IEEJ Outlook 2023

Energy, Environment and Economy

Challenges for achieving both energy security and carbon neutrality

Overview

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Executive summary

Global energy supply and demand outlook (Reference Scenario)

Energy consumption will continue to increase despite energy efficiency that will improve to address climate change and energy security

- Under the Reference Scenario, and from the perspective of climate change and energy security, the rate at which the world's energy intensity per unit of gross domestic product (GDP) will decline is faster than in the past. However, as the macroeconomy expands beyond the rate of decline, global energy consumption in 2050 will increase by 1.3 times from 2020 to 17 649 million tonnes of oil equivalent (Mtoe). The Reference Scenario incorporates past trends and the expected effects of the extension of energy and environmental policies and technologies to date.
- The lack of upstream investment and the Russian invasion of Ukraine have raised concerns about a stable and sufficient supply of fossil fuels to meet the overall consumption which will continue to increase at an annual rate of 0.8%. The use of natural gas will grow at an annual rate of 1.3%, mainly to supply the power generation sector and will approach oil which is the largest energy source. Oil will expand at an annual rate of 0.7%, increasing mainly in the aviation, shipping, and petrochemical feedstocks sectors. Against the backdrop of air pollution and climate change, coal will peak around 2030 and begin to decline, falling below 2020 levels in 2050.
- Expectations for more non-fossil energy are growing as many countries aim to become carbon neutral. Solar photovoltaics, wind, and others will see the largest growth, increasing 3.9 times in 2050 compared to 2020. However, the share of non-fossil energy in total primary energy consumption will increase only slightly, from 20% in 2020 to 23% in 2050.
- Consumption in China, which had until recently driven the global demand growth, will peak around 2030 before turning downward while demand in India, the Middle East and North Africa, and the Association of Southeast Asian Nations (ASEAN) will continue to increase. India's consumption will surpass that of the United States and ASEAN's will surpass that of the European Union in the 2040s, making Emerging Market and Developing Economies in the energy and environmental fields all the more important.

Middle Eastern oil producers take advantage of their low production costs to lead crude oil supply. Russia is suffering from a severe shortage of upstream investment due to embargoes and sanctions, and its rate of decline is accelerating.

- In the medium-term, until 2030, the Organization of the Petroleum Exporting Countries (OPEC) and non-OPEC will both increase crude oil production. However, in Europe and Eurasia, where oil production was expected to decline over the medium to long term even before the Ukrainian war, the impact of Western countries' embargoes and sanctions will deepen Russia's lack of upstream investment and accelerate the pace of decline. Production in North America, led by the United States which increased output dramatically in the 2010s, will peak around 2030.

- From 2030, OPEC, especially the Middle East OPEC members with their abundant oil reserves and cheap production costs, will become increasingly prominent despite increases in production from Latin America. The share of OPEC crude oil in the global oil supply will rise from 34% in 2020 to 44% in 2050.
- Total world crude oil trade will increase as a result of rising oil demand. Imports will fall in Organisation for Economic Co-operation and Development (OECD) countries, where demand will decline, but imports from non-OECD countries will increase at a faster pace. Asia's dependence on imports will continue to rise, and while inflows from the Americas will increase, the Middle East will remain the largest supplier. Non-OECD Europe/Central Asia, especially Russia, will see an accelerated decline in exports to Europe and become more dependent on the Chinese market.

The LNG market is expanding due to abundant supply potential, but the outlook is uncertain

- The United States, the world's largest producer and consumer of natural gas, will continue to increase its production of natural gas, especially shale gas. Until about 2030, production will increase at an annual rate of about 1% and then stabilise.
- Australia, which slightly surpassed Qatar as the world's largest exporter of liquefied natural gas (LNG) in 2020, will experience steady growth in production. The increase is in part due to projects centring on the provision of complementary gas to existing LNG production facilities. The increase will moderate after 2030.
- In the Russian Arctic, construction is progressing for a second major LNG export project which had reached the investment decisions. However, the future of this project is uncertain due to the Russian invasion of Ukraine in February 2022.

Achieving decarbonisation is, realistically, a long-term commitment

- Decarbonisation has accelerated faster in Advanced Economies such as the United States and Europe. Emerging Market and Developing Economies have announced their intention to become carbon neutral, despite a long run coal demand that will expand in Asia, including India and ASEAN excluding China, and Africa. Global coal production will increase until the early 2030s in response to demand but after that, it will start to decline; the downward trend will intensify in the 2040s.
- Steam coal production will increase from 5 950 Mt in 2020 to 6 537 Mt in 2040 mainly due to increased demand for power generation. It then begins to slowly decline, reaching 6 311 Mt in 2050. Production of coking coal, used mainly as a raw material for steel production, will gradually decline from 1 014 Mt in 2020 to 824 Mt in 2050.

Electricity generation is expanding rapidly in Asia. Natural gas-fired power generation is the biggest source of electricity

- Global electricity generation will grow at an annual rate of 1.8%, rising to 45 777 TWh in 2050, 1.7 times higher than in 2020. 95% of that increase comes from Emerging Market and Developing Economies. Continuing its rapid economic growth, electricity generation in Asia will increase at an annual rate of 2.1% to reach 23 313 TWh in 2050, roughly half of the world's requirements.
- Although coal has the largest current share of the global power generation mix, natural gas will be the largest source of electricity in 2050. With a continuing upward trend in electricity demand in both Advanced Economies and Emerging Market and Developing Economies, ensuring a stable supply of natural gas remains an urgent and a long-term issue.
- In Advanced Economies, renewable energy will overtake natural gas as the largest source of electricity in the first half of the 2020s due to its rapid adoption. Of these, solar photovoltaic and wind, which have output variability, will account for 25% of the electricity generated in 2050. Measures to deal with these output fluctuations and the expansion of the network connecting the sites suitable for power generation and the location of demand will be issues.
- In Emerging Market and Developing Economies, renewable energy, especially wind, will continue to increase and replace coal as the largest power source in 2050. However, the role of coal-fired power generation in supporting the robust demand for electricity is no small matter, and it is necessary to develop a highly predictable investment environment and address environmental issues, such as air pollution.
- The role of nuclear is being recognised anew in Japan, Europe, and other countries from the perspectives of climate change countermeasures and ensuring energy security, especially after Russia invaded Ukraine. However, although new construction starts are underway, mainly in Asia, nuclear will not grow faster than the rate of increase in electricity demand through 2050, reducing its share of the power generation mix to 7%.

Advanced Technologies Scenario

Even under the Advanced Technologies Scenario, reaching global carbon neutrality by 2050 is far from being achieved. Further promotion of energy efficiency and climate change measures will require the full mobilisation of all means possible.

- The "Advanced Technologies Scenario" anticipates maximum carbon dioxide (CO_2) emission reduction measures based on the application opportunities and acceptability in society, including the full-scale introduction of newly factored hydrogen, and enhanced energy security measures. It should be noted that this outlook is a forecast-type of exercise that projects in the future based on the premise of the introduction of technology, etc. It contrasts with a backcast-type analysis that defines a future "landing point" and charts a possible path to reach it. Global final energy consumption under the Advanced

Technologies Scenario will be reduced by 5.2% in 2030 and 23.5% in 2050 compared to the Reference Scenario.

- Primary energy consumption will decline by 4.4% relative to the Reference Scenario in 2030 but will increase relative to 2020. After 2030, the reduction will accelerate as energy efficiency continues to improve. The reduction from the Reference Scenario in 2050 will only reach 18.5%, which is less than that of final energy consumption of 23.5%. This is due to the increased use of electricity and hydrogen, which have energy transformation losses.

- Fuel switching will also advance, reducing fossil fuel primary energy consumption by 1.1 Gtoe relative to the Reference Scenario in 2030 and 5.1 Gtoe in 2050. Despite a substantial growth in non-fossil energy of 0.4 Gtoe in 2030 and 1.8 Gtoe in 2050, the world cannot continue to maintain and improve its economy, society, and livelihoods without fossil fuels, even in the Advanced Technologies Scenario.

- Energy-related CO_2 emissions will be 31.2 Gt in 2030 (down 1.4% from 2020) and 16.9 Gt in 2050 (down 46.5%). In this scenario, CO_2 emissions would significantly reduce to levels equivalent to the *Announced Pledges Scenario* of the International Energy Agency (IEA) released in its "World Energy Outlook 2021". Consequently, such scenario is still far from a worldwide "Net Zero" emissions. The reduction from the Reference Scenario will amount to 20.1 Gt in 2050, of which China and India accounted for 38.1%.

- One of China's 2030 targets for Nationally Determined Contribution is to reduce CO_2 emissions intensity per GDP by more than 65% from 2005 levels, which is roughly equivalent to the Reference Scenario results. India's target of a 45% reduction in intensity, in its 2022 update, is roughly equivalent to results in the Advanced Technologies Scenario. On the other hand, the set targets to reduce emissions by the United States (50% to 52% reduction from 2005 levels), the European Union (55% reduction from 1990 levels), and Japan (45% reduction from 2013 levels), will fall short of the Advanced Technologies Scenario results.

- As expected, the Advanced Technologies Scenario requires less investment in fossil fuels than in the Reference Scenario, but further low-carbon investment in renewable energy and energy efficient equipment is required. The investment required in the 2040s, under the Advanced Technologies Scenario, is $35 trillion (at 2015 prices), $20 trillion more than in the 2010s, or an increase of $6 trillion from the Reference Scenario in the 2040s. The cumulative global energy investment requirement by 2050 will reach $88 trillion, or an average of $2.9 trillion per year.

Energy security strategy to address the Ukraine crisis and the energy transition

- A growing number of Asian countries are declaring themselves as also aiming at carbon neutrality. In addition to building a new energy infrastructure, free of carbon emissions, the world must focus on big problems that cannot be solved easily in the limited time we have (between 30 and 40 years). The problems include the mass disposal of existing equipment and job displacement, due to reworking the energy system. There is also a great deal of uncertainty surrounding the specific means of realisation.

- Asia faces a variety of challenges stemming from energy security. In emerging and developing Asia, where high economic growth is expected, it is essential to provide stably and inexpensively a large amount of energy. Considering the current trend toward a return to coal due to soaring energy prices, the amount of renewable energy available and their integrating costs, the transition from coal to natural gas is the realistic path forward. In doing so, the first phase of switching from coal to natural gas will involve increasing supply investments outside Russia while presenting a practical solution to the supply and cost problem. In the second phase, decarbonisation will be achieved by adding various measures, including the use of renewable energy and decarbonised natural gas.

- The so-called "4R technologies" is a tool to realise the decarbonisation of fossil fuels. Among them are the use of blue hydrogen produced by capturing CO_2 generated during manufacturing, the introduction of carbon capture and storage (CCS) technology in manufacturing plants and power plants, and carbon recycling technology that uses the captured CO_2 for other purposes.

Response to strengthening stable power supply and importance of nuclear power generation

- Under electricity deregulation, power generation facilities that are used infrequently in the market – with fewer generating opportunities – will be suspended and decommissioned. The introduction of renewables power generation has been expanded based on government support measures and in part caused the suspension and abolition of thermal power generation in many developed countries due to the decline in operating rates and the deterioration of profitability. As a result, the remaining power supply capacity of the entire electricity system declined. With a sudden surge in demand for electricity triggered by extreme heat or severe winter, combined with output declines and outages of power generation facilities (also caused by heat and cold waves), there are situations in which the balance between supply and demand becomes tight.

- Until now, the assessment of a stable supply of electricity has been to evaluate the possibility of a shortage of generating capacity (kW shortage) in response to increased demand. As decarbonisation policies proceed in the future, it is expected that dependence on a small number of power sources will increase. Another major issue is how to assess the risk of a shortfall in the amount of electricity generated (kWh shortage) when facing unforeseen events in a power source that the system heavily depends on.

- In a climate dominated by low-carbon arguments, the sharp rise in global fossil fuel prices since around 2021 and the Russian invasion of Ukraine in February 2022 put greater emphasis on securing a stable supply of energy. The role of nuclear in energy security is once more being recognised in Japan, Europe and elsewhere. The importance of its utilisation as a stable large-scale baseload power source under fossil fuel-fired power generation constraints has been highlighted anew.

- France and other countries announced ambitious nuclear targets while analysing the best mix with renewables. Plans to build new nuclear power plants are also underway in the United Kingdom and Eastern European countries. Expanding the operation of existing nuclear power plants and restarting them in Japan attract global interest. Attention is being paid to initiatives such as the introduction of a Regulated Asset Base (RAB) model, which is under consideration in the United Kingdom and can be considered as providing regulated returns to secure new investment in nuclear that will simultaneously achieve decarbonisation and stable supply.
- Nuclear is considered important from the standpoint of energy security, but it is also important for companies and countries in which nuclear is developed. A series of new projects by Western companies have faced delays in construction times and higher costs that far exceeded their original estimates. In one instance, it was pointed out that the company lost its construction know-how and was forced to change its design after construction began, due to regulatory requirements.

Critical mineral issues and energy, and economic security

- To achieve carbon neutrality, a massive adoption of renewable energy, electric vehicles, hydrogen and other low-carbon technologies is necessary. A new energy security challenge is emerging, caused by tight supply and demand for rare minerals (critical minerals), which are considered essential for these technologies. Like for fossil fuels, these resources are unevenly distributed around the globe.
- In the Advanced Technologies Scenario, the supply and demand for lithium, cobalt, neodymium, and dysprosium will be tight by the mid-2030s, mainly due to the increased penetration of electric vehicles. For nickel and cobalt, there are concerns that the cumulative demand by 2050 will exceed the sum of the total recycled supply and the resource reserves to cover long-term demand.
- Resources are concentrated in Chile, Argentina, Australia, and China for lithium, Indonesia and the Philippines for nickel, the Democratic Republic of Congo for cobalt, and China for the rare earth's neodymium and dysprosium.
- There are short-term and long-term perspectives on energy security. Unlike "flow-type" commodities such as oil and natural gas, which can face a significant impact in the event of a sudden supply disruption caused by some disturbance, "stock-type" materials are more resistant to short-term risks because even if a supply disruption occurs, the portion already imported can be incorporated into renewable energy facilities to provide energy. On the other hand, from a long-term perspective, it will be difficult to achieve carbon neutrality based on renewable energy, electric vehicles, hydrogen, etc., unless measures are prepared in advance to address the tightening of global supply and demand and uneven distribution of resources for critical minerals. While it will be essential to increase production at existing mines and promote the development of new mines for those types of ore that are feared to be in short supply, there are concerns that resource development

and export controls will be tightened in supplier countries in the future. Therefore, it goes without saying that demand countries are required to not only strengthen resource diplomacy aimed at securing interests, but they are also required to reduce import dependency and increase recycling rates to diversify sources of procurement, and to promote the development of technologies for non-use and reduced usage, as well as alternative technologies.

- On the other hand, supplier policies and the prospects for developing recycling, shifting and alternative technologies all involve uncertainty. Therefore, from the perspective of energy and economic security, consideration should also be given to balanced technology choices aimed at avoiding excessive reliance on specific carbon-neutral technologies[1].

Economic impact of green investment

- When investments in climate change measures create a virtuous cycle of emissions reductions and economic growth, it is called "Green growth". The results, however, may not be realised or they may appear differently in different economies and entities. It could create new disparities – (1) among developed economies and emerging/developing economies, (2) between developed and emerging/developing economies, (3) between economies that rely on fossil fuel exports and those that do not, and (4) within the population and citizens of the same economies.
- The cumulative additional green investment and consumption to realise the Advanced Technologies Scenario amounts to $14 trillion (at 2015 prices). If this green investment and consumption were carried out in a "No Financial Constrained" situation where the total amount of funds available could be increased at will, the GDP in 2050 would increase by $20 trillion (11.2%, an annual average of 0.4%). On the other hand, under a "Financial Constrained" situation in which the total amount of funds cannot be changed due to limited economic and financing capacity, GDP would be reduced by $6.2 trillion (3.5%, an annual average of 0.1%). "Financial constrained" means that incremental green investments will be offset by declines in investment and consumption in other areas.
- Under the No Financial Constrained Case, GDP and output would increase in many economies, but would decrease in economies such as those in the Middle East and the former Soviet Union that are highly dependent on mining (fossil fuels). In the Financial Constrained Case, GDP and output will decrease in many economies. However, in some developed countries and China, the decrease in the value of energy imports due to green investment and consumption is significant and GDP and output will increase, outweighing the decrease in investment in other sectors due to financial constraints.
- Investment is a new demand and a source of growth. However, if other investments are reduced in proportion to new investments in a situation of financial constraints and

[1] With the permission of the Japan Oil, Gas and Metals National Corporation (JOGMEC), this article presents a part of the results of its commissioned study, "Survey of Mineral Resource Supply and Demand to Achieve Carbon Neutrality" (FY2022), and details of the results will be reported at a seminar scheduled to be held by JOGMEC on 10 November 2022.

budget constraints, no new demand is created as a total amount. In addition, green investment is unlikely to be a source of growth because it is not itself an investment to expand production capacity. Relaxing financial constraints and providing sufficient funds are the key to achieving green growth.

- For smooth financing, it is necessary to use not only government budgets but also green finance, which is mainly funded by the private sector. It is important to clarify the direction of the environmental policies to limit risks and encourage investment. How to limit negative economic impacts and how to even out the different impacts between economies and industries is important.

The 442nd Forum on Research Work

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Global Energy Supply and Demand Outlook by 2050

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What is IEEJ Outlook 2023?

- Quantify the global energy supply and demand structure up to 2050
- Forecast-based outlook using econometric models and other tools
  The forecast type is a method of looking ahead to the future with various assumptions, starting from the present. On the other hand, the backcast type is a method of thinking about how to take measures from the present, setting goals for the future.
- Conduct scenario analyses of technological and policy developments and trends

Reference Scenario

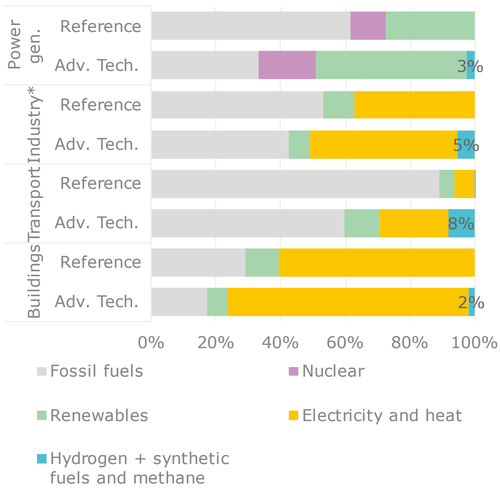
A scenario in which the prevailing changes will continue against the backdrop of current energy and environmental policies

Advanced Technologies Scenario

A scenario in which energy and environmental technologies are introduced to the maximum extent possible to ensure a stable supply of energy and strengthen measures against climate change

A part of last year's "Circular Carbon Economy/4Rs Scenario" is reflected.
- Hydrogen-fired power generation, hydrogen direct combustion, hydrogen reduction ironmaking, fuel cell vehicles, and synthetic fuel and synthetic methane technologies are assumed.
- Supply limited to blue hydrogen or green hydrogen.

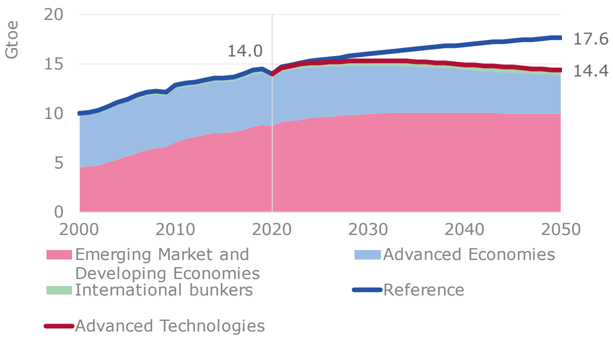
Energy consumption composition (2050)



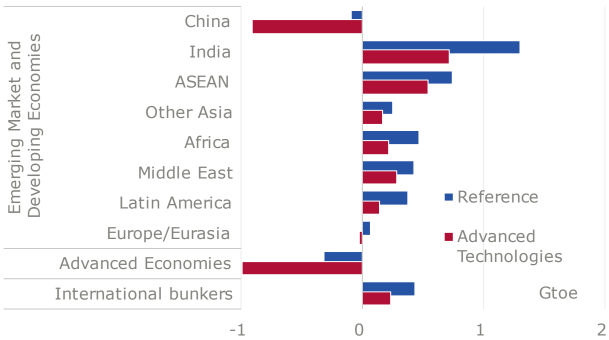
* Includes the steel blast furnace sector

Increase in energy demand centring on India and ASEAN

Primary energy demand outlook



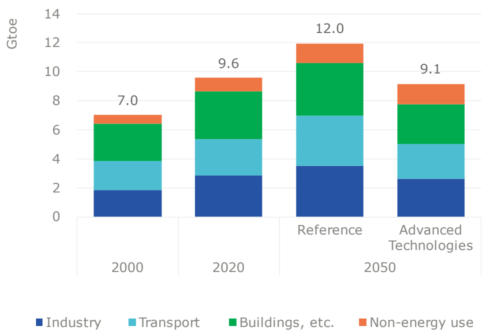
Changes in primary energy demand (2020-2050)



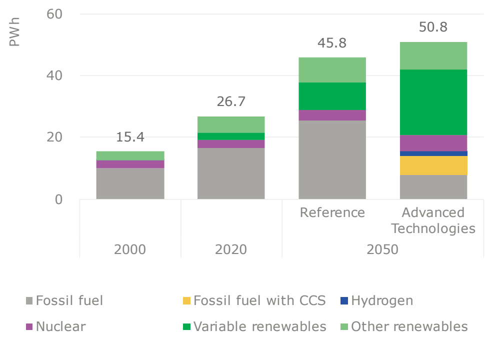
- (Reference) Primary energy demand will continue to grow, increasing 1.3-fold in 2050.
- (Advanced Technologies) After peaking in the early 2030s, it will gradually decrease. Emerging Market and Developing Economies remain largely unchanged after the 2030s.
- In both scenarios, demand growth is centred on India and ASEAN. China, which has been driving demand growth, will ~~also~~ peak by 2030 in the Reference Scenario.

Significant progress will be made in energy efficiency and low-carbon power generation (Advanced Technologies Scenario)

Final energy consumption outlook



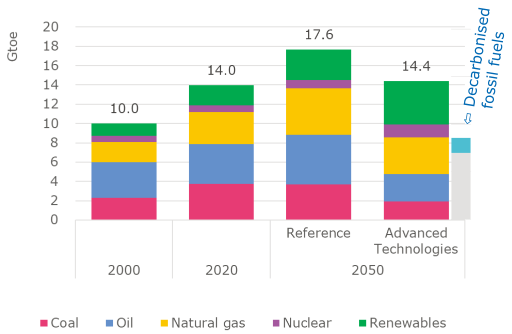
Electricity generated outlook



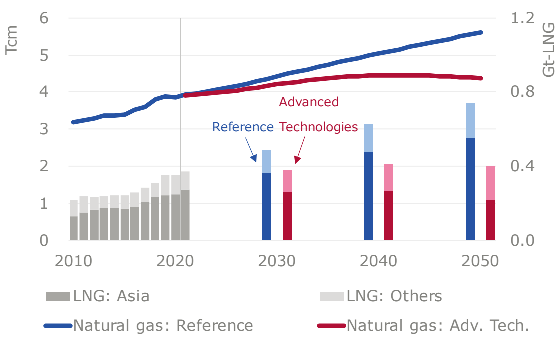
- (Reference) Final consumption increases 1.2-fold. More than 40% of the increase will come from transportation, and more than 60% from electricity.
- (Advanced Technologies) Energy savings of 23% relative to the Reference Scenario. The electrification of consumption is increasing. The share of electricity will rise to 39% (from 20% in 2020).
- Electricity demand will increase significantly in both scenarios. In the Reference Scenario, fossil fuel-fired as well as renewables will meet the increased demand. In the Advanced Technologies Scenario, the share of renewables will rise to 60%. The zero-emission power source, including thermal with CCS, exceeds 80%.

Dependence on fossil fuels continues

Primary energy demand outlook



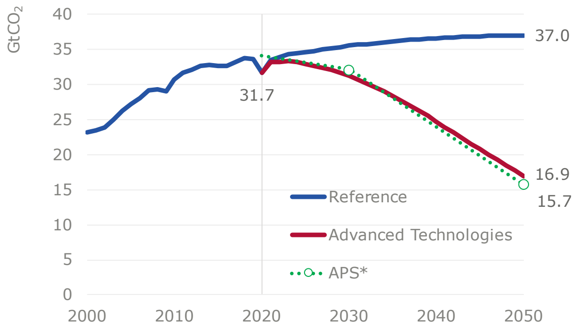
Natural gas and LNG demand outlook



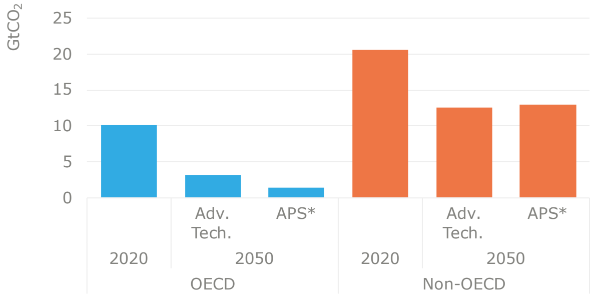
- (Reference) Oil will continue to increase slightly, natural gas will increase 1.5 times, and coal will decline after peaking around 2030. Demand for natural gas, mainly for power generation, grows, while LNG demand doubles. Asian demand, in particular, will be the driving force.
- (Advanced Technologies) Oil and coal will decline in the 2020s, while natural gas will be the only fossil fuel to grow more than it is today. LNG demand remains around 400 million tonnes. Nuclear and renewables will each double, but the share of non-fossil fuels as of 2050 is around 40%. However, about 20% of fossil fuels are decarbonised (by CCS).

Emerging Market and Developing Economies key to achieving carbon neutrality

Energy-related CO_2 emissions outlook



CO_2 emissions outlook by region



- Energy-related CO_2 emissions under the Reference Scenario continue to increase. On the other hand, under the Advanced Technologies Scenario, it will peak in the first half of the 2020s and decrease to 17 $GtCO_2$ by 2050. It would be on a par with the APS*, which incorporates countries' carbon neutral declarations.
- In both the Advanced Technologies Scenario and the APS*, overall non-OECD emissions are only about 40% lower. Reducing emissions in developing countries is key to achieving global carbon neutrality. It will also be necessary to keep an eye on whether developed countries can follow through on the declaration.

*APS: Announced Pledges Scenario (updated), estimates when countries' stated policy goals are realised. Includes industrial processes. IEEJ estimates from IEA "World Energy Outlook 2021" (October 2021) and "Technical note on the emissions and temperature implications of COP 26 pledges" (November 2021).

Conclusion

- Energy demand in China, which has been until recently driving global demand growth, will peak and decline by around 2030. Instead, India and ASEAN will be the focus of increased demand.
- Electricity demand will increase significantly in both the status quo world (Reference Scenario) and the decarbonising world (Advanced Technologies Scenario). Stable power supply and security will become more important in the future.
- Dependence on fossil fuels will continue. Fossil fuels accounts for 80% in 2050 under the Reference Scenario and 60% in the Advanced Technologies Scenario (about 20% of which is decarbonised). Stable supply of fossil fuels remains a key issue.
- Even the Advanced Technologies Scenario is far from achieving global carbon neutrality in 2050. In particular, further promotion of energy conservation and decarbonisation in developing countries will be key to the progress of global decarbonisation.

Challenges and Response Strategies for Energy Security Under the New Reality

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A new reality

- In recent years, climate change has been at the centre of energy and climate policy debates.
- But over the past year or so, the energy security crisis has never been greater.
  - Energy prices in Europe have soared since the middle of 2021 due to weather conditions (low temperatures in Spring 2021, prolonged wind deterioration) and unforeseen factors, such as a decline in natural gas supply due to breakdowns.
  - Russia invaded Ukraine in February 2022. Subsequently, Western countries decided to impose a (gradual) embargo on Russian energy. Russia responded by using its own energy exports as a weapon (Reduce export volume, take over assets).
  - Shortage of physical energy supply, especially natural gas, is a real threat.
  - International prices for all kinds of fossil fuels are at historic highs, in part because of the escalating geopolitical risks of conflict with no way out.
  - In some developing countries, soaring prices of imported energy have strained their finances and hindered fuel procurement.
- Energy security is the foundation of people's lives and all economic activities, and in the short term at least, securing energy supplies has become a top priority.
- However, there is no time to wait for action on climate change, and ***the question is how to reconcile energy security and climate action***.

