IEEJ Outlook 2025

Energy, Environment and Economy

How to address the uncertainties surrounding the energy transition

Overview

IEE JAPAN

Naoko DOI
Seiya ENDO
Ryou ETOU
Tatsuya HAGITA
Hiroshi HASHIMOTO
Rino HIROSE
Takehiro IWATA
KAN Sichao
Kenji KIMURA
Yoshikazu KOBAYASHI
Ken KOYAMA
Ichiro KUTANI
Tomoko MATSUMOTO
Tetsuo MORIKAWA
Soichi MORIMOTO
Taiju MORIMOTO
Tomoko MURAKAMI
Yu NAGATOMI
Yuto NAKANO
Yasushi NINOMIYA
Junichi OGASAWARA
Kenichi ONISHI
Atsuo SAGAWA
Toshiyuki SAKAMOTO
Yoshiaki SHIBATA
Yoshiaki TAKAHASHI
Kazuki YAMAMOTO
Yukari YAMASHITA
Akira YANAGISAWA

Summary

Global energy supply and demand outlook through 2050

Future primary energy: India and ASEAN drive demand expansion

- Our analysis presents two scenarios[1] for global energy supply and demand through 2050. Following current trends, the Reference Scenario projects a 14% increase in global primary energy demand from 2022 to 2050. In contrast, the Advanced Technologies Scenario, which assumes the ambitious deployment of energy and environmental technologies, shows demand will peak by 2030 and fall 6% below 2022 levels by 2050.

- Both scenarios indicate declining energy demand in Advanced Economies and China while Emerging and Developing Economies—particularly India and Association of Southeast Asian Nations (ASEAN)—emerge as the primary growth drivers.

Key CO_2 reduction pathways: focus on efficiency, renewables, and CCUS

- The Reference Scenario shows global energy-related carbon dioxide (CO_2) emissions plateauing at 32.7 Gt by 2050, as efficiency gains offset demand growth. The Advanced Technologies Scenario projects a significant 62% reduction to 12.9 Gt. The massive reduction requires the convergence of various technologies and mainly relies on three key pillars: energy efficiency improvements, renewable energy expansion (primarily solar photovoltaics and wind), and carbon capture, utilisation and storage (CCUS) deployment.

- Energy efficiency improvements could deliver 6.2 Gt-CO_2 in reductions between the scenarios. The greatest potential lies in Emerging and Developing Economies, where implementing proven technologies from Advanced Economies is crucial. This is especially critical for China, India, and ASEAN, where industrial energy consumption is set to surge.

- However, we must recognise the lag time between efficiency measures and results—it typically takes over a decade for improvements in new equipment to significantly impact overall stock efficiency for users. Meeting the Advanced Technologies Scenario's 2050 targets require immediate action for efficiency improvement.

- Renewable energy shows dramatic growth potential, reaching nearly 60% of global electricity generated in the Advanced Technologies Scenario (excluding hydro). This penetration level means many regions will have variable renewable power generation capacity exceeding their average load, requiring significant investments in grid-scale energy storage, transmission infrastructure, demand response systems integration with existing pumped storage hydro and thermal power generation backup, and so on.

- Overall electricity generated is projected to increase 1.6 times (Reference Scenario) to twice (Advanced Technologies Scenario) from 2022 levels by 2050, requiring substantial grid infrastructure expansion.

[1] The scenarios in IEEJ Outlook represent forward-looking projections based on current trends and technology pathways, distinct from backward-planning approaches that start with specific targets (e.g., net zero emissions by 2050) and work backward.

- CCUS emerges as a critical technology, capturing 5.1 Gt-CO_2 annually by 2050. While particularly important for power generation, CCUS—alongside hydrogen—becomes essential for hard-to-abate industrial sectors like steel and cement production, where electrification alone cannot achieve complete decarbonisation.

Fossil fuel outlook: significant uncertainty

- The scenarios reveal widely divergent paths for fossil fuels. The Reference Scenario shows increased oil and natural gas demand through 2050, while the Advanced Technologies Scenario projects declined by 40% for oil and 7% for natural gas from 2022 levels. Key variables for oil demand are road sector; electric vehicle (EV) penetration, hybrid vehicle uptake, and internal combustion engine (ICE) vehicle efficiency improvement. Natural gas and coal demand largely depends on power generation and industry sectors.
- Despite this uncertainty, fossil fuels will remain significant in the global energy mix for decades. Given natural production declines in existing fields, maintaining adequate investment in fossil fuel infrastructure remains critical for energy security, even as we accelerate the clean energy transition.

The critical role of LNG

LNG plays an important role—demand is expected to grow further

- Liquefied natural gas (LNG) is expected to play an important role as a realistic solution toward the energy transition—as a pragmatic and reliable energy source—enhancing energy security and contributing to decarbonisation at the same time. In its history, LNG has expanded and demonstrated its role in response to the demands of each era.
- Global LNG demand in 2050 is projected to increase by 74% from the present level in the Reference Scenario of the IEEJ Outlook 2025. Even in the Advanced Technology Scenario, global LNG demand is projected to expand until around 2040 and then decline, but demand in 2050 is projected to be at the same level as of today. One of the focal points of increasing demand is Southeast Asia's emerging markets, notably the power generation sector. If the energy efficiency improvements assumed in these scenarios are not realised, LNG demand would increase further.
- With the Ukraine crisis increasing the importance of stable energy supply and the emphasis on controlling energy costs under the energy transition, expectations on the important role of LNG in the long-term have been stepping up. The stability of the LNG market should be valued even further. LNG provided the flexibility to respond to the latest energy crisis. The recent instability of supply-demand balances and prices shows the importance of measures to stabilise the market from a long-term perspective.

LNG supply stability requires sustaining investment

- The LNG production sector requires additions of 10-20 million-tonne-per-year capacity each year until 2050. These include brand-new LNG production projects, back-fill gas supply development to existing LNG plants, and rejuvenations existing facilities, to meet incremental demand and to supplement reductions of productivity of existing gas fields and processing facilities.

- The capacity for which final investment decisions (FIDs) were made during the past three years apparently exceeded the above-mentioned required capacity. However, uncertainty should be noted over realisation and timely implementation of those sanctioned projects.

Long-term agenda toward the stable LNG market

- As expectations are high for LNG's role as a viable solution to transition uncertainty, efforts of the LNG market and industry players are necessary to meet these expectations. Companies should make efforts to better manage methane and greenhouse gas (GHG) emissions, to set higher goals, and to disclose appropriate and timely information. It is important to make the entire LNG value chain even cleaner. It is also helpful if the industry can make LNG look more attractive as an investment and financing target.
- In order to expand and maintain LNG production in gas producing countries, including North America and Australia, it is important for companies and governments in consuming countries to encourage stabilisation of regulatory aspects and project development in LNG producing countries, as well as to participate in such development.
- Medium- to long-term demand aggregation and market development support, including those in emerging markets in Southeast Asia, will lead to expansion of the global LNG market and support for LNG production development.

Issues surrounding LNG production project development

- The rapid expansion of LNG supply since the early 2010s has shifted its focus from Qatar to Australia, and then to the United States. While development costs have been on the rise, efforts have been also made to reduce costs such as floating LNG production, small- and medium-scale liquefaction, and modularisation of construction.
- Imminent LNG export from the West Coast of North America should be a gamechanger in LNG marine transportation—avoiding transportation bottlenecks, shortening and diversifying transportation routes.
- LNG export capacity in the United States is expected to grow steadily over the next few years, although long-term development is uncertain due to the non- free trade agreement (FTA) export authorisation pause and regulatory uncertainty. No FIDs have been made on new LNG production projects in the United States so far in 2024. Some projects under construction or development face court-challenge risks and completion risks. Proactive participation in LNG production projects from an LNG importing country, as well as visible expressions of expectation of increasing LNG supply, would be even more important.
- The steady realisation of FIDs over the past few years was driven by long-term commitments by LNG buyers. Portfolio players have become increasingly important in these commitments, while commitments of Japan LNG buyers represent a smaller portion than in the past.
- A steady increase of LNG production capacity is expected in the medium term, although construction delays are now the norm. As the increasing supply is likely to be absorbed by markets in Asia and elsewhere, widely touted "oversupply" around the end of the decade is unlikely.
- Major LNG export regions with gas resource potential face their respective agenda and challenges. Australia should maintain stable LNG production through further development of gas fields surrounding existing LNG development areas. Qatar is implementing mega expansion projects while incorporating value-chain cleaning measures, and additional

marketing activities from the projects are a point of interest. East Africa with a large resource potential has yet to step up to full-fledged development.

Bottlenecks of LNG transportation and troubles at LNG production plants have impacts on the balance of the market

- Bottlenecks on important shipping routes are likely to be a major obstacle in times of tight supply and demand. It is necessary to develop a long-term LNG transportation strategy.
- Increasing unplanned outages at LNG production facilities are likely to exacerbate supply-demand imbalances, which also necessitate countermeasures with long-term perspectives.

Risk scenarios for energy security

- Securing the necessary amount of energy at an affordable price is essential for society and the economy. However, history has proven that a stable supply of energy can be threatened by a variety of factors. Various risks affect the stable supply of energy, and it is important to correctly understand where the risks lie and their effects, and to take the necessary countermeasures. In the following, we identify and discuss five risks that are considered to be of particular importance in light of today's international energy context.

Risks of fossil fuel underinvestment

- According to the Reference Scenario of the IEEJ Outlook 2025, fossil fuels will still provide 73% of global energy demand in 2050. Asia will become more important in terms of demand regions, while the Middle East and North America (oil and natural gas) and Asia (coal) will have a higher share in supply regions. Stable investments, especially in these supply regions, are of vital importance for the stable supply of fossil fuels. During the long transitional period, fossil fuel supply and demand will become tight if sufficient investments are not made.
- Some argue that no new investment in fossil fuels will be necessary as fossil fuel demand will decline rapidly in the "ideal" carbon neutral society. The risk of fossil fuel underinvestment due to gap between the "ideal world" and reality has become apparent. Without additional investment, oil and natural gas production in 2050 will be drastically reduced to about one-tenth of the current level due to the natural decline of production. It would create a large gap with fossil fuel demand in the real world.
- Tight supply and demand balance for oil and natural gas due to underinvestment is likely to lead to higher prices. A hypothetical 50% increase in oil and natural gas import prices would increase the share of net oil and natural gas imports in the GDP of major Asian importing countries and regions by 1%-3% points. The impact on developing economies such as India and ASEAN is of greater concern, especially.

More serious and diverse geopolitical risks

- Geopolitical risks continue to be a major concern for energy security. As Japan's dependence on the Middle East for crude oil imports reach to historical high 95% in 2023, the geopolitical risks in the Middle East region for Japan are becoming more serious due to the escalation of the situation in Gaza and the deepening conflict between Iran and Israel.
- In addition to the risk of political instability in resource-exporting countries and regions, policy changes in advanced economies have also become a risk factor in recent years. Japan's

coal and LNG imports are highly dependent on advanced economies (81% for coal and 50% for LNG in 2023), but the United States and Australia have introduced policies that increase uncertainty about the future of domestic resource development and exports, reflecting domestic voices concerning climate change issues. This could pose a challenge for market stability over the medium to long term.

Risks of electricity supply instability

- The advancement of digitisation and electrification is increasing society's dependence on electricity. In particular, the deployment of electric vehicles and the expansion of data centres are driving increase of electricity demand. Efforts for decarbonisation will further promote electrification of demand.
- The energy transition is pushing solar photovoltaic and wind power, whose output fluctuates with the weather and the seasons, to become the mainstay of electricity supply. It is necessary to ensure a stable supply of electricity as the share of these variable power sources increases.
- On the electricity supply side, risks of supply stability include supply shortage and price fluctuation of fossil fuels, geopolitical risks, and fluctuations in the output of renewable power sources. On the electricity demand side, there is the risk of an increase in electricity demand and uneven distribution of electricity demand. To address these risks, it will be necessary to secure fossil fuel procurement and baseload power sources such as nuclear, secure supply capacity, and optimise the power system. It is also essential to pursue the best mix for stable supply.

Risks of critical mineral supply

- Manufacturing capacity of some decarbonisation technologies and critical minerals, which are essential for and raw materials for clean energy investments, have high market concentration and are increasingly recognised as a new risk in the energy transition.
- Critical minerals market is smaller and less mature than the fossil fuel market, making it more prone to market dominance, supply-demand imbalances, and the resulting price volatility. The high uncertainty that exists regarding future demand for clean technologies and the fact that it takes about 10 years or more to develop new resources make it difficult to invest in supply source diversification. The intensifying international competition to secure strategic commodities and the heightened resource nationalism should also be taken into account.
- Risk mitigation is possible through combining various technologies with different nature of risks. Development and market creation of those technologies must be promoted.

Increasing risks of cyber-attacks

- Since mid-2010s, the number of critical cyber-attack events has increased significantly worldwide. The energy transition, with its accompanying electrification, digitisation, and network connectivity, has resulted in an increase in the severity of cyber-attacks as a potential risk factor.
- There are diverse patterns of cyber-attacks, with different actors, objectives and targets of attack. In looking at the future international energy situation, cyber-attacks against fundamental energy infrastructure, will become a key issue in energy security. Geopolitical

risks should not be underestimated, and the possibility of weaponisation in the form of threats to energy supply should also be taken into account.

The 448th Forum on Research Work

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Tokyo, 18 October 2024

The Institute of Energy Economics, Japan

IEEJ Outlook 2025
Global Energy Supply and Demand Outlook to 2050

The Institute of Energy Economics, Japan

Seiya ENDO
Senior Economist, Energy Data and Modelling Center

Key Points

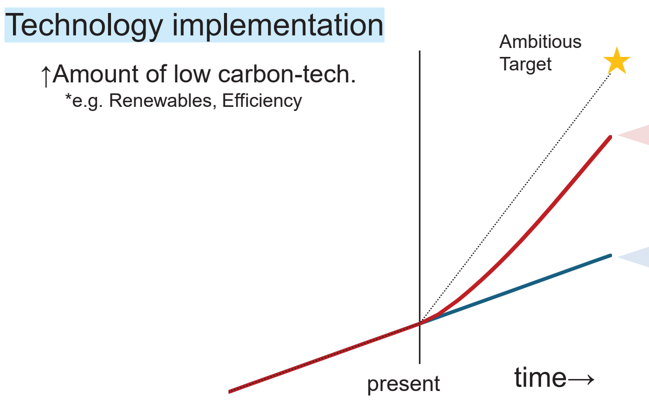
- ✓ Quantitative assessment of global energy supply and demand through 2050, using two scenarios:
  (**Reference**: Current Trends & **Adv.Tech.**: Maximum Climate Action)

- ✓ CO_2 reduction requires deployment of all available technologies across sectors.
  (1) energy efficiency, **(2) renewables** (especially solar and wind), and in the longer term, **(3) CCUS** will make particularly significant contributions. The outlook and implementation challenges for each are analyzed.

- ✓ Fossil fuel demand faces significant uncertainty. Stable supply remains essential over the coming decades.

Scenario Framework

- Created global energy supply and demand outlook through 2050.
  - Conducted model analysis incorporating the latest energy and socioeconomic data. Estimated energy demand by type and CO_2 emissions for 44 global regions plus international bunkers.
- Established two scenarios with different technology and policy progression assumptions.
  - Both are **forecast-type** scenarios examining "what if" scenarios, not **backcast-type** scenarios (which calculate backward from targets to determine "what should be done"). Target achievement is not necessarily incorporated.



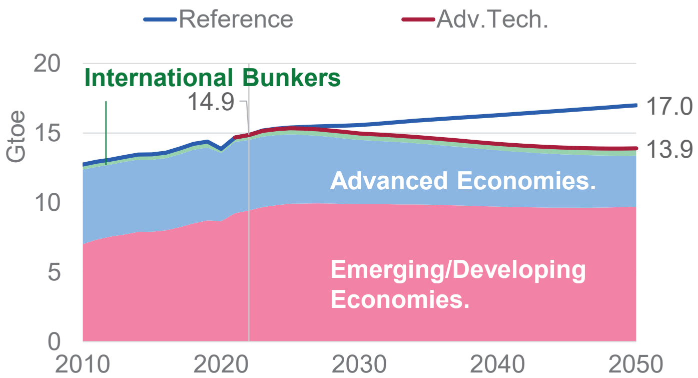
[Advanced Technologies] (Adv.Tech.)
Maximum implementation of policies for energy security and climate action, with technologies deployed to maximum extent.
(considering feasibility and acceptance)

[Reference]
Continuation of current trends in energy and environmental policies.
*Does not imply fixed current policies/technologies

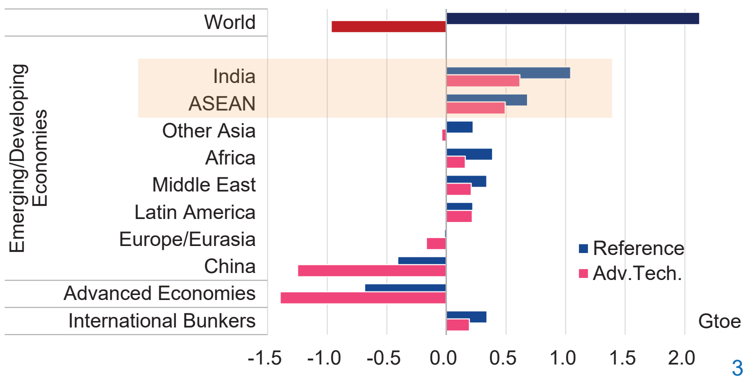
Primary Energy Demand: India and ASEAN at Center of Demand Growth

- **Reference:** Primary energy demand increases 14% from 2022 to 2050.
  - Real GDP doubles during this period. Efficiency improvements and industrial structure transformation suppress demand.
- **Adv.Tech:** Energy efficiency improvements accelerate, primary demand peaks before 2030.
- India and ASEAN drive demand growth in both scenarios, pushing up global demand.
  - Global emissions reduction requires engagement of these two regions plus other emerging/developing economies.

Primary Energy Demand (Global)

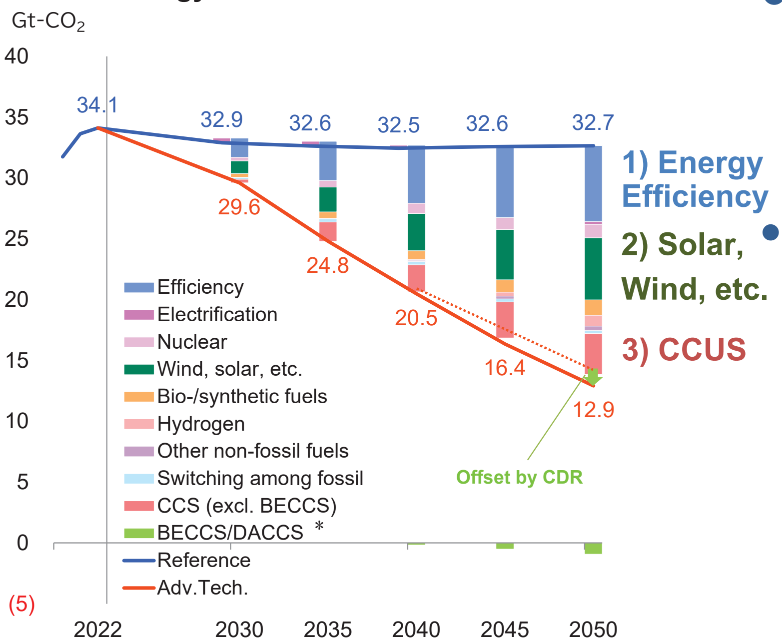


Primary Energy Demand Change(2022-2050)



CO2 Reduction: Energy Efficiency, Renewables and CCUS

Energy-Related CO2 Emission（World）

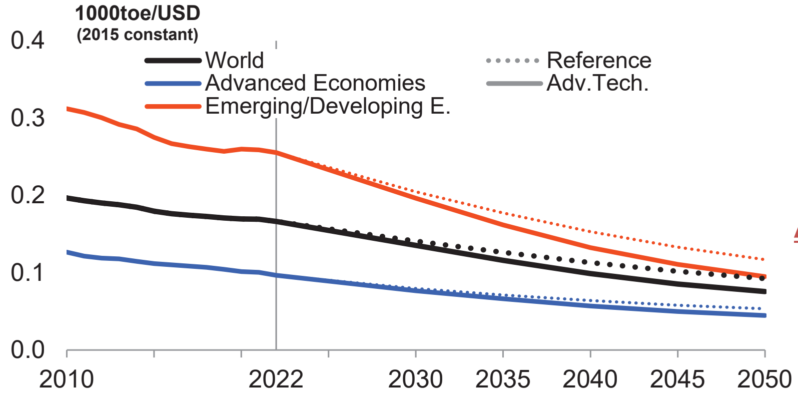


*Although not originally applicable to energy-related CO2, the offsetting effect is included for reference.

- **Reference**
  - While energy demand continues to grow, renewables expansion and electrification/natural gas switching in demand sectors suppress emissions.
- **Adv.Tech**
  - Major contributions to CO2 reduction primarily from (1) energy efficiency, (2) solar/wind, and (3) CCUS.
  - (1) and (2) contribute significantly from 2030, CCUS expands after 2040
  - Gap remains between the "2050 Net Zero" target, particularly challenging for emerging/developing nations and non-power sectors.

1)Energy Efficiency:
Major Acceleration Post-2030, in Emerging Economies

Primary Energy Intensity:
※Primary demand/Real GDP[2015･MER]



Average annual improvement of primary energy intensity (world)

		2010-2022	2022-2030	2030-2040	2040-2050
TPES/GDP	Reference	-1.4% (history)	-2.0%	-2.2%	-2.0%
	Advanced		-2.5%	-3.1%	-2.7%

References

- **Primary energy intensity improves faster than recent history.**
  - Recent demand-side progress (e.g., hybrid vehicles) drives intensity improvement
  - *Efficiency improvements, renewable powers, and industrial structure shifts contribute to intensity improvement.

Adv.Tech.

- **Intensity halves from 2022 to 2050, with major acceleration 2030-2040.**
  - Time lag between policy implementation and equipment deployment means limited improvement rates until 2030.
- **Emerging economies show particularly significant improvement (-63% vs 2022)**
  - Cost-effective reductions possible, but requires regulatory framework and technology transfer from advanced economies.

1) Energy Efficiency:
Different Priority Areas by Region/Economic Level

Sectors with particularly effective efficiency improvements vary by region.

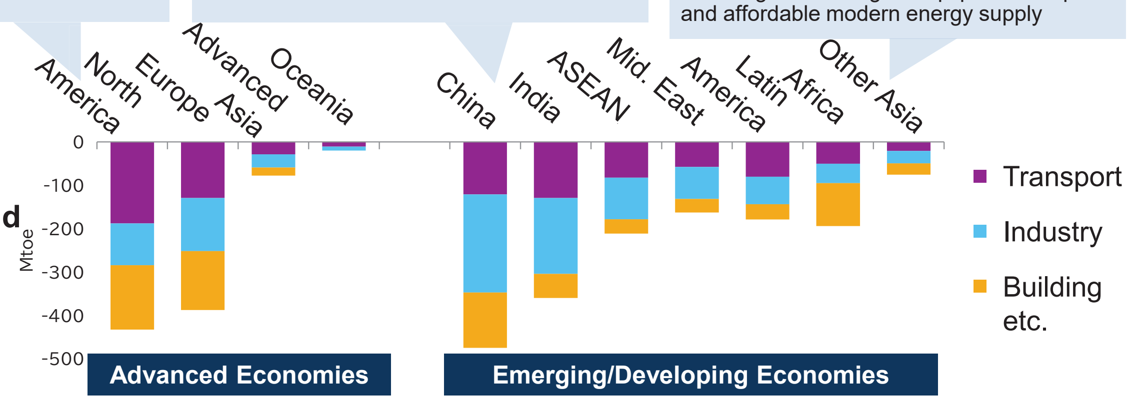
- **Advanced economies show improvement in efficiency across sectors.**
  Transportation shows particularly large reductions due to next-generation vehicles (EVs, hybrids) with better efficiency.

- **Emerging economies (especially China, India, ASEAN) focus on industry.**
  Major industrial production in China and expected growth in India/ASEAN make industrial efficiency improvements effective.

- **Developing economies (Africa, Other Asia) show major reductions in residential.**
  Household transition from traditional biomass (wood) to LPG, city gas, and eventually electricity.
  Challenges: Funding for equipment adoption and affordable modern energy supply

Difference in Final Energy Demand
[Adv.Tech.-Reference]

(2050)



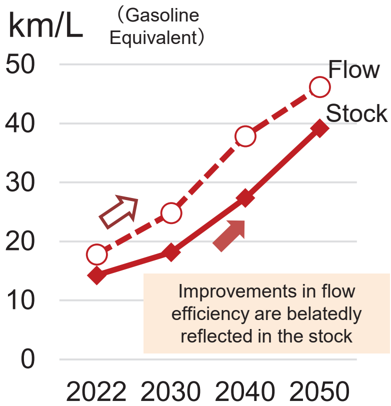
1) Energy Efficiency: Delayed Effect of Improvements

- Energy Efficiency: Delayed Effect of Improvements.
  - Intensity improvements in **Adv.Tech** become particularly evident after 2030.
- Flow efficiency (new equipment) reflects in stock efficiency (existing equipment) with delay.
  - Particularly pronounced in industrial sector with long equipment lifespans
  - Early action necessary for significant energy savings by 2050.

Average annual improvement of primary energy demand intensity (World)

		2010-2022	2022-2030	2030-2040	2040-2050
TPES/GDP	Reference	-1.4% (history)	-2.0%	-2.2%	-2.0%
	Advanced		-2.5%	-3.1%	-2.7%

Average fuel economy of passenger vehicles (Adv.Tech, World)

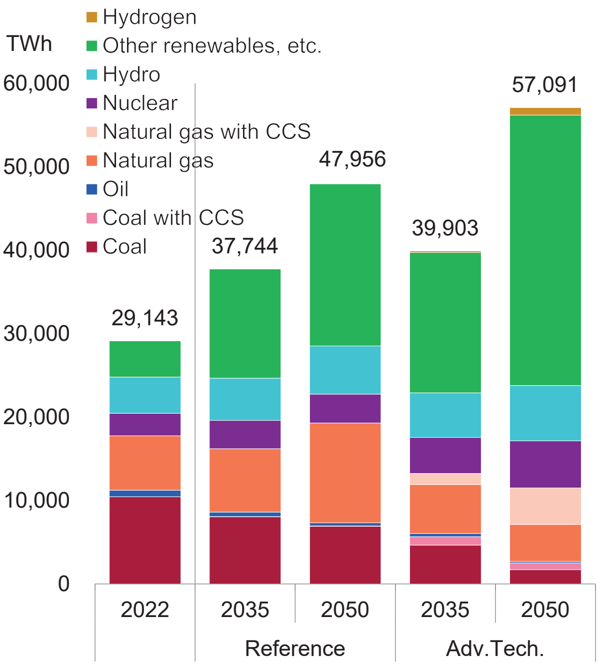


Average years of equipment use (example)

Sector	Facilities	Lifetime (year)
Industry	Blast Furnace	10～25
	Boiler	20～40
Building	Air Conditioner	10～20
	House	30～
Transport	Passenger Vehicles	10～15
	Airplanes	20～30
Power	Thermal	25～40
	Solar PV	15～30

2) Renewables(excl. hydro): 60% in Advanced, with Total Generation Increasing Significantly

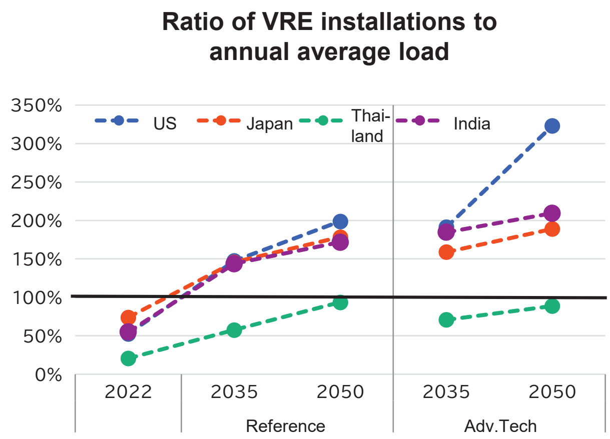
Power Generation (World)

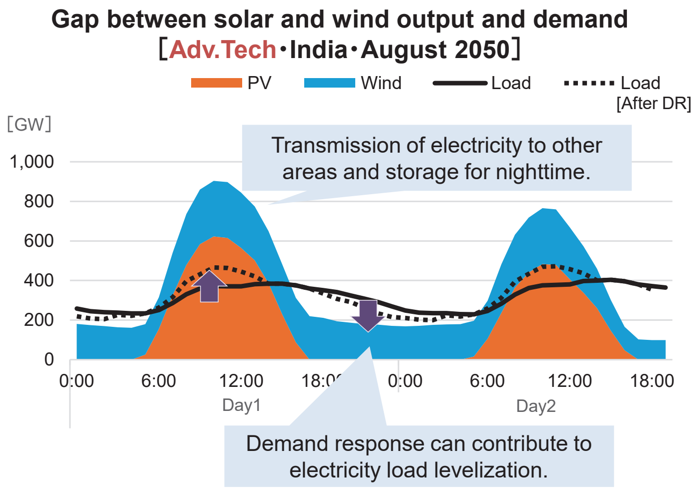


- **Power generation in 2050 requires 1.6x (Reference) and 2.0x (Adv.Tech.) vs 2022 levels.**
  - Substantial power demand increase is unavoidable in both scenarios.
  - Particularly in emerging/developing economies; urgent need for generation and transmission expansion.
- **Adv.Tech: "Renewables (excl. hydro)" increase dramatically to 60% of power.**
  - Mostly solar and wind; implementation at this scale requires fundamental intermittency countermeasures.
- **Nuclear expands particularly in emerging/developing economies.**

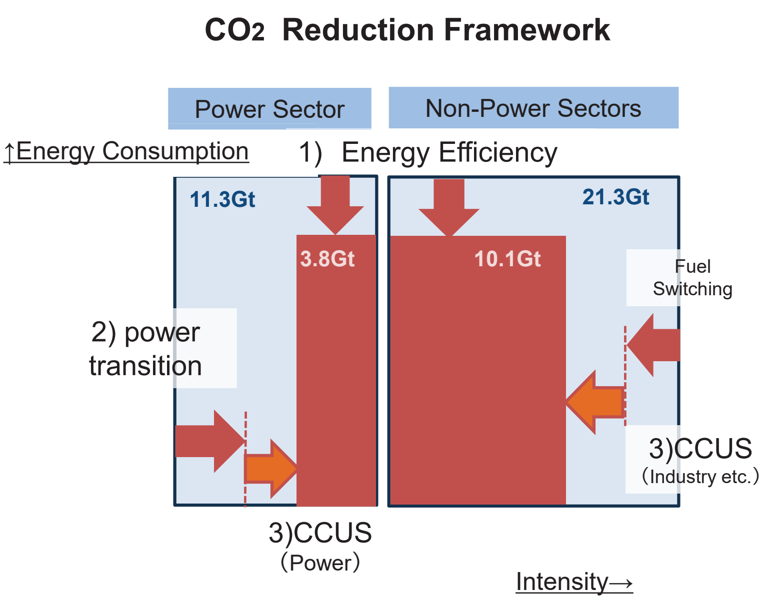
2) Renewables: Large Power Supply-Demand Gaps from Massive Deployment

- In **Adv.Tech**, major variable renewable (solar, wind) deployment, many regions see variable renewable capacity exceed twice the annual average load.
  - May require large-scale storage facilities, grid expansion, demand response utilization, and CO_2-mitigated thermal power beyond existing pumped storage and thermal capacity.

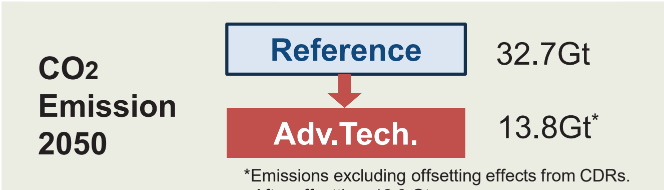




3) CCUS: Reducing Emissions from Hard-to-Abate Non-Power Sectors



*Arrow and rectangle widths do not exactly match the emissions in each scenario.



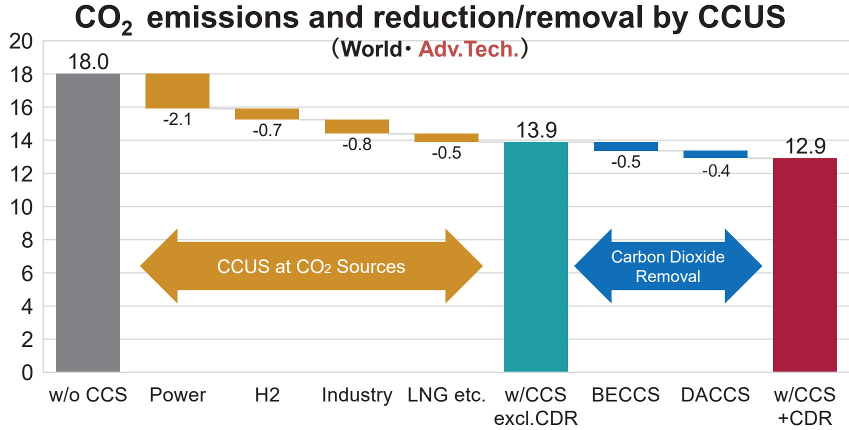
*Emissions excluding offsetting effects from CDRs. After offsetting, 12.9 Gt.

- Energy consumption (vertical axis) can be reduced through **1)energy efficiency** in both power and non-power consumption.
- intensity (horizontal axis) can be significantly reduced in power generation through **2) power transition**, but harder to reduce in non-power consumption.
- **3)CCUS** is effective for both power and non-power emission reduction.

3) CCUS: Major Deployment Potential in Industry and Power Generation

- **Adv.Tech.** projects total CCUS deployment of 5.1 Gt-CO2 by 2050.
  - Power sector shows the largest reduction potential for point-source CCUS.
  - In industry sector, becomes a key decarbonization method for sectors with limited electrification potential, like steel and cement.
  - Carbon removal (BECCS, DACCS* in this outlook) expected to be higher cost but valuable for offsetting residual emissions from sectors where capturing is difficult (Building/ Transport).

CO_2 emissions and reduction/removal by CCUS
(World・Adv.Tech.)



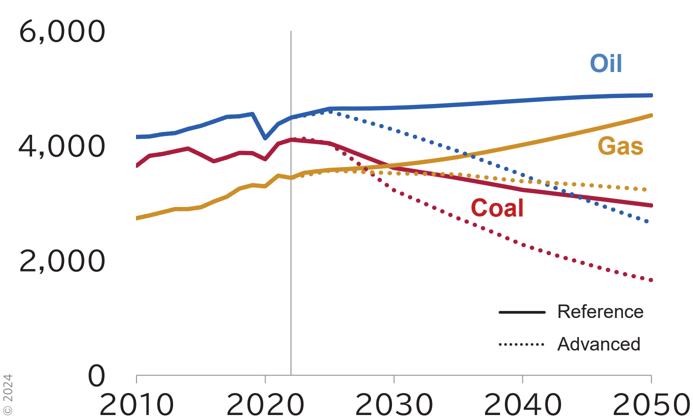
For Additional reduction…
- Addition of various CCUS/
- Nature-based Carbon Removal
 (e.g.) Forests, Agricultural lands, and other land uses, Blue carbon, etc.

*BECCS: Bioenergy with CCS, DACCS: Direct Air Carbon Capture and Storage
Both qualify as negative emission technologies directly reducing atmospheric CO2

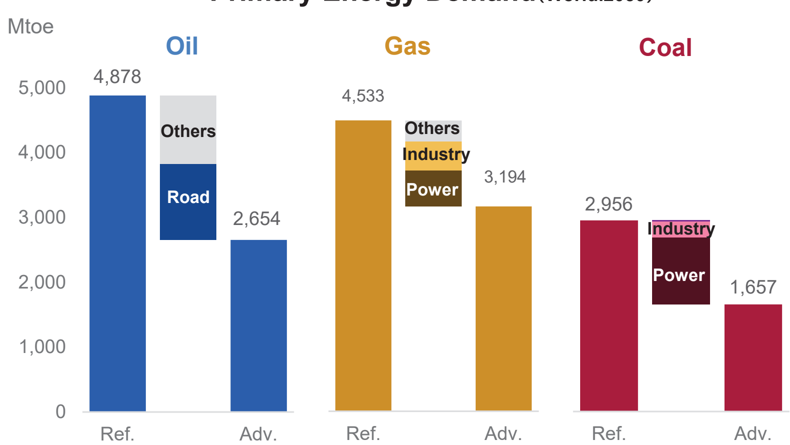
Fossil Fuel Demand Uncertainty: Wide Gap Between Scenarios

- Large divergence in fossil fuel demand between **Reference** and **Adv.Tech.** scenarios. While pursuing energy transition, a stable fossil fuel supply remains necessary.
  - Oil shows the largest demand difference, with road transport accounting for over half. Uncertainty in EV/HEV adoption, and ICE efficiency improvements.
  - Natural gas and coal demand differences are primarily driven by power generation and industry.

