Challenges to Overcome Global Energy Trilemma and Its Implication to Malaysia (Based on IEEJ Outlook 2020)

Energy Talk at UNITEN
November 12th, 2019

Prof. Dr. Ken Koyama

Chair in Energy Economics of Energy Commission at UNITEN
Chief Economist, Institute of Energy Economics, Japan

Energy is indispensable for human beings

- **Energy is essential goods for human life, economic activity and national security**

- **It is critically important to provide energy**
  - **in a stable manner;**
  - **at affordable prices;**
  - **in an environmentally sustainable manner**

- **Pursuit of energy security, environment protection and economic efficiency is needed**

- **But the 3Es often face trade-off: Trilemma**

Emerging global energy landscape

- Volatile crude oil price
- Impacts of US “Shale Revolution”
- Asia as a gravity center of world energy demand
- Energy Geopolitics revisited
- Climate change and air pollution as emerging risks
- Expectation for advanced and innovative technology
- Complicated roles played by market, government and technology

Asia’s Challenges for “3E”

<Energy Security>

- **Rising import dependence and energy security**
  - High oil import dependence. Gas import dependence rising
  - High Middle East dependence, Sea-lane dependence

<Environment Protection>

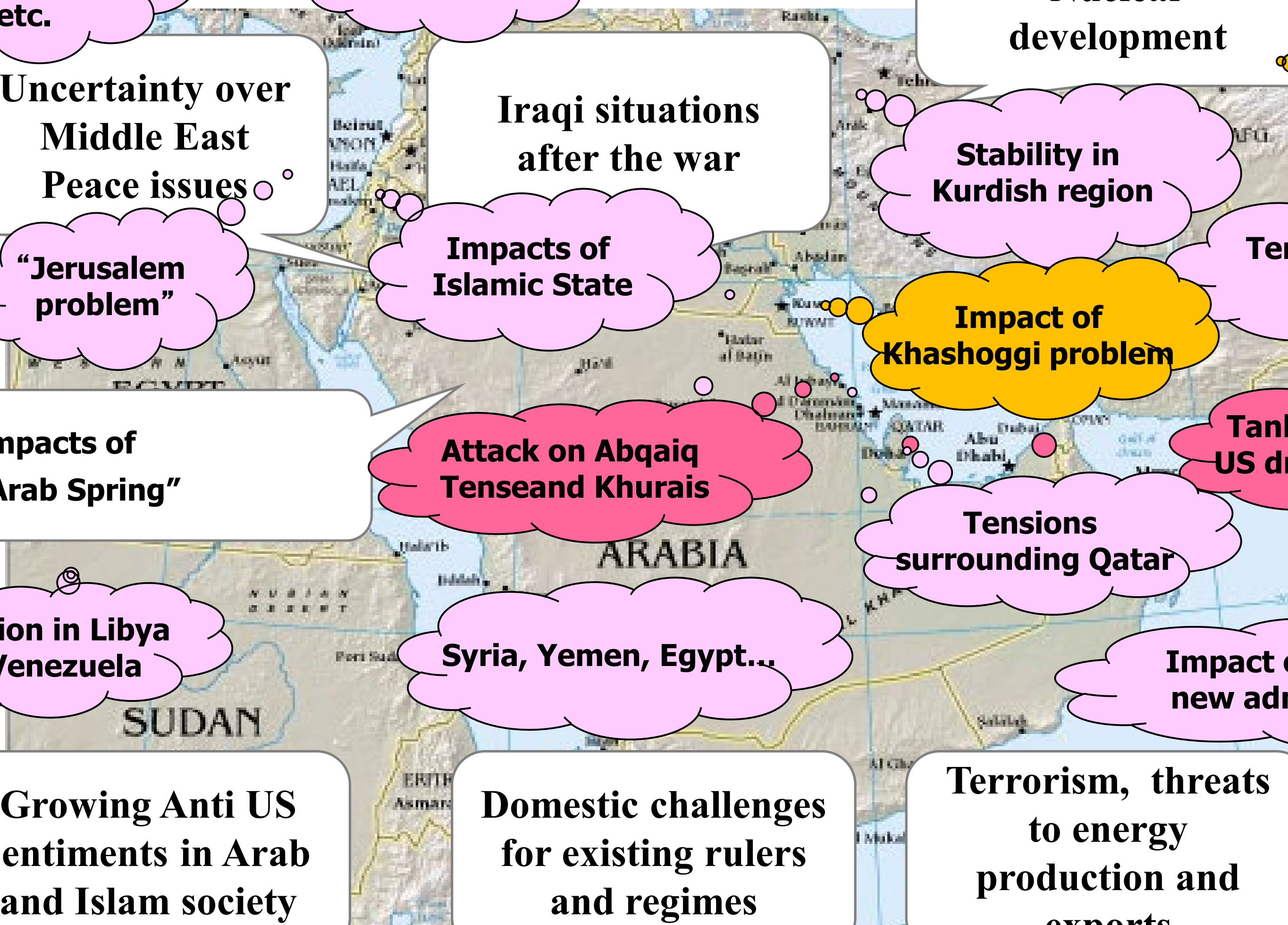
- **High coal dependence and environment loads**
  - Challenges for both climate change and pollution problems

<Economic Efficiency>

- **Need for energy market reform**
  - Japan leads the way. Reform for both energy market and NOCs

IEE JAPAN

Instability in the Middle East



Terrorist Attacks In Paris, Brussels, etc.

Immigrants to Europe

Tensions on Iran Nuclear development

Tense Us-Iran relation

Uncertainty over Middle East Peace issues

Iraqi situations after the war

Stability in Kurdish region

"Jerusalem problem"

Impacts of Islamic State

Tense Saudi-Iran Relations

Impact of Khashoggi problem

Impacts of "Arab Spring"

Attack on Abqaiq Tenseand Khurais

Tanker attacks and US drone shoot down

Tensions surrounding Qatar

Disruption in Libya and Venezuela

Syria, Yemen, Egypt...

Impact of US policy by new administration

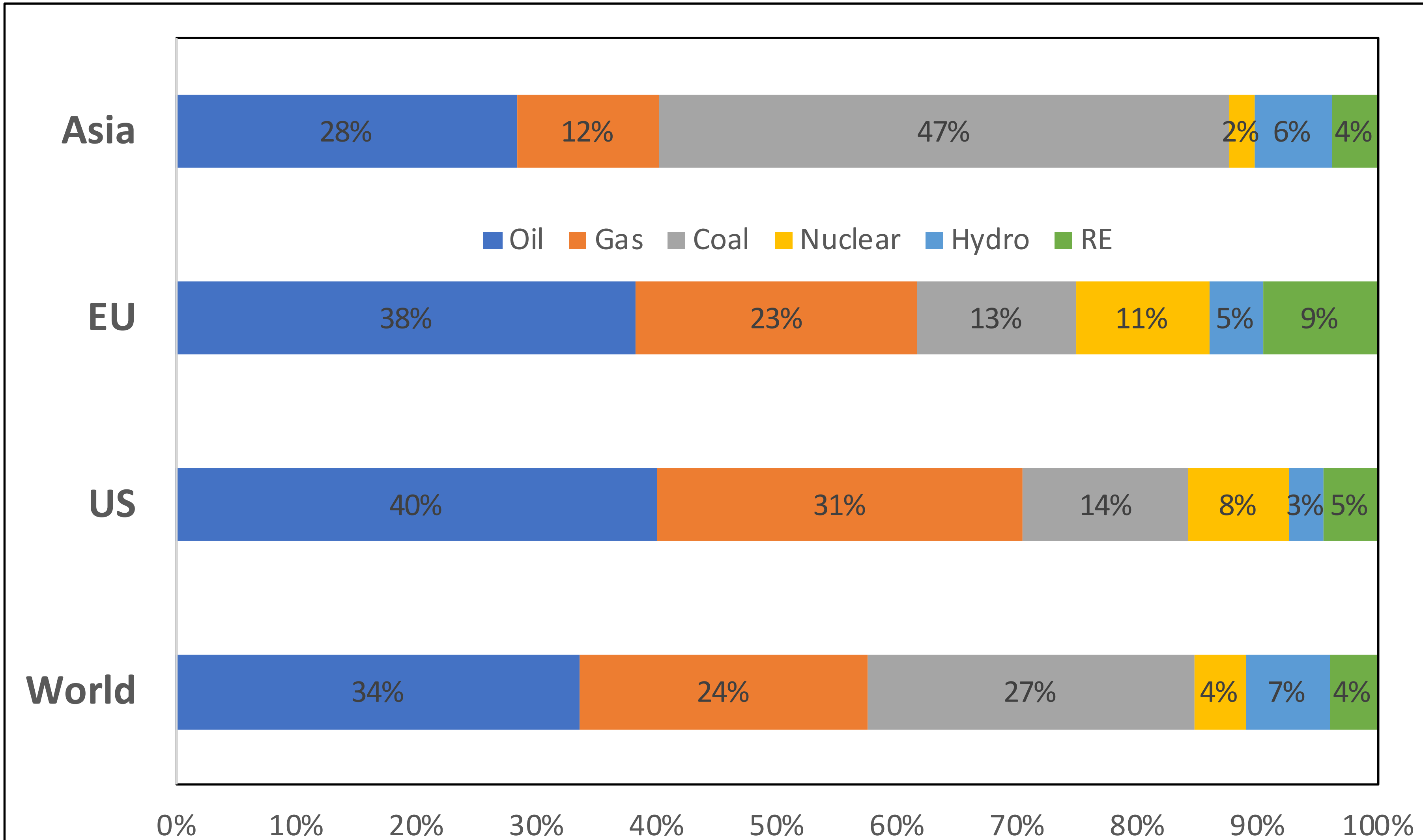
Growing Anti US sentiments in Arab and Islam society