Key points of this report

1. Energy security strategy in view of war in Ukraine and energy transition

- ✓ Japan needs to prepare for unforeseen circumstances while continuing to seek to maintain its procurement of Russian LNG. To avoid a "scramble under a zero-sum game", it is necessary to reacknowledge the role of LNG and the importance of upstream investment, and to take concrete steps to expand supply.
- ✓ In Asia, decarbonisation, which follows the process of first shifting from coal to natural gas, is considered a realistic path considering the amount of renewable energy available and the economics considering integration costs. If the promotion of natural gas and LNG investment becomes a reality, it will help stabilise markets and avoid the negative impact of Asia's energy transition on regional economies.
- ✓ Blue hydrogen and ammonia will play a major role in the decarbonisation of fossil fuels, but the high price of natural gas makes them uncompetitive. Therefore, it is necessary to stabilise the natural gas market to ensure the introduction of blue hydrogen and ammonia.

2. Strengthening stable power supply and importance of nuclear power generation

- ✓ In advanced countries, lopsided power generation mix and reduced supply capacity have increased vulnerability to risks such as heat waves, cold waves and earthquakes. The shortage of kWh caused by fuel shortages due to fuel price hikes and fuel supplier risk has also become a problem. Securing a stable supply has become an issue.
- ✓ With the growing importance of energy security, the role of nuclear power generation is being reviewed and new plans are being developed. Construction by China and Russia is currently dominant in the global market. Western companies are urged to apply the lessons learned from current projects.

3. Critical mineral issues in energy and economic security

- ✓ The supply and demand for critical minerals such as lithium may become tight as the introduction of electric vehicles, renewable energy and storage batteries increases. A multifaceted response is required to develop new mines, strengthen resource diplomacy, promote recycling, and develop technologies for non-use and reduced usage to ensure a stable supply. In addition, the supply and processing of critical minerals is highly dependent on specific countries, and diversification of the supply chain is also a challenge.

4. Economic impact of green investment

- ✓ In the real world, "green growth" may not be realised depending on the availability of funds and differences in industrial structures. How to limit negative economic impacts and how to even out the different impacts between economies and industries is important.

Structure of this report

1. Energy security strategy in view of war in Ukraine and energy transition

2. Strengthening stable power supply and importance of nuclear power generation

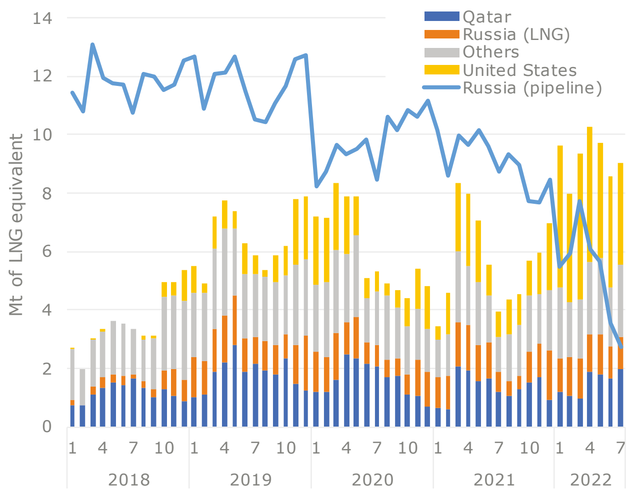
3. Critical mineral issues in energy and economic security

4. Economic impact of green investment

1.1 The challenges of response strategies toward ending dependence on Russian natural gas

- The European Union's policy of ending dependence on Russia is different from Japan's.
  - ✓ EU countries were highly dependent on Russian natural gas, but Japan's introduction of Russian LNG was more about source diversification.
- The EU is set to end its dependence on Russia by 2027, but it must ensure stable supplies until the time.
  - ✓ In the short term, they are exposed to Russia's threat amid uncertainty about securing alternative supplies.
  - ✓ This has led to a tightening of the global LNG market.
- For Japan, it is desirable to continue to secure Sakhalin 2 LNG both in terms of equity participation and supply.
  - ✓ Meanwhile, urgently needed to prepare for unexpected loss of equity participation and supply.

LNG and Russian Pipeline Gas Supplies to EU and UK



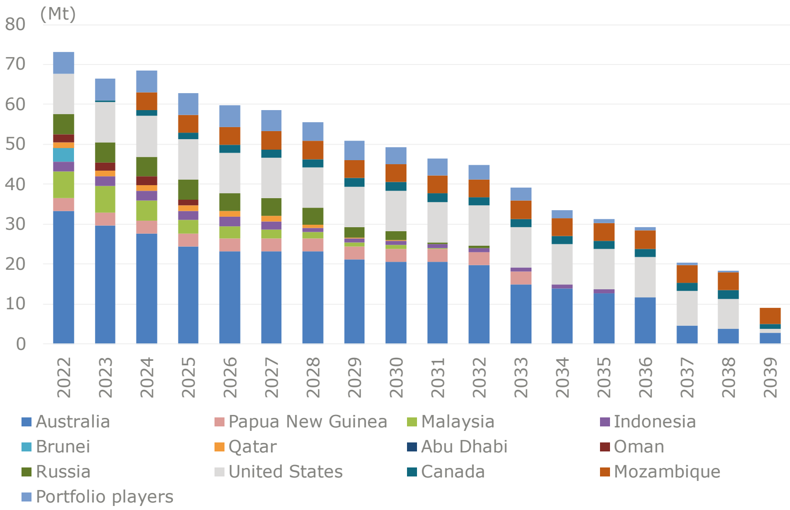
Source: Compiled from Cedigaz LNG Services, Eurostat, British trade statistics, and Gazprom

1.1 The challenges of response strategies toward ending dependence on Russian natural gas

[Measures for Japan]

- Until 2025, Japan is expected to secure supplies from other projects and portfolio players.
- From 2026 onward, it is vital to secure long-term LNG contracts from other sources including new projects, and to ensure investment to support these new projects.
- New development projects in Russia will recede. The path to restoring Russia's future credibility as an investment destination and source of import is even more distant.
- As a way of laying the groundwork for the future, clear message should be advocated that both investment and procurement from the project are legitimate rights under the contract and there is no reason to be threatened by unilateral Russian notification.

Prospect of existing LNG term contracts by Japanese companies



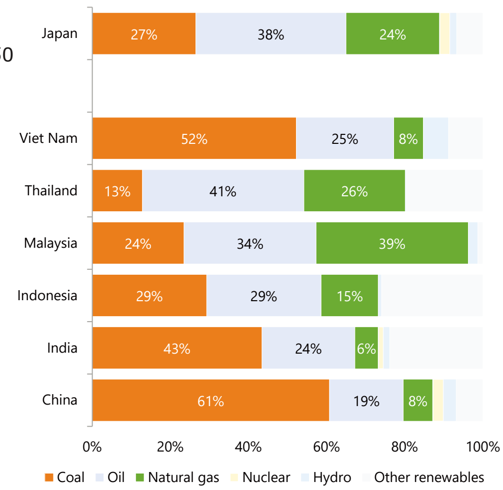
Source: Estimates based on various sources

1.2 The role and challenges of natural gas in Asia's energy transition and energy security

- A growing number of Asian countries have also declared themselves carbon neutral (CN), but the roadmap to achieve this is unclear.

  e.g., China by 2060, India by 2070, Indonesia by 2060, Viet Nam by 2050
- The energy supply and demand structure of Asian countries is highly carbon intensive, and to realise CN, they need to re-structure energy system in the limited time frame of the next three or four decades.
- In addition, developing countries have unique challenges.
  - ✓ Energy demand will inevitably continue increasing in the future, necessitating a stable supply of large amounts of energy.
  - ✓ Cheap energy supplies are essential in light of protecting low-income people as well as industrial development,.
- Challenges exist in Asia's energy transition.
  - Renewable energy lacks strength to supply the fast growing energy demand.
  - Some countries have limited renewable energy availability.
  - There is a strong demand for energy affordability, and the cost of integrating variable renewable energy will become an issue.

Energy mix of major Asian countries



Source: Compiled from IEA "World Energy Balance 2022"

1.2 The role and challenges of natural gas in Asia's energy transition and energy security

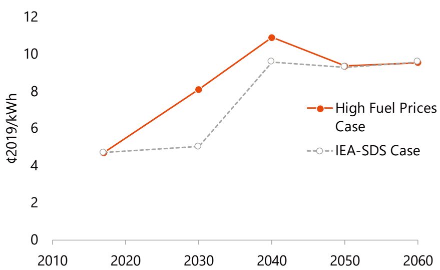
- A two-stage decarbonisation scenario that takes advantage of natural gas (*) could be a realistic solution for Asia, which faces the challenge of energy transition (see previous page). But there are challenges.

  * Can stably supply large amount of energy (high energy density). Can lower GHG emission by switching from coal.

Asian decarbonisation taking advantage of natural gas	Challenges of natural gas
Stage 1: Satisfy energy needs and achieve low carbonisation by switching from coal to natural gas Stage 2: Decarbonisation by commercialising various technologies under development (hydrogen, CCUS) as well as avoiding making natural gas asset stranded.	• The economics of natural gas has declined due to soaring prices. • There is concern that the role of natural gas will diminish as investments in other decarbonised energy increase if the price remains extremely high for an extended period of time.

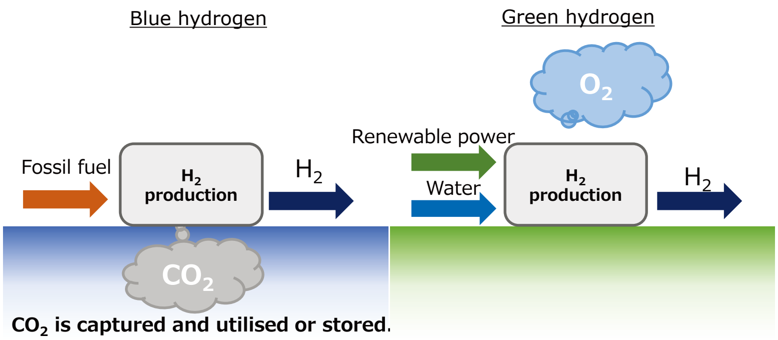
- Asia's energy transition/security will be more costly (right figure) and could weaken Asia's relative economic power against other region if constraints on natural gas investment trigger its high price.
- The promotion of natural gas and LNG investment will not only help to stabilise the markets, but will also contribute to curbing the cost of energy transition/security in Asia and averting negative impacts on the regional economy.
- Therefore, it is necessary to develop an environment for appropriate use of natural gas.
  - Clarify its role as a transition energy
  - Promotion of natural gas-related investment
  - Supporting technology to decarbonise natural gas (CCS, CCUS, hydrogen)

The impact of fossil fuel prices on the marginal cost of electricity in ASEAN



1.3 Importance of stabilising markets to decarbonise fossil fuels (natural gas)

- Blue hydrogen and ammonia play a central role in the decarbonisation of fossil fuels.
  - Blue hydrogen/ammonia is also expected to play a role in shaping the market in the early stages of hydrogen/ammonia introduction (Green hydrogen/ammonia is more difficult to implement early in terms of both quantity and price).
  - The natural gas market needs to be stabilised in order to ensure the introduction of blue hydrogen/ammonia because blue hydrogen/ammonia cannot be competitive to materialise the scenario when natural gas price is high.



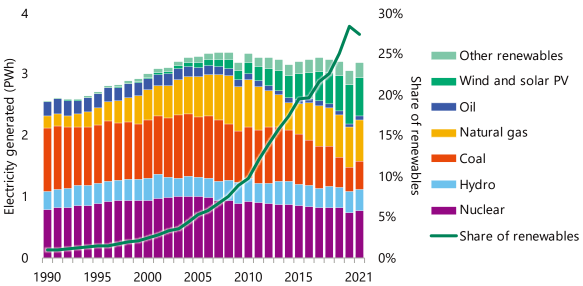
Structure of this report

2.1 The challenges of stable electricity supply under market deregulation, mass introduction of REs and soaring fuel prices

- In advanced economies, the power generation mix has changed significantly throughout the 2010s due to delegulation of electricity market, the promotion of decarbonisation policies, the expansion of renewable power generation, and low primary energy prices through 2020, resulting in a downward trend in conventional power generation capacities. Overall, there is less reserve capacity and greater vulnerability to shocks.
- Electricity supply and demand becomes more vulnerable against external shocks such like heat waves, cold waves, earthquakes, and prolonged bad wind conditions. Examples include tight supply due to summer heat wave at the California ISO from 2020 to 2022, rolling blackout due to cold wave at ERCOT, Texas in February 2021, and tight supply in Tokyo area due to outage of power station due to earthquake combined with cold/heat wave in March/June 2022.

- In advanced economies, increasing number of country/region are introducing capacity markets, which are a mechanism to pay for the availability of supply capacity, to secure investment for new capacities as well as to ensure operation of existing capacities. But even in these countries, there have been cases in which they are fail to secure sufficient supply capacity at a time when demand actually increases.
- Withdrawal of power station for economic reasons is difficult to predict, making long-term reliability assessment difficult thereby investment in new power generation difficult. The United Kingdom is attempting to introduce technologies that can both decarbonise and provide a stable supply through a support mechanism that takes into account the characteristics of each next-generation technology. It is likely that similar policies will prevail among countries and regions.

Electricity generated by source in EU 28



Source: Compiled from IEA "World Energy Balance 2022"

2.1 The challenges of stable electricity supply under market deregulation, mass introduction of REs and soaring fuel prices

- In Europe, where many countries are abolishing coal-fired power generation as a policy in their efforts to decarbonise, wind power generation has become low in output since around the autumn of 2021, and wholesale electricity spot prices have soared due to rising natural gas prices. This, combined with war in Ukraine, has led to a protracted crisis. In addition, during the summer of 2022, a combination of heat waves caused power station to shut down and output to fall, further tightening the reserve capacity. A shortage of natural gas supplies from Russia heading into winter could lead to electricity shortages.
- In China and India, where the share of coal-fired power generation is high, planned power outage due to coal shortages also occurred in 2021 and 2022. In January 2021, wholesale electricity spot prices soared in Japan due to LNG shortages. These are all issues of "kWh shortage" associated with fuel constraints. The conventional kW shortage still needs to be addressed, but in addition, the kWh shortage also needs to be addressed.
- Until now, the adequacy of supply capacity (the possibility of a kW shortage) has been an indicator to assess supply stability. However, on the other hand, quantitative assessment of risk of a kWh shortage, including the risks in the fuel supply countries, is difficult. Quantitative assessment of the kWh shortage risk would be a major issue for future policy response.

2.2 Trends to promote nuclear power under the new reality and future challenges

- Nuclear power generation is promising as a zero-emission baseload power source. In addition, nuclear could play a role by taking advantage of its characteristics as the demand for energy security intensifies.
- In the case of the United Kingdom and France, to reach ambitious policy goal, bold measures are taken that diverge in part from the market deregulation policy. These policy examples may have important implications for Japan.

Examples in United Kingdom

Adhering to the necessity of nuclear

- The Government announced the Energy Security Strategy in early April 2022. The strategy includes an ambitious target for nuclear to cover 25% of electricity supply by installing up to 24 GW by 2050.
  - ✓ Nuclear, which is capable of stable power generation, is considered to have attracted renewed attention because the country is necessary to prepare for the situation in which the output of wind power, which is increasing every year, is not as expected, and it is also necessary to break away from dependence on fossil fuels, including natural gas, in the future.

Supporting measures

- A review of the support mechanism (so called RAB model) is under consideration to promote the investment for new reactors.
  - ✓ The current mechanism (Contract for Difference, CfD) is designed to support only when power station start operation, and it does not sufficiently contain the uncertainty of nuclear project, which requires large investments and long construction period before generate a profit.

Examples in France

Strategies based on a long-term perspective

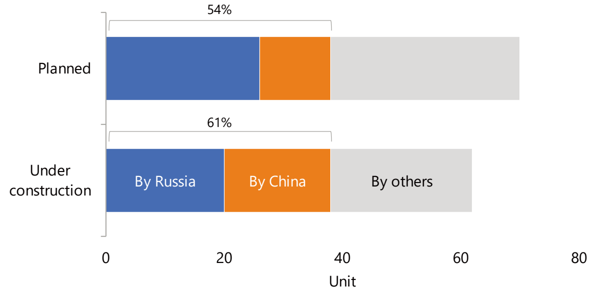
- In February 2022 (before the Russian invasion of Ukraine), President Emmanuel Macron said at least six of the next generation of the European pressurised water reactors (EPR 2) would be built and eight more would be considered.
  - ✓ This strategy is sought to be based on the results of an analysis published in October 2021 by transmission system operator RTE.
  - ✓ Scenario analysis of the long-term power mix. The study resulted to identify that achieving carbon neutrality without new nuclear power capacity is unrealistic, and that the total cost of the electricity system, including integration costs, is cheaper in a scenario where assumes the addition of nuclear capacity.
- Planning and implementation based on the long-term perspective is ideal since decision-making and construction of nuclear power takes a long time.

Strengthening the state-led implementation system

- In July 2022, Prime Minister Élisabeth Borne announced a plan to fully nationalise power giant Électricité de France (EDF) in order to make a strong push for decarbonisation.

2.2 Trends to promote nuclear power under the new reality and future challenges

- China and Russia dominate the world nuclear market (figure), although there is a trend away from dependence on Russia.
  - Finland cancelled its contract to build the Hanhikivi 1
  - Ukraine plans to install nine Westinghouse-built light water reactors.
  - Poland has established partnerships with U.S. and French companies.
  - On the other hand, construction of Russian nuclear reactors is underway in China, India, Turkey, Bangladesh, Hungary, Egypt and other countries.
- Delays and cost overruns have been seen in new development of Western countries in recent decades due to a sharp decline in the number of new projects and the loss of construction know-how.
  - Growing emphasis on energy security alone cannot ensure Western companies to seize business. The key is whether they can take advantage of the lessons learned from current projects.



World's under construction and planned nuclear reactors (As of 1 January 2022)

Source: Compiled from "World Nuclear Power Plants" (2022 edition) of Nuclear Power in the World, published by the Japan Atomic Industrial Forum.

Structure of this report

1. Energy security strategy in view of war in Ukraine and energy transition
2. Strengthening stable power supply and importance of nuclear power generation
3. Critical mineral issues in energy and economic security
4. Economic impact of green investment

Analysis framework

- Analysed supply and demand balance of critical minerals.
  ➔ Comparing supply and demand, and comparing cumulative demand and resource reserves + recycled supply as time series (up to 2050)

Subjected technologies and minerals

- Carbon neutral (CN) technologies: renewable energy, stationary storage batteries, electric vehicles, fuel cell vehicles, water electrolysis, etc. (decreases in mineral demand due to abolish of conventional technologies are also considered. Demand for non-carbon neutral technologies also considered)
- Critical minerals: Copper, lithium, nickel, cobalt, graphite, silicon, dysprosium, neodymium, platinum, palladium, rhodium, and vanadium

Methodology

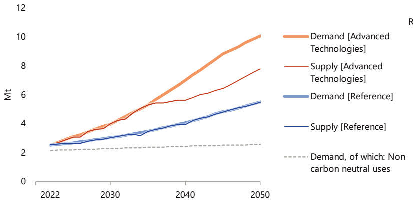
- Demand = Amount of CN technology installed × Mineral resource intensity of technology
  − Conventional technology to be replaced × Mineral resource intensity of technology.
- Supply = Mine production + Recycling supply.
  Production from mine = *f*(mine development stage, production capacity),
  Recycled amount = Waste amount × Product recovery rate × Recycling rate.

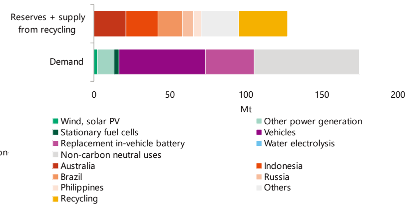
Analysis: example of Nickel and Lithium

Supply-demand outlook | Comparison of cumulative demand and reserves (+ recycled supply)

Nickel (Ni) (used in lithium-ion batteries)

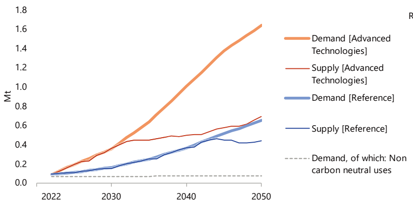
- In the Advanced Technologies Scenario (ATS) in which the electrification of the automobile advances greatly, the demand will increase more than 3 times from current levels by 2050.
- In ATS, demand will exceed supply (mine production + recycling) around 2035.
- Cumulative demand in ATS through 2050 will exceed reserves (+ recycled supply).

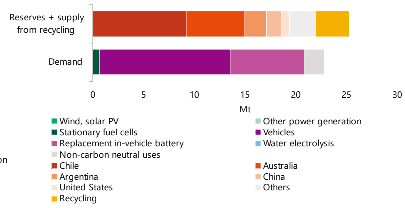




Lithium (Li)

- Demand will grow significantly mainly with the increase in electric vehicles. In ATS, it will increase by more than 10 times from current levels by 2050.
- In ATS, demand will exceed supply (mine production + recycling) around 2030.
- Cumulative demand in ATS through 2050 will be slightly below reserves (+ recycled supply).





Uneven distribution of critical minerals

- Reserves of many critical minerals are unevenly distributed around the globe.
- However, geographical distribution of reserves and downstream processes is often different. For example, Indonesia has the largest share of nickel production, while China has the largest share of primary nickel production after refining.

Country-wise share of reserves

	Cu (copper)	Co (cobalt)	Ni (nickel)	Li (lithium)	V (vanadium)	PGM (platinum group)	REO (rare earth)
United States	5%	1%	0%	3%	0%	1%	2%
Canada	1%	3%	2%	0%	0%	0%	1%
Mexico	6%	0%	0%	0%	0%	0%	0%
Brazil	0%	0%	17%	0%	1%	0%	18%
Peru	9%	0%	0%	0%	0%	0%	0%
Chile	23%	0%	0%	42%	0%	0%	0%
Argentina	0%	0%	0%	10%	0%	0%	0%
Cuba	0%	7%	0%	0%	0%	0%	0%
Australia	11%	18%	22%	26%	25%	0%	3%
Indonesia	3%	8%	22%	0%	0%	0%	0%
Philippines	0%	3%	5%	0%	0%	0%	0%
Viet Nam	0%	0%	0%	0%	0%	0%	18%
China	3%	1%	3%	7%	40%	0%	37%
Kazakhstan	2%	0%	0%	0%	0%	0%	0%
Russia	1%	3%	8%	0%	21%	6%	18%
Zimbabwe	0%	0%	0%	1%	0%	2%	0%
DR Congo	4%	46%	0%	0%	0%	0%	0%
South Africa	0%	0%	0%	0%	15%	90%	1%
Others	33%	9%	21%	11%	0%	0%	4%

Note: Compiled from USGS Mineral Commodity Summaries 2022

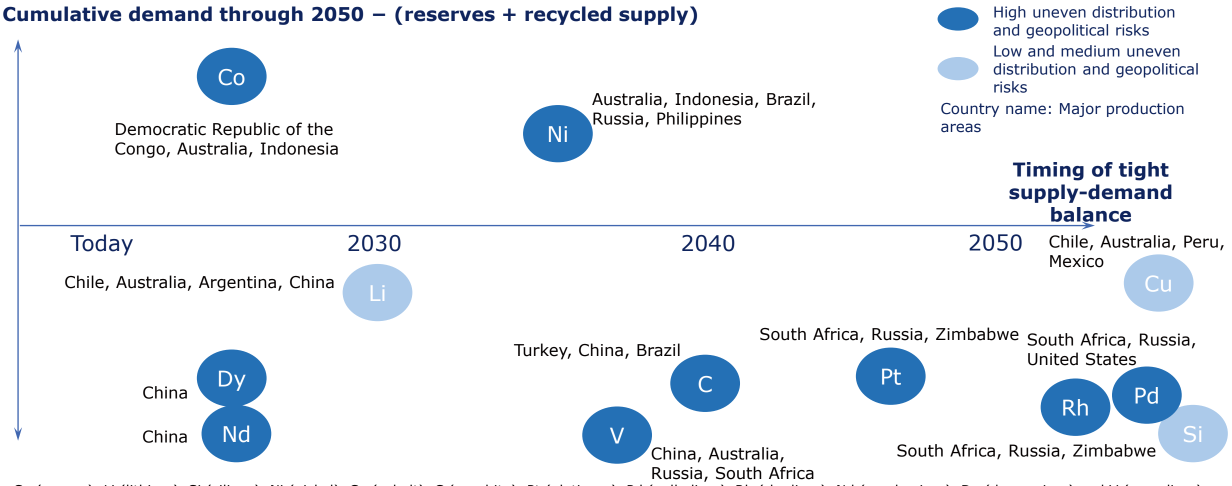
Country-wise production share of ore and primary nickel (2019)

	Ore production	Primary nickel production
Americas	11%	12%
Europe	2%	17%
Japan	0%	8%
China	4%	34%
Indonesia	35%	16%
Philippines	13%	0%
Other Asia	8%	3%
Oceania	6%	8%
Russia	9%	0%
Africa	2%	3%
Others	10%	0%

Supply and demand balance (Advanced Technologies Scenario)

- Reserves + recycling < Cumulative demand (until 2050): Nickel and cobalt
- Early supply shortage concerns: lithium, cobalt, neodymium and dysprosium
- Uneven distribution and geopolitical risks: nickel, cobalt, graphite, platinum-group metals, neodymium, dysprosium and vanadium

Cumulative demand through 2050 − (reserves + recycled supply)



Note: Cu (copper), Li (lithium), Si (silicon), Ni (nickel), Co (cobalt), C (graphite), Pt (platinum), Pd (palladium), Rh (rhodium), Nd (neodymium), Dy (dysprosium) and V (vanadium)

Reference: Major uses of critical minerals

Ore	Major uses
Cu (copper)	Wind power generation, solar photovoltaics power generation, electric vehicles, batteries. However, it is often used outside of CN technology.
Li (lithium)	Lithium-ion battery
Si (silicon)	Solar PV. However, it is often used outside of CN technology.
Ni (nickel)	Lithium-ion batteries. However, stainless steel and heat-resistant steel are the main applications.
Co (cobalt)	Lithium-ion batteries, special steel
C (graphite)	Lithium-ion batteries, metal crucibles, molds, electric furnace electrodes, etc.
Pt (platinum)	Exhaust gas catalysts for automobiles, electrocatalysts for fuel cells and water electrolysers
Pd (palladium)	Exhaust gas catalysts for automobiles, electrocatalysts for fuel cells and water electrolysers
Rh (rhodium)	Exhaust gas catalysts for automobiles
Nd (neodymium)	Electric vehicle motors, magnets in wind power generators
Dy (dysprosium)	Electric vehicle motors, magnets in wind power generators
V (vanadium)	Electrolyte for redox flow batteries. Other than CN technology, additives to steel are main.

Response required

- Under the Advanced Technologies Scenario, the cumulative demand for nickel and cobalt by 2050 will exceed the reserves (+ recycled supply). Also, demand for lithium, cobalt, neodymium and dysprosium will exceed supply by around 2030.
- With respect to these critical minerals, it is necessary to develop technologies that contribute to increasing the recycling rate, in conjunction with increasing production at existing mines and developing new mines.
- In order to secure critical minerals, it is necessary to develop recycling, non-use and reduced usage technologies, as well as acquisition or rights and long-term purchase contracts. Diversification of critical minerals is also important.
- Currently, the supply of critical minerals is an oligopoly of several countries. The introduction of new regulations and tax regime on resource development and exports in producing countries may cause supply constraints for demand countries. Therefore, it is necessary to pay close attention to the policy trends of producing countries. Diversification of the supply chain is also an issue to be addressed, since processing such as refining is concentrated in specific countries such as China.
- There are uncertainties in policies of resource producing country, prospects for developing technologies for recycling, non-use and reduced usage. Therefore, it is important to balance technology choices from the perspective of energy and economic security and the sustainability of critical minerals.

