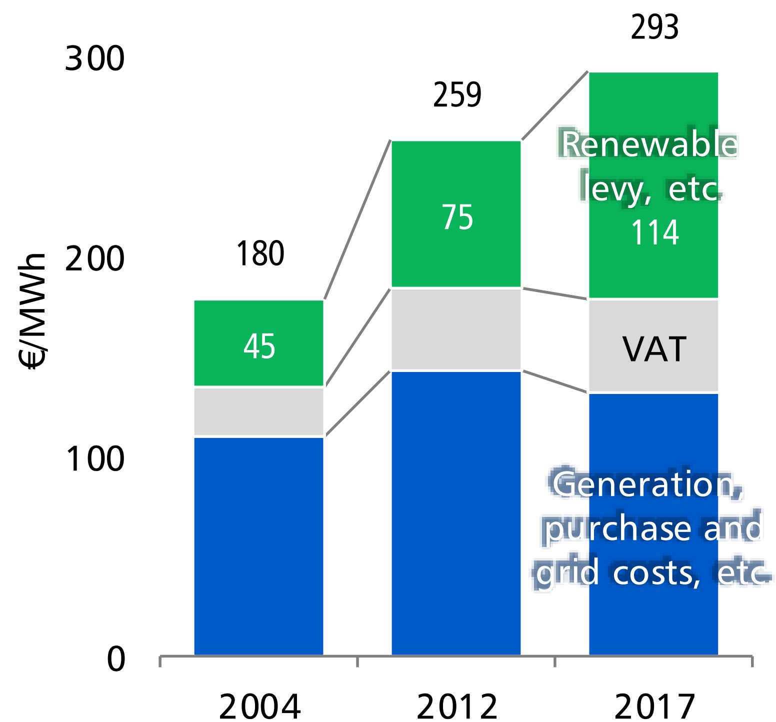
Source: OECD/NEA "The Full Costs of Electricity Provision"

Electricity cost and price

❖ Changes in real electricity cost and price



❖ Electricity price (Germany, household)



Transition from the Reference Scenario to the No New Coal-fired Power Plant (Renewables Substitution) Case raises electricity cost by 10% in Asia in 2050.

Electricity prices do not depend on only power generation costs. In Germany, renewable levy mainly leads rise of electricity prices despite buying price reduction.

Source: IEA "Energy Prices and Taxes" [OECD end-user price]

Source: BDEW "BDEW - Strompreisanalyse Mai 2018"

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