Domestic challenges for existing rulers and regimes

Terrorism, threats to energy production and exports

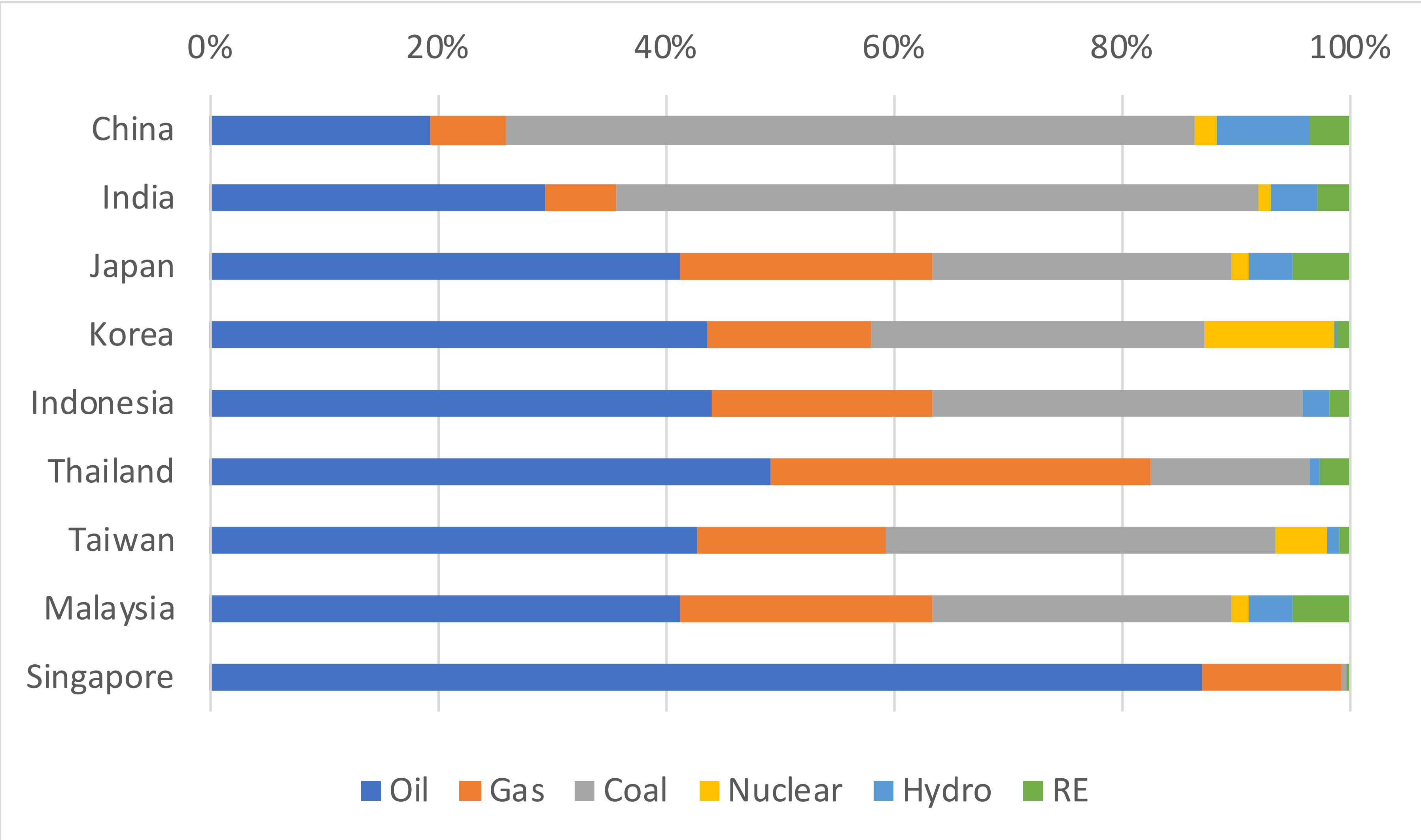
Source: Prepared by IEEJ

Asia, heavily dependent on coal



Source: Prepared from "BP Statistical Review of World Energy 2019"

Asian countries, diversified energy position



Source: Prepared from "BP Statistical Review of World Energy 2018"

Environmental challenges in Asia

- *Growing energy/power demand*
- *Climate change and air pollution*

NDC under Paris Agreement

Party	Date of submission	Target type	Reduction target	Base year	Target year	Coverage
EU	Mar 6 2015	Absolute emissions	40%	1990	2030	GHG
United States	Mar 31 2015	Absolute emissions	26～28%	2005	2025	GHG including LULUCF
Russia	Apr 1 2015	Absolute emissions	25～30%	1990	2030	GHG
China	Jun 30 2015	GDP intensity	60～65% Total emission peak out before 2030	2005	2030	CO_2
Japan	Jul 17 2015	Absolute emissions	26%	2013	2030	GHG
Indonesia	Sep 24 2015	Reduction from BAU	29%	BAU	2030	GHG
Brazil	Sep 30 2015	Absolute emissions	37% (43% for 2030)	2005	2025	GHG
India	Oct 1 2015	GDP intensity	33～35%	2005	2030	GHG

Air pollution in China

What actually done to reform market?

Privatization (if applicable)

- State dominant companies to be exposed to market forces
- "Principal-Agent theory"

Deregulation

- Introduction of competition (power generation, retail)
- Creation of wholesale (spot) market
- Unbundling
- Remove tariff/profit control
- Regulator to check/monitor competition situation
- Etc.

Impact

- Market mechanism starts to function
- Pricing principle: "Full-cost pricing (cost-pass-on)" to "Market driven"

Liberalized market and “Energy Mix”

- **Liberalization tends to lead to cost minimization**
- **Investment in “Zero-emission” power generation may not be regarded as “cost minimum”**
- **New mechanism required to address the challenges**
  - **UK: Introduction of “FIT/CFD”**
  - **US (states level): Introduction of “ZEC”**
  - **US considers to support “baseload power”**

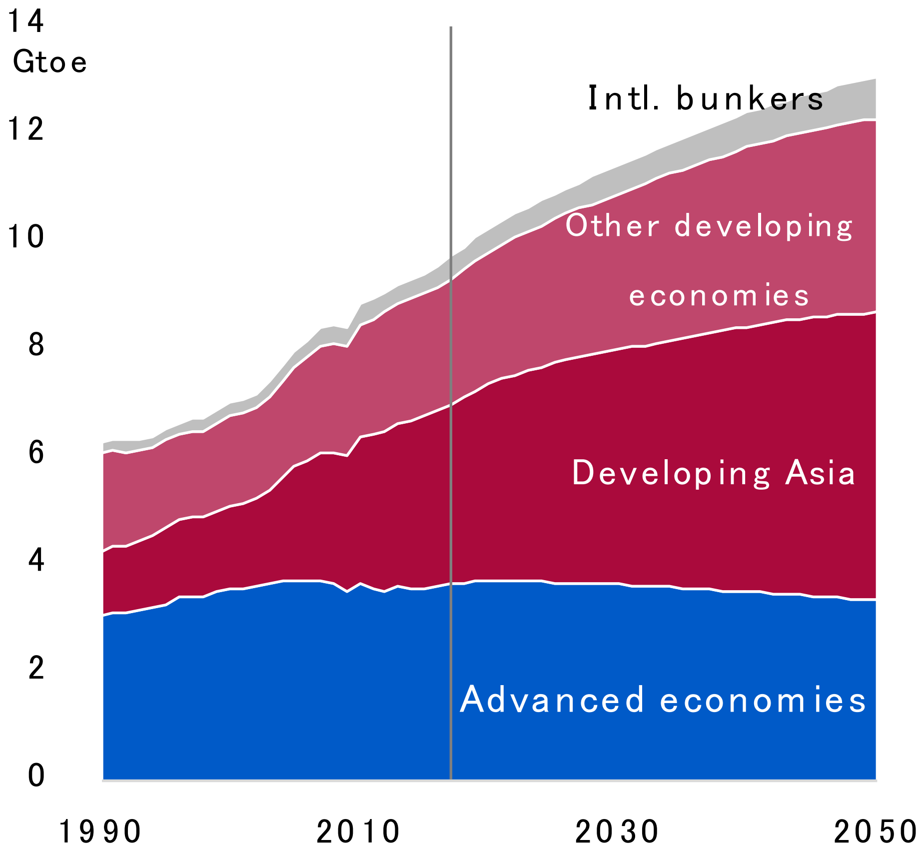
Basic scenarios in IEEJ Outlook

	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.
Social-economy structure	Stable growth led by developing economies despite slower population growth. Rapid diffusion of energy consuming appliances and vehicles due to higher income.	
International energy price	**Oil** supply cost increases along with demand growth. **Gas** price convergences among Europe, N. America and Asia markets. **Coal** keeps unchanged with today's level. [LNG in Asia] Higher/lower price cases	Slower price increase due to lower demand growth (coal price decreases).
Energy policies	Gradual reinforcement of low-carbon policies with past pace.	Further reinforcement of domestic policies along with international collaboration.
Energy technologies	Improving efficiency and declining cost of existing technology with past pace.	Further declining cost of existing and promising technology.

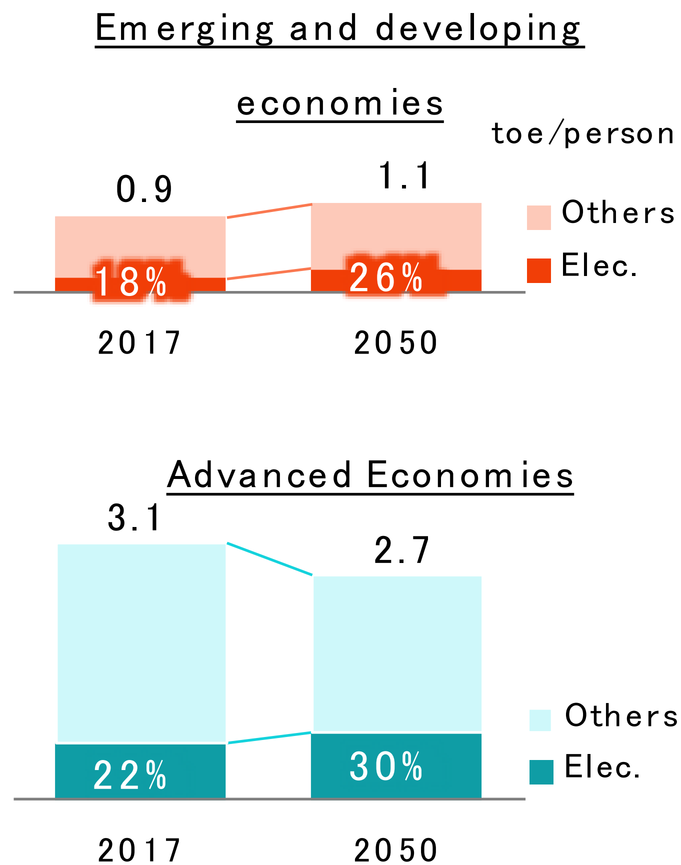
Source: "IEEJ Outlook 2020" (IEEJ, October 2019)

Per capita demand still low in developing economy

❖ Final energy demand



❖ Energy demand per capita



Global final energy demand increases by 30% by 2050 while advanced economies reduce demand.

In emerging and developing economies, demand per capita remains under half of advanced economies even in 2050.

Electricity demand continues to increase, and electrification rate rises in final energy demand.