Structure of this report

1. Energy security strategy in view of war in Ukraine and energy transition
2. Strengthening stable power supply and importance of nuclear power generation
3. Critical mineral issues in energy and economic security
4. Economic impact of green investment

Background of the analysis

Last year, IEEJ Outlook 2022 raised issues that should be considered during the course towards carbon neutrality.

- “Green growth” is expected, in which investments in climate action will form a virtuous cycle of emissions reductions and economic growth, but the effects may vary by economy and actor.

- That can create new gaps: (1) disparities among advanced economies and among developing economies, (2) disparities between advanced and developing economies, (3) disparities between economies that depend on fossil fuel exports and those that do not, and (4) disparities among citizens.

In this background, “IEEJ Outlook 2023” provides a quantitative assessment of how climate change investment (green investment) impacts countries or regions, and what disparities may arise.

Analytical method

- Quantitative assessment of the impact of green investment* on national economies

* Regard difference of investment in the Advanced Technologies Scenario to the Reference Scenario.

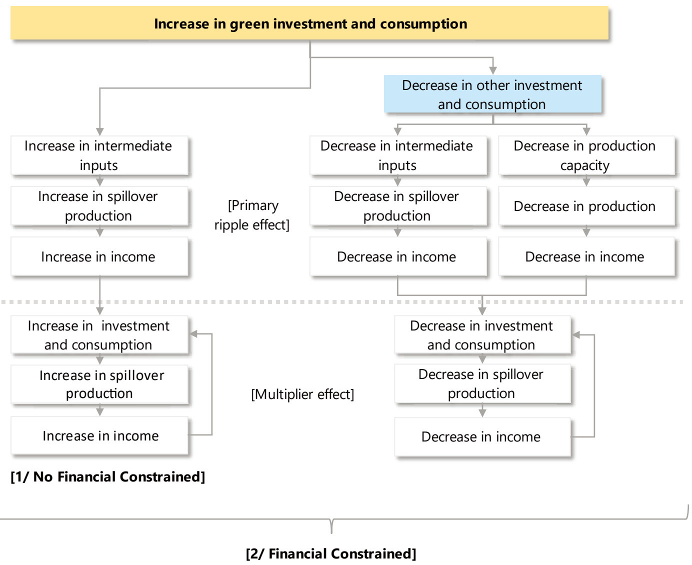
«Case settings»

1/ No Financial Constrained Case

Additional green investment will have a positive spillover effect as well as multiplier effect through 1) an increased demand ➔ 2) Increased income ➔ 3) increased consumption
(This case represent common concept of green growth)

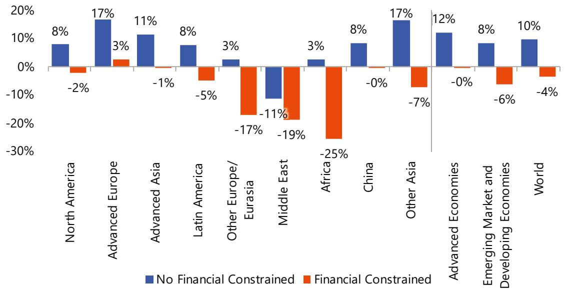
2/ Financial Constrained Case

Since funds have a constrain, the amount spent on green investments reduces other investments. Furthermore, since green investment itself is not an investment to expand production capacity, it is also considered that production and income will decrease through a decrease in production capacity due to a decrease in other investments.



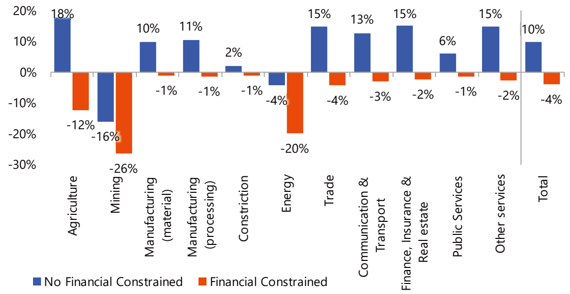
Green growth is unlikely when there are constraints in funds

Changes in production in 2050
(By region. Compared to Reference Scenario)



- Without financial constraints, global production would increase by 9.8%, while with constraints it would decrease by 3.7%.
- Regardless of financial constraints, the production value will decline in economies such as the Middle East, which is highly dependent on mining (fossil fuels).
- Advanced economies are more likely to enjoy green growth, while developing countries are not.

Changes in production in 2050
(By industry. Compared to Reference Scenario)



- Regardless of financial constraints, the production value of mining and energy supply related to fossil fuel will decrease.
- GDP accelerates by an average of 0.4% a year without financial constraints and decelerates by 0.1% with constraints
  (IEA analysed acceleration of 0.4% in the 2020s in their Net Zero Emissions by 2050 Scenario *).

* IEA (2021), Net Zero by 2050 - A Roadmap for the Global Energy Sector

Conclusion

- Although "green growth" is expected in green investment, many economies are unable to enjoy it if there are financial constraints.
- Regardless of financial constraints, advanced economies are more likely to enjoy green growth, whereas emerging and developing economies are not. In the real world, there are advanced economies with money to spare and developing economies without money to spare, and the economic gap between the two can become wider.
- In order to raise funds smoothly, it is necessary to utilise green finance, which mainly consists of private funds, as well as government budgets. It is important to clarify the direction of environmental policy in order to limit risks and encourage investment.
- Regardless of financial constraint, economies highly dependent on fossil fuel exports are negatively affected. It is necessary to break away from dependence on the fossil fuel industry, and re-education (reskilling) of workers will be important for smooth labour movement from declining industries to other industries.
- In a world striving for a low-carbon society, new disparities between economies or industries may arise. It is important to limit negative economic impacts and to even out the different impacts among economies and industries. If the availability of funds lead to greater inequality, it is also necessary for advanced economies to provide financial support to emerging and developing economies that cannot afford it.

Thank you for your attention.

Co-authors

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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

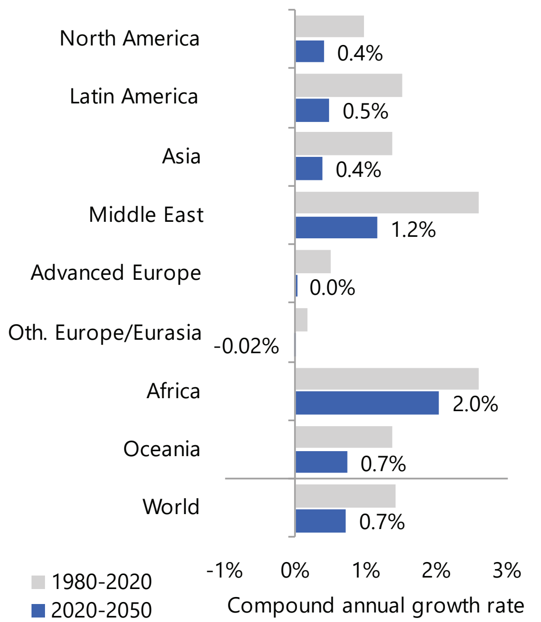
Calculate future GHG concentration in the atmosphere, temperature rise, damage caused by climate change, etc.

Basic scenarios in IEEJ Outlook

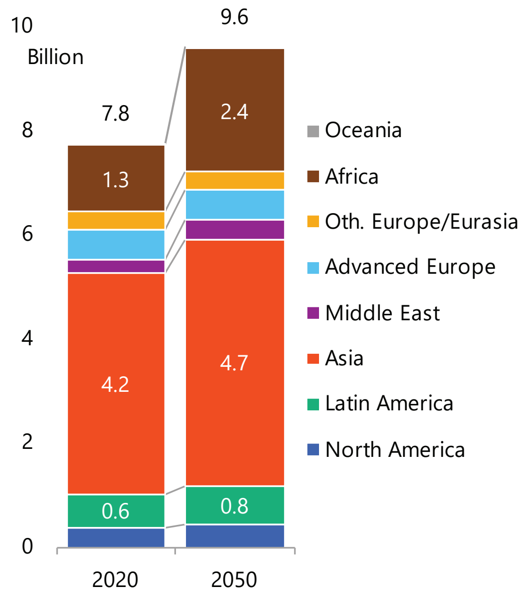
	Reference Scenario	Advanced Technologies Scenario
	Reflects past trends with technology progress and current energy policies, without any aggressive policies for low-carbon measures	Assumes introduction of powerful policies to address energy security and climate change issues with the utmost penetration 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** price decreases due to request for decarbonization.	All prices decrease along with decrease in demand due to progress in energy saving and request for decarbonization
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

Population

CAGR

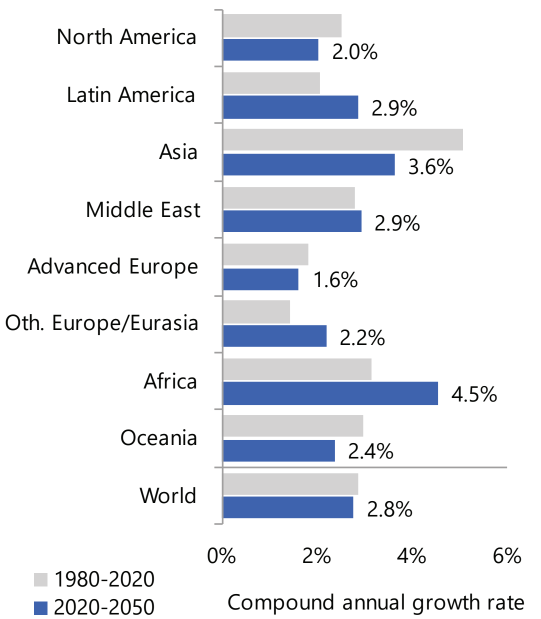


Composition

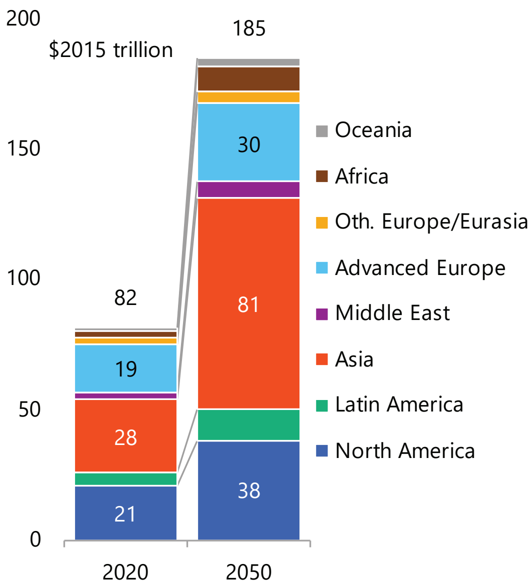


Real GDP

CAGR



Composition

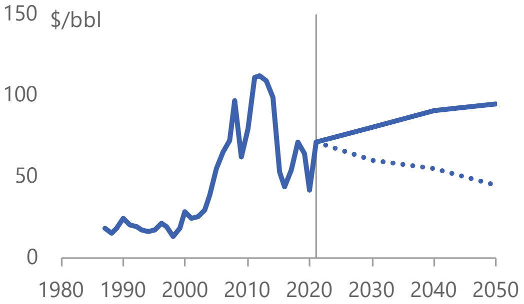


Assumptions

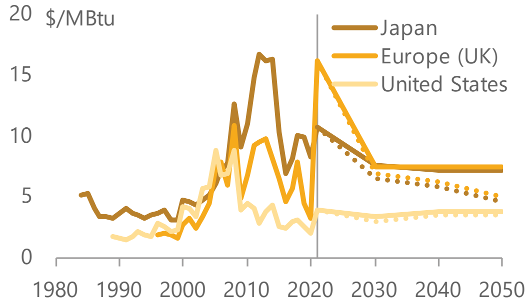
International energy prices

Reference :
Advanced Technologies :

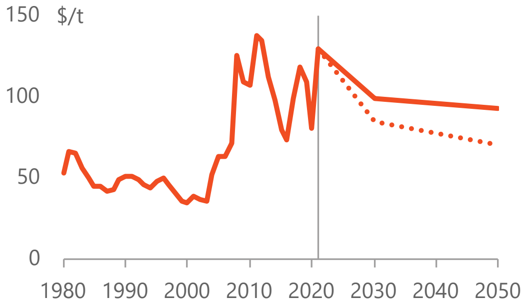
Crude oil



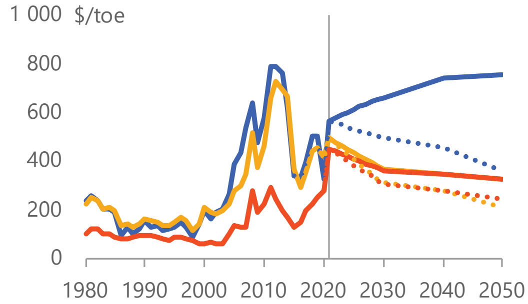
Natural gas



Coal



CIF import prices for Japan



Note: Historical prices are nominal. Assumed future prices as real in $2021.

Assumptions

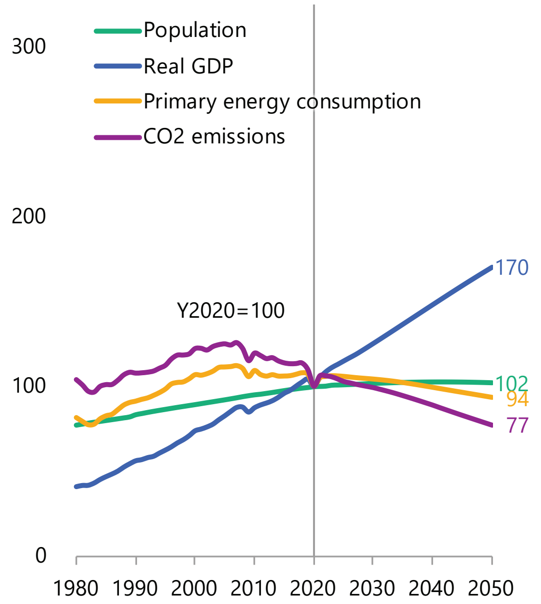
Energy and environmental technology

		2020	2050 Reference	2050 Advanced Technologies	Assumptions for Advanced Technologies Scenario
Improving energy efficiency					
Industry	Intensity in steel industry (ktoe/kt)	0.266	0.254	0.200	100% penetration of Best Available Technology by 2050.
	Intensity in non-metallic minerals industry	0.089	0.070	0.054	
Transport	Electrified vehicle share in passenger car sales	8%	66%	95%	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)	14.5	26.7	40.2	
Buildings	Residential total efficiency (Y2020=100)	100	161	215	Efficiency improvement at twice the speed for newly installed appliance, equipment and insulation.
	Commercial total efficiency	100	155	189	Electrification in space heating, water heater and cooking (clean cooking in developing regions).
Power	Thermal generation efficiency (Power transmission end)	38%	45%	46%	Financial scheme for initial investment in high-efficient thermal power plant.
Penetrating low-carbon technology					
Biofuels for transport (Mtoe)		91	154	268	Development of next generation biofuel with cost reduction. Relating to agricultural policy in developing regions.
Nuclear power generation capacity (GW)		408	477	767	Appropriate price in wholesale electricity market. Framework for financing initial investment in developing regions.
Wind power generation capacity (GW)		731	2 243	4 460	Further reduction of generation cost. Cost reduction of grid stabilization technology.
Solar PV power generation capacity		708	3 033	6 013	Efficient operation of power system.
Thermal power generation capacity with CCS (GW)		0	0	1 247	Installing CCS after 2030 (regions which have storage potential except for aquifer).
Zero-emission generation ratio (incl. CCS)		38%	44%	84%	Efficient operation of power system including international power grid.

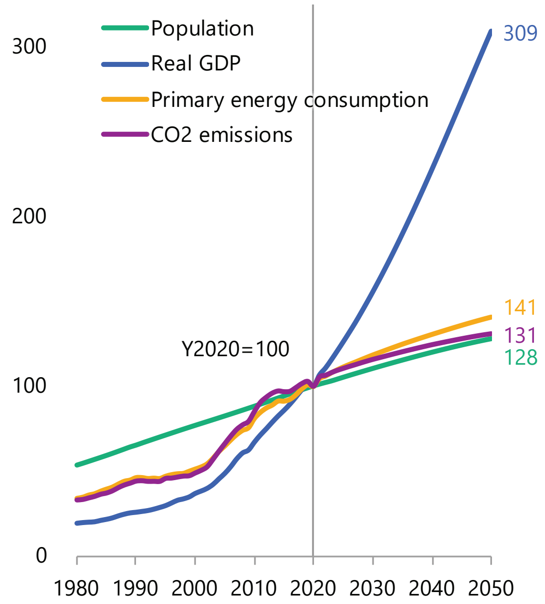
Reference Scenario

Population, GDP, energy and CO_2

Advanced Economies



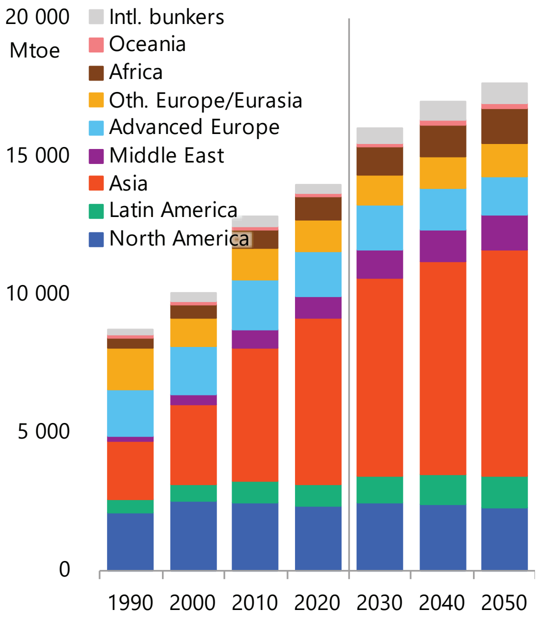
Emerging Market and Developing Economies



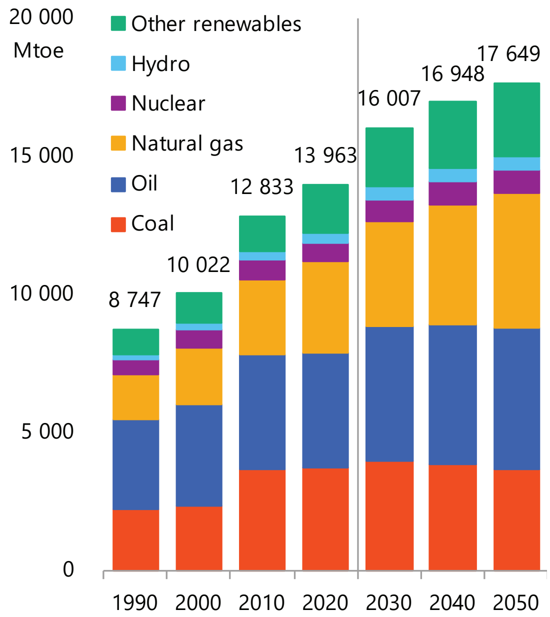
Reference Scenario

Primary energy consumption

By region



By energy source

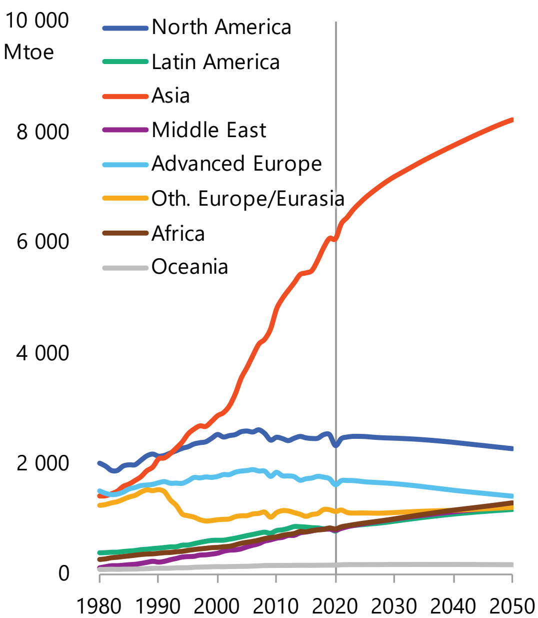


Reference Scenario

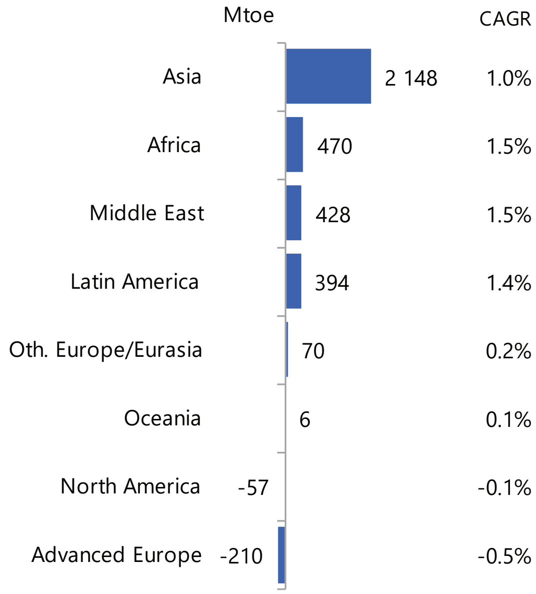
Primary energy consumption (by region)

IEE JAPAN

Energy consumption



Changes (2020-2050)

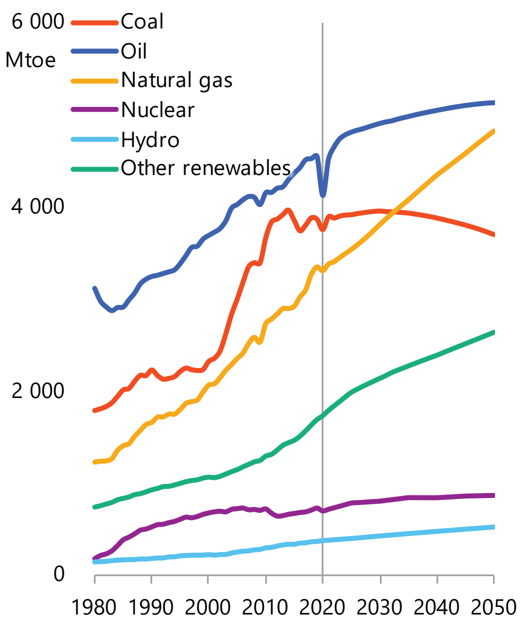


Reference Scenario

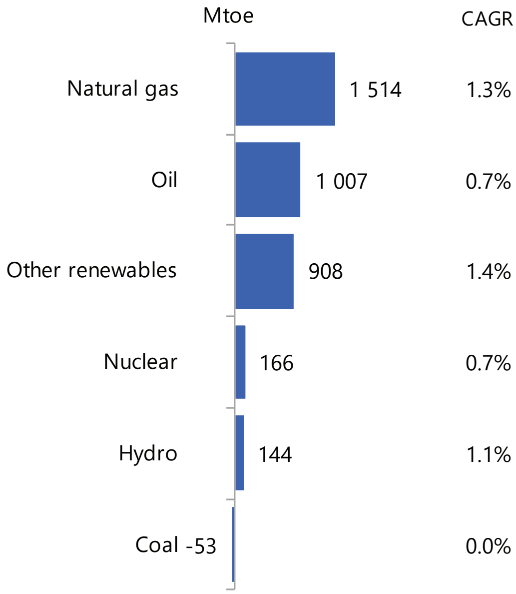
Primary energy consumption (by energy source)

IEE JAPAN

Energy consumption



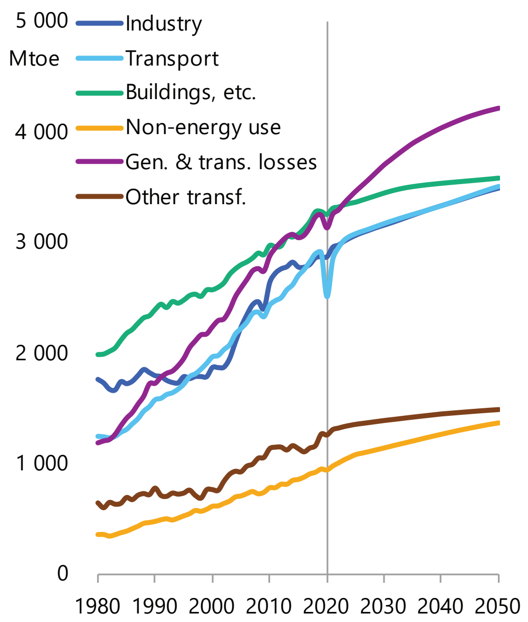
Changes (2020-2050)



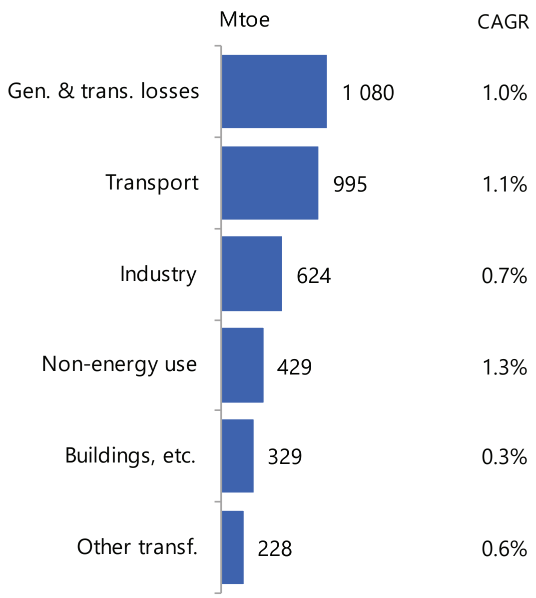
Reference Scenario

Primary energy consumption (by sector)

Energy consumption



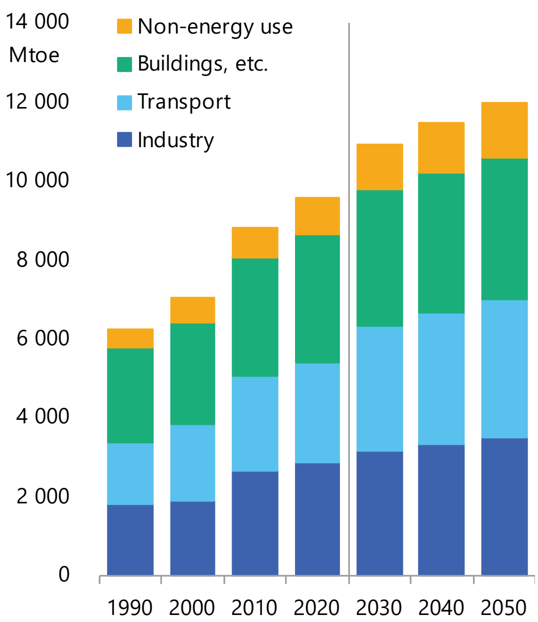
Changes (2020-2050)



