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IEEJ Outlook 2022

Energy, Environment and Economy

Challenges toward carbon neutrality: Voyage in uncharted territory

Overview

The Institute of Energy Economics, Japan

Rejean CASAUBON
Seiya ENDO
Hiroshi HASHIMOTO
Ryohei IKARII
Yoko ITO
Takehiro IWATA
KAN Sichao
Yasuaki KAWAKAMI
Kenji KIMURA
Yoshikazu KOBAYASHI
Ken KOYAMA
Ichiro KUTANI
Yuji MATSUO
Tetsuo MORIKAWA
Tomoko MURAKAMI
Yu NAGATOMI
Masayoshi NOGUCHI
Hideaki OBANE
Hideaki OKABAYASHI
Keisuke OTA
Takashi OTSUKI
Atsuo SAGAWA
Yoshiaki SHIBATA
Shigeru SUEHIRO
Takahiko TAGAMI
Yukari YAMASHITA
Akira YANAGISAWA
Emiri YOKOTA

Executive summary

Global energy supply and demand outlook (Reference Scenario)

India, MENA and ASEAN account for three quarters of the global energy consumption growth

- Under the Reference Scenario, which incorporates the expected effects of past trends and extends the energy and environmental policies and technologies to date, global primary energy consumption will increase by about 20% between the current level and 2050. As the macroeconomy expands beyond the increase rate for consumption, the world's energy consumption intensity is decreasing, reflecting efficiency improvements and energy conservation efforts.
- India, the Middle East and North Africa (MENA), and the Association of Southeast Asian Nations (ASEAN) will lead the global increase in primary energy consumption. The global share of these three will increase from 18% in 2019 to 28% in 2050. They will account for 76% of the increase in consumption between 2019 and 2050.
- Although non-fossil energy increases substantially in this scenario, it appears very difficult that they could alone cover all the energy consumption. In the timeline to 2050, it is realistic for the world to expect a combination of fossil fuels and non-fossil energy, especially in the Emerging Markets and Developing Economies where consumption will increase.

Middle Eastern oil producers lead oil supply at low production costs

- In the medium-term, until 2030, global oil demand will increase at an annual rate of 0.5%. In response, the Organization of Petroleum Exporting Countries (OPEC) and non-OPEC countries will both increase crude oil production. In the longer run, oil production in North America will peak out, while production in Middle Eastern OPEC countries, which boast abundant oil reserves, will continue to increase.
- As the main axis of crude oil production will shift to Middle Eastern oil producing countries, Asia's dependence on crude oil from the Middle East will once again intensify. Asia's share will reach almost 80% of the global crude oil imports in 2050, and the world's largest oil importer will shift from China to India, with future imports exceeding those of China today.

Sustained expansion of LNG market due to abundant supply potential

- In the United States, the world's largest producer and consumer of natural gas, production of shale gas will continue to increase at an annual rate of about 1% for a decade or so and stabilise thereafter. Liquefied natural gas (LNG) exports will play an important role in expanding sales channels and improving trade balance.

- East and West Africa, the frontier regions of the world's natural gas, will overtime increase supply. As there are offshore and, in some cases, small- and medium-sized gas resources in these regions, floating LNG production will be considered a practical option for development,.

Reduced supply flexibility and unstable supply-demand balance for coal

- Coal production will increasingly be limited to specific countries and regions, as the trend toward decarbonisation is gradually becoming accepted and coal-related investments and loans are severely constrained. Demand remains highly uncertain as the supply structure becomes less flexible.
- By type of coal, production of steam coal will temporarily expand due to an increase in demand for power generation but will decline after peaking around 2040. Coking coal used mainly as feedstocks for steel production will decrease from 1 050 Mt in 2019 to 800 Mt level by 2040.

Power generation is rapidly expanding in Asia. Natural gas will become the largest power source

- Global electricity generation will increase at an annual rate of 1.7%, and by 2050 will be 1.7 times the 2019 level. The increase is equivalent to 2.3 times China's current generation, the world's largest electricity generator. 95% of the increase is coming from the Emerging Markets and Developing Economies.
- Natural gas will be the largest source of energy for electricity generation by 2050. As the introduction of renewable energies increases, the role of balancing supply and demand of electricity will become more important than ever. Coal will continue to play a role as a base-load power source, but its share will fall below current levels.
- It has become difficult for Japan, Korea, the United States and some European countries to build new nuclear power plants as planned. On the other hand, China and a few other countries continue to promote the use of nuclear, while some Middle East countries, and others, are introducing nuclear. As a result, global capacity will gradually increase through 2050.
- Variable renewable energies, such as wind and solar photovoltaics, will generate 8 409 TWh in 2050, increasing their presence to 19% of the electricity generation mix. Achieving harmony with energy and social systems is an important issue.

Advanced Technologies Scenario

Advanced Technologies Scenario is still far from achieving global carbon neutrality in 2050, and it is necessary to mobilise all possible means to further promote energy conservation and climate change measures.

- In the 'Advanced Technologies Scenario', maximum reduction measures for carbon dioxide (CO_2) emissions are expected based on social opportunities and acceptability. Relative to the reference scenario, the reduction in primary energy consumption in 2050 will be 2.9 billion tonnes of oil equivalent (Gtoe) and the reduction in CO_2 emissions will be 15.8 Gt or 42% less than for the Reference Scenario. Although many countries have declared carbon neutrality targets since 2020, it would seem extremely difficult for the world to achieve carbon neutrality as early as 2050.

- The CO_2 emission reduction rates for 2030 will be 33% in the United States (compared to 2005), 40% in the European Union (compared to 1990), 37% in Japan (compared to 2013), and 10% in Canada (compared to 2005). All those reductions fall short of the nationally determined contribution (NDC) rate of reduction in greenhouse gas (GHG) emissions previously announced by those countries. It is clear that further policies and measures beyond those considered in the Advanced Technologies Scenario are required.
- China, the United States, the European Union and Japan have announced net zero emissions and carbon neutral targets. Scenarios from many of these countries and regions are expected to reduce emissions by around 80% in 2050, but none of them will reach their target. It is necessary to further develop and quickly introduce emission reduction technologies that are not commercialised yet.
- Compared to the Reference Scenario, investment in fossil fuels decreases while investment in renewable energy increases. The overall investment cost will be $34 trillion in the 2040s.

Road to carbon neutrality

- Since the Paris Agreement in 2015, many countries, including the United States, the European Union, China, Japan and the United Kingdom, have set carbon-neutral targets for the middle of this century. Carbon neutrality, however, is by no means an easy target given the current high dependence on fossil fuels and the path-dependent effects of existing infrastructure and supply systems.
- While there is of course a positive effect of green growth policies, we should not turn our attention away from the fact that climate change policies inherently have associated costs and growth constraints. Measures to achieve carbon neutrality should not be explained from the perspective of ‘growth’ but should be positioned as a global ‘norm’ that each country should pursue while bearing a certain burden.
- One of the major concerns in the process towards carbon neutrality is the emergence and potential expansion of new disparities. Factors such as economic conditions, resource endowment and technological capabilities naturally vary from country to country. Differences in these factors can produce new disparities by creating winners and losers.
- As we move towards carbon neutrality, we will see more electrification, and electricity security will become one of the most important energy security issues. The stable supply of mineral resources (critical minerals), which plays an important role in promoting the introduction of renewable energy and the electrification, is also a new important element for energy security.
- The suspension of new investment in crude oil production does not cause a tight supply-demand situation in a few months. However, in both the Reference Scenario and the Advanced Technologies Scenario in which demand growth slows down, the global oil

supply-demand balance will be a shortage of supply and an excess of demand in 2024. The suspension of new investment could lead to tight supply and demand and higher prices in the not too distant future.

Circular Carbon Economy/4Rs Scenario

- The concept of circular carbon economy is an extension of the conventional concept of circular economy. In contrast to the concept of circular economy in which the use of resources and the generation of waste are controlled through the three 'R's of 'reduce', 'reuse', and 'recycle', the concept of circular carbon economy is to control the total amount of CO_2 in the atmosphere through the four 'R's with 'remove' added.
- In the 'Circular Carbon Economy/4Rs Scenario', which anticipates the spread of more diverse decarbonisation technologies than in the Advanced Technologies Scenario, global CO_2 emissions in 2050 will be reduced to 15.7 Gt, less than half of the current level. Compared to the Advanced Technologies Scenario, more than half of the additional reductions will be in the non-power sector.
- Total primary energy consumption will increase slightly from the Advanced Technologies Scenario because the introduction of various decarbonisation technologies will generate additional demand for energy transformation. The share of fossil fuels in 2050 will be 60%, which is almost the same level as in the Advanced Technologies Scenario. By actively introducing decarbonisation technologies for fossil fuels, significant reductions in emissions can be achieved while continuing to use fossil fuels.
- Clean hydrogen (blue hydrogen and green hydrogen) plays an important role in various sectors and Asia is a particularly large market. The supply will mainly come from North America, the Middle East and Russia, where fossil fuel resources for blue hydrogen are abundant.

The 439th Forum on Research Work

IEEJ Outlook 2022

Challenges toward carbon neutrality: Voyage in uncharted territory

Energy, Environment and Economy

Tokyo, 15 October 2021

The Institute of Energy Economics, Japan

Energy Supply and Demand Outlook by 2050

REF ATS CCE

IEEJ Outlook 2022

What is IEEJ Outlook?

- Study to quantify the future global energy supply and demand situation until 2050.
- Outlook with forecast-approach, using econometric models etc.
- Scenario analysis on progress and trends in technologies and policies.

[Reference Scenario (REF)]
A scenario in which trends and changes continue while reflecting current energy and environmental policies.

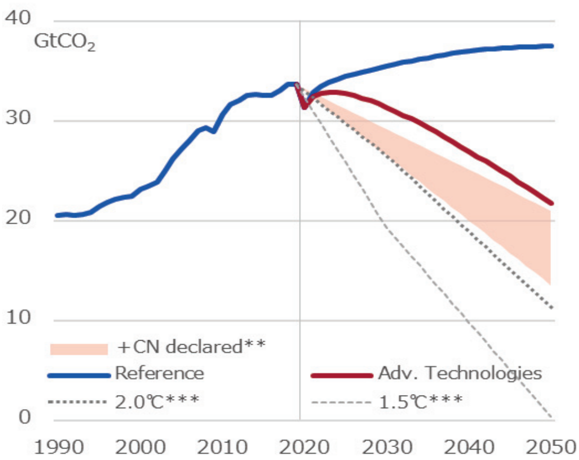
[Advanced Technologies Scenario (ATS)]
A scenario in which energy and environmental technologies are introduced to the maximum extent in order to secure a stable energy supply and strengthen climate change countermeasures.

[Circular Carbon Economy/4R Scenario (CCE)]
A scenario based on the concept of a circular carbon economy with the "4Rs" (Reduce, Reuse, Recycle, Remove). The scenario reflects not only the Advanced Technologies Scenario assumptions, but also examines the maximum introduction of decarbonization technology using fossil fuels.

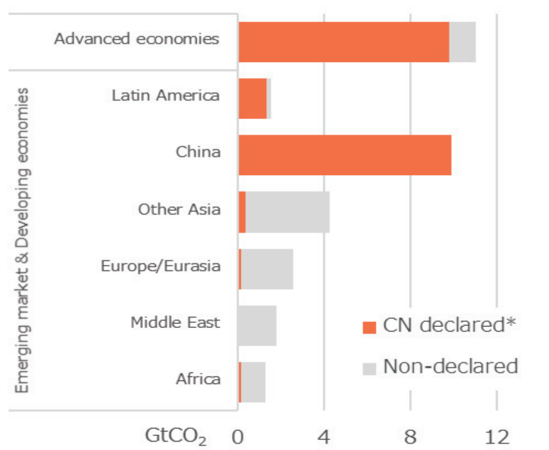
REF ATS

Emitters of two-thirds of the emissions declare CN, but…

Energy-related CO_2 emissions (global)



Breakdown of CO_2 Emissions (2019)



* United States, Brazil, South Korea, Poland, China and Climate Ambitions Alliance (121 countries). ** When the CN-stated countries achieve zero emissions in 2050 based on the emissions in the Reference / Advanced Technologies scenarios (For China, that announced 2060 CN, the emissions as of 2050 by linear interpolation between today and 2060). *** Average paths referred to the IPCC "Global Warming of 1.5°C".

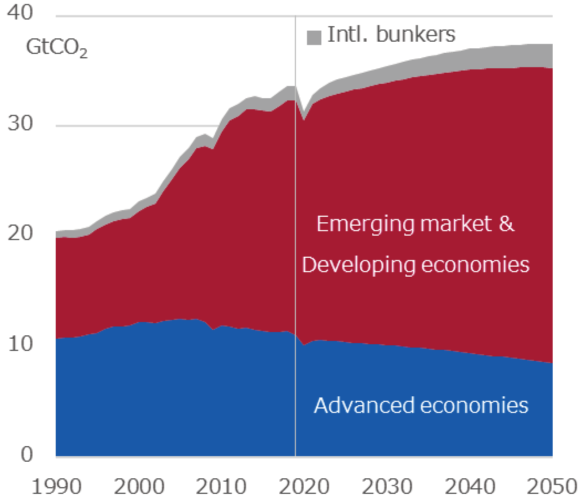
There is a worldwide movement to pursue carbon neutral (CN).

Currently, countries and regions emitting about two-thirds of the world's CO_2 emissions have announced CN. Even if those countries succeed, global emissions in 2050 will be only half of current levels.

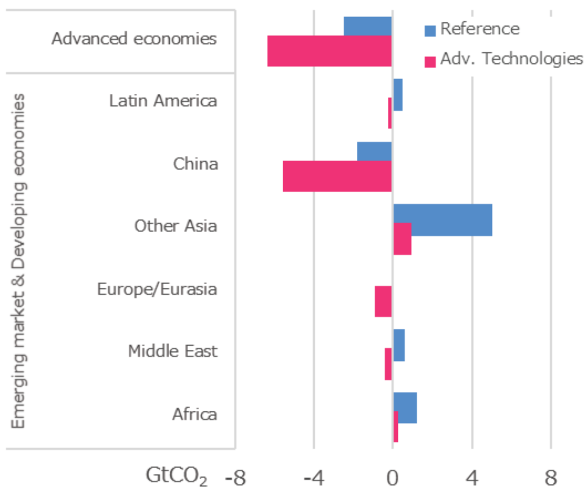
REF ATS

Emissions in countries that have not declared CN increase

Energy-related CO_2 emissions (Reference)



Changes in emissions (2019-2050)



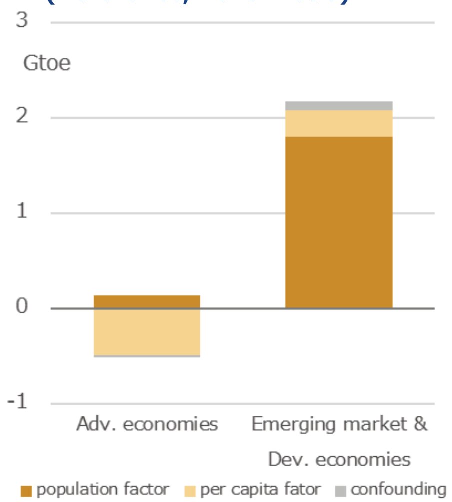
In the REF, CO_2 emissions are expected to increase in Asian, including India and ASEAN, Middle Eastern and African countries, which have not declared pursuing CN.

Even in the ATS, it is not easy to turn emissions into declines in these regions.

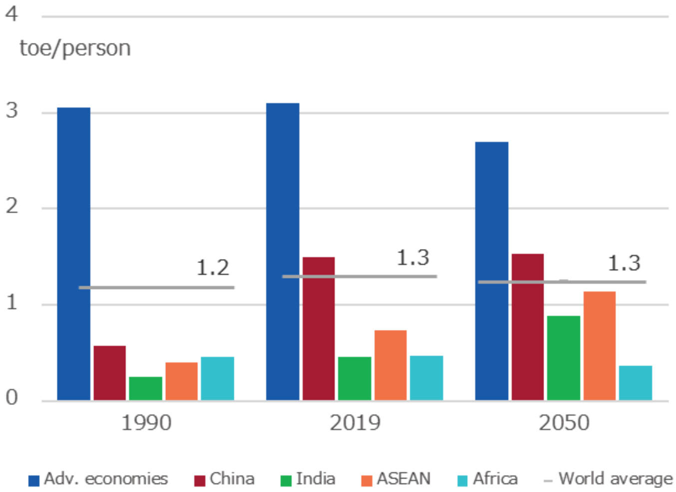
REF

Developing economies need more energy

Decomposition of the increase in final energy consumption (Reference, 2019-2050)



Energy consumption per capita



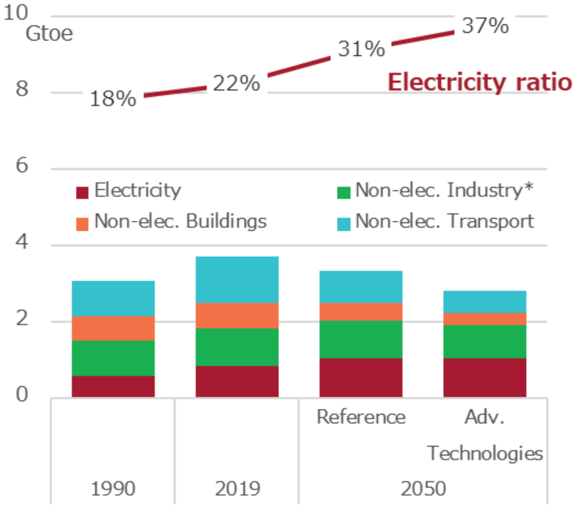
Energy demand in developing economies is growing significantly, but the growth is mainly due to a growing population.

In developing economies, the energy consumption per capita is still small compared to advanced economies, and there is much room for further increase in demand.

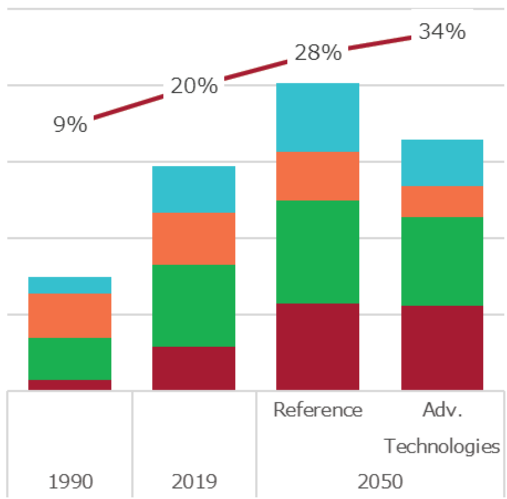
REF ATS

Power demand is certain to grow

Final Energy Consumption (Advanced Economies)



Final Energy Consumption (Emerging and Developing Economies)



* Industry includes agriculture, forestry and fisheries and non-energy sector.

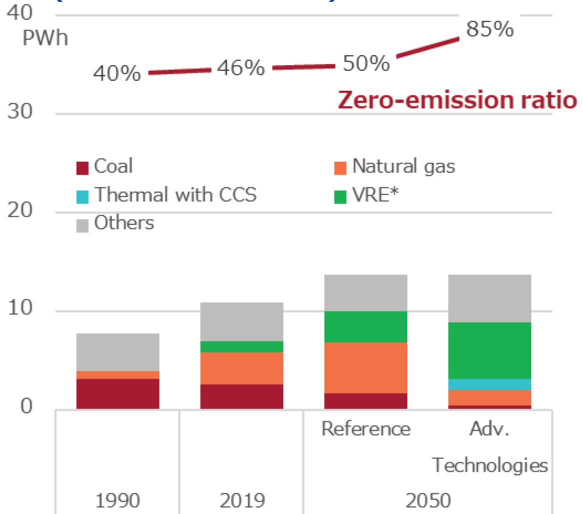
Energy demand in both developed and developing countries will be electrified more. Although the electrification of heat demand in the industrial sector is limited, the electricity ratio will rise further in the ATS.

Electricity demand is not much different between both scenarios. The stability, reliability and security of electricity supply are issues that must be addressed.

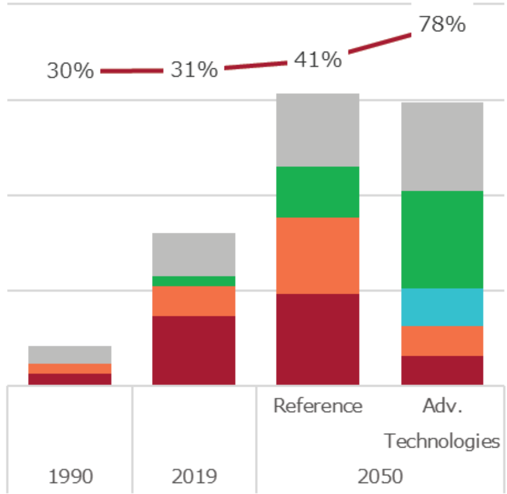
REF ATS

Decarbonization of the power sector is progressing

Power Generation Mix (advanced economies)



Power Generation Mix (Emerging and Developing Economies)



* VRE (Variable Renewable Energy): photovoltaic power, wind power, etc.

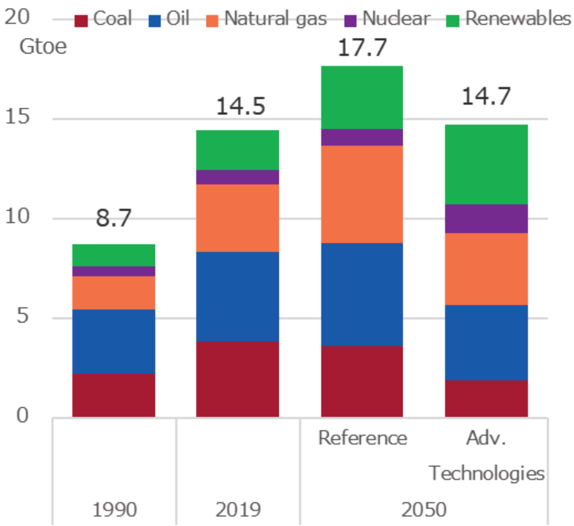
In the REF, more than half of the increase in electricity demand is supplied by VRE. However, in emerging and developing economies, thermal power generation remains necessary to meet a strong electricity demand.

In the ATS, the decarbonization of the power generation sector will be greatly advanced by a large introduction of VRE and thermal power with CCS.

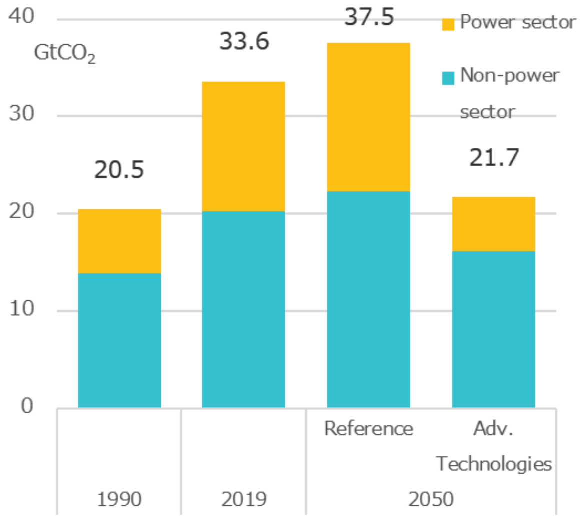
REF ATS

Decarbonization of non-power generation sector is difficult

Primary energy demand



Energy-related CO_2 emissions



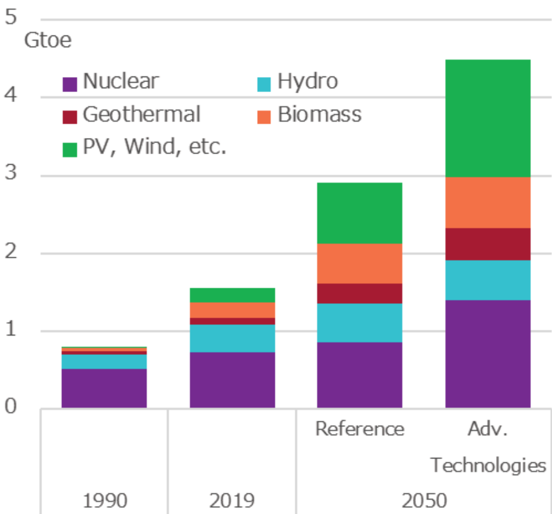
The primary energy demand in the ATS in 2050 is almost the same as today. Demand for fossil fuels declines, but still accounts for 60% of the total.

On the other hand, CO_2 emissions are two-thirds of current levels. The emissions reduction from the power generation sector is significant, however, the reductions in the non-power generation sector are not progressing much.

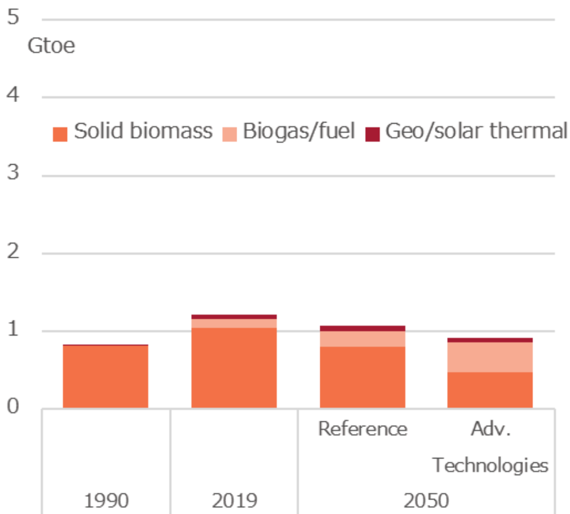
REF ATS

The introduction of non-fossil energy in non-power sectors is a challenge

Non-fossil energy in the power generation sector



Non-fossil energy in the non-power generation sector



The introduction of non-fossil energy is progressing in the power generation sector, while only a few in the non-power generation sector.

Electrification is being promoted in the non-power generation sector, but there are limits in the industrial sector, which often uses high-temperature heat. Decarbonization other than electrification is a challenge.