Primary Energy Demand (World)



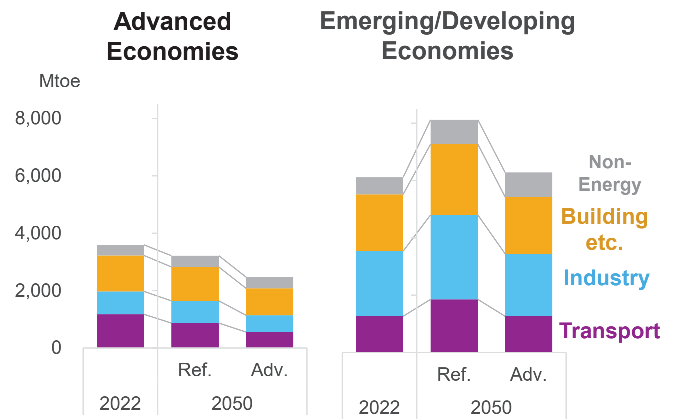
Primary Energy Demand (World.2050)



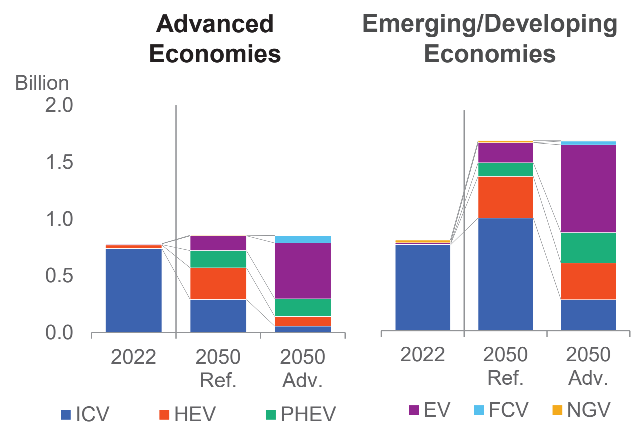
Final Energy Demand: Transport (Especially Road) Shows Major Divergence

- [**Reference**]Transport sector demand grows significantly in emerging economies.
  - Vehicle ownership in emerging/developing economies more than double by 2050 from 2022. Oil demand varies greatly depending on fuel efficiency improvements and powertrain choices.
- [**Adv.Tech.**]Efficiency improves particularly in road transport.
  - While EVs see mass adoption, ICEs and hybrids maintain presence, especially in emerging/developing economies. Vehicle choice is important based on power mix, range requirements, and usage frequency.

Final Energy Demand (Sectoral)



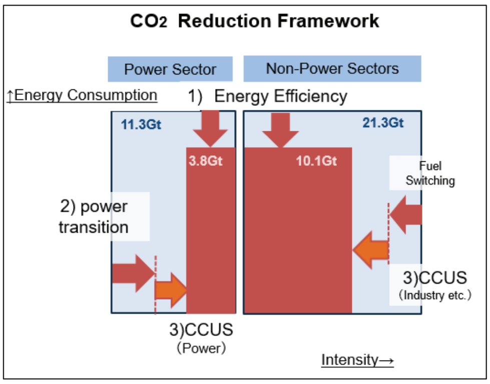
Vehicle Ownership (By Powertrain)



Summary

✓ CO_2 reduction relies primarily on (1) energy efficiency, (2) renewables, and long-term (3) CCUS. [**Adv.Tech.**]

- Energy efficiency enhancement provides 6.2 Gt-CO_2 reduction; early action is essential due to implementation lag.
- Renewables (excl. hydro) reach ~60% of total generation; variable renewable capacity exceeds twice the average load.
- CCUS promising for large emission sources in power and industry; 5.1 Gt-CO_2/year capture (including CDR).



✓ **Primary Demand and Power Generation Trends**

- **India, ASEAN show dramatic primary energy demand increase.** International climate action must include these regions.
- Global power generation in 2050: 1.6x (**Reference**), 2.0x (**Adv. Tech.**) vs 2022.

✓ **Significant Fossil Fuel Demand Uncertainty.**

- Under current trends, gas and oil demand may continue growing through 2050.
- Uncertainty drivers: road transport for oil; industry and power generation for gas/coal.
- Stable fuel supply remains critical through 2050. Sustained adequate investment essential.

IEEJ Outlook 2025
Risk scenarios of energy security

Ichiro Kutani

Senior Research Director
Director, Energy Security Unit
The Institute of Energy Economics, Japan

1. Risks of Fossil Fuel Underinvestment
2. More Serious and Diverse Geopolitical Risks
3. Risks of Electricity Supply Instability
4. Risks of Critical Mineral Supply
5. Increasing Risks of Cyberattacks

Co-Authors
Dr. Tetsuo Morikawa, Energy Security Unit (1)
Mr. Yoshikazu Kobayashi, Senior Research Director, Research Strategy Unit (2)(5)
Mr. Kenichi Onishi, Executive Researcher, Electric Power Industry Unit (3)

Summary

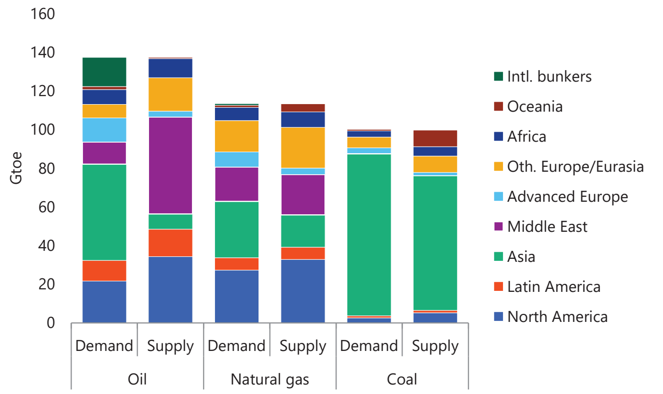
- Risks of Fossil Fuel Underinvestment
  - ✓ According to the IEEJ Outlook Reference Scenario, fossil fuels will still provide 73% of global energy demand in 2050. Without additional investment, oil and natural gas production in 2050 would plummet to about one-tenth of current levels. Underinvestment will result in a large gap from fossil fuel demand in the real world.
- More Serious and Diverse Geopolitical Risks
  - ✓ Geopolitical risks in the Middle East region are becoming more serious as Japan’s dependence on the region for crude oil imports increases. In addition, policy changes in developed countries have also become a risk factor in recent years.
- Risks of Electricity Supply Instability
  - ✓ Electricity supply is subject to various risks on both supply and demand sides. In order to achieve stable supply, it is necessary to take measures in the fields such as ensuring fossil fuel, securing baseload power like nuclear power, securing supply capacity, and optimising the power system. It is also essential to pursue the best power mix for stable supply.
- Risks of Critical Mineral Supply
  - ✓ Some critical minerals that are essential raw materials for clean technologies have high market concentration and emerging as a risk to the energy transition. Risks can be mitigated by combining various technologies with different nature of risk.
- Increasing Risks of Cyberattacks
  - ✓ The number of critical cyber attack incidents has increased significantly around the world. Cyber-attacks against energy, a fundamental infrastructure, becoming a key issue in energy security.

Risks of Fossil Fuel Underinvestment

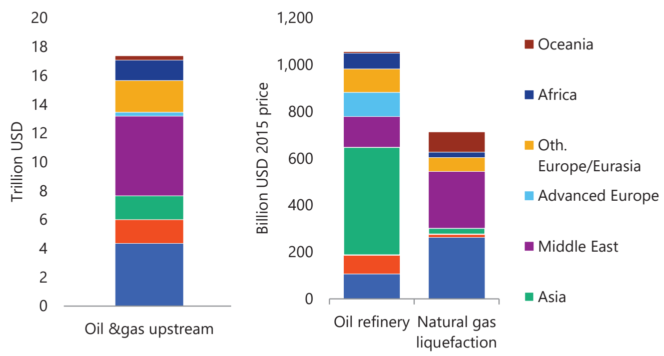
Supply-demand and investment of fossil fuel

- In the Reference Scenario, fossil fuels will still provide 73% of global energy demand in 2050.
- Asia is the center of demand growth, while the Middle East and North America (oil and natural gas) and Asia (coal) have the highest shares in the supply region.
- Stable investment, particularly in these regions, is vital for the stable supply of fossil fuels.

Fossil fuel demand



Selected oil and gas investment amount



Cumulative total of 2022-2050 in the Reference Scenario
Source: IEEJ

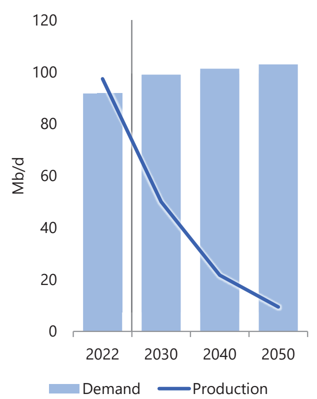
Increasing hurdles to investment

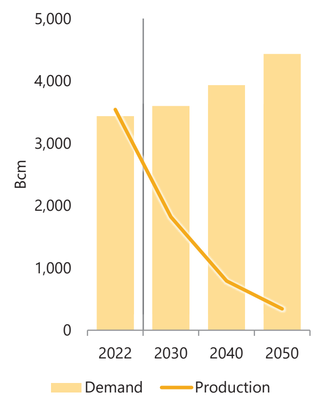
- Underinvestment is currently not serious, but the risk of underinvestment due to climate change concerns and decarbonisation policies has become apparent.
- Without additional investment, oil and natural gas production in 2050 will be about 1/10th of current levels.

Head wind against fossil fuel projects

Oil	Natural gas	Coal
Financial institutions and pension funds restrict investment in fossil fuel development and coal-fired projects		
Upstream asset sales by IOCs ($290 billion over 2015-2023)		Thermal coal asset sale by coal majors
Europe: Refining capacity may decrease by 1-1.5 million b/d by 2030	Suspend LNG projects with high environmental impact. (e.g. Natuna field in Indonesia)	Ban of new coal-fired power in OECD countries

Prospect of oil and gas production without investment and demand in the Reference scenario





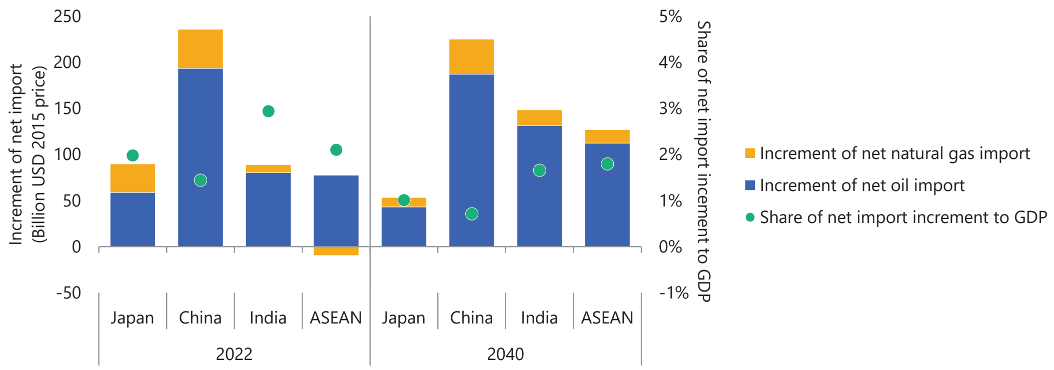
IOC = international oil companies
Source: IEEJ, IEA, Bloomberg

Source: IEEJ

Economic impact of price increases

- Tight supply and demand leads to higher prices: the average Brent price in 2021 was 70% higher than the previous year, partly due to lack of upstream investment during the pandemic period as well as a recovery in demand after the pandemic.
- For a 50% price increase, the share of oil and natural gas imports in the GDP of Asian importing countries rises by 1-3 percentage points. The rise in India and ASEAN is relatively large and the impact on the economy is more worrying.

Impact of crude oil and natural gas price increase on import bill

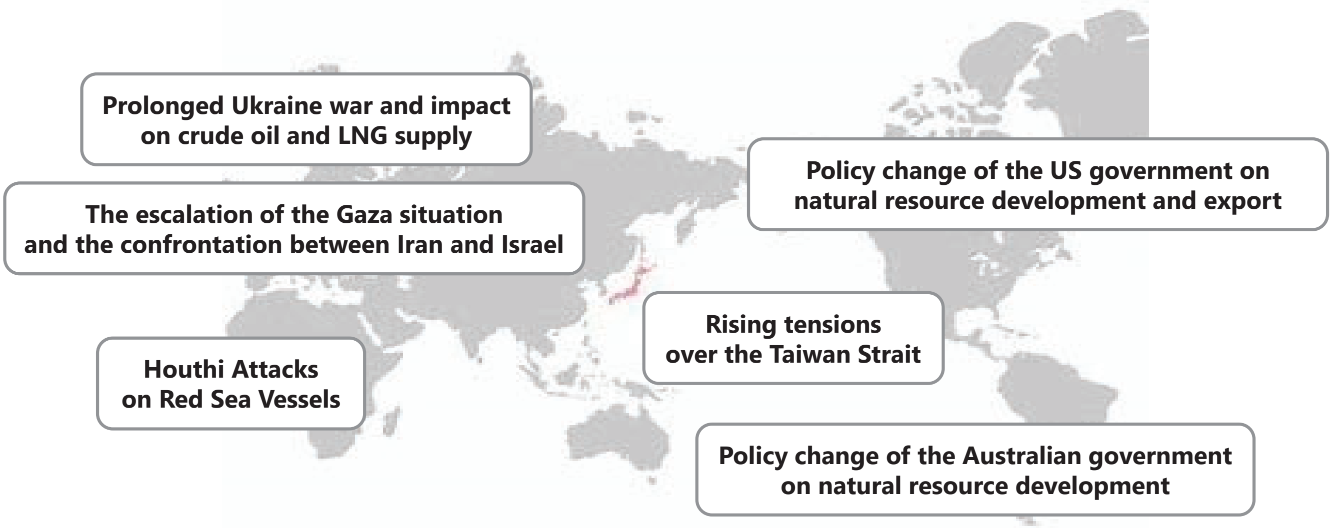


Assume that oil and natural gas import prices will be 50% higher than actual (2022) or preconditioned (2040) due to tight supply and demand caused by underinvestment. Source: IEEJ

More Serious and Diverse Geopolitical Risks

More diverse geopolitical risks

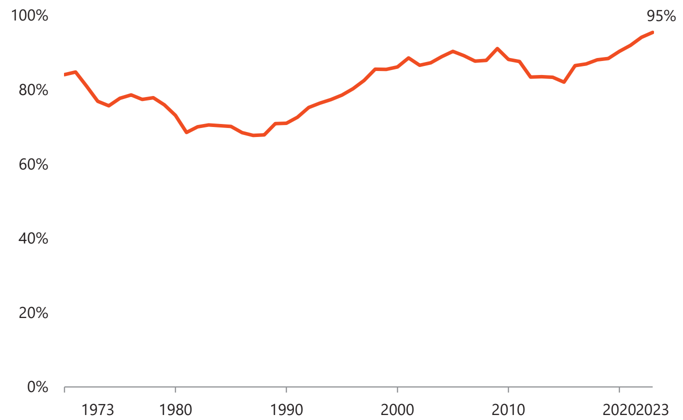
- Geopolitical risks remain a major concern in energy security.
- In addition to the risk of political instability in resource-exporting countries/regions, policy changes in developed countries have also been a risk factor in recent years.



More serious geopolitical risks in the Middle East

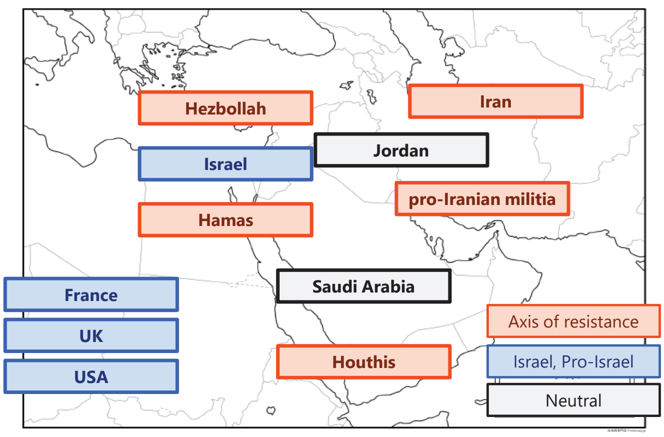
- As Japan's dependence on the Middle East crude oil rises, the geopolitical risks in the region, escalation of conflicts surrounding Israel, are becoming even more serious for Japan.
  - In particular, the worsening of Iran-Israel relations could be a factor linking the situation in Palestine to energy supplies in the Persian Gulf, and the impact of these developments would be very significant.

Middle East dependency of Japan's crude oil import



Source: Ministry of Finance, "Trade statistics"

Israel and the Axis of Resistance

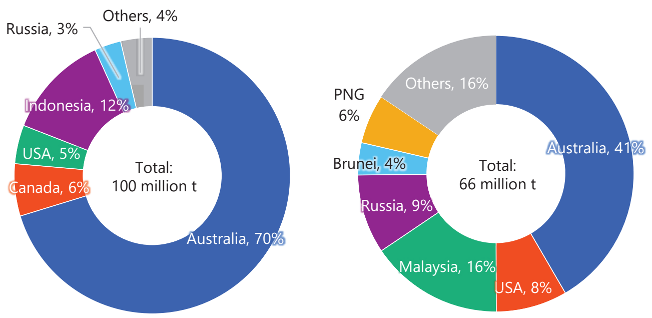


Source: JIME, IEEJ

Policy change risks in developed countries

- Coal and LNG imports are highly dependent on developed countries (81% for coal and 50% for LNG: 2023).
- There are concerns that policies have been introduced in the US and Australia that place restrictions on the development and export of domestic fossil resources, reflecting domestic interest in climate change issues, which may pose a challenge to market stabilisation.

Import partners of Coal (left) and LNG (right) supply in Japan (2023)



PNG = Papua New Guinea
Source: Ministry of Finance, "Trade statistics"

Recent policy developments in the US and Australia that would affect their LNG export

US	• In January 2024, the Biden administration announced a pause on the review and approval of export licence applications for new LNG projects for non-FTA countries as part of its response to the global climate crisis.
Australia	• In October 2022, the ADGSM was amended to restrict gas exports in the event of a domestic gas supply crisis. • July 2023, requiring GHG emissions from designated large emission sources, including LNG liquefaction and coal mines, to be reduced by 4.9% annually. Requires new LNG facilities to have net-zero emissions from the start of operations.

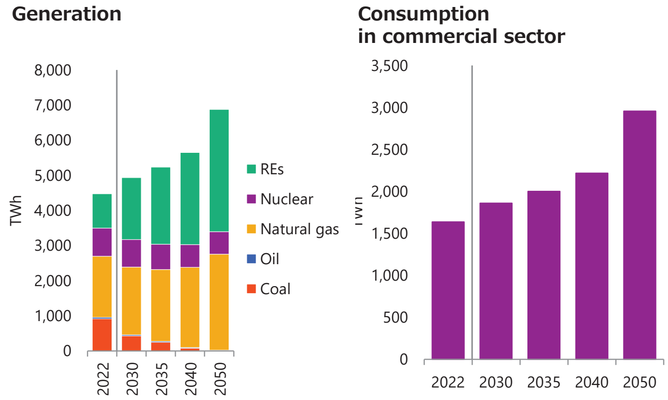
ADGSM = Australian domestic gas security mechanism
Source: Ministry of Finance, "Trade statistics"

Risks of Electricity Supply Instability

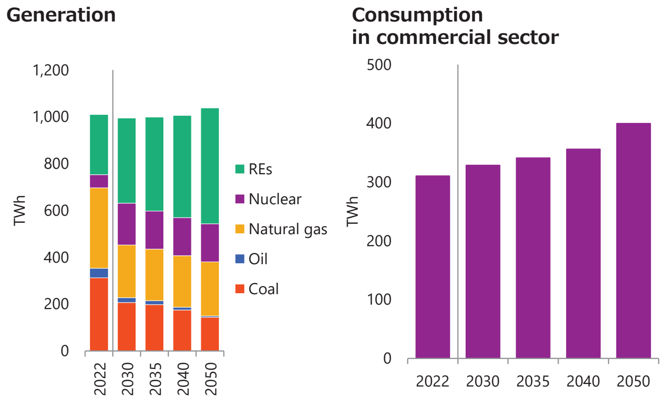
Increasing electricity demand and VREs

- Society is becoming increasingly reliant on electricity as the digitalisation of the economy and the electrification of demand continue. Electric vehicles and the expansion of data centres are the key drivers of demand growth.
- The energy transition is pushing solar photovoltaic and wind power, whose output fluctuates with the weather and the seasons, to become the mainstay of electricity supply.

Electricity demand and supply in the US



Electricity demand and supply in Japan



Reference Scenario
Source: IEEJ

Reference Scenario
Source: IEEJ

Risks, challenges, and measures of supply security

- On the supply side, risks of supply stability include supply shortage and price fluctuation of fossil fuels, geopolitical risks, and fluctuations in the output of renewable energy sources.
  While on the demand side, there is the risk of an increase in electricity demand and uneven distribution of electricity demand.
- To address these risks, it will be necessary to secure fossil fuel procurement and baseload power sources such as nuclear power, secure supply capacity, and optimise the power system.

Risks, challenges, and measures against risks of electricity supply instability

Risks	Challenges	Measures
• Shortage of fossil fuel supply • Fluctuation of fossil fuel price • Geopolitical risks • Fluctuation of RE power output	• Procurement of fossil furl • Securing baseload power	• Attach conditions for long-term fuel procurement to PPA contracts • Procurement of stable power sources such as nuclear and geothermal
• Increase of demand	• Secure supply capacity	• Introduction of support schemes for new power supply installations • Consumers own back-up power generation
• Uneven distribution of demand	• Optimise power system	• Locate demand proximity to power generator • Announce areas with surplus supply capacity • Introduce dynamic line rating to transmission line

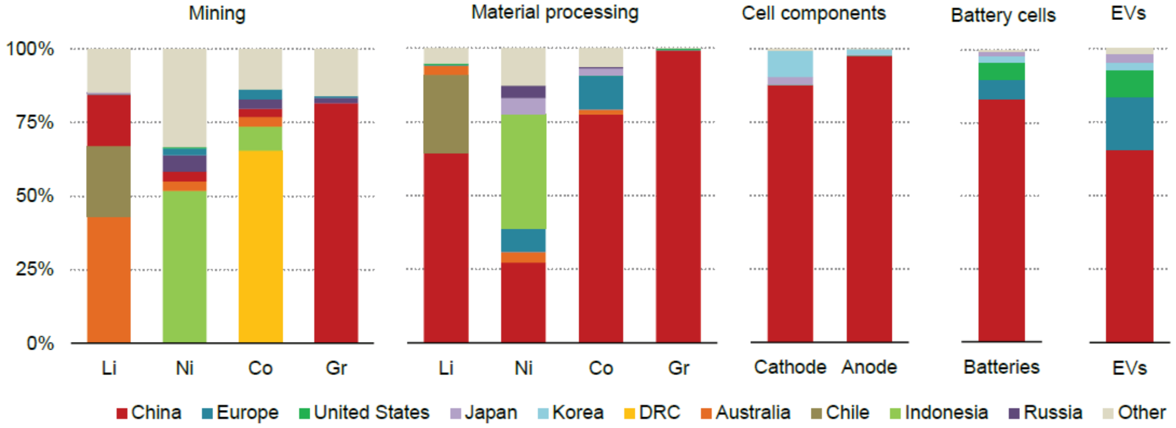
RE = renewable energy
Source: IEEJ

Risks of Critical Mineral Supply

Risks of clean technologies

- High market concentration observed in some clean technology production and in the supply of critical minerals that are essential for clean technologies. This is increasingly recognised as an emerging risk to the energy transition.
- Demand for critical minerals is expected to increase in the future. Therefore, the impact of supply disruptions (risk of supply shortages and price spikes) will also increase

Structure of on-board battery supply chain

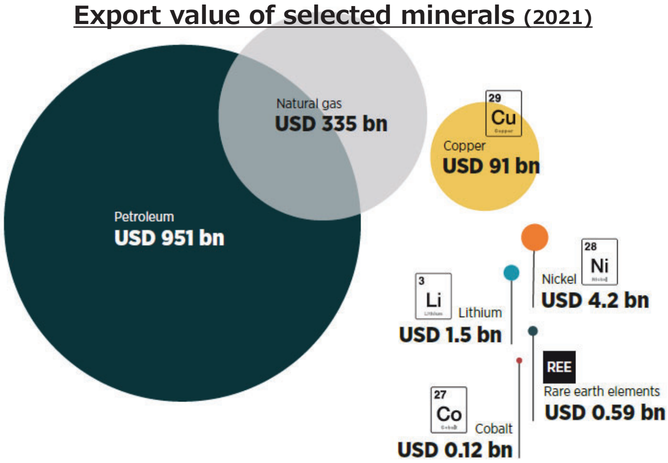


Li = lithium, Ni = nickel, Co = cobalt, Gr = graphite
Source: IEA (2024) "Global Critical Minerals Outlook 2024"

Challenges of stable supply of critical minerals

- The critical minerals market is small and immature, making it prone to the exercise of market power, cause supply-demand gaps and the resulting price volatility.
- As refining is energy-intensive and high environmental load, it is not easy for developed countries to make it competitive.
- Increasing international competition to secure key minerals and heightened resource nationalism should also be reminded.
- Uncertainty in future demand for critical minerals due to the potential for technological innovation.
- Long lead times for the development of new resources make it difficult to invest in supply source diversification.
- Overcoming these requires 1) consistent policy and 2) coherent development of supply and demand.

Export value of selected minerals (2021)



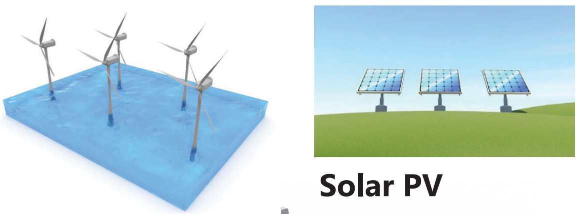
Source: (UN COMTRADE database).
Note: Numbers represent trade in raw, unprocessed fuels and ores only.

Source: IRENA (2023) "Geopolitics of energy transition, Critical Minerals"

Technology mix for risk control

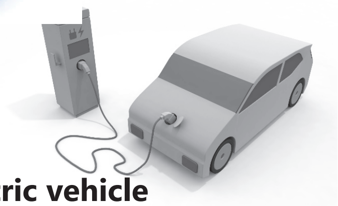
- Risks can be mitigated by combining different technologies with different risk characteristics.
- Development of those technologies and market creation is needed.

Technologies with higher market concentration



Wind power

Solar PV



Battery
Battery electric vehicle

Technologies with lower market concentration

- **Fossil power with CCS**
- **Hydrogen and ammonia power**
- **Nuclear power**
- **CN synthetic methane as city gas**
- **ICEV, HEV, and PHEV run by CN fuels** (biofuel, synthetic fuel)

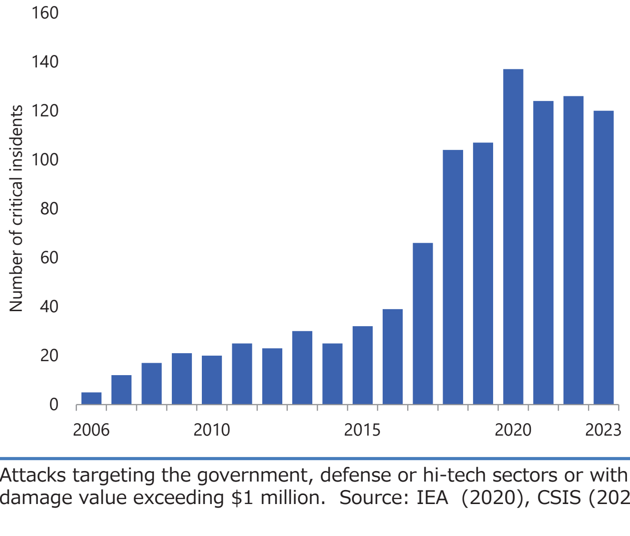
CN = carbon neutral, ICEV = internal combustion engine vehicle, HEV = hybrid vehicle, PHEV = plug-in hybrid vehicle
Source: IEEJ

Increasing Risks of Cyberattacks

Growing cyber risks to energy supply

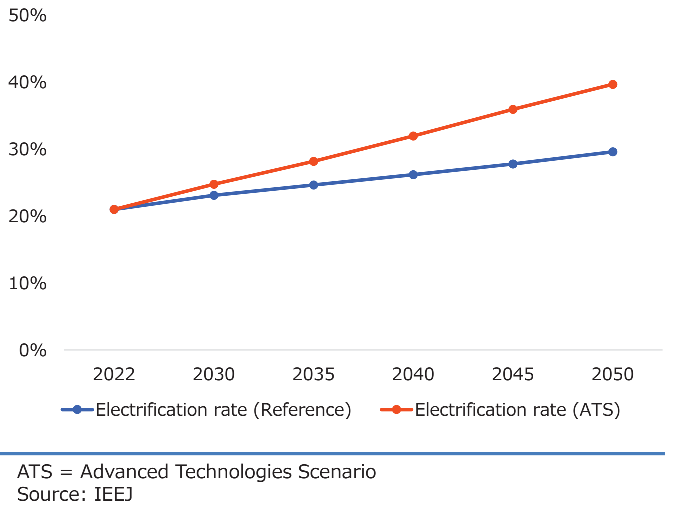
- Since mid-2010, the number of critical cyber-attack events has increased significantly worldwide.
- The energy transition, with its accompanying electrification, digitisation, and network connectivity, will result in an increase in the severity of cyber-attacks as a potential risk factor.

Number of critical cyber incidents



Attacks targeting the government, defense or hi-tech sectors or with a damage value exceeding $1 million. Source: IEA (2020), CSIS (2024)

Share of electricity in final consumption in the world



ATS = Advanced Technologies Scenario
Source: IEEJ

Increased cyber vulnerability

- As the energy transition progresses, vulnerability to cyber-attacks increases in the energy supply, storage and demand sectors.

Increase of vulnerability against cyberattack due to energy transition

Energy supply	Energy storage	Energy demand
• Upgrading of operational management systems - Operations management systems are integrated with information systems and connected to the internet - Increased use of cloud services and automation increases the impact in the event of an attack. • Increase in the number and diversification of distribute power operators - Increased number of attack points along the entire power supply chain, making it more difficult to build defenses.	• Increased reliance on storage batteries - Potential impact of cyber-attacks on the operation of storage batteries (storage and discharge) due to an internet-connected storage battery management system (BMS)	• Increase in the number of EVs - EVs connected to each other and to the internet for diverse services - Potential intrusion into systems controlling energy-using equipment in dwellings via charging points • Smart dwellings and IoT in buildings - Possible attack points for cyber-attacks due to the introduction of systems that collect data on electricity use and temperature control in dwellings and control energy equipment

BMS = battery management system, EV = electric vehicle, IoT = internet of things
Source: Dawda, Herath, and Maccall (2022)

Scenarios of cyber-attack

- There are diverse patterns of cyber-attacks, with different actors, objectives and targets of attack.
- Considering Ukraine war, geopolitical risks should not be underestimated, and the possibility of weaponisation in the form of threats to energy supply should also be taken into account.

Types of cyber-attacks on energy assets

Types	Methods	Incidents
Remote control and systemmalfunctioning by malware	Malware (malicious software) is fed into the attack target's internal network to remotely control the attack target's energy supply facilities from the outside, affecting the actual energy supply or causing the attack target's PCs or network to malfunction. State actors may also adopt this method.	2022, Germany: Wind power company 2022, Italy: Energy agency 2015, Ukraine: Power sysem
Securing ransom through ransomware	The same as above until the malware is sent to the internal network of the attack target. It then encrypts the internal data of the attack target and affects the operation of the system by the attack target. The attacks are often carried out by private actors.	2021, US: Oil pipeline company (the company stopped the operation for a week as a precaution)
System down through mass access	Concentrating large amounts of access against an attack target aim to bring down the target's systems.	2022, Lithuania: Energy company

Source: IEEJ

countermeasures against cyber-attacks

- It is difficult to provide 100% protection against cyber-attacks with their diverse patterns.
- However, the following measures can be taken to limit the damage caused by attacks and ensure early recovery.

Major countermeasures against cyber-attacks

Measures	At the government	At both ends	At the private sector
Institutional arrangement	• Develop policies to clarify the responsibilities of actors and encourage them to respond • Develop a framework for cooperation between actors	• Raise awareness of cyber security	-
Identify the risks	• Encouraging operators to identify cyber vulnerabilities and analyse risks	• Information sharing	• Identify and assess the risks • Identify and classify the risks of assets
Manage and minimise the risk	• Develop risk management processes • Prioritise response measures	• Develop and share methods for ensuring resilience • Human capacity building	• Develop risk management method • Prioritise response measures
Monitor the risks	• Develop risk monitoring processes • Cooperation with the National Intelligence Unit	-	• Regular monitoring of identified risks and vulnerabilities
Recovery from an attack	• Develop recovery plans / procedures and regular drills.	• Learning and preparation through sharing of past attack cases and lessons learnt	• Develop recovery plans / procedures and regular drills.