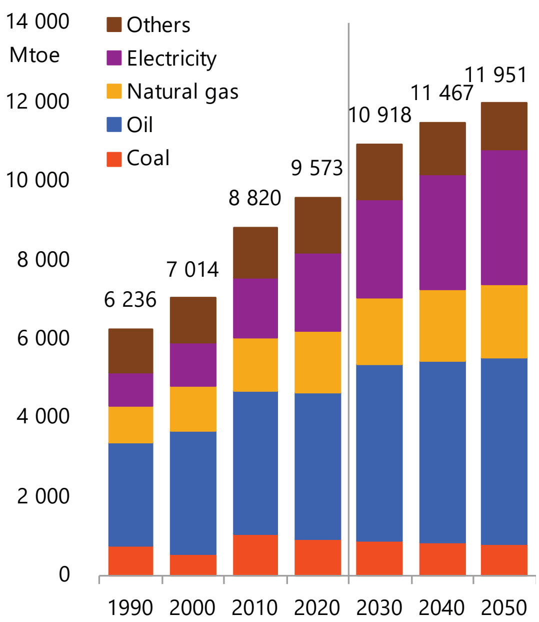
Reference Scenario

Final energy consumption

By sector



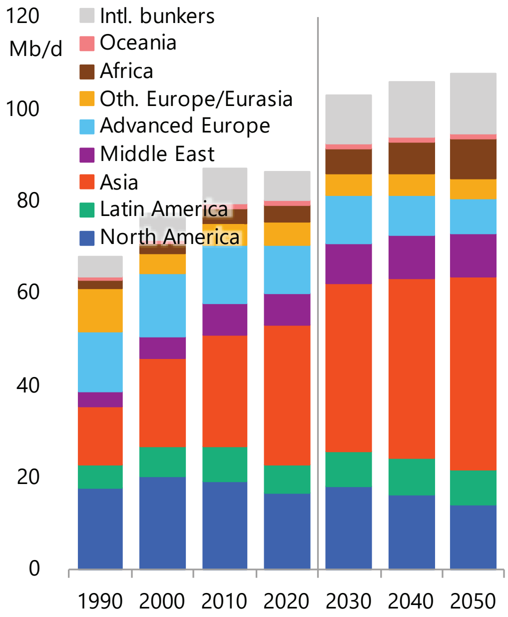
By energy source



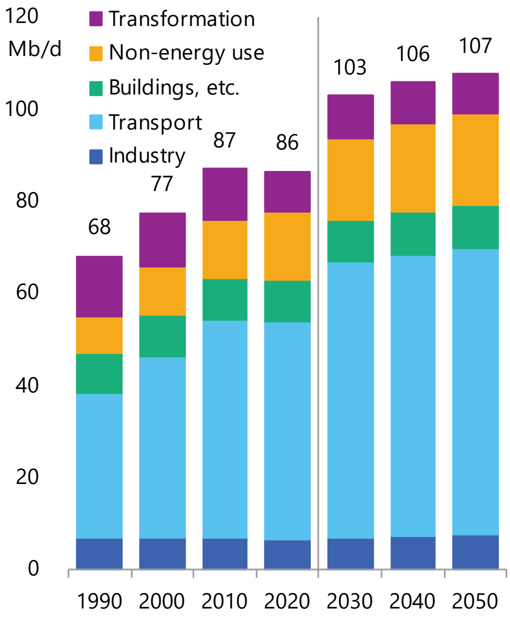
Reference Scenario

Oil consumption

By region



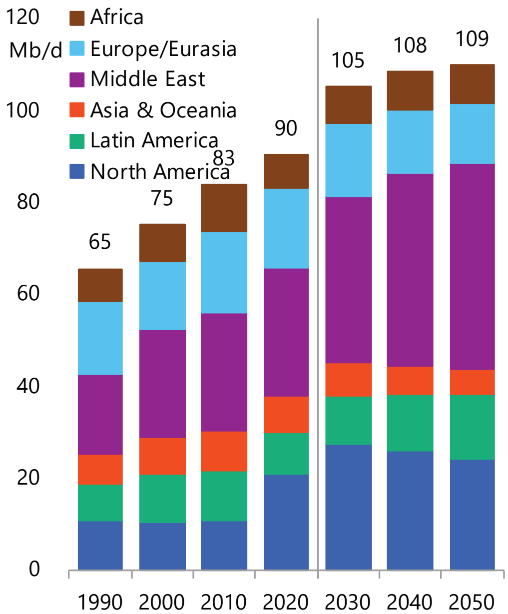
By sector



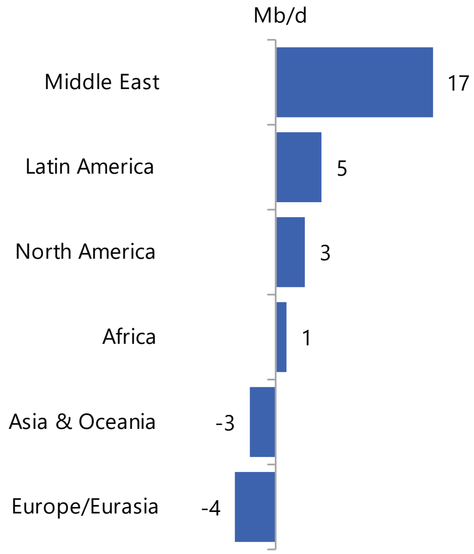
Reference Scenario

Crude oil production

By region

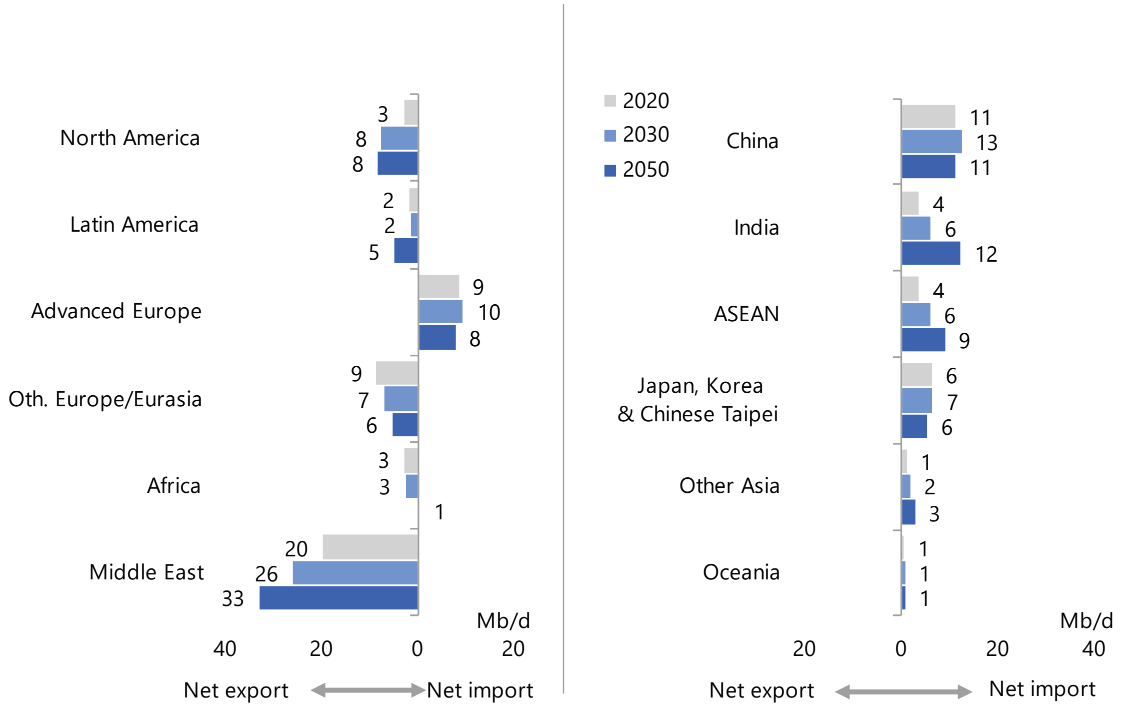


Changes (2020-2050)



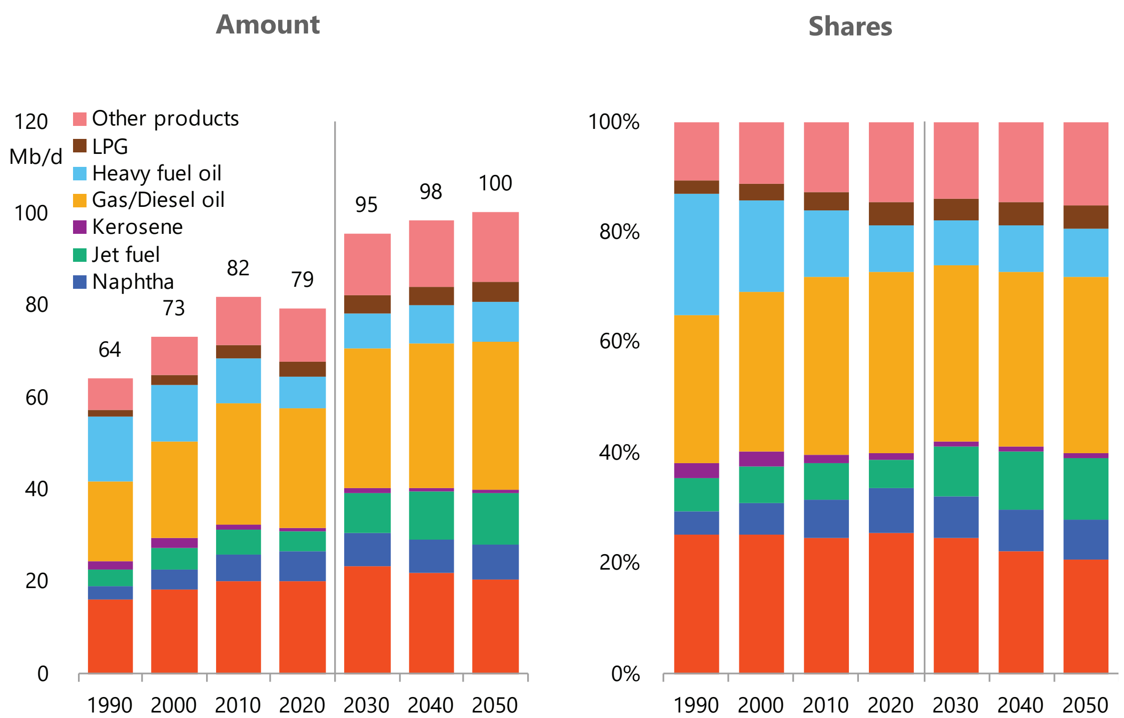
Reference Scenario

Net exports and imports of oil



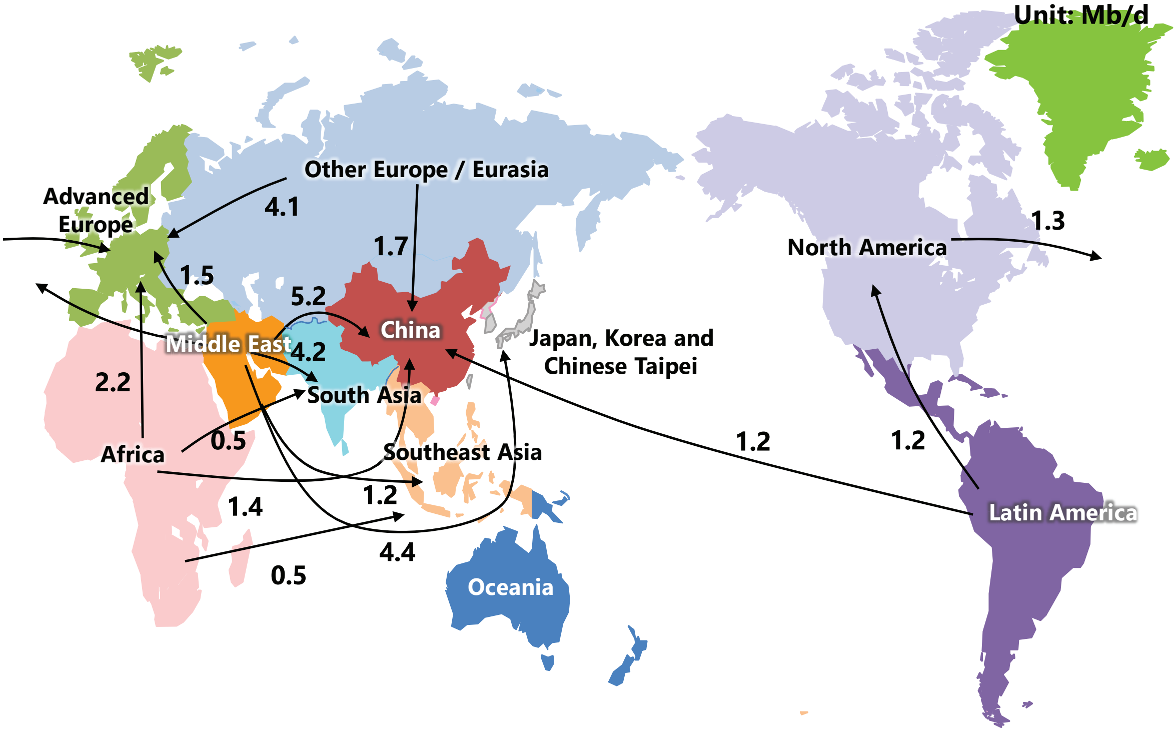
Reference Scenario

Petroleum product consumption



Reference Scenario

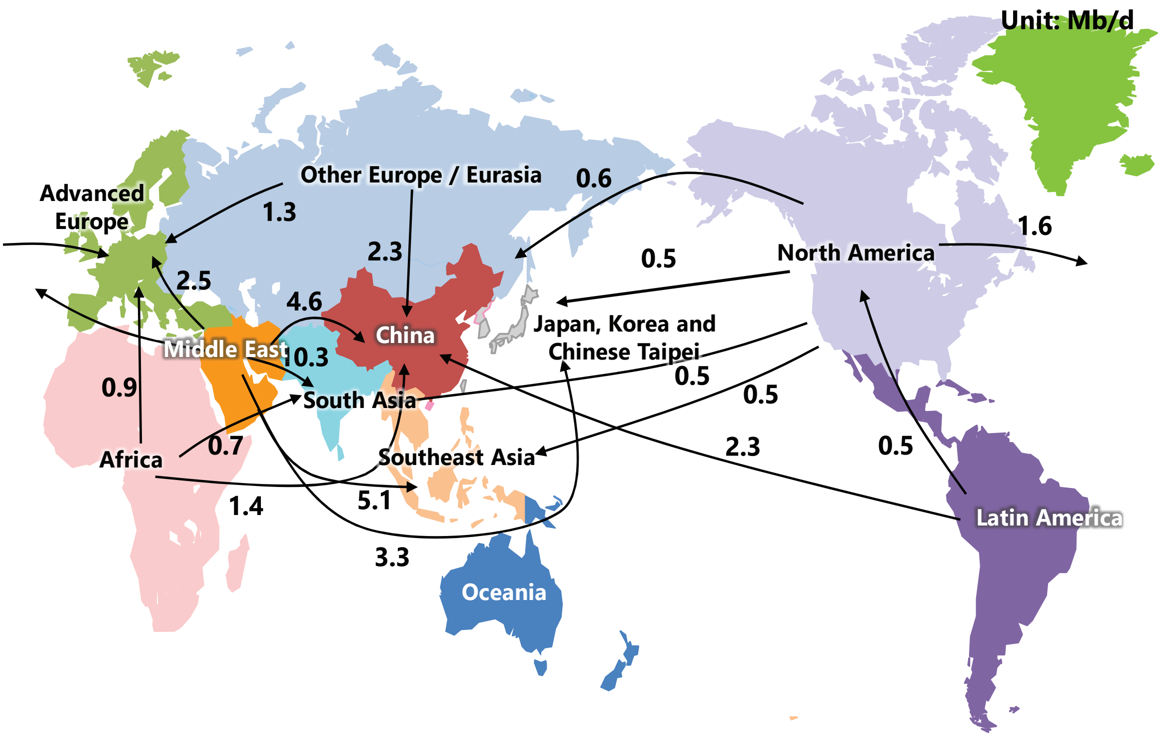
Major trade flows of crude oil (2021)



Note: 0.5 Mb/d or more are shown

Reference Scenario

Major trade flows of crude oil (2050)

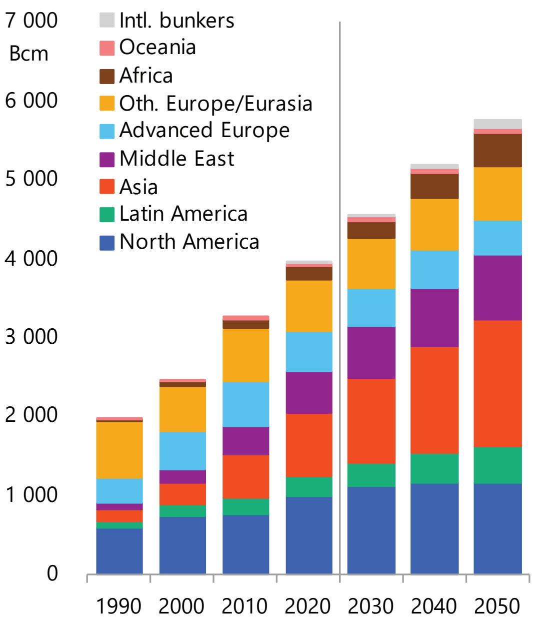


Note: 0.5 Mb/d or more are shown

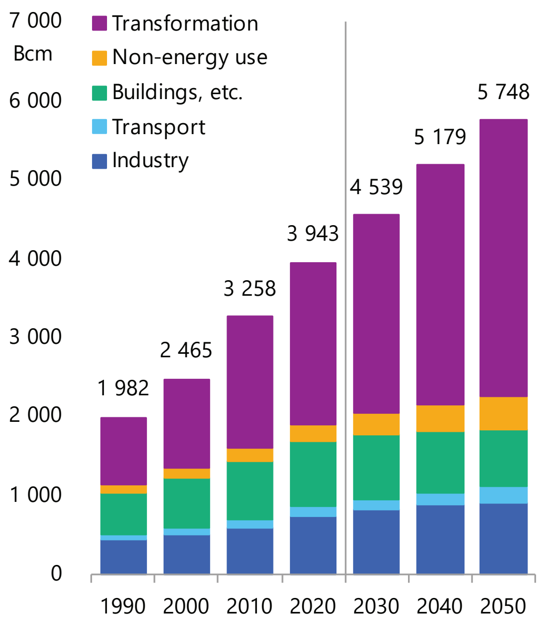
Reference Scenario

Natural gas consumption

By region



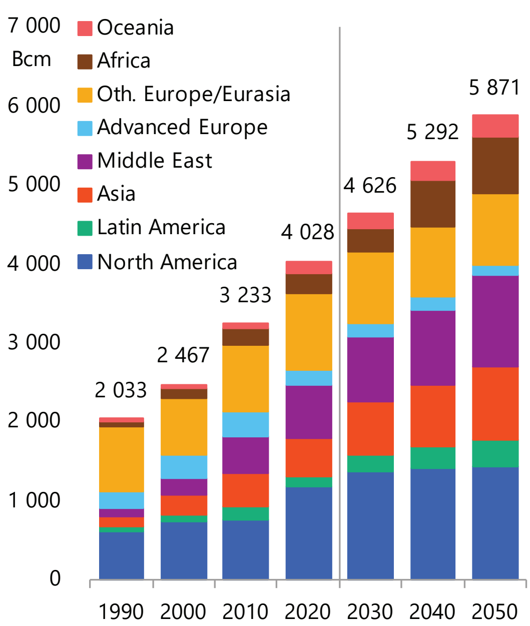
By sector



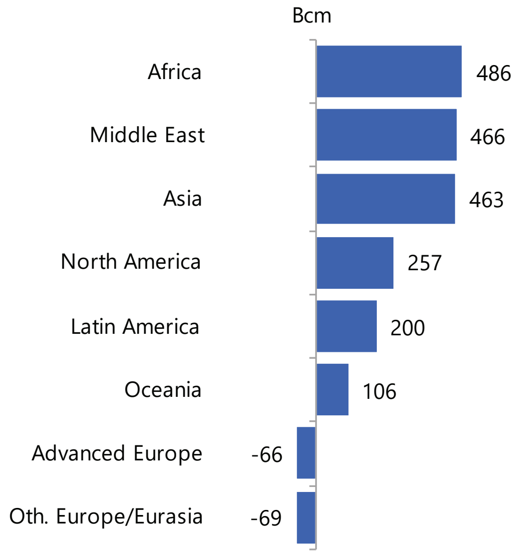
Reference Scenario

Natural gas production

By region

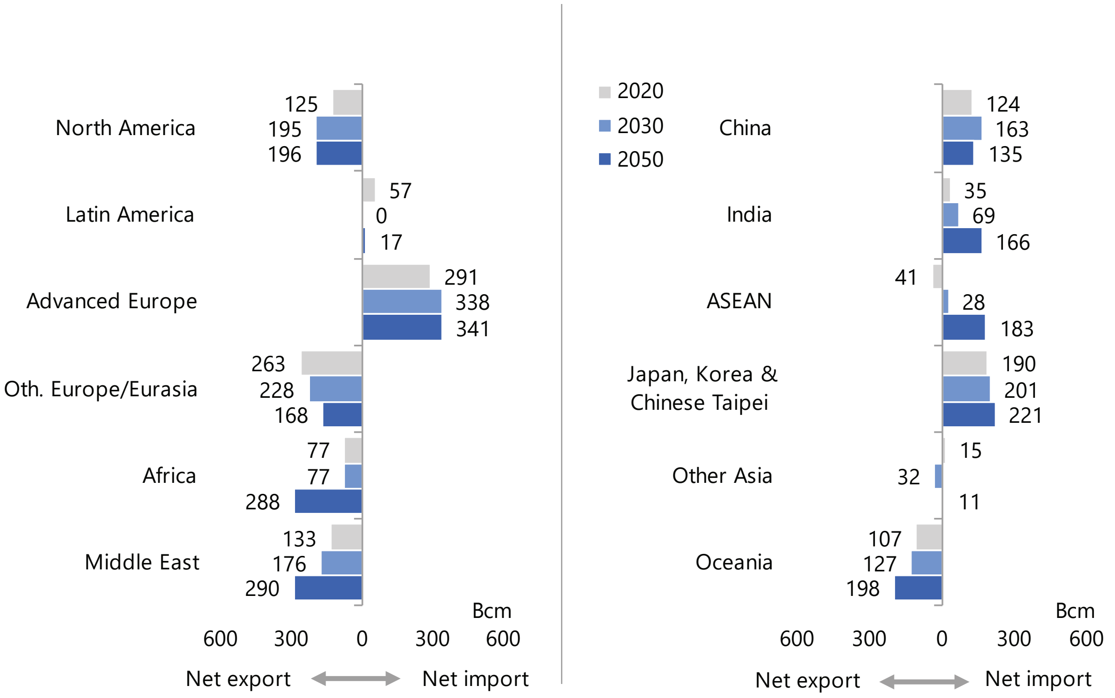


Changes (2020-2050)



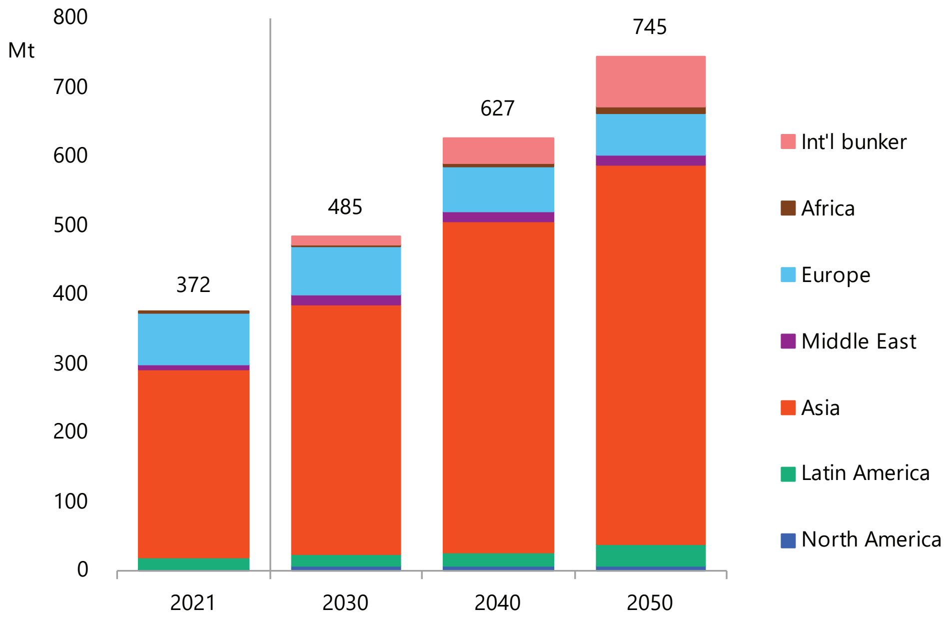
Reference Scenario

Net exports and imports of natural gas



Reference Scenario

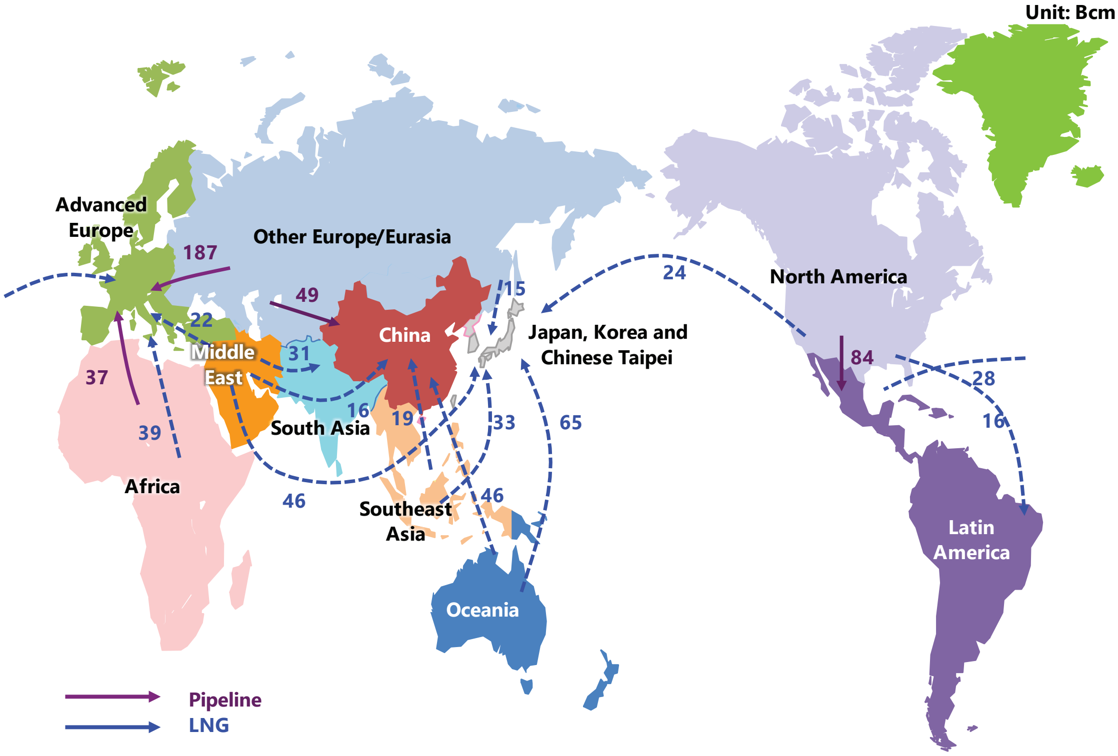
LNG demand



Reference Scenario

Major trade flows of natural gas (2021)