CCE

Circular Carbon Economy/4R Scenario

Assumptions in CCE (in addition to the ATS)

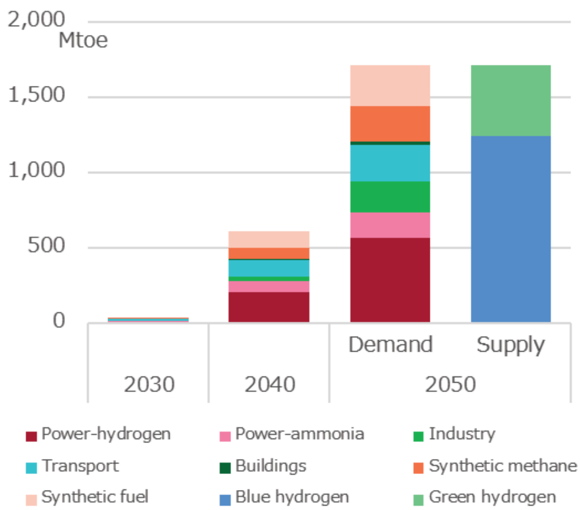
4R	Technology	Assumptions
Reduce	Hydrogen for power generation	Adopt hydrogen/ammonia power generation for 50-75% of coal- and gas-fired power plants without CCS facility as of 2050.
	Hydrogen for transportation	Replace 10-15% of liquid fuels demand in the road sector in advanced economies and 20-30% in the international bunkers with hydrogen as of 2050.
	Hydrogen in industry sector	Replace 10-30% of natural gas demand in the industry sector with hydrogen as of 2050 in advanced economies with abundant hydrogen supply.
	Direct reduction in steel making by hydrogen	Adopt direct reduction technology utilizing blue hydrogen to 25% of crude steel production in advanced economies, China, India and Brazil as of 2050.
	Hydrogen in building sector	Replace 10% of natural gas demand in the building sector with hydrogen as of 2050 in advanced economies.
	Reduction of cement production	Reduction of cement production by 25% utilizing coal ash and limestone and calcined clay as of 2050
Reuse	Algae synthesis to produce biofuel	Increase algae-based bio-diesel by 50% from ATS as o 2050.
Recycle	Concrete curing capturing CO_2	Adopt concrete curing capturing CO_2 technology to 25-50% of the world concrete production as of 2050.
	Synthetic methane	Replace 20-40% of natural gas demand in the industry and building sectors with synthetic methane as of 2050.
	Synthetic fuels	Replace 10-20% of liquid fuels demand in the transport sectors with synthetic fuels as of 2050.
Remove	Carbon capture and storage	Adopt CCS for blue hydrogen production.

From the perspective of decarbonizing fossil fuel utilization, this scenario considers the maximum introduction of 4R (Reduce, Reuse, Recycle, Remove) technologies in addition to the ATS assumptions.

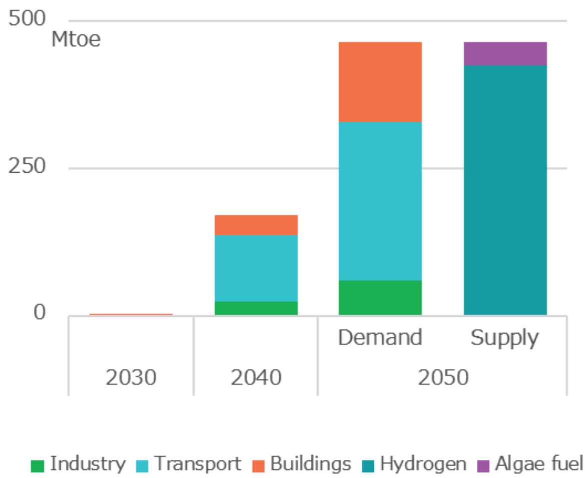
CCE

Utilize clean hydrogen/ammonia

Supply and demand of hydrogen/ammonia



Supply and demand of synthetic methane/fuel

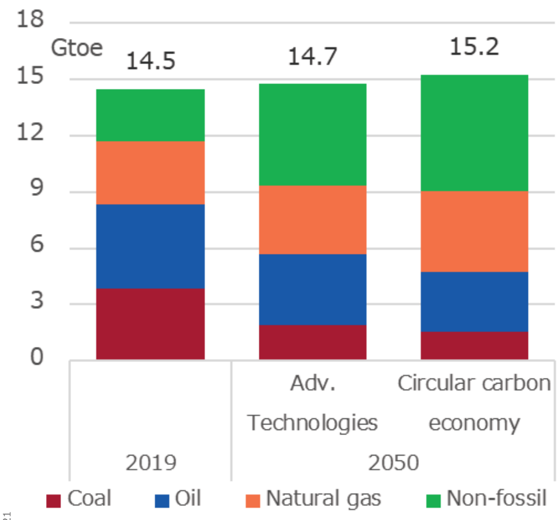


Hydrogen/ammonia, not emit CO_2 during combustion, are utilized in the industry sector and for power generation. Hydrogen production could be blue, using fossil fuels and CCS, or green, using renewable energy.

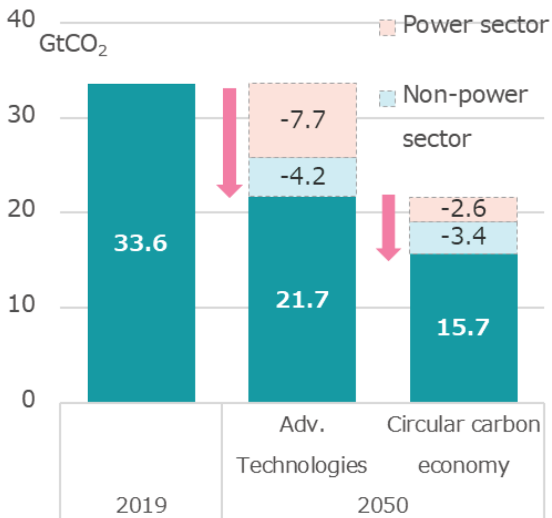
Synthetic methane and fuels produced from clean hydrogen can be used in sectors where electrification is difficult, by utilizing existing infrastructure in the non-power generation sector.

Reduce CO_2 emissions without reducing fossil fuels

❖ Primary energy demand



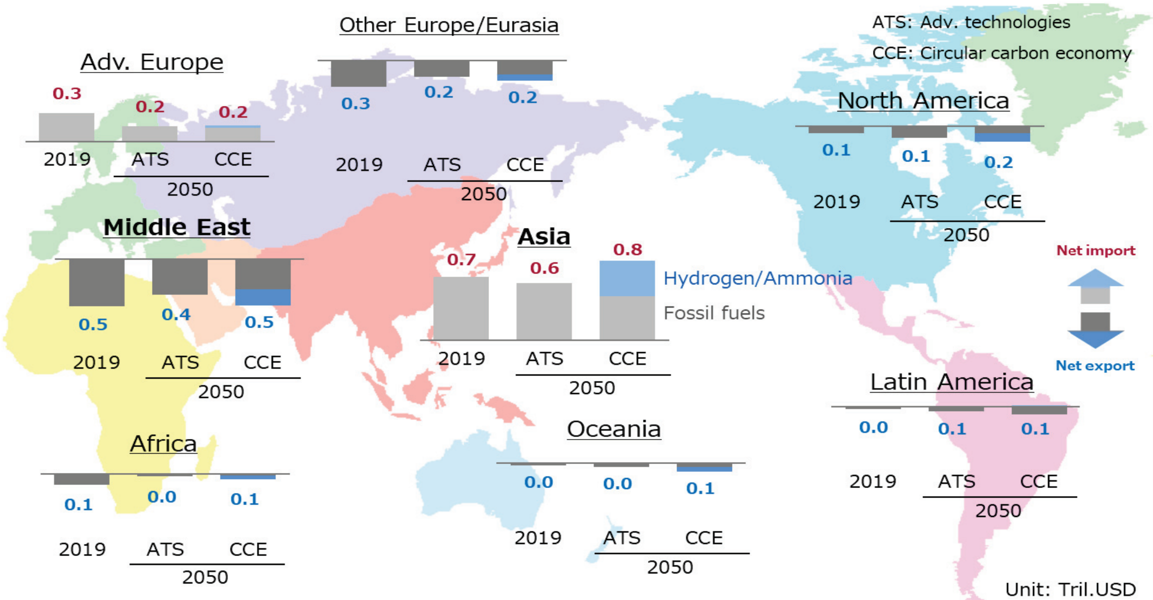
❖ Energy-related CO_2 emissions



Fossil fuel consumption in the CCE scenario is almost the same as that in the ATS. Demand for natural gas for hydrogen production will increase slightly.

On the other hand, the CO_2 emissions decline significantly. The center of gravity for emission reductions is shifting to the non-power generation sector.

Asia-Middle East relations remain unchanged

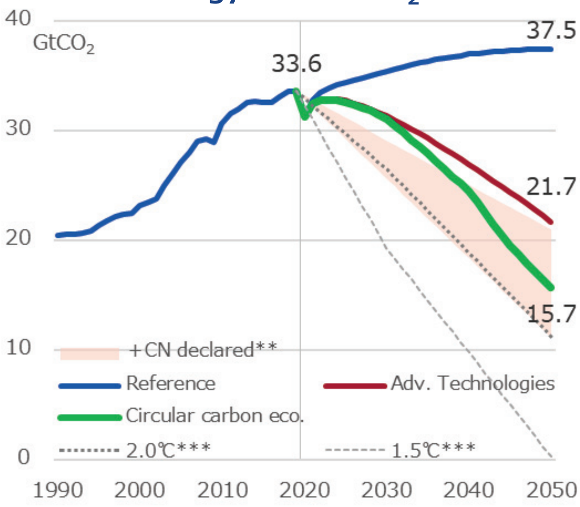


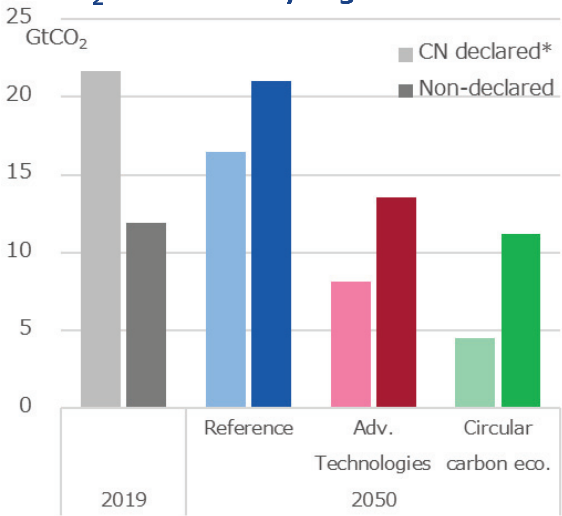
In the CCE, there is a shift from fossil fuel trade to hydrogen/ammonia trade.

In the Middle East, hydrogen exports compensate for the decline in oil and gas exports. On the other hand, imports of hydrogen will increase significantly in Asia. Even in a world aiming for decarbonization, the importance of trade relations between Asia and the Middle East remains unchanged.

REF ATS CCE

There remain many challenges for CN in the world





* United States, Brazil, South Korea, Poland, China and Climate Ambitions Alliance (121 countries). ** When the CN-stated countries achieve zero emissions in 2050 based on the emissions in the REF / CCE scenarios (For China, that announced 2060 CN, the emissions as of 2050 by linear interpolation between today and 2060). *** Average paths referred to the IPCC "Global Warming of 1.5°C".

To realize CN, it is essential to utilize new decarbonization technologies such as hydrogen and CCUS in addition to existing clean technologies. Reducing emissions is a must for all countries, not only developed economies but also emerging and developing economies.

It is important to promote and share decarbonization technologies under international cooperation, in order to reduce emissions in the world-scale.

REF ATS CCE

Summary

【 **Reference** and **Advanced Technologies Scenarios**】

- CO_2 emissions are expected to grow in countries that have not expressed carbon neutrality (CN), such as India, ASEAN, the Middle East, Africa, and others.
- Electricity demand increases in both the Reference Scenario that reflects the current situation and in the Advanced Technologies Scenario where decarbonization is progressing. The stability and security of electricity supply must be improved.
- CO_2 reduction in the power generation sector is likely to proceed, but emission reductions in the non-power generation sectors will not progress much. Decarbonization in the non-power generation sector is key to achieve CN.

【**Circular Carbon Economy Scenario**】

- In order to decarbonize the non-power generation sector, clean hydrogen/ammonia and synthetic methane/fuels using these materials will be required.
- There is a shift from fossil fuel trade to hydrogen/ammonia trade, but the importance of trade relations between Asia and the Middle East remains unchanged.
- In order to achieve a world-wide CN, it is important to promote and share decarbonization technologies under international cooperation.

Challenges and Issues toward Carbon Neutrality

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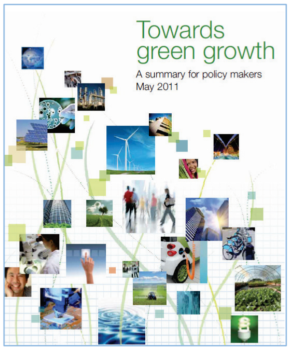
Growing interests in carbon neutrality

- An increasing number of countries announced reaching carbon neutrality (CN) as a target by mid-century. Interest in CN is growing globally.
- Climate actions are expected to not only achieve emissions reduction but should also provide multiple economic benefits.
- Given that the world depends on fossil fuels for over 80% of its energy requirements, achieving CN will not be an easy task. Several challenges and issues lie ahead.
- The net balance between benefits and costs of climate actions can vary across country, organization, and individual.

- **Examples of challenges and issues related to CN**
  - ✓ Positive and negative economic effects of climate actions
  - ✓ Disparity caused by climate actions
  - ✓ Energy security issues growing in complexity
  - ✓ Supply stability issue caused by restrained upstream investments
  - ✓ Geopolitical impacts

Economic benefits of climate actions

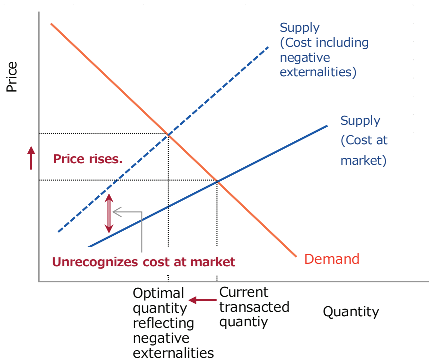
- Green growth and Green deal
  - "Green growth" is a condition where economic growth and carbon emissions are decoupled (OECD 2011; UNEP 2011; World Bank 2012).
  - "Green deal" is a government's policy that aims to simultaneously achieve economic stimulus, development of a clean energy industry with job creation, along with emissions reduction (Friedman 2019; European Commission 2021).
- Economic benefits of Green deal
  - EU estimates its Green deal will create over 160,000 jobs through the development of a clean energy market and products until 2030 (European Commission 2021).
  - IEA's Net Zero scenario is estimated to add 4% to the world's GDP and generate 25 million jobs through the development of clean energy industry by 2030 (IEA 2021).



Two kinds of economic costs of climate actions

- Costs associated with negative externalities
  - Climate change is a typical case of negative externalities.
  - Addressing negative externalities means to account for unrecognized costs that could eventually raise prices and reduce the transacted volume of traded goods and services (Baumol and Oates 1988).
  - An increase in prices may result in leakage of national wealth.
- Costs associated with carbon lock-in
  - Carbon lock-in is the "inertia" caused by consumer behaviors and existing fossil fuel infrastructure. It inhibits or delays the adoption of emissions reduction technologies (Seto *et al.* 2016)
  - Carbon lock-in occurs in sectors where large-scale infrastructure or supply network development are needed.
  - Realizing CN means overcoming the lock-in effect with significant investments in new infrastructures, the replacement of existing facilities while requiring job switching and vocational training.

Internalization of negative externalities

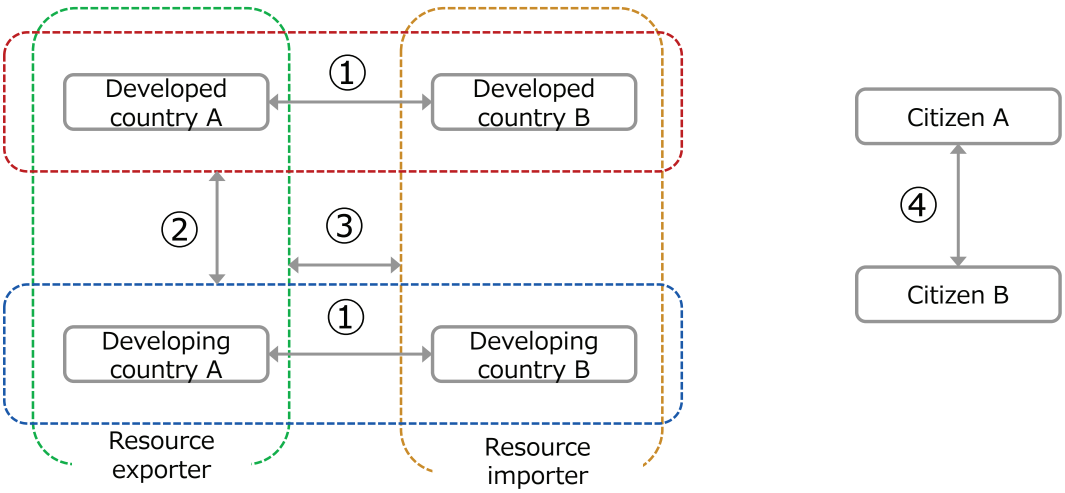


Balance of positive and negative effects

- Various views on the net effect of climate actions exist.
  - Concepts of Green growth or Green deal expect that the world benefits from the net positive effects of climate actions through stimulated economic activities and job creation
  - Concepts of negative externalities and carbon lock-in, by contrast, suggest that climate actions cannot be free from increased economic burdens, and would result in net overall negative economic effects.
  - If climate actions and emission reductions are recognized by all as a new global "norm", it may be sufficient as a justification and the responsibility for everybody to accept the negative economic impacts.
- The net balance between the positive and negative effects can vary for each country, organization, and individual.
  - External factors: Geographical factors, indigenous resources, renewable energy resources, etc.
  - Internal factors: Administrative capabilities and leadership of the government, technological capacity, financial capacity, entrepreneurship, industrial structure, liquidity in labor market, containment of COVID-19, etc.

Disparity caused by climate actions

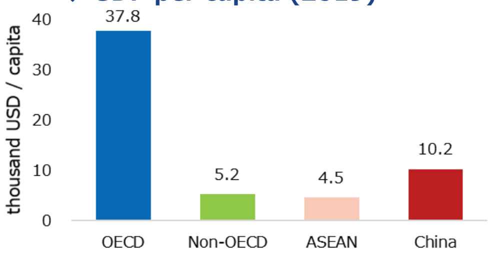
- Climate actions can widen disparity of various kinds because of differed capacities and resource endowments of each actor.
  ① Disparity among developed countries and among developing countries.
  ② Disparity between developed and developing countries
  ③ Disparity between resource exporting country and importing country
  ④ Disparity between citizens within same country



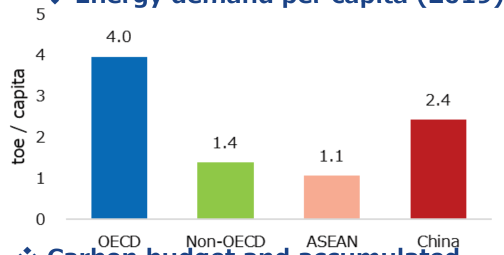
Comparison between developed and developing countries

- The existing differences are large.

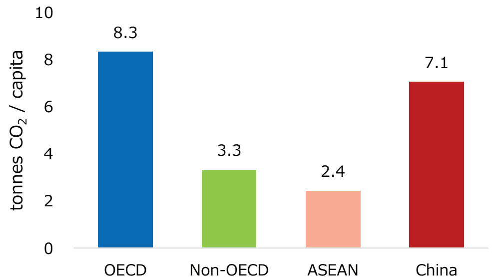
❖ GDP per capita (2019)



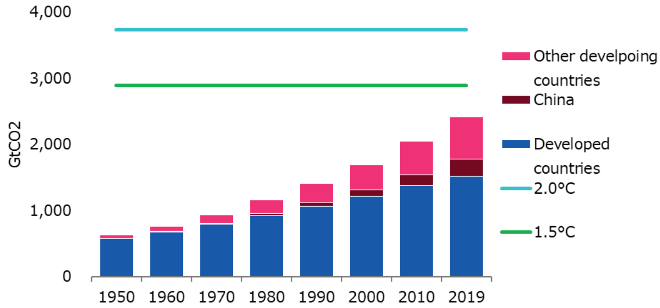
❖ Energy demand per capita (2019)



❖ CO_2 emissions per capita (2019)



❖ Carbon budget and accumulated emissions

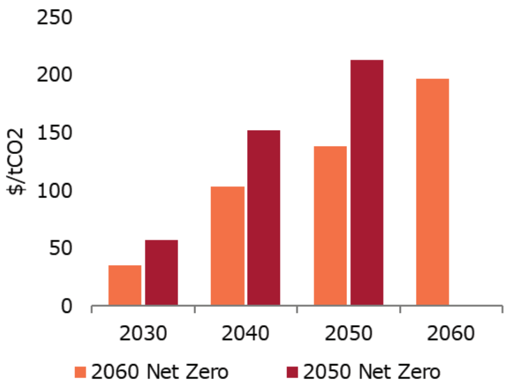


Note: Carbon budget figure are 50% expectation values
Source : IEA, IPCC, Global Carbon Budget 2020; Friedlingstein et al (2020); IEEJ estimate

Economic burden for the developing world (in the case of ASEAN)

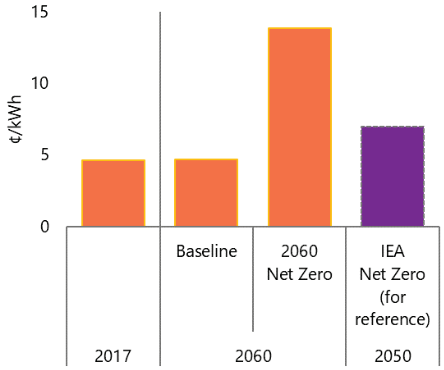
- Seeking for CN in a shorter period may cause a significant burden for ASEAN.
  - Average reduction cost for CN in 2050 or 2060 will be around \$200/t-CO_2.
  - Electricity price for CN in 2060 will triple from current levels.
  - Additional costs for CN in 2050 and 2060 will be equivalent to 2.9% and 2.5% of annual GDP, respectively.
  - Supports to make a pragmatic roadmap toward CN are needed.

❖ Average CO_2 reduction cost in ASEAN



Source : IEEJ; IEA

❖ Electricity price in ASEAN

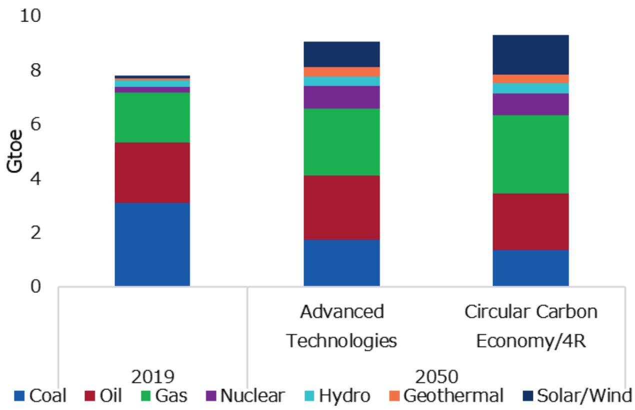


Note : Figure of IEA Net Zero is based on the estimated increased rate of electricity price in the world (+50%)
Source: IEEJ; IEA

Use of decarbonized fossil fuels in the developing world

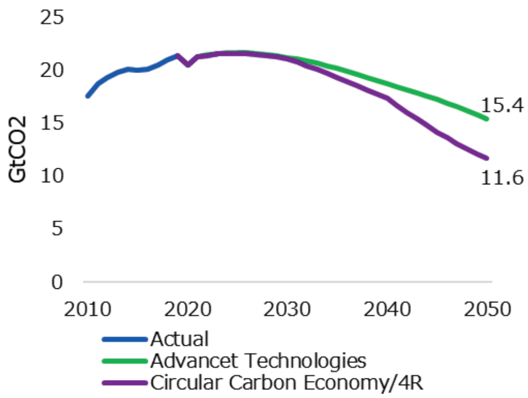
- The use of decarbonized fossil fuels can be an effective mean of emissions reduction in developing countries.
  - CCE scenario in this outlook shows that 3.8Gt of CO_2 emissions reduction is feasible while maintaining the share of fossil fuels.

Primary energy supply of developing countries



Source: IEEJ

CO_2 emissions of developing countries



Source: IEEJ

Two different scenarios toward CN

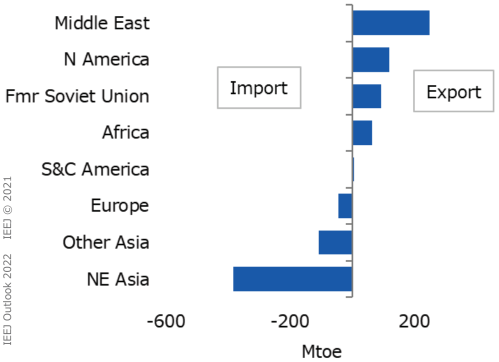
- Reduction of transition cost and its extensive sharing will drive the Bright Future scenario.

Bright Future	Hard Future
• Developed countries lead the technological development, which is smoothly transferred to developing countries. • Decarbonization of fossil fuel resources and exports of (hydrogen, ammonia, etc.) will proceed with a significant reduction in costs. • An increasing number of countries is adapting well to a CN world. • Adverse economic effects of climate actions will be minimized as new industries and business opportunities will spread and the entire economic structure will ~~be~~ adapte~~d~~ to CN.	• Only a few succeed in achieving CN, and a large number of countries are "left behind.“ • The rise of unilateralism emphasizes the rights to advanced technologies and hinders the spread of successful adaptation to CN. • The economic traction and job creation effects of new industries and businesses created by climate actions cannot fully offset various costs. • Widening of disparities in the world will make countries to prioritize their national interests and weaken the motivation to pursue climate actions as a normative efforts.

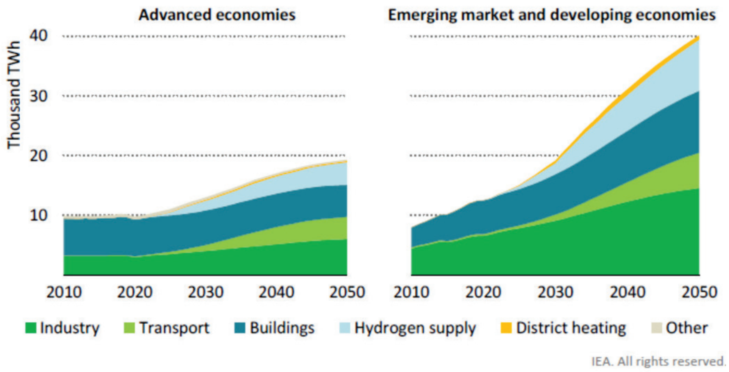
Energy security with increased complexity

- Energy security risks growing in significance
  - The world continues to depend on fossil fuels during the transition to CN.
  - Existing resource exporters may reinvent themselves as exporters of decarbonized fossil fuels, such as hydrogen and ammonia.
  - As power demand grows, issues of electricity supply security becomes far more important while VRE's intermittency, system reform, cyber attacks remain important critical issues.
  - Supply security of critical minerals emerged as a new potential security issue.

❖ Hydrogen trade balance as of 2050 in CCE scenario



❖ Electricity demand in IEA Net Zero scenario

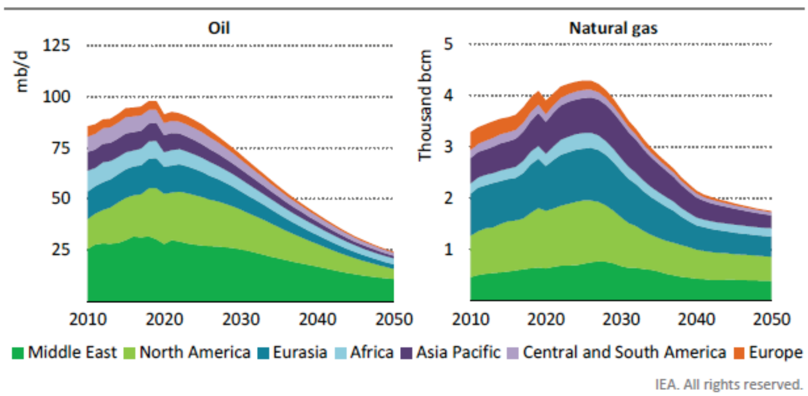


Source : IEA, Net Zero by 2050

No new upstream investment is needed to achieve CN by 2050?