Source: Ecofys (2018); IEA (2021), World Energy Council (2022); METI･IPA (2022)

18 October 2024 The 448th Forum on Research Works

IEEJ Outlook 2025
The Critical Role of LNG

The Institute of Energy Economics, Japan - IEEJ

Hiroshi Hashimoto
Senior Fellow, Energy Security Unit

Abstract

✓ **LNG plays an important role - demand is expected to grow further**
- LNG is expected to play an important role as a realistic solution toward the energy transition - as a pragmatic and reliable energy source - enhancing energy security and contributing to decarbonization at the same time.
- Global LNG demand in 2050 is projected to increase by 74% from the present level in the Reference Scenario of the IEEJ Outlook 2025 - with Southeast Asia in focus

✓ **LNG supply stability requires sustaining investment**
- The LNG production sector requires additions of 10 - 20 million-tonne-per-year capacity addition each year
- Even with steady FIDs (final investment decisions) during the past three years, uncertainty should be noted over realisation and timely implementation of the projects

✓ **Long-term agenda toward the stable LNG market**
- Efforts of the LNG market and industry players are necessary to meet the expectations
- It is important for companies and governments in consuming countries to encourage stabilization of regulatory aspects and LNG production project development
- Demand aggregation and market development support lead to expansion of the market

[Issues surrounding LNG production project development with long-lasting implications]

✓ **Issues and challenges related to LNG production project development**
- In parallel of rising LNG production project development costs, progress has been made in FLNG and small and medium size LNG liquefaction
- Upcoming launch of LNG export from the West Coast of North America is expected to be a gamechanger of LNG marine transportation
- While LNG export capacity is expected to expand, long-term development activities face uncertainty caused by the "pause"

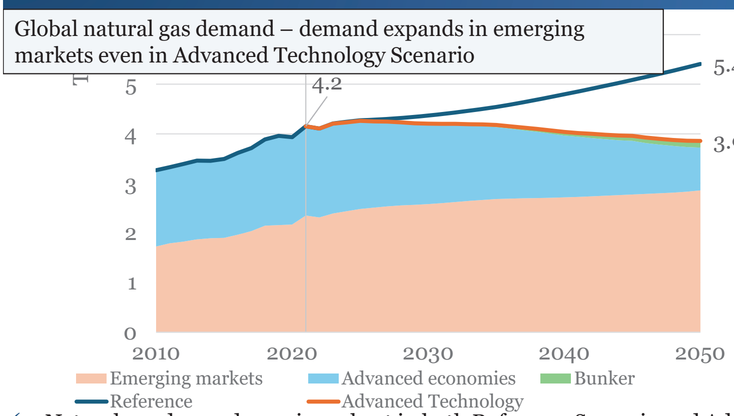
✓ **LNG transportation bottlenecks and unplanned outages of LNG production plants affect the market balance**
- Longer distances of LNG transportation and bottlenecks at canals and routes require a long-term strategy of transportation
- Unplanned outages at LNG production facilities are likely to exacerbate supply-demand imbalances

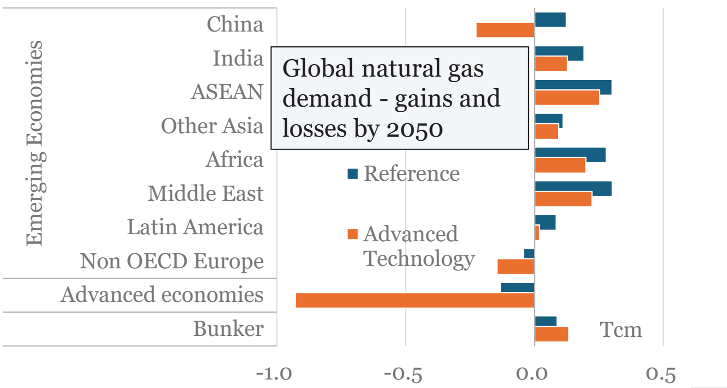
LNG Has A Role to Take Care of Uncertainty under the Energy Transition

- In its 60-year growth history, LNG has expanded and demonstrated its role in response to the demands of each era to enhance energy security
- A wide variety of reserves and backup mechanisms have been introduced to enhance resilience of LNG supply along with LNG's expanded role
- Progress has been made in supply source diversification and international partnerships to enhance LNG supply security

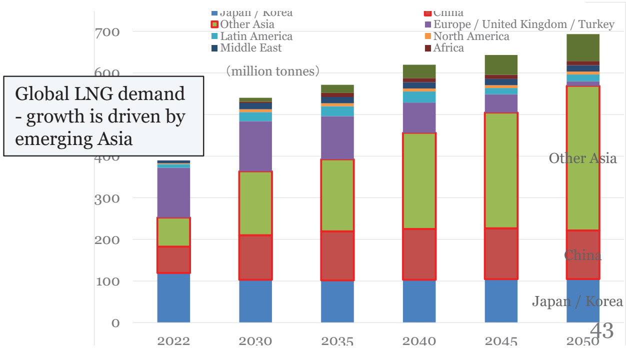
Era and issues	LNG's role of the era and expectation
Late 20th century ✓ Oil crisis ✓ Air Pollution	✓ The share of LNG expands as an alternative and clean energy source (Japan and Korea) ✓ LNG is a gas supply source alternative to pipeline gas (Europe) ✓ LNG mitigates impacts of the oil crisis with an increasing share in the primary energy mix
2010s ✓ Replacing lost nuclear power ✓ Meeting increasing energy demand	✓ LNG demonstrates flexibility to swiftly respond to shortages of baseload electricity supply ✓ A wider range of participants in each segment of the LNG value-chain have mitigated burdens at each segment of liquefaction, marine transportation and regasification, revealing LNG's flexibility more vividly in emergency cases
2021 - 2022 ✓ Energy demand surge after the pandemic ✓ Russian war and gas shortages	✓ Europe's increasing LNG import offsets decreasing pipeline gas supply from Russia even before Russia's invasion in Ukraine ✓ Increasing LNG supply mainly from the United States takes care of loss of Russian pipeline gas import after Russia's invasion in Ukraine and the sabotage against the pipeline into Germany
Into the future ✓ A realistic solution taking care of uncertainty of the energy transition	✓ LNG provides a realistic solution toward the energy transition enhancing energy security and contributing to decarbonization at the same time ➢ LNG supports economic growth in emerging markets and provides stable energy supply to matured markets ➢ LNG contributes to the energy transition, partnering with new energy sources ➢ Assuming efforts to make LNG cleaner, LNG can be utilized further longer

Natural Gas Demand Is Robust and Asia's Share in LNG Grows



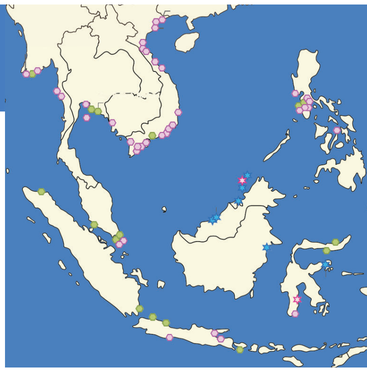


- ✓ Natural gas demand remains robust in both Reference Scenario and Advanced Technology Scenario
  - ➢ Global LNG demand in 2050 increases by 74% from the current level in the Reference Scenario
  - ➢ Global LNG demand increases until around 2040 and stays at the current level in 2050 in the Advanced Technology Scenario
  - ➢ If energy efficiency improvements do not materialize, LNG demand could be higher
- ✓ Demand increases center on Southeast Asia and Power Generation
  - ➢ Natural gas plays a role in emission reductions in the industrial sector and demand and supply balance management in power generation, being an economically viable energy source, reducing costs of the energy transition
- ✓ Instability of demand and supply balance and volatile prices indicate the importance of long-term measures for stability of the market

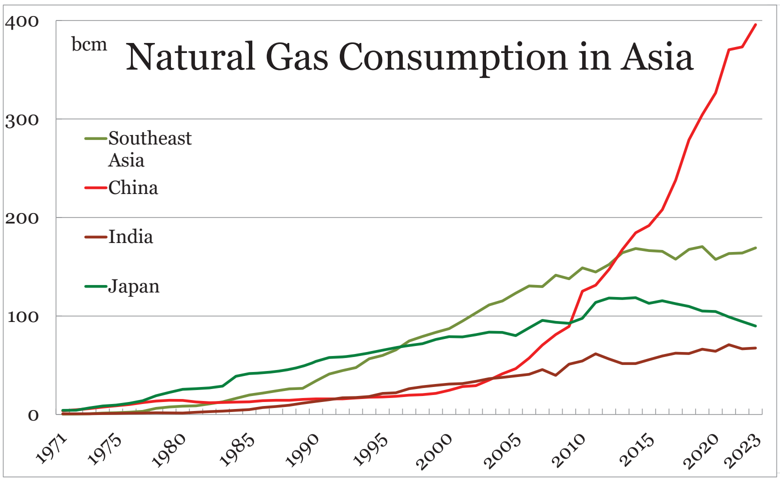


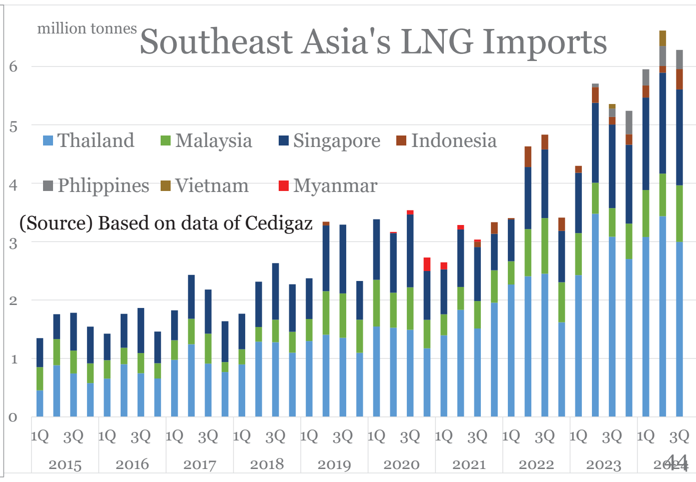
Southeast Asia Has A Potential to Expand Use of LNG

- ✓ Southeast Asia has expanded use of natural gas in tandem with LNG export project development after the 1970s
- ✓ Traditional gas producing countries anticipate larger consumption
- ✓ Seven countries have started LNG imports since 2011 – within and from outside of the region
- ✓ Share of LNG in natural gas consumption in Southeast Asia is projected to increase from current one-sixth to one-third
- ✓ Near-shore land areas and island areas have potential to expand LNG utilization infrastructure



LNG infrastructure in Southeast Asia Existing and planned LNG production plants (star, existing in blue and planned in red) and LNG receiving terminals (hexagon, existing in green and planned in pink) are spread around





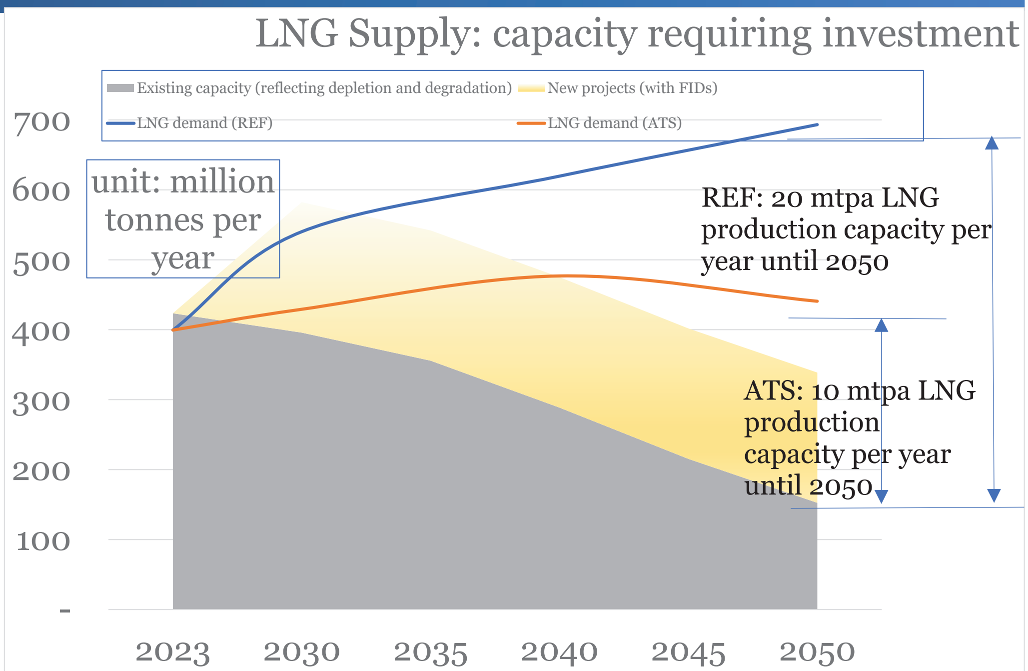
Investment - to Meet Demand, to Replace Existing Capacity - Is Required

The LNG production sector requires additions of 10 - 20 million-tonne-per-year capacity each year until 2050

- ✓ To meet incremental demand and to supplement reductions of productivity of existing gas fields and processing facilities

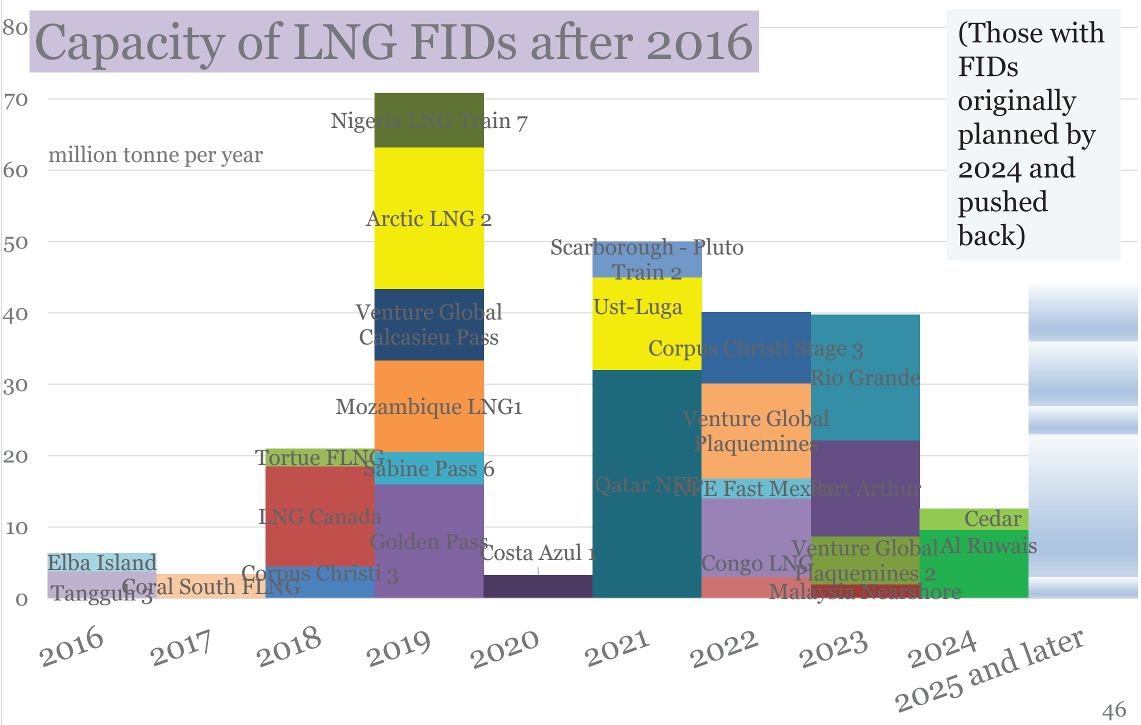
1. New projects
2. Backfill supply from other fields
3. Offsetting decreasing gas supply
4. Rejuvenating existing liquefaction facilities

- ✓ Uncertainty over timely realization of those projects under construction (yellow)
- ✓ As construction delays are now the norm and the increasing supply is likely to be absorbed by markets in Asia and elsewhere, widely touted "oversupply" around the end of the decade is unlikely



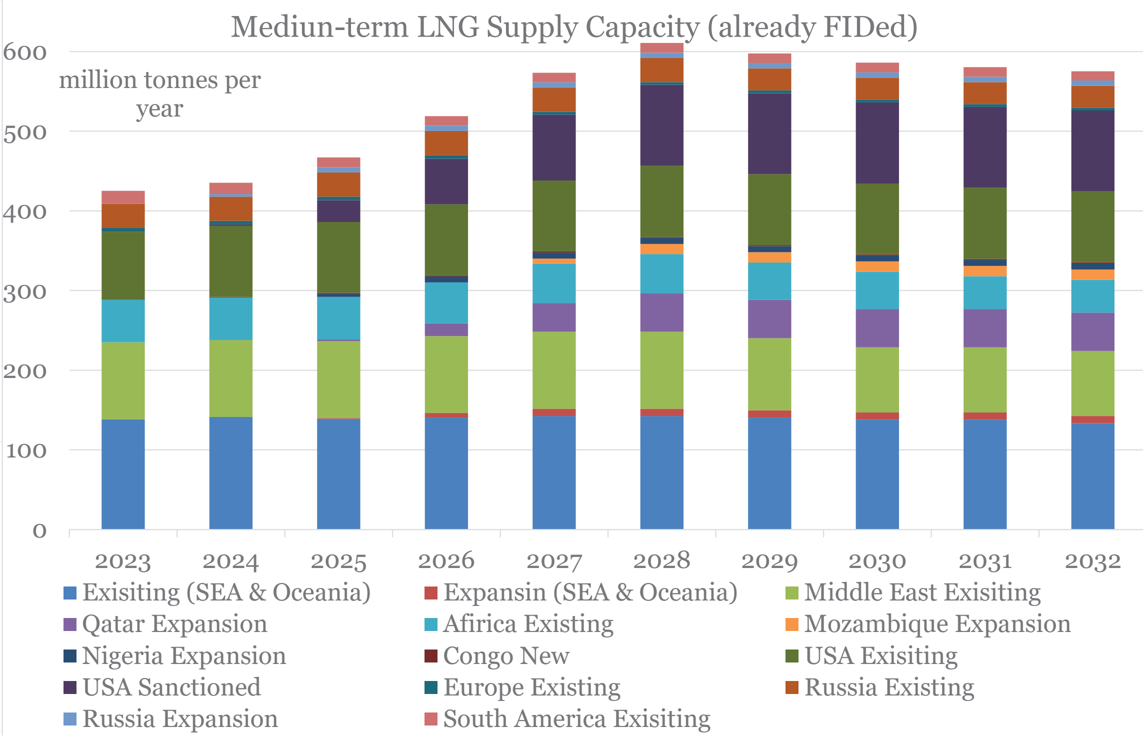
After Many FIDs 2021-2023, Uncertainty Thereafter and Uncertainty of Completion

- ✓ After the energy crisis in 2022, LNG development activities have been accelerated
- ✓ The capacity for which FIDs were made in 2021-2023 apparently exceeded the above-mentioned required capacity
- ✓ The pause of non-FTA export authorization and regulatory uncertainty have slowed down FIDs in the United States in 2024
- ✓ Uncertainty and delays should be noted over realization and timely implementation of those sanctioned projects



Medium-Term LNG Production Capacity Additions Entail Uncertainty

- ✓ If LNG production projects currently under construction are completed as scheduled, the total capacity is expected to exceed demand around 2030
- ✓ However, there are some uncertainties with those projects under construction
  - ✓ Uncertainty of new projects in Russia
  - ✓ Suspended construction due to political instability
  - ✓ Project delays caused by prolonged negotiations regarding additional cost allocations between project owners and contractors
  - ✓ Court decisions to suspend construction permits triggered by environmental claims
- ✓ Price sensitive LNG users are likely to commit more LNG offtakes based on prospective increases of LNG production
- ✓ "Glut" of LNG capacity around 2030 is illusive



(Source) compiled by the author

Issues Surrounding LNG to Function as A Realistic Solution

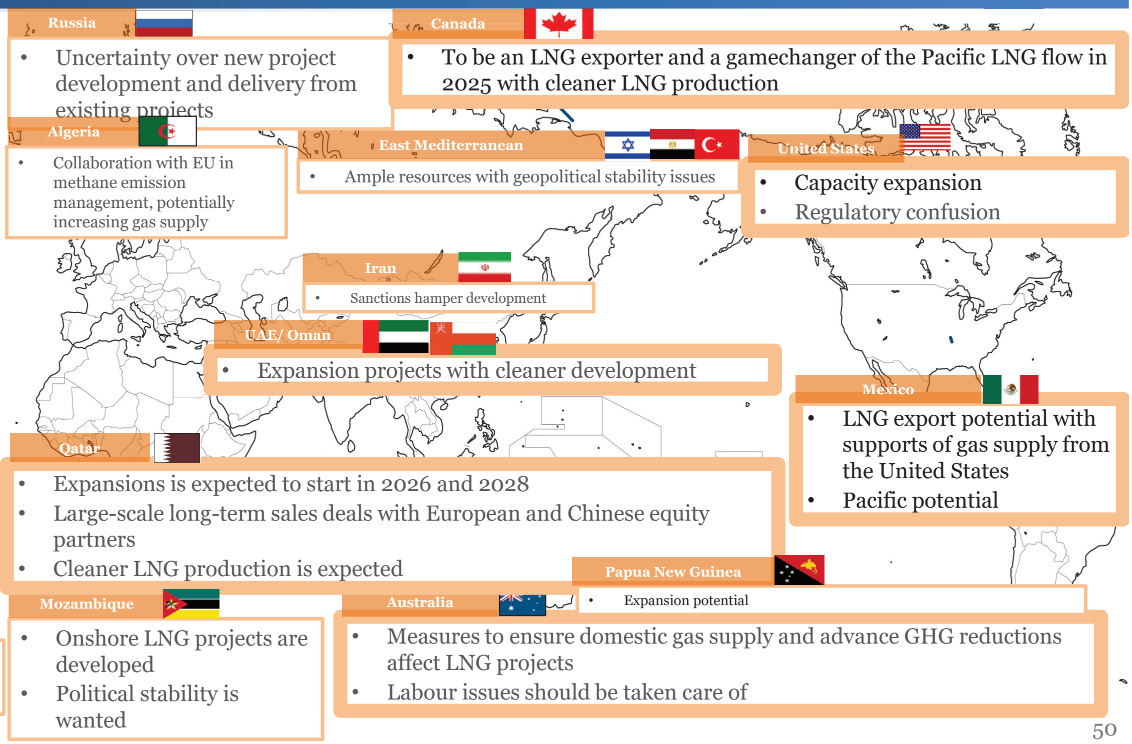
1. The role of LNG in the energy transition and energy supply security is important
   i. Efforts of the LNG market and industry players are necessary to meet these expectations toward stable supply and cleaner LNG
   ii. Clearer standards of LNG that could fit the goal are necessary
   iii. Companies should make efforts to better manage methane and GHG emissions, to set higher goals, and to disclose appropriate and timely information. It is important to make the entire LNG value chain even cleaner
   iv. It is also helpful if the industry can make LNG look more attractive as an investment and financing target
2. LNG consuming countries have roles in expanding and maintaining production
   i. it is important for companies and governments in consuming countries to encourage stabilization of regulatory aspects and project development in LNG producing countries,
   ii. as well as to participate in such development
3. Demand aggregation engaging emerging markets and market development supports help expand the global LNG market and support LNG production development
   i. Medium- to long-term demand aggregation and market development support, including those in emerging markets in Southeast Asia
   ii. The resulting expansion of the global LNG market will support LNG production development

Trends in LNG Production Projects in Recent Years

	Major trends	Factors promoting projects
2010-2014	• Northeast Asian LNG demand surge • Australian LNG project boom	• Development activities are stimulated elsewhere
2015-2020	• Activities shifted to the United States with moderated cost escalations in upstream and liquefaction sectors • Feedgas supply in the United States is not necessarily cheap but is expected to be stable on the long-term basis	• Conversion of receiving infrastructure into export facilities • Separated gas production and transportation sectors • FLNG (floating LNG production) as a competitive option
2021-	• Logistical constraints caused by the pandemic and the war have delayed construction activities • Instability in some countries has caused delays • Difficulties in absorbing cost escalations • Uncertainty in export authorisation and construction approvals in the United States	• Small and mid-scale liquefaction applications • Modular and design-one-and-build-many strategy • Phasing out from Russian gas - activities elsewhere
	• Prices of materials are on the rise • CCS and electrification add costs • Financial costs are on the rise	• Developers pursue cost reductions

LNG Supply Sources Have Advantages and Challenges

- ✓ Although the United States leads capacity expansion for several years to come, additional regulatory uncertainty has emerged including the pause of non-FTA LNG export authorization and the suspension of construction approvals
- ✓ New LNG supply sources have potential advantages of increasing supply, avoiding transportation bottlenecks, and shorter and diversified transportation
- ✓ Qatar is expected to further advance its LNG marketing activities beyond partners in expansion projects
- ✓ Australia needs measures to maintain stable supply and risk mitigation



The "Pause" and Court Decisions to Suspend Construction Approvals Cause Uncertainty

- January 2024 Pause of non-FTA authorization and economic and environmental impact study
- Certain LNG projects suffer delays and uncertainty - credibility in limbo
- After a court order to stop "pause" of 2 July, a non-FTA approval of a Mexican project on 31 August
- Another court vacated two FERC authorizations on 6 August
- FERC plans to conduct additional environmental reviews of two front-running projects
- **Uncertainty over LNG export authorization and over construction approval should be removed**

Issues to be considered on the "pause"	Points to be noted
Direct impact of the "pause"	30 mt out of 150 mt/y LT deals in 2022/2023
"48 bcf/d (365 mt/y) authorised; 26 bcf/d (200 mt/y) to be realised"	22 bcf/d without FIDs, no assurance
Disagreements between commercial and regulatory progress	Regulators do not directly take account of commercial arrangements, but something should be done
License extensions are said to be unaffected	Extension reviews are closely watched
Uncertain when the review process will resume	Exactly when new reviews will resume after the election
Public comment period	Parties should start preparation
Other LNG projects may benefit from the pause	Some projects within and outside of the United States
Possible outcomes of the studies	Upper and/or time (adjustable) limits of LNG exports Tougher (adjustable) standards for license extensions

The Shale Revolution in the United States and Its Global Impact

- The Shale Revolution evolves with interaction with the global LNG market
- The United States is now the largest exporter in the world, contributing to Europe's phasing out of Russian gas supply
- **Incremental LNG production project development should support LNG market development focusing on emerging markets**

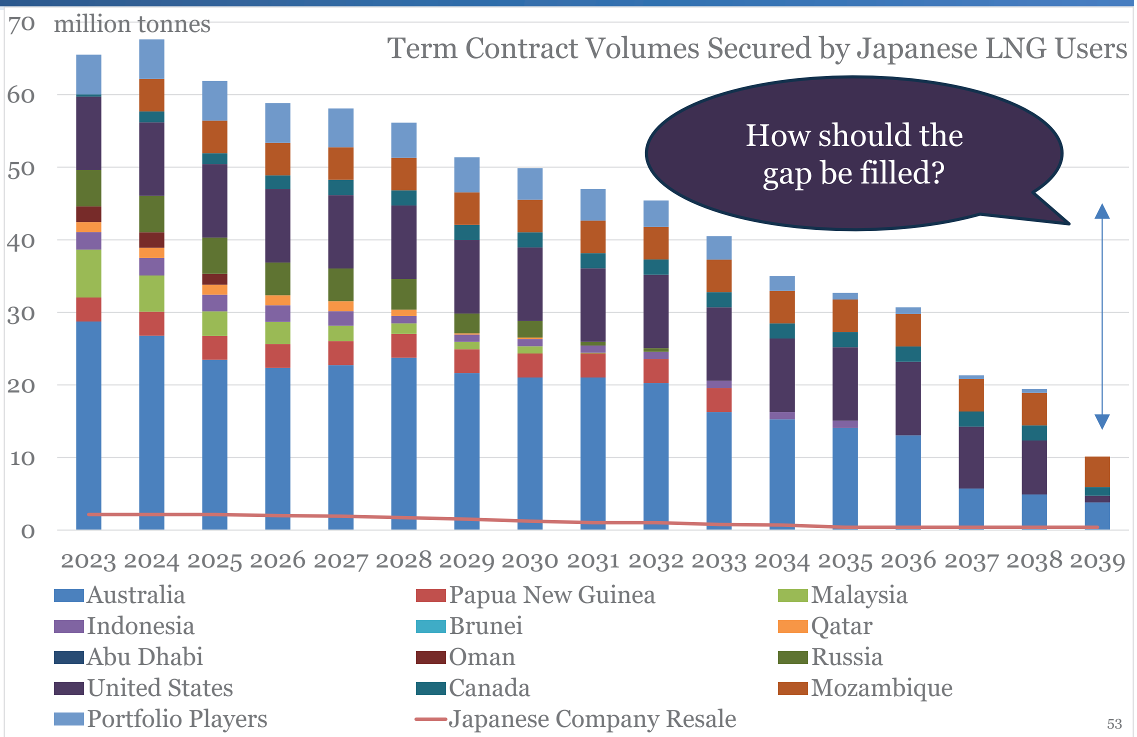
	Natural gas market in the United States	Global LNG market	Interaction
- 2007	Rising prices encourage more production	Gas and crude prices rise	LNG export projects target the United States
2008 -	Shale Revolution starts from natural gas Gap widens between gas and oil prices	Qatar and Russia increase LNG exports	LNG prices present Asian premiums (especially after nuclear shutdowns in Japan)
2014 -	LNG export projects commence and expand Increasing crude production increases gas	LNG exports increase mainly from Australia	LNG from the United States brings about flexibility in international LNG trades
2019	30 out of 70 million-tonne-per-year LNG export FIDs in the world come from the United States	Increasing supply lowers LNG and gas prices	A gap between domestic and international gas prices encourage projects in the United States
2020	Many LNG cargoes are cancelled in the Northern Hemisphere summer	Lowest ever LNG and gas prices with convergence between regions	Sluggish global gas prices lead to LNG cargo cancellations in the United States
2021	The United States dominates the incremental LNG supply in the global LNG market	Gas prices maintain high levels from the second half of 2021	LNG investment decisions are few despite higher LNG prices due to uncertainty
2022 -	**The United States becomes No 1 LNG exporter in 2023** **LNG project development entails uncertainty due to the pause of non-FTA export authorization and the court order to suspend construction approvals** A brief period of higher gas prices in the United States	**Significant reduction of Russian pipeline gas supply** **EU increases LNG imports supported by LNG from the United States** Natural gas prices become much volatile	LNG production development is accelerated around the world **The United States is expected to continue being a stable and enormous supply source to the global LNG market. Supports and encouragements from importing countries gain more importance**

LNG Procurement by Japanese Expects More Partnerships and Portfolio Players

- ✓ The task is how the gap between the already secured volume and projected future demand should be filled
- ✓ The Reference Scenario projects 45 million tonnes in 2050
  - ➢ It is increasingly difficult for an individual company to make a long-term procurement deal with large volume
  - ➢ Smaller volume requirement could lead to a weaker bargaining position

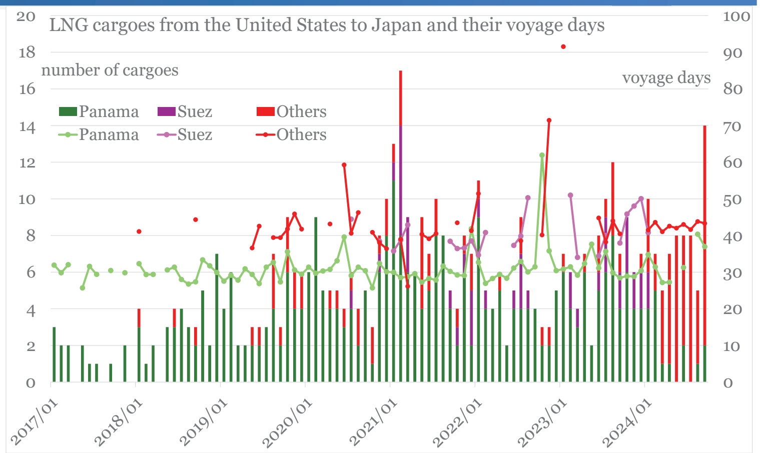
↓

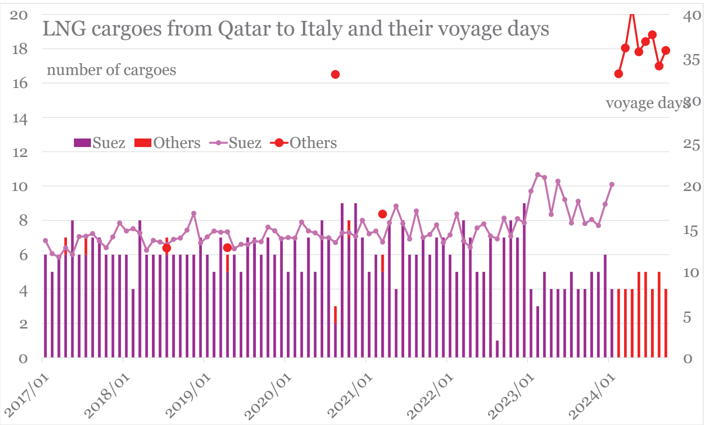
- ✓ Policy supports and company - government collaborations gain importance



The More LNG Is Transported, The More Evident Bottlenecks Are

- ✓ Bottlenecks on important shipping routes are likely to be a major obstacle in times of tight supply and demand
- ✓ After the Panama Canal was expanded in 2016, more LNG has been transported from the Atlantic to Asia
- ✓ In addition to the transit capacity limit, draughts restricts traffic, leading to alternative longer transportation routes
- ✓ The Red Sea - Suez Canal route has its own obstacles
- ✓ A long-term LNG transportation strategy is needed





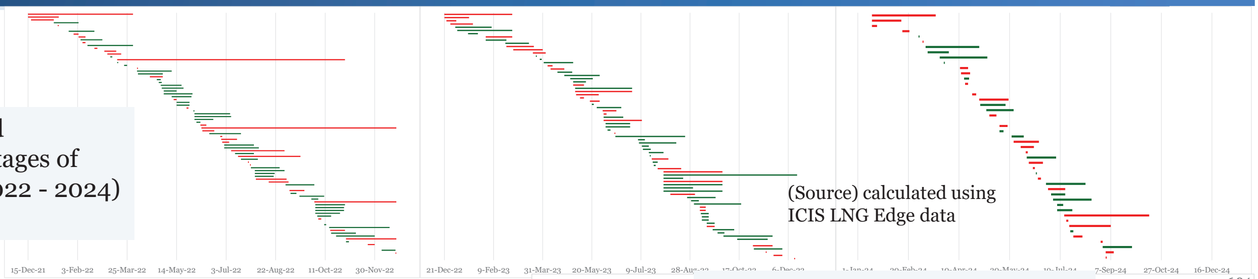
Average LNG voyage days from the United States to Japan →

	Panama	Suez	Others	Total
2016				
2017	30			30
2018	30		43	31
2019	30		41	33
2020	31	41	43	33
2021	30	39	39	32
2022	32	40	50	34
2023	31	44	49	35
2024	32	41	42	39

(Source) calculated using ICIS LNG Edge data

Unplanned Outages of LNG Production Amplify Market Imbalances

Planned (green) and unplanned (red) outages of LNG production (2022 - 2024) --->



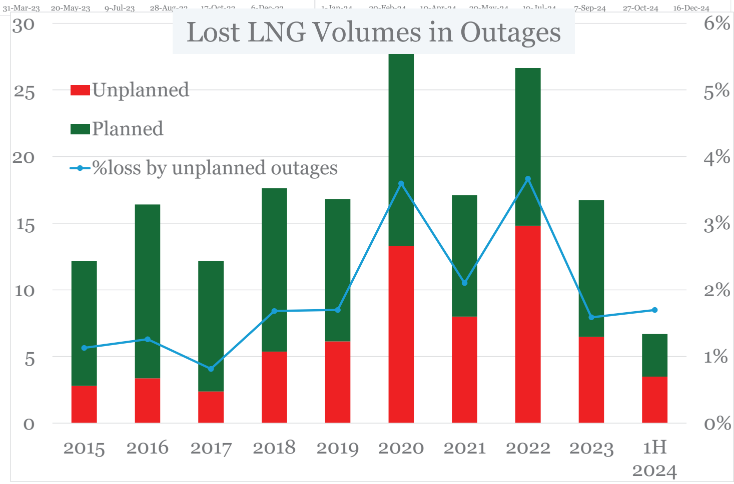
(Source) calculated using ICIS LNG Edge data

- ✓ There was a lengthy unplanned outage caused by a fire incident at a large-scale LNG export facility in the United States in 2022, as well as relatively long unplanned outages in other producing countries
- ✓ At the time of slim supply margins, spot prices were further pushed up by the loss caused by unplanned outages

Average day changes of spot gas and LNG prices

	2010	2011	2012	2013	2014	2015	2016
TTF	0.12	0.13	0.09	0.07	0.13	0.07	0.09
Spot LNG	0.09	0.12	0.12	0.11	0.15	0.11	0.12

2017	2018	2019	2020	2021	2022	2023	2024
0.08	0.13	0.13	0.09	0.85	2.42	0.61	0.26
0.10	0.16	0.11	0.19	1.01	2.37	0.52	0.25



Reference materials

Geographical coverage

- Countries/regions in the world are geographically aggregated into 44 regions.
- Especially the Asian energy supply/demand structure is considered in detail, aggregating the area into 17 regions. That of the Middle East is also aggregated into eight 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.

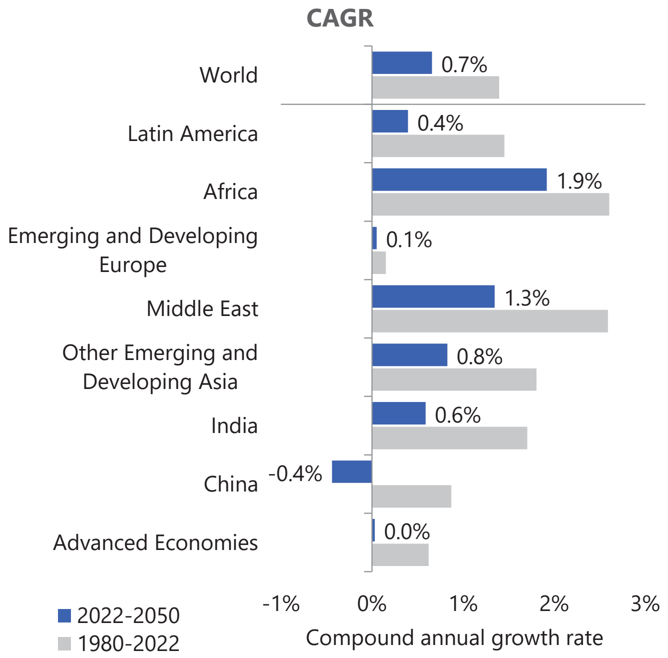
Climate change model
Calculate future GHG concentration in the atmosphere, temperature rise, damage caused by climate change, etc.