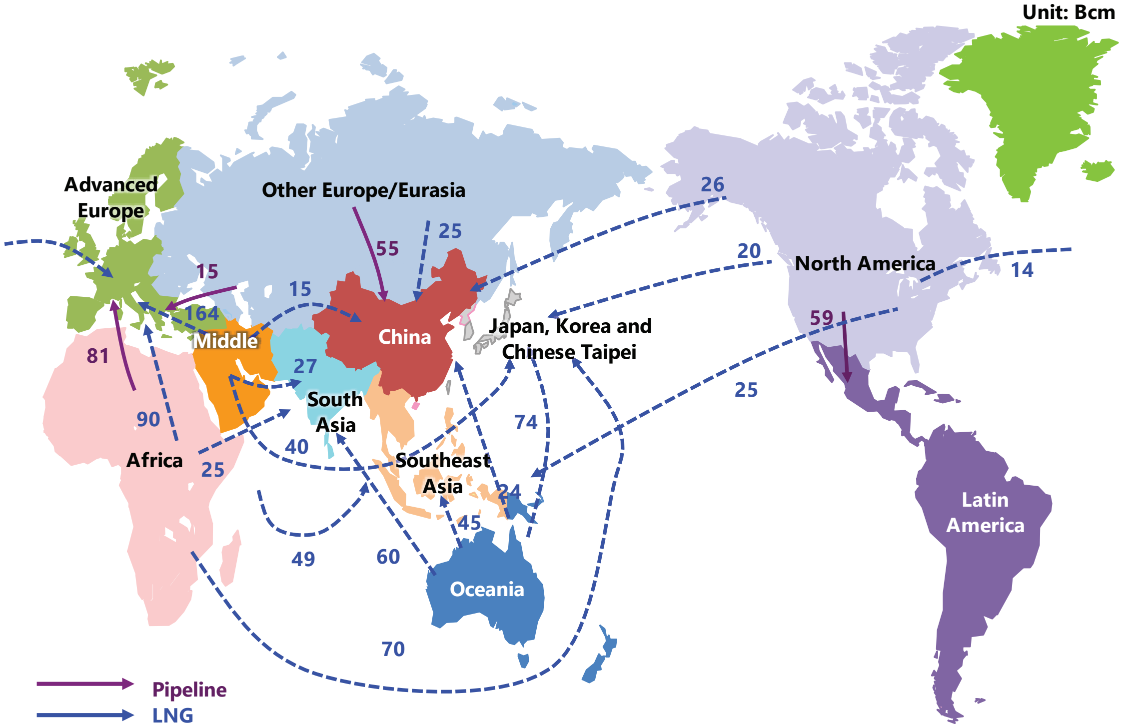
Unit: Bcm



Reference Scenario

Major trade flows of natural gas (2050)

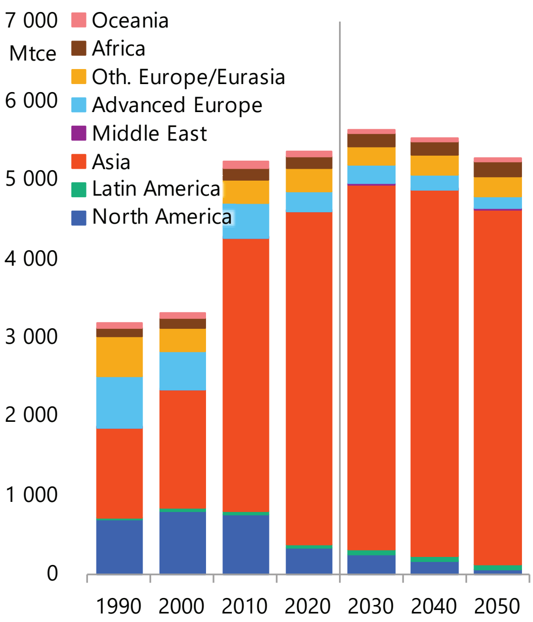
Unit: Bcm



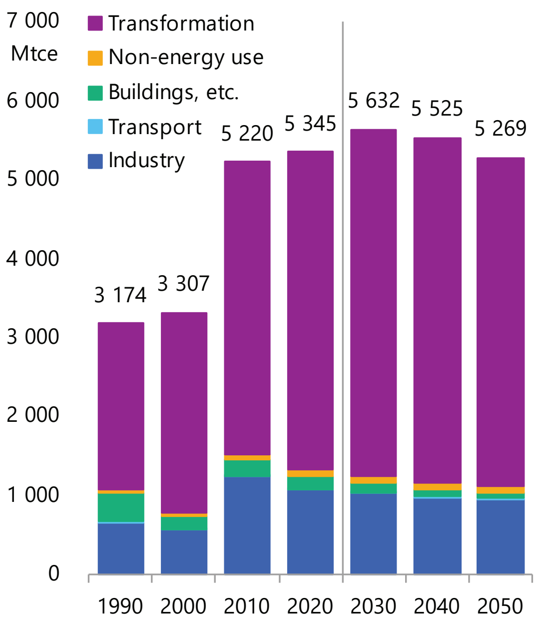
Reference Scenario

Coal consumption

By region



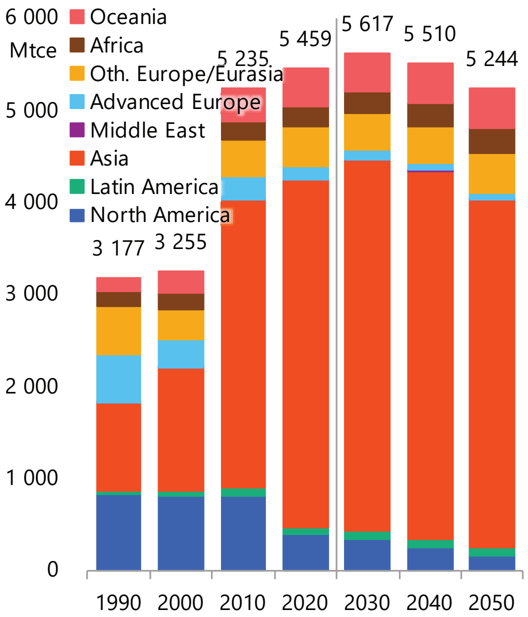
By sector



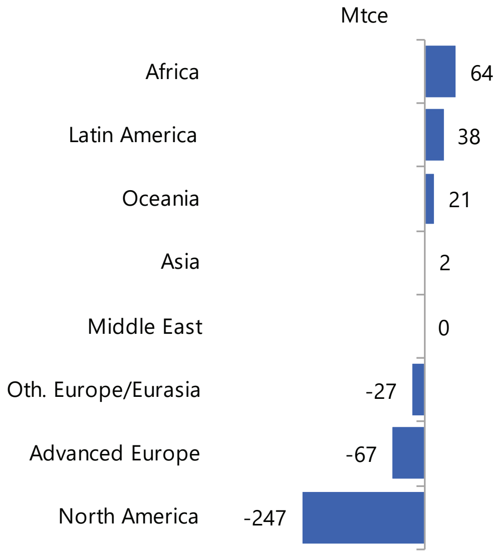
Reference Scenario

Coal production

By region

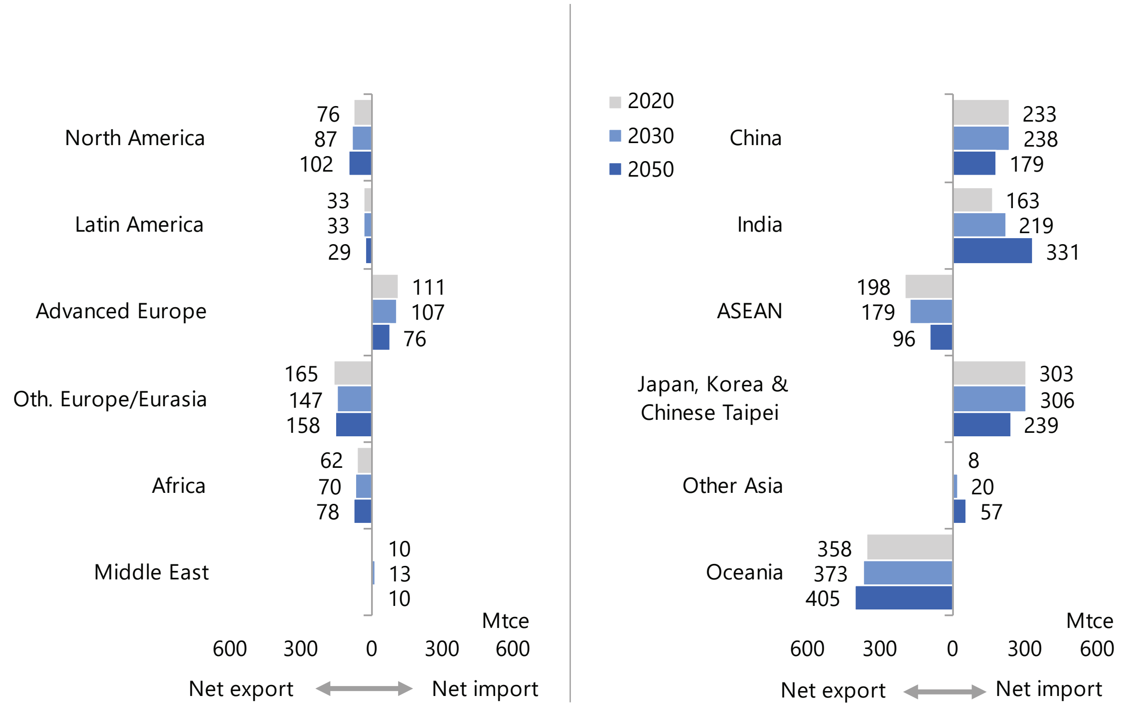


Changes (2020-2050)



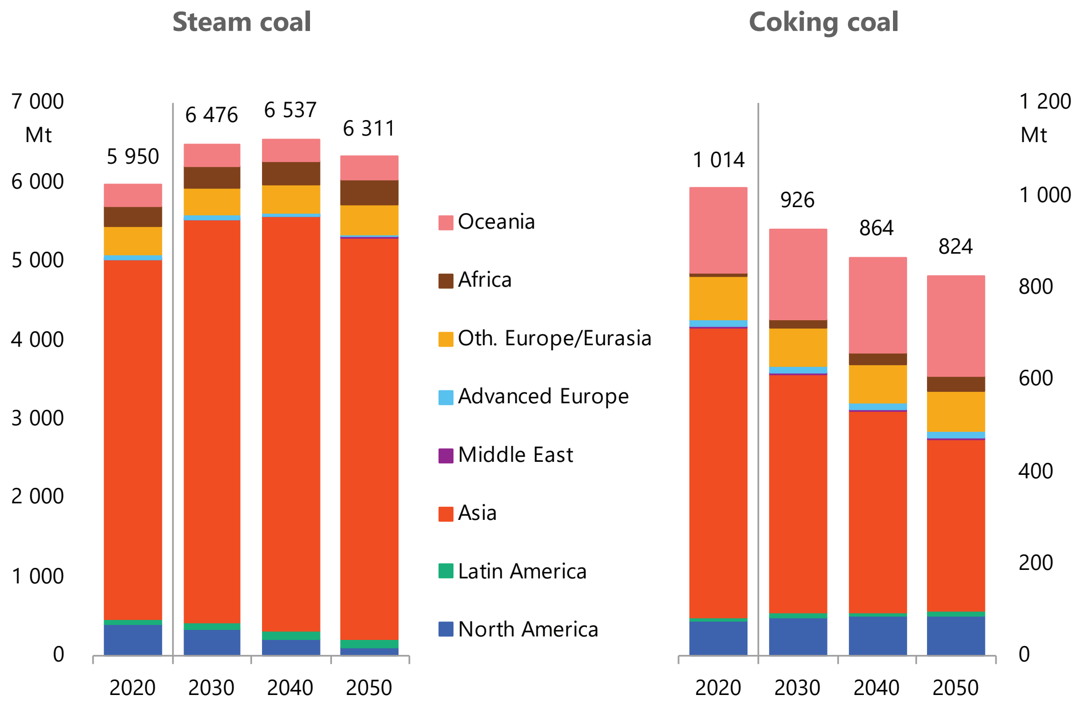
Reference Scenario

Net exports and imports of coal



Reference Scenario

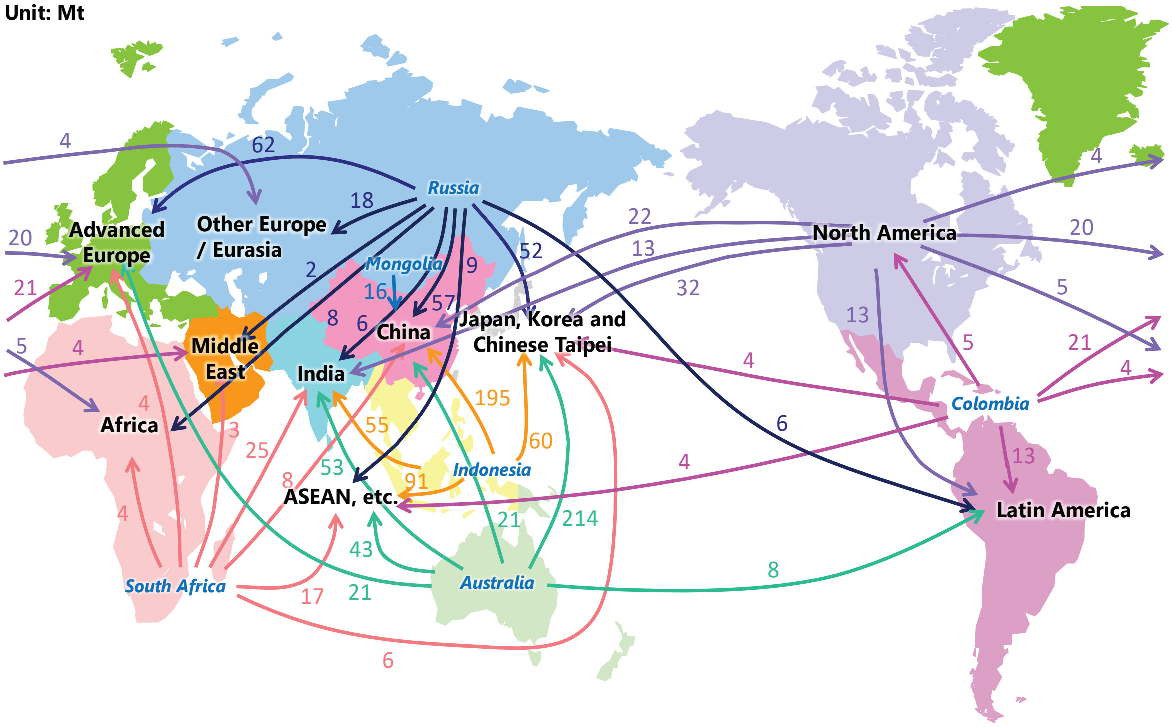
Coal production (steam and coking coal)



Reference Scenario

Major trade flows of steam and coking coal (2021)

Unit: Mt



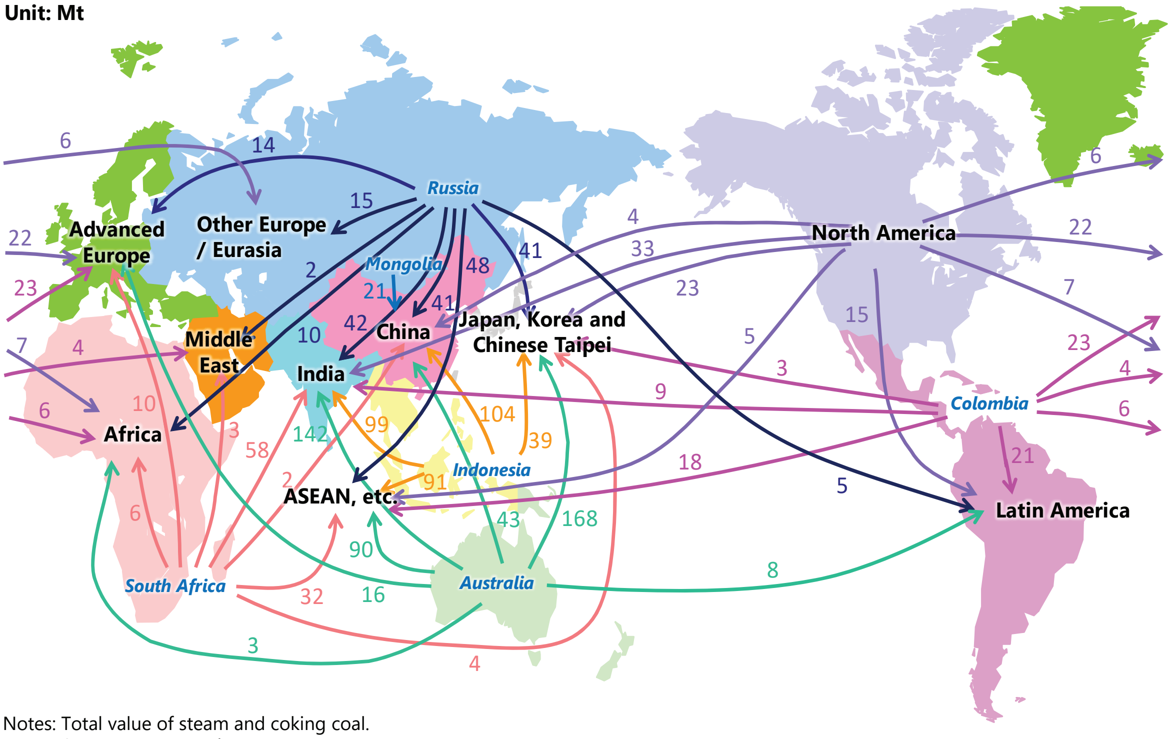
Notes: Total value of steam and coking coal. 2 Mt or more are shown. South Africa includes Mozambique.

Source: Estimated from IEA "Coal Information 2022", "TEX Report", etc.

Reference Scenario

Major trade flows of steam and coking coal (2050)

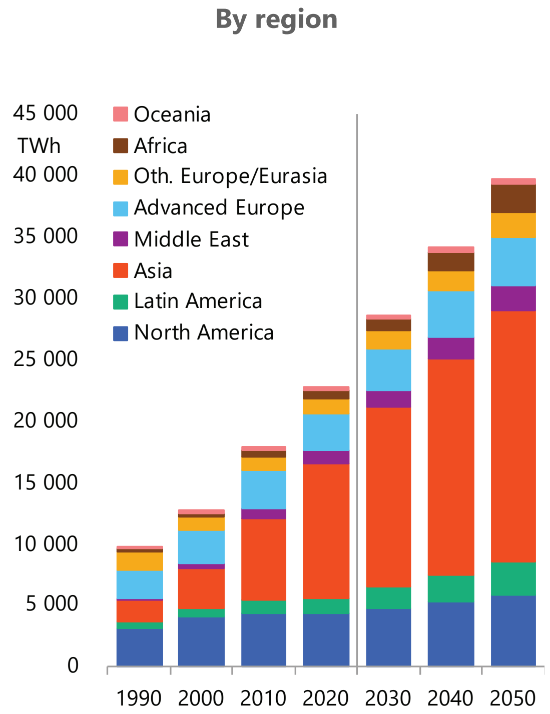
Unit: Mt

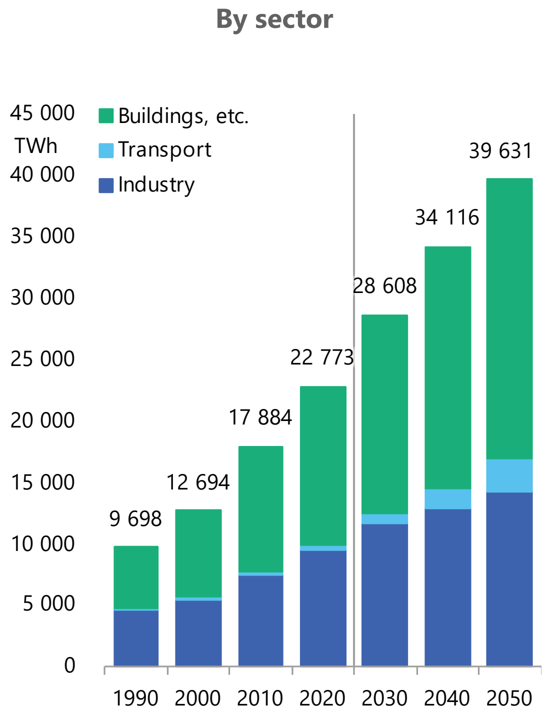


Notes: Total value of steam and coking coal.
2 Mt or more are shown.
South Africa includes Mozambique.

Reference Scenario

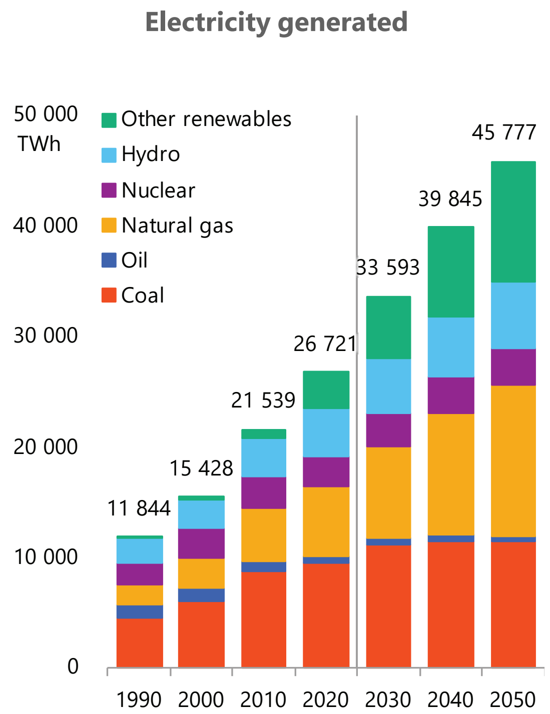
Final consumption of electricity

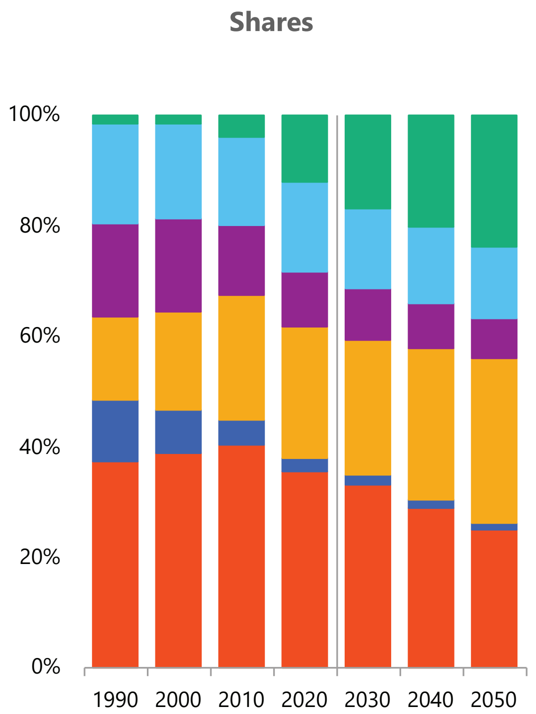




Reference Scenario

Power generation mix

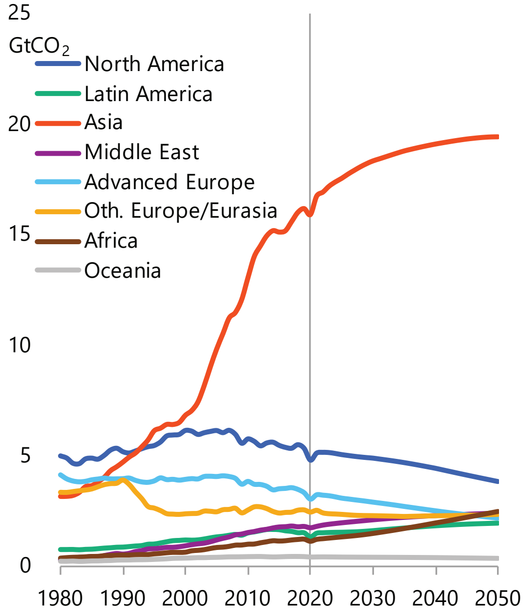




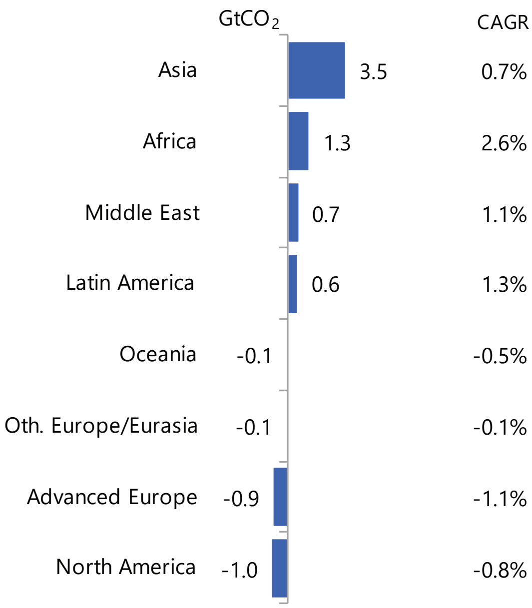
Reference Scenario

Energy-related CO_2 emissions

Emissions



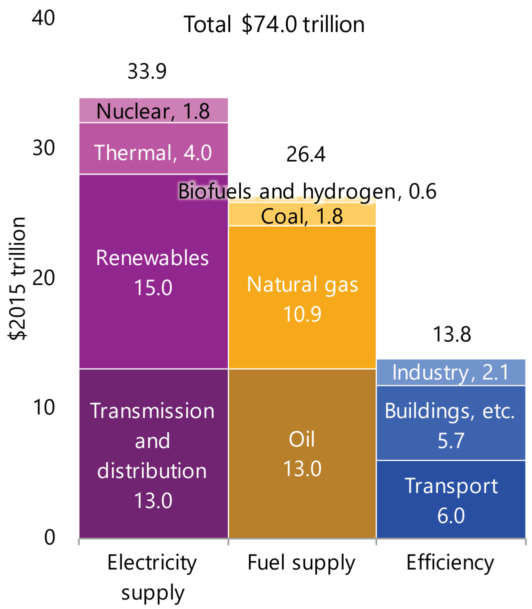
Changes (2020-2050)



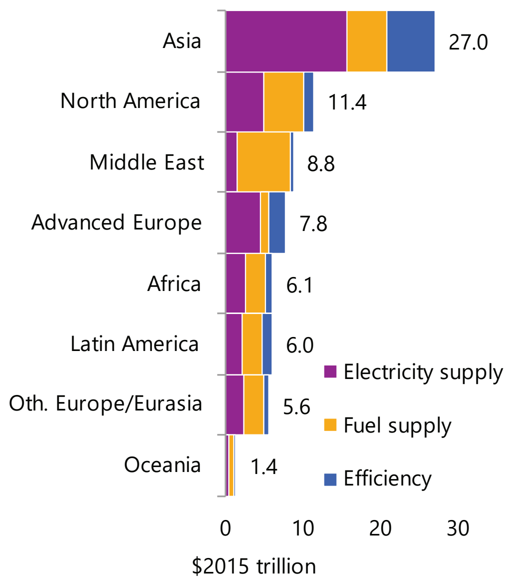
Reference Scenario

Energy-related investments (2021 – 2050)

By sector

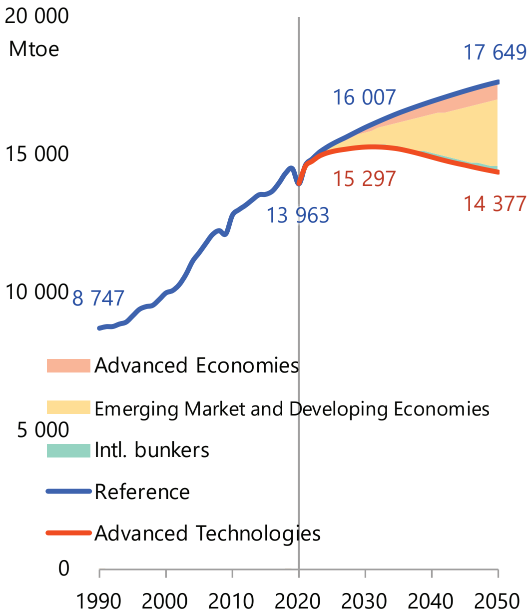


By region

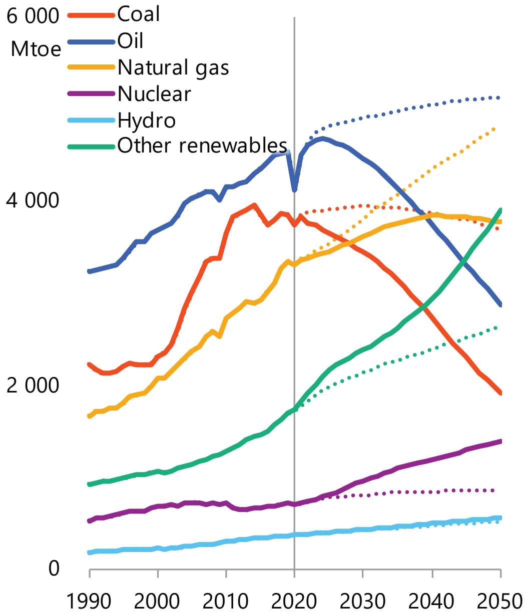


Primary energy consumption

By region



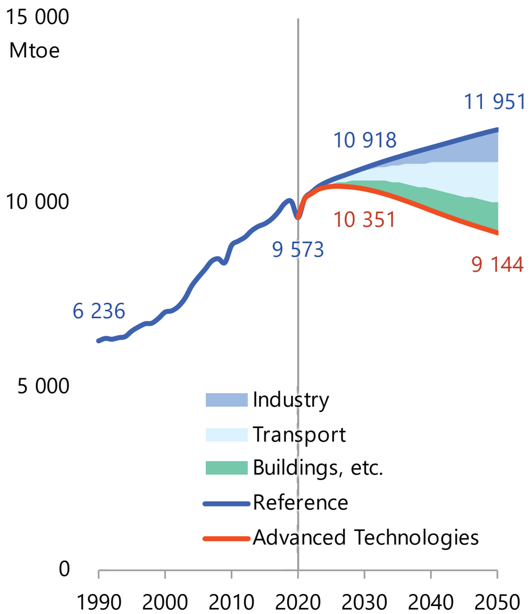
By energy source



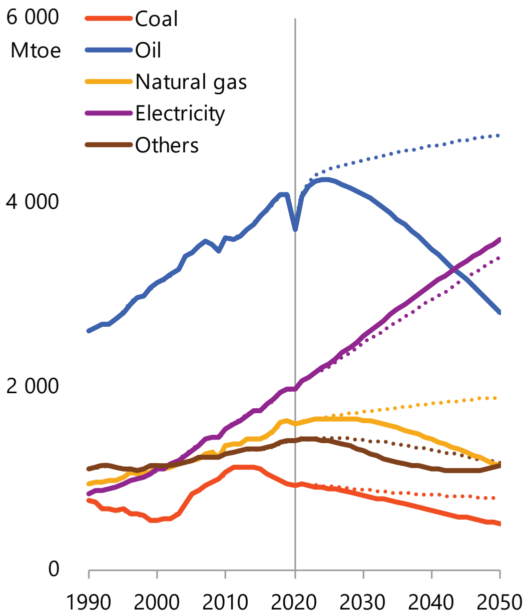
Note: Solid lines stand for Advanced Technologies Scenario and dotted lines stand for Reference Scenario.