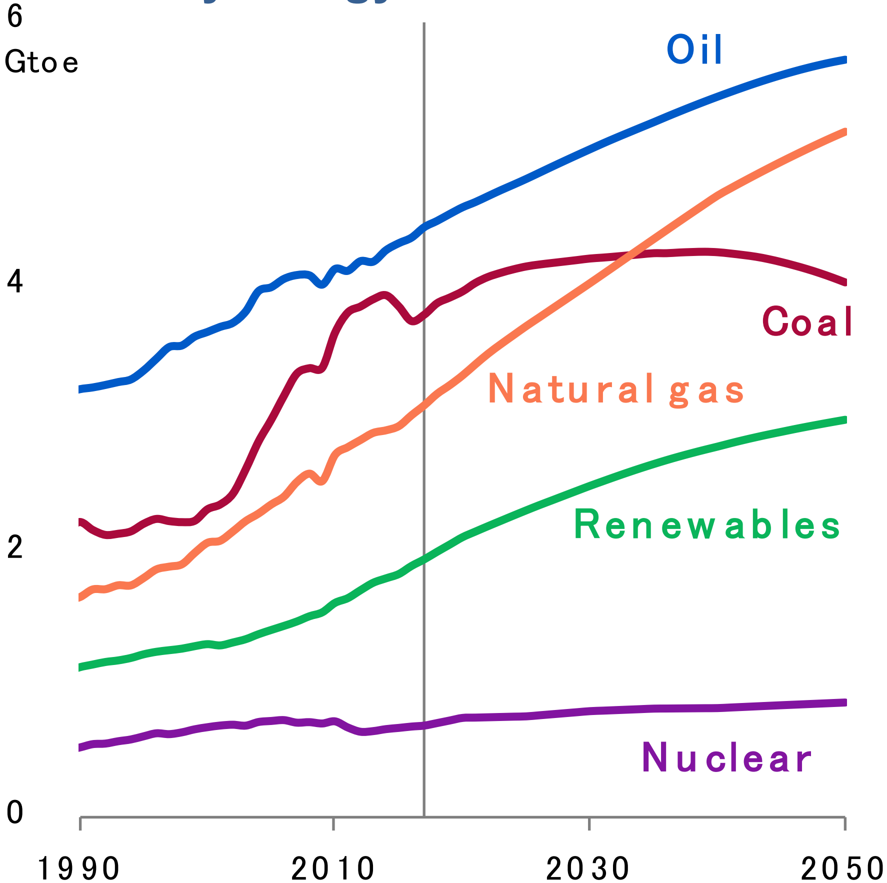
Source: "IEEJ Outlook 2020" (IEEJ, October 2019)

Reference material

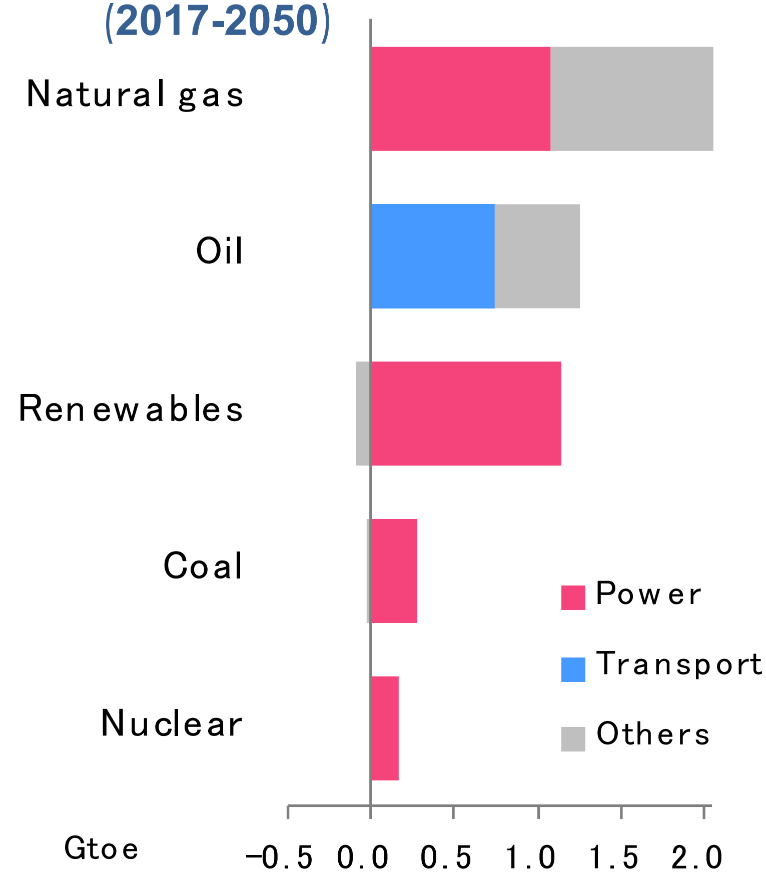
Reference Scenario

World continues to depend on fossil fuels

❖ Primary energy demand



❖ Change in energy demand (2017-2050)



Natural gas increases by 1.7 times especially in the power sector, becoming a second-position energy.

Coal hits a peak at 2040 and oil remains the most important energy.

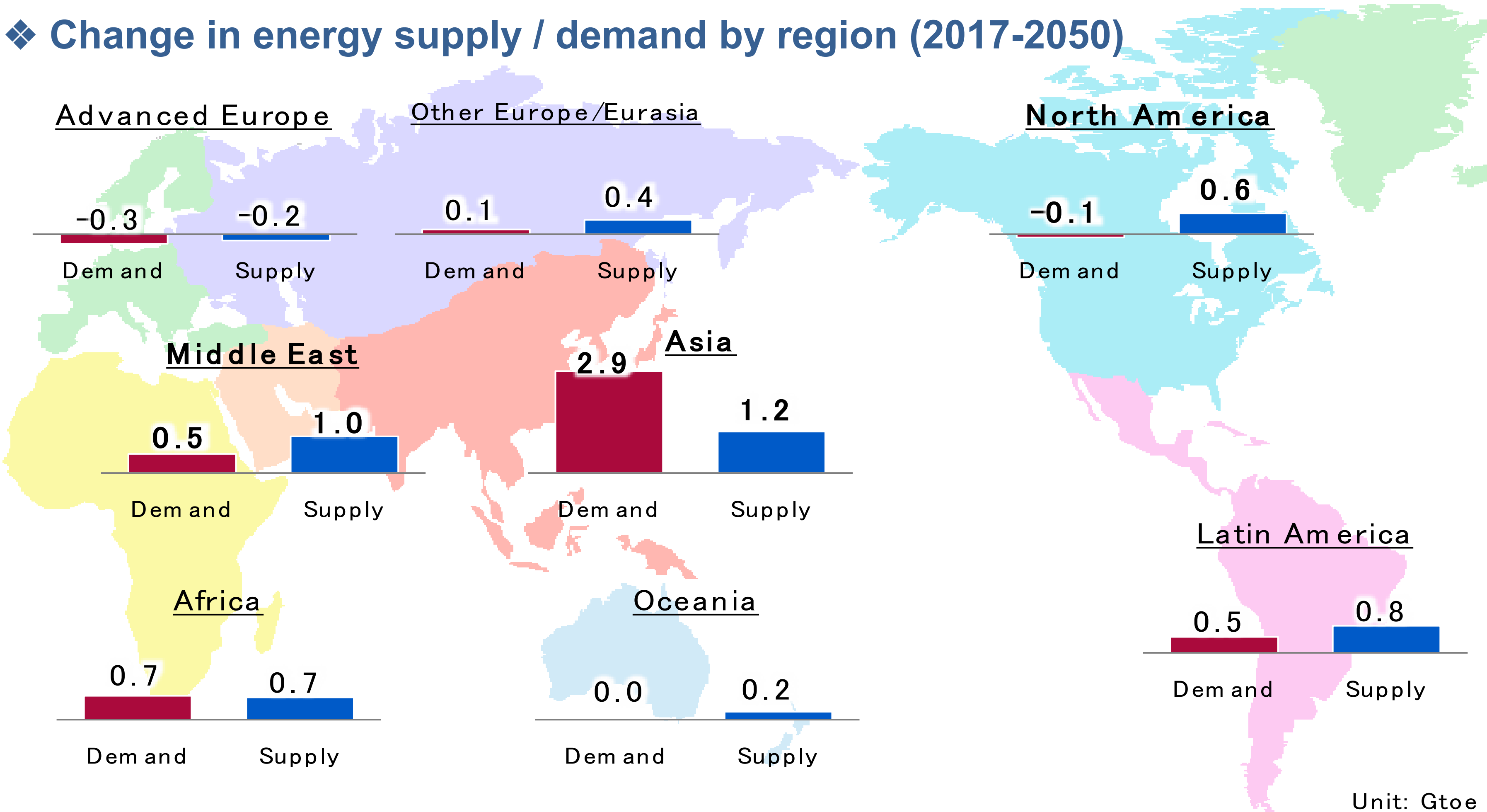
Renewables grow rapidly but their share of primary demand mix increase only to 16% from 14%. Lessing dependency on fossil fuels progresses slowly.

Source: "IEEJ Outlook 2020" (IEEJ, October 2019)

Reference Scenario

Demand overwhelms supply in Asia

❖ Change in energy supply / demand by region (2017-2050)



Over 60% of global demand growth comes from Asia. Meanwhile its energy supply cannot catch up, resulting in dropping energy self sufficiency from 72% to 61%.

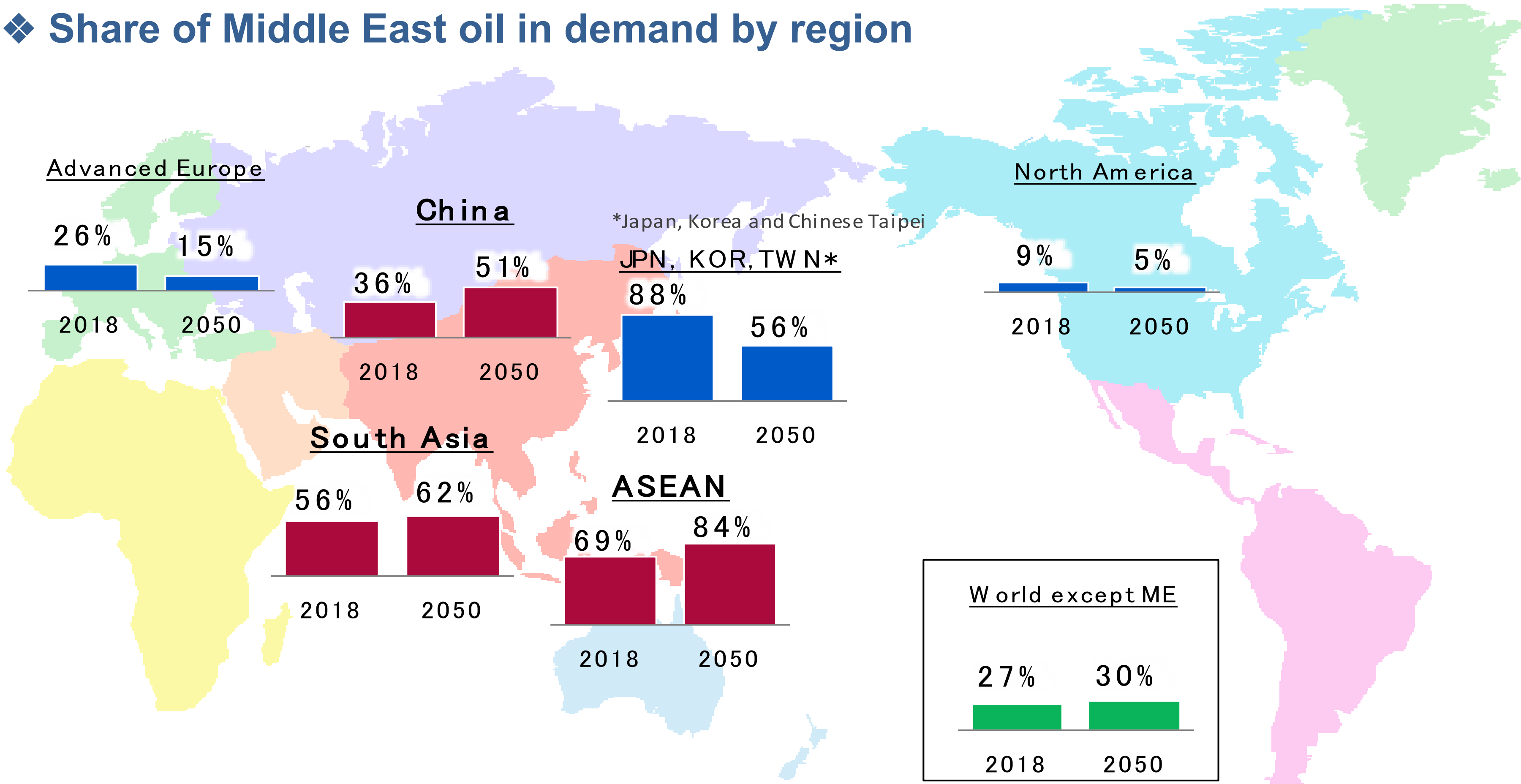
North America and the Middle East increase surplus export capacity and enlarge their presences as energy suppliers.