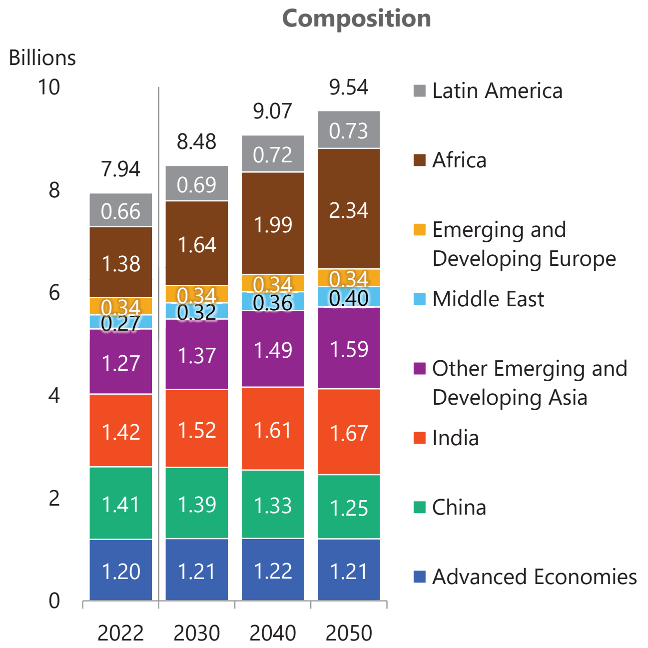
Basic scenarios in IEEJ Outlook

	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

Assumptions

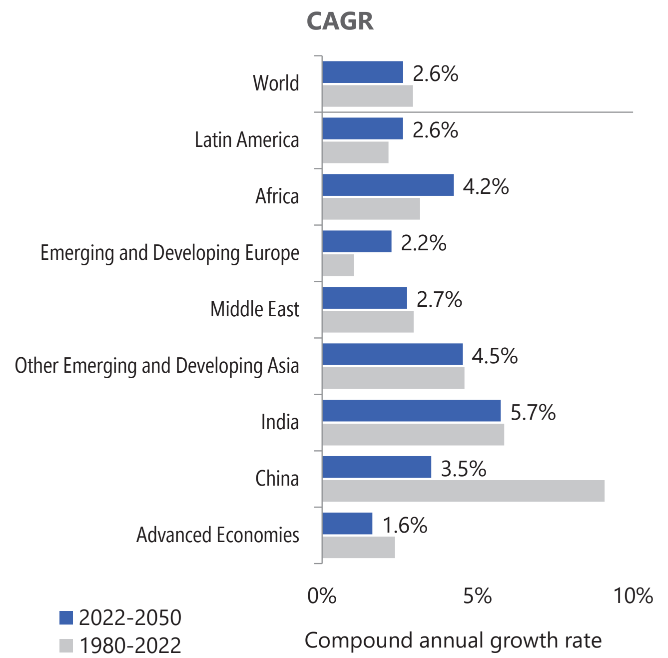
Population

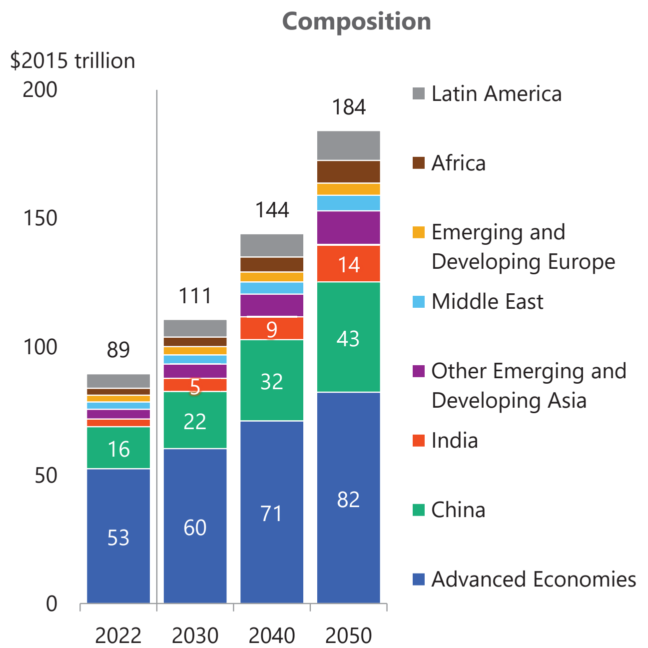




Assumptions

Real GDP

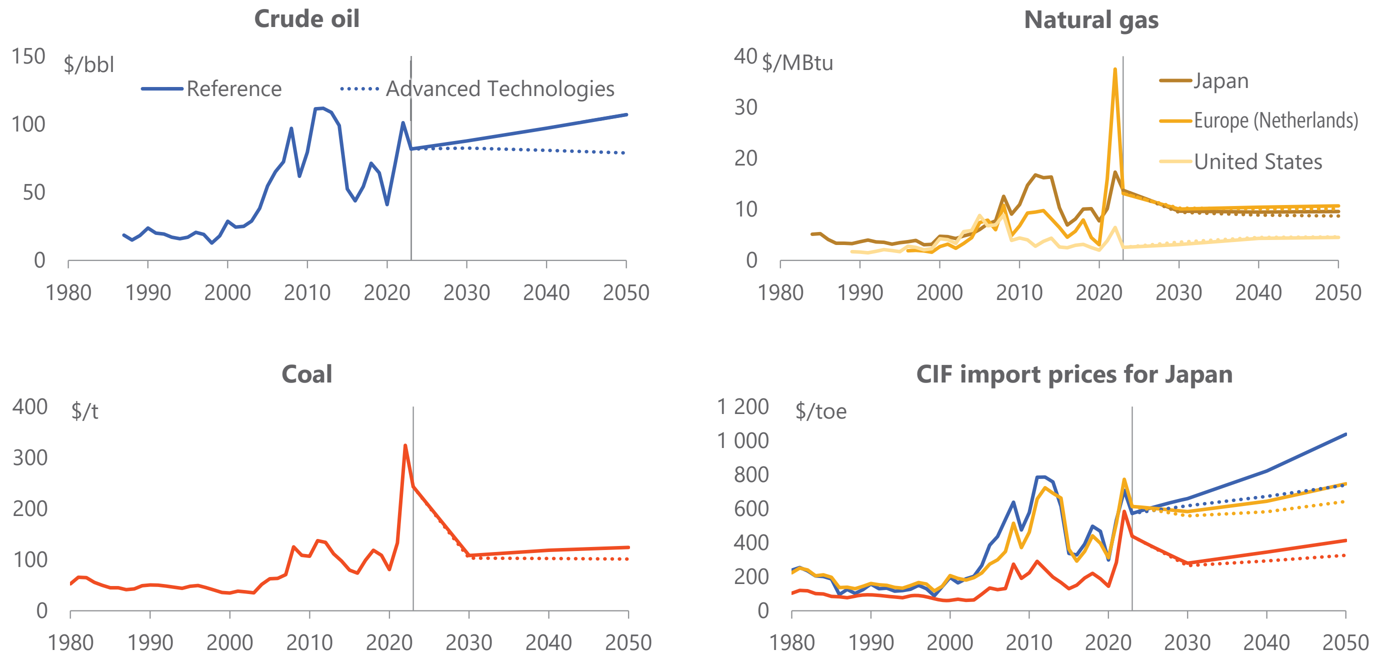




Assumptions

International energy prices

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



Note: Historical prices are nominal. Assumed future prices are real in $2023.

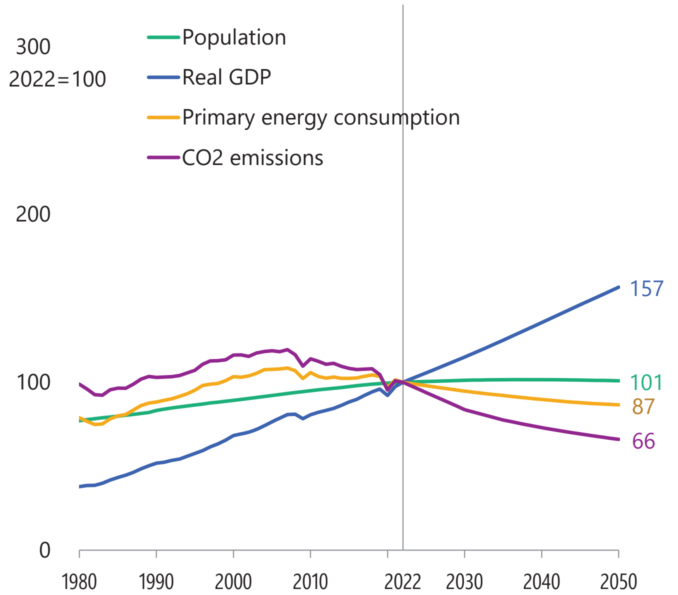
Assumptions

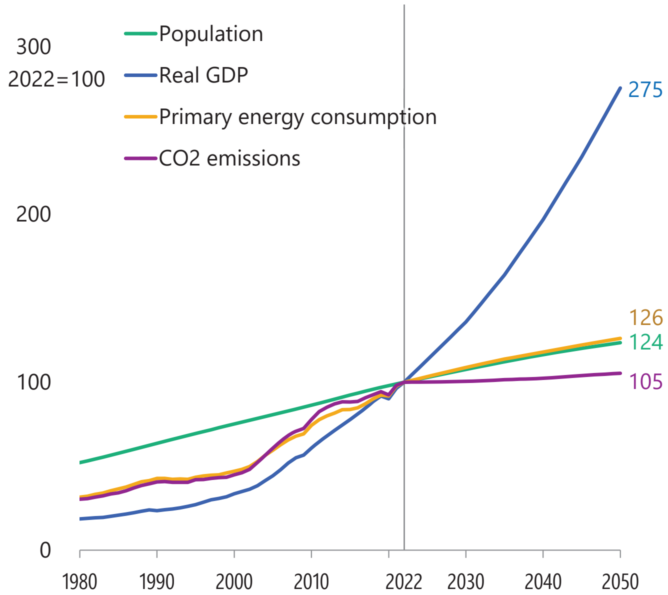
Energy and environmental technology

			2022	2050 Reference	2050 Advanced Technologies	Assumptions for Advanced Technologies Scenario
Improving energy efficiency	Industry	Intensity in steel industry (ktoe/kt)	0.270	0.260	0.201	100% penetration of Best Available Technology by 2050.
		Intensity in non-metallic minerals industry	0.095	0.074	0.065	
	Transport	Electrified vehicle share in passenger car sales	17%	60%	96%	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)	17.8	27.2	46.2	
	Buildings	Residential total efficiency (Y2022=100)	100	141	175	Efficiency improvement at 1.7 times the speed for installed appliance, equipment and insulation. Electrification in space heating, water heater and cooking (clean cooking in developing regions).
		Commercial total efficiency	100	131	172	
	Power generation	Thermal generation efficiency (Power transmission end)	37%	45%	48%	Financial scheme for initial investment in high-efficient thermal power plant.
Penetrating low-carbon technology	Biofuels for transport (Mtoe)		99	178	303	Development of next generation biofuel with cost reduction. Relating to agricultural policy in developing regions.
	Nuclear power generation capacity (GW)		387	498	814	Appropriate price in wholesale electricity market. Framework for financing initial investment in developing regions.
	Wind power generation capacity (GW)		962	3 548	5 156	Further reduction of generation cost. Cost reduction of grid stabilization technology. Efficient operation of power system.
	Solar PV power generation capacity		1 107	8 214	10 693	
	Thermal power generation capacity with CCS (GW)		0	0	1 137	Installing CCS after 2030 (regions which have storage potential except for aquifer).
	Zero-emission generation ratio (incl. CCS)		39%	60%	87%	Efficient operation of power system including international power grid.

Reference Scenario

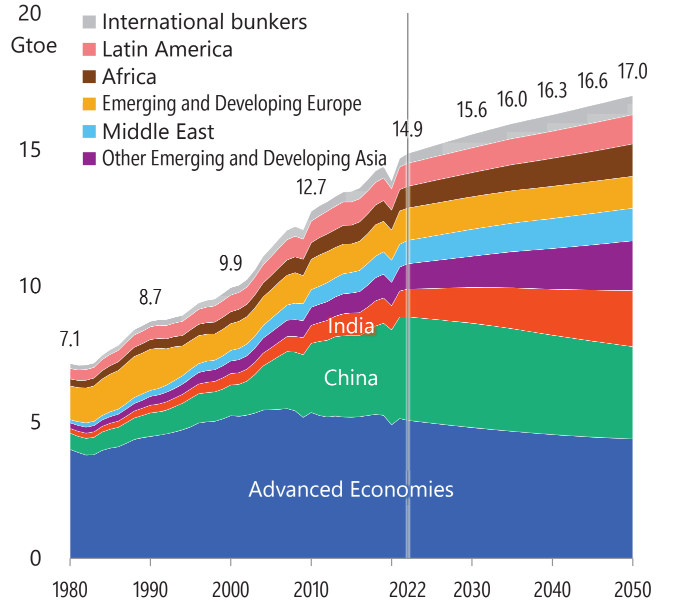
Population, GDP, energy and CO_2

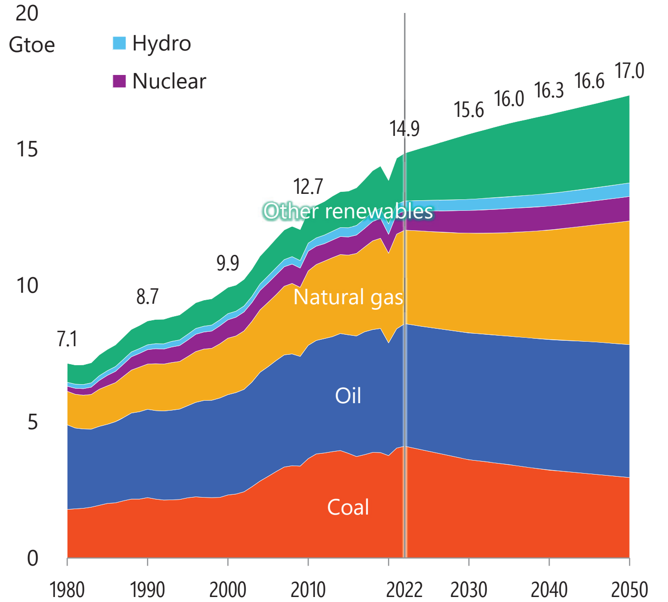




Reference Scenario

Primary energy consumption

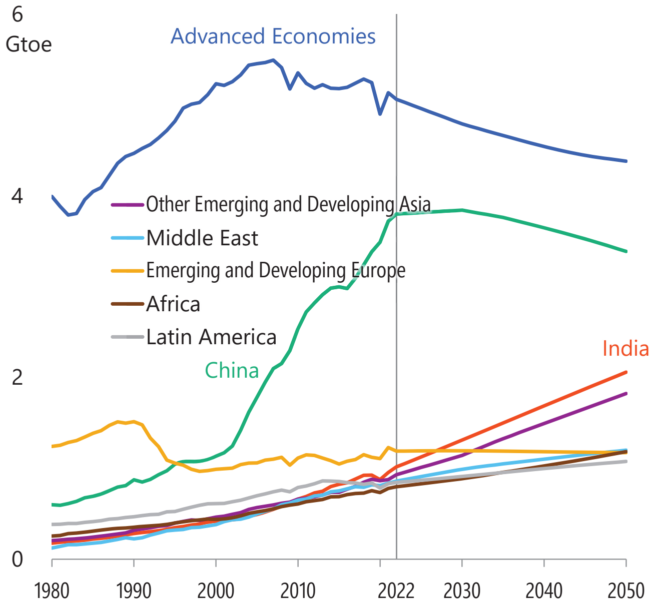




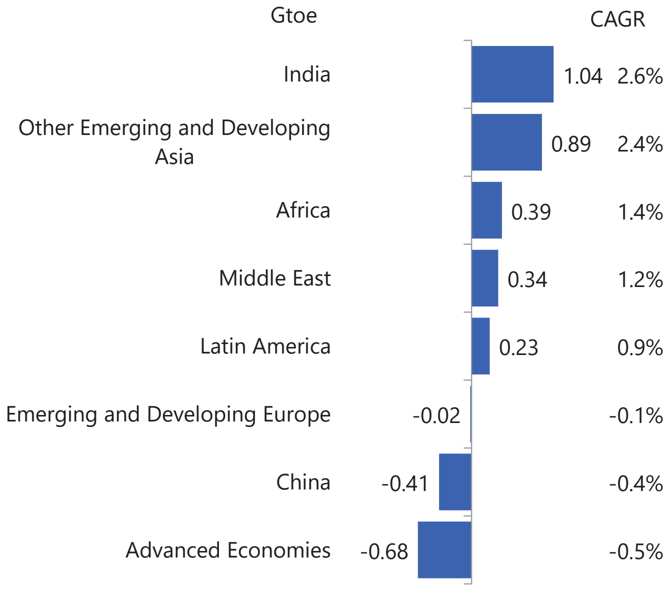
Reference Scenario

Primary energy consumption (by region)

Energy consumption



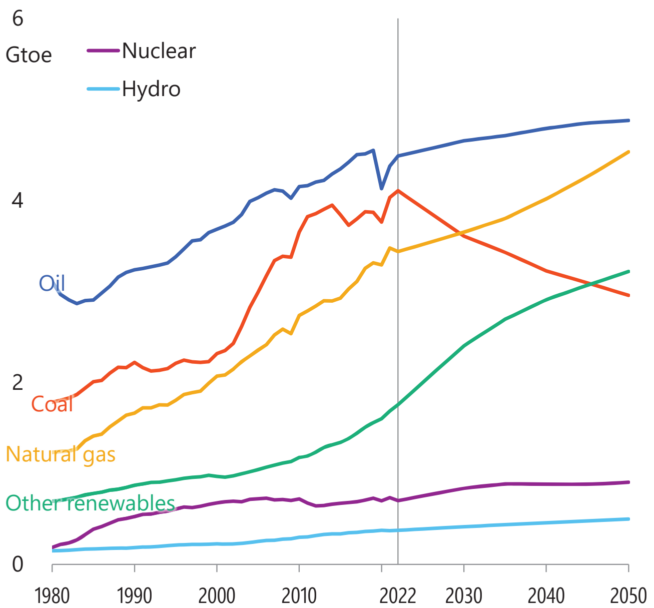
Changes (2022-2050)



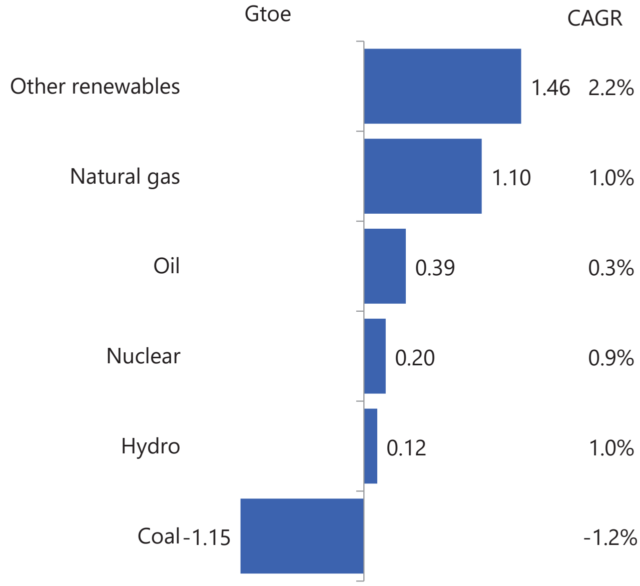
Reference Scenario

Primary energy consumption (by energy source)

Energy consumption

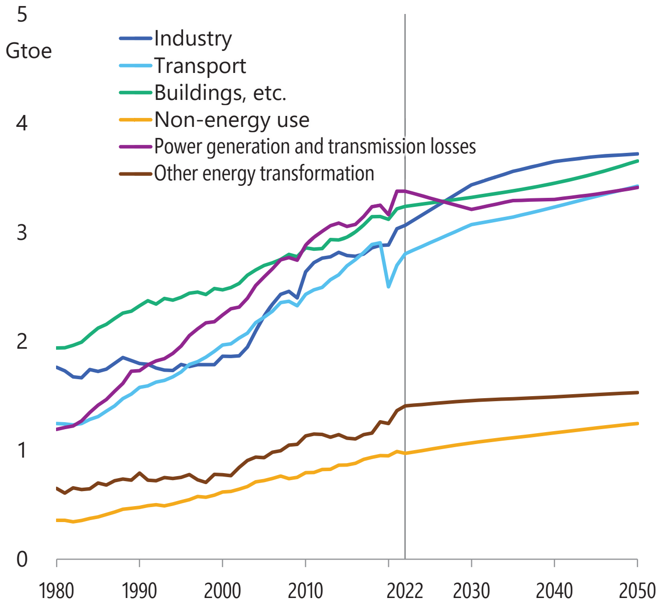


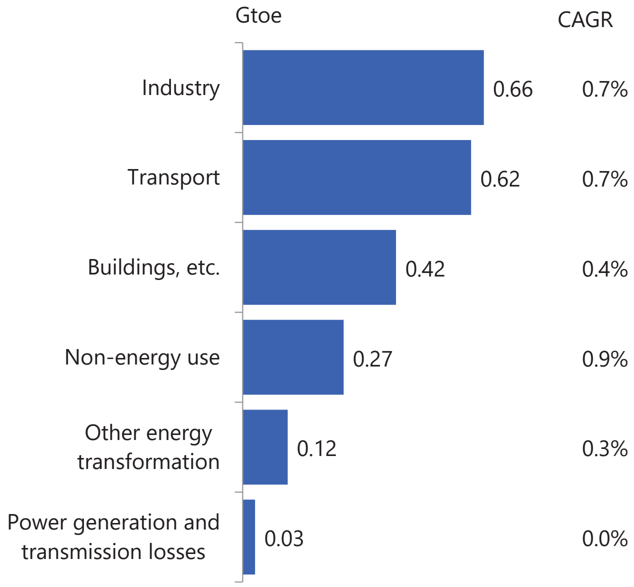
Changes (2022-2050)



Reference Scenario

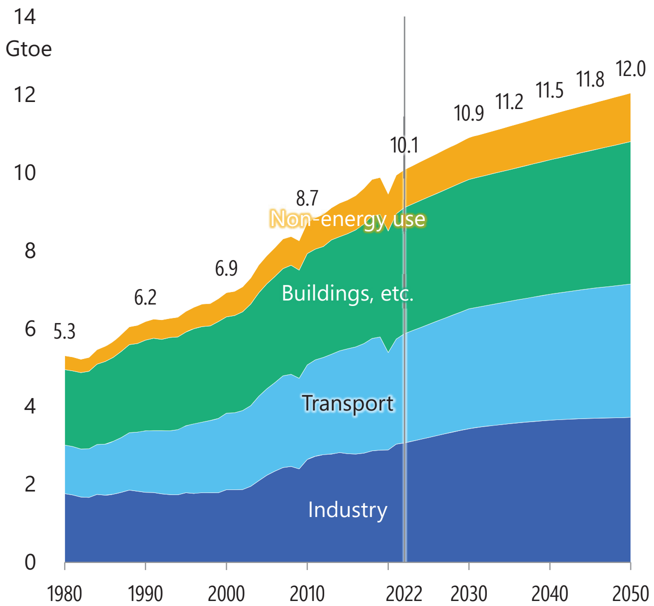
Primary energy consumption (by sector)

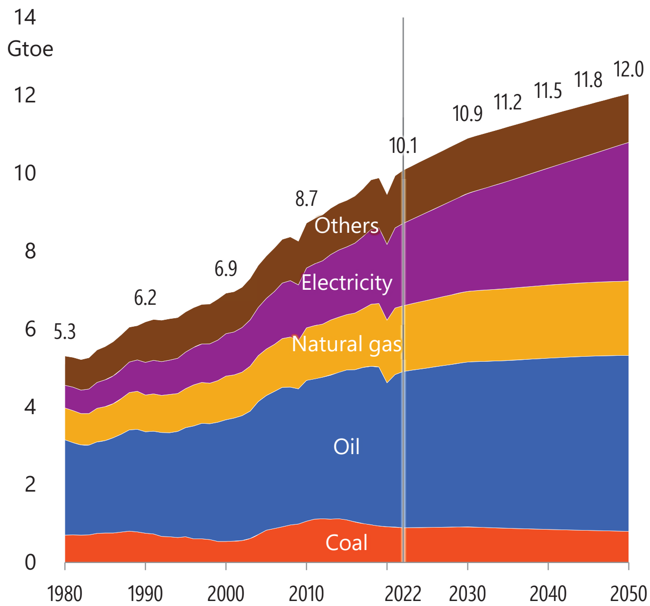




Reference Scenario

Final energy consumption

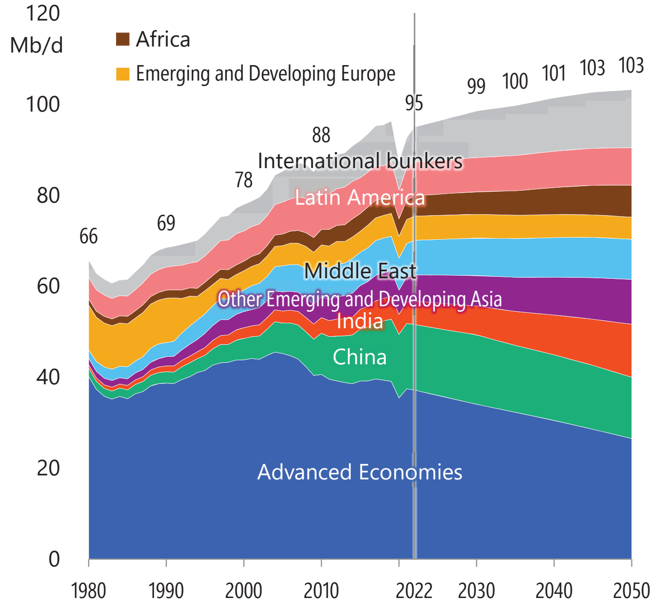




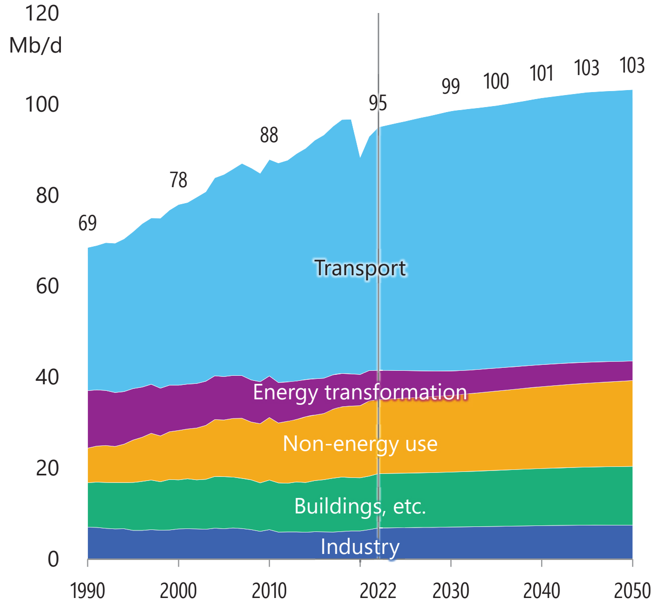
Reference Scenario

Oil consumption

By region



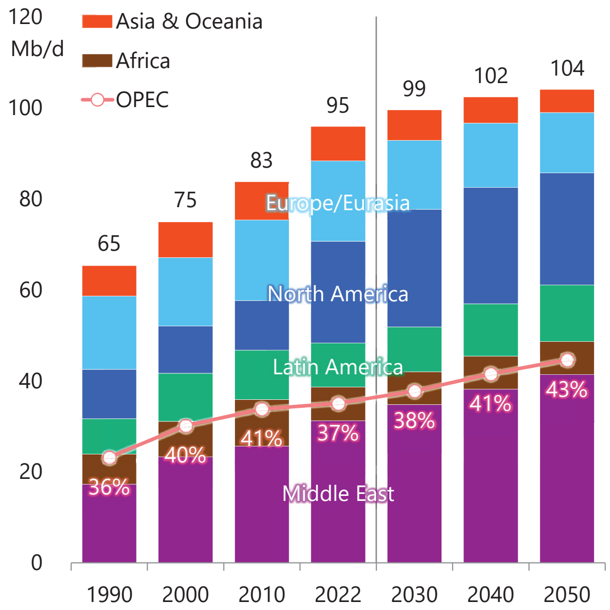
By sector



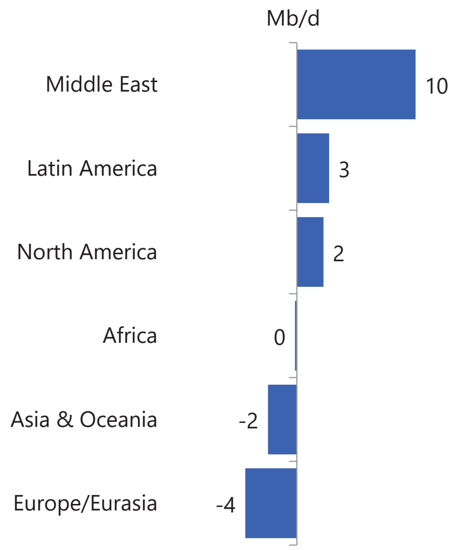
Reference Scenario

Crude oil production

By region

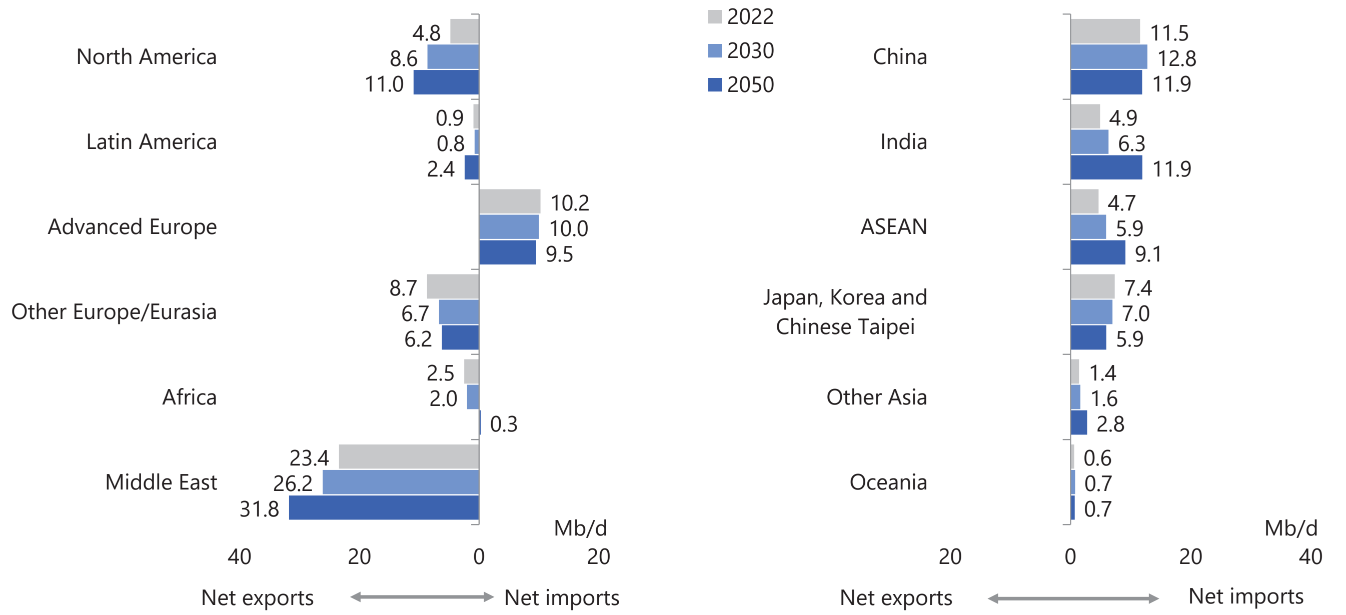


Changes (2022-2050)



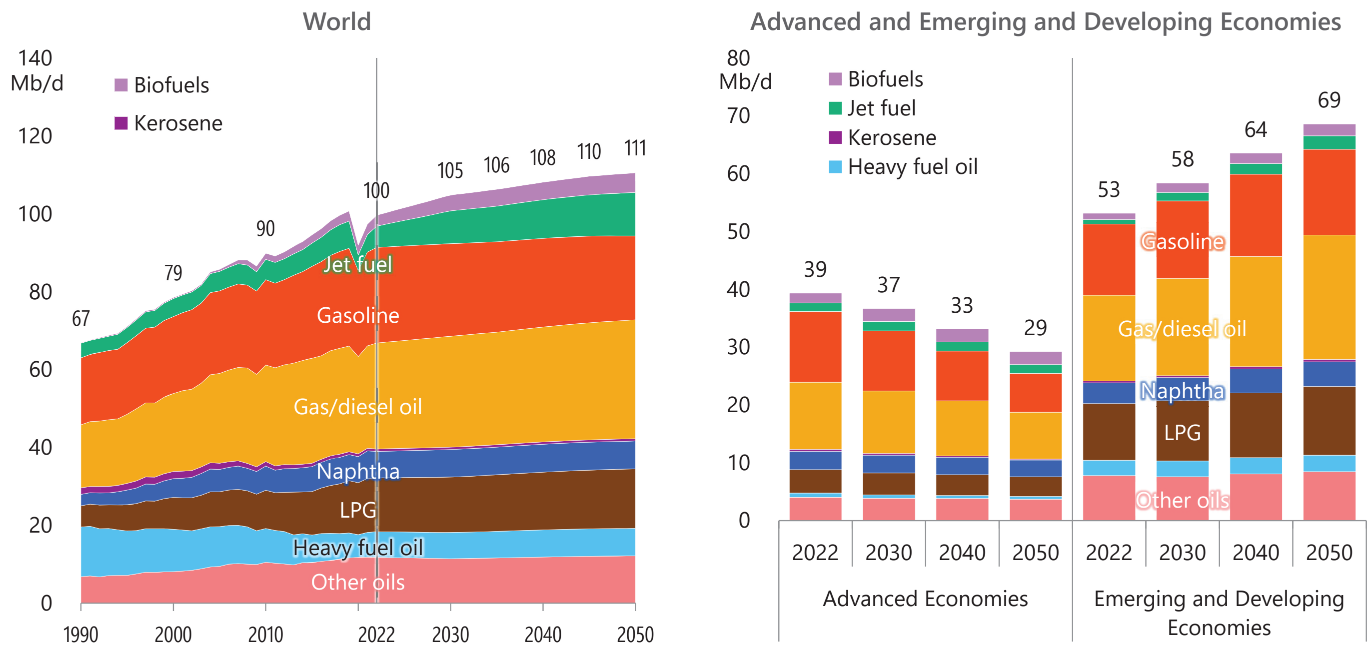
Reference Scenario

Net exports and imports of oil



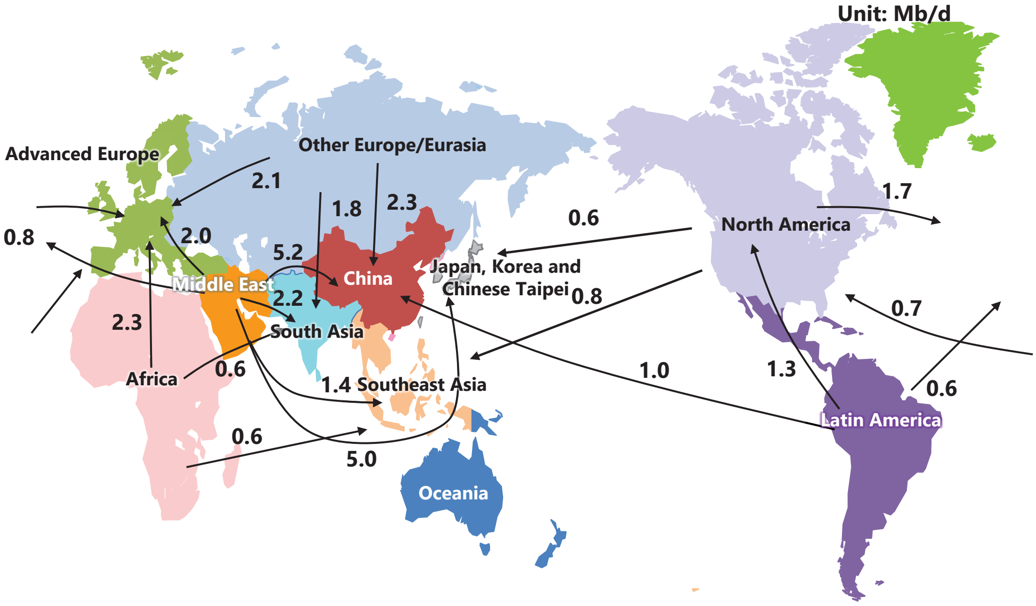
Reference Scenario

Petroleum product demand



Note: Other oils includes crude oil (direct consumption), asphalt, refinery gas, gas-liquefied oil [GTL], etc.