- The "No new upstream investment" conclusion from IEA's Net-zero scenario
  - In May, IEA provided a back-casting scenario to achieve CN in 2050 and implied that there are no need for new oil and gas field to be approved for development and that no new coal mines or mine extensions are required.
  - IEA did not necessarily recommend no new upstream investments.
  - In the net zero scenario, the crude oil price will fall to \$35/bbl in 2030 and \$24/bbl in 2050. Likewise, the LNG price will decline to \$4.4/mmbtu in 2030, and \$4.1/mmbtu in 2050.

Figure 3.3 ▷ Oil and natural gas production in the NZE

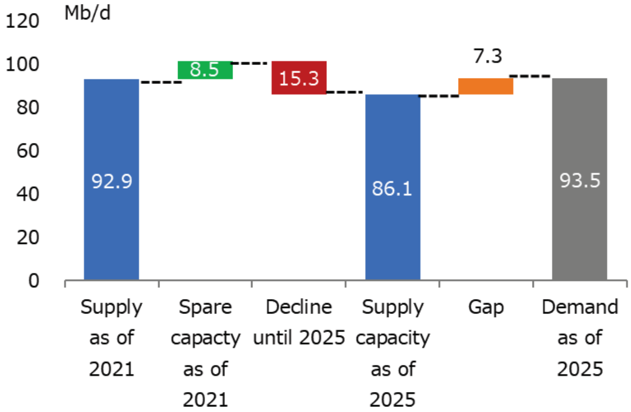


Source : IEA

What if investments in oil markets stop?

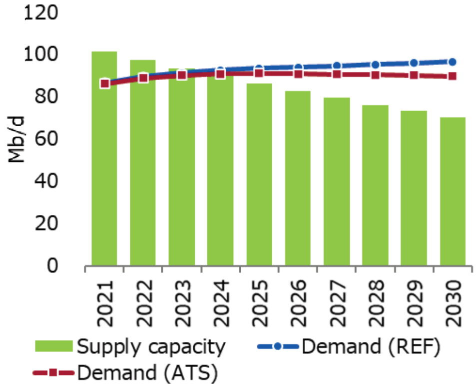
- If investment in new oil and gas field development stops, demand will surpass supply capacity by 2024.
  - No outright supply crunch expected because of large spare capacities
  - World oil demand may return to a growing trend in the post-COVID world; the "No new upstream investment" conclusion may bring "chilling effect" on legitimate investments to meet such growing demand.

❖ World oil demand and supply capacity as of 2025 if investment stops



Note: Bio fuels are excluded. Supply capacity is assumed to decline by 4% annually.
Source : IEA; IEEJ estimate

❖ World oil demand and supply capacity if investment stops

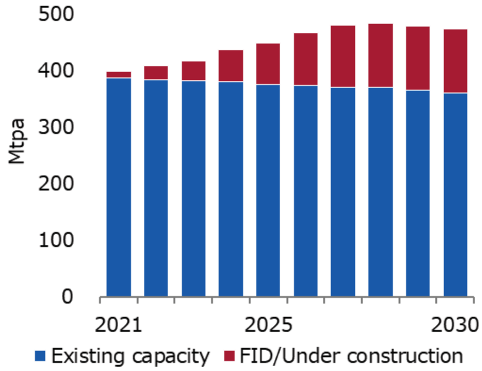


Note: Demand excludes biol fuels.
Sources: IEA, IEEJ estimates

What if no new investments are made in the LNG market?

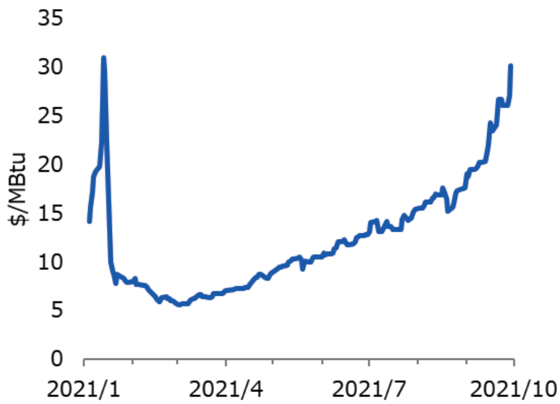
- LNG supply capacity is expected to grow until the late 2020s.
- LNG spot prices have sharply risen
  - Multiple factors such as post-COVID demand recovery, switching to low-carbon power sources, wind condition in Europe caused recent spike in prices.
  - Restrained investments will aggravate the market's uncertainties and trigger price instabilities.

❖ World LNG supply capacities



Source: IEEJ

❖ Spot LNG prices in Asia (2021)



Source: ICIS

Further uneven distribution of sources

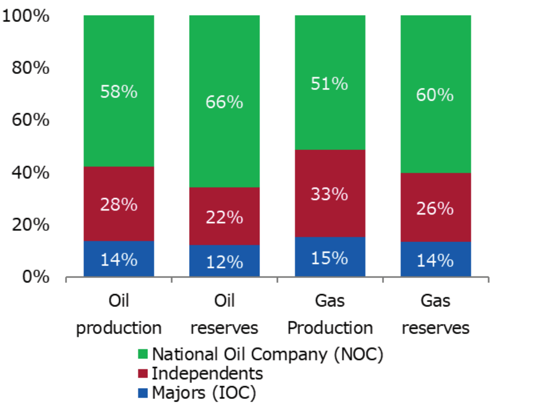
- As developed countries consider not investing in fossil fuels, the financing may come from oil-exporting countries and emerging economies in the future.
  - International oil companies (IOC) in developed countries are less likely to invest in upstream while they are allocating a growing capital to decarbonization technologies.
  - Meanwhile, state-owned oil companies (NOCs) in oil-producing and emerging countries, are more likely to invest in fossil fuels than decarbonization and will become more influential in international markets.

Allocation of CAPEX by major IOCs

Company	Investment plan
Chevron	Invest over 300M$ to energy transition.
Shell	Share of upstream investments wil be lowered from 42% to 25-30% from 2020 to 2025; Share of gas and chemical will be lowered from 43% to 30-40%; Share of renewable and markteing will be raised from 16% to 35-40%.
bp	Share of low-carbon electricity and energy and consumer and mobility will be raised from 15% in 2019 to 40% in 2030.
TotalEnergies	Share of investment to LNG will be maintained at 15-20% until 2030; Share of renewable and electicity will be raised from 10% (from 2016 to 2020) to 15% (2021 to 2025) and 20% (from 2026 to 2030).
ENI	Share of upstream investments will be 65% from 2021 to 2024. Share of green and marketing will be 20%.
Repsol	Share of upstream investments will be 44% from 2021 to 2025; Share of downstream (incl bio fuels) will be 25%; Share of low carbon power generation will be 22%.
Equinor	Share of renewable and low carbon sectors will be raised from 4% in 2020 to more than 50% in 2030.

Source: each company's web-site

Share of IOC and NOC in the world oil and gas supply in 2018

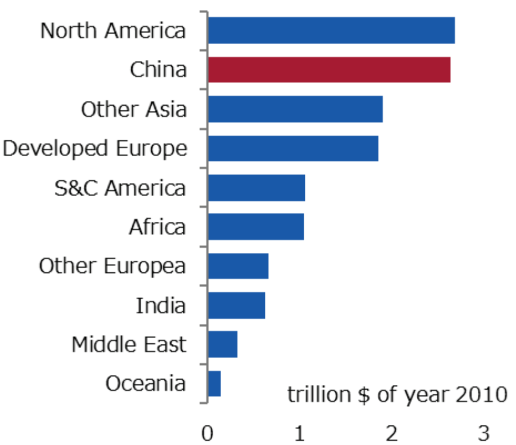


Source: IEA, Oil and Gas Industry in Energy Transitions

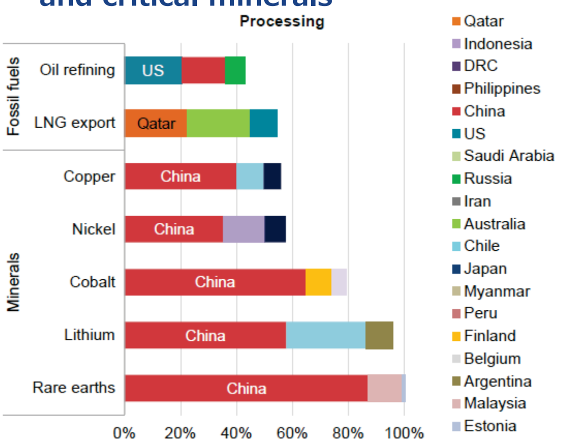
China's growing presence in a CN world

- China's presence is likely to expand in a world heading toward CN.
  - Its presence will grow in the field of renewable energy, critical minerals, as well as fossil fuels.
  - A high level of competition with developed countries could lead to international divisions or conflicts.

Investments in renewable power generation in Reference scenario



Process capacity of fossil fuels and critical minerals



Source : IEA, The Role of Critical Minerals in Clean Energy Transitions

Summary

- The transition to CN will provide positive economic impacts, as well as incur costs.
  - The net impact varies from country to country.
- The traditional energy security issues are becoming multidimensional and complex.
  - Issues of import dependence on resources, issues of power supply security and issues of securing critical minerals.
- The “no new upstream investment” conclusion is an added risk factor that could destabilize supply.
  - It is necessary to design a pragmatic CN transition process based on actual supply and demand conditions of existing energy sources, and based on the current situation of each consuming country’s energy market.
- The transition to CN should proceed in an inclusive manner.
  - The diverse energy and economic profiles of each country should be respected so as not to cause disproportionate burdens to achieve CN.
  - Assistance to develop a realistic roadmap for CN, cooperation for the introduction of fossil fuel decarbonization technologies, provision of financing, human resource development need to be provided for smooth transition to CN by developing countries.

Reference materials

Geographical coverage

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

Especially the Asian energy supply/demand structure is considered in detail, aggregating the area into 15 regions. That of the Middle East is also aggregated into 8 regions.

Source: [Map] www.craftmap.box-i.net

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.

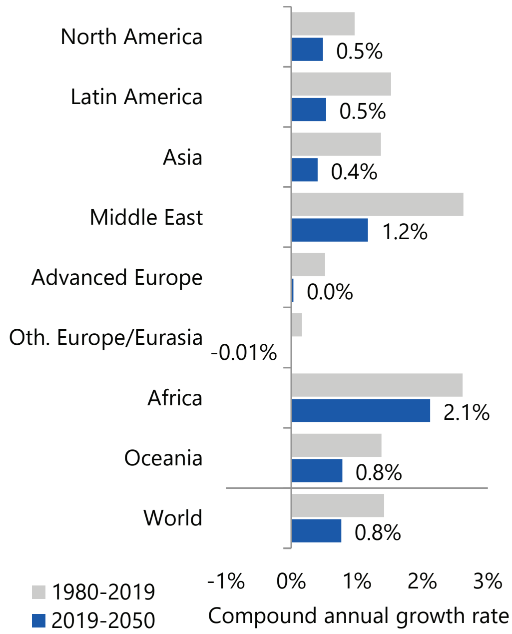
Basic scenarios in IEEJ Outlook

	Reference Scenario	Advanced Technologies Scenario
	Reflects past trends with technology progress and current energy policies, without any aggressive policies for low-carbon measures	Assumes introduction of powerful policies to address energy security and climate change issues with the utmost penetration of low-carbon technologies
Socio-economic structure	Stable growth led by developing economies despite slower population growth. Rapid penetration of energy consuming appliances and vehicles due to higher income.	
International energy prices	**Oil** supply cost increases along with demand growth. **Natural gas** prices converge among Europe, North America and Asia markets. **Coal** keeps unchanged with today's level.	Slower price increase due to lower demand growth (coal price decreases)
Energy and environmental policies	Gradual reinforcement of low-carbon policies with past pace	Further reinforcement of domestic policies along with international collaboration
Energy and environmental technologies	Improving efficiency and declining cost of existing technology with past pace	Further declining cost of existing and promising technology

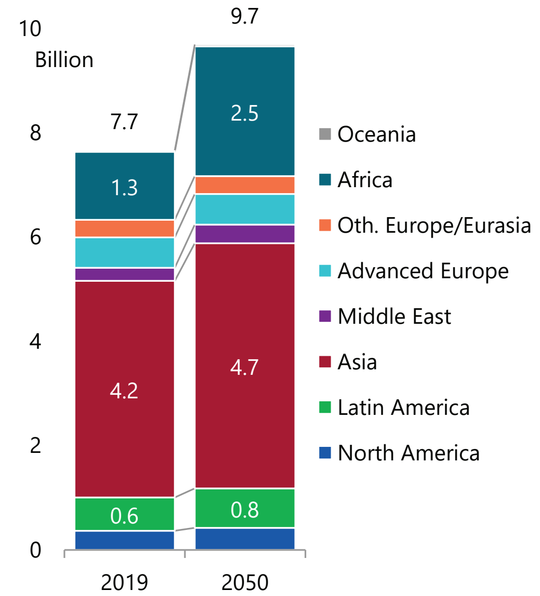
Assumptions

Population

CAGR



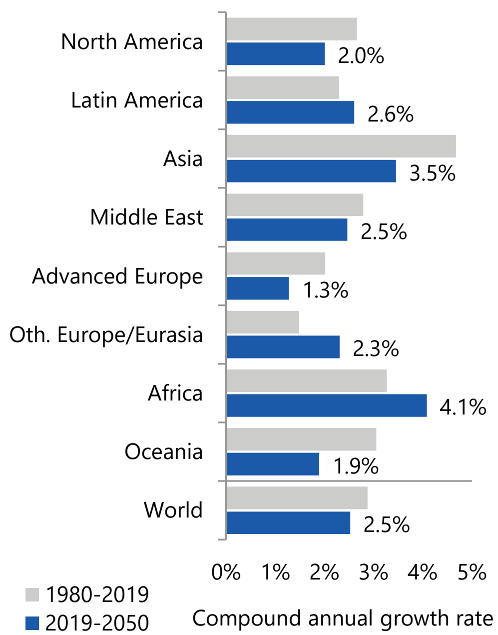
Composition



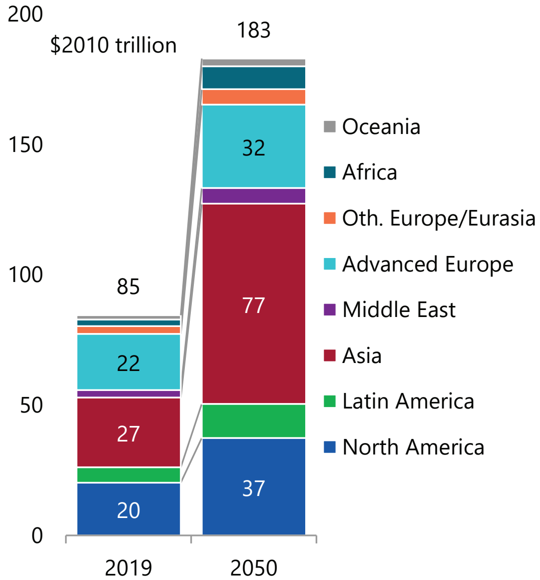
Assumptions

Real GDP

CAGR



Composition

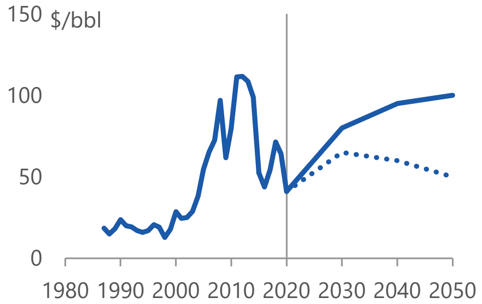


Assumptions

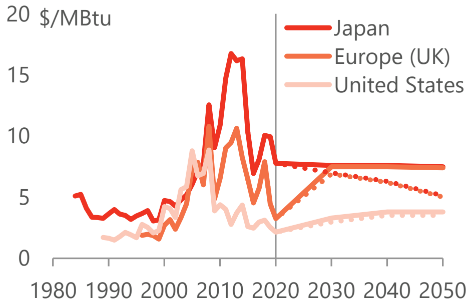
International energy prices

Reference : ——
Advanced Technologies : ·········

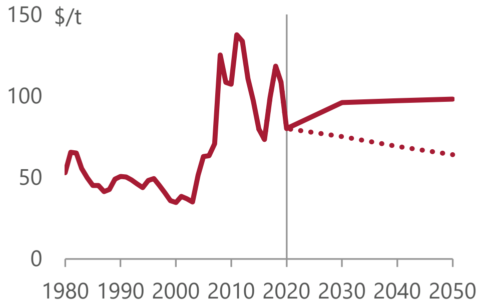
Crude oil



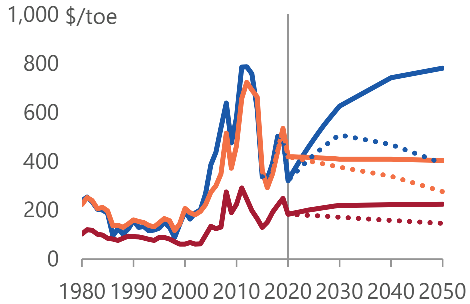
Natural gas



Coal



CIF import prices for Japan



Note: Historical prices are nominal. Assumed future prices as real in $2020.

Assumptions

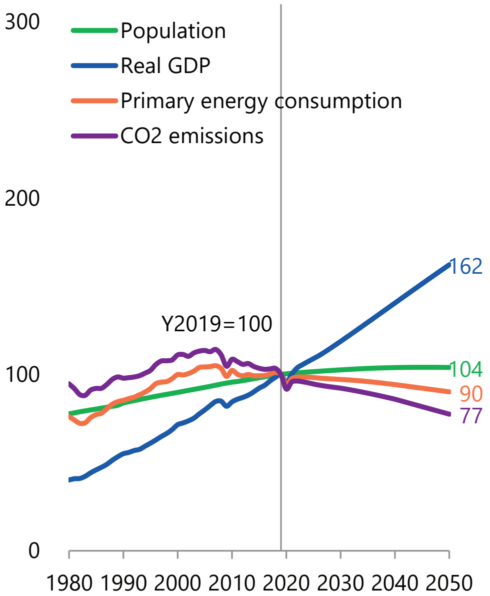
Energy and environmental technology

		2019	2050 Reference	2050 Advanced Technologies	Assumptions for Advanced Technologies Scenario
Improving energy efficiency					
Industry	Intensity in steel industry (ktoe/kt)	0.271	0.244	0.205	100% penetration of Best Available Technology by 2050.
	Intensity in non-metallic minerals industry	0.092	0.076	0.064	
Transport	Electrified vehicle share in passenger car sales	5%	63%	91%	Cost reduction of electrified vehicles. Promotion measures including fuel supply infrastructure. *electrified vehicle includes hybrid vehicle, plug-in hybrid vehicle, electric vehicle and fuel-cell vehicle
	Average fuel efficiency in new passenger car (km/L)	14.4	26.8	37.0	
Buildings	Residential total efficiency (Y2019=100)	100	157	201	Efficiency improvement at twice the speed for newly installed appliance, equipment and insulation.
	Commercial total efficiency	100	153	178	Electrification in space heating, water heater and cooking (clean cooking in developing regions).
Power	Thermal generation efficiency (Power transmission end)	38%	46%	46%	Financial scheme for initial investment in high-efficient thermal power plant.
Penetrating low-carbon technology					
Biofuels for transport (Mtoe)		95	145	268	Development of next generation biofuel with cost reduction. Relating to agricultural policy in developing regions.
Nuclear power generation capacity (GW)		428	476	731	Appropriate price in wholesale electricity market. Framework for financing initial investment in developing regions.
Wind power generation capacity (GW)		622	1,981	3,890	Further reduction of generation cost. Cost reduction of grid stabilization technology. Efficient operation of power system.
Solar PV power generation capacity		581	3,015	5,427	
Thermal power generation capacity with CCS (GW)		0	0	1,152	Installing CCS after 2030 (regions which have storage potential except for aquifer).
Zero-emission generation ratio (incl. CCS)		37%	44%	80%	Efficient operation of power system including international power grid.

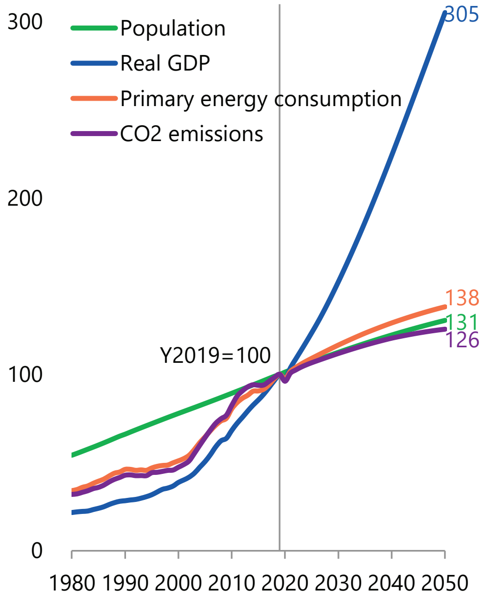
Reference Scenario

Population, GDP, energy and CO_2

Advanced Economies



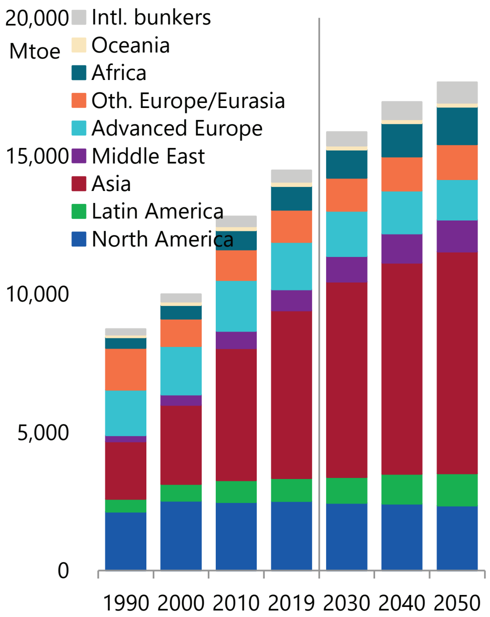
Emerging Market and Developing Economies



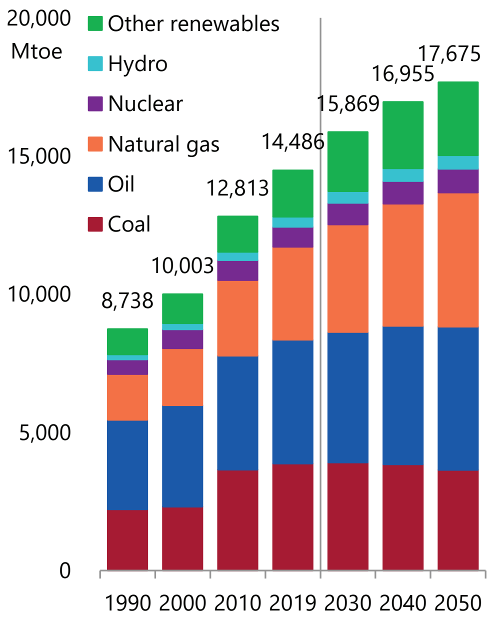
Reference Scenario

Primary energy consumption

By region



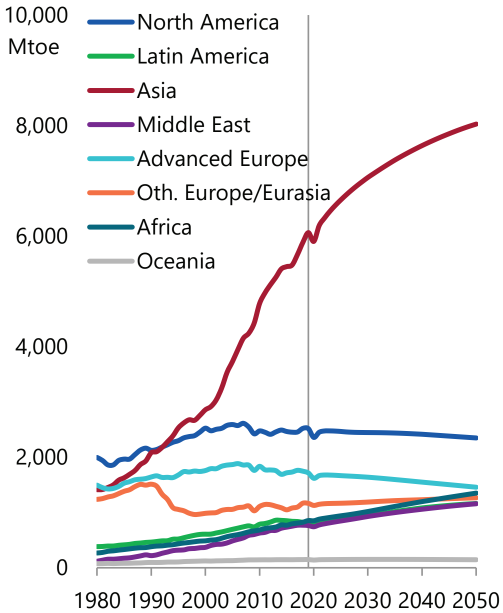
By energy source



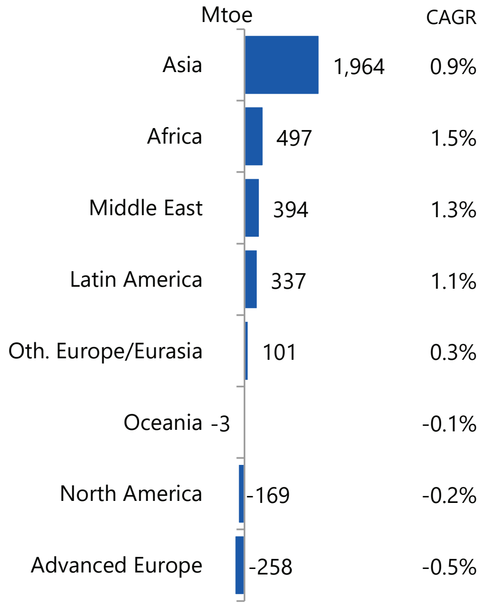
Reference Scenario

Primary energy consumption (by region)

Energy consumption



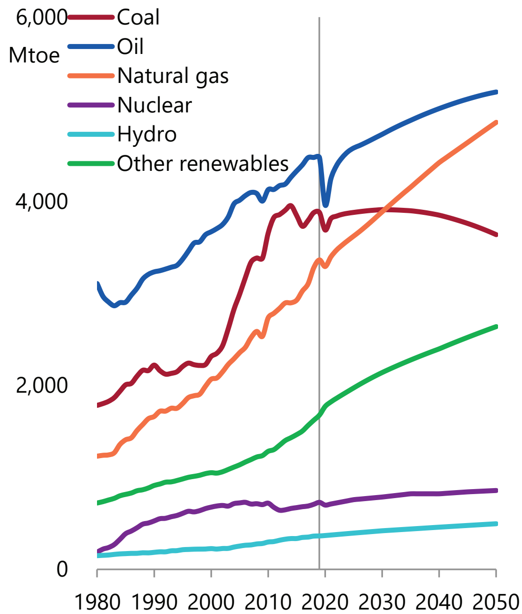
Changes (2019-2050)