Source: "IEEJ Outlook 2020" (IEEJ, October 2019)

Reference Scenario

Emerging Asia sees rising dependence on ME

❖ Share of Middle East oil in demand by region



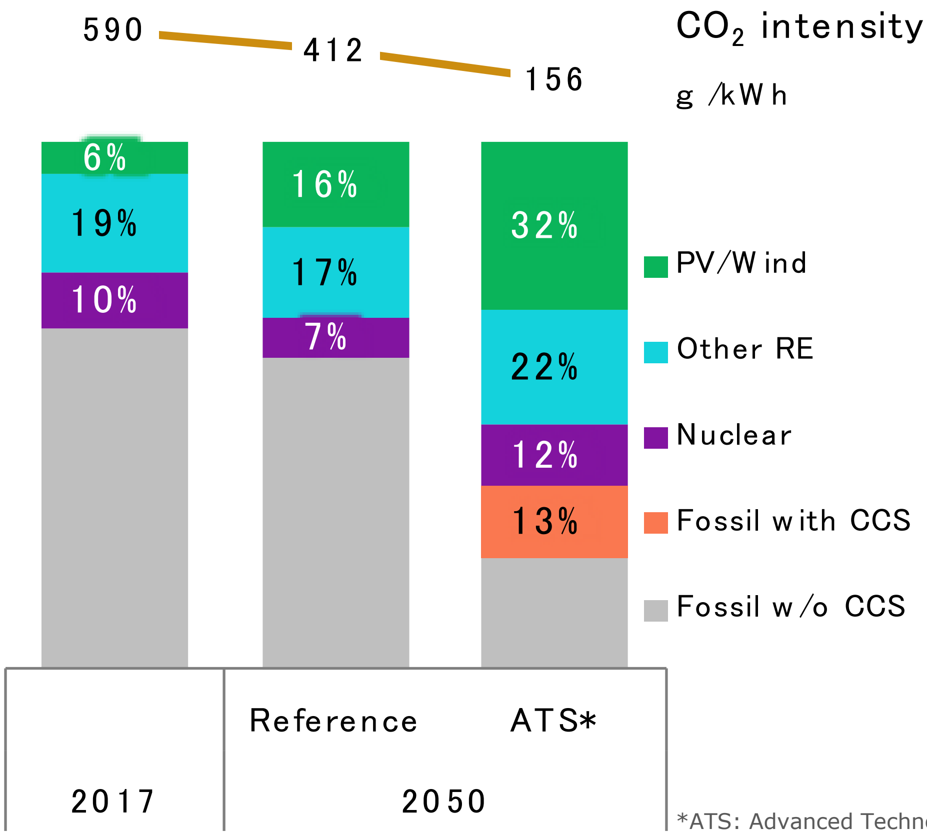
Developing Asia increases dependence on Middle East oil and mitigating risk of supply disruption remains one of the priority issues.

Meanwhile, North America and Advanced Europe reduce the dependence rapidly but would be affected by higher oil price when emergency due to higher dependence at the global level.

Source: "IEEJ Outlook 2020" (IEEJ, October 2019)

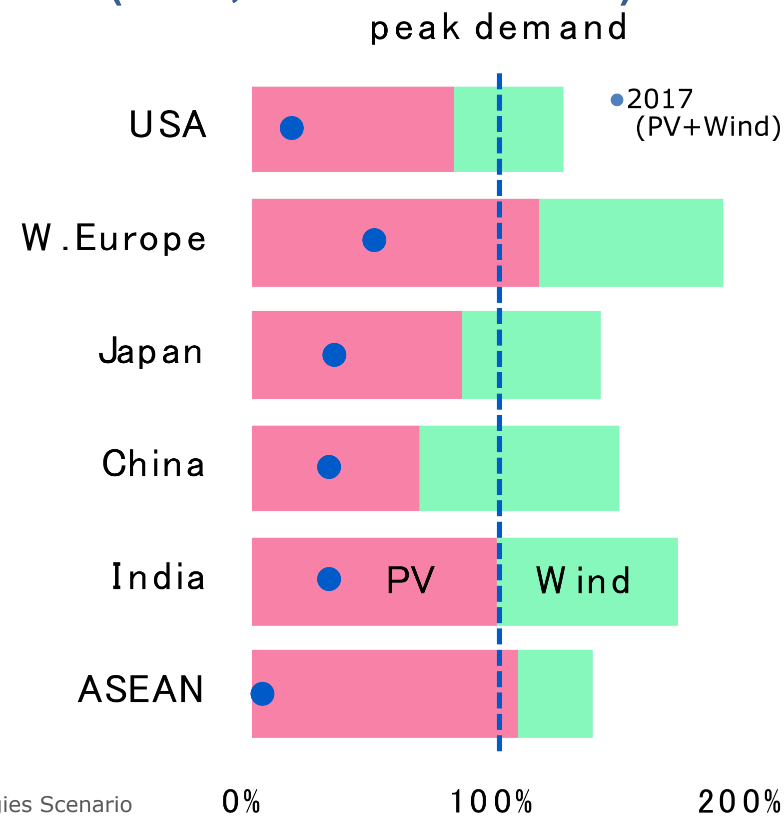
VRE capacity surpass peak demand

❖ Power mix and CO_2 intensity



*ATS: Advanced Technologies Scenario

❖ Ratio of capacity to peak demand (2050, Advanced Tech.)



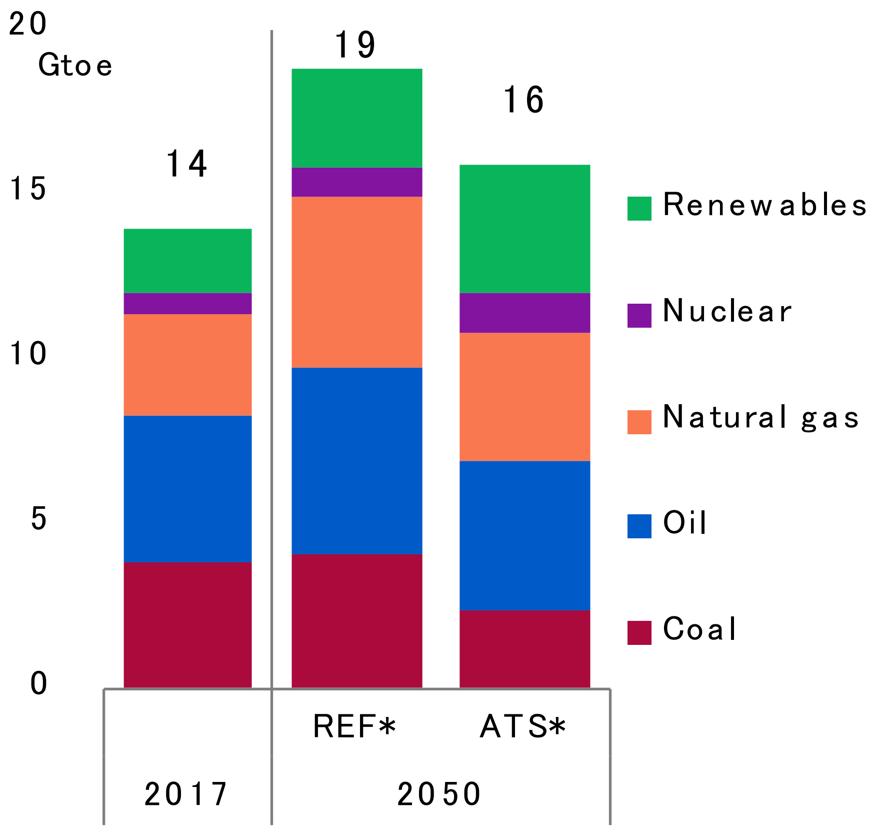
Zero-emission power generation (renewables, nuclear and fossil thermal with CCS) dominates 80% of power generation mix in the Advanced Technologies Scenario.

Generation capacity of variable renewable energy (VRE), such as solar PV and wind, exceeds peak electricity demand. Some regions need system stability measures, such as battery storage.

Source: "IEEJ Outlook 2020" (IEEJ, October 2019)

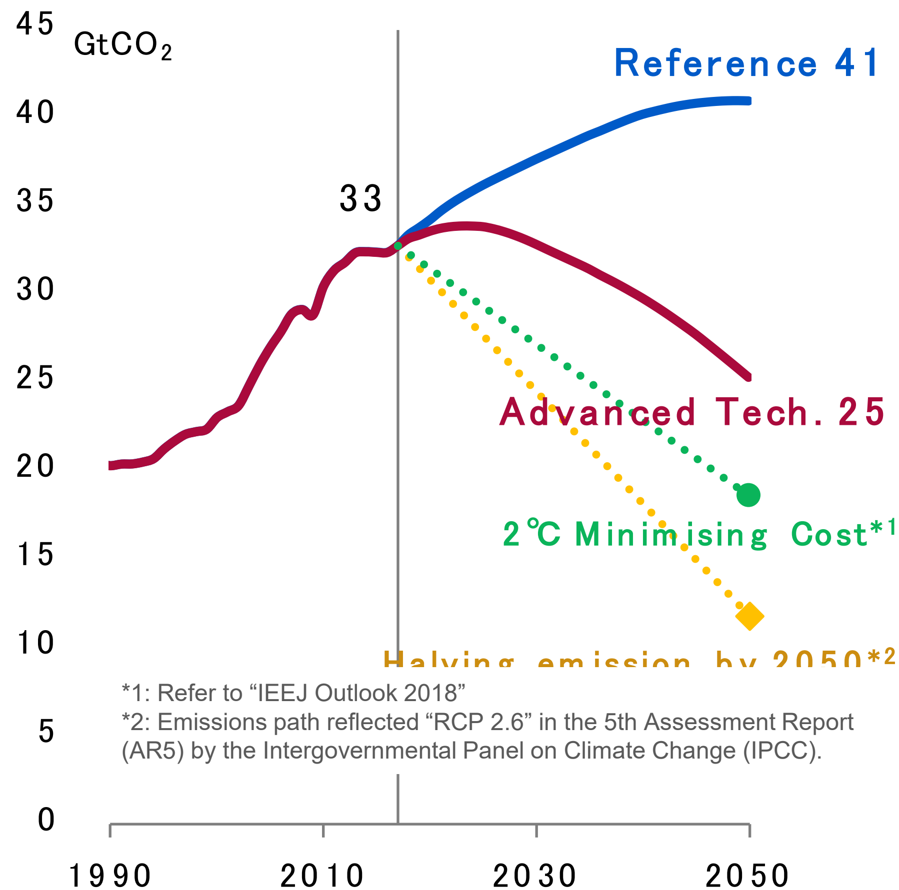
ATS sees large reduction, 2°C goal still far

❖ Primary energy demand



*REF: Reference Scenario, ATS: Advanced Technologies Scenario

❖ Energy-related CO_2 emissions



In the Advanced Technologies Scenario, dependence on fossil fuels drops to 70%, still high level.