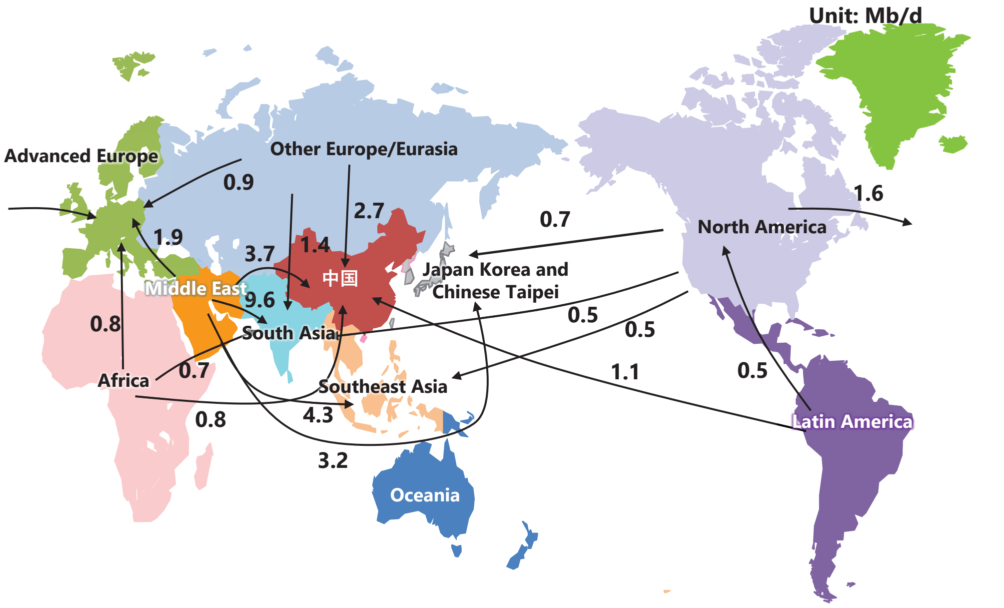
Major trade flows of crude oil (2023)



Note: 0.5 Mb/d or more are shown

Reference Scenario

Major trade flows of crude oil (2050)

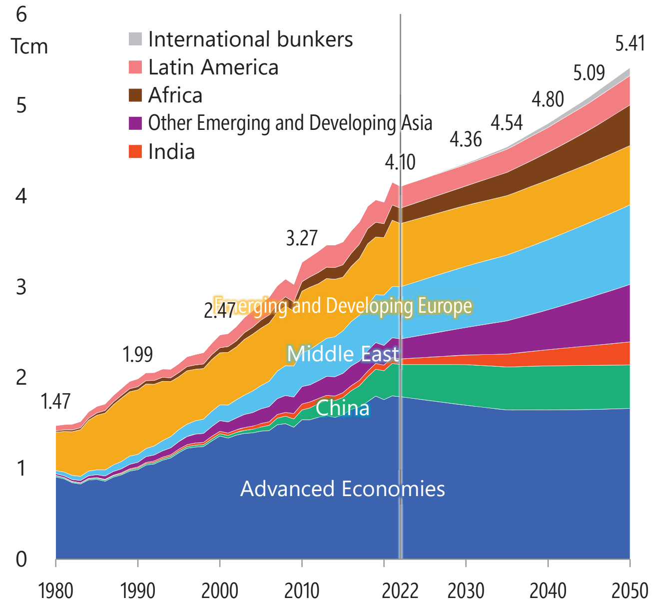


Note: 0.5 Mb/d or more are shown

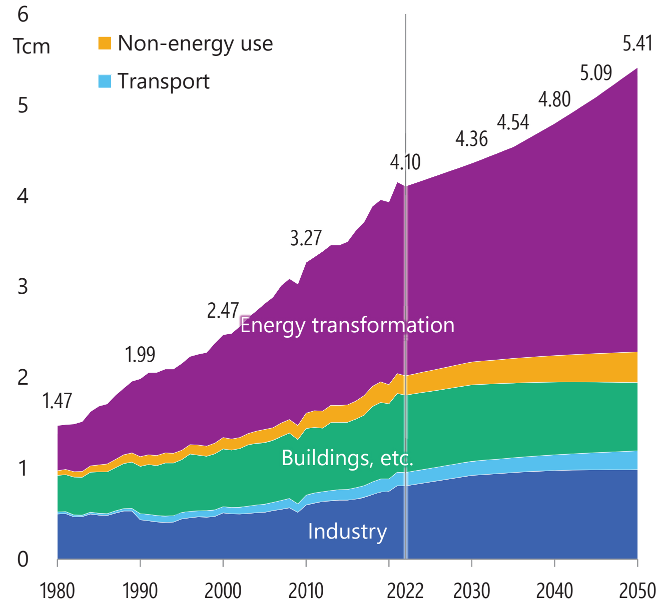
Reference Scenario

Natural gas consumption

By region



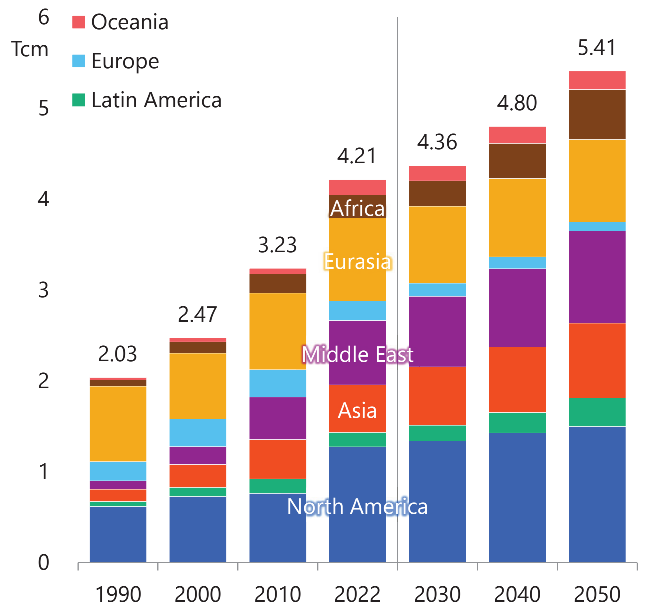
By sector



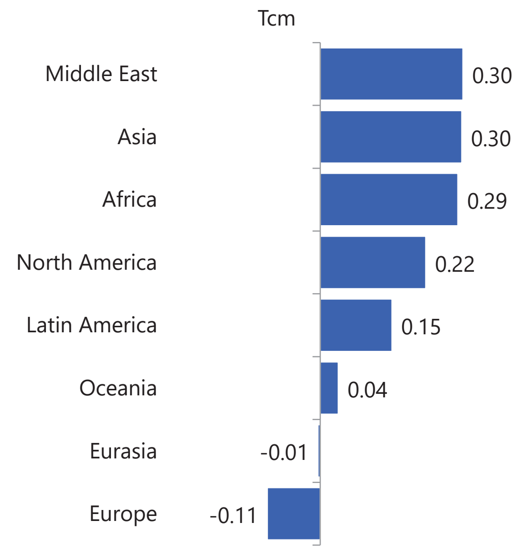
Reference Scenario

Natural gas production

By region

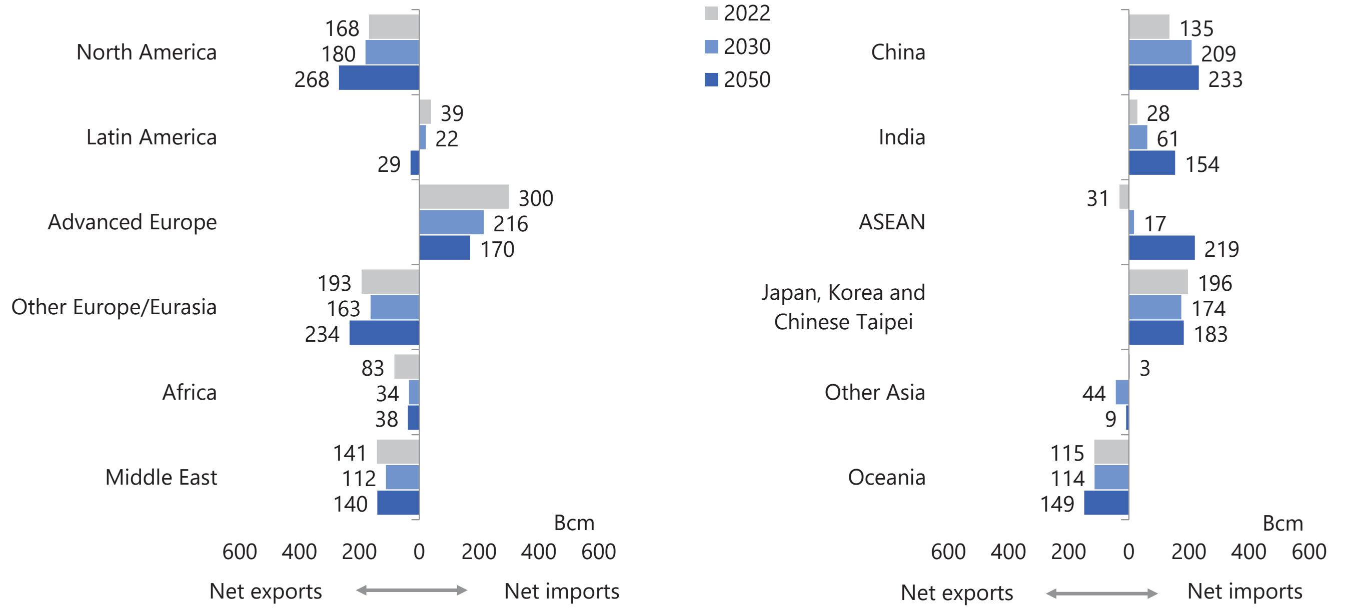


Changes (2022-2050)



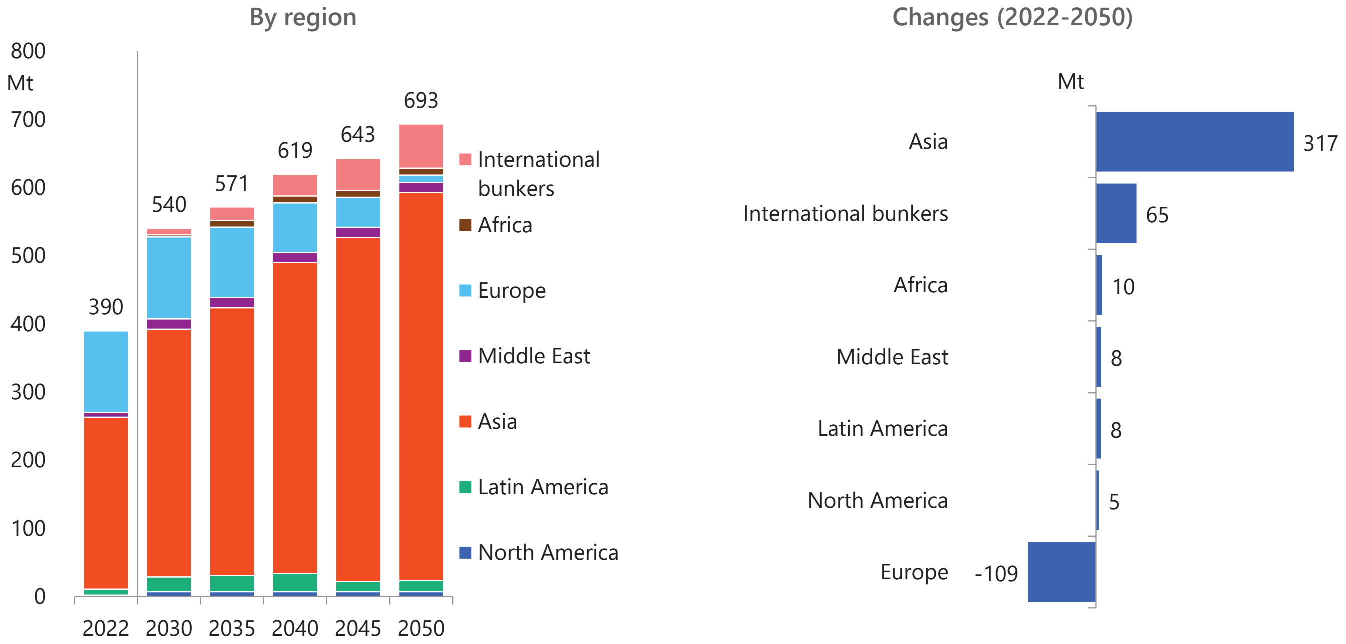
Reference Scenario

Net exports and imports of natural gas

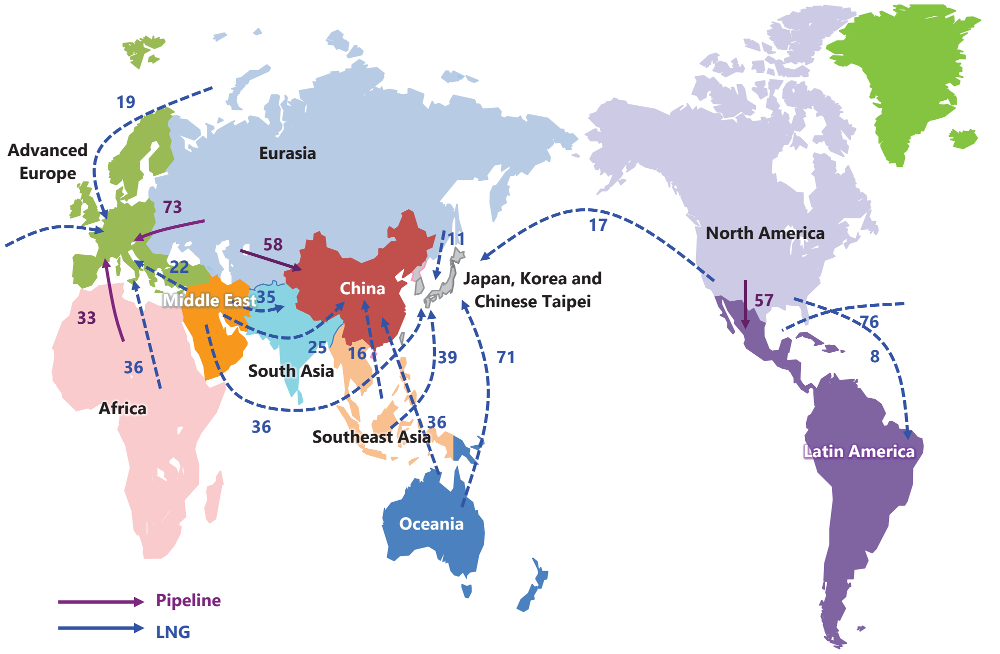


Reference Scenario

LNG demand



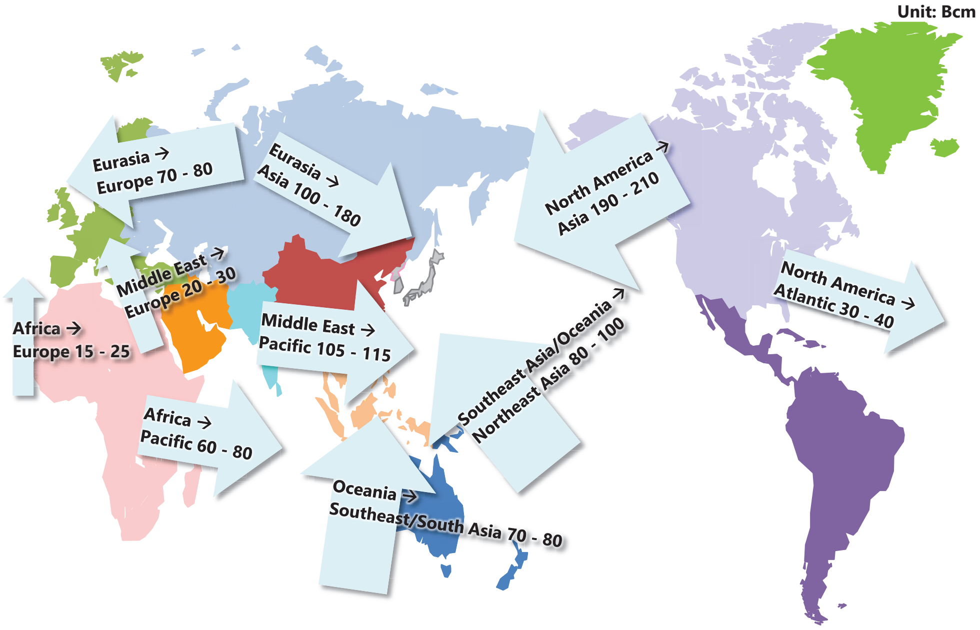
Major trade flows of natural gas (2023)



Note: This figure shows the main interregional trade and does not include the total trade volume.

Reference Scenario

Major trade flows of natural gas (2050)

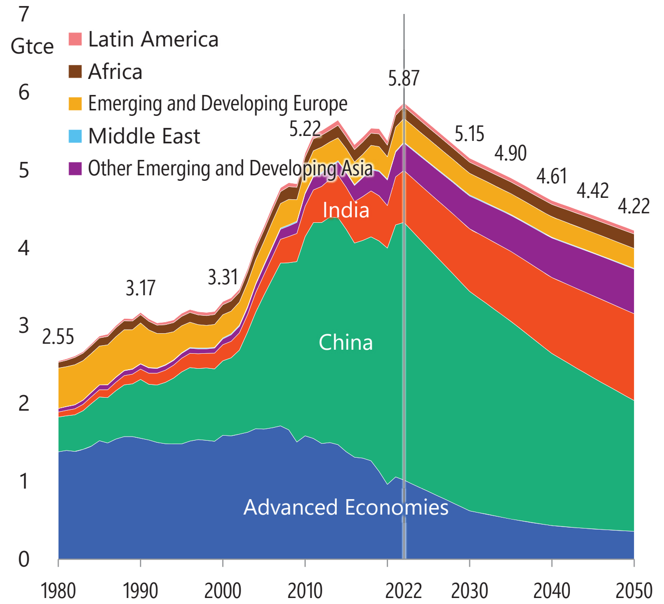


Note: This figure shows the main interregional trade and does not include the total trade volume.

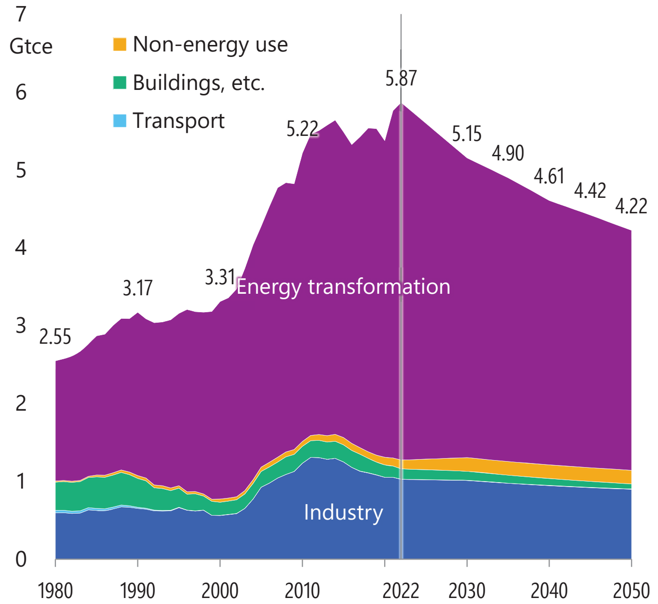
Reference Scenario

Coal consumption

By region



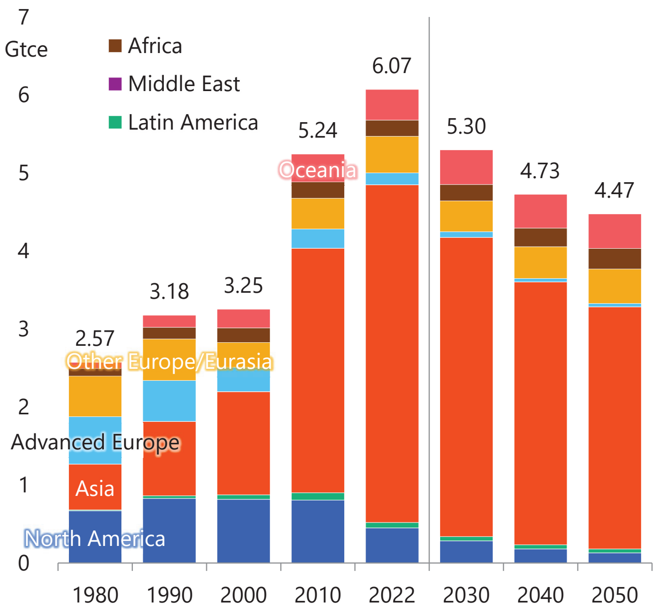
By sector



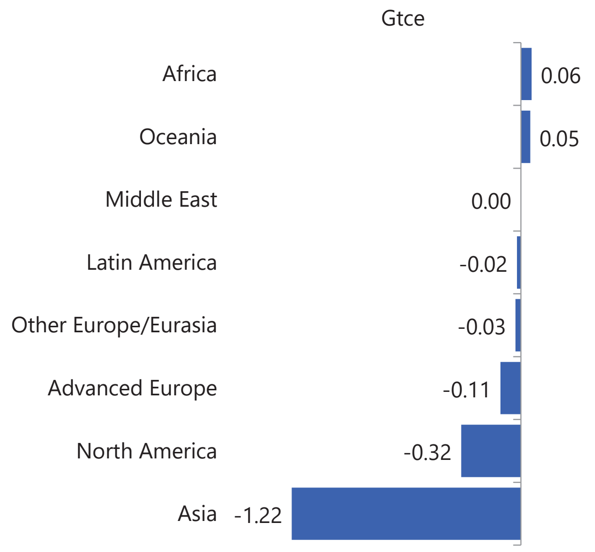
Reference Scenario

Coal production

By region

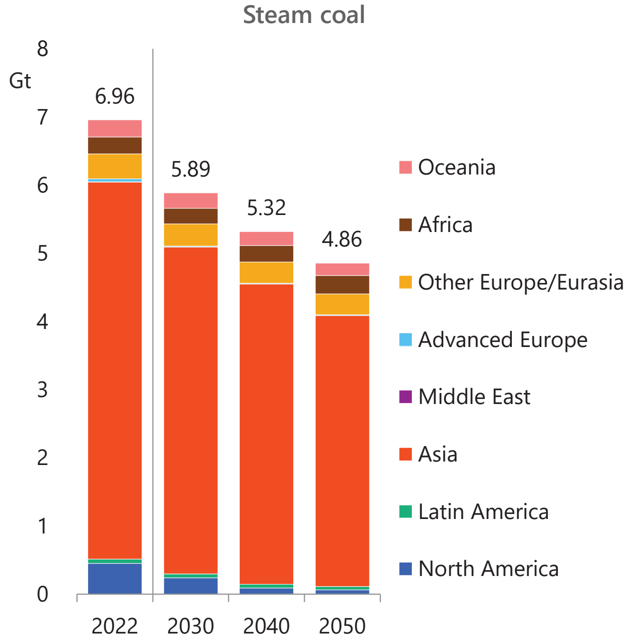


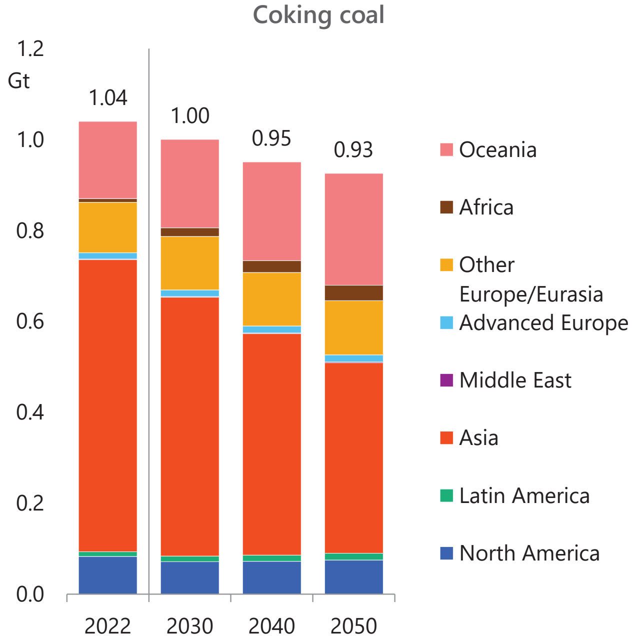
Changes (2022-2050)



Reference Scenario

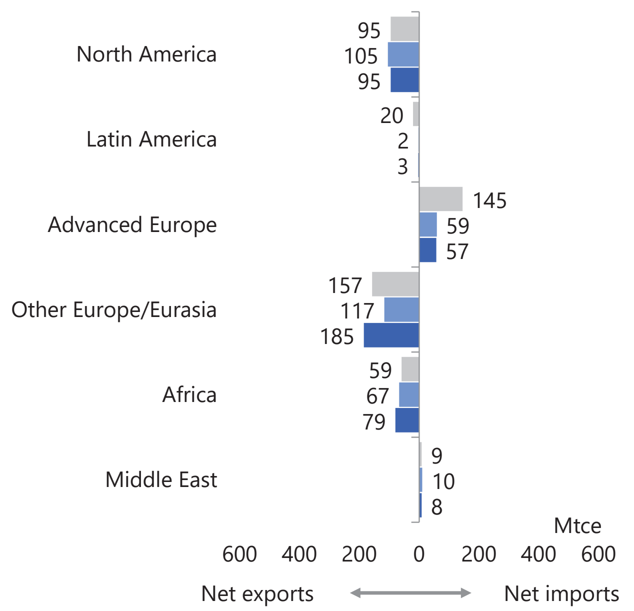
Coal production (steam and coking coal)

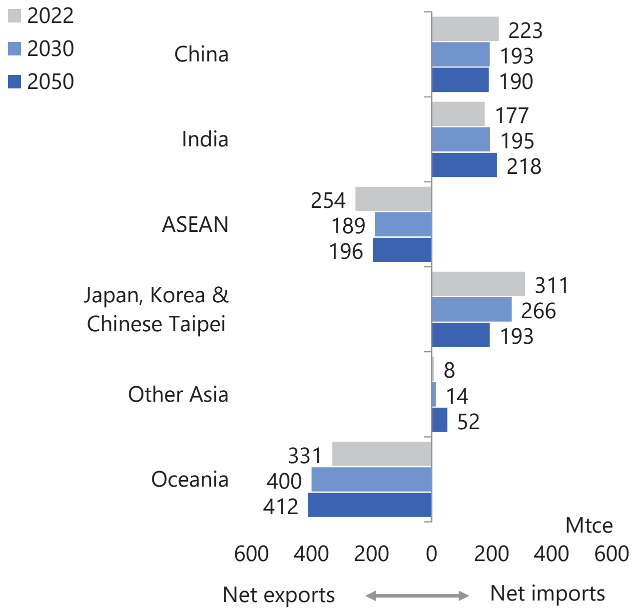




Reference Scenario

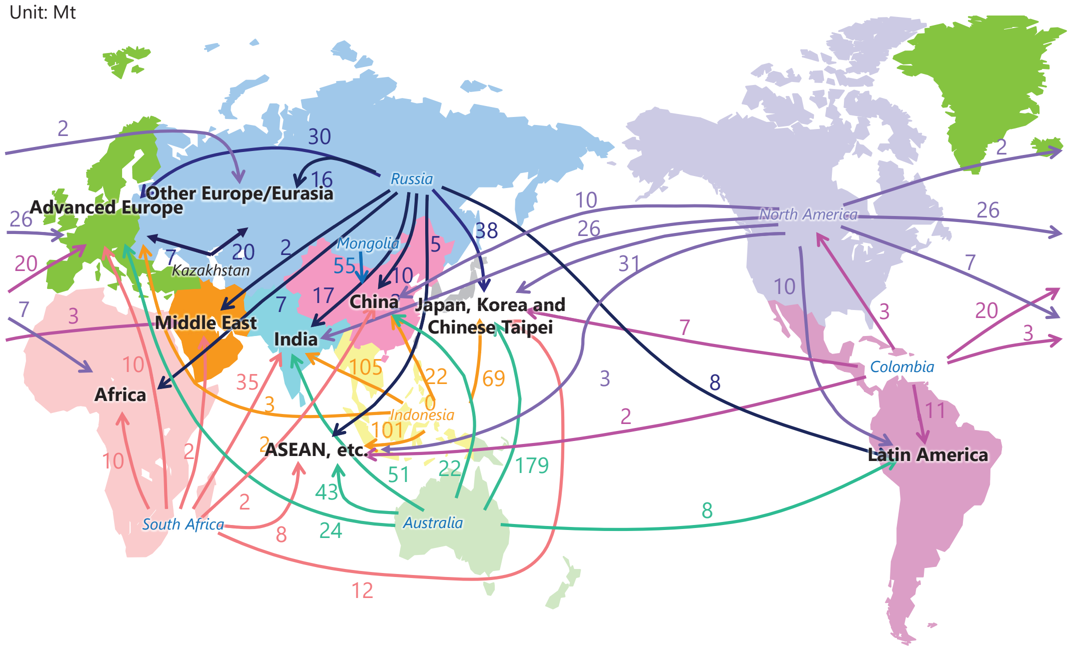
Net exports and imports of coal





Major trade flows of steam and coking coal (2023)

Unit: Mt

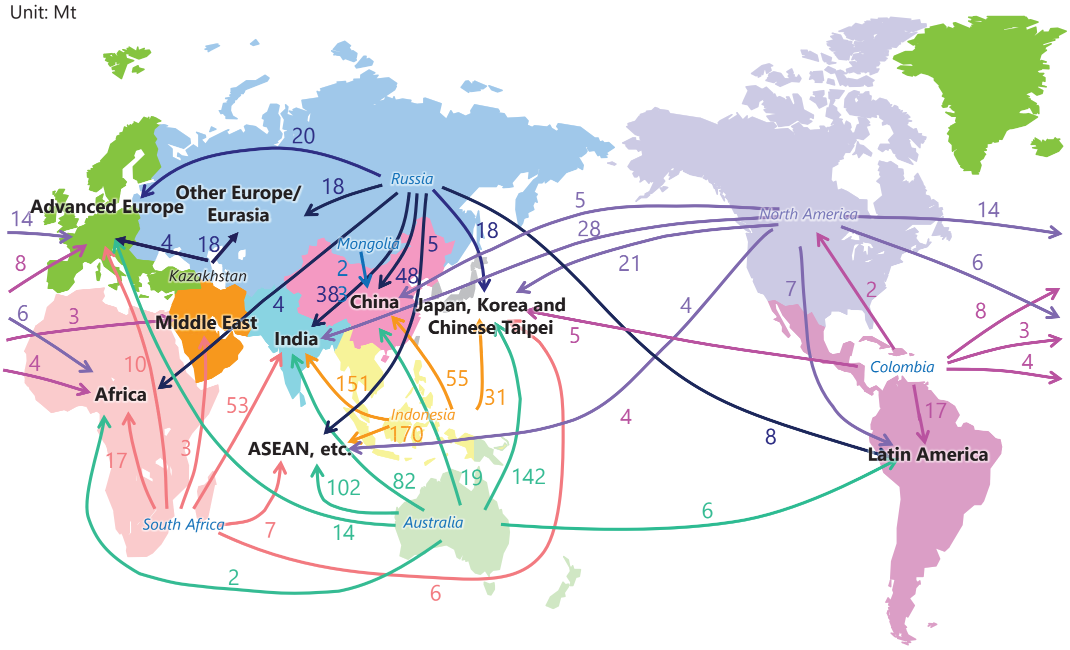


Notes: Total value of steam and coking coal. 2 Mt or more are shown. South Africa includes Mozambique. Source: Estimated from IEA "Coal Information 2024", "TEX Report", etc.

Reference Scenario

Major trade flows of steam and coking coal (2050)

Unit: Mt

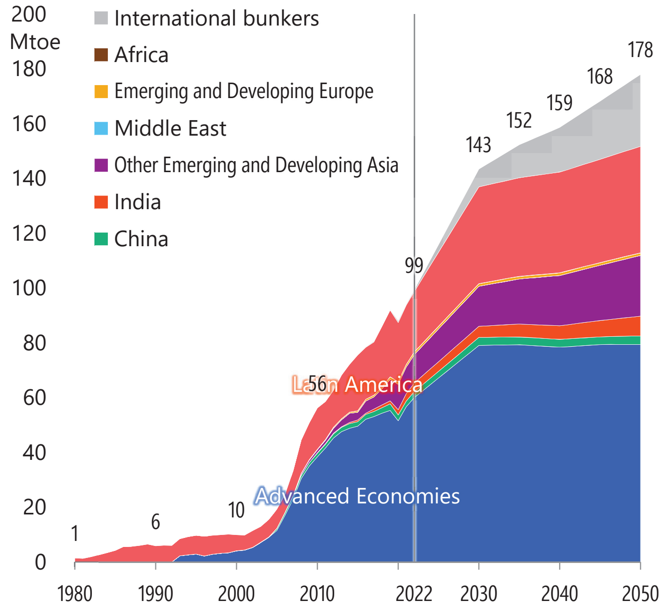


Notes: Total value of steam and coking coal. 2 Mt or more are shown. South Africa includes Mozambique.