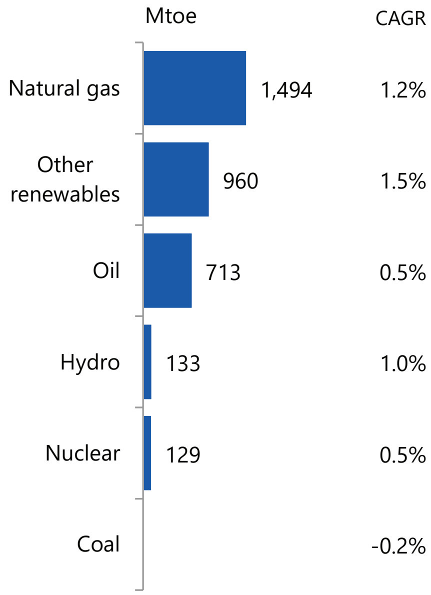
Reference Scenario

Primary energy consumption (by energy source)

Energy consumption



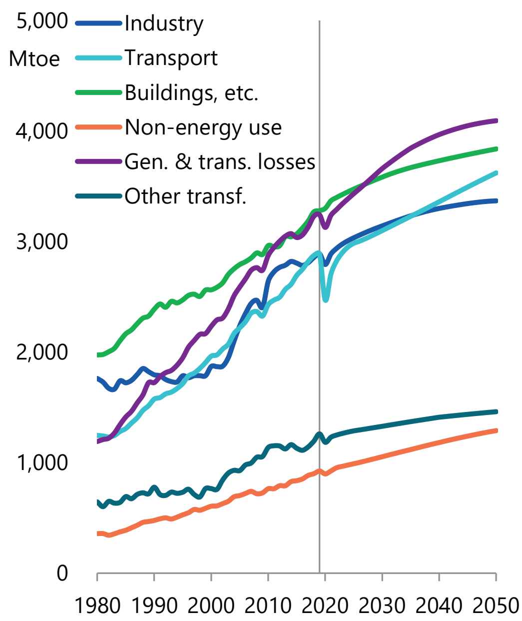
Changes (2019-2050)



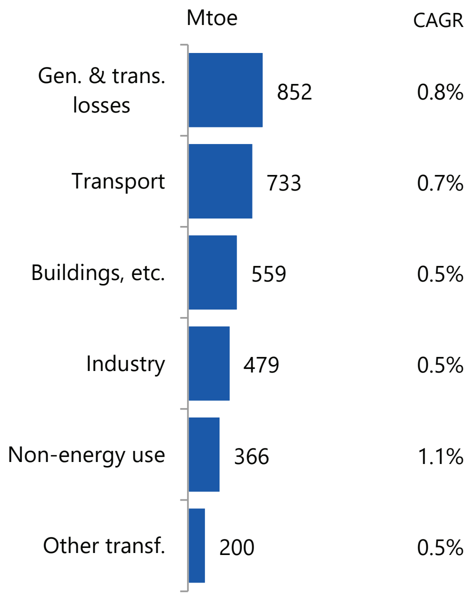
Reference Scenario

Primary energy consumption (by sector)

Energy consumption



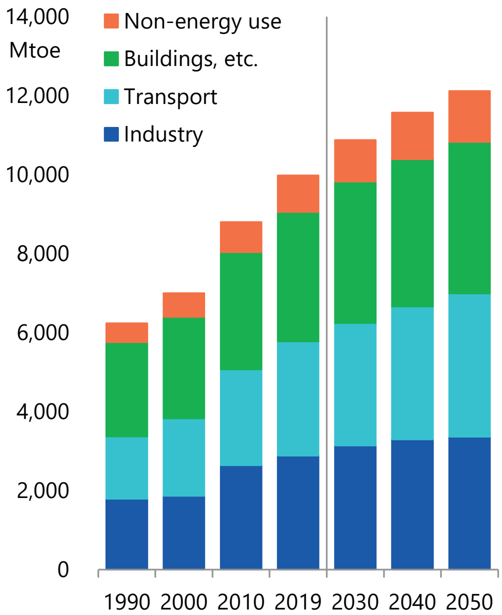
Changes (2019-2050)



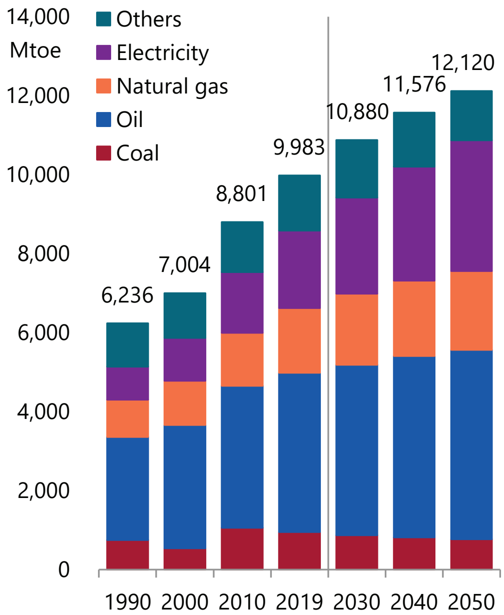
Reference Scenario

Final energy consumption

By sector



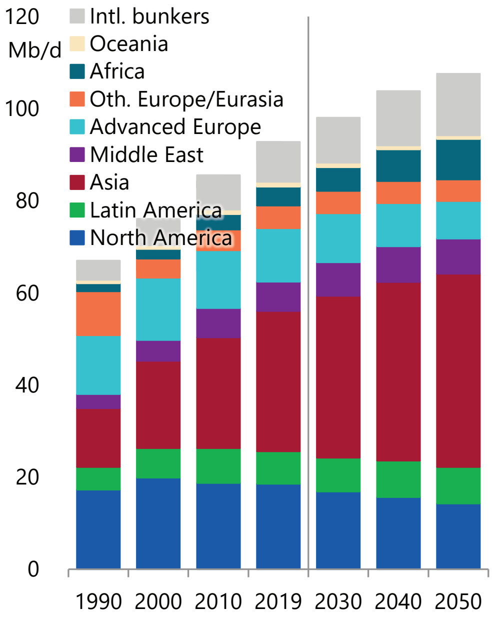
By energy source



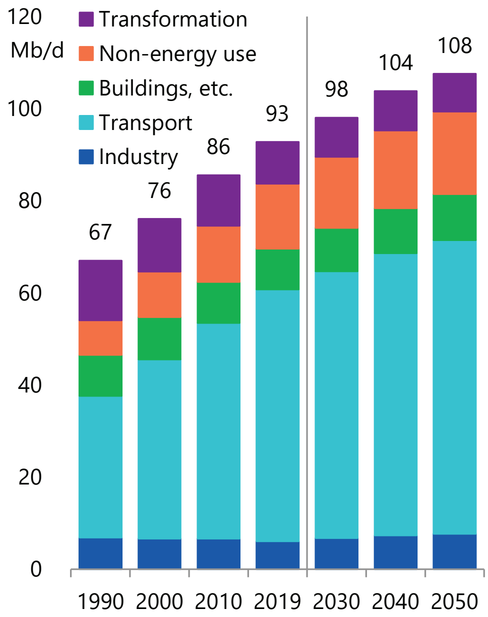
Reference Scenario

Oil consumption

By region



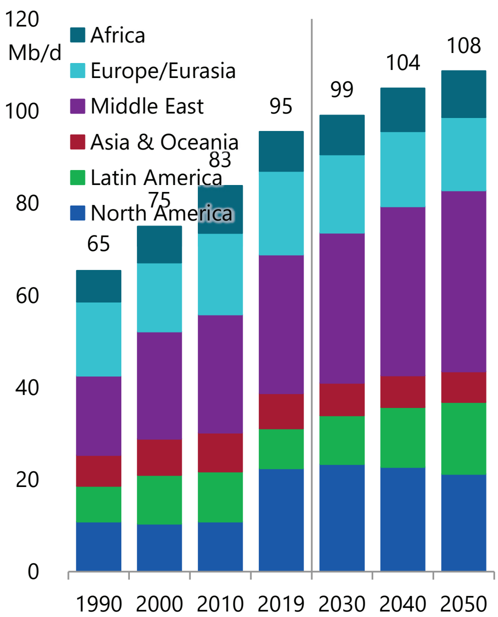
By sector



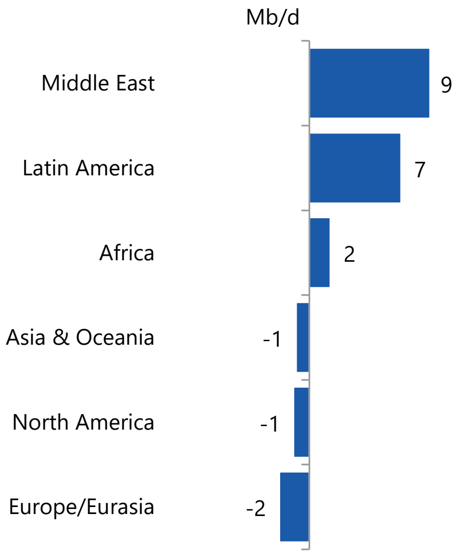
Reference Scenario

Crude oil production

By region

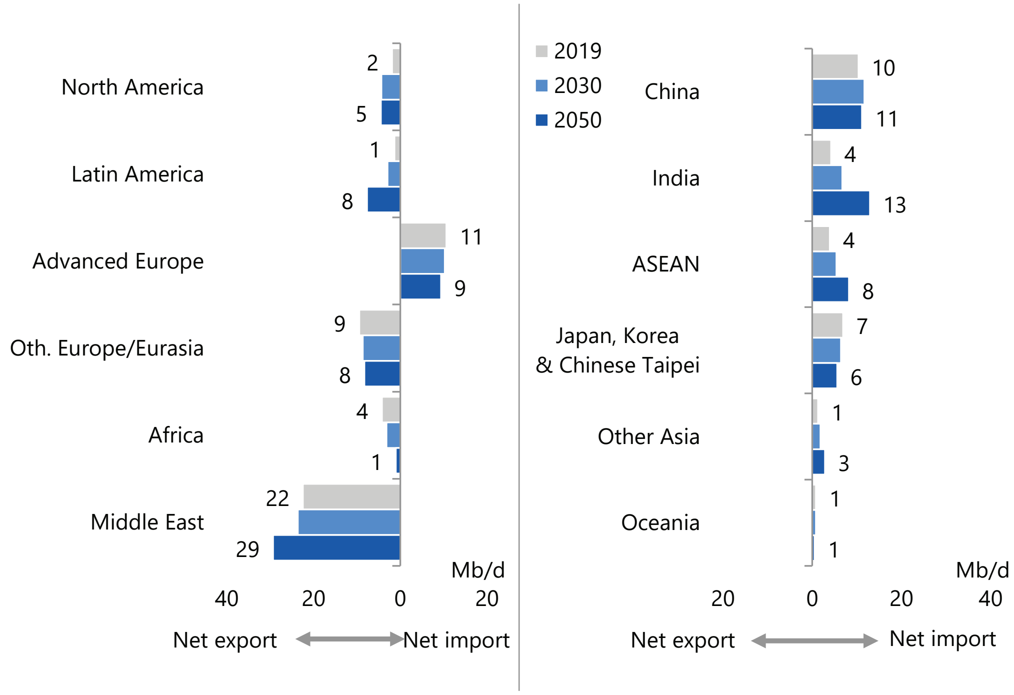


Changes (2019-2050)



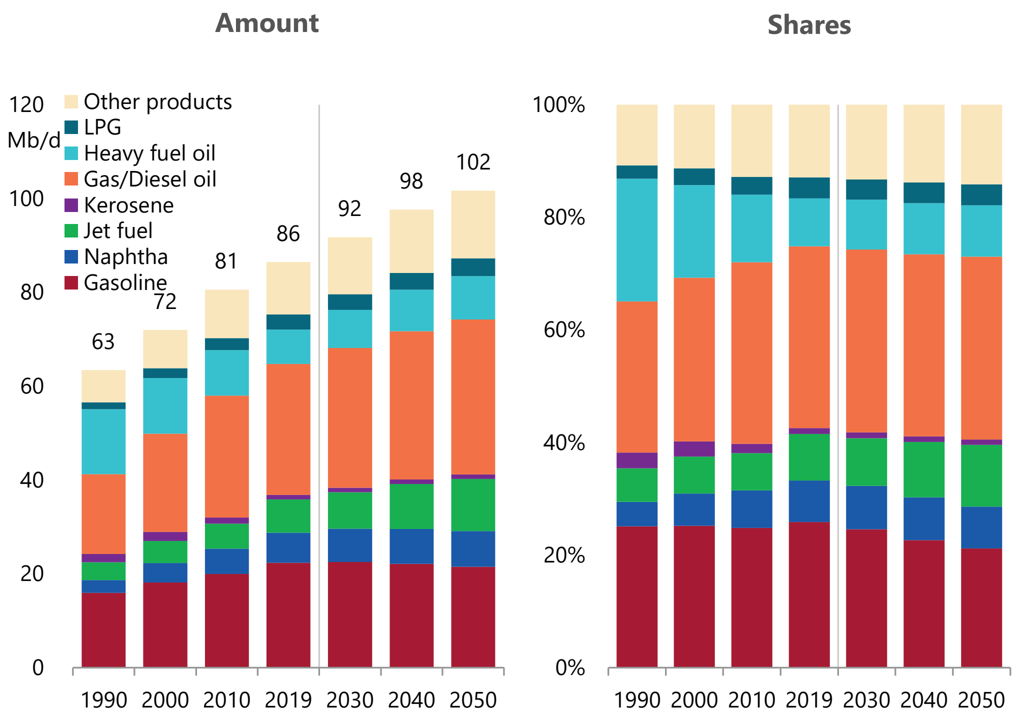
Reference Scenario

Net exports and imports of oil



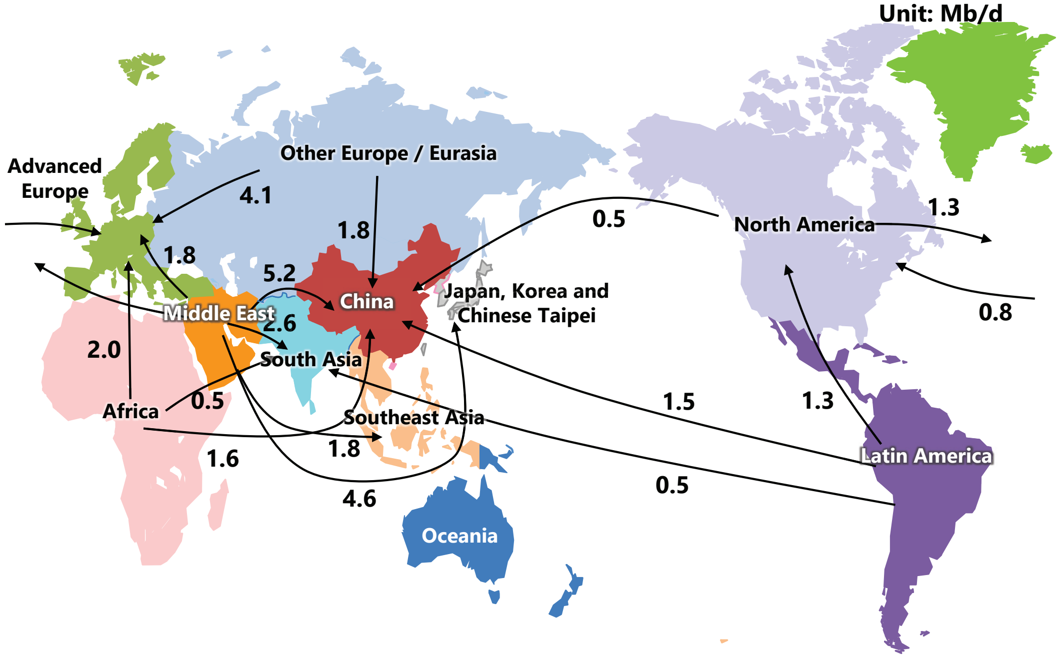
Reference Scenario

Petroleum product consumption



Reference Scenario

Major trade flows of crude oil (2020)

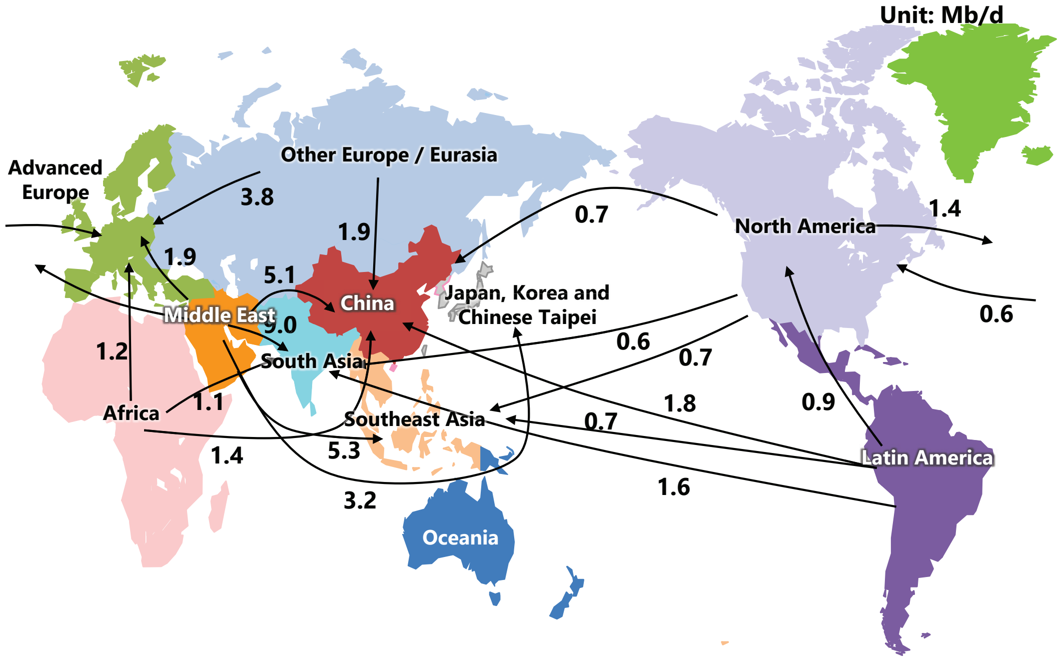


Note: 0.5 Mb/d or more are shown

IEEJ Outlook 2022 IEEJ © 2021

Reference Scenario

Major trade flows of crude oil (2050)



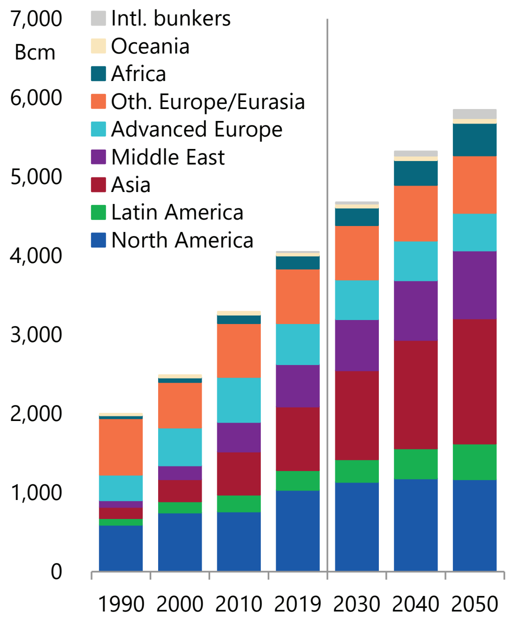
Note: 0.5 Mb/d or more are shown

IEEJ Outlook 2022 IEEJ © 2021

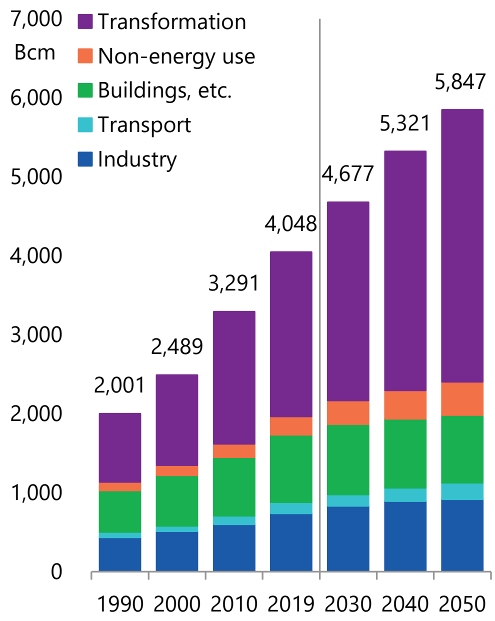
Reference Scenario

Natural gas consumption

By region



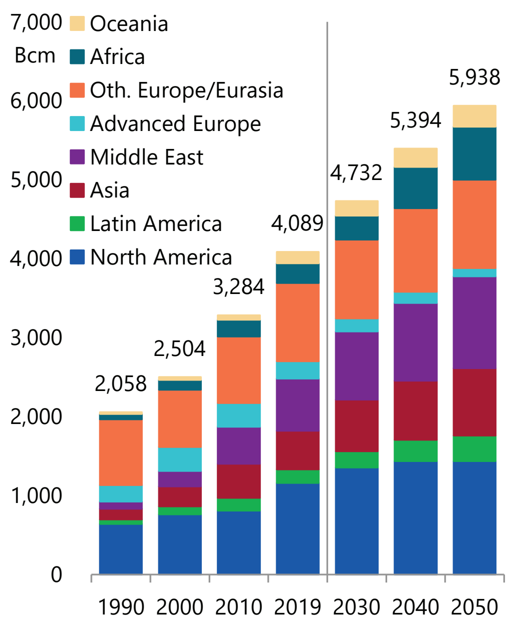
By sector



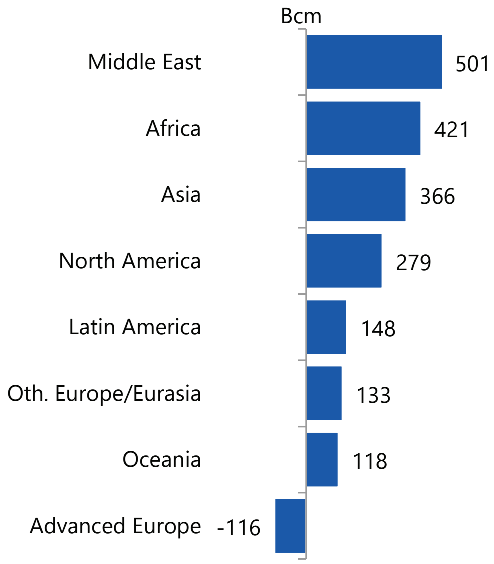
Reference Scenario

Natural gas production

By region

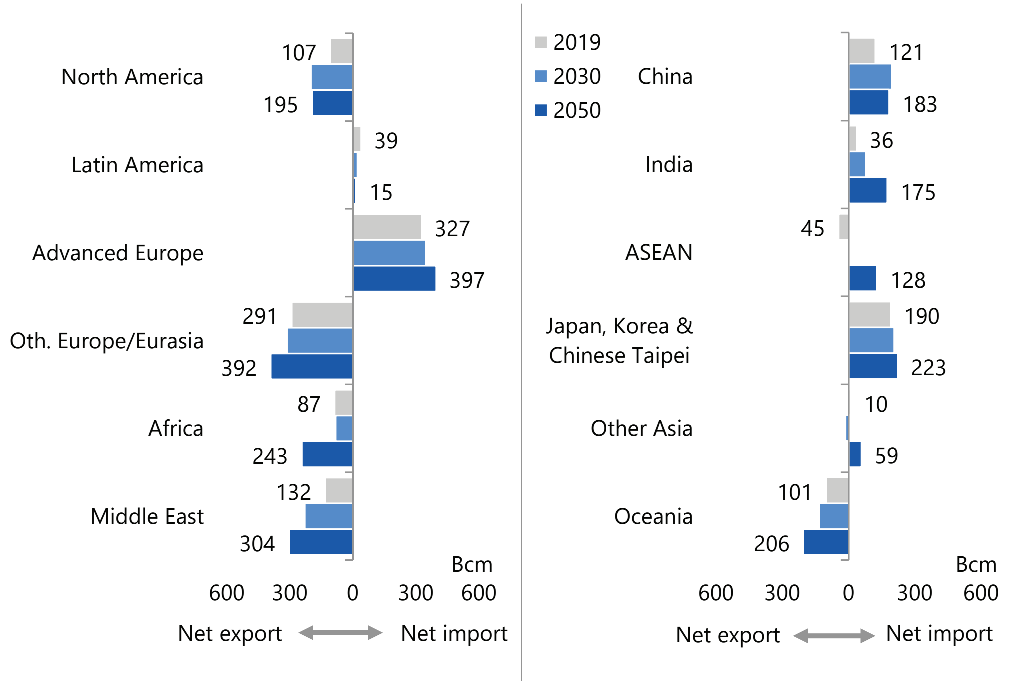


Changes (2019-2050)