Energy-related CO_2 emissions peak at the middle of 2020s and decrease by 23% vs. 2017 in 2050.

To keep temperature rise to below 2 degrees Celsius, additional programs and innovative technologies are required.

Source: "IEEJ Outlook 2020" (IEEJ, October 2019)

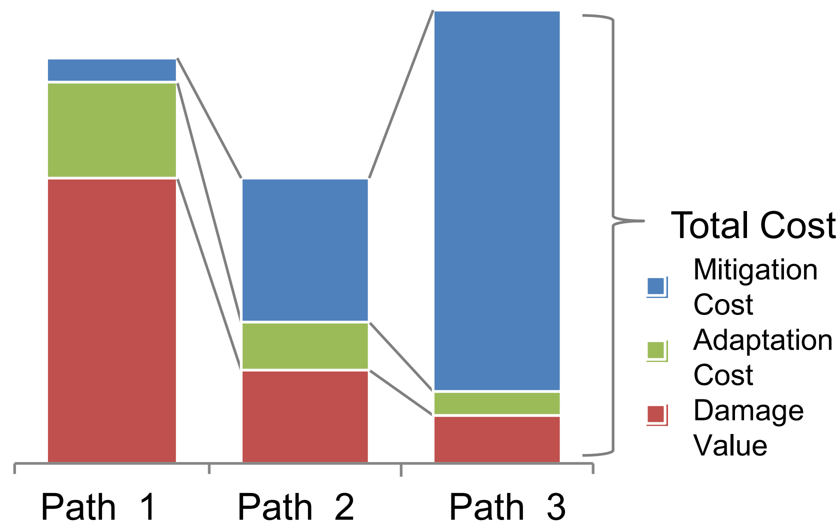
IEE JAPAN

Rule for ultra long-term: Minimize the total cost

❖ Mitigation+Adaptation+Damage=Total Cost

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

❖ Illustration of Total Cost for Each Path



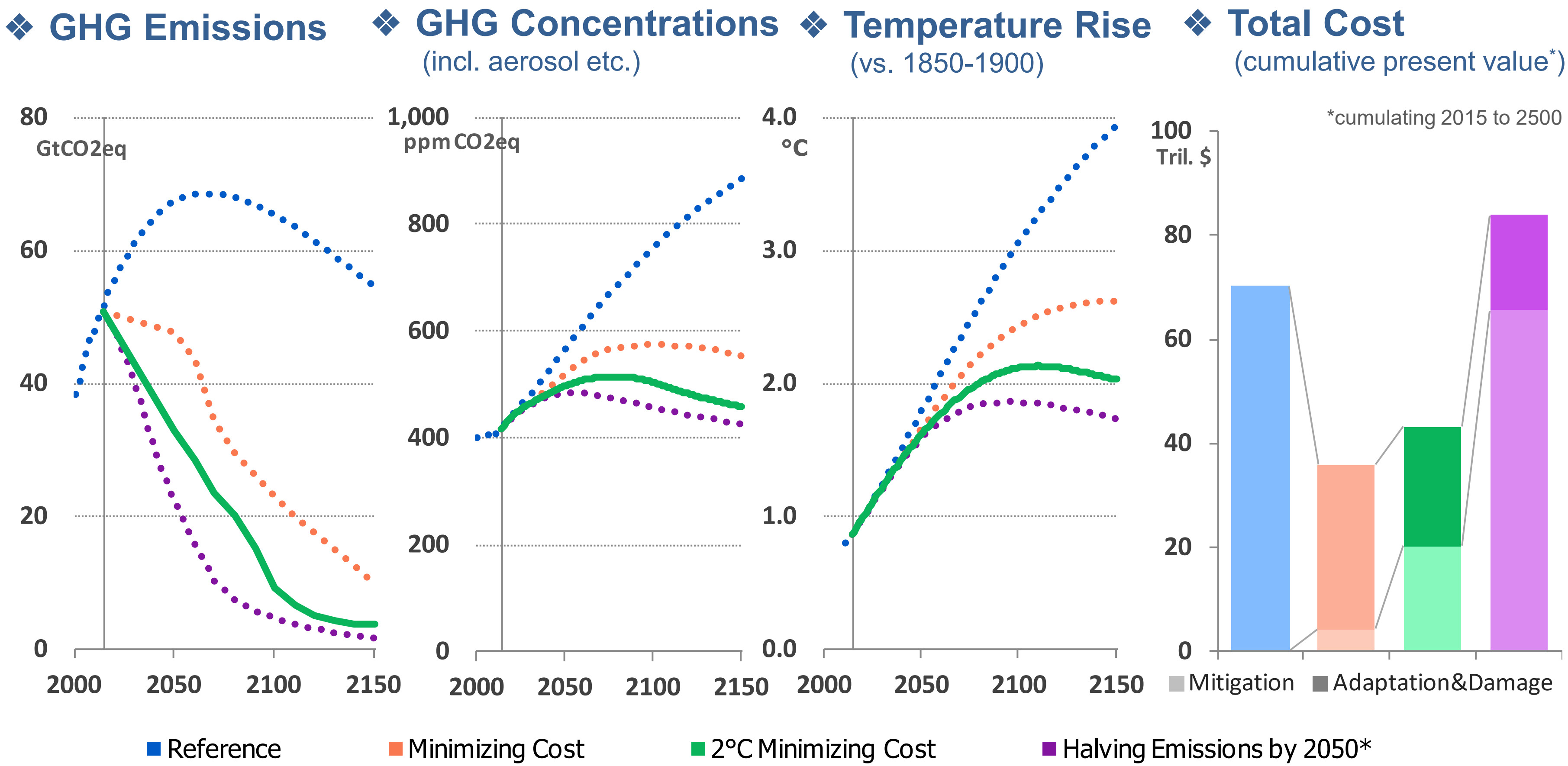
Path 1	Path 2	Path 3	
Too Small	Reasonable	Too Big	Mitigation
Big	Medium	Small	Adaptation
Big	Medium	Small	Damage

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

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

Source: "IEEJ Outlook 2020" (IEEJ, October 2019)

Cost-benefit analysis for “2°C target”
(IEEJ Outlook 2018)



“2° C Minimizing Cost”, for example, is a path that minimizes total cost under the condition of 2° C temperature rise in 2150. Its total cost is 20% higher than “Minimizing Cost” without the temperature limit, but still 50% lower than “Having Emissions”. GHG emissions decrease by 30% in 2050 and needs almost zero-emissions after 2100. Temperature rises to slightly above 2° C by 2100 and then declines to 2° C.

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

Source: “IEEJ Outlook 2020” (IEEJ, October 2019)

Challenges for total cost minimum analysis

1) Is the damage function accurate?

- Estimation of the damages caused by climate change involves great uncertainties. Although research is progressing around the world, sufficient knowledge has not been accumulated.*1。
- It is important to refine the damage function (relationship between temperature rise and damage value) based on the latest scientific knowledge.

*1:Most integrated assessment models do not cover all types of damages, and do not consider the interaction between them. Critics say that in many cases the estimated damages for relatively low temperatures (temperature rise of about 1 to 3 °C) for Europe and the United States are applied to other regions and to higher temperatures, possibly resulting in considerable underestimation.

2) Modeling tipping elements

- If the progress of an event exceeds the critical point, the automatic absorption of GHG by the Earth system will stop functioning, and the change may be accelerated.
- For example, as Siberian permafrost melting progresses due to global warming, underground methane and CO_2 are released into the atmosphere. The release itself contributes to global warming, further thawing the frozen soil.
- They point out that there is a risk of shifting to a different equilibrium state, for example, “Hothouse Earth” where the temperature is higher by several degrees or more than before as a result.

3) Other theoretical issues

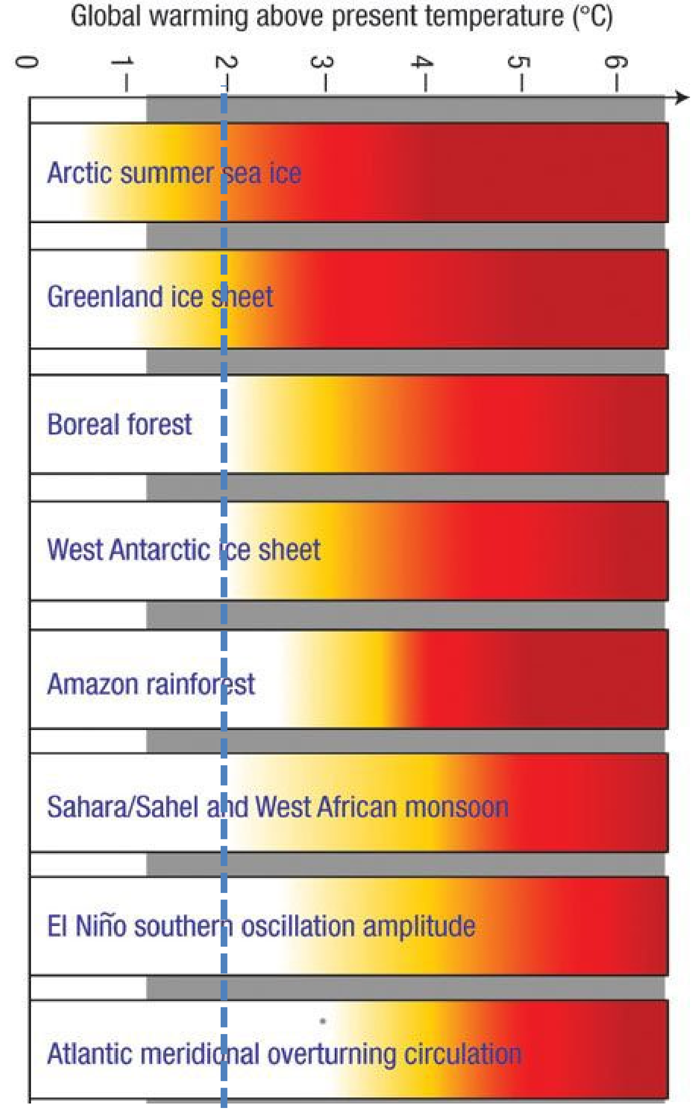
- Issues related to long-term discount rates, “fat tails*2”, etc.
- Discussions continue, and no consensus has been found among many researchers at present.

*2:It has been pointed out that the tail of the probability distribution of the damage by climate change may be thick (i.e. higher probability of occurrence than the normal distribution).