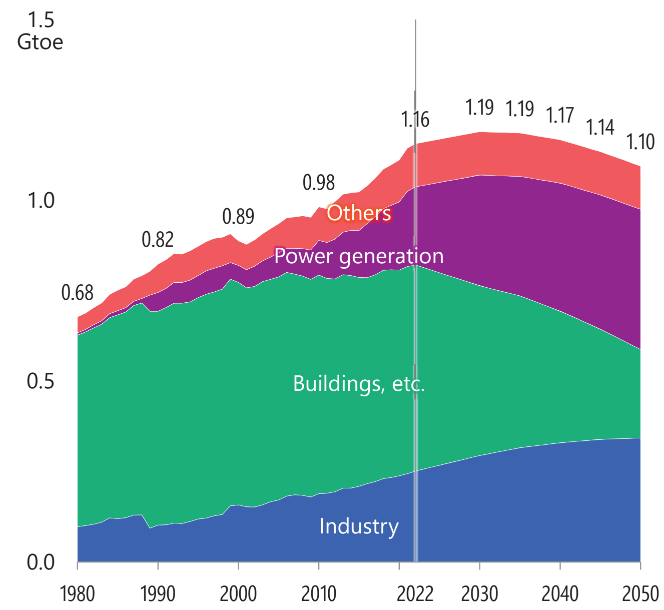
Reference Scenario

Biomass consumption

Biofuels for transport



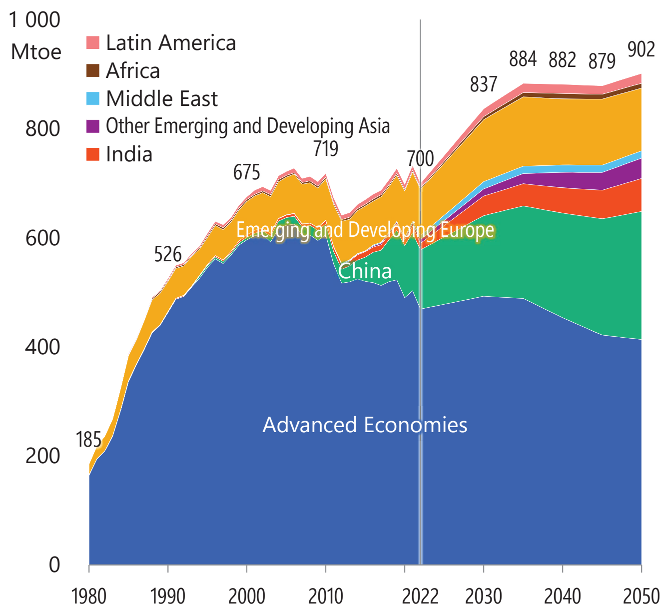
Solid biomass



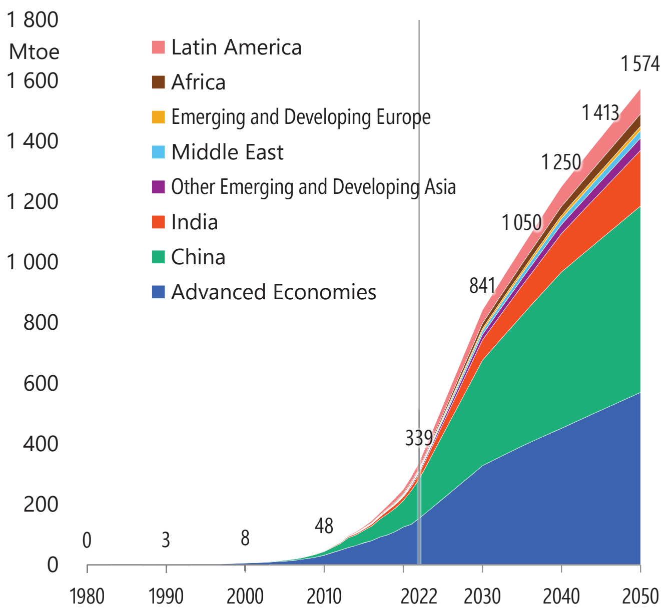
Reference Scenario

Consumption of nuclear and solar/wind/other

Nuclear



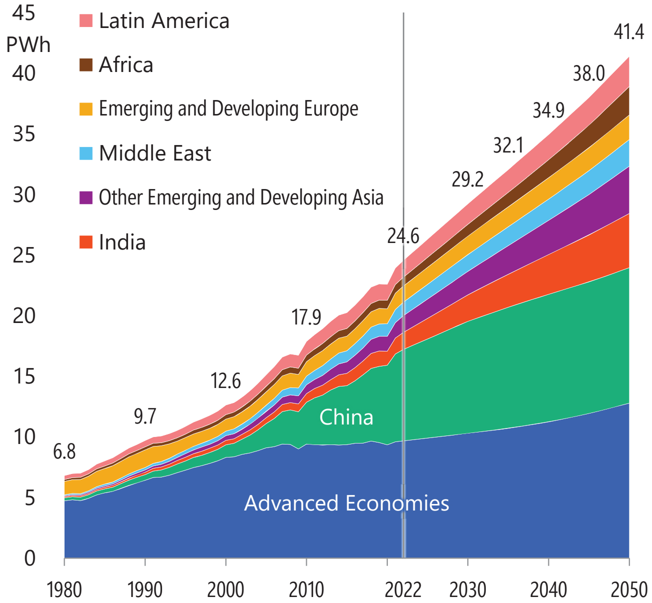
Solar/wind/other



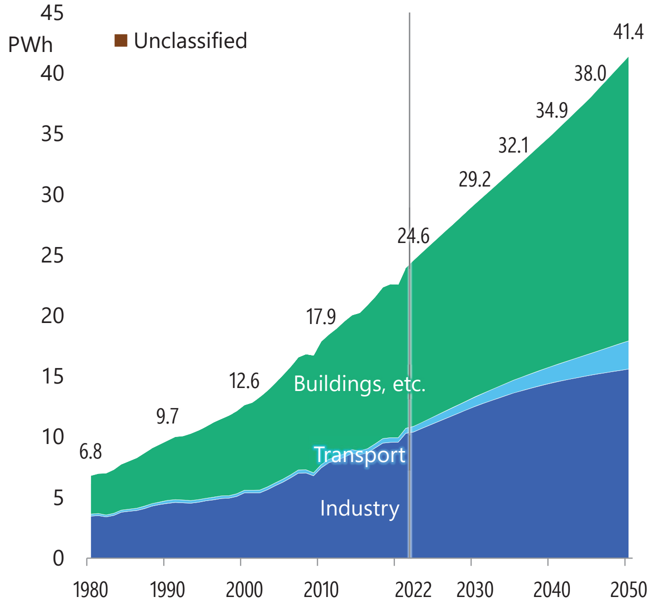
Reference Scenario

Final consumption of electricity

By region



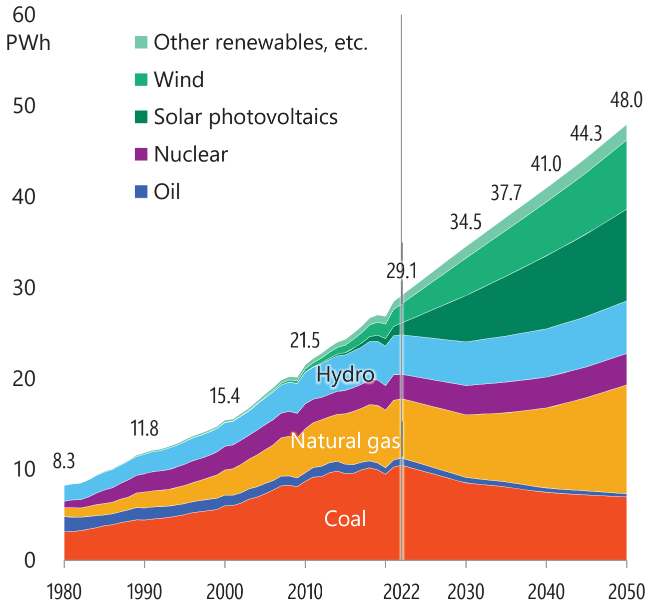
By sector



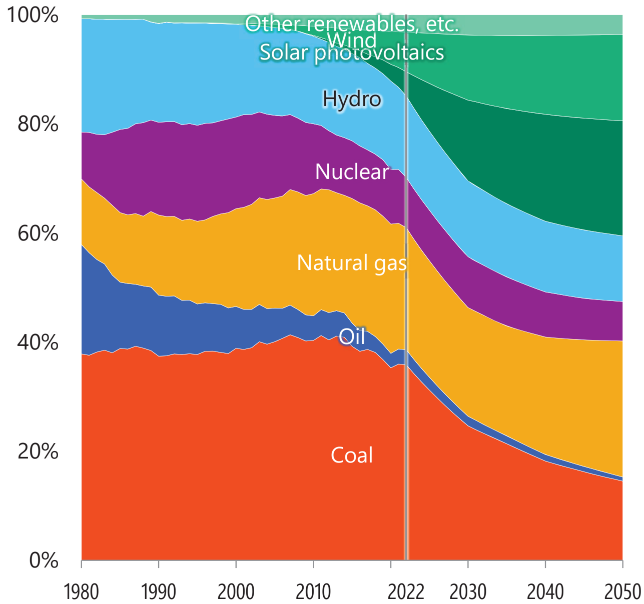
Reference Scenario

Power generation mix

Electricity generated



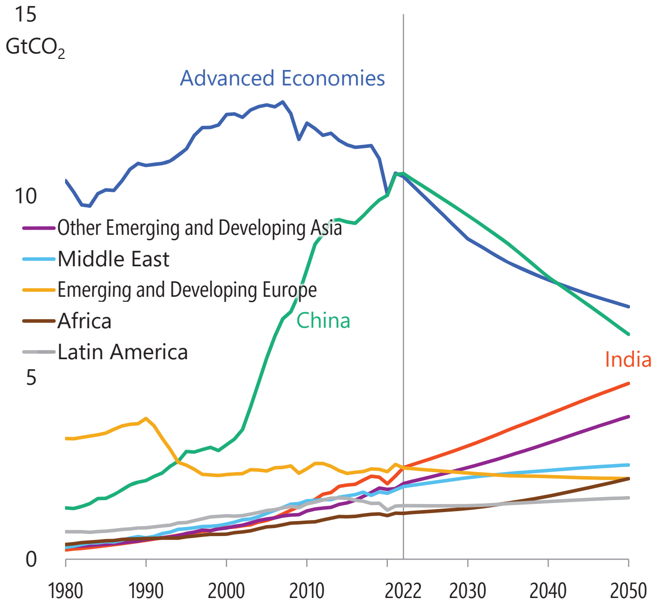
Shares



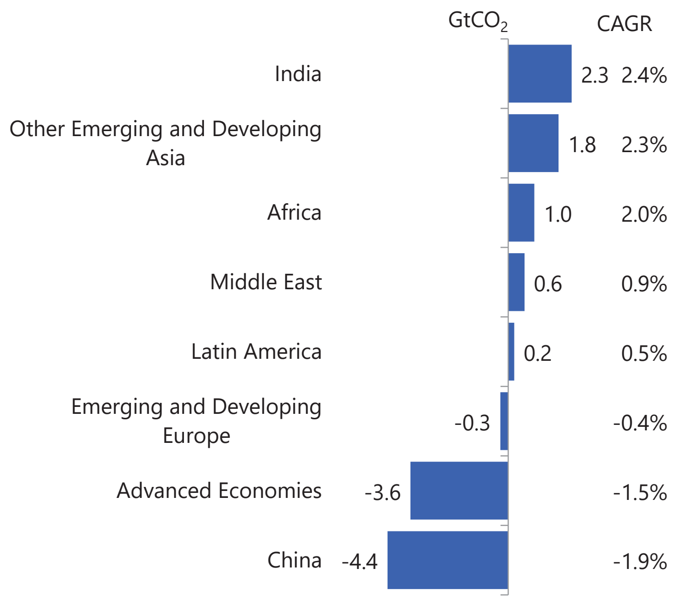
Reference Scenario

Energy-related CO_2 emissions

Emissions



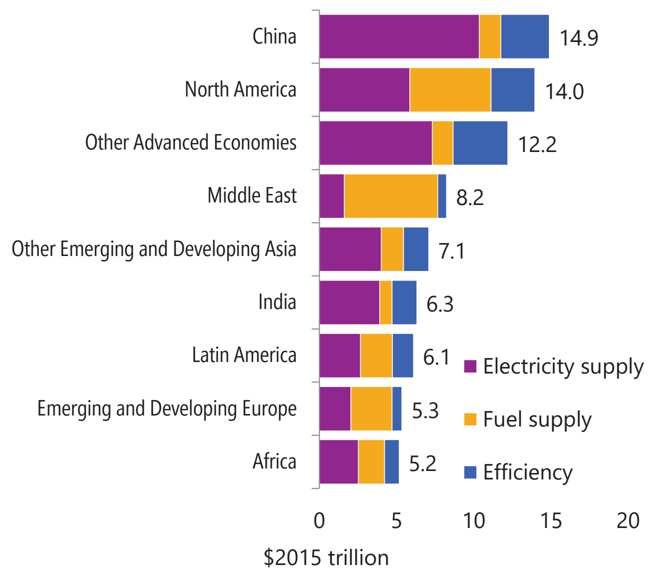
Changes (2022-2050)



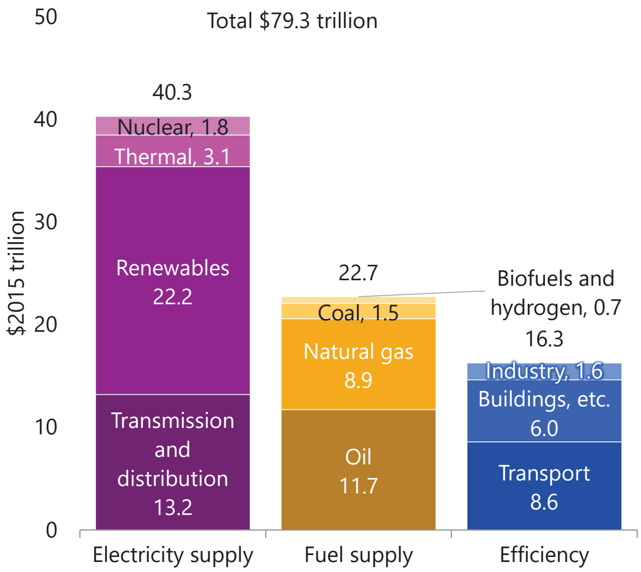
Reference Scenario

Energy-related investments (2023–2050)

By region



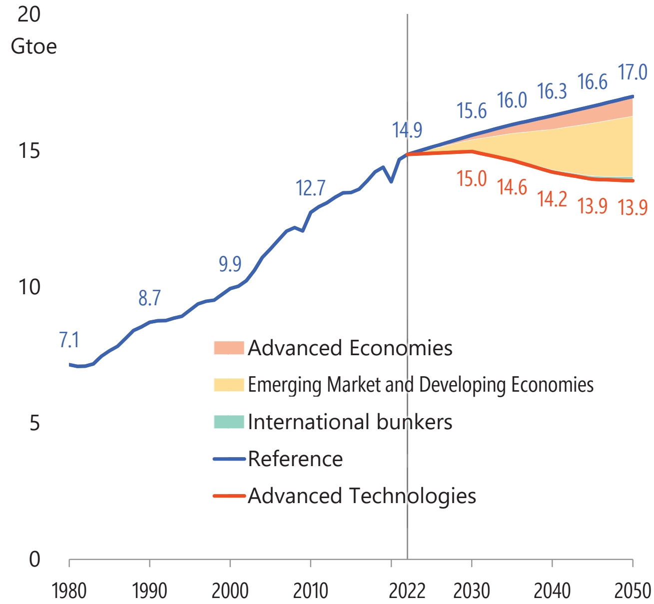
By sector



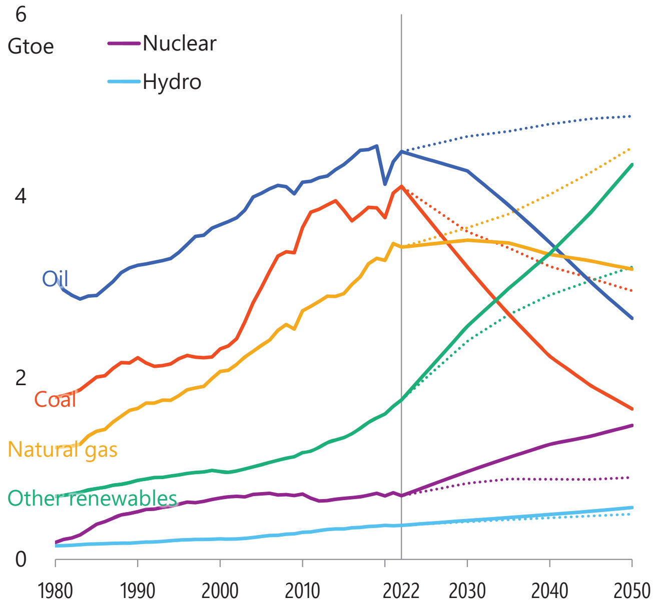
Advanced Technologies Scenario

Primary energy consumption

By region



By energy source

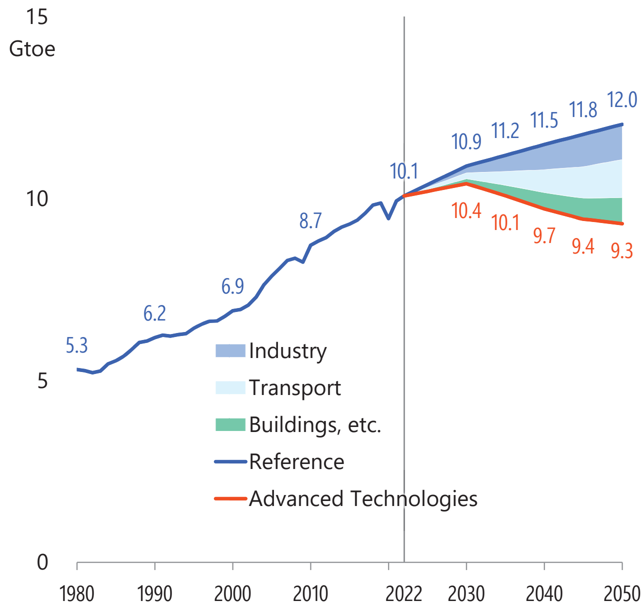


Note: Solid lines stand for Advanced Technologies Scenario and dotted lines stand for Reference Scenario.

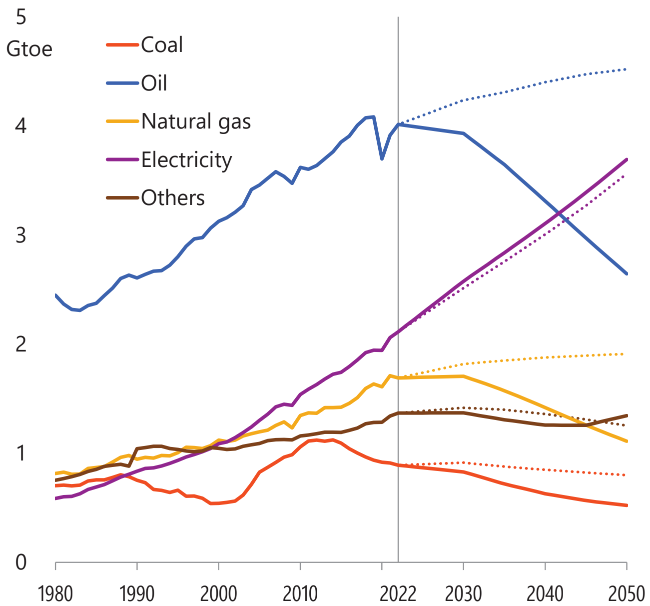
Advanced Technologies Scenario

Final energy consumption

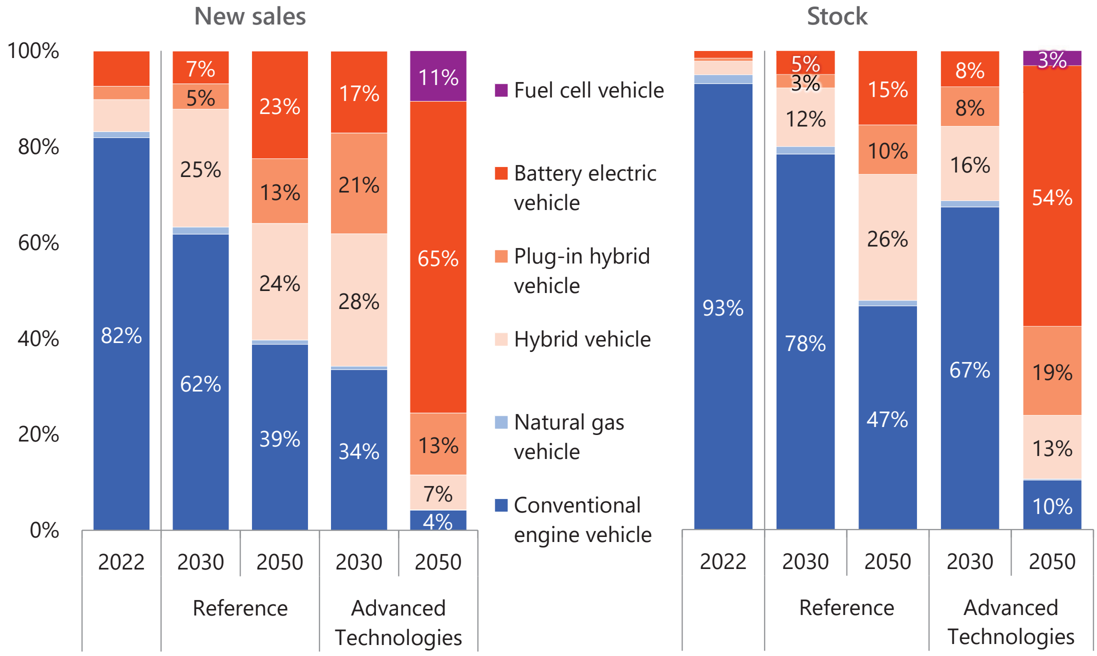
By sector



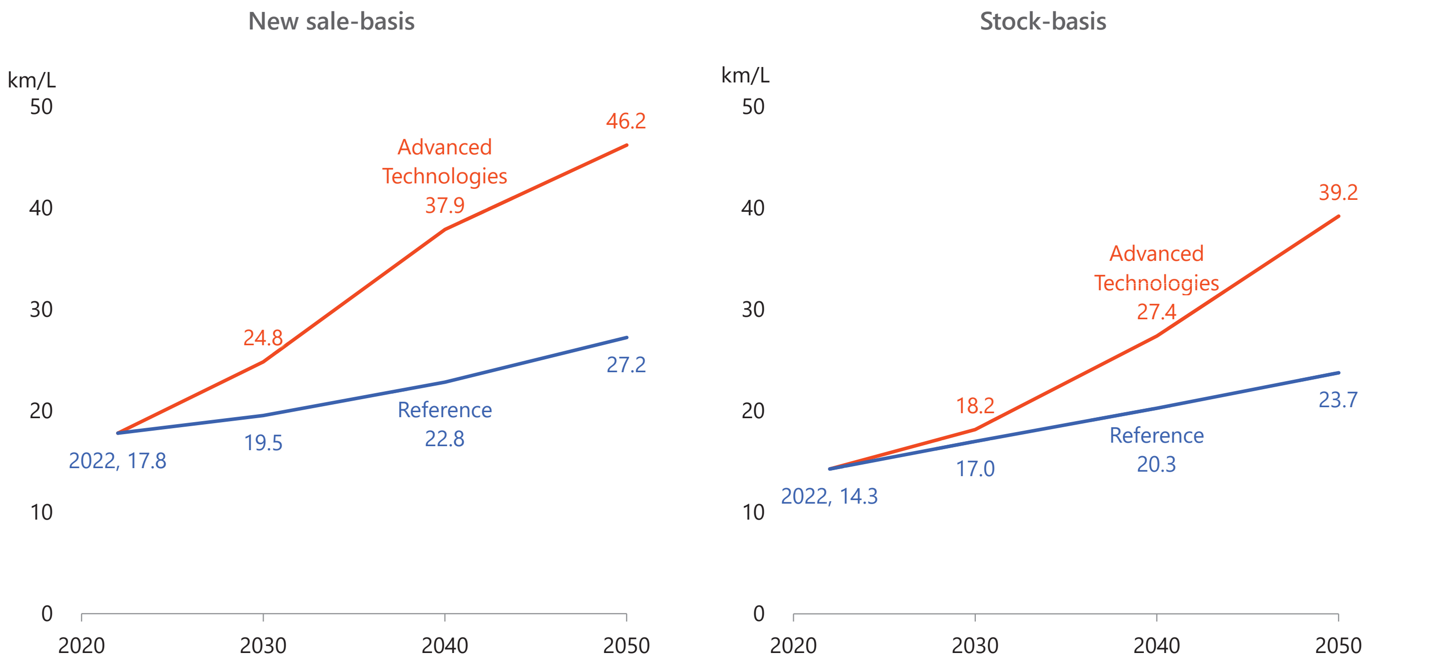
By energy



Share of passenger vehicle



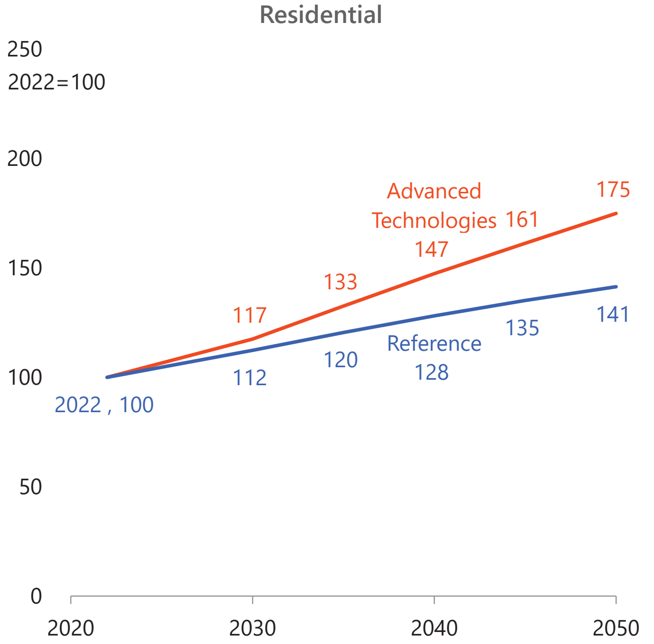
Fuel efficiency of passenger vehicle

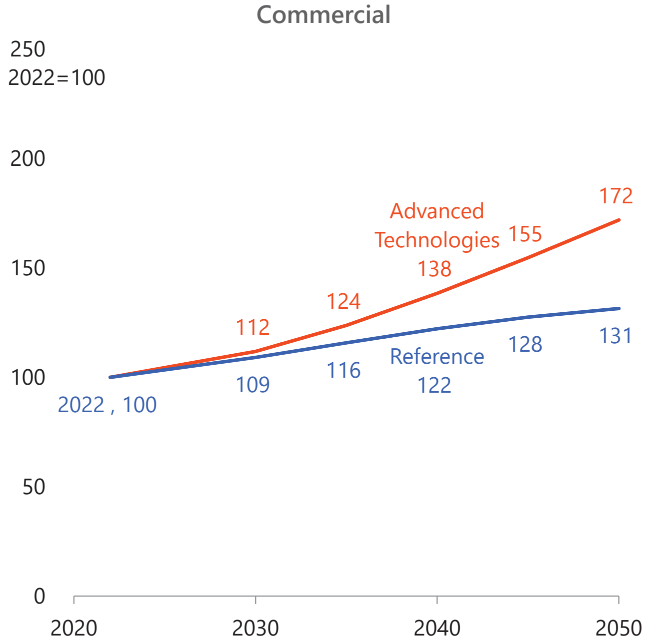


Note: Litres of gasoline equivalent

Advanced Technologies Scenario

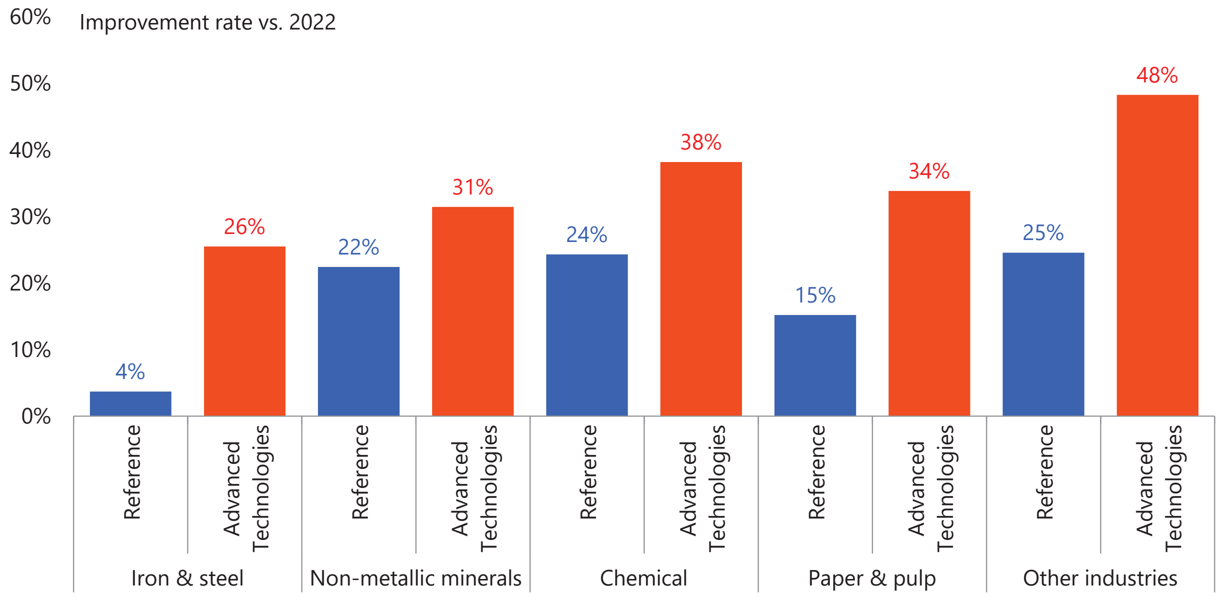
Energy efficiency in buildings sector





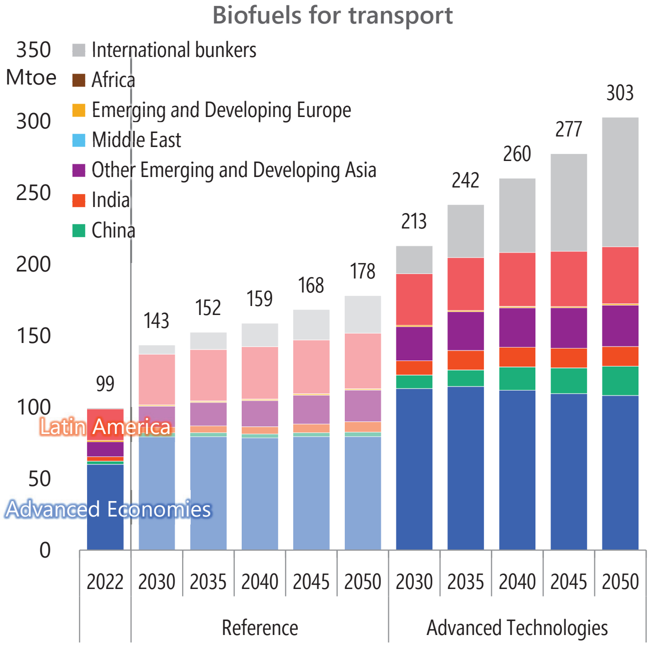
Advanced Technologies Scenario

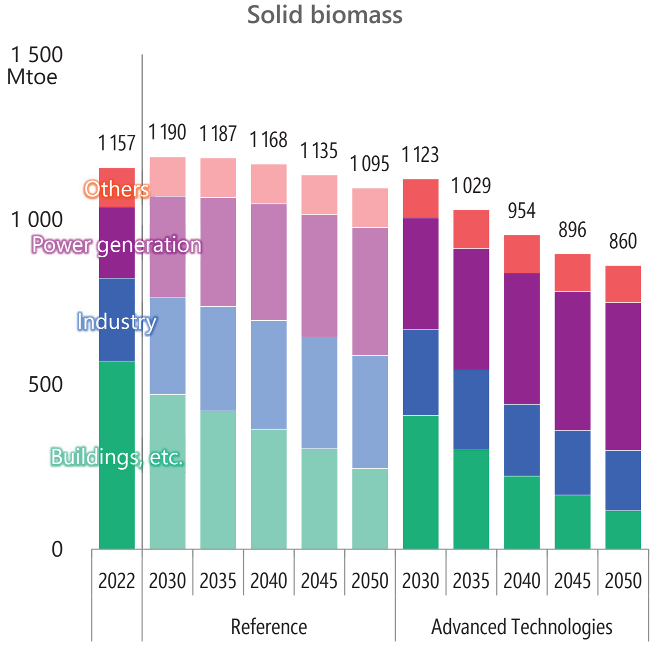
Energy intensity improvement in industry sector



Advanced Technologies Scenario

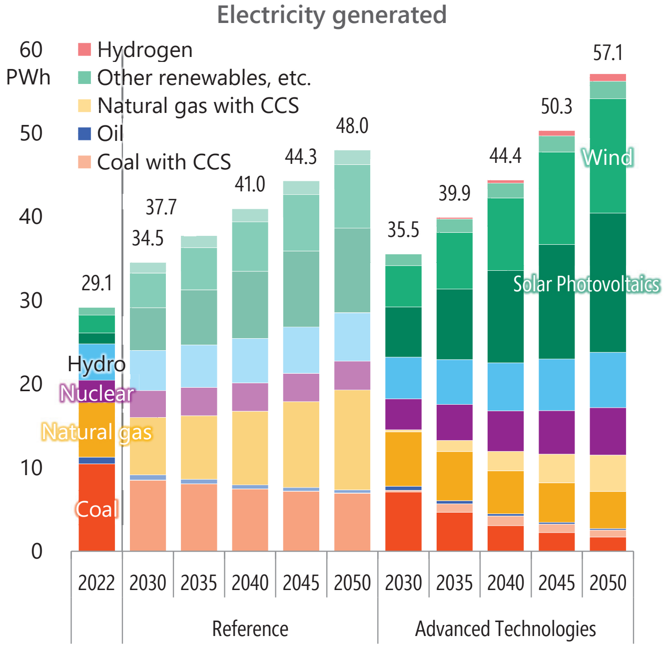
Biomass consumption

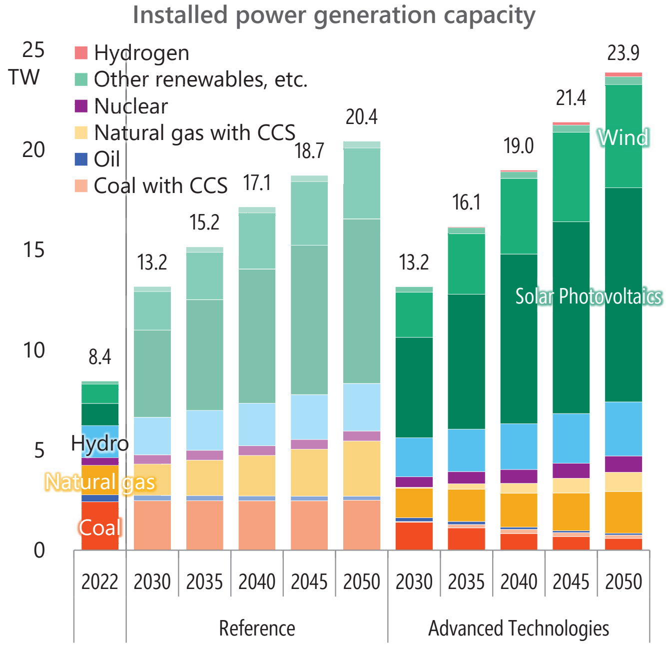




Advanced Technologies Scenario

Power generation mix

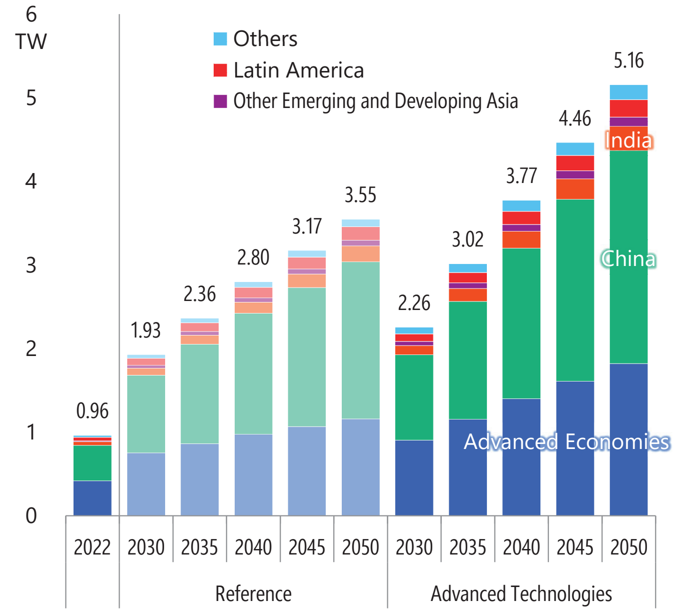




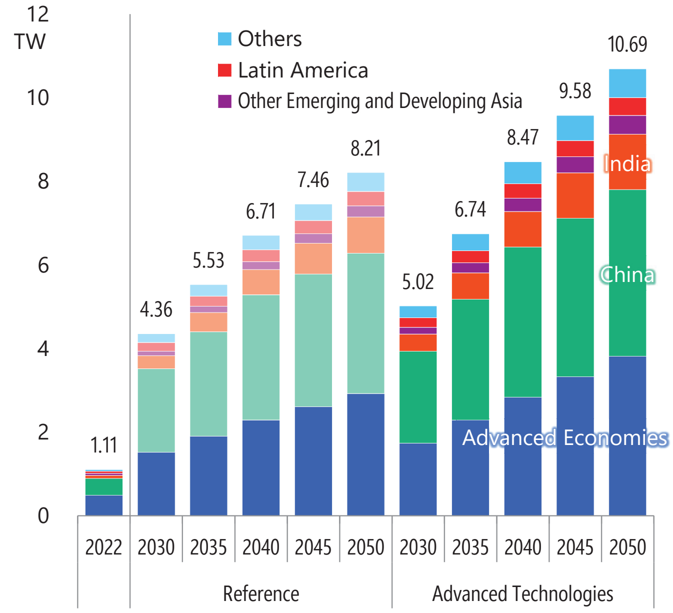
Advanced Technologies Scenario

Installed wind and solar PV power generation capacity

Wind



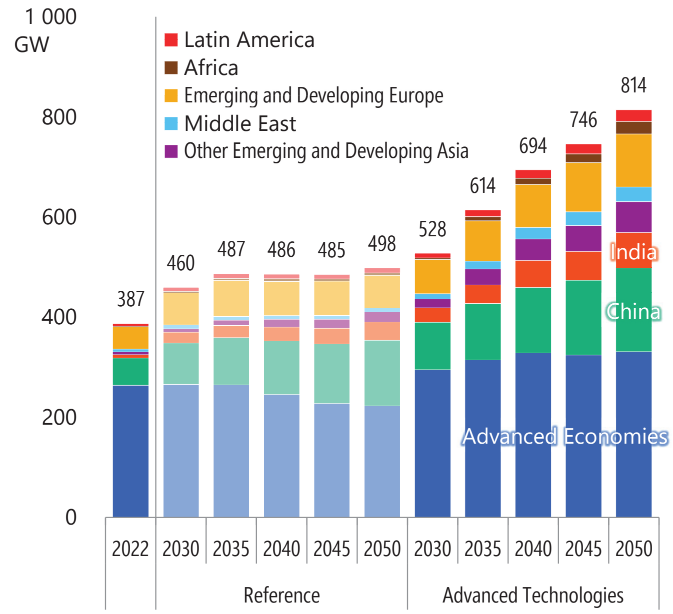
Solar photovoltaics



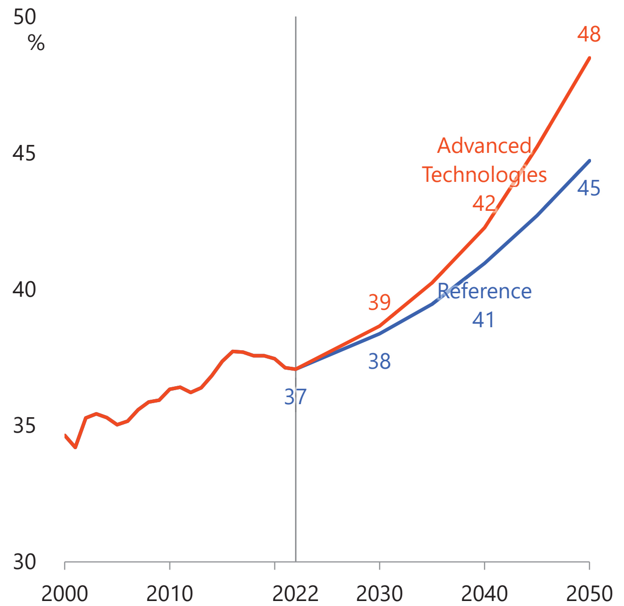
Advanced Technologies Scenario

Installed nuclear power generation capacity and thermal power generation efficiency

Nuclear

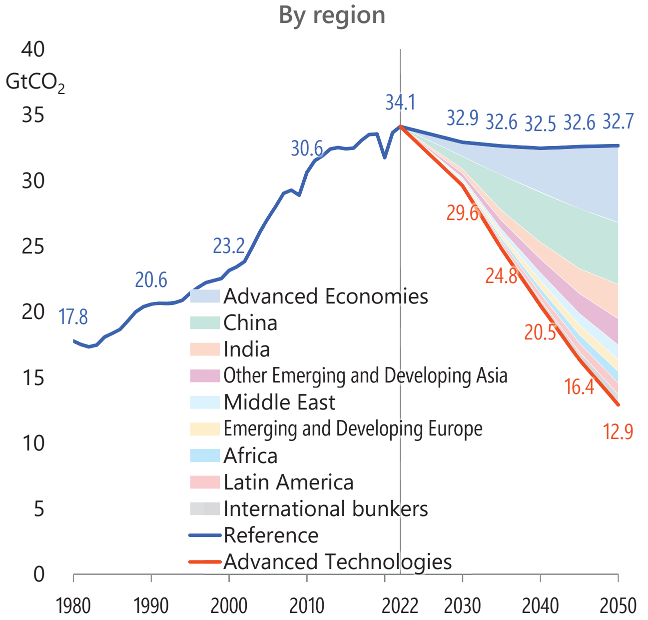


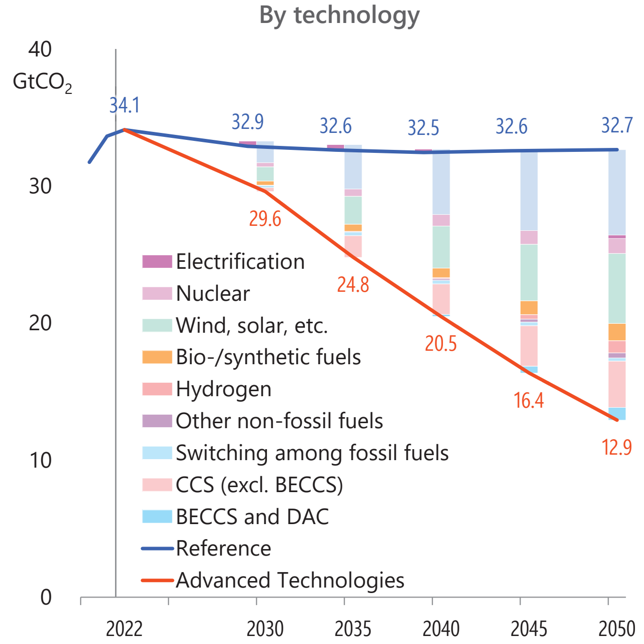
Thermal power generation efficiency (generation end)