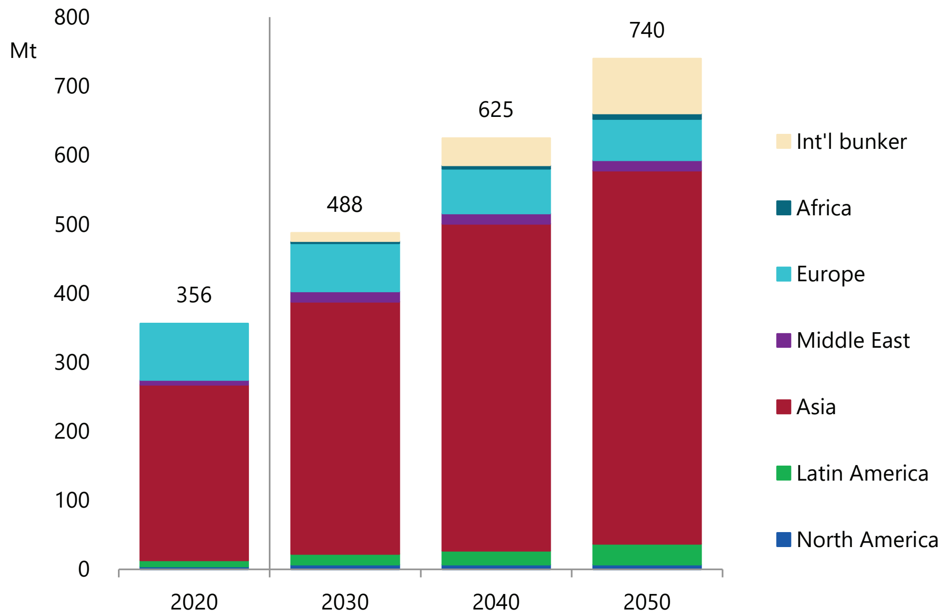
Reference Scenario

Net exports and imports of natural gas



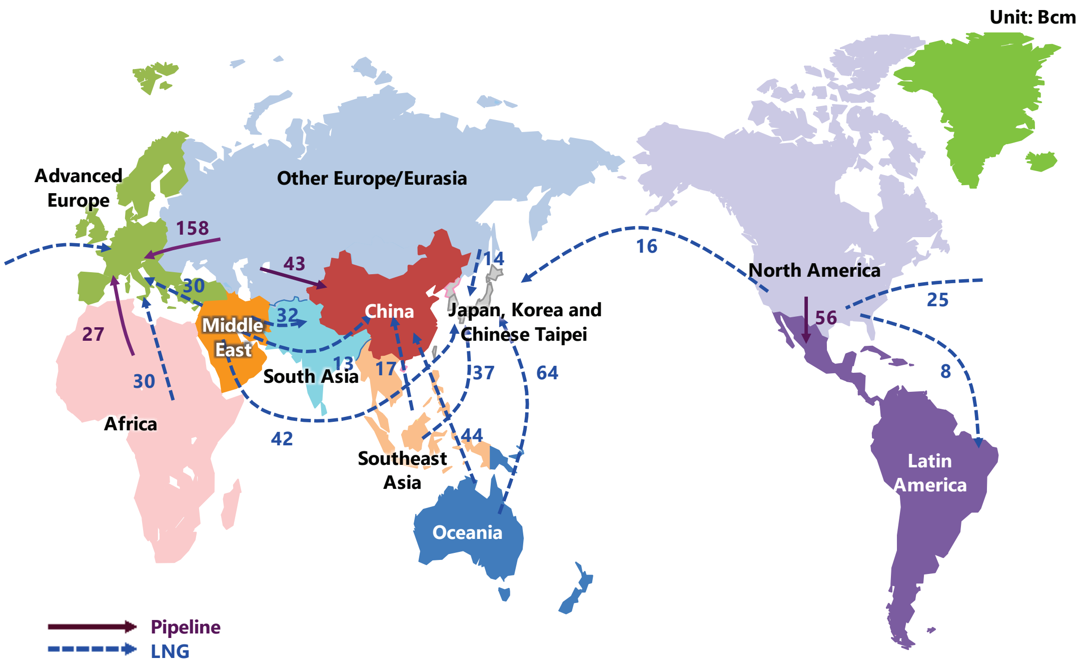
Reference Scenario

LNG demand in selected regions



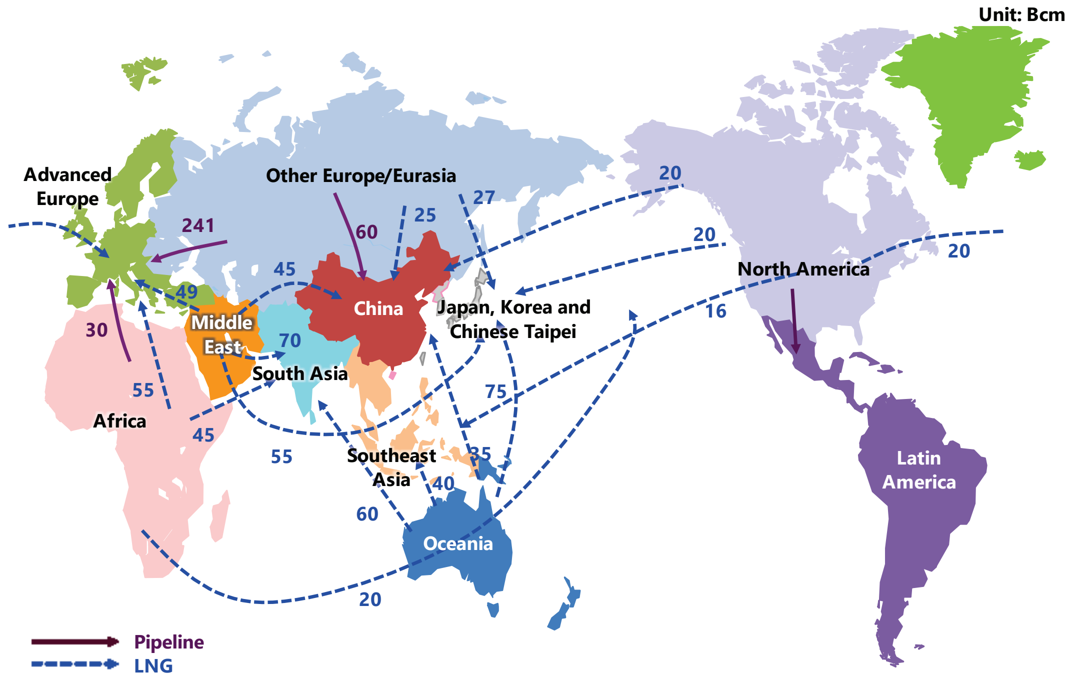
Reference Scenario

Major trade flows of natural gas (2020)



Reference Scenario

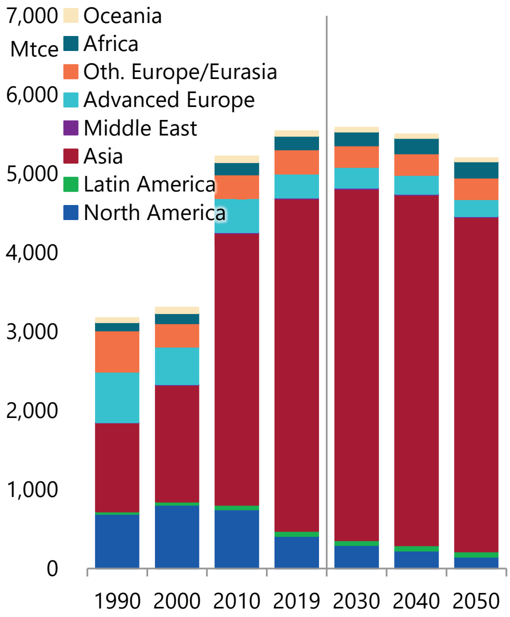
Major trade flows of natural gas (2050)



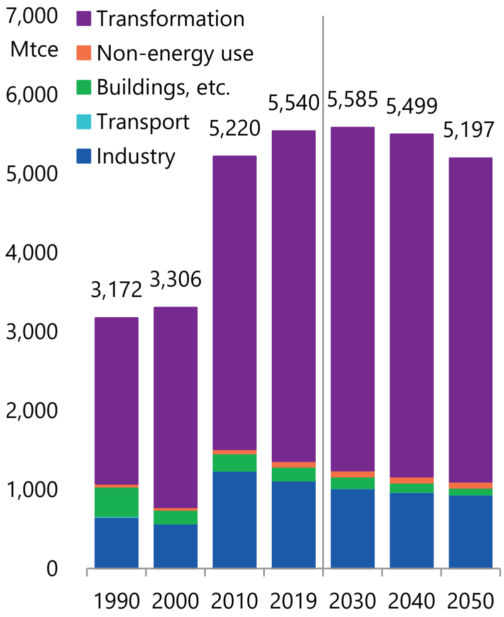
Reference Scenario

Coal consumption

By region



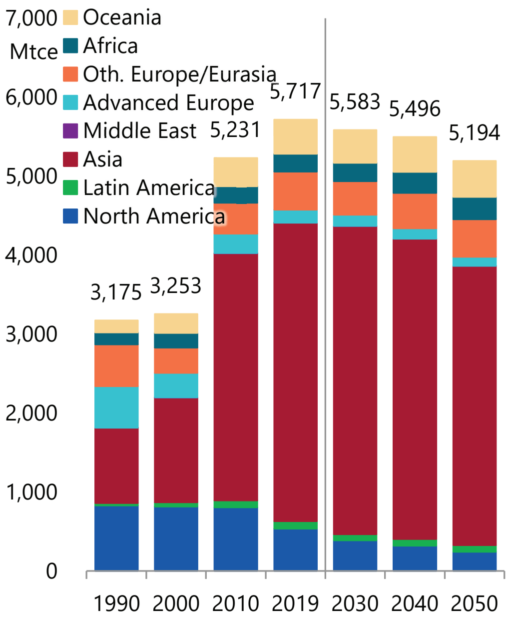
By sector



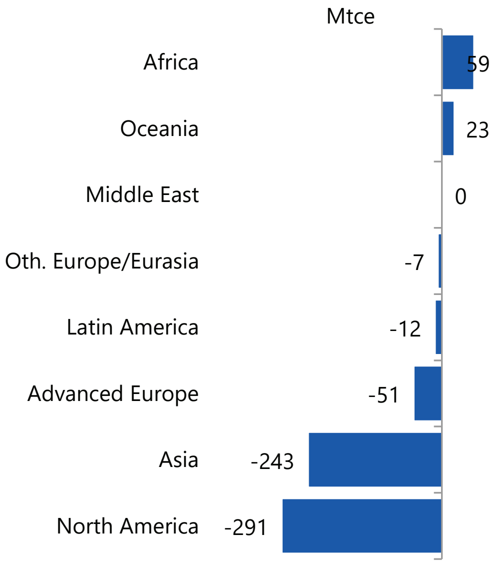
Reference Scenario

Coal production

By region

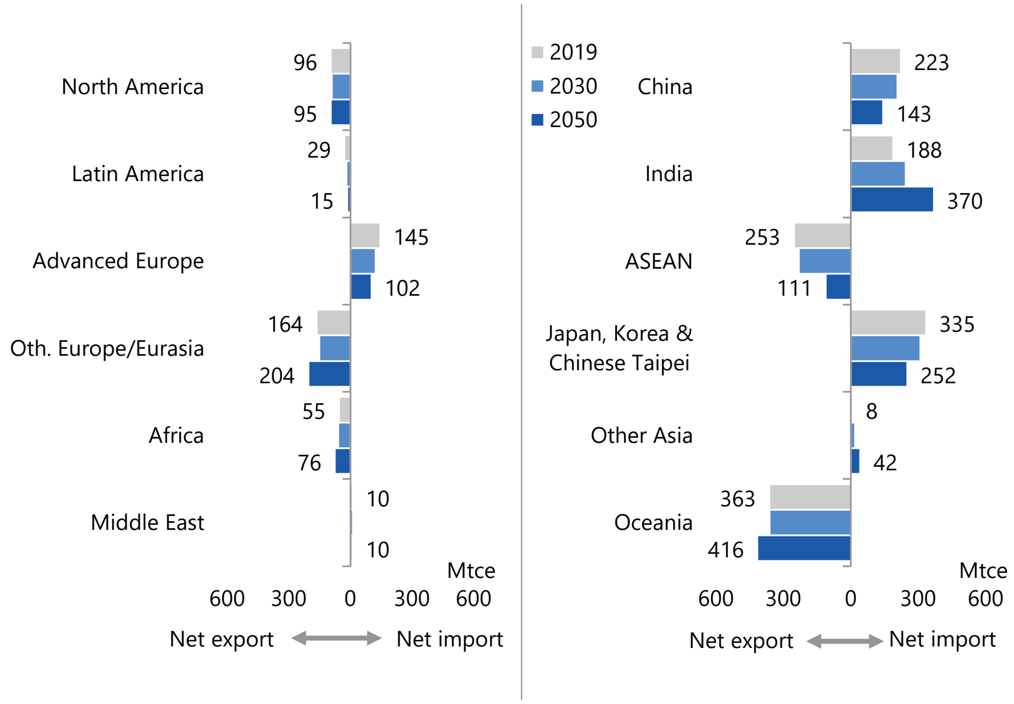


Changes (2019-2050)



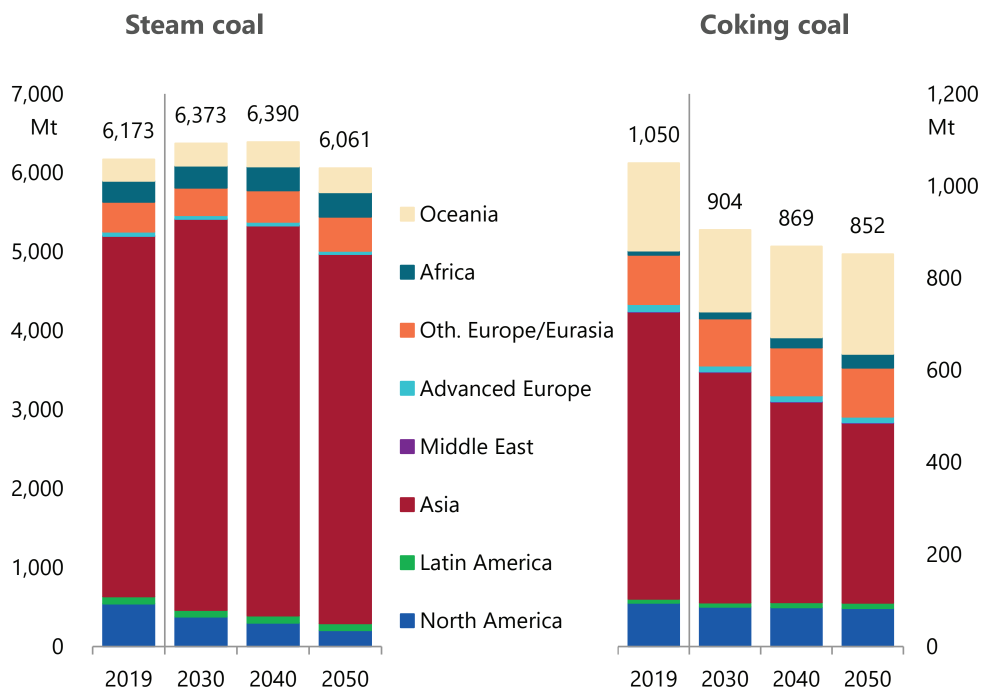
Reference Scenario

Net exports and imports of coal



Reference Scenario

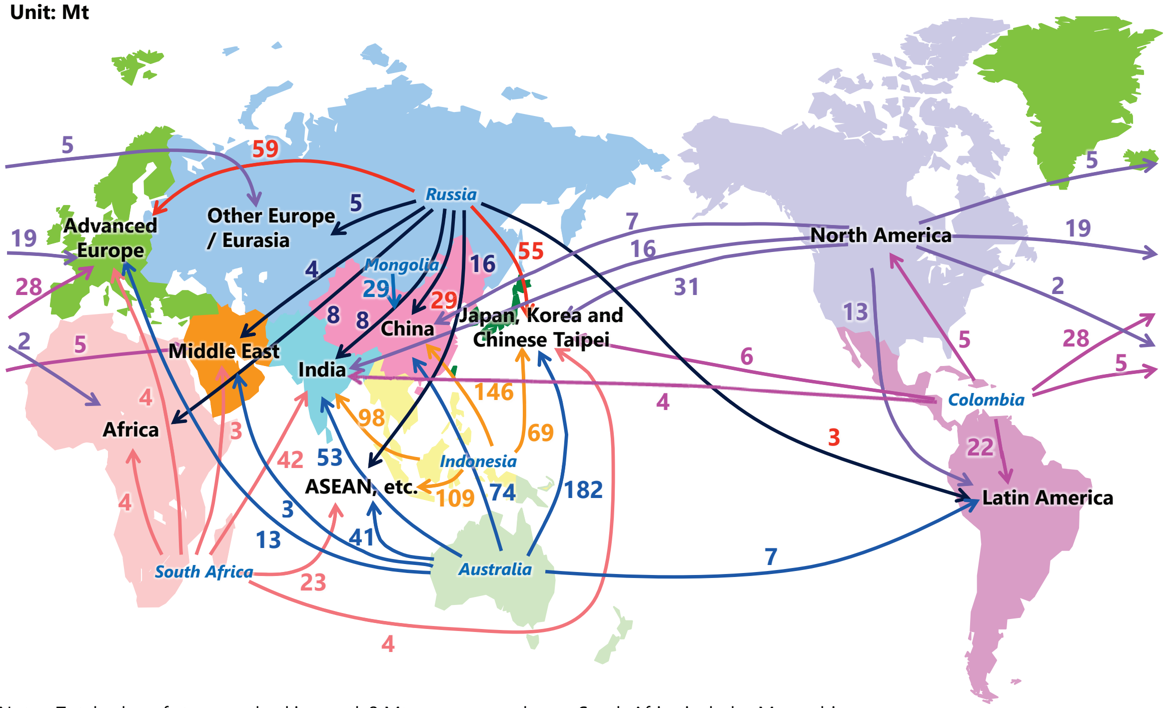
Coal production (steam and coking coal)



Reference Scenario

Major trade flows of steam and coking coal (2020)

Unit: Mt

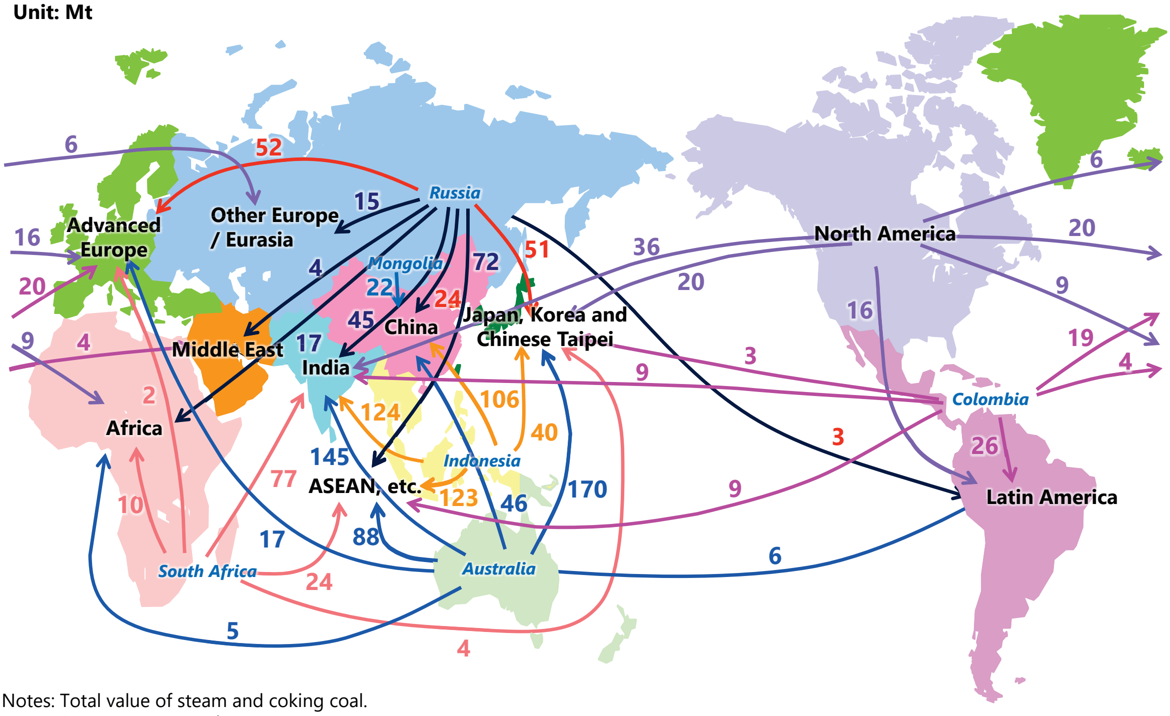


Notes: Total value of steam and coking coal. 2 Mt or more are shown. South Africa includes Mozambique.
Source: Estimated from IEA "Coal Information 2021", "TEX Report", etc.

Reference Scenario

Major trade flows of steam and coking coal (2050)

Unit: Mt

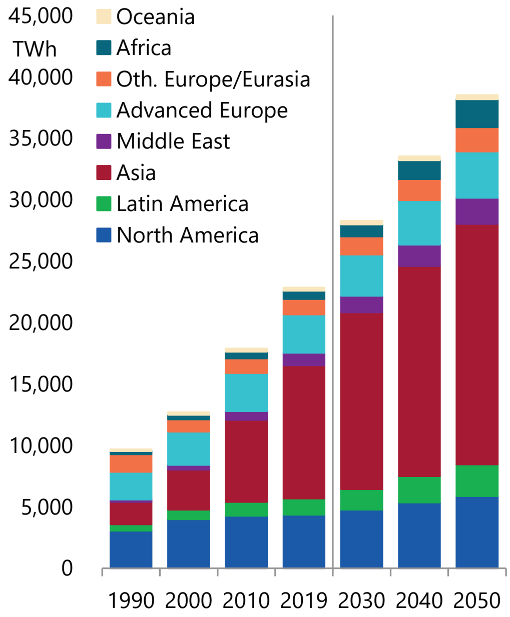


Notes: Total value of steam and coking coal.
2 Mt or more are shown.
South Africa includes Mozambique.

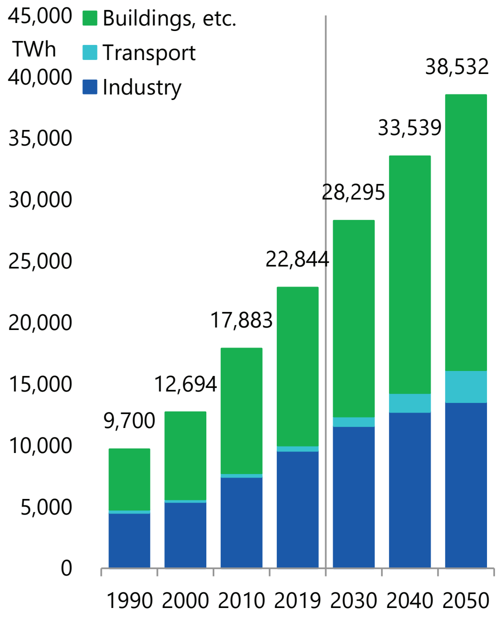
Reference Scenario

Final consumption of electricity

By region



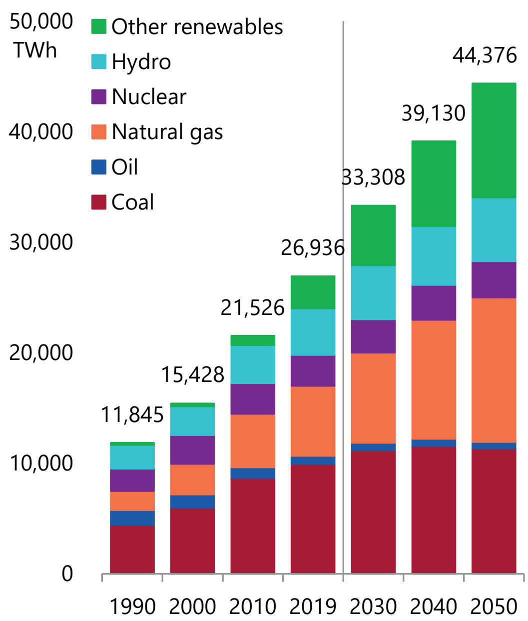
By sector



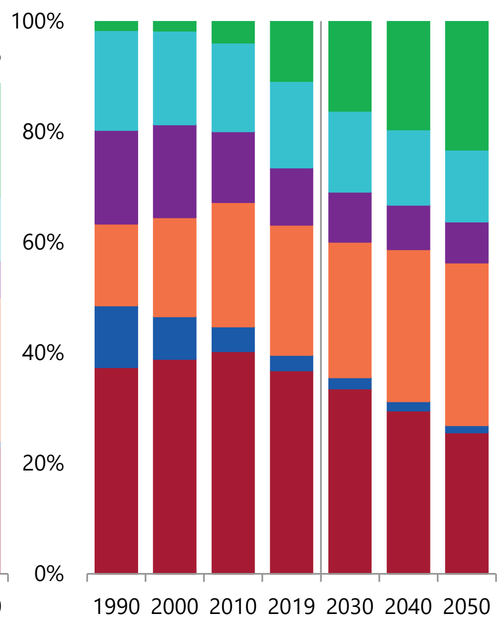
Reference Scenario

Power generation mix

Electricity generated



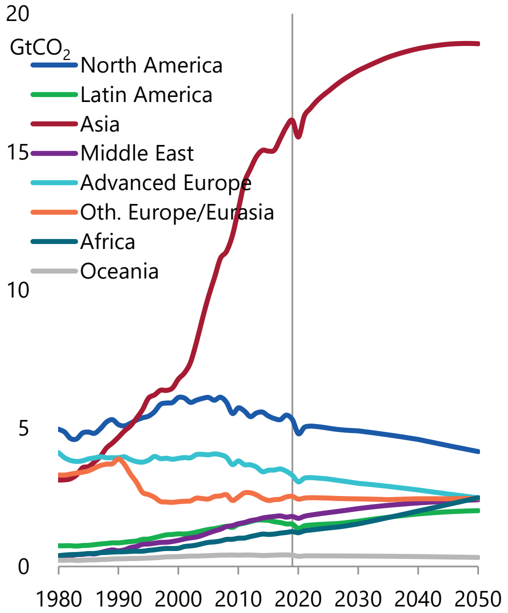
Shares



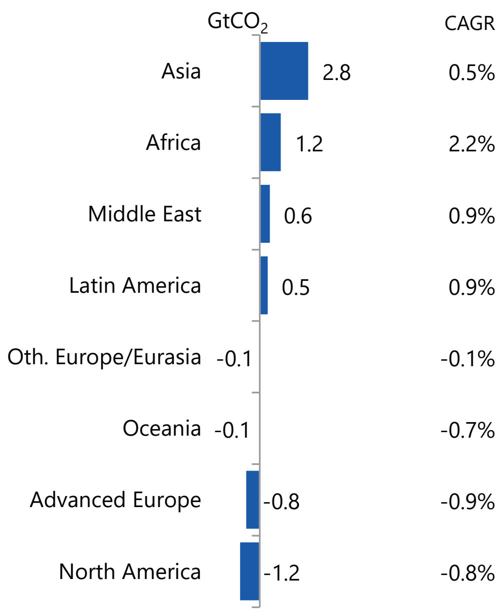
Reference Scenario

Energy-related CO_2 emissions

Emissions



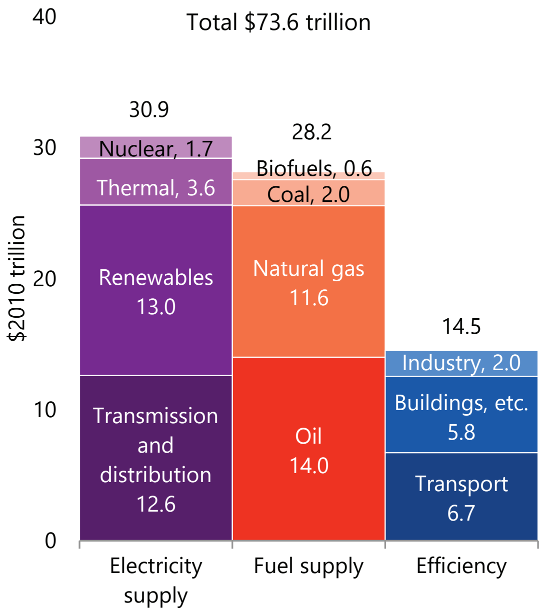
Changes (2019-2050)



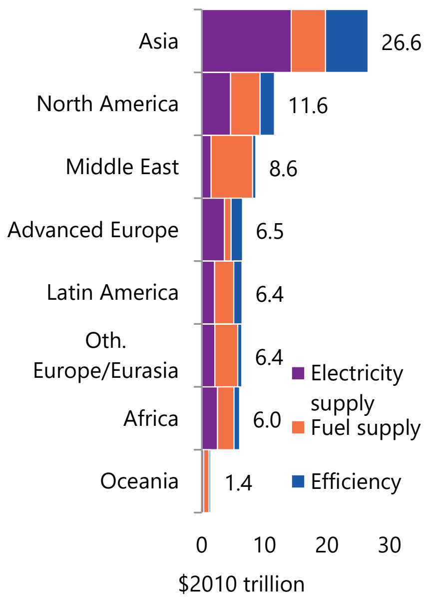
Reference Scenario

Energy-related investments (2021 – 2050)

By sector



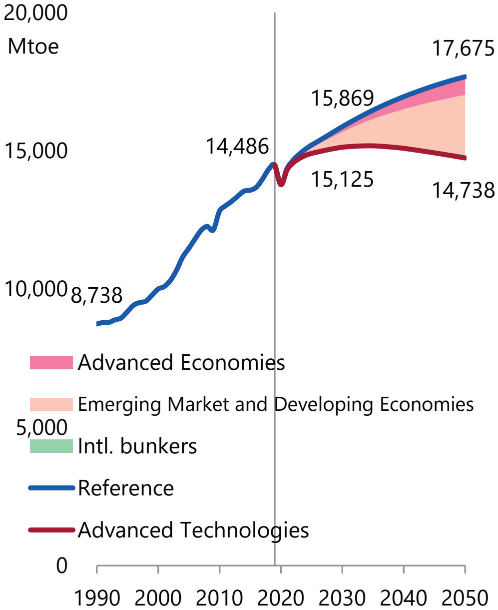
By region



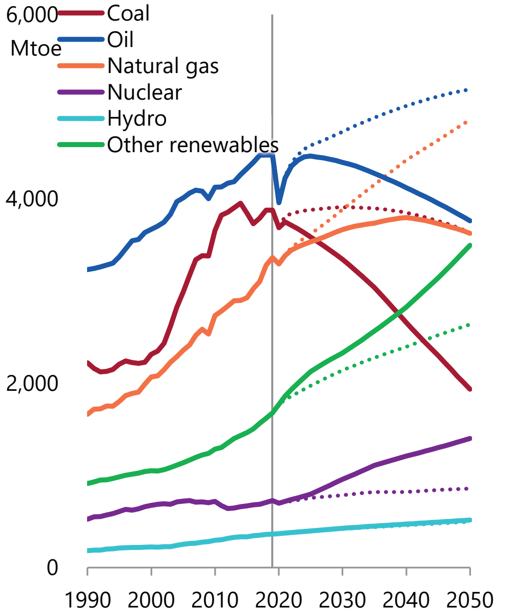
Advanced Technologies Scenario

Primary energy consumption

By region



By energy source

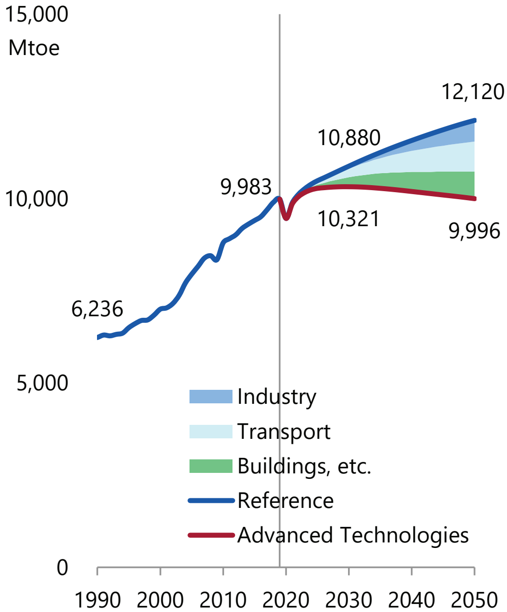


Note: Solid lines stand for Advanced Technologies Scenario and dotted lines stand for Reference Scenario.