Final energy consumption

By sector



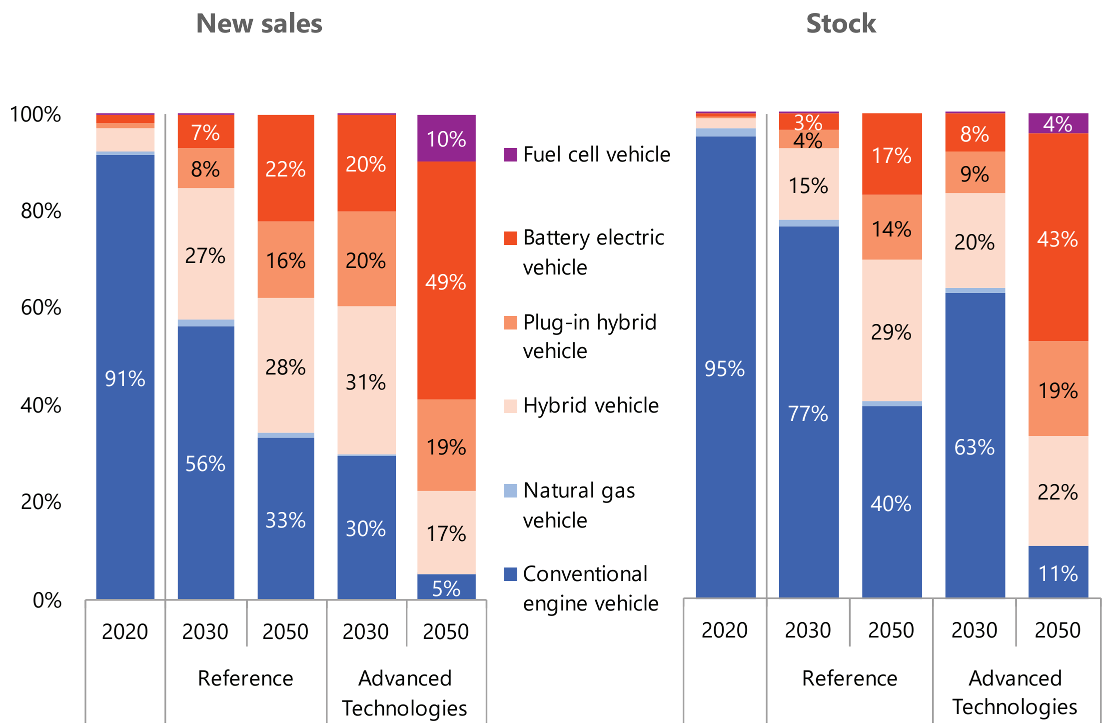
By energy



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

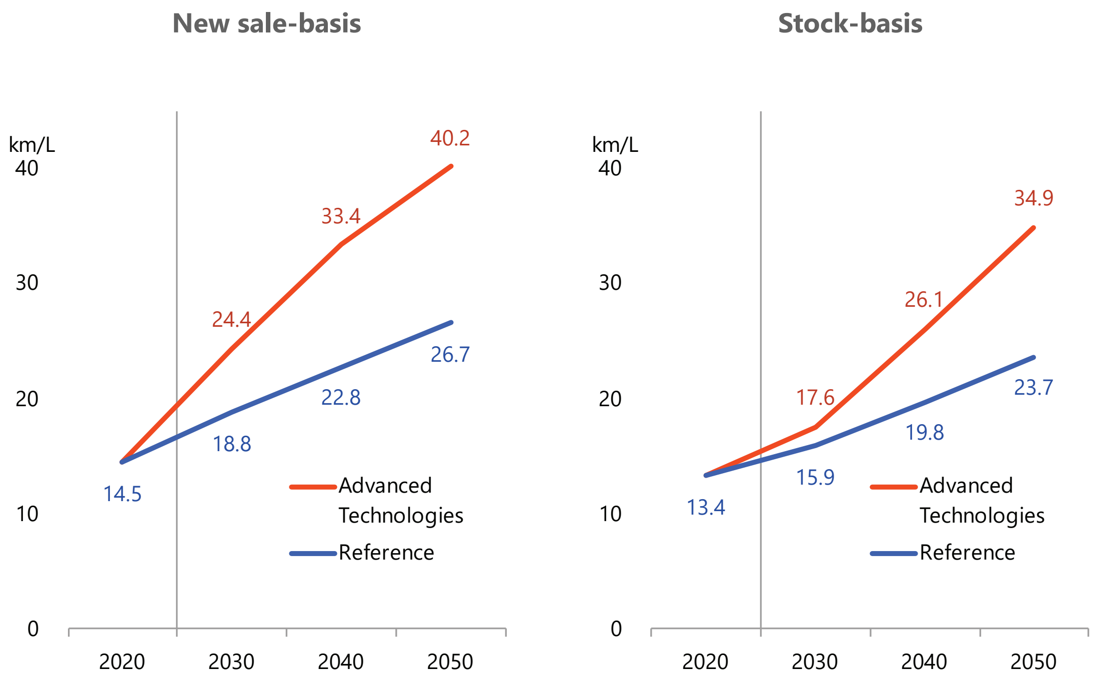
Advanced Technologies Scenario

Share of passenger vehicle



Advanced Technologies Scenario

Fuel efficiency of passenger vehicle

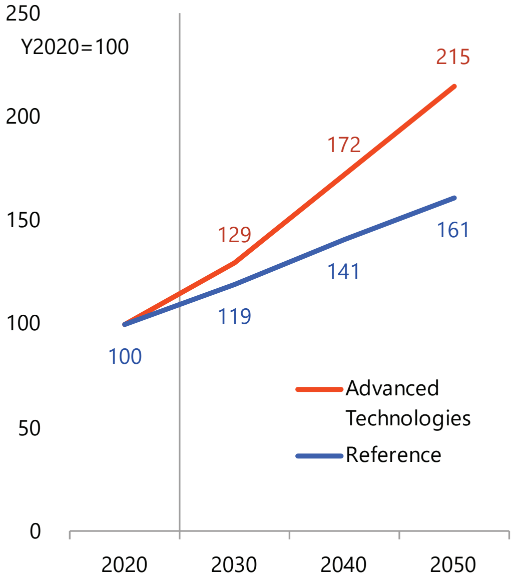


Note: Litres of gasoline equivalent

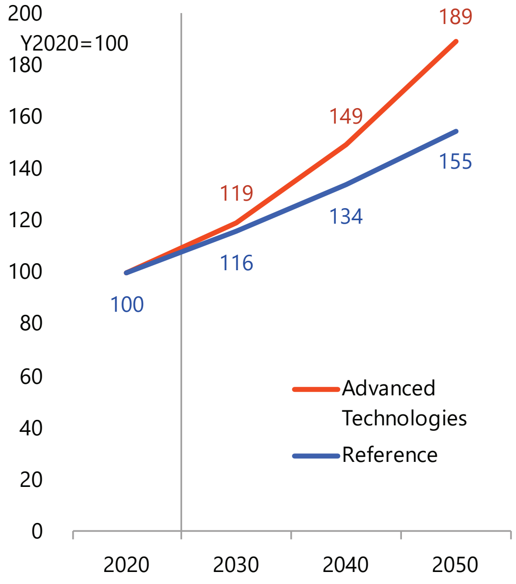
Advanced Technologies Scenario

Energy efficiency in buildings sector

Residential

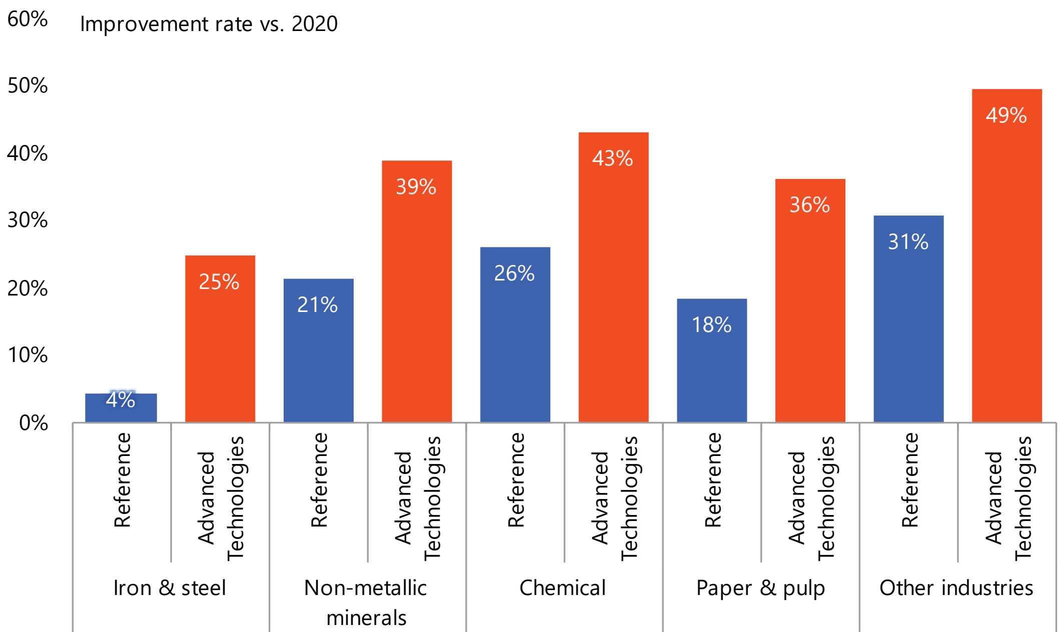


Commercial



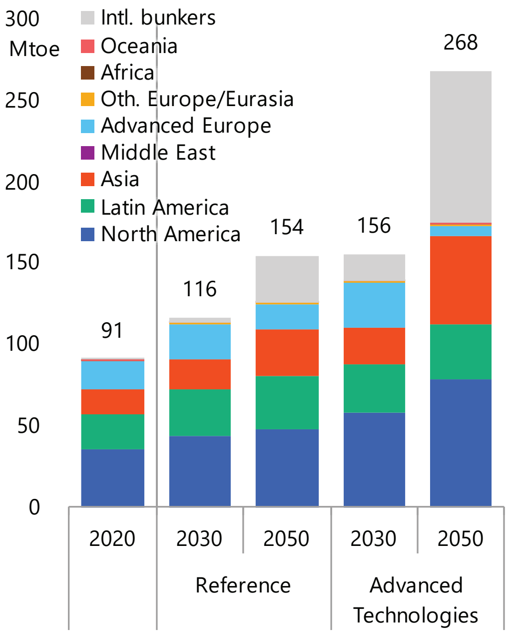
Advanced Technologies Scenario

Energy intensity improvement in industry sector

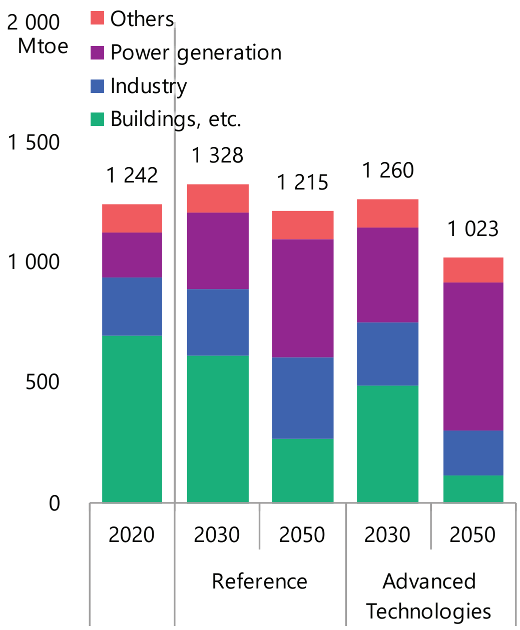


Biomass

Biofuels for transport

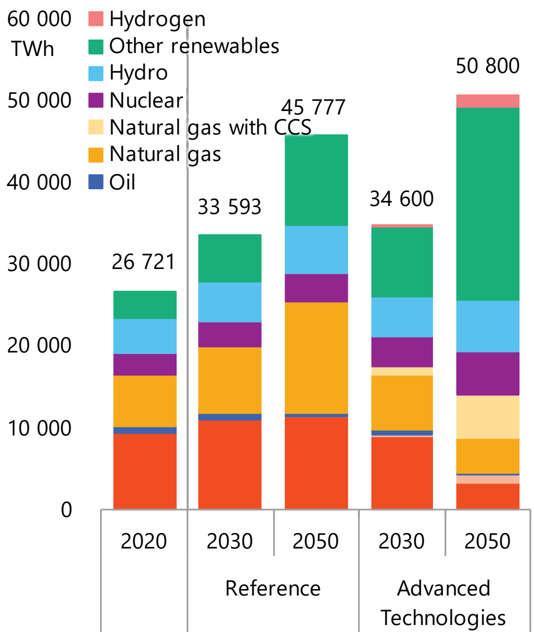


Solid biomass

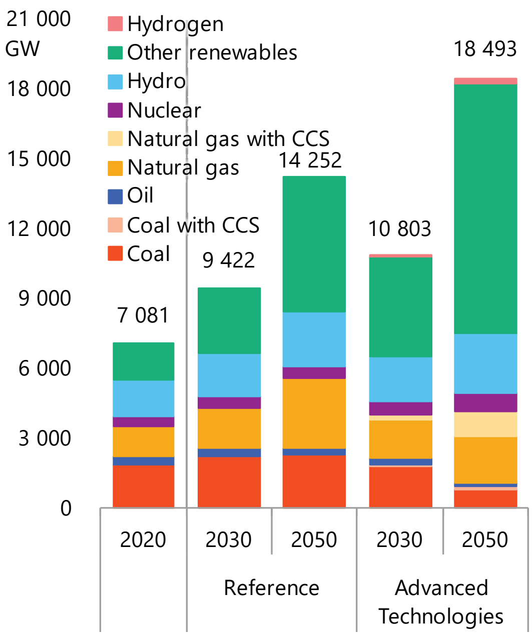


Power generation mix

Electricity generated



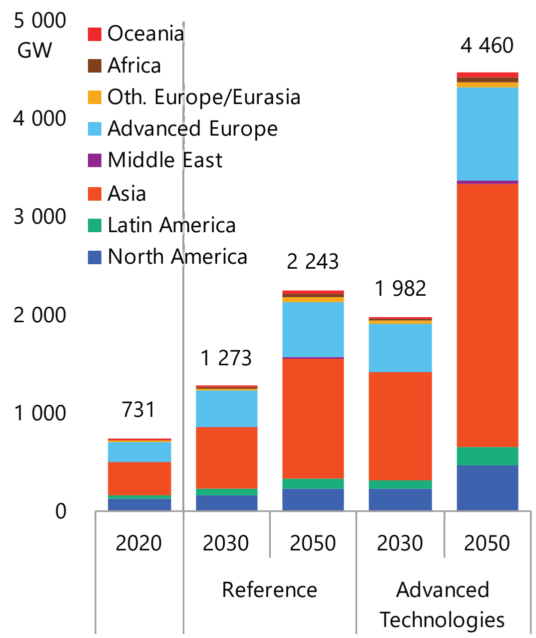
Power generation capacity



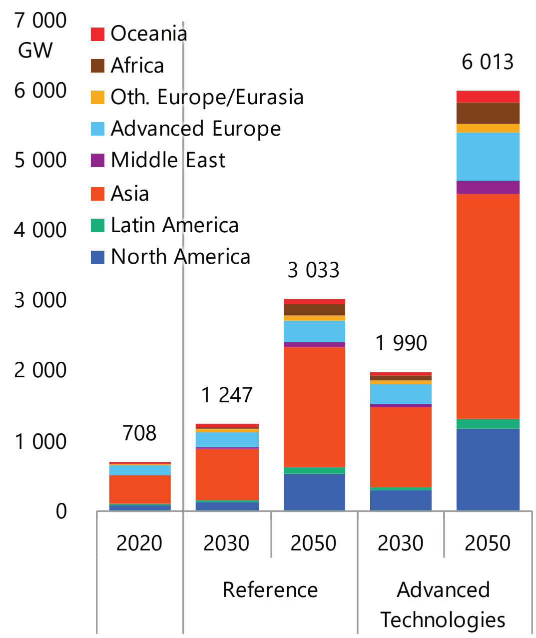
Advanced Technologies Scenario

Wind and solar PV power generation capacity

Wind



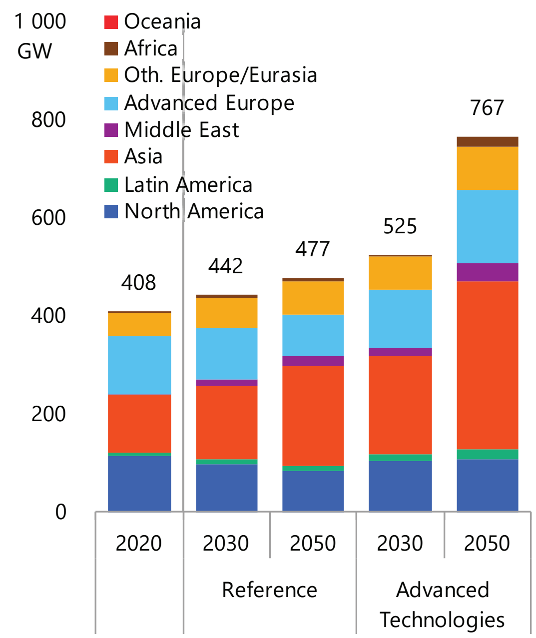
Solar PV



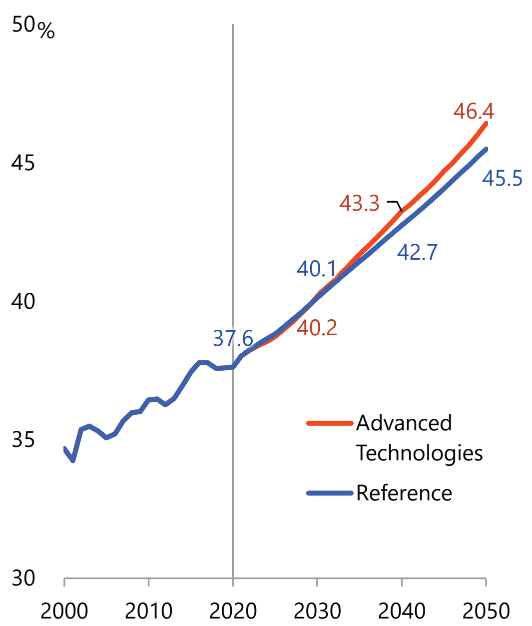
Advanced Technologies Scenario

Nuclear power generation capacity and thermal power generation efficiency

Nuclear



Thermal power generation efficiency (generation end)

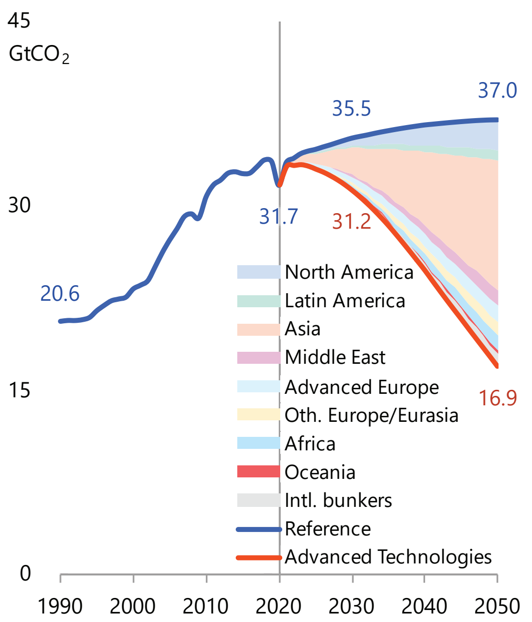


Advanced Technologies Scenario

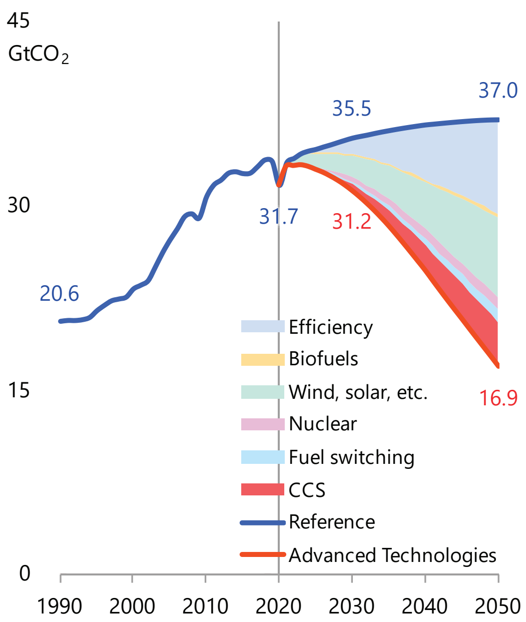
Energy-related CO_2 emissions

IEE JAPAN

By region



By technology

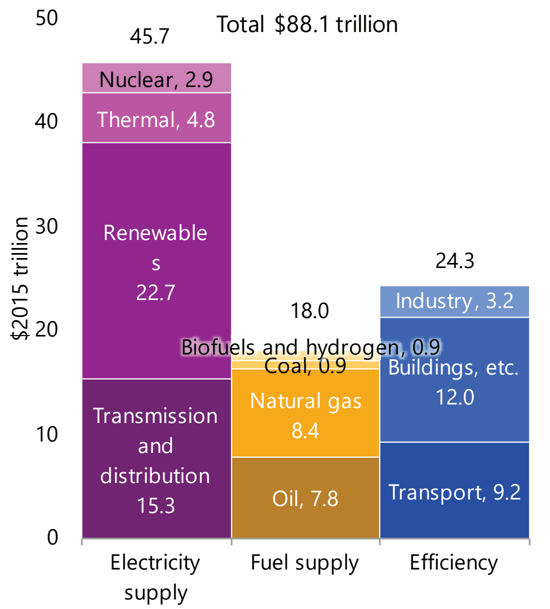


Advanced Technologies Scenario

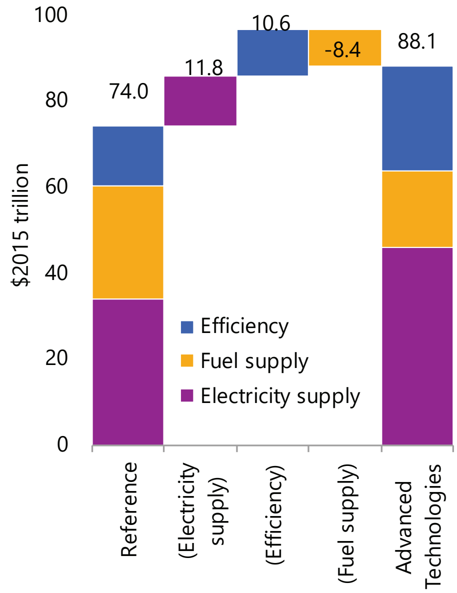
Energy-related investments (2021 – 2050)