Advanced Technologies Scenario

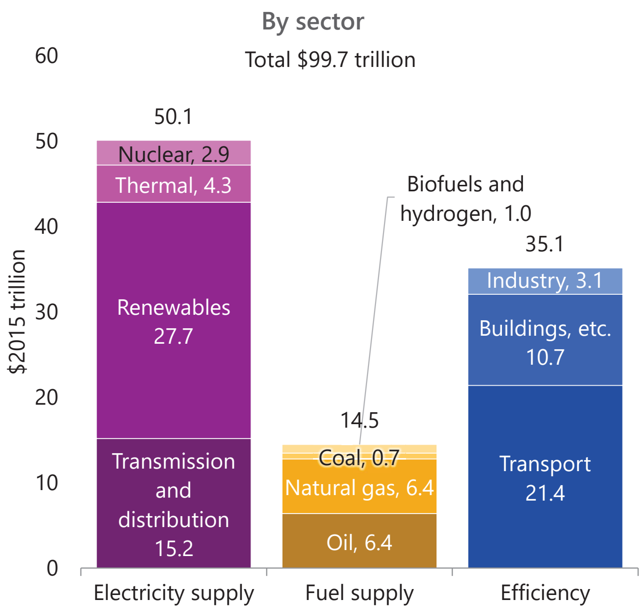
Energy-related CO_2 emissions

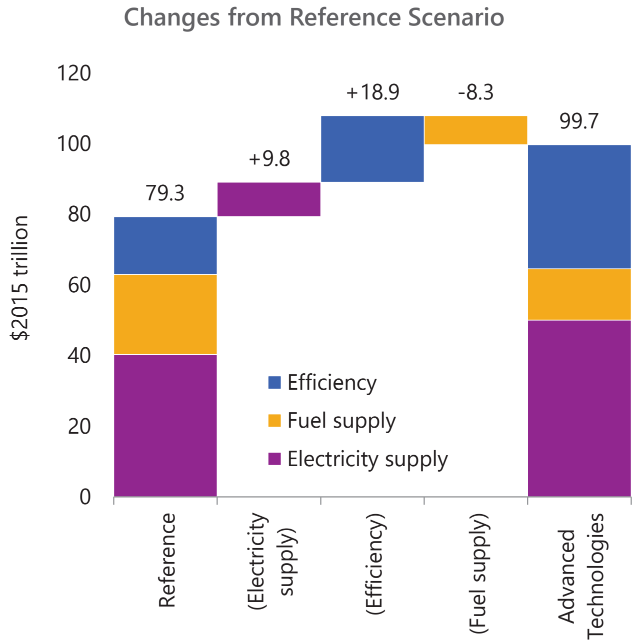




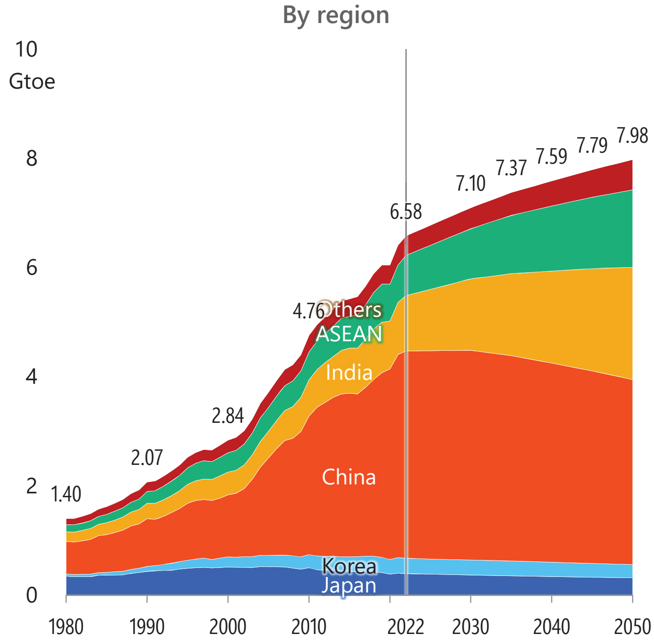
Advanced Technologies Scenario

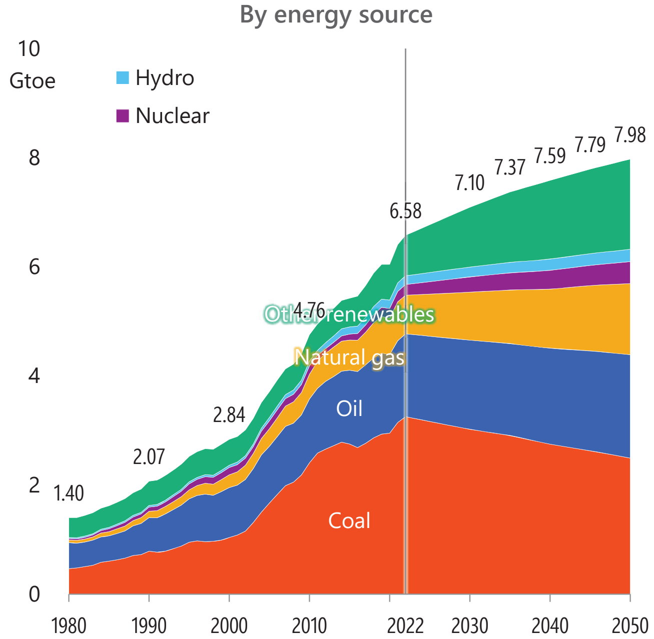
Energy-related investments (2023–2050)



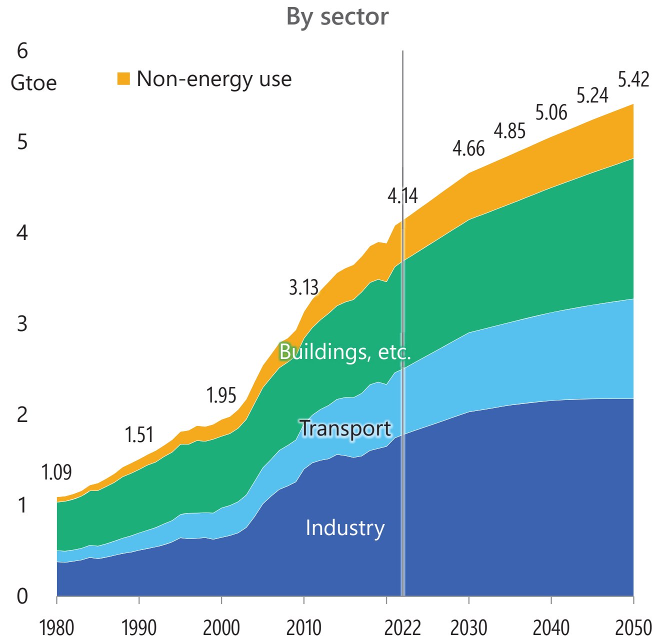


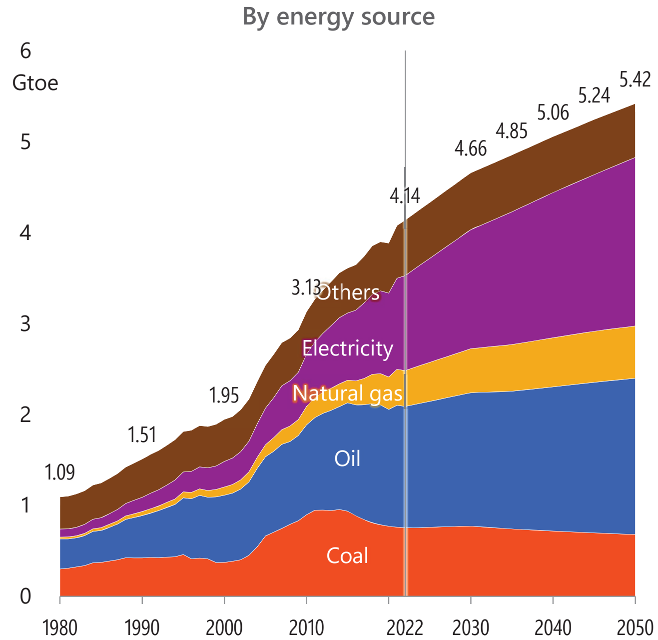
Primary energy consumption



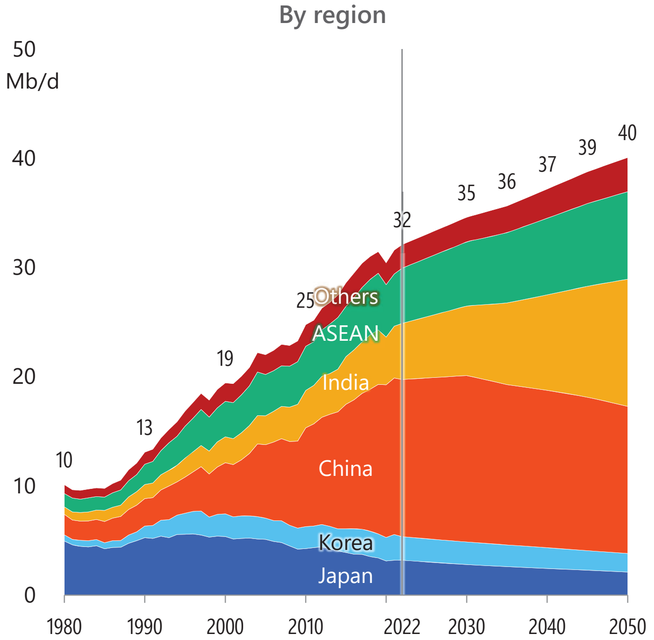


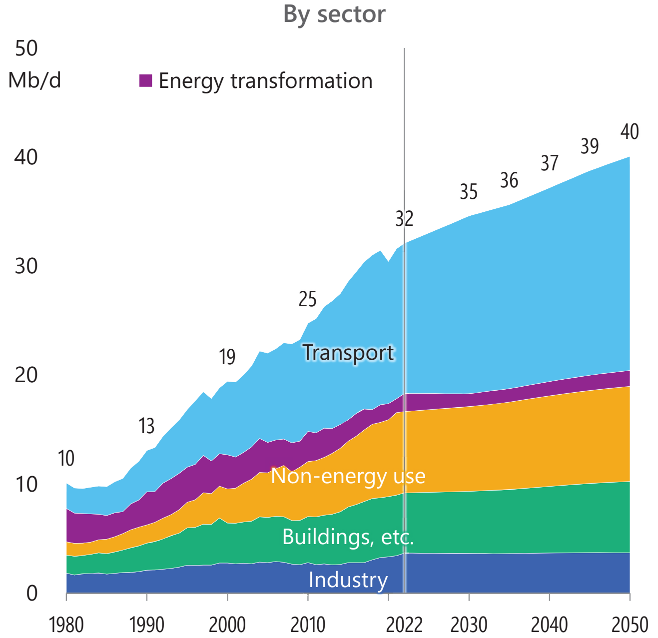
Final energy consumption



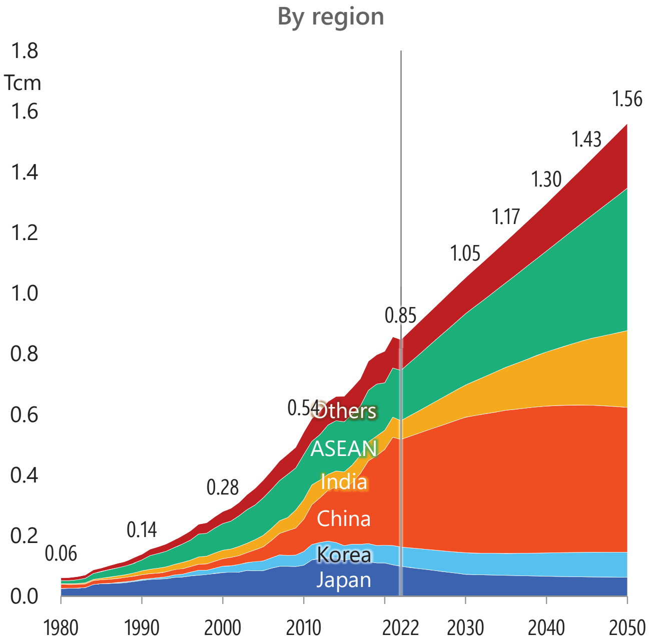


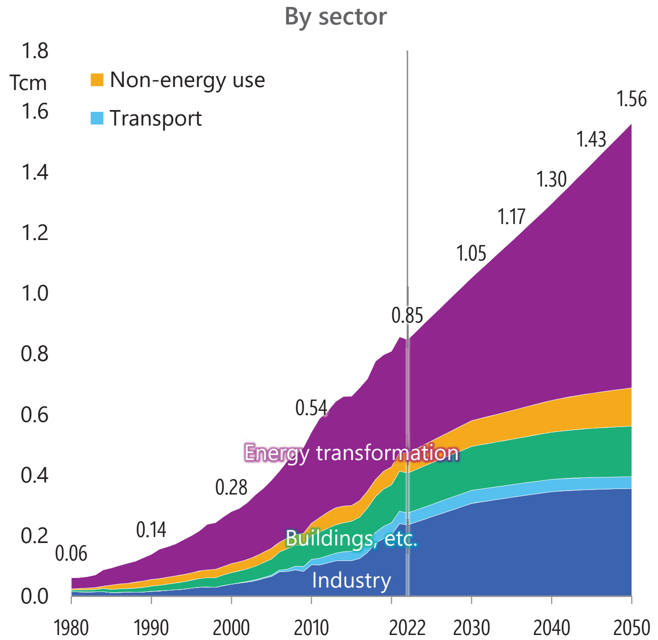
Oil consumption





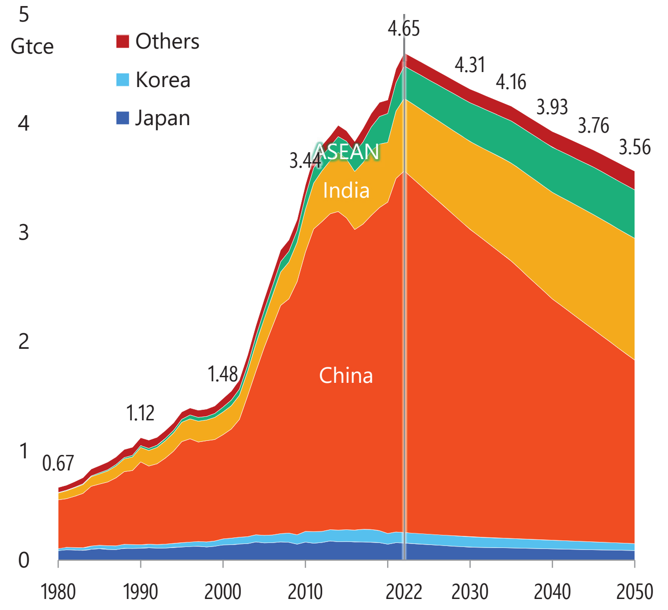
Natural gas consumption



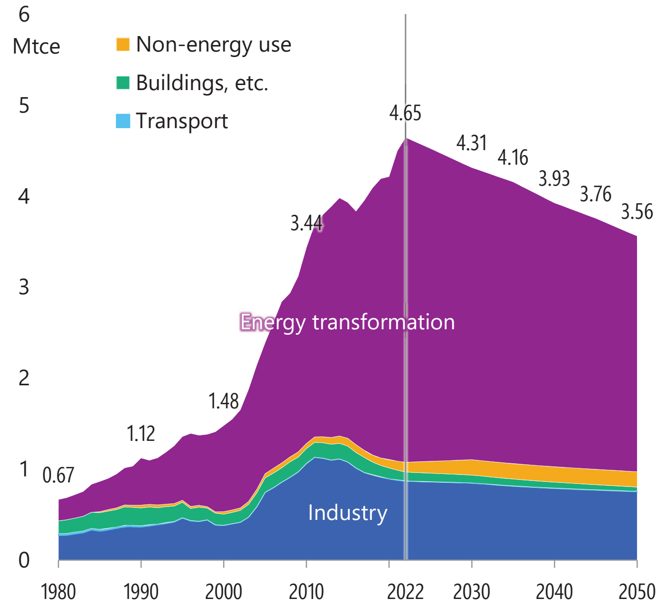


Coal consumption

By region

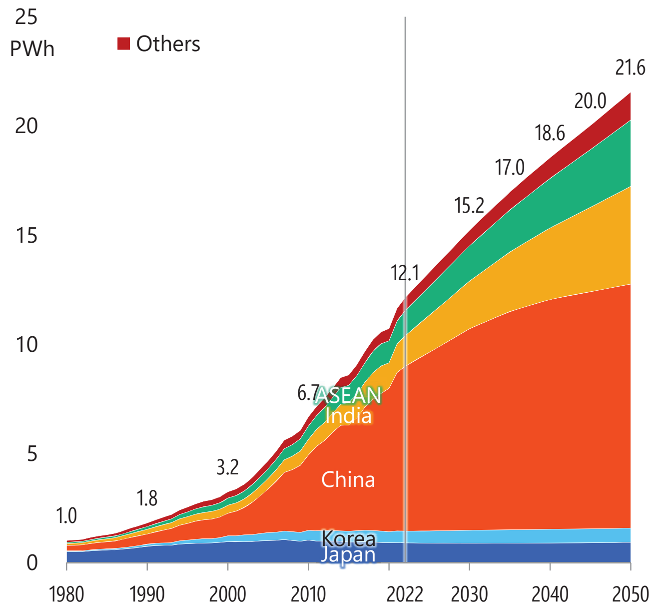


By sector

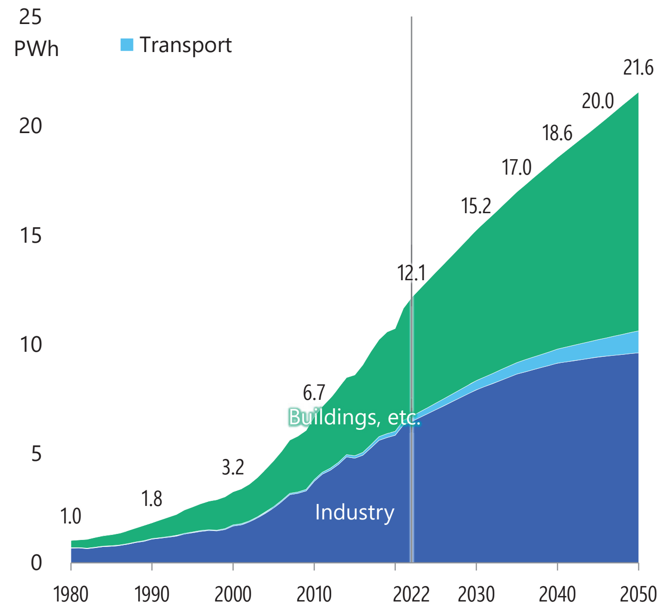


Final consumption of electricity

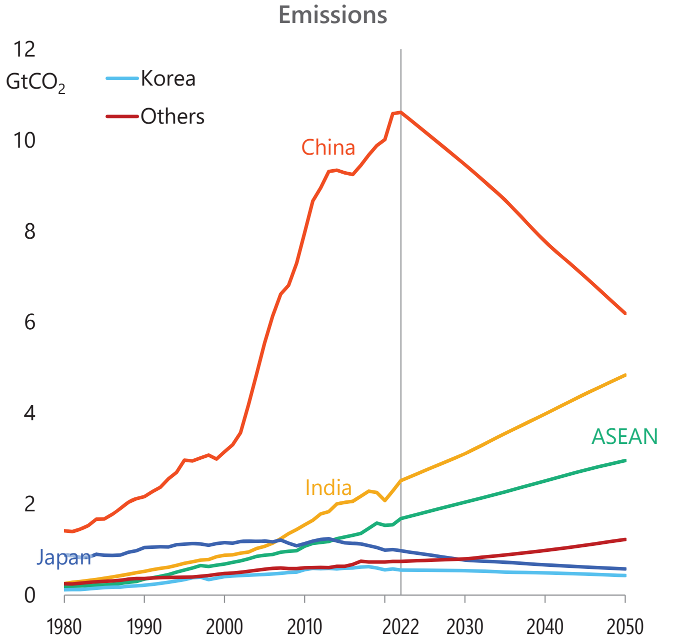
By region

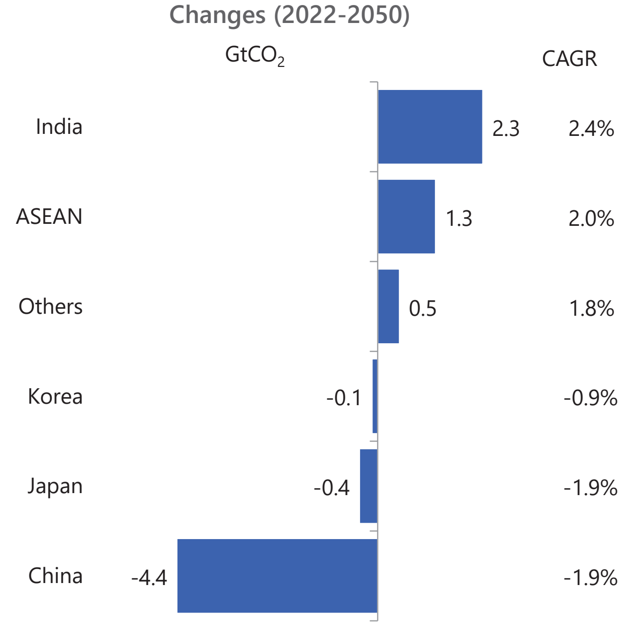


By sector

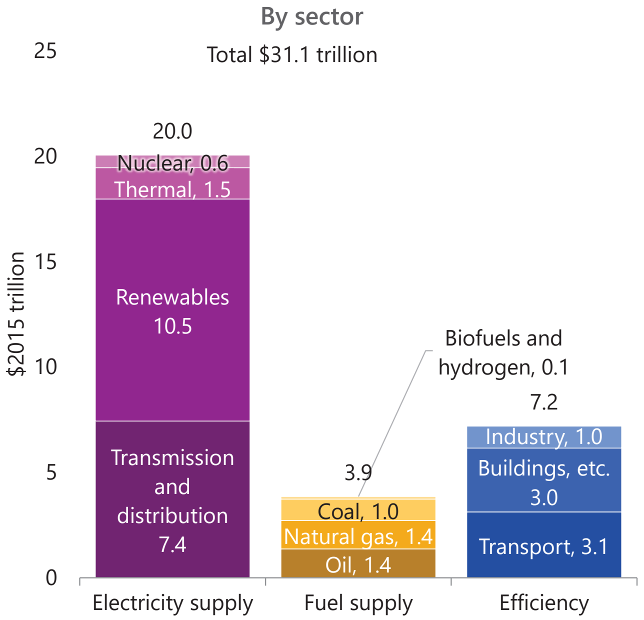


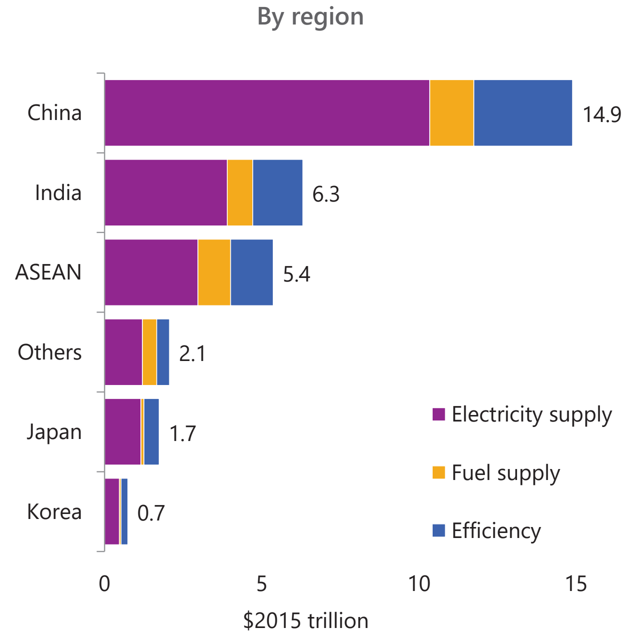
Energy-related CO_2 emissions



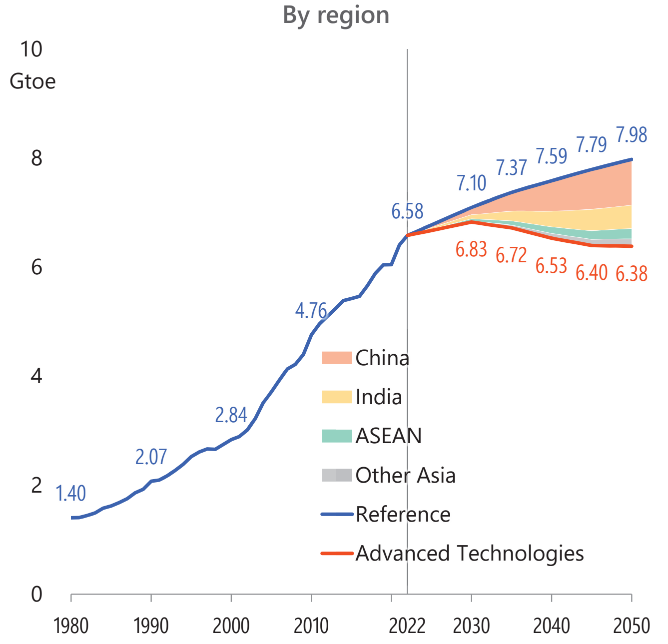


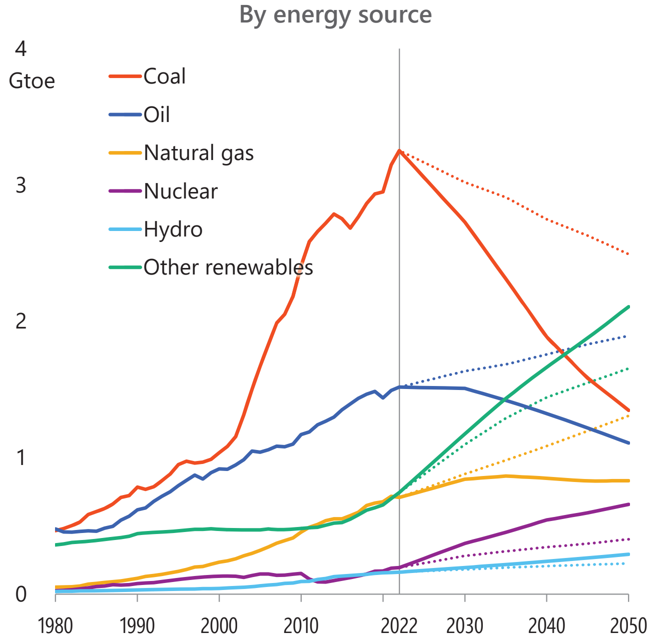
Energy-related investments (2023–2050)





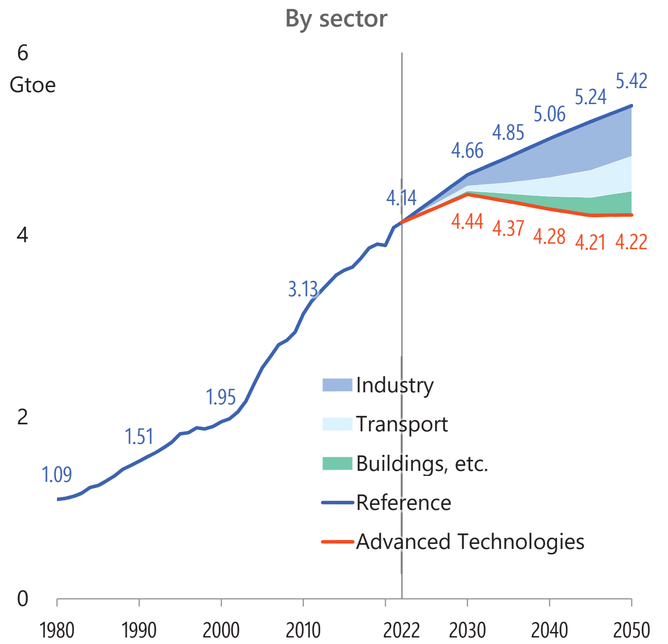
Primary energy consumption

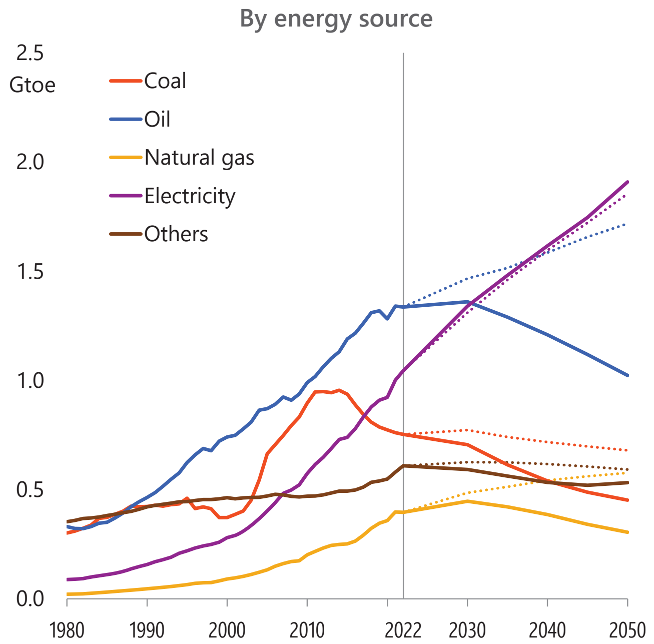




Note: Solid lines stand for Advanced Technologies Scenario and dotted lines stand for Reference Scenario.

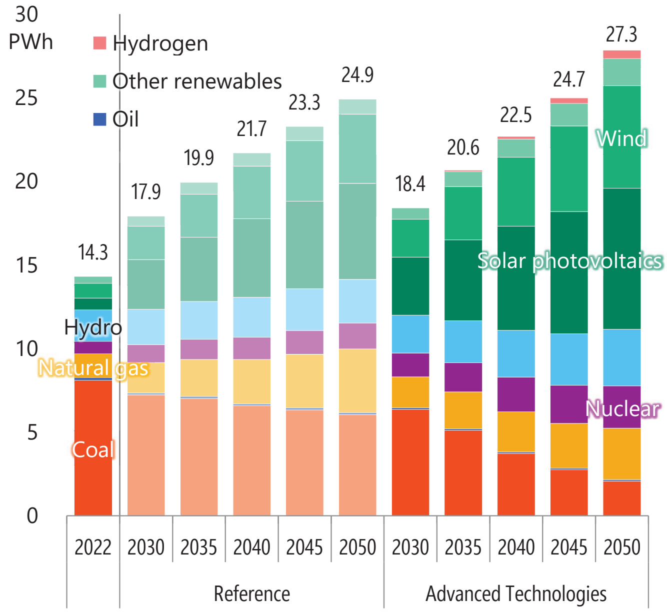
Final energy consumption



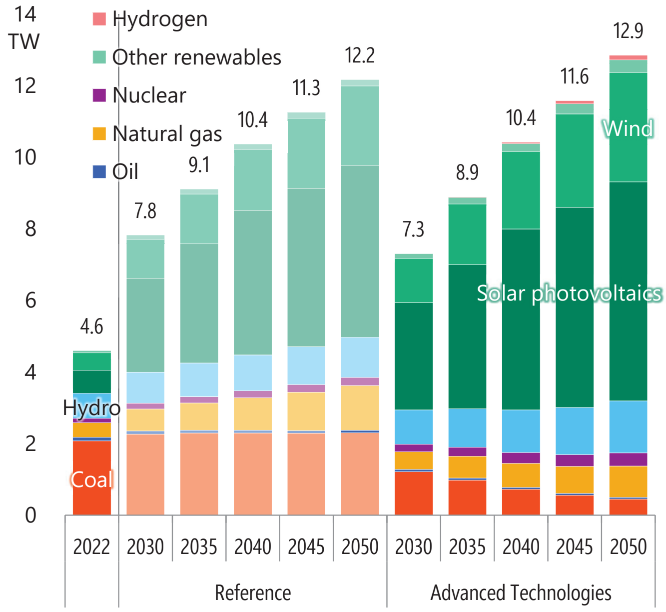


Power generation mix

Electricity generated

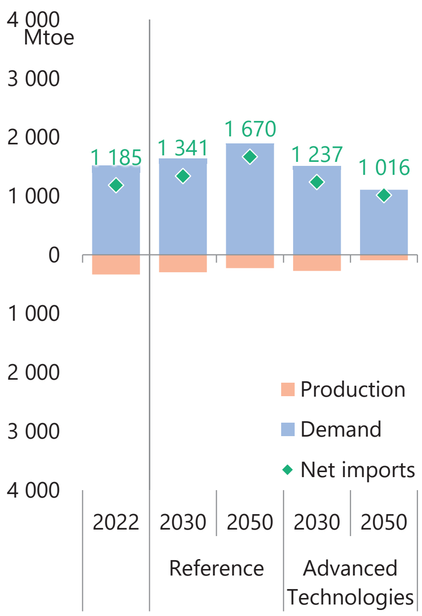


Installed power generation capacity

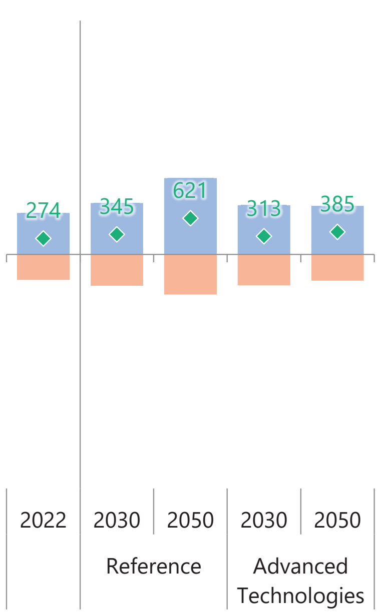


Supply and demand balance of fossil fuels

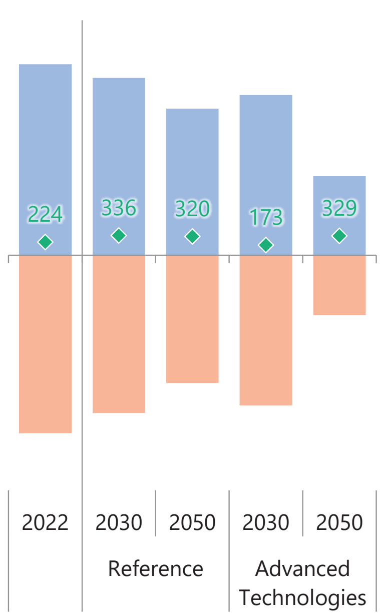
Oil



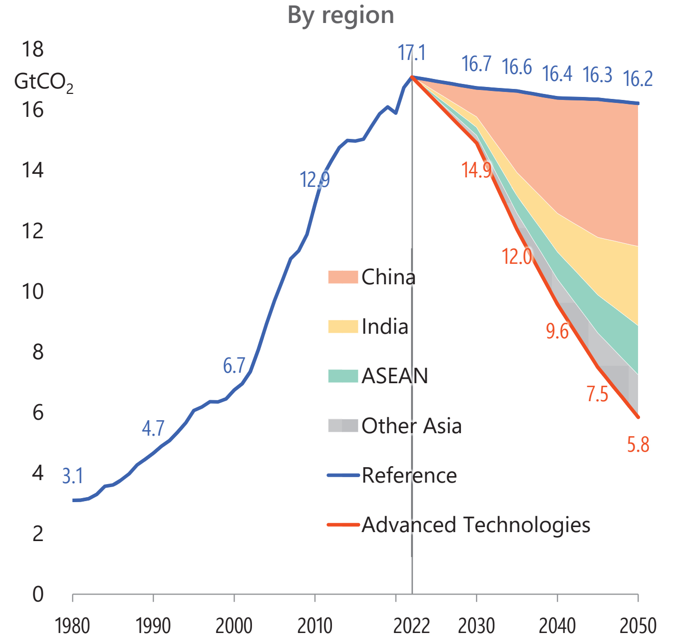
Natural gas

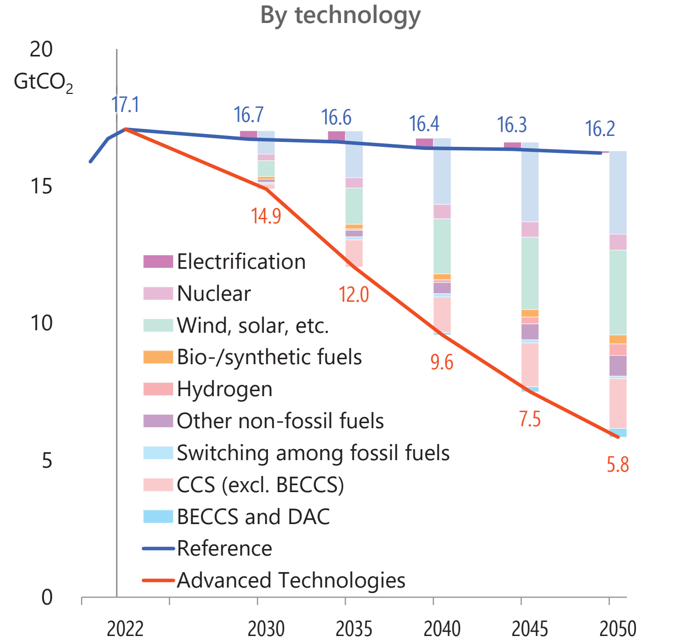


Coal

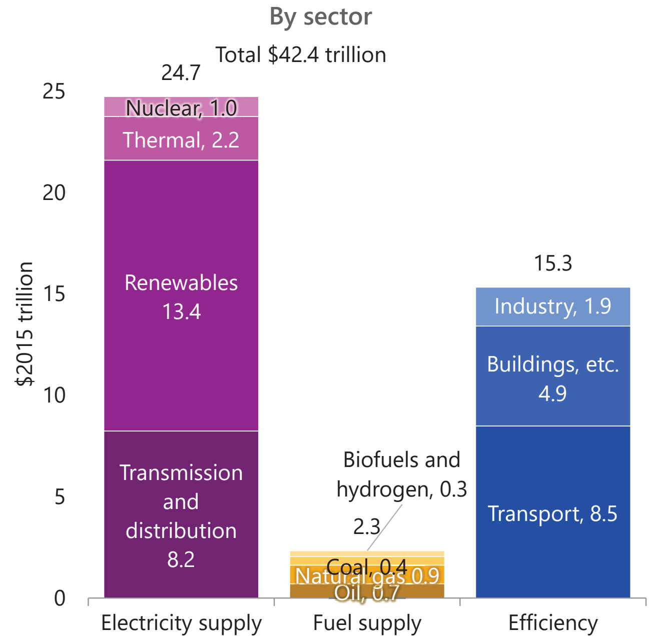


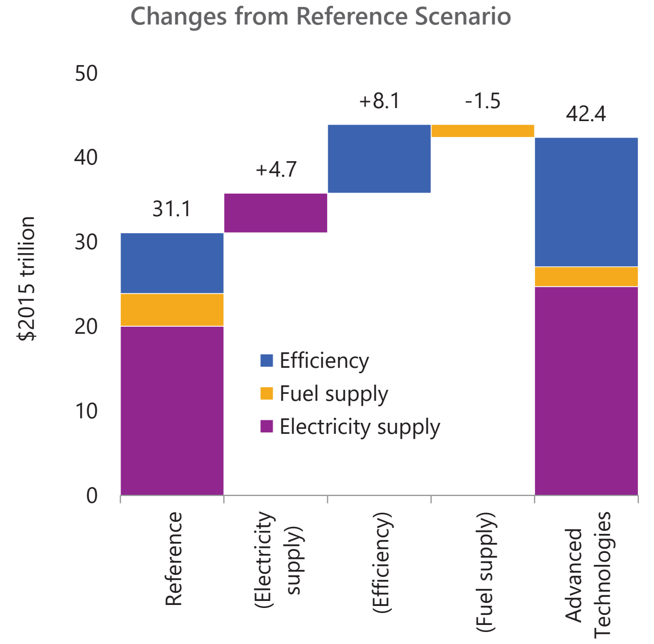
Energy-related CO_2 emissions





Energy-related investments (2023–2050)