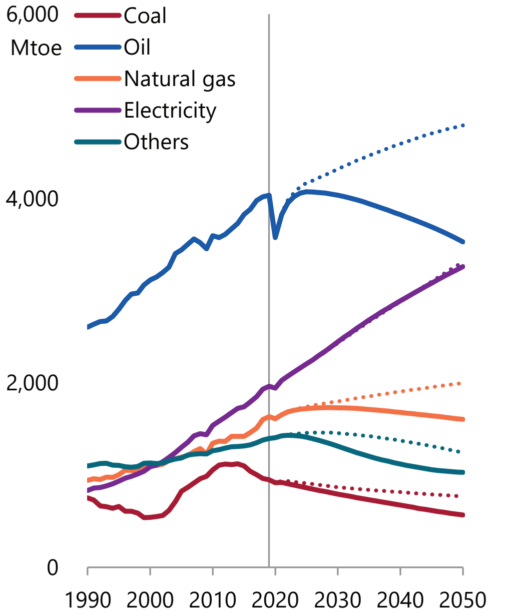
Advanced Technologies Scenario

Final energy consumption

By sector



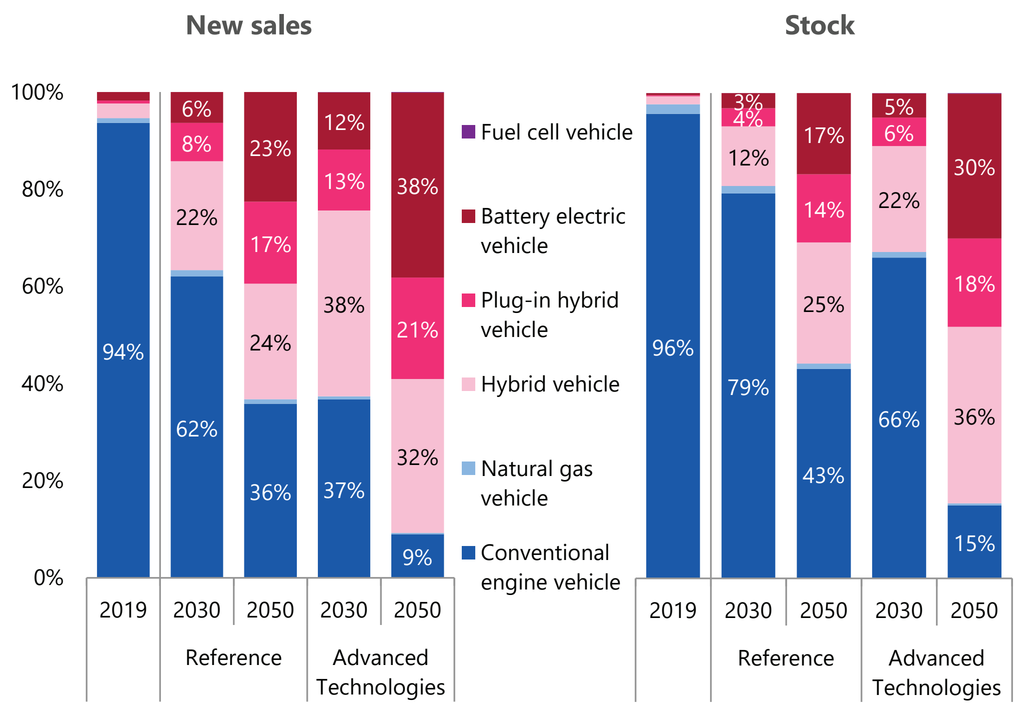
By energy



Note: Solid lines stand for Advanced Technologies Scenario and dotted lines stand for Reference Scenario.

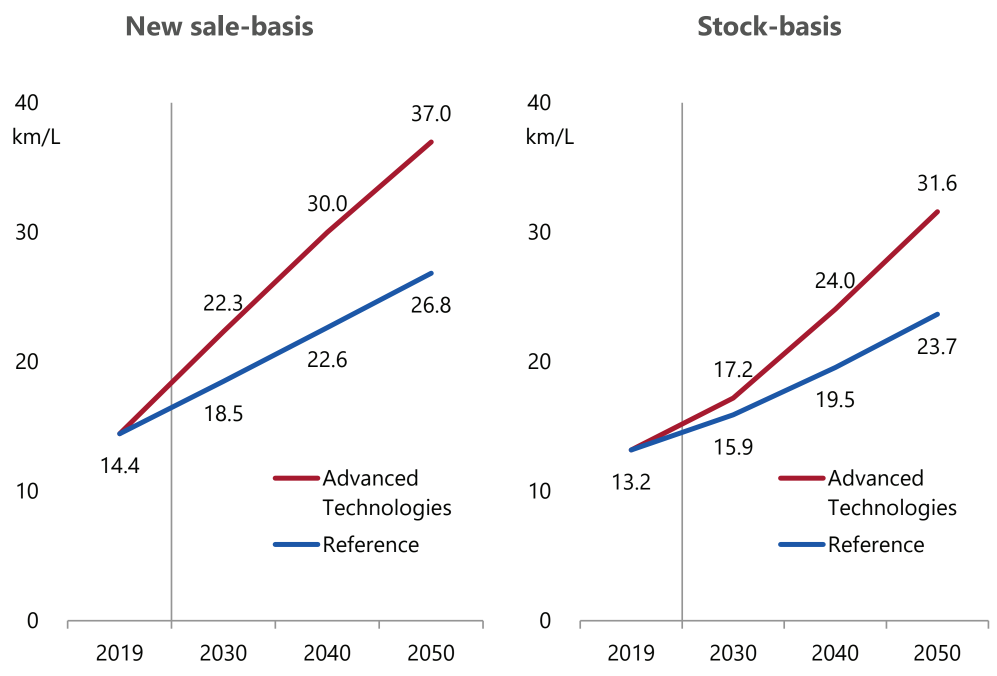
Advanced Technologies Scenario

Share of passenger vehicle



Advanced Technologies Scenario

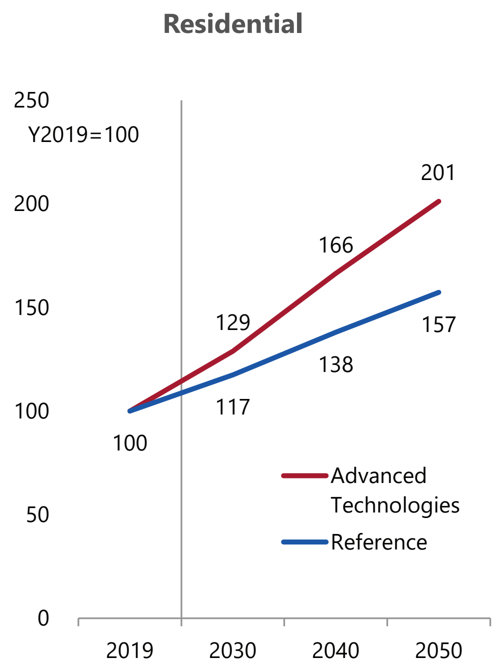
Fuel efficiency of passenger vehicle

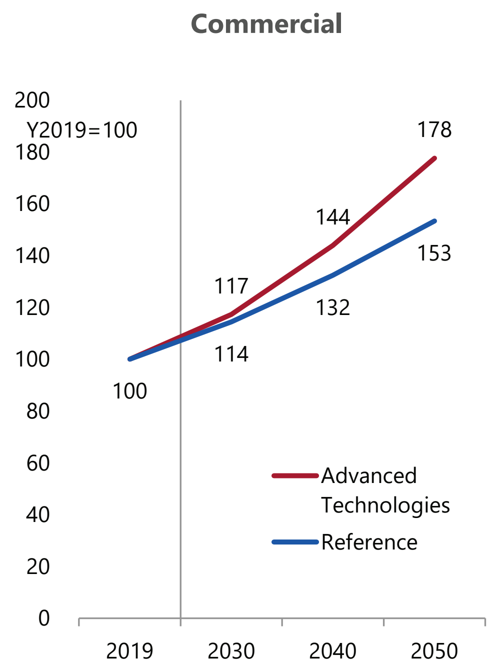


Note: Litres of gasoline equivalent

Advanced Technologies Scenario

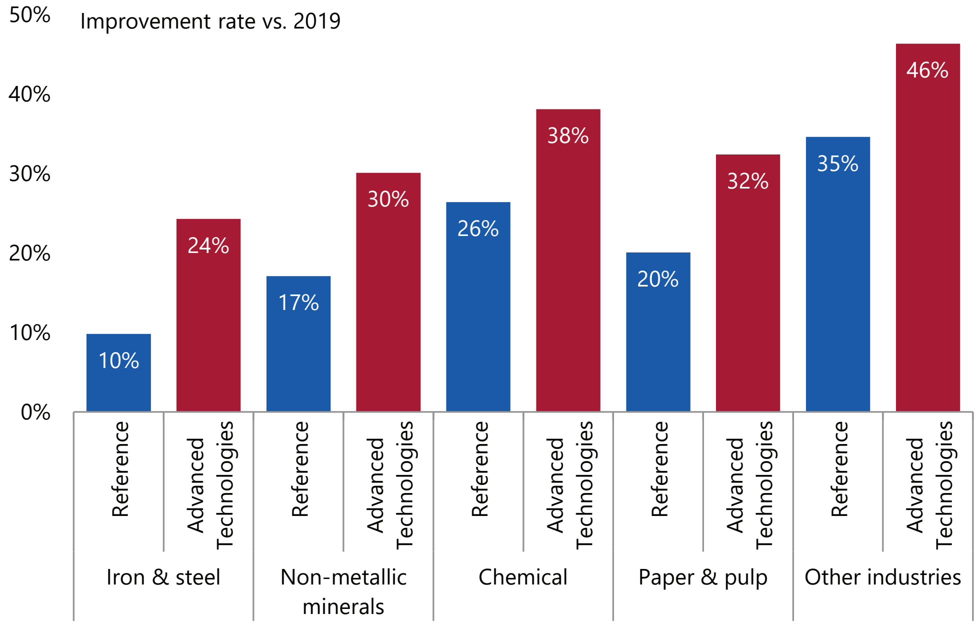
Energy efficiency in buildings sector



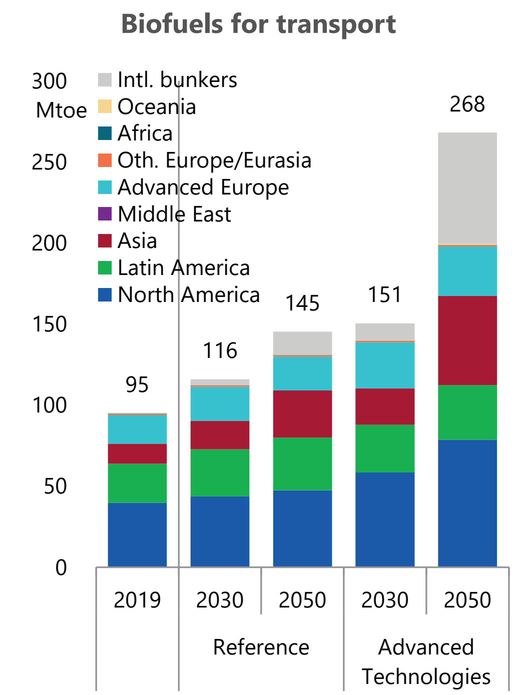


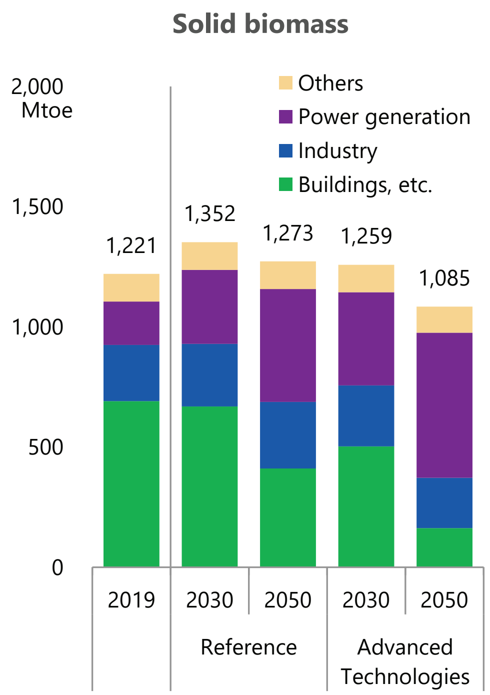
Advanced Technologies Scenario

Energy intensity improvement in industry sector

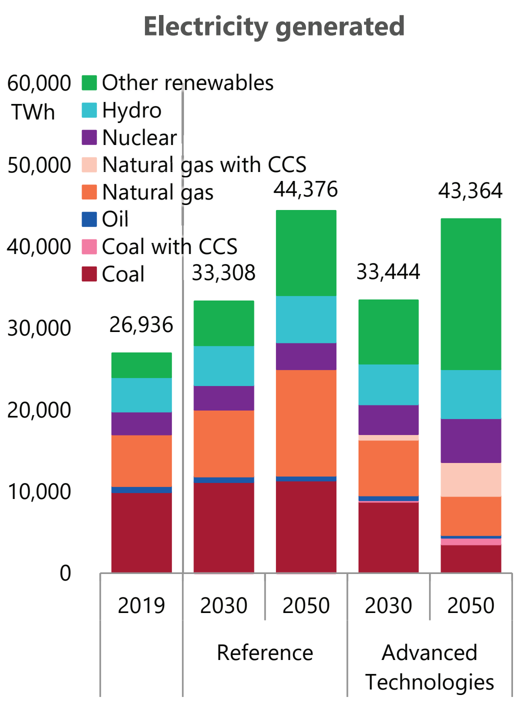


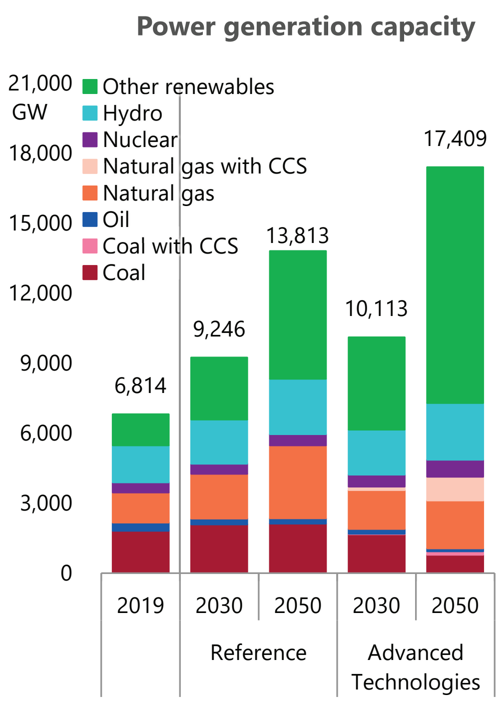
Biomass





Power generation mix

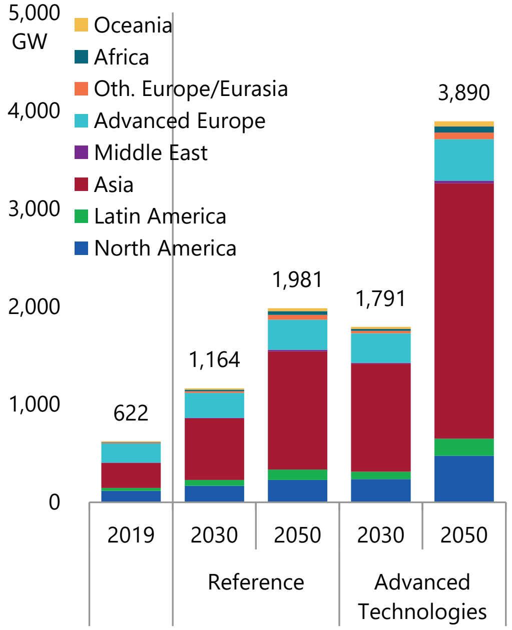




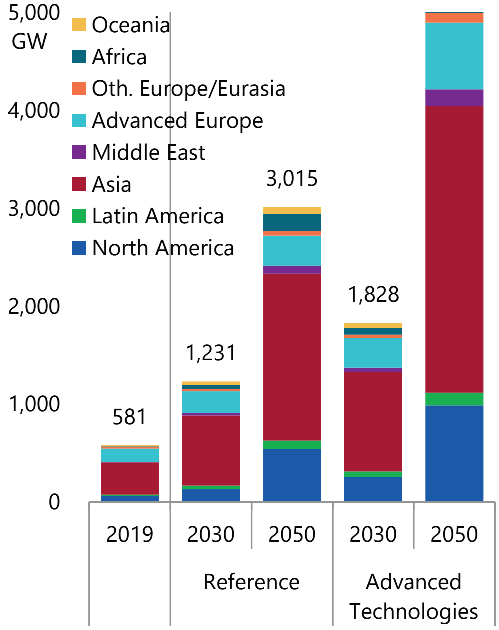
Advanced Technologies Scenario

Wind and solar PV power generation capacity

Wind



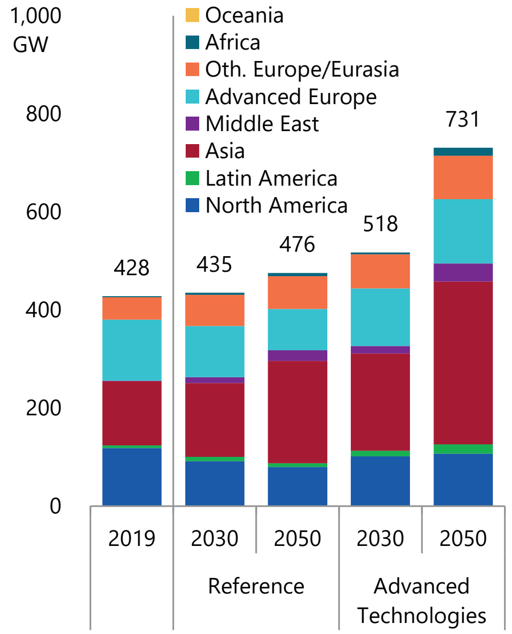
Solar PV



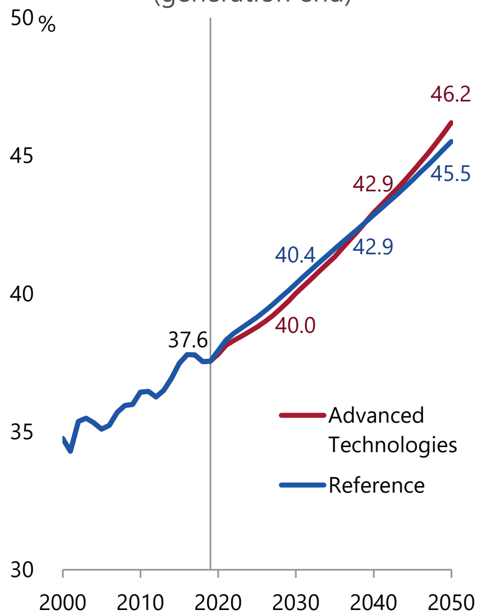
Advanced Technologies Scenario

Nuclear power generation capacity and thermal power generation efficiency

Nuclear



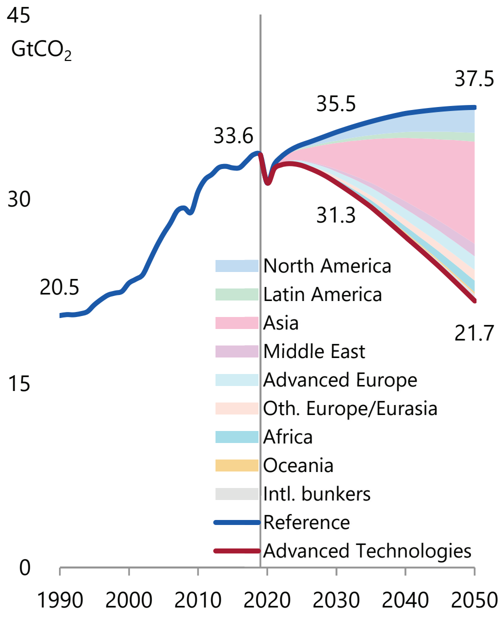
Thermal power generation efficiency
(generation end)



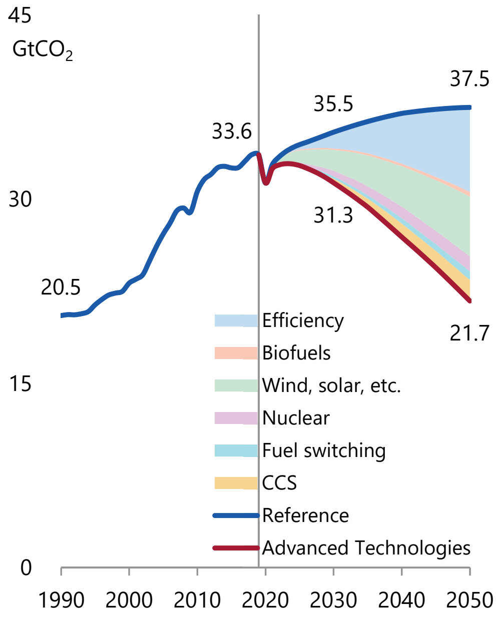
Advanced Technologies Scenario

Energy-related CO_2 emissions

By region



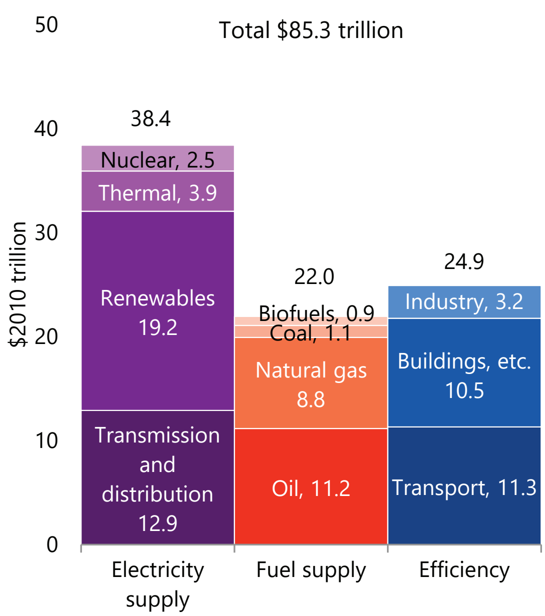
By technology



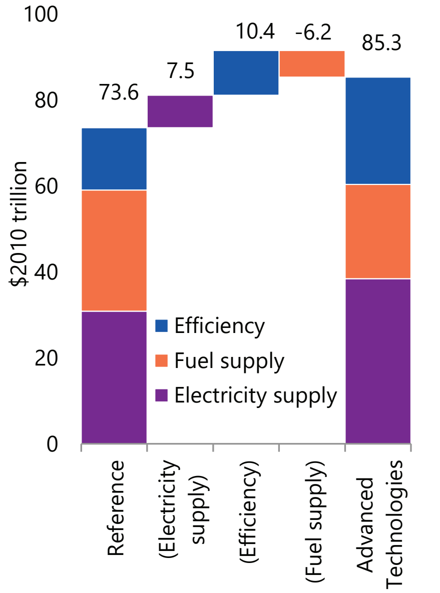
Advanced Technologies Scenario

Energy-related investments (2021 – 2050)