Source: “IEEJ Outlook 2020” (IEEJ, October 2019)

Examples of tipping elements

1. Arctic summer sea ice: decrease in areal extent----------
   Decreased albedo, amplified warming
2. Greenland ice sheet: decrease in ice volume--------------
   Decreased albedo, sea level rise
3. Boreal forest: decrease in tree fraction-------------------
   Greenhouse gas emissions, biome switch
4. West Antarctic ice sheet: decrease in ice volume----------
   Decreased albedo, sea level rise
5. Amazon rainforest: decrease in tree fraction--------------
   Greenhouse gas emissions, biodiversity loss
6. Sahara/Sahel and West African monsoon: increased carrying capacity---
   Increase in vegetation fraction
7. El Nino southern oscillation: increase in amplitude--------
   Drought in Southeast Asia and elsewhere
8. Atlantic meridional overturning circulation: decrease in overturning---
   Regional cooling, ITCZ (Intertropical convergence zone) shift



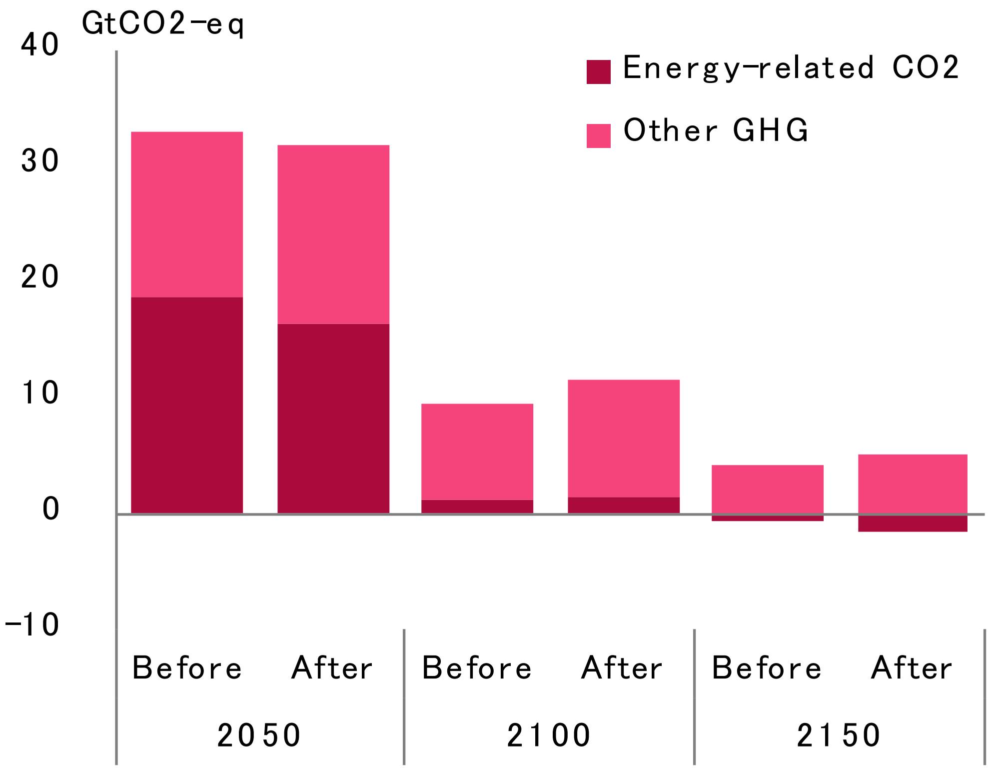
* The deeper red, the more likely to occur.

T. M. Lenton and H. J. Schellnhuber, 2007. Tipping the scales. *Nature Report Climate Change*, 1, 97-98.

Source: "IEEJ Outlook 2020" (IEEJ, October 2019)

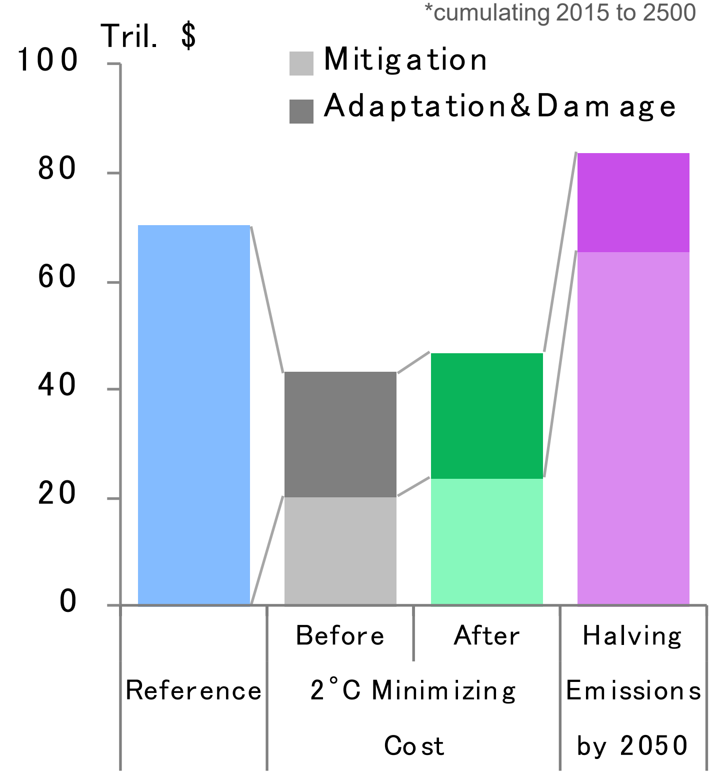
Total cost minimum analysis incorporating tipping elements

❖ GHG Emissions (2°C Minimizing Cost)



❖ Total cost (cumulative present value*)

*cumulating 2015 to 2500



Incorporating the three tipping elements will reduce the amount of energy-related CO_2 emissions and increase the total cost. However, since the damage effect occurs over a long period of time, the impact on the results of cost-benefit analysis is not significant.

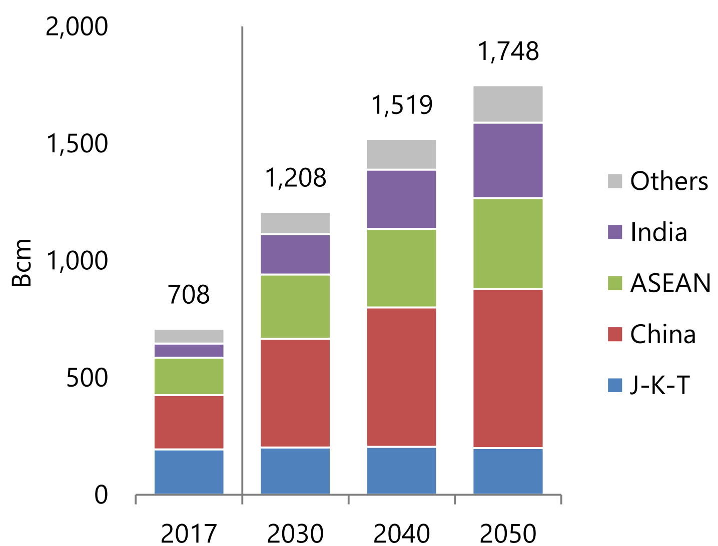
The tipping elements incorporated into the model: (1) Melting of the Greenland ice sheet, (2) CO_2 and CH_4 release due to melting of permafrost, (3) Changes in albedo (sunlight reflection) due to decrease in Arctic sea ice

Source: "IEEJ Outlook 2020" (IEEJ, October 2019)

Expanding Asian gas market

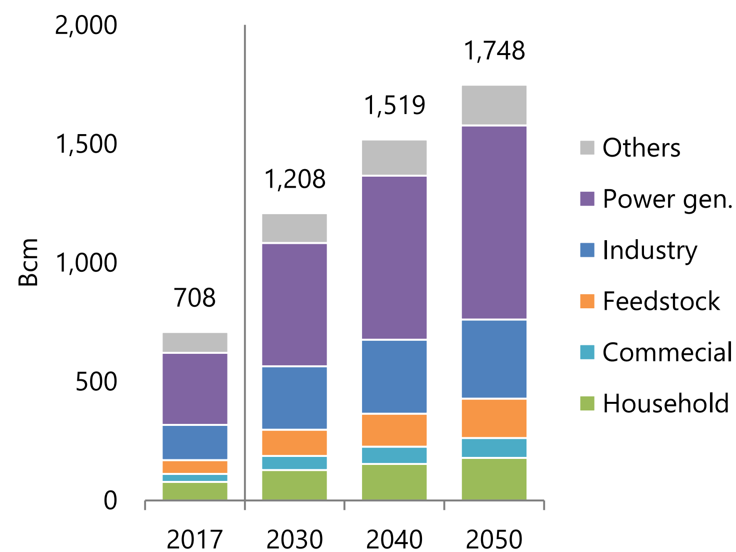
- Natural gas, which has the lowest environmental footprint among fossil fuels, is anticipated to play a bigger role in the future in Asia.
- Though China and India present the largest demand growth, ASEAN is expected to show remarkable growth as well.
- In terms of demand sectors, power generation is the fastest growing. However, LNG cannot avoid competition with coal in the sector.

❖ Natural gas demand outlook in Asia by region



J-K-T = Japan, Korea, and Chinese Taipei
Source: IEEJ

❖ Natural gas demand outlook in Asia by sector



Source: IEEJ

Source: "IEEJ Outlook 2020" (IEEJ, October 2019)

Reference material

Assumption of LNG price in Asia

- **Reference Scenario**: Real LNG import price in Asia maintains present price range, \$10.1/MBtu in 2018.
  - Assume reduction of amount of oil-linked pricing contract or milder slope of oil linkage.
  - Competitiveness of LNG is low in developing Asia under the current price range.
- **High Price Case**: Oil-linked pricing at an average slope in 2018 in Asia continues until 2050.
  - LNG will lose competitiveness in the power generation sector thus the demand will be slashed.
- **Low Price Case**: Historically low spot LNG price (average from Jan to Aug 2019) continues until 2050.
  - Requires substantial cost reduction in every aspect of supply chain including liquefaction and shipping.