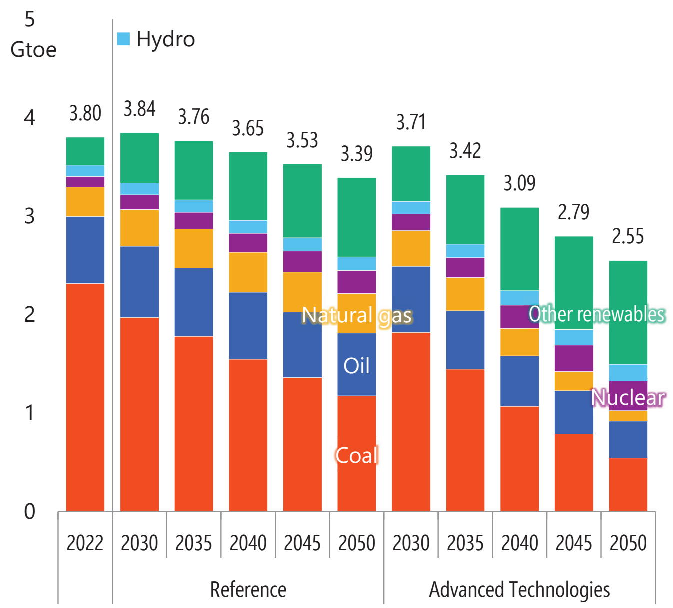




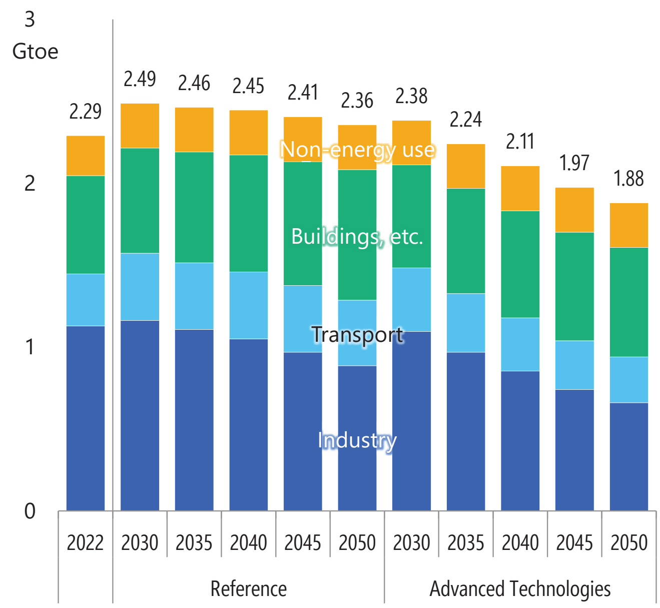
China

Energy consumption

Primary energy consumption



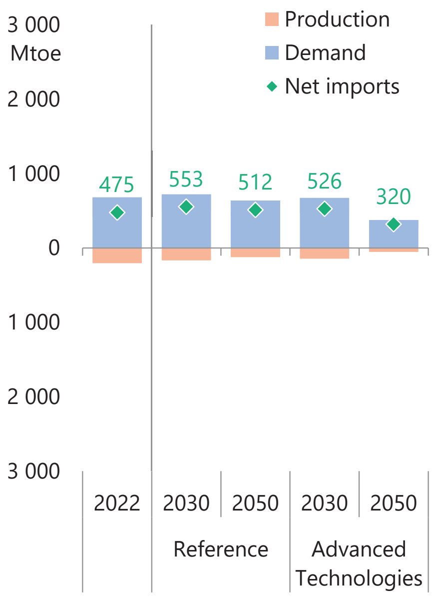
Final energy consumption



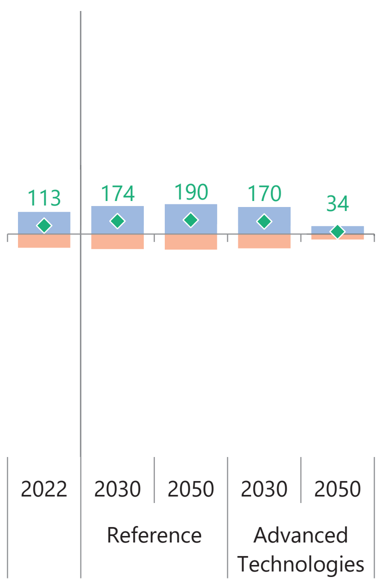
China

Supply and demand balance of fossil fuels

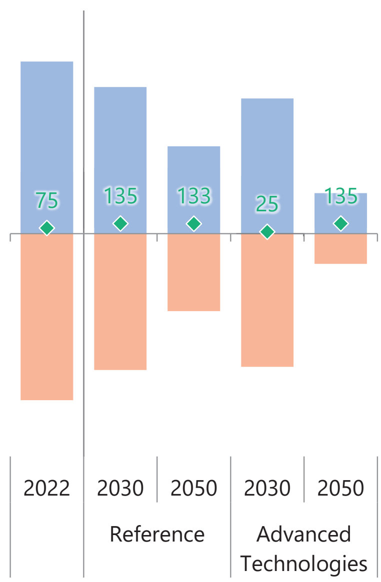
Oil



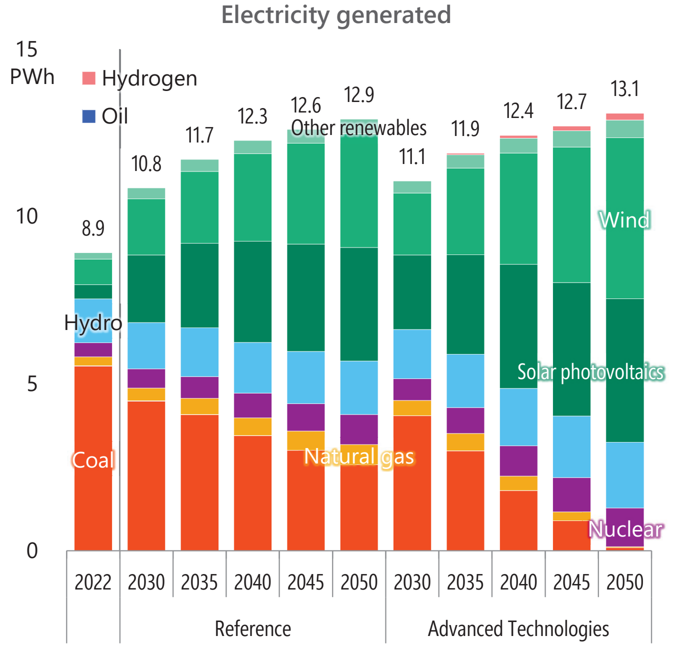
Natural gas

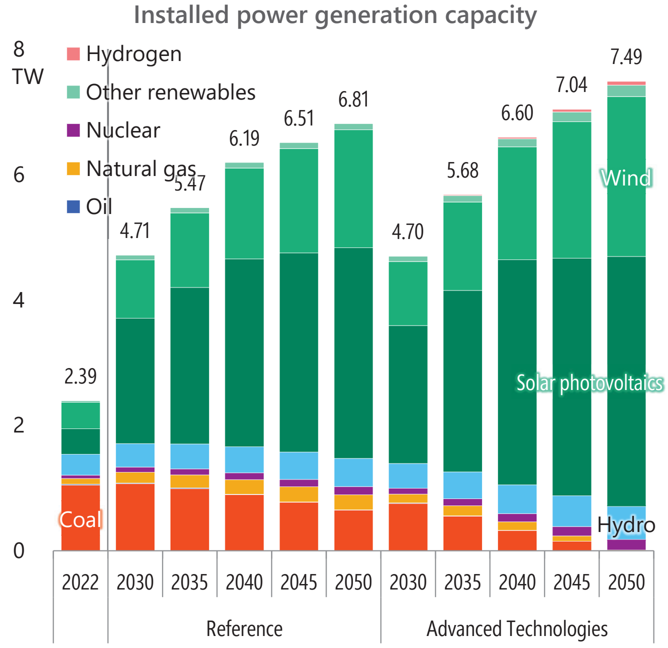


Coal

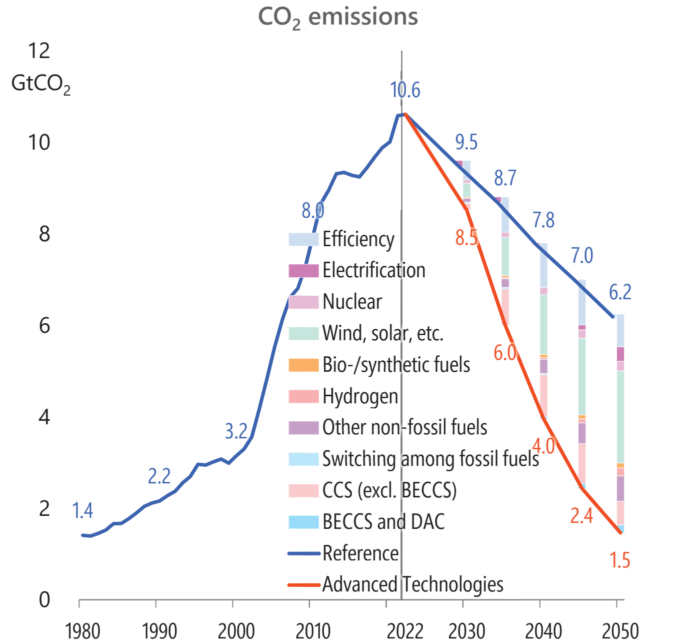


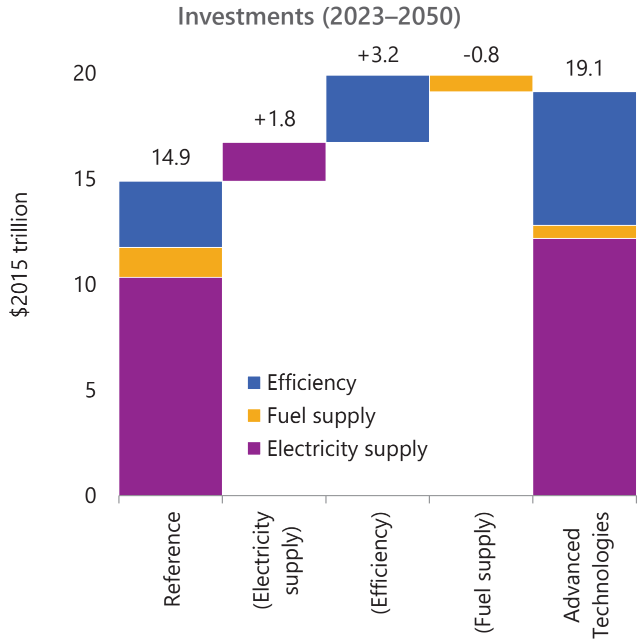
Power generation mix





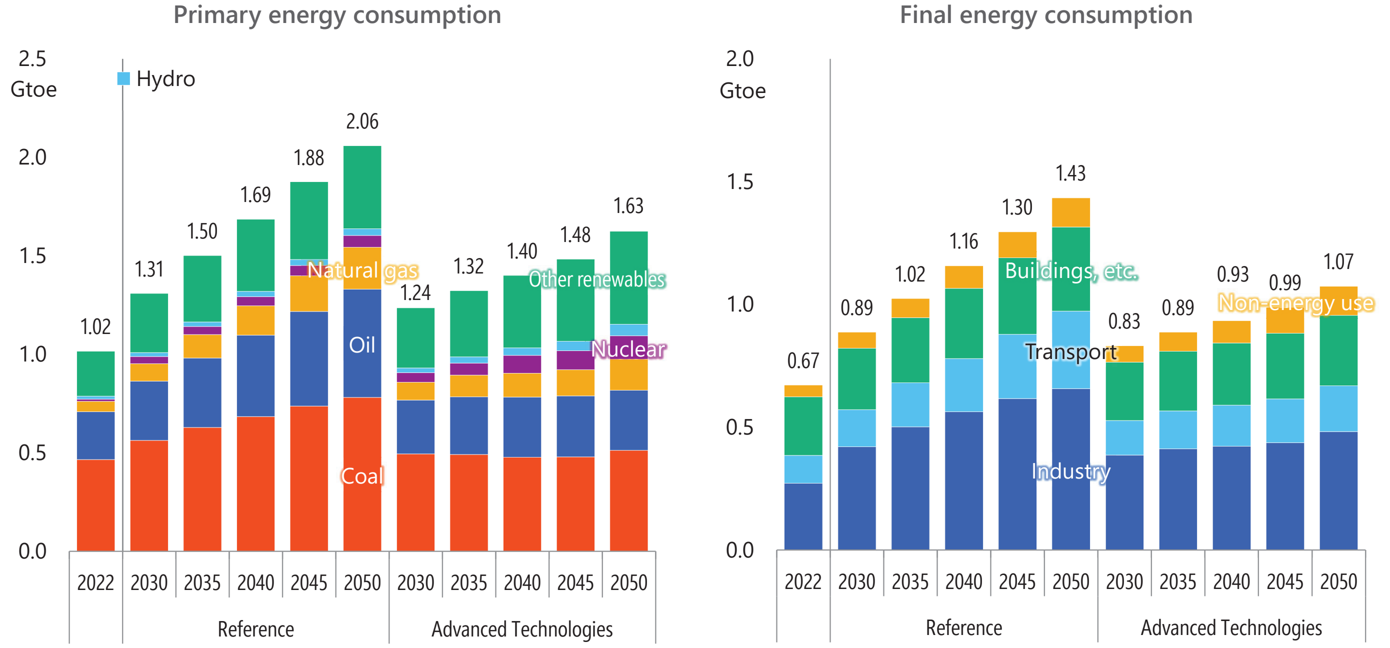
Energy-related CO_2 emissions and investments





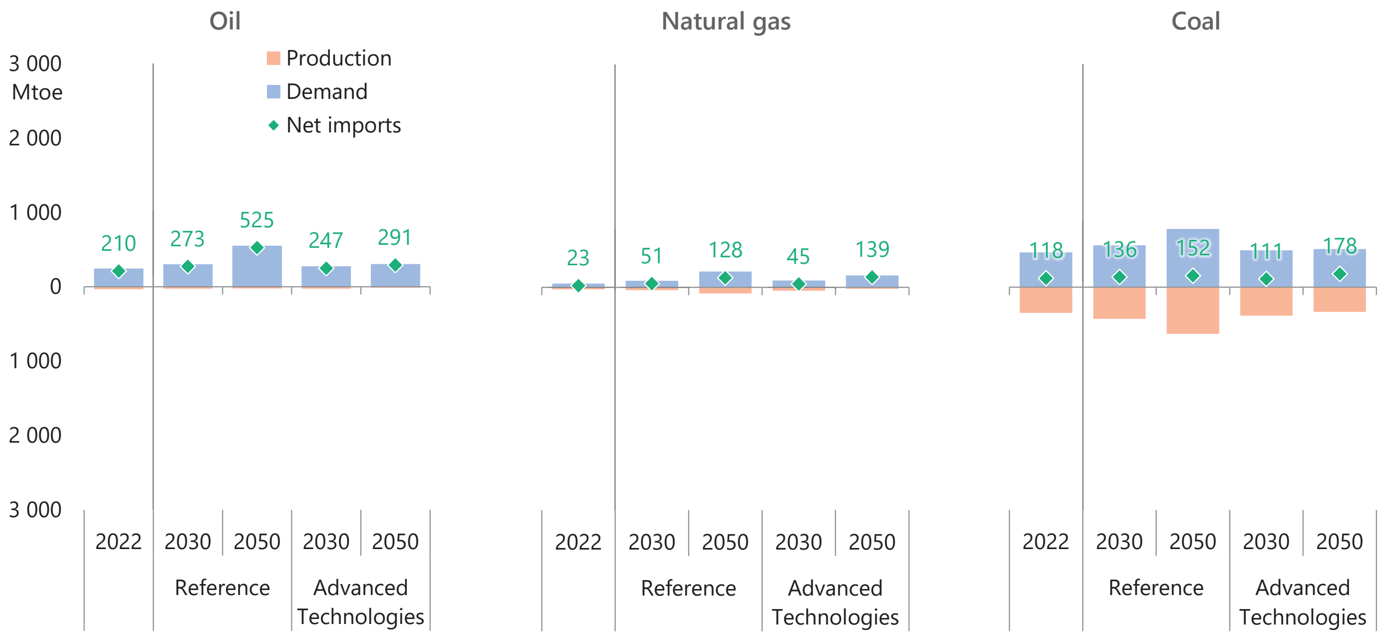
India

Energy consumption

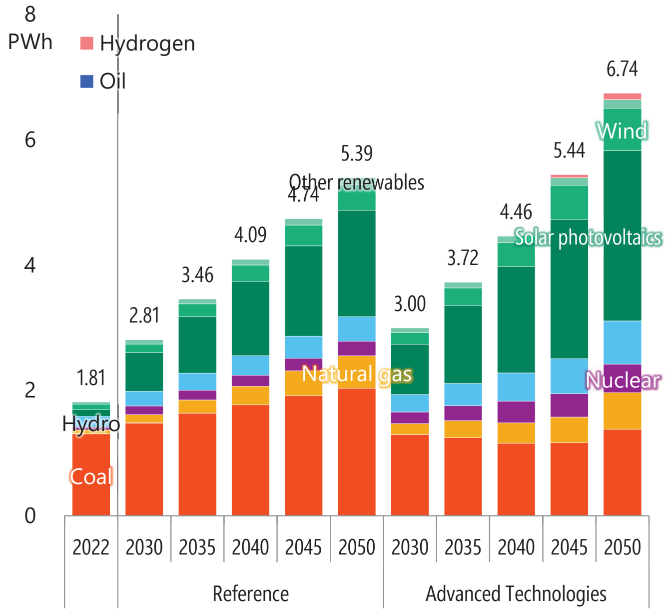


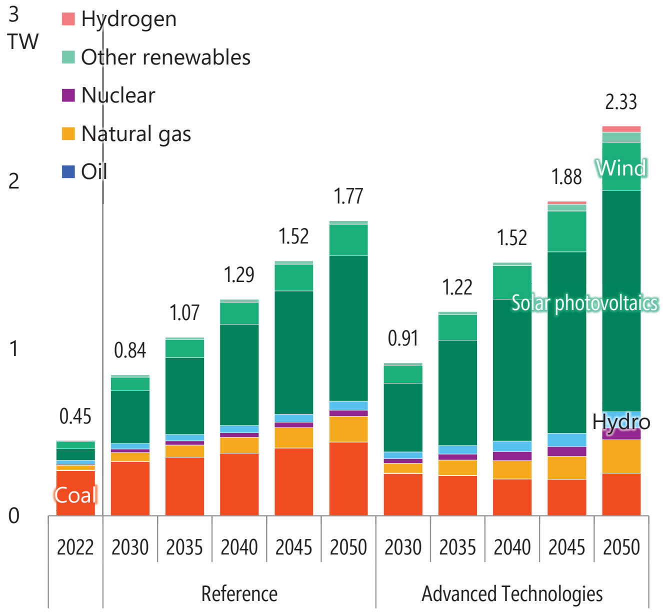
India

Supply and demand balance of fossil fuels

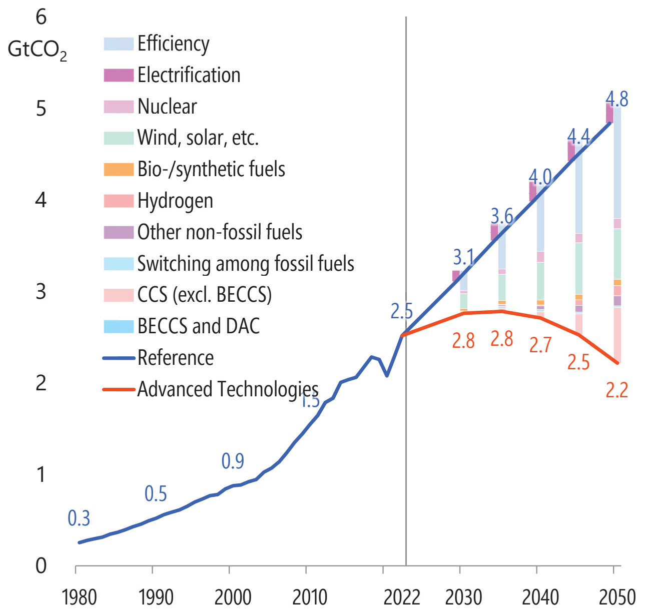


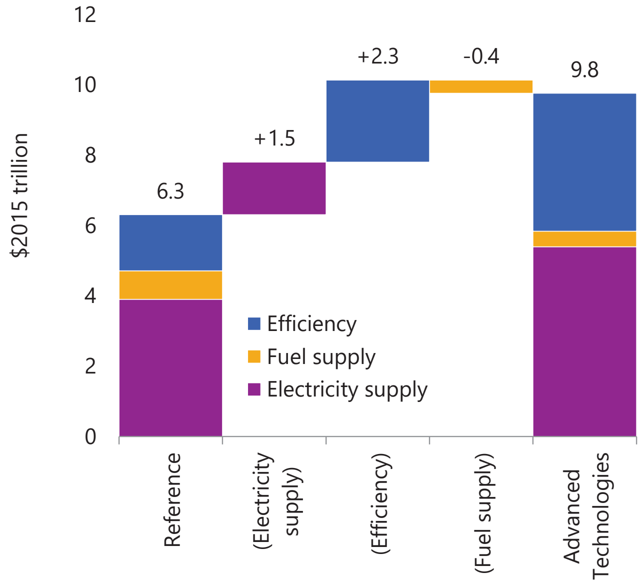
Power generation mix



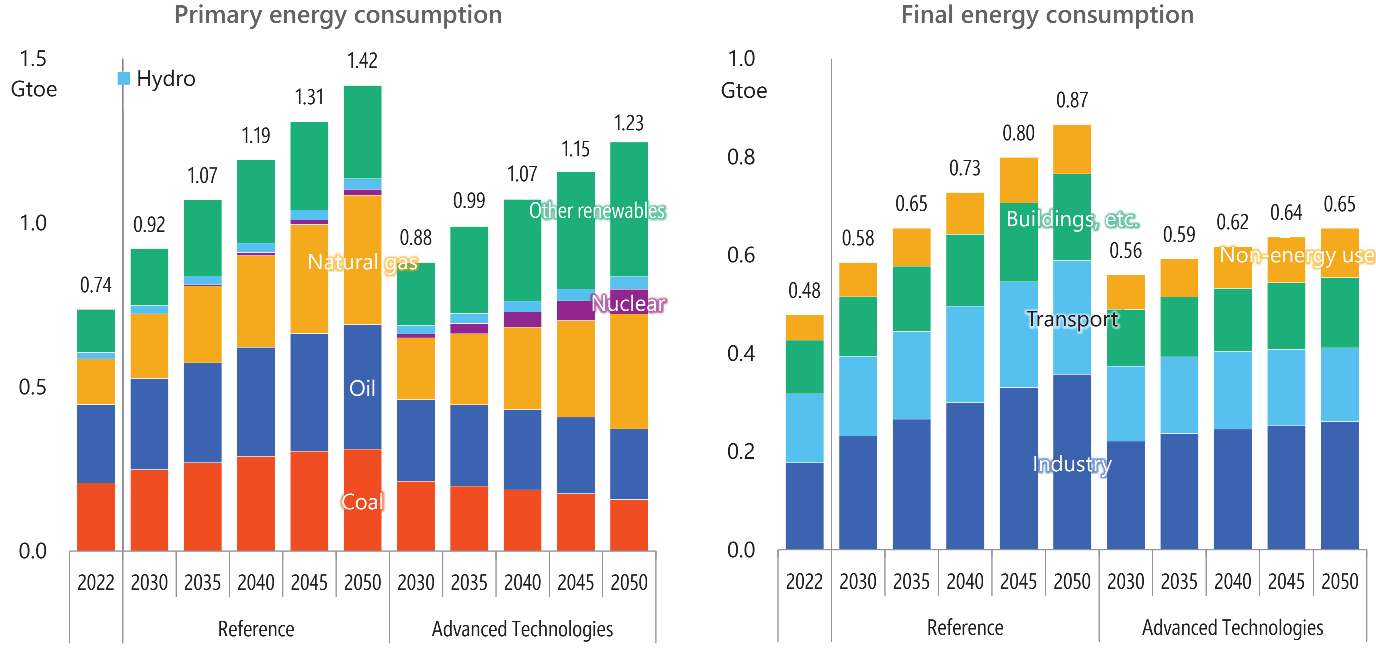


Energy-related CO_2 emissions and investments

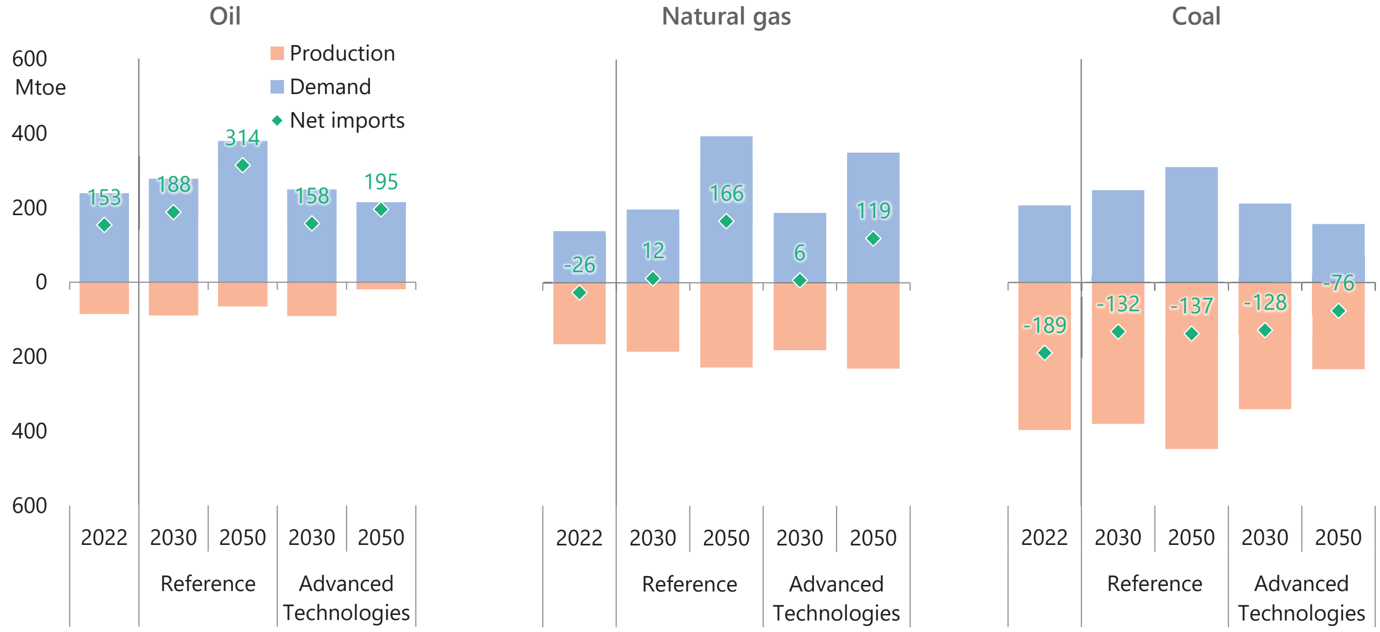




Energy consumption



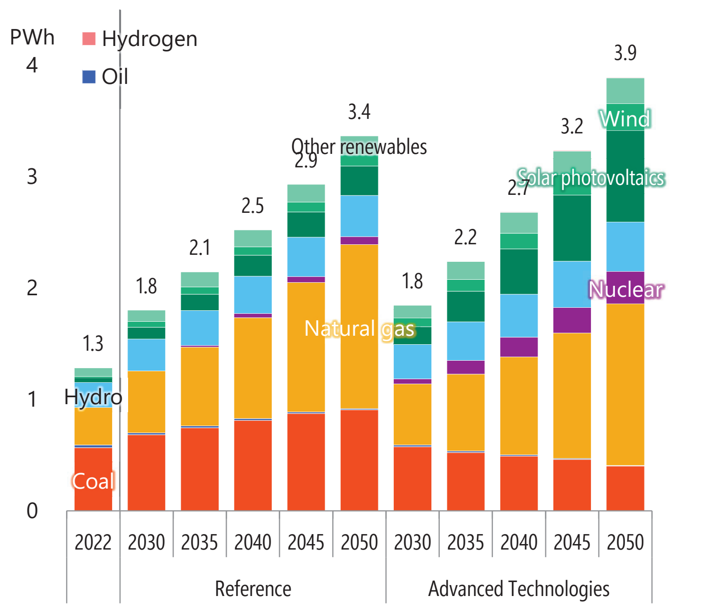
Supply and demand balance of fossil fuels



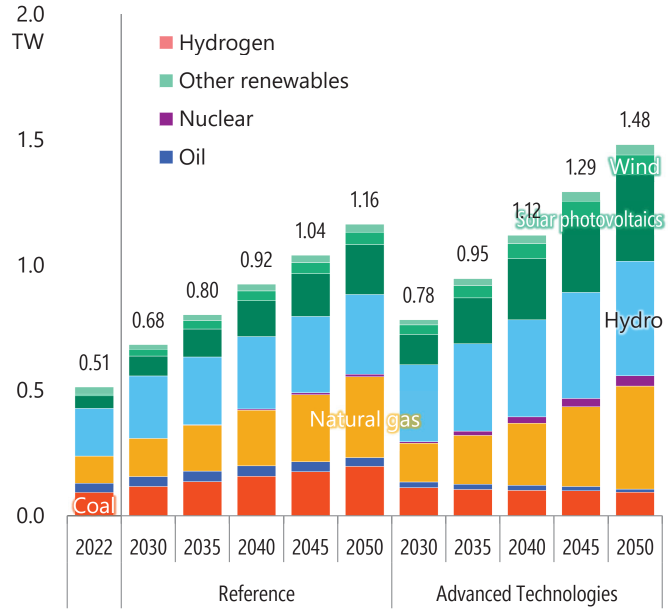
ASEAN

Power generation mix

Electricity generated



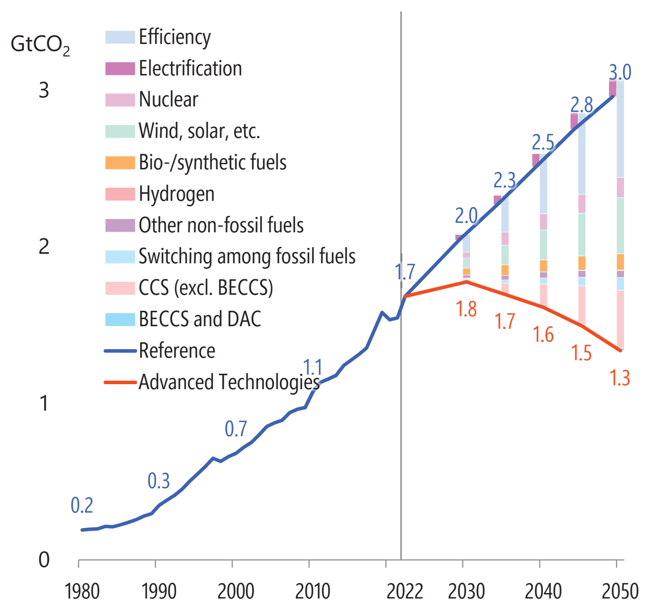
Installed power generation capacity



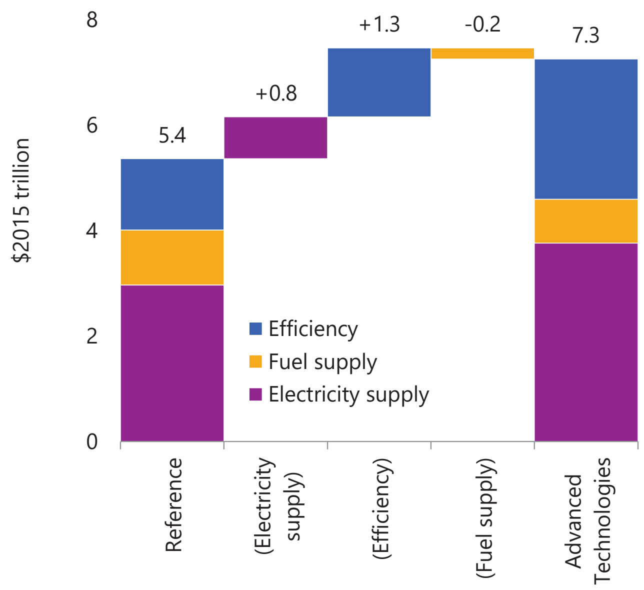
ASEAN

Energy-related CO_2 emissions and investments

CO_2 emissions



Investments (2023–2050)



The tables for IEEJ Outlook 2025 are currently available at https://eneken.ieej.or.jp/en/whatsnew/448.html.

The full text will be available early 2025 at the same URL.

IEEJ Outlook 2025

October 2024

The Institute of Energy Economics, Japan