By sector



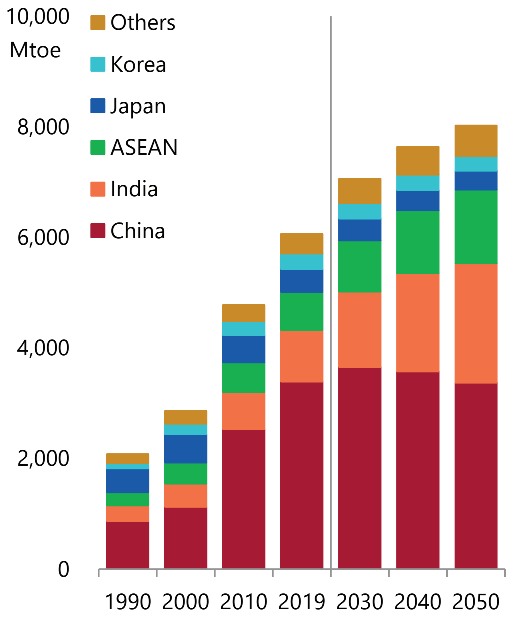
Changes from Reference Scenario



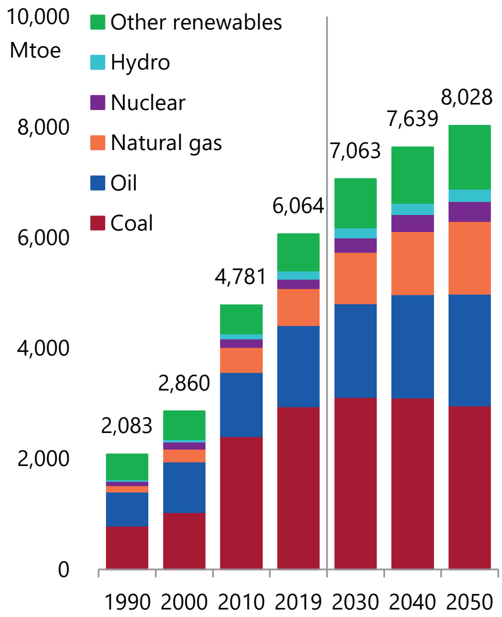
Asia | Reference Scenario

Primary energy consumption

By region



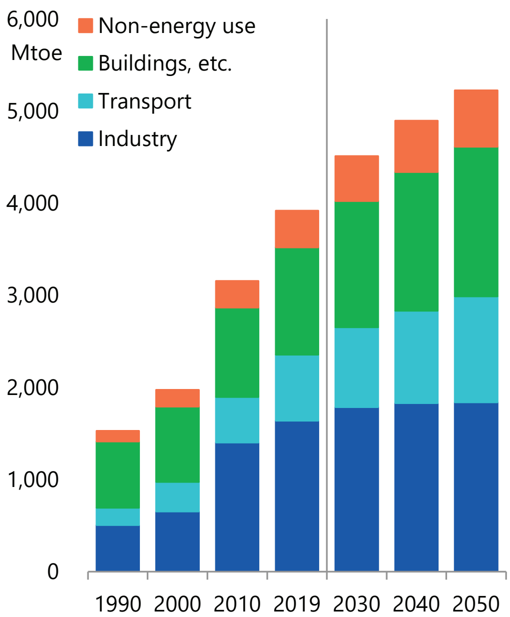
By energy source



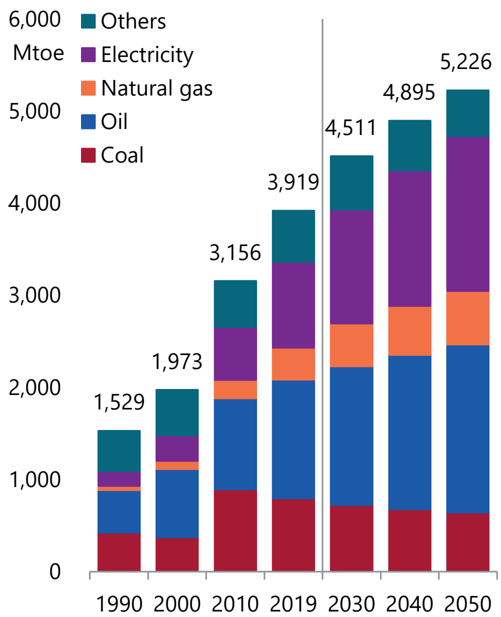
Asia | Reference Scenario

Final energy consumption

By sector



By energy source

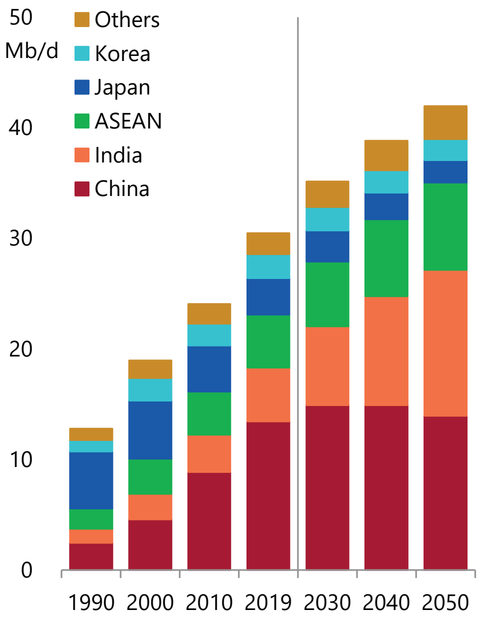


Asia

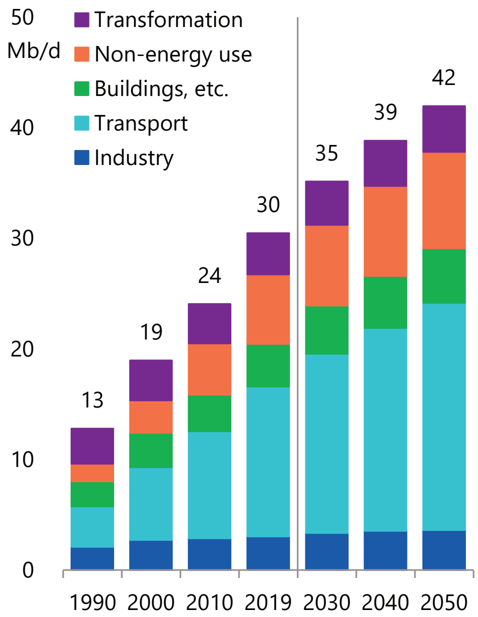
Reference Scenario

Oil consumption

By region



By sector

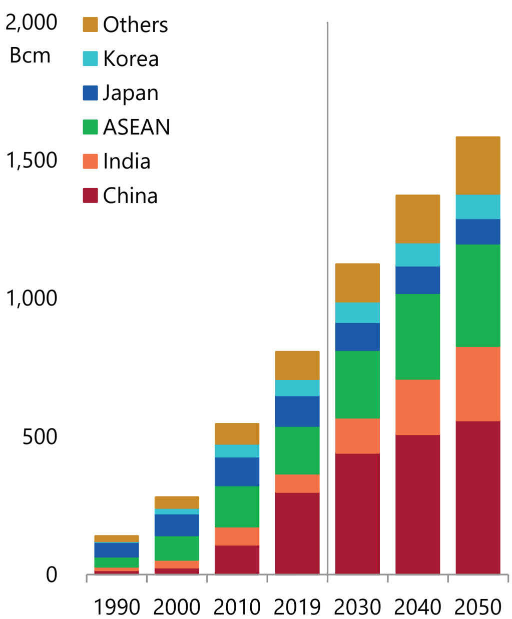


Asia

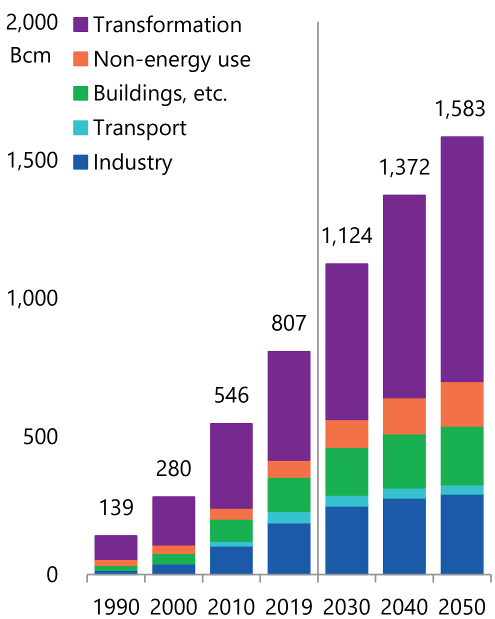
Reference Scenario

Natural gas consumption

By region



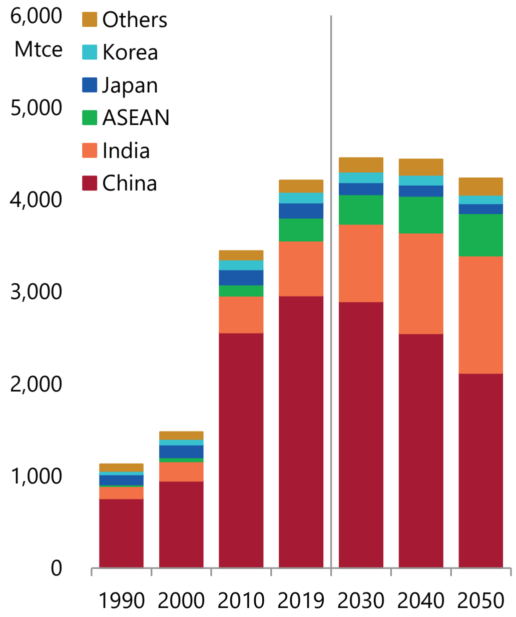
By sector



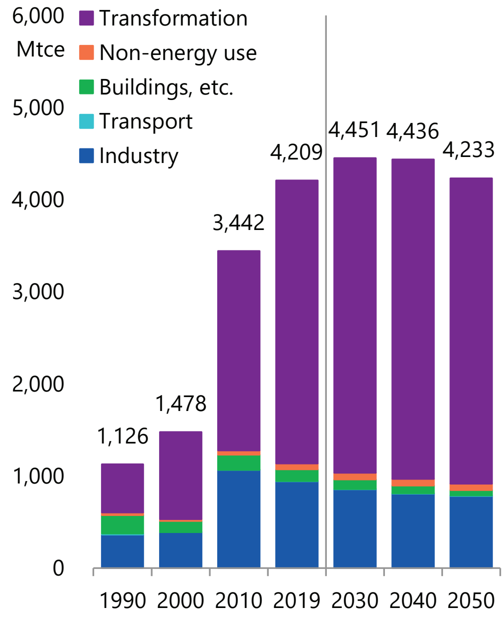
Asia | Reference Scenario

Coal consumption

By region



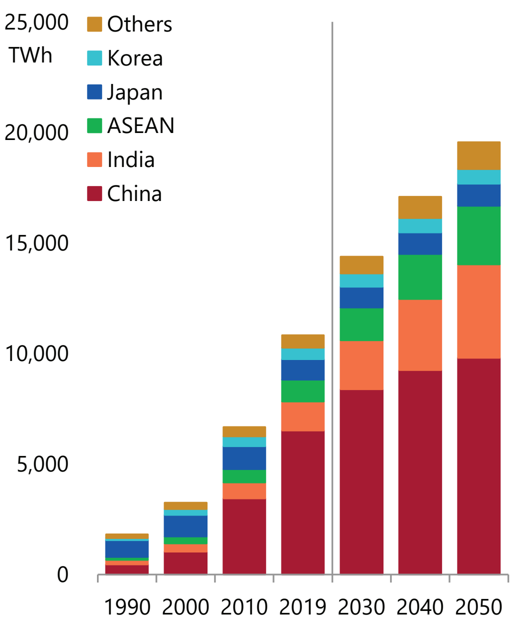
By sector



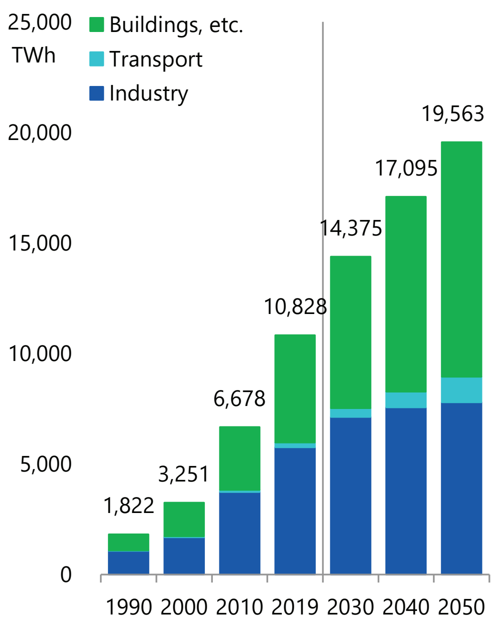
Asia | Reference Scenario

Final consumption of electricity

By region

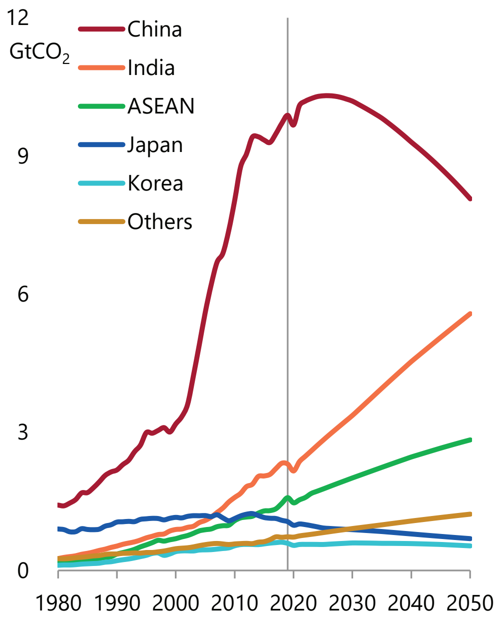


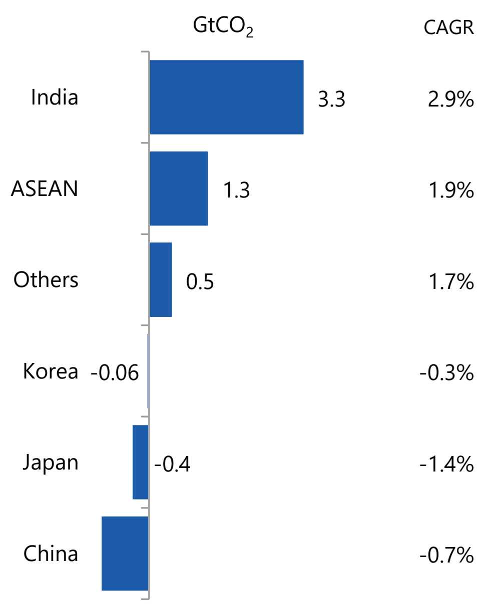
By sector



Asia | Reference Scenario

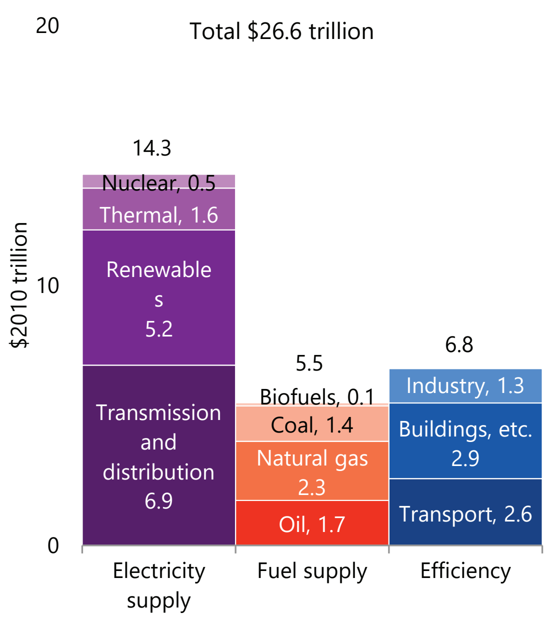
Energy-related CO_2 emissions

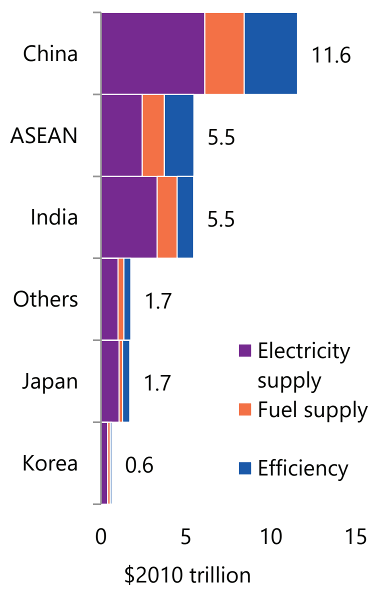




Asia | Reference Scenario

Energy-related investments (2021 – 2050)



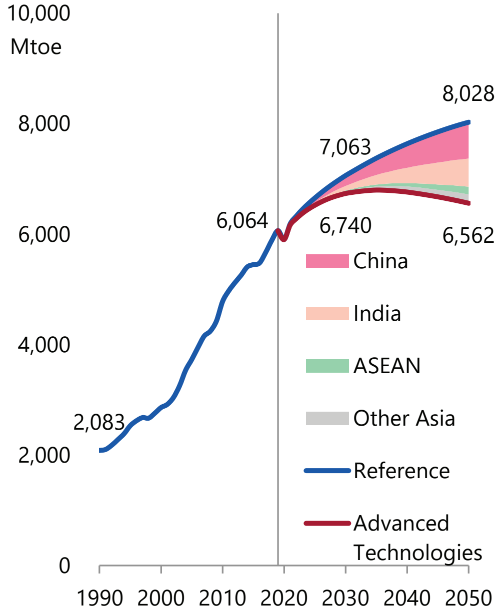


Asia

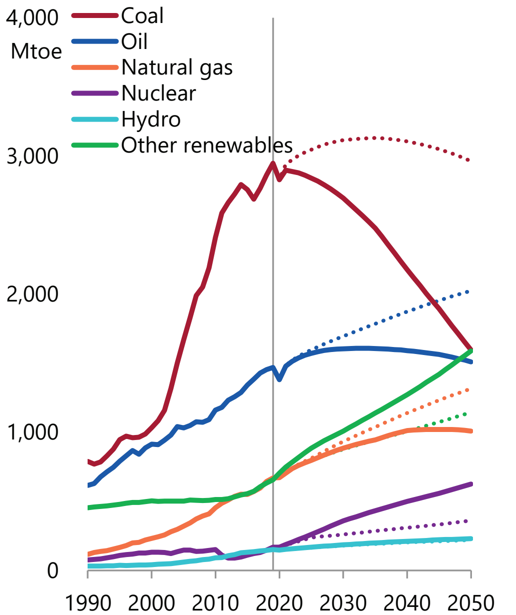
Advanced Technologies Scenario

Primary energy consumption

By region



By energy source



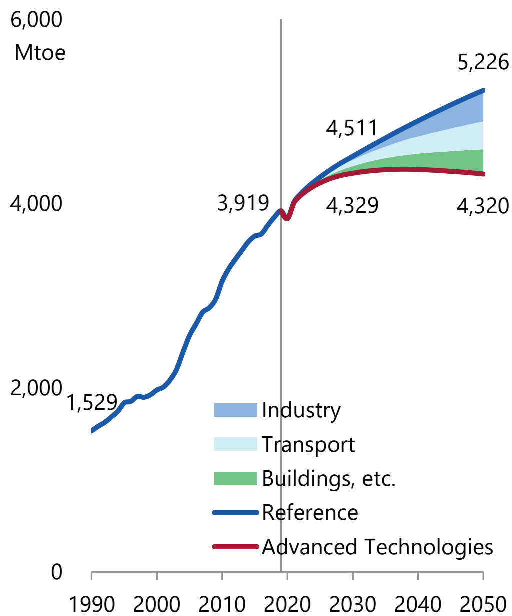
Note: Solid lines stand for Advanced Technologies Scenario and dotted lines stand for Reference Scenario.

Asia

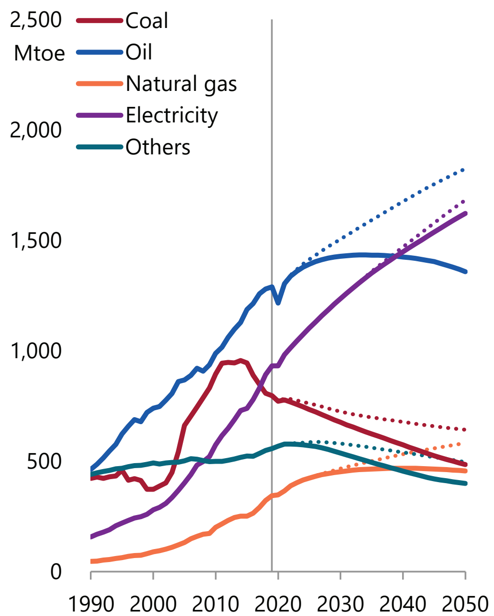
Advanced Technologies Scenario

Final energy consumption

By sector



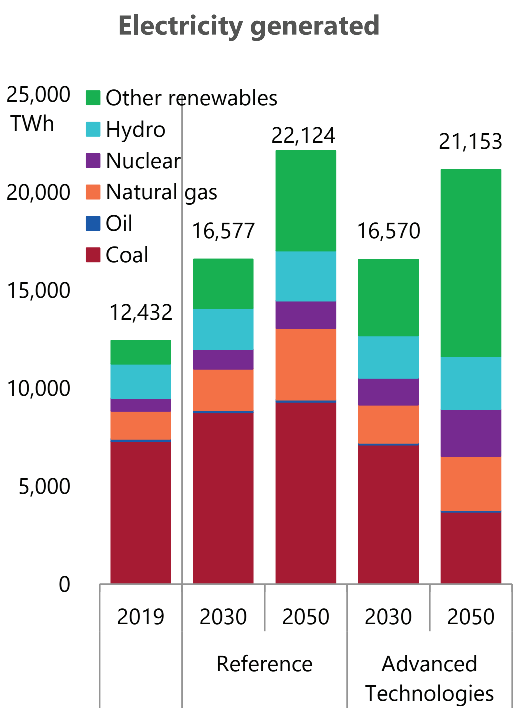
By energy source

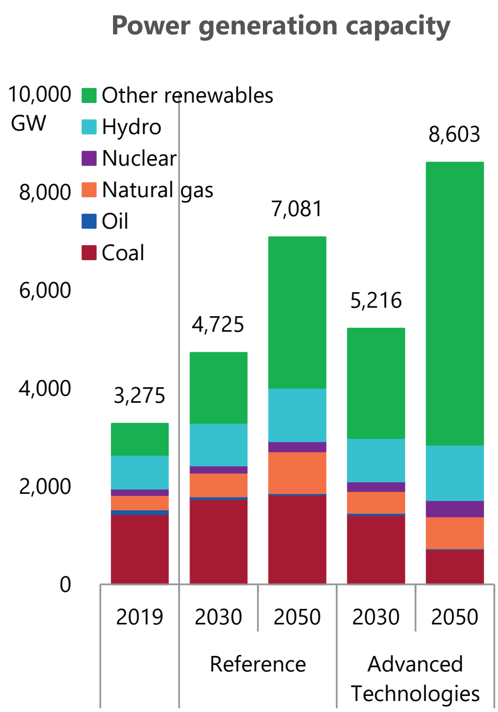


Note: Solid lines stand for Advanced Technologies Scenario and dotted lines stand for Reference Scenario.

Asia | Advanced Technologies Scenario

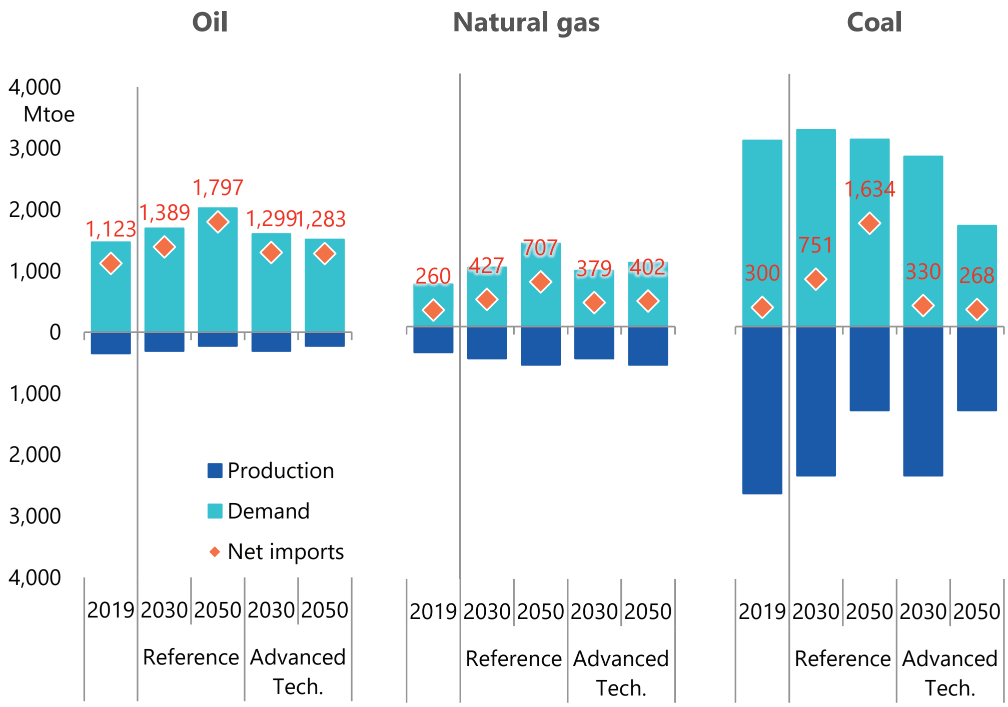
Power generation mix





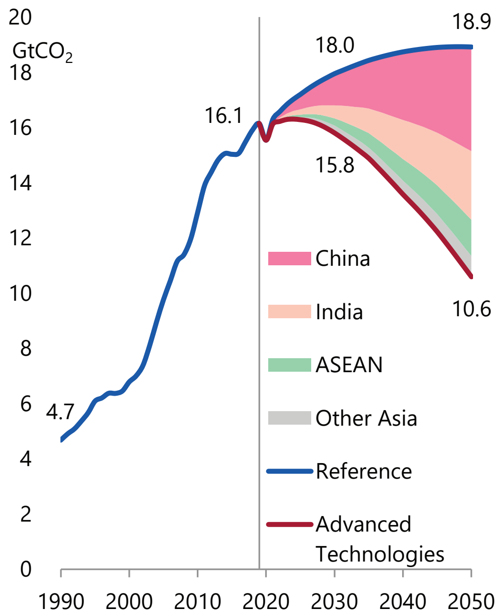
Asia | Advanced Technologies Scenario

Supply and demand balance of fossil fuels

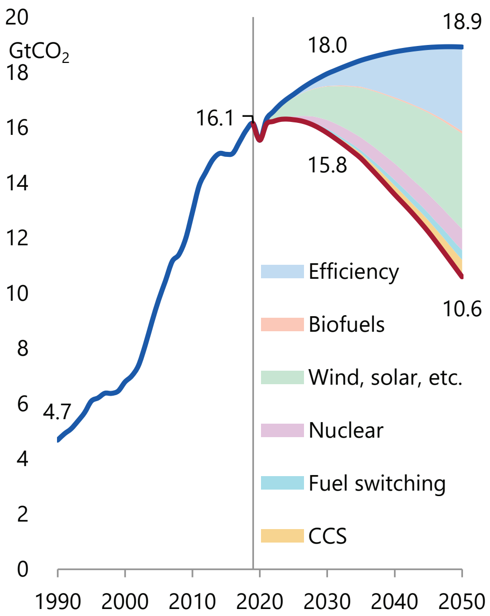


Energy-related CO_2 emissions

By region

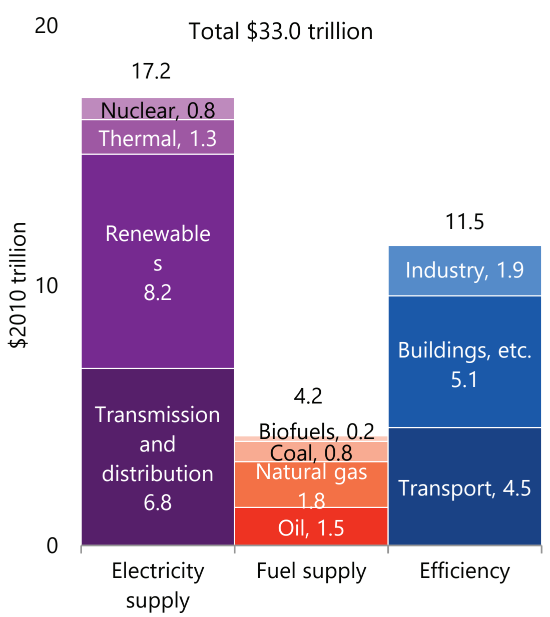


By technology

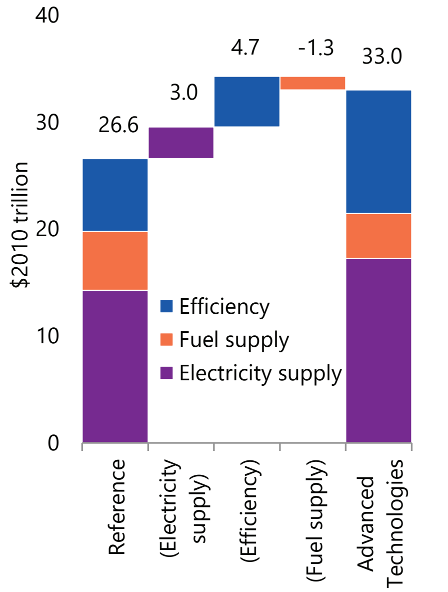


Energy-related investments (2021 – 2050)