❖ Assumption of LNG price in Asia (\$2018/MBtu)

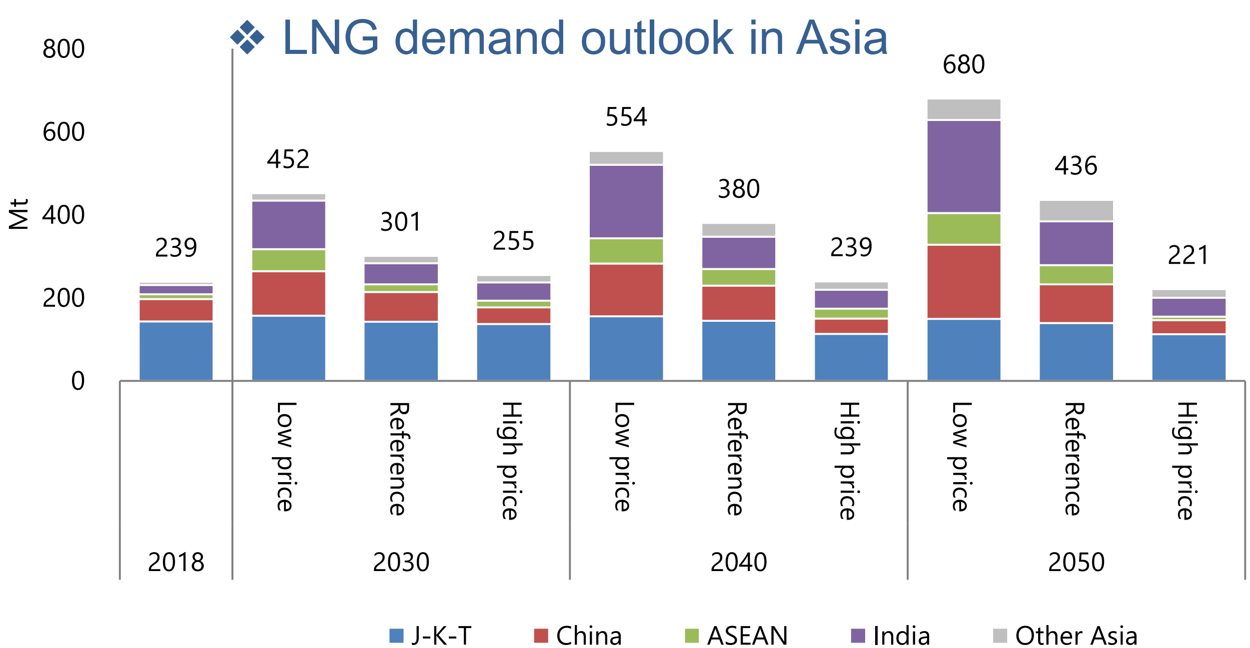
	2018	2030	2040	2050
Reference Scenario	10.1	10.0	10.2	10.4
Ref. Crude oil price price	*\$71.31/bbl*	*\$95/bbl*	*\$115/bbl*	*\$125/bbl*
High Price Case	10.1	13.3	16.1	17.5
Low Price Case	10.1	5.4	5.4	5.4

Source: IEEJ

Source: “IEEJ Outlook 2020” (IEEJ, October 2019)

LNG demand outlook in Asia by case

- **Reference Scenario**: LNG demand in Japan, Korea and Chinese Taipei won't increase. Meanwhile, ASEAN and India will see high (CAGR = 4.4-6.2%) demand growth.
- **High Price Case**: will see substantial reduction of new development of gas-fired power plants. LNG demand will stagnate (CAGR = -0.1%).
- **Low Price Case**: will see shifting investment from coal-fired to gas-fired power plants resulting in a higher LNG demand increase (CAGR = 3.3%).



J-K-T = Japan, Korea, and Chinese Taipei Source: IEEJ

Source: "IEEJ Outlook 2020" (IEEJ, October 2019)

Action to enhance LNG security

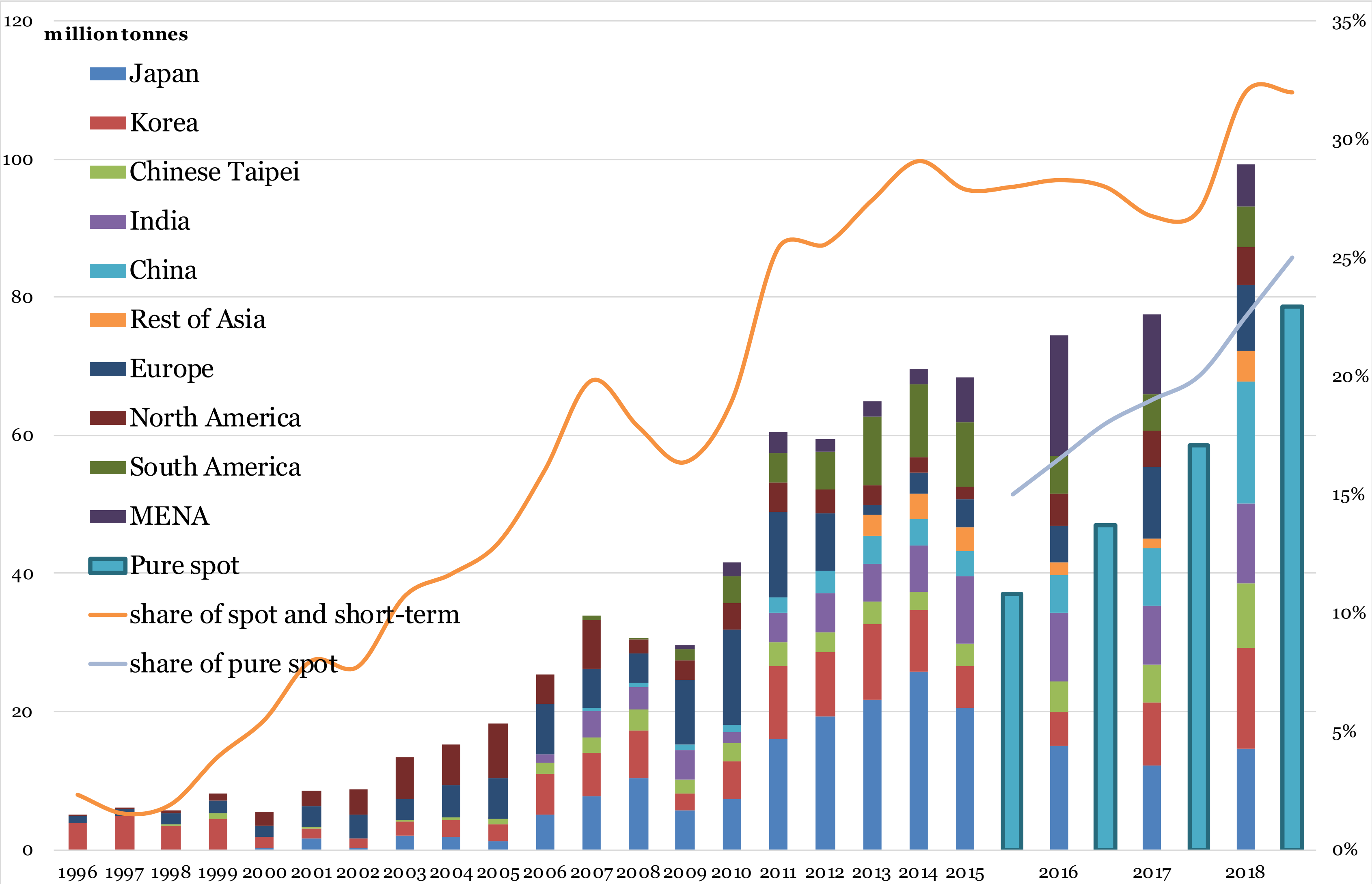
■ LNG supply security would become more important when LNG represents larger part of energy supply.

❖ **Actions to enhance LNG supply security**

Existing action	**Diversify supply sources and/or routes** Import from other sources when a source is disrupted.
	Reduce energy demand by energy efficiency Reduce import requirement and decrease risks.
	Strong tie with suppliers under long-term contracts Establish a strong tie with suppliers to ensure LNG supply.
Possible	**Create a flexible global LNG market** Import necessary volumes of LNG in time from the flexible global market.
	Cooperation with other gas markets Construct a mechanism to balance LNG supply-demand in cooperation markets, e.g. China, EU, US.

Source: IEEJ

More Volumes Are Sold Short Term

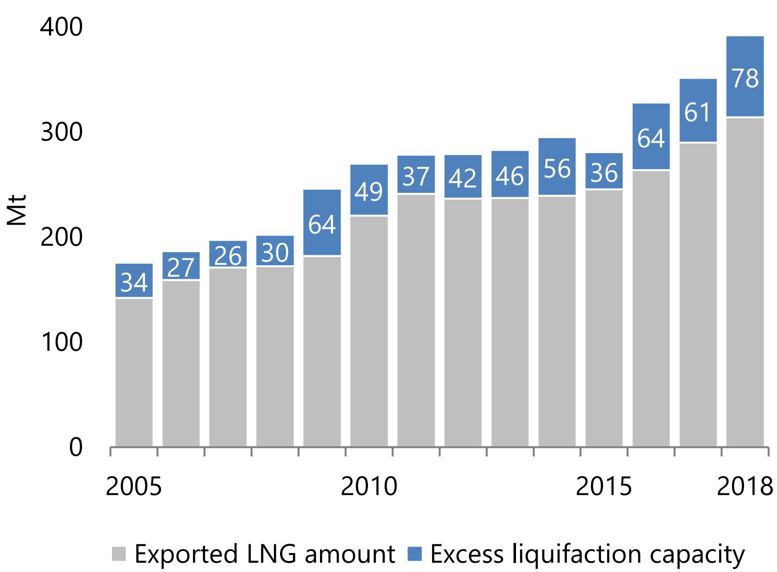


(Source) Hiroshi Hashimoto (IEEJ), "LNG Market and Flexibility Developments", April 18, 2019

Possibility to utilize flexibility in global LNG market

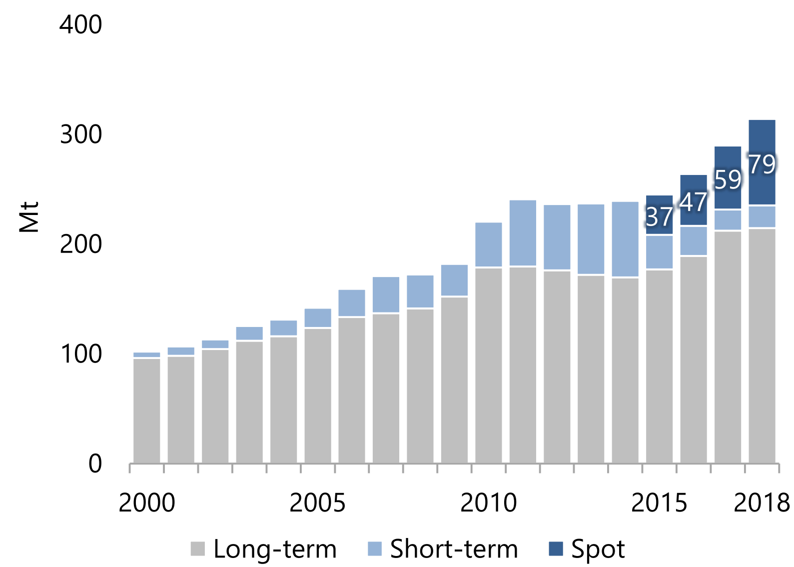
- Favorable changes for LNG supply security are underway in the global market.
  - Robust building up of new liquefaction capacity
  - Increasing supply and transactions of flexible LNG

❖ Exported LNG volumes and excess liquefaction capacity



Excess liquefaction capacity = total liquefaction capacity – idling liquefaction capacity – exported LNG volumes
Source: based on data from GIIGNL