IEE JAPAN

By sector

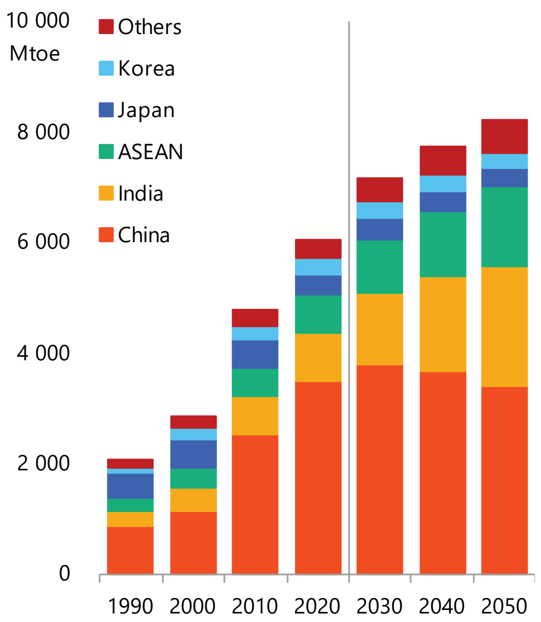


Changes from Reference Scenario

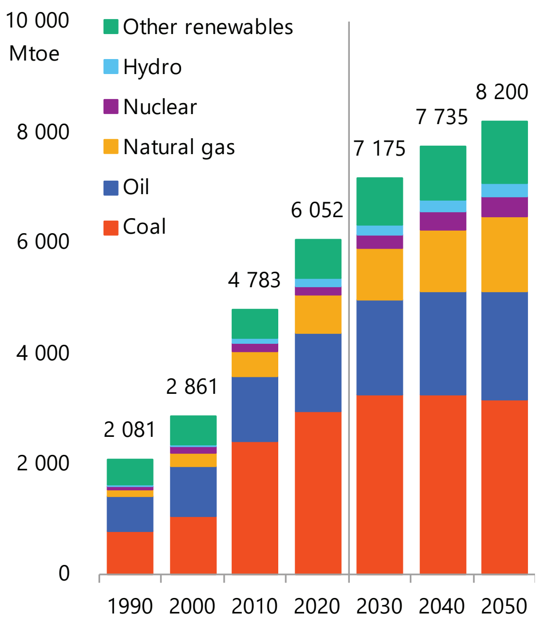


Primary energy consumption

By region

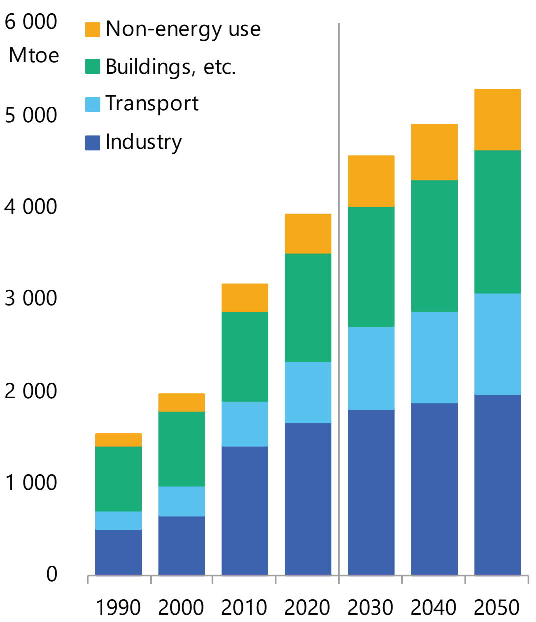


By energy source

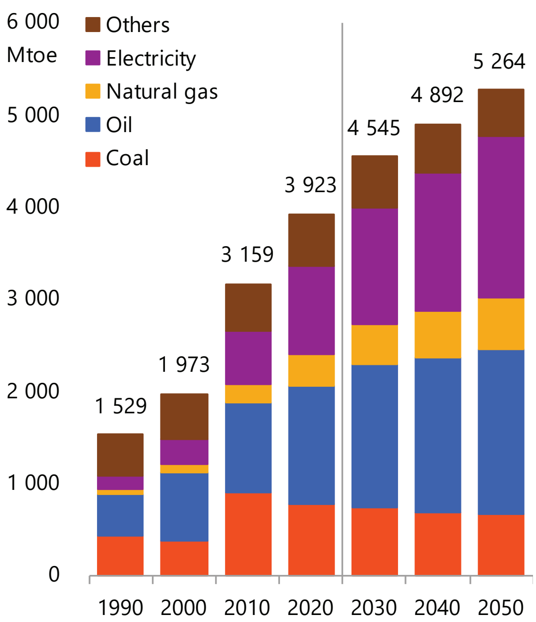


Final energy consumption

By sector



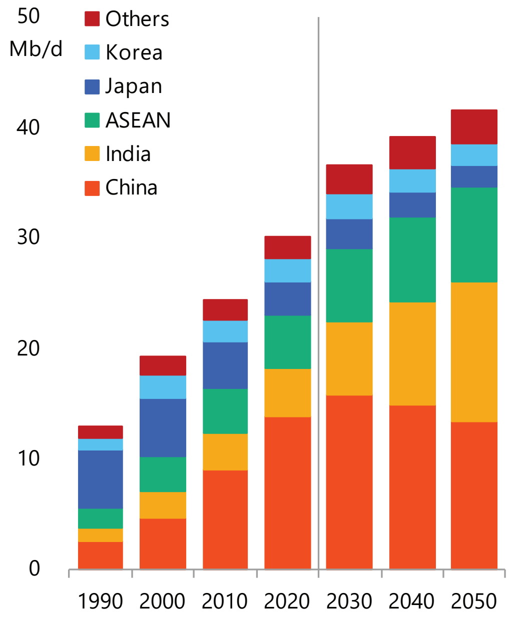
By energy source



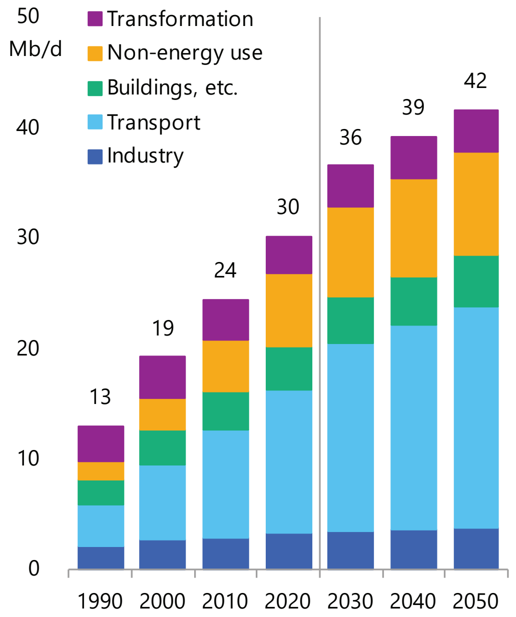
Asia | Reference Scenario

Oil consumption

By region



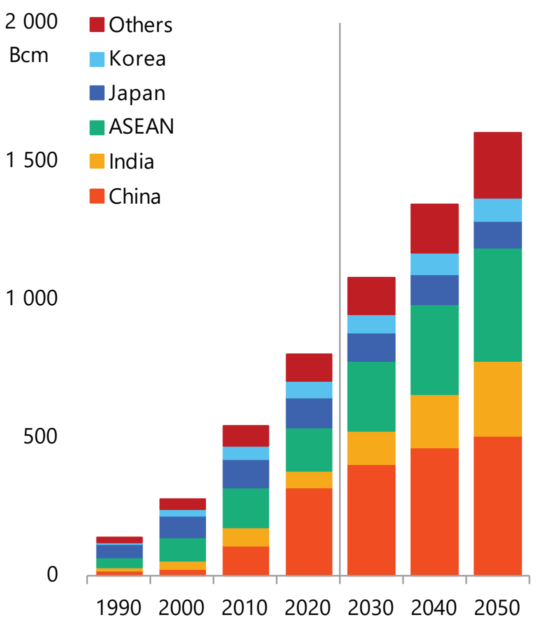
By sector



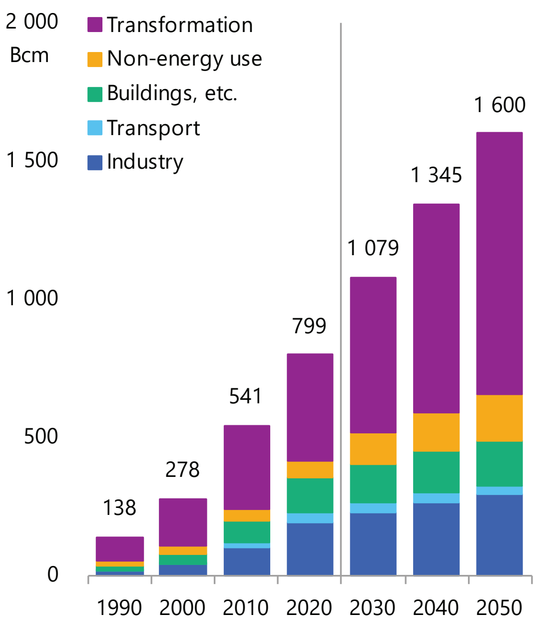
Asia | Reference Scenario

Natural gas consumption

By region



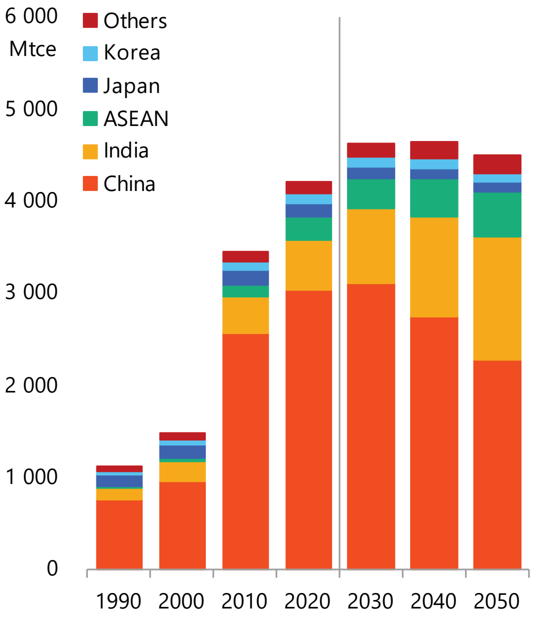
By sector



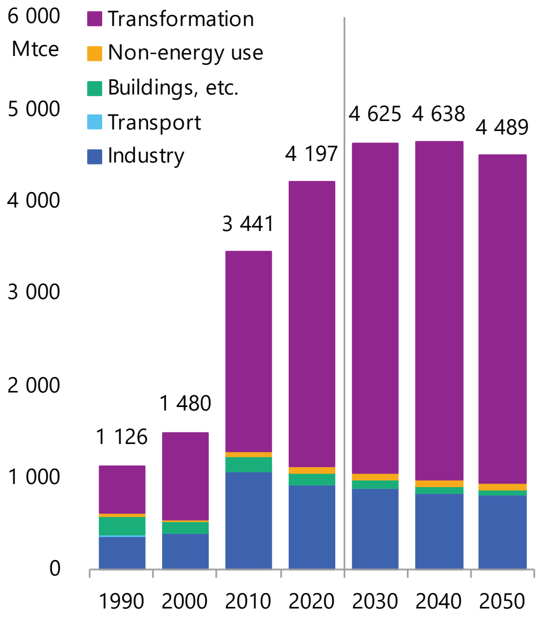
Asia | Reference Scenario

Coal consumption

By region



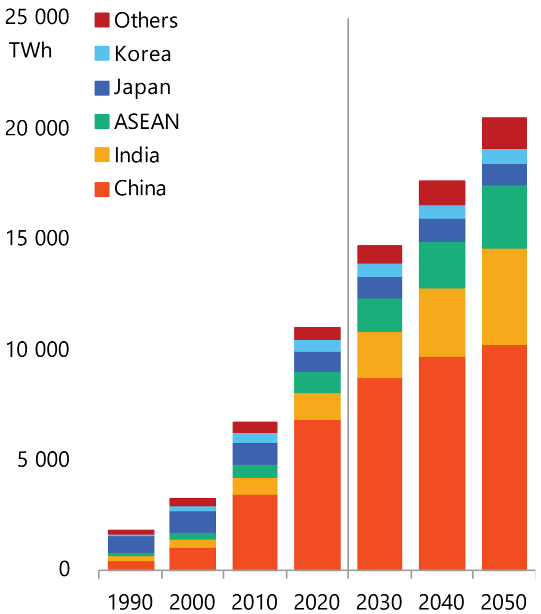
By sector



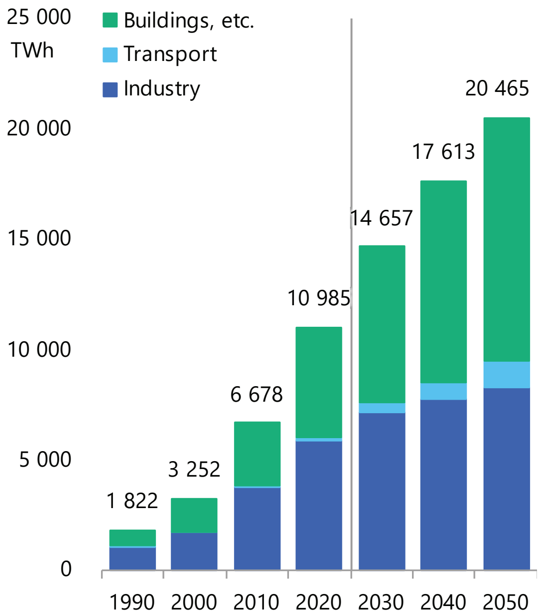
Asia | Reference Scenario

Final consumption of electricity

By region



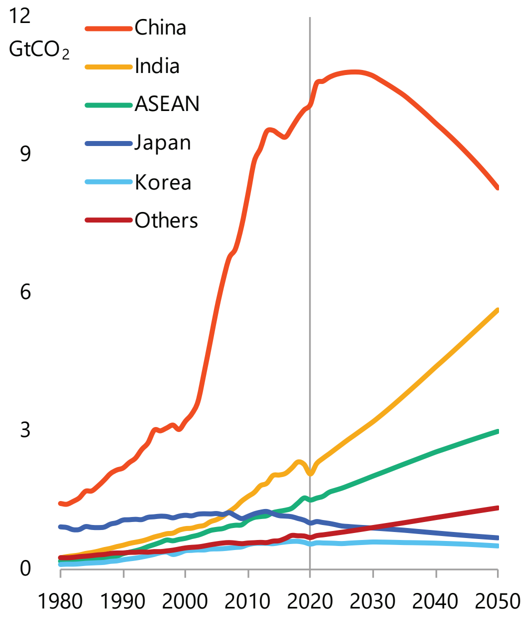
By sector



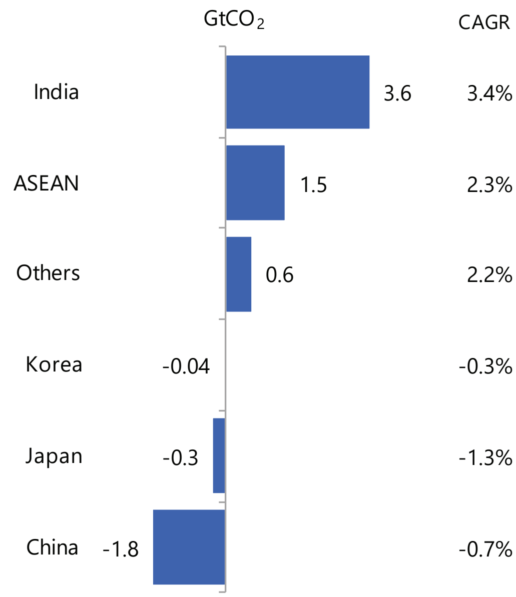
Asia | Reference Scenario

Energy-related CO_2 emissions

Emissions



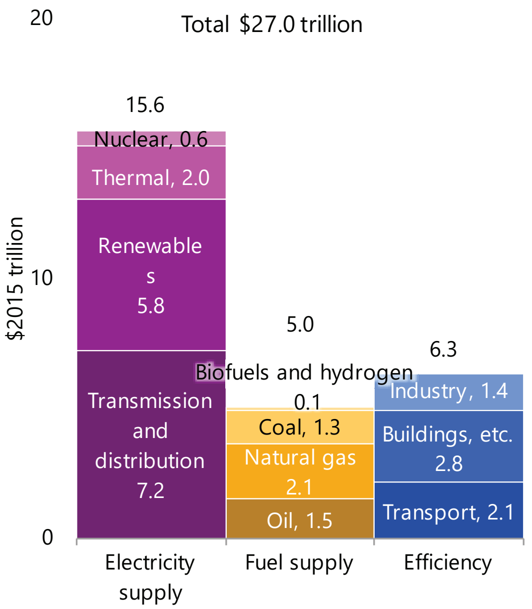
Changes (2020-2050)



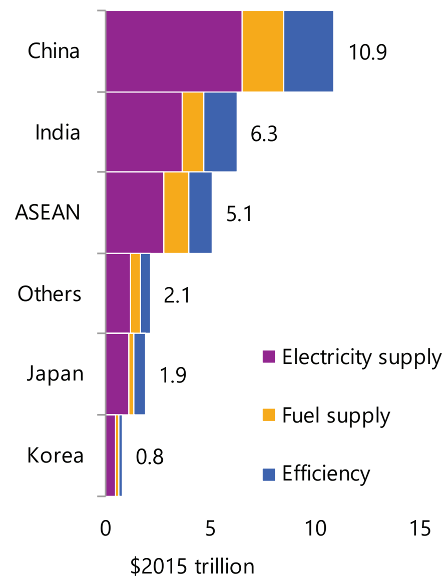
Asia | Reference Scenario

Energy-related investments (2021 – 2050)

By sector



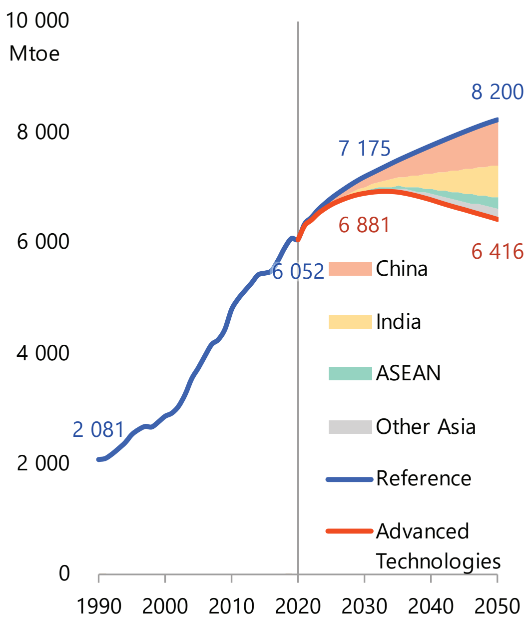
By region



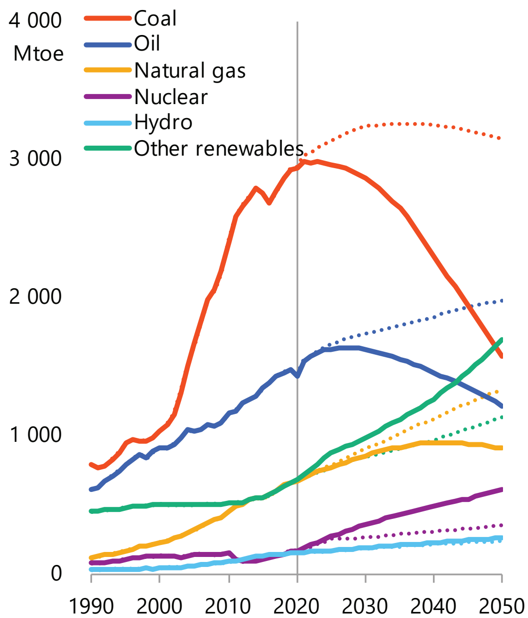
Asia | Advanced Technologies Scenario

Primary energy consumption

By region



By energy source

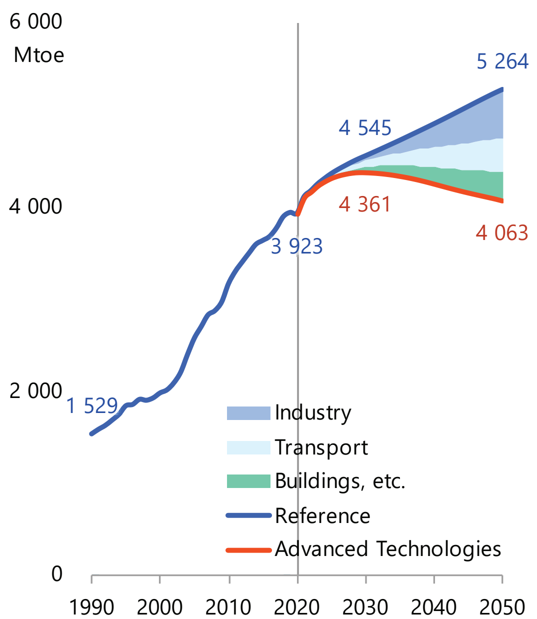


Note: Solid lines stand for Advanced Technologies Scenario and dotted lines stand for Reference Scenario.

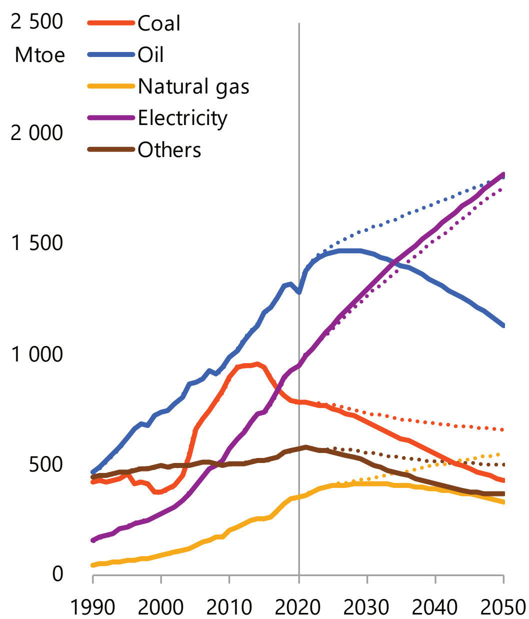
Asia | Advanced Technologies Scenario

Final energy consumption

By sector



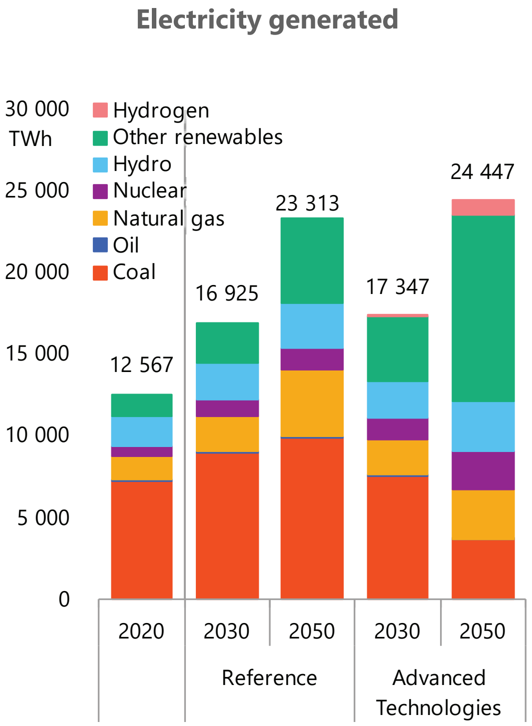
By energy source

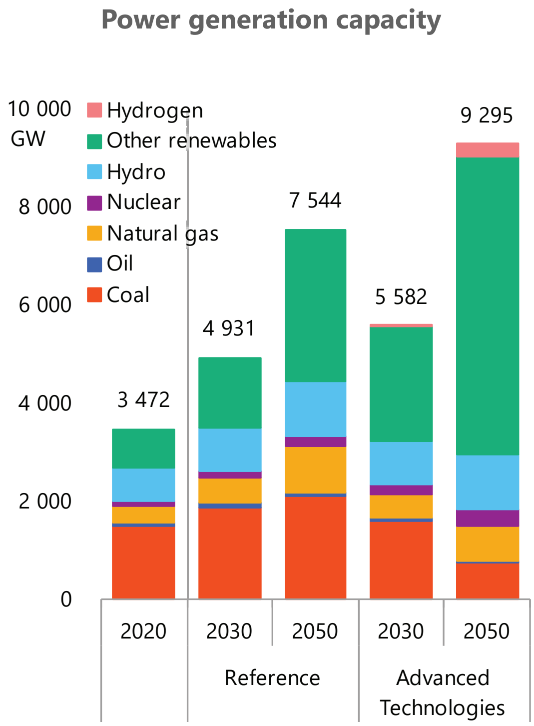


Note: Solid lines stand for Advanced Technologies Scenario and dotted lines stand for Reference Scenario.

Asia | Advanced Technologies Scenario

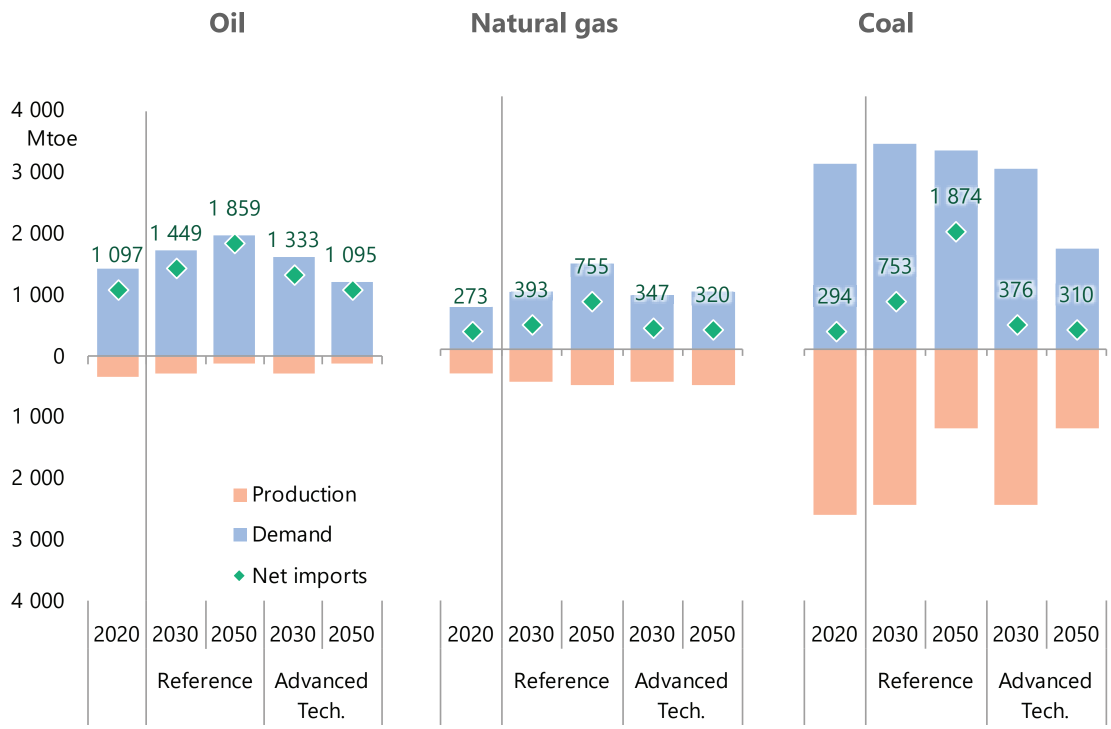
Power generation mix





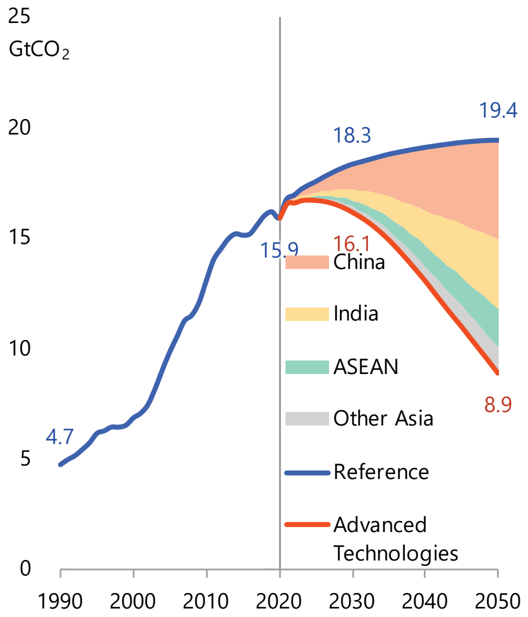
Asia | Advanced Technologies Scenario

Supply and demand balance of fossil fuels

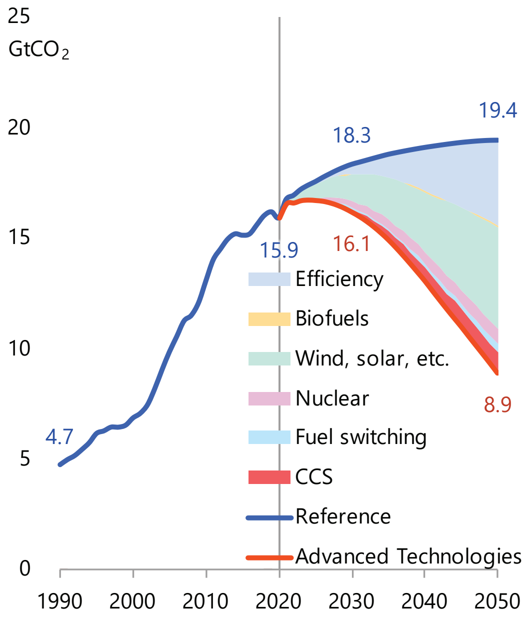


Energy-related CO_2 emissions

By region

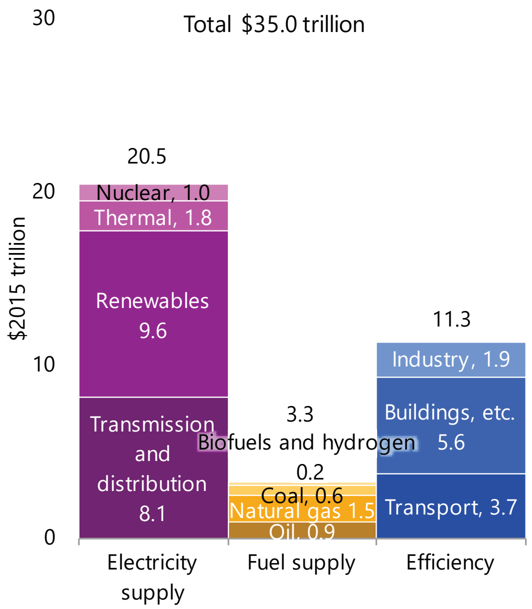


By technology

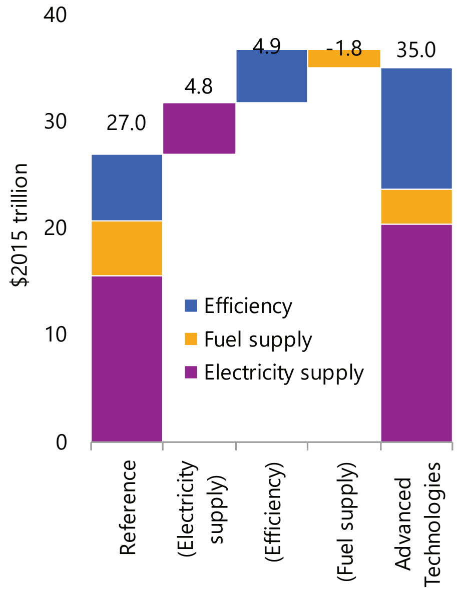


Energy-related investments (2021 – 2050)