By sector



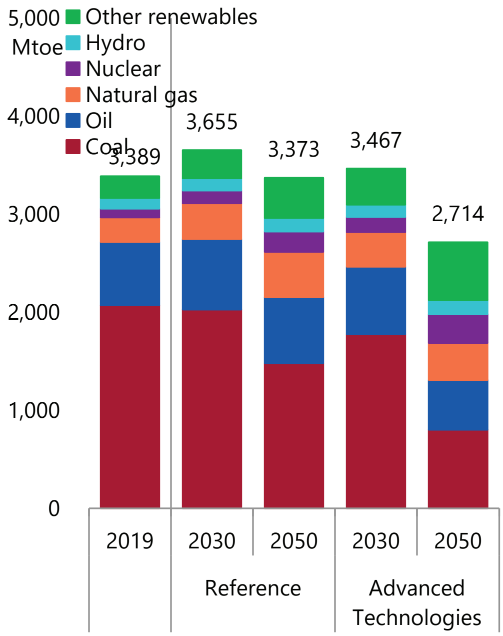
Changes from Reference Scenario



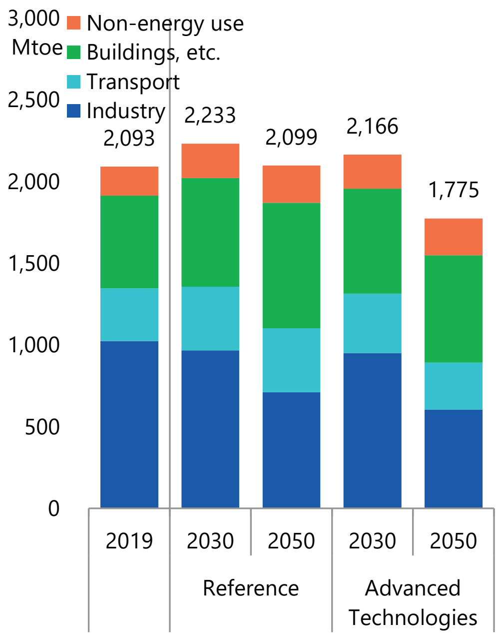
China

Energy consumption

Primary energy consumption



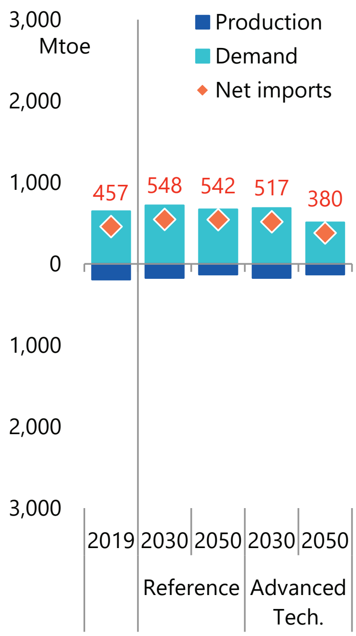
Final energy consumption



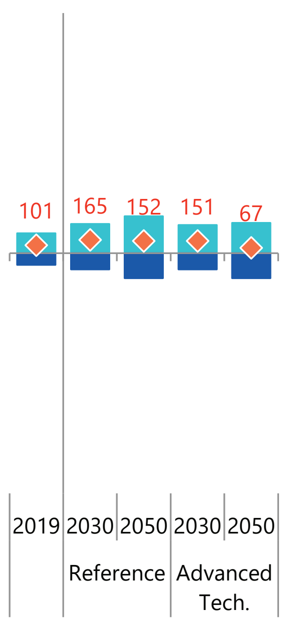
China

Supply and demand balance of fossil fuels

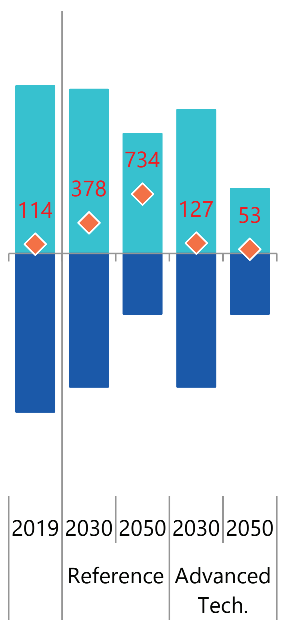
Oil



Natural gas



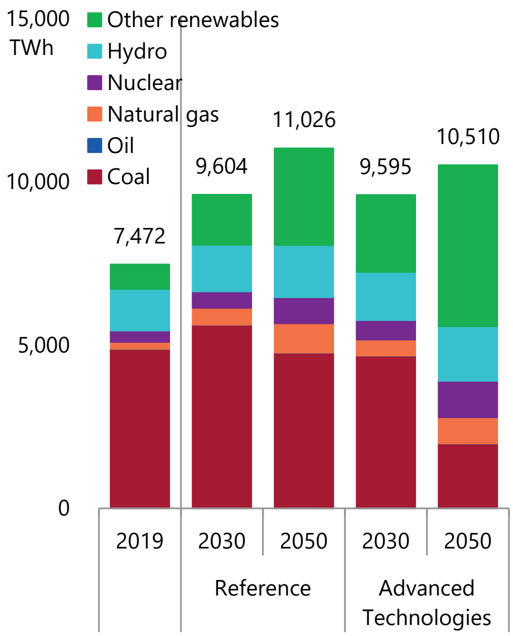
Coal



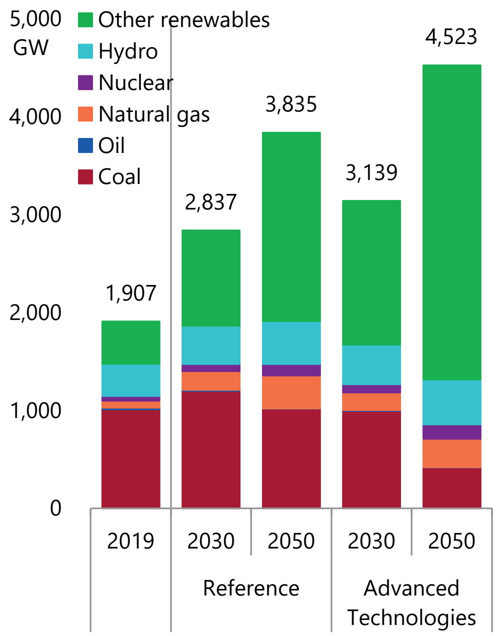
China

Power generation mix

Electricity generated



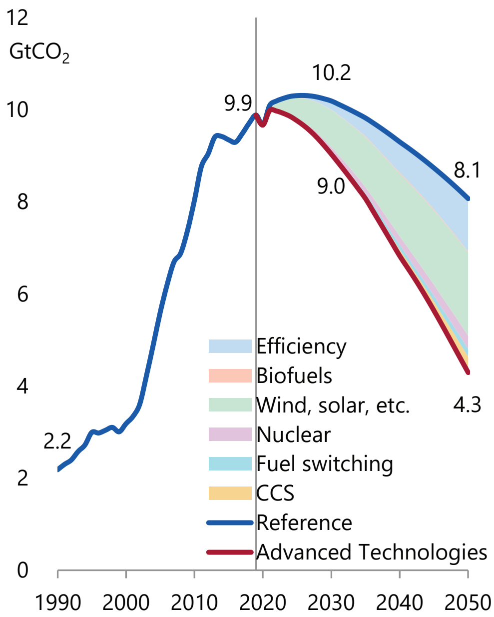
Power generation capacity



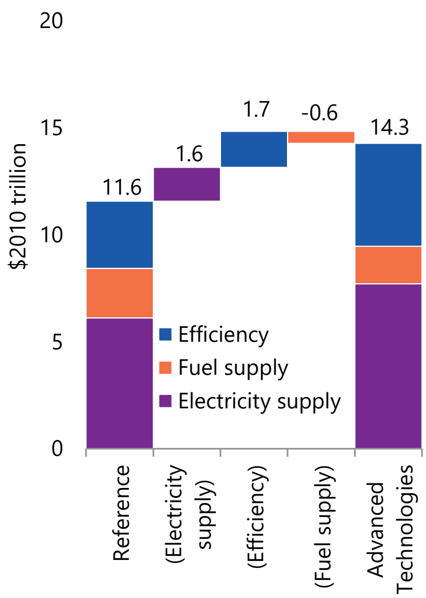
China

Energy-related CO_2 emissions and investments

CO_2 emissions



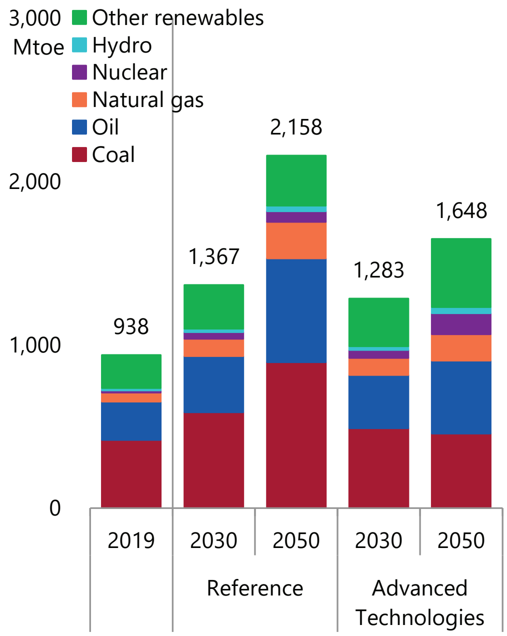
Investments
(2021 – 2050)



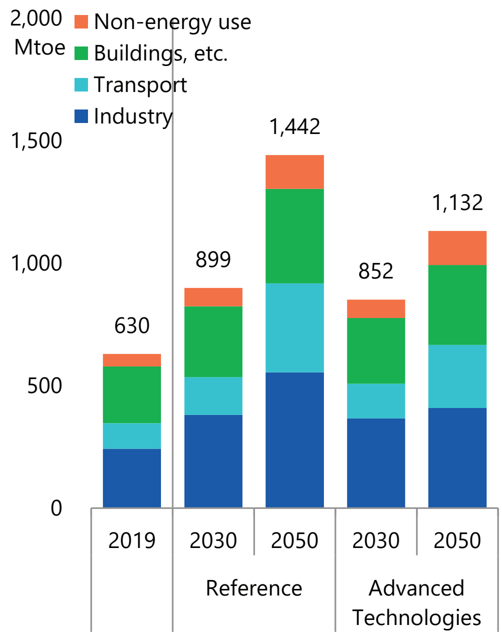
India

Energy consumption

Primary energy consumption



Final energy consumption



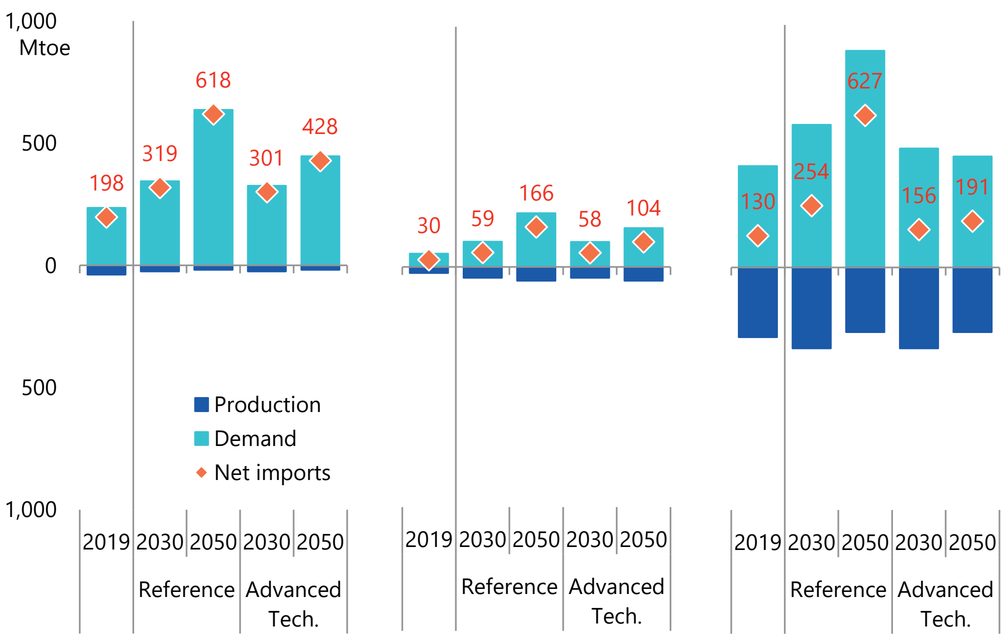
India

Supply and demand balance of fossil fuels

Oil

Natural gas

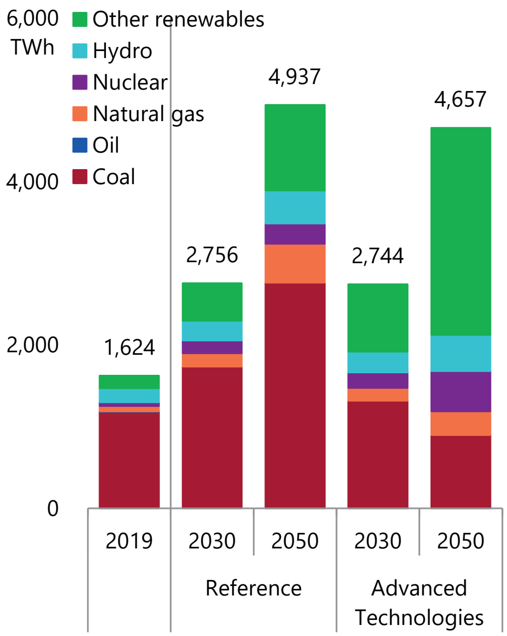
Coal



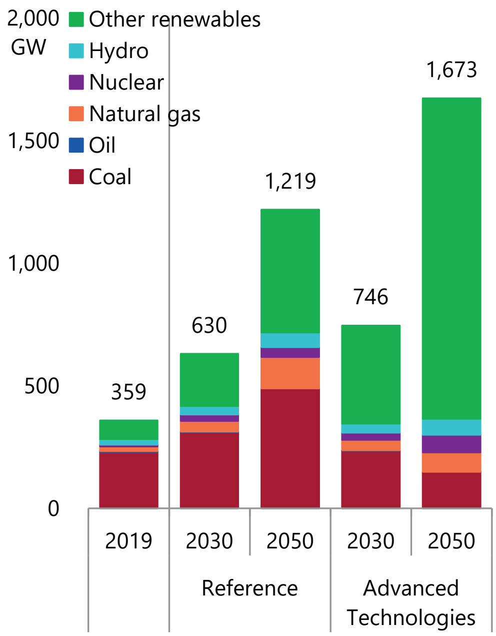
India

Power generation mix

Electricity generated



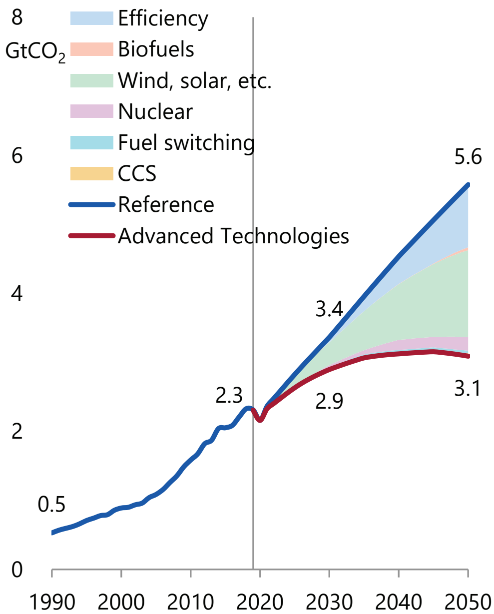
Power generation capacity



India

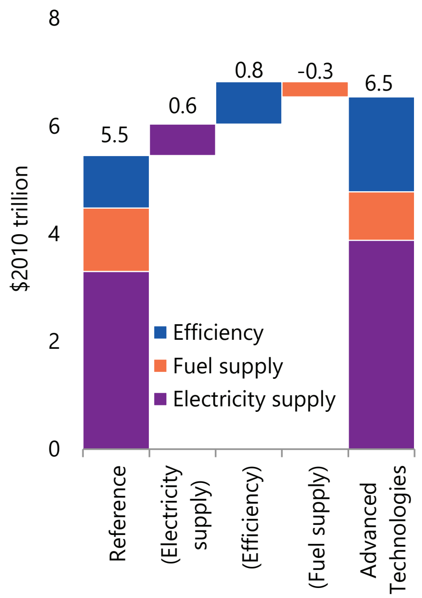
Energy-related CO_2 emissions and investments

CO_2 emissions



Investments

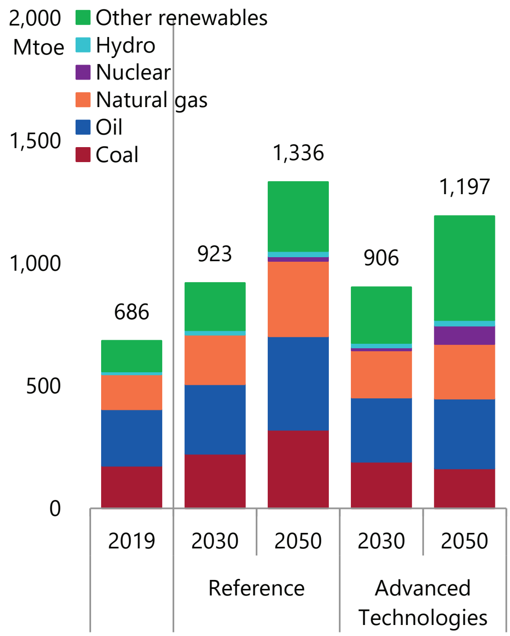
(2021 – 2050)



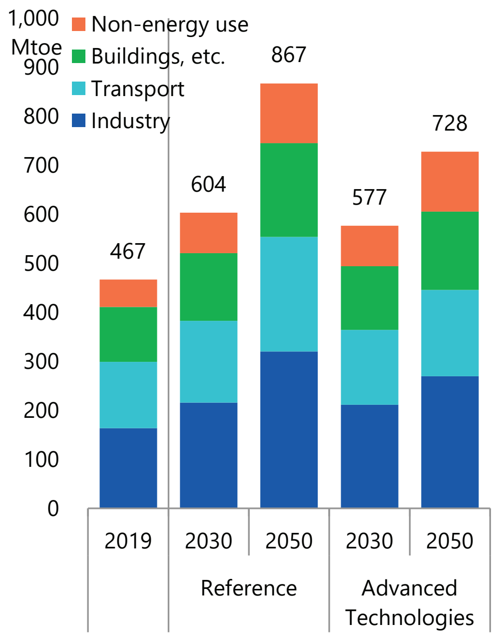
ASEAN

Energy consumption

Primary energy consumption



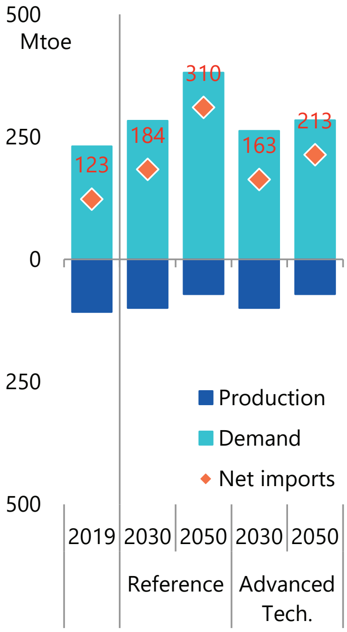
Final energy consumption



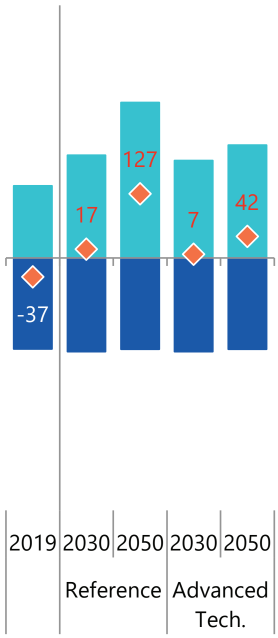
ASEAN

Supply and demand balance of fossil fuels

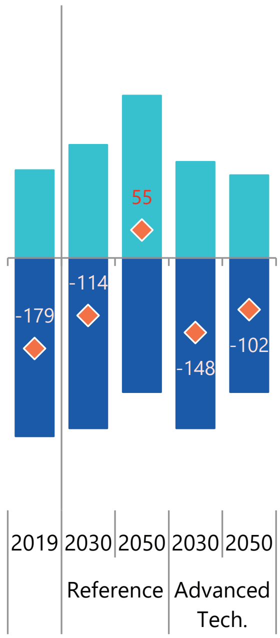
Oil



Natural gas

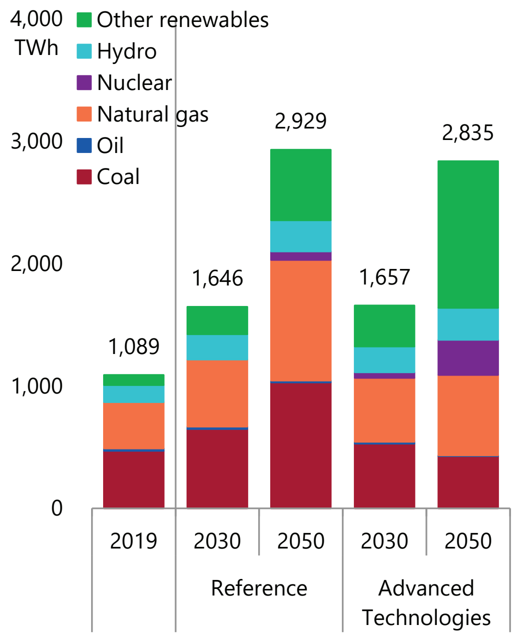


Coal

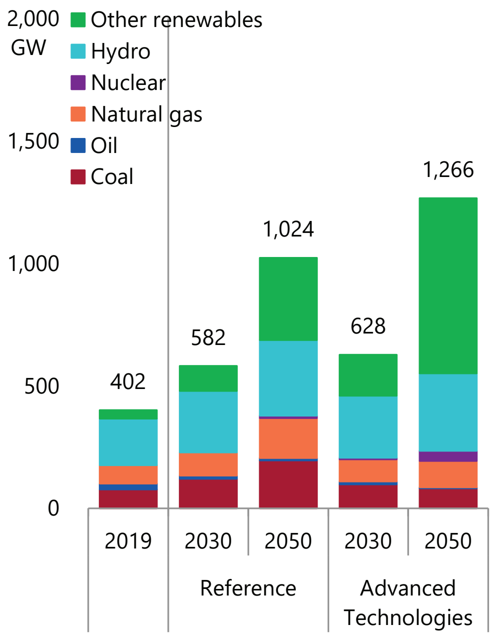


Power generation mix

Electricity generated

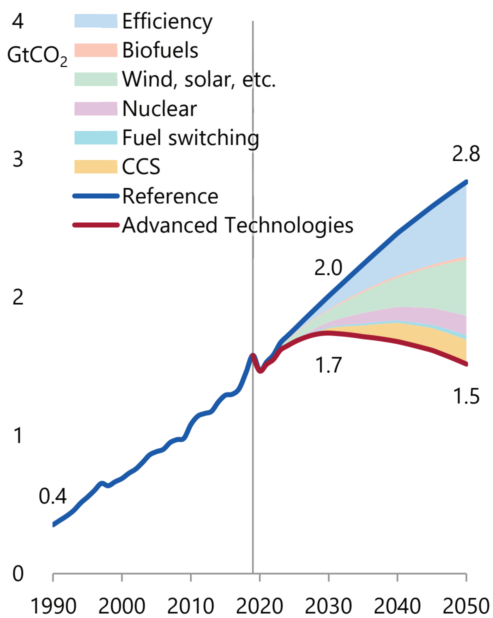


Power generation capacity

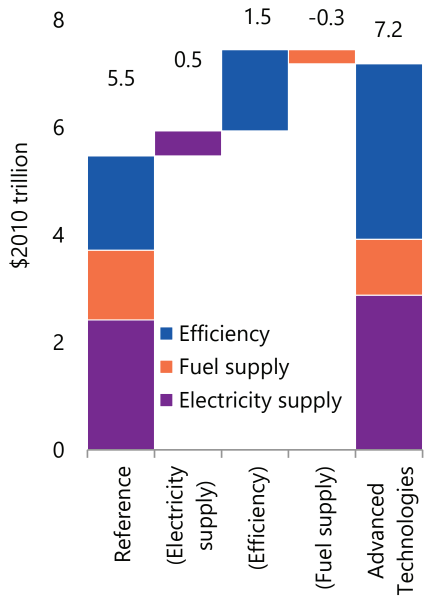


Energy-related CO_2 emissions and investments

CO_2 emissions



Investments
(2021 – 2050)



The tables for IEEJ Outlook 2022 are currently available at https://eneken.ieej.or.jp/en/whatsnew/439.html.

The full text will be available early 2022 at the same URL.

IEEJ Outlook 2022

October 2021

The Institute of Energy Economics, Japan

Contact: report@tky.ieej.or.jp