By sector

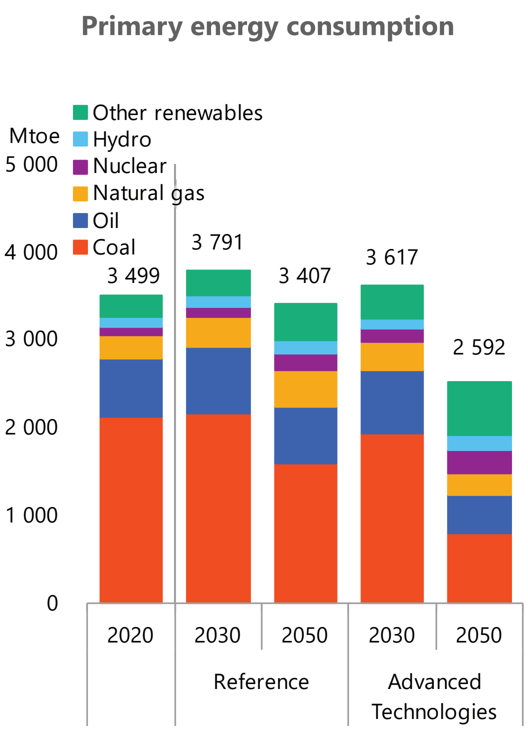


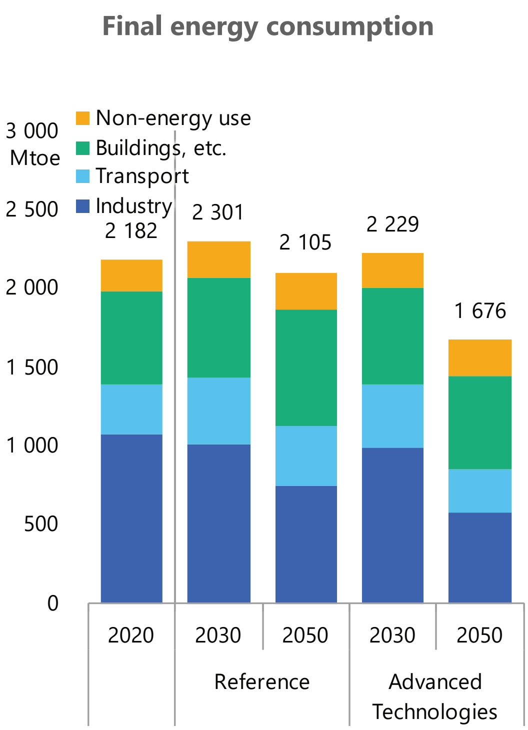
Changes from Reference Scenario



China

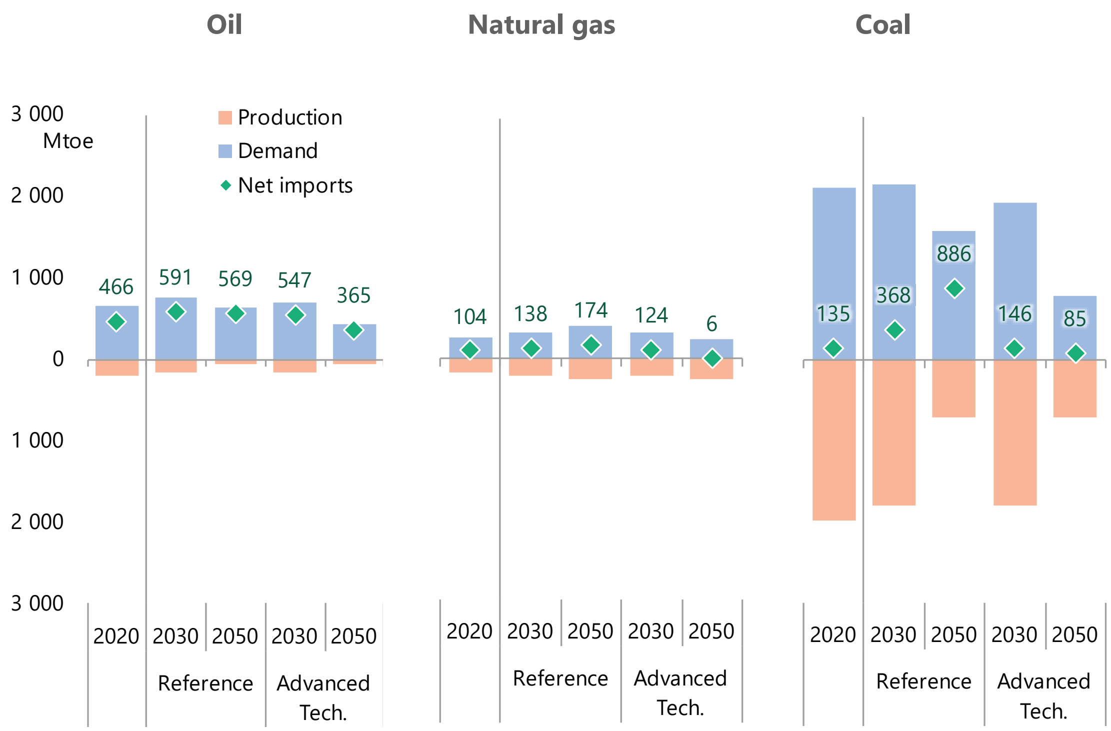
Energy consumption





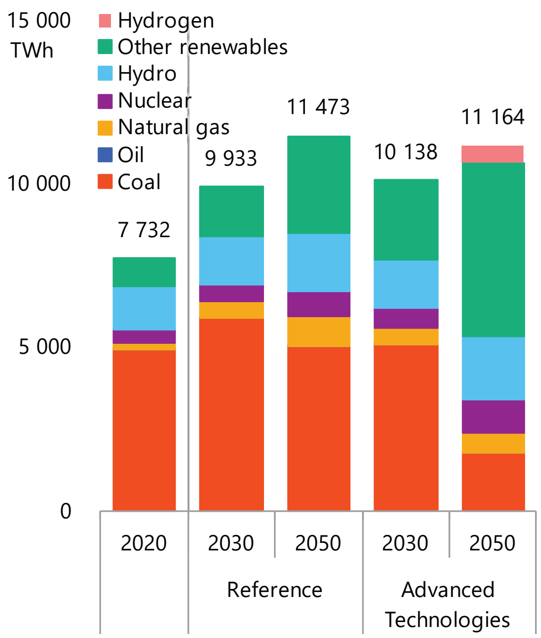
China

Supply and demand balance of fossil fuels

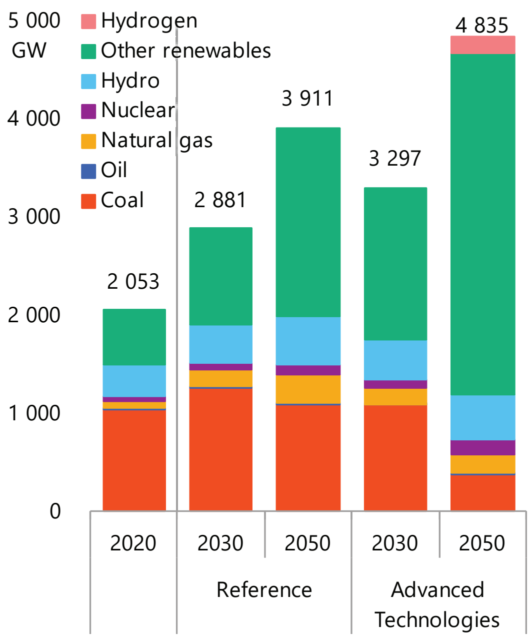


Power generation mix

Electricity generated

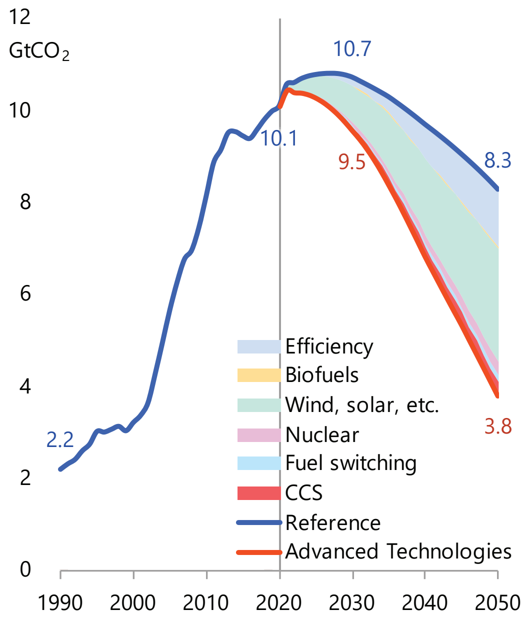


Power generation capacity



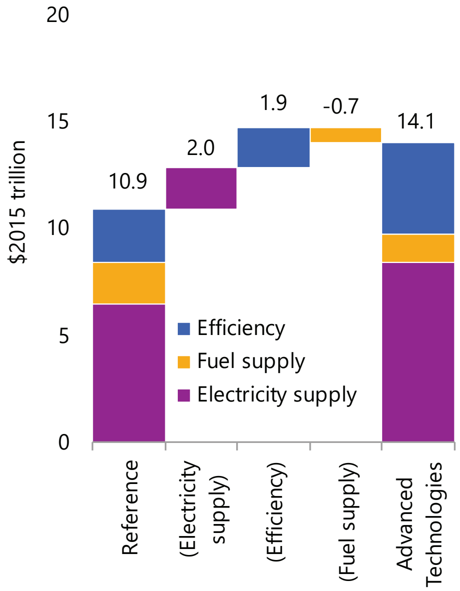
Energy-related CO_2 emissions and investments

CO_2 emissions



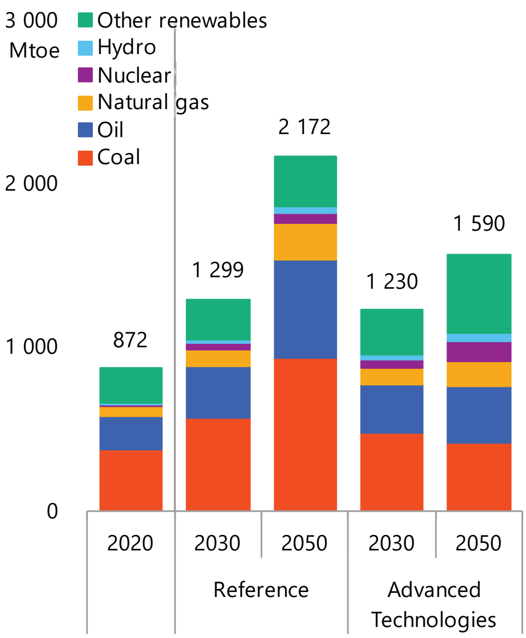
Investments

(2021 – 2050)

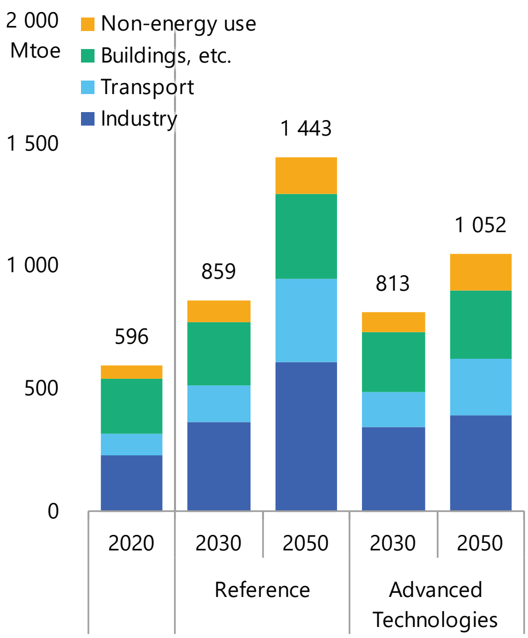


Energy consumption

Primary energy consumption



Final energy consumption

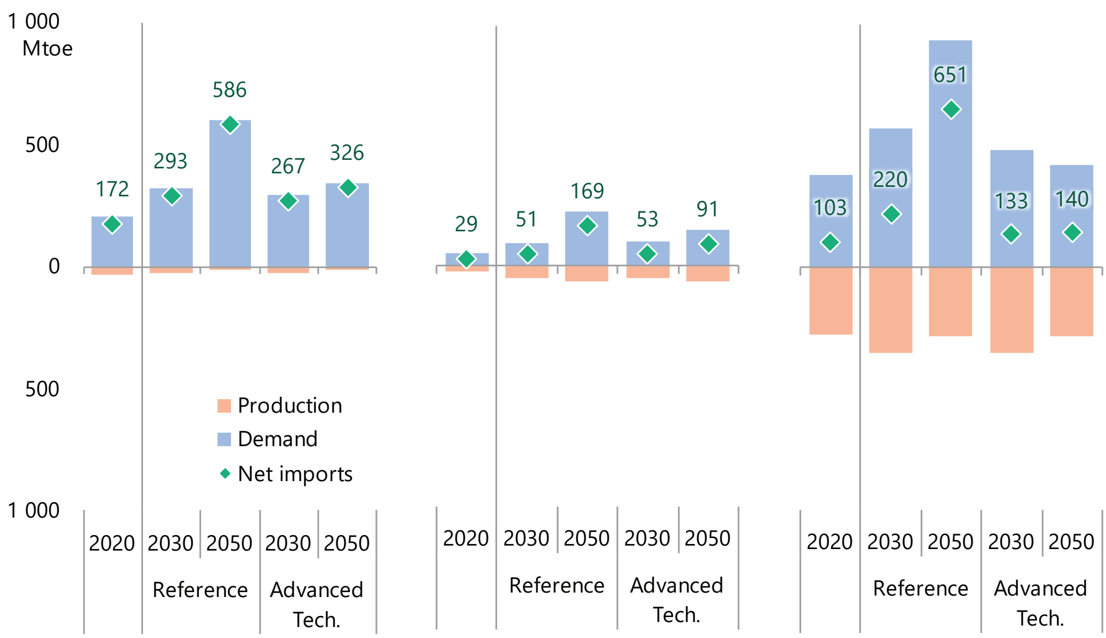


Supply and demand balance of fossil fuels

Oil

Natural gas

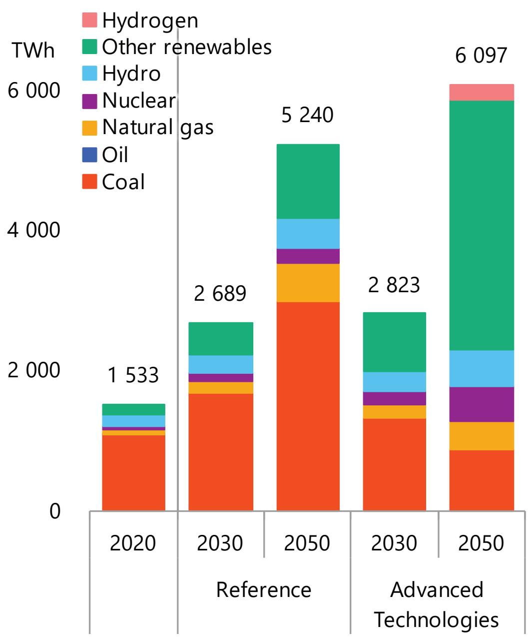
Coal



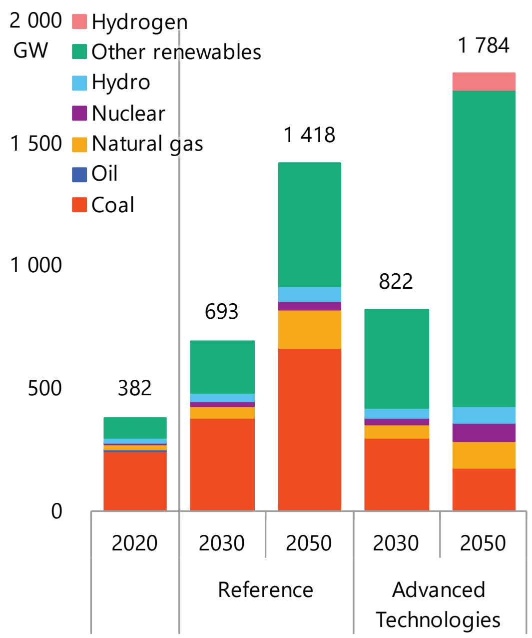
India

Power generation mix

Electricity generated



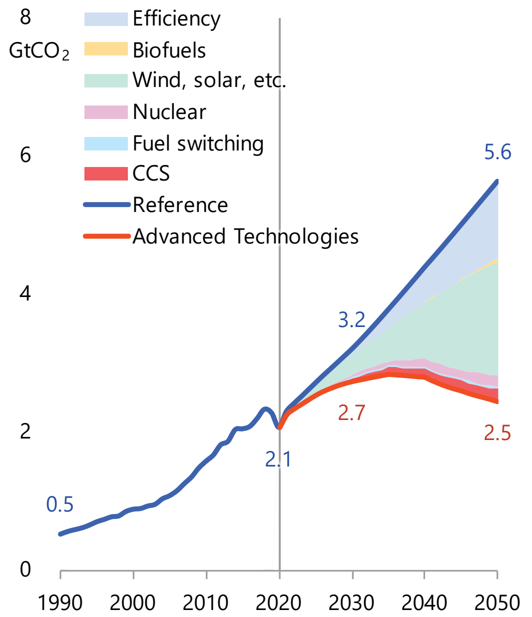
Power generation capacity



India

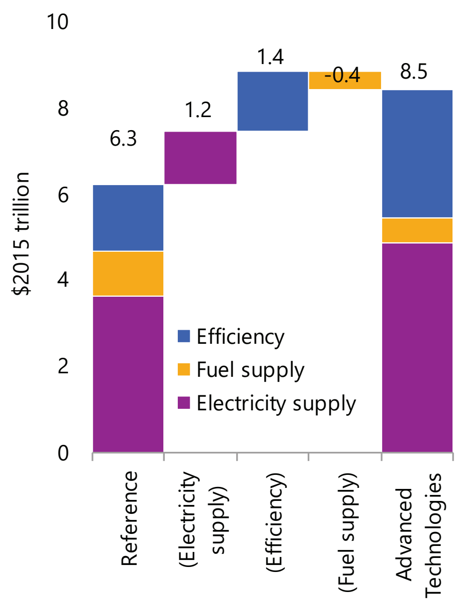
Energy-related CO_2 emissions and investments

CO_2 emissions



Investments

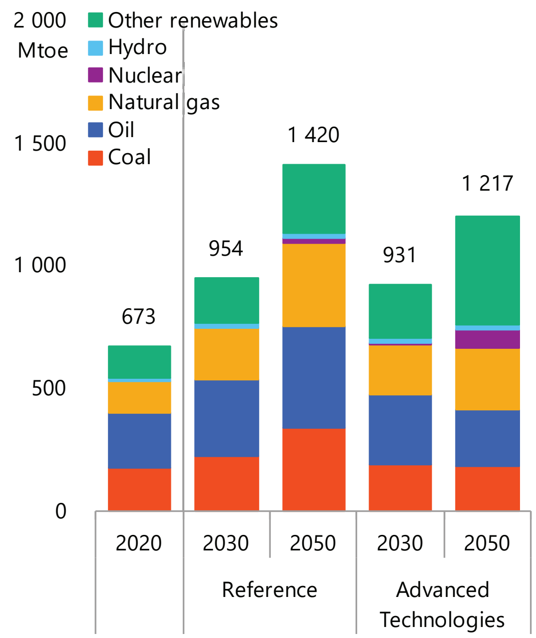
(2021 – 2050)



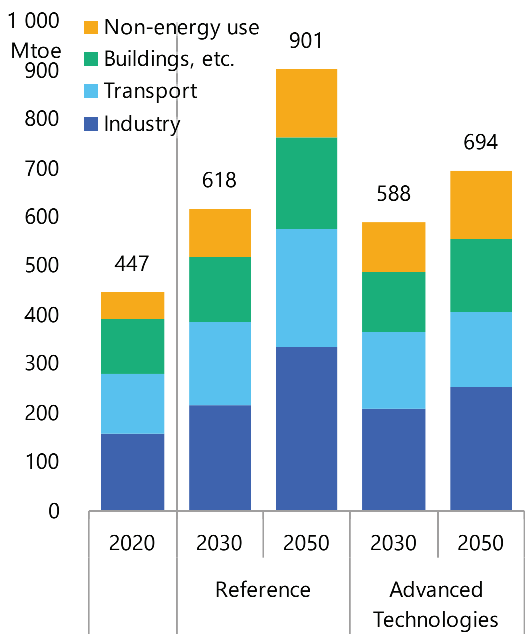
ASEAN

Energy consumption

Primary energy consumption



Final energy consumption



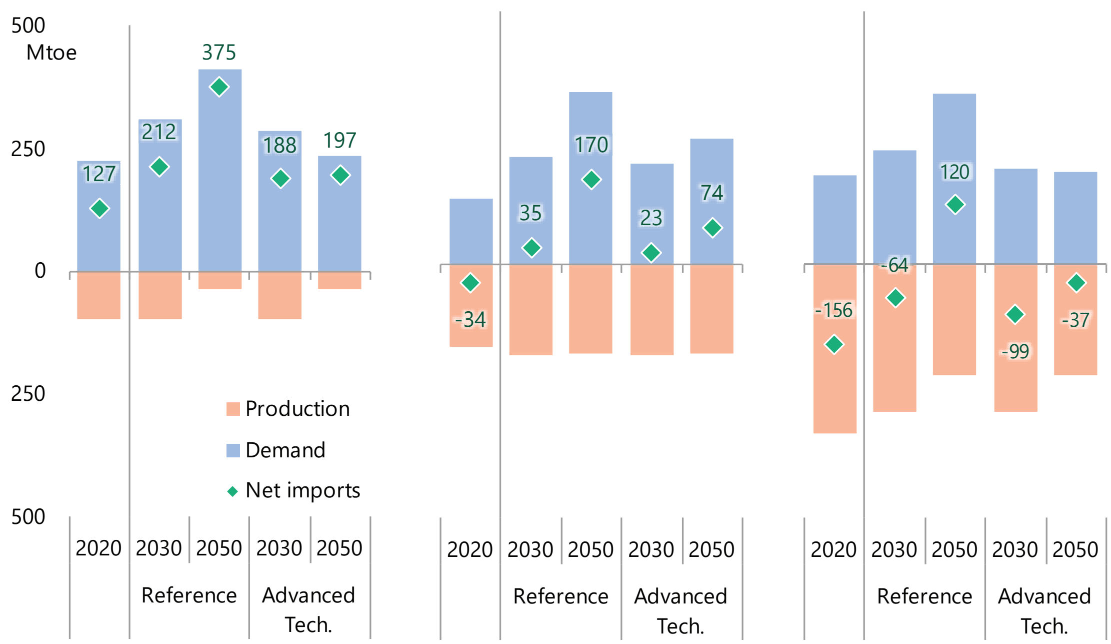
ASEAN

Supply and demand balance of fossil fuels

Oil

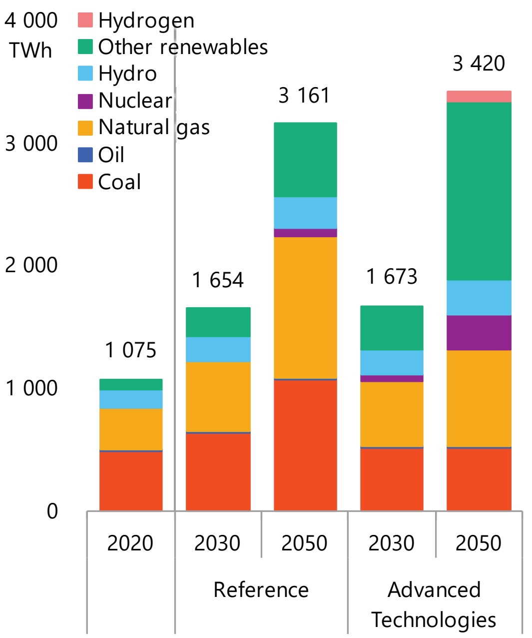
Natural gas

Coal

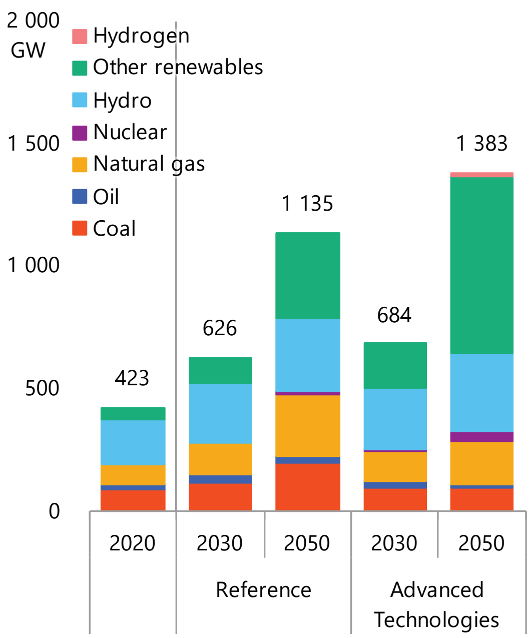


Power generation mix

Electricity generated

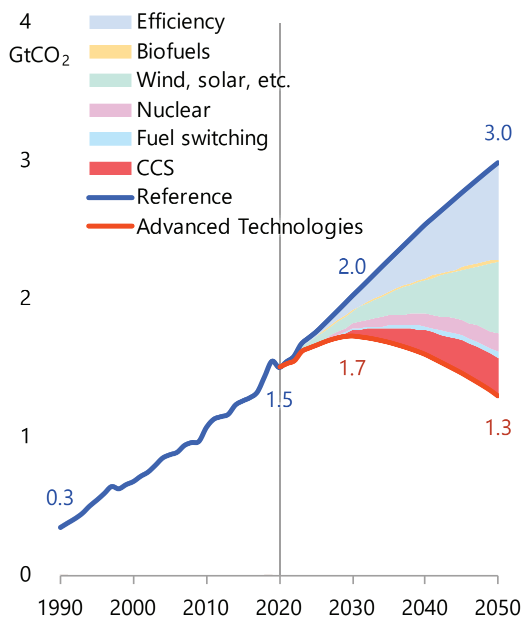


Power generation capacity



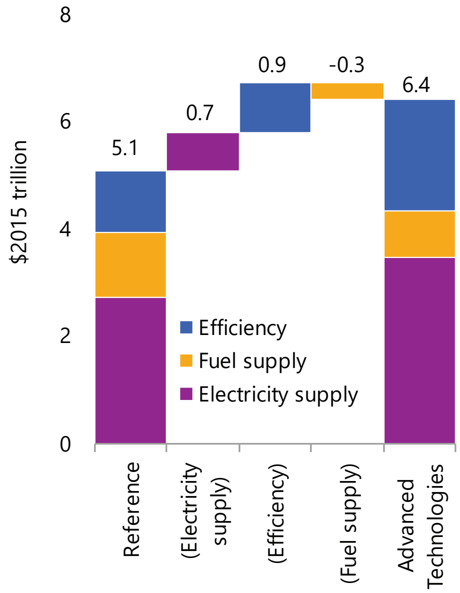
Energy-related CO_2 emissions and investments

CO_2 emissions



Investments

(2021 – 2050)



The tables for IEEJ Outlook 2023 are currently available at https://eneken.ieej.or.jp/en/whatsnew/442.html.

The full text will be available early 2023 at the same URL.

IEEJ Outlook 2023

October 2022

The Institute of Energy Economics, Japan

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