❖ LNG export by contract period



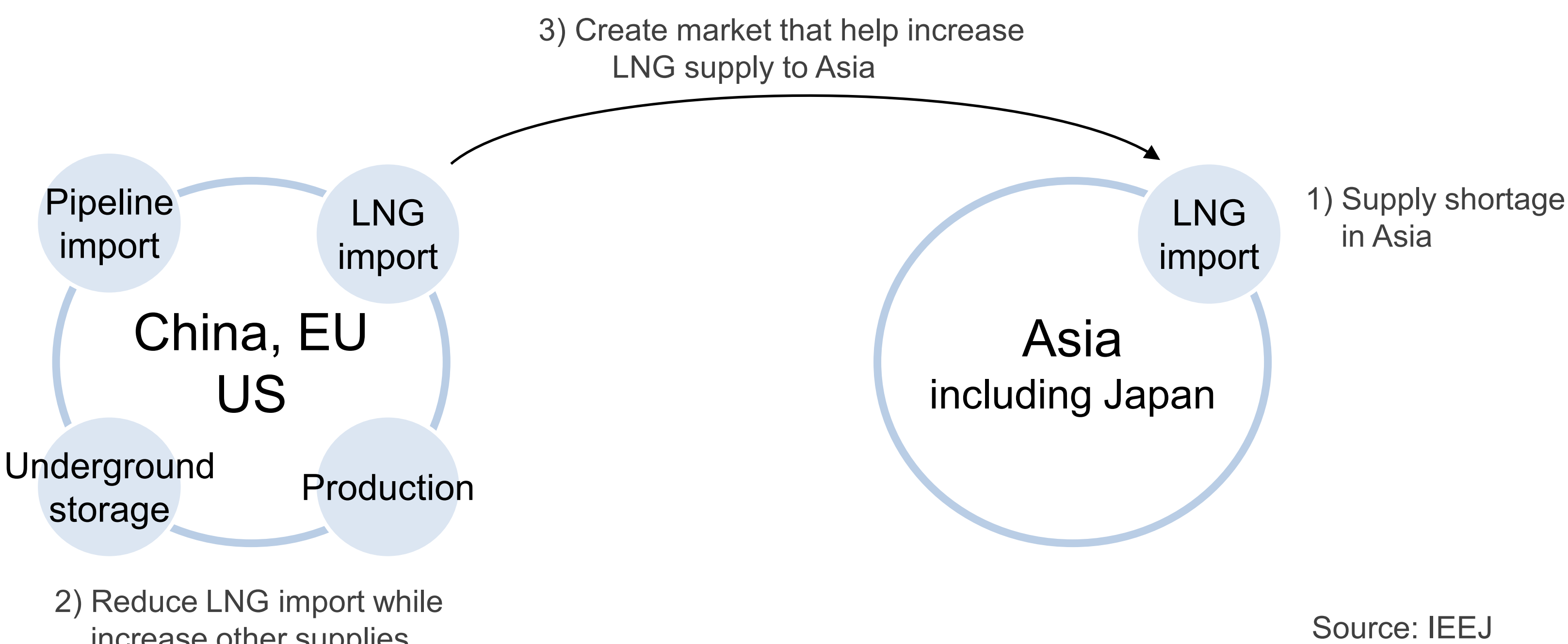
The "short-term (contract period 4 years or less)" from 2000 to 2014 including "spot" transactions.
Source: based on data from GIIGNL

Source: "IEEJ Outlook 2020" (IEEJ, October 2019)

Cooperation with other gas markets

- Some markets, e.g. China, EU, and US, have multiple natural gas supply options. Asia can strengthen LNG supply security by benefiting from flexibility of such markets under their cooperation.
- Is the supply security depending on other counties unstable?
  - Oil market has good examples and records.
  - Important to make energy cooperation as a catalyst to strengthen a regional tie.

❖ **Concept to best utilize flexibility in other gas market**

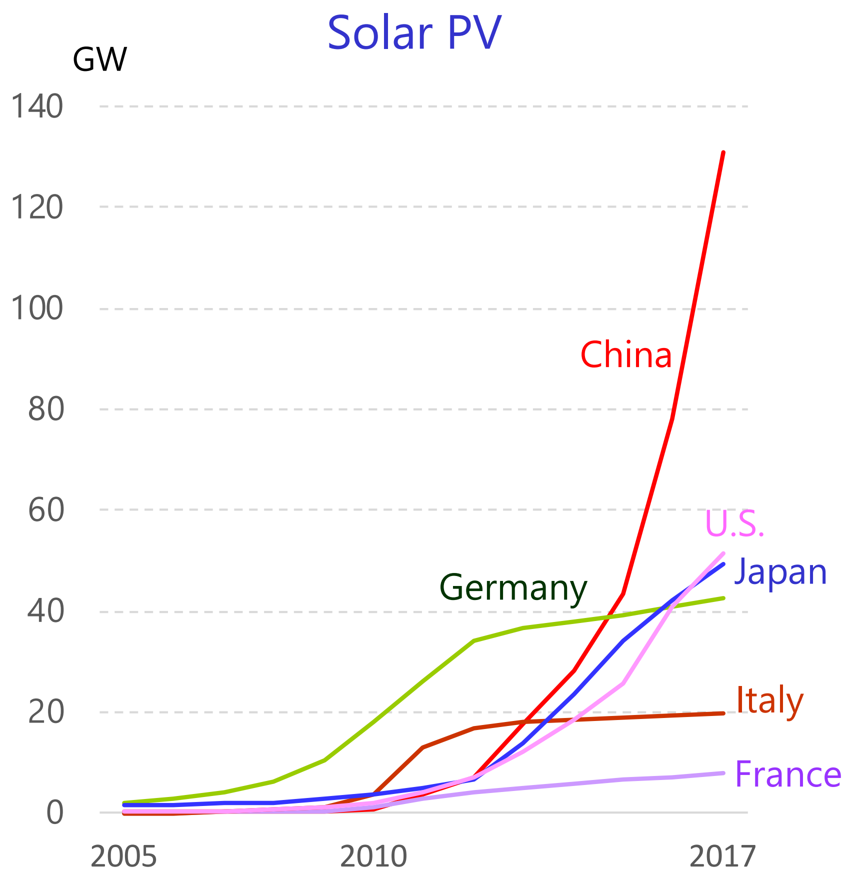


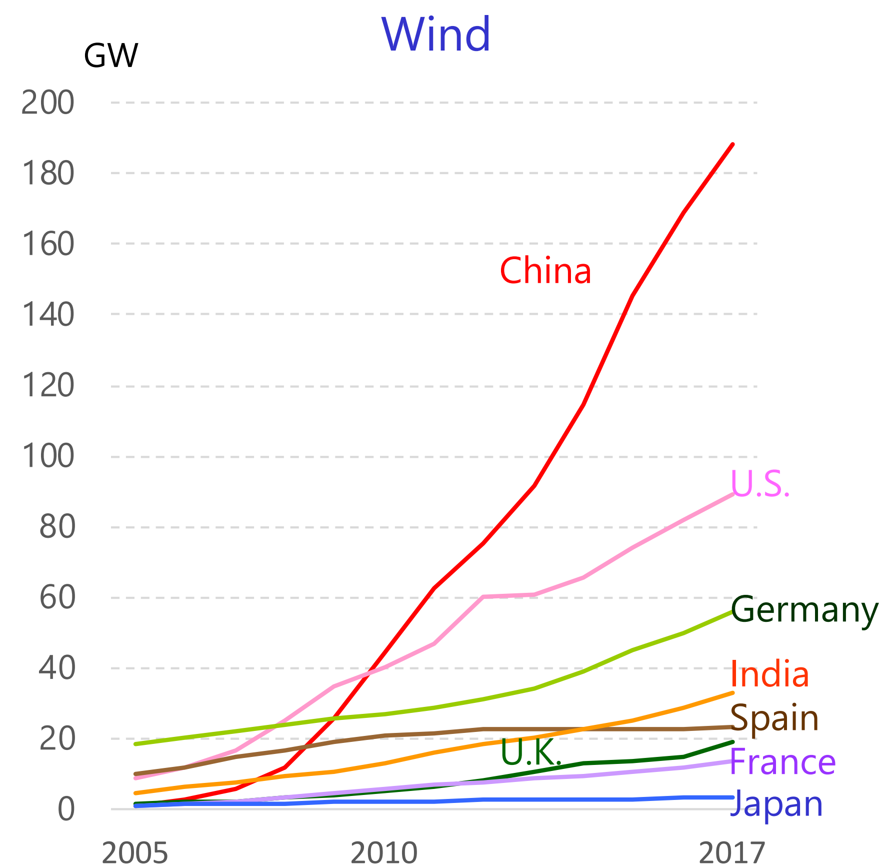
Source: IEEJ

Source: "IEEJ Outlook 2020" (IEEJ, October 2019)

Expanding installed capacity of VREs

Source: IEA



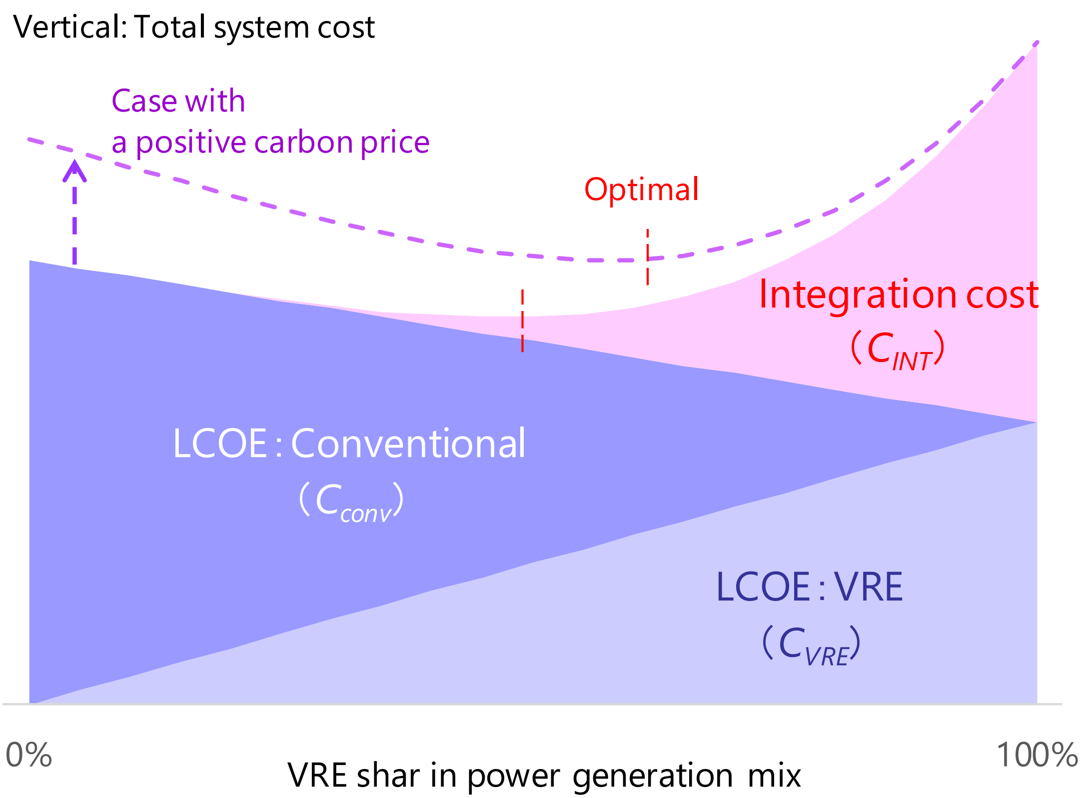


- Recent trends exhibit rapid expansion of the power generating capacities of ***Variable Renewable Energies (VREs)***, such as solar and wind, due to growing concerns over climate change issues and continuous cost declines.

- VREs are expected to continue the rapid expansion in the long-term, although we should anticipate several challenges as stated below.

Source: "IEEJ Outlook 2020" (IEEJ, October 2019)

System integration cost: A conceptual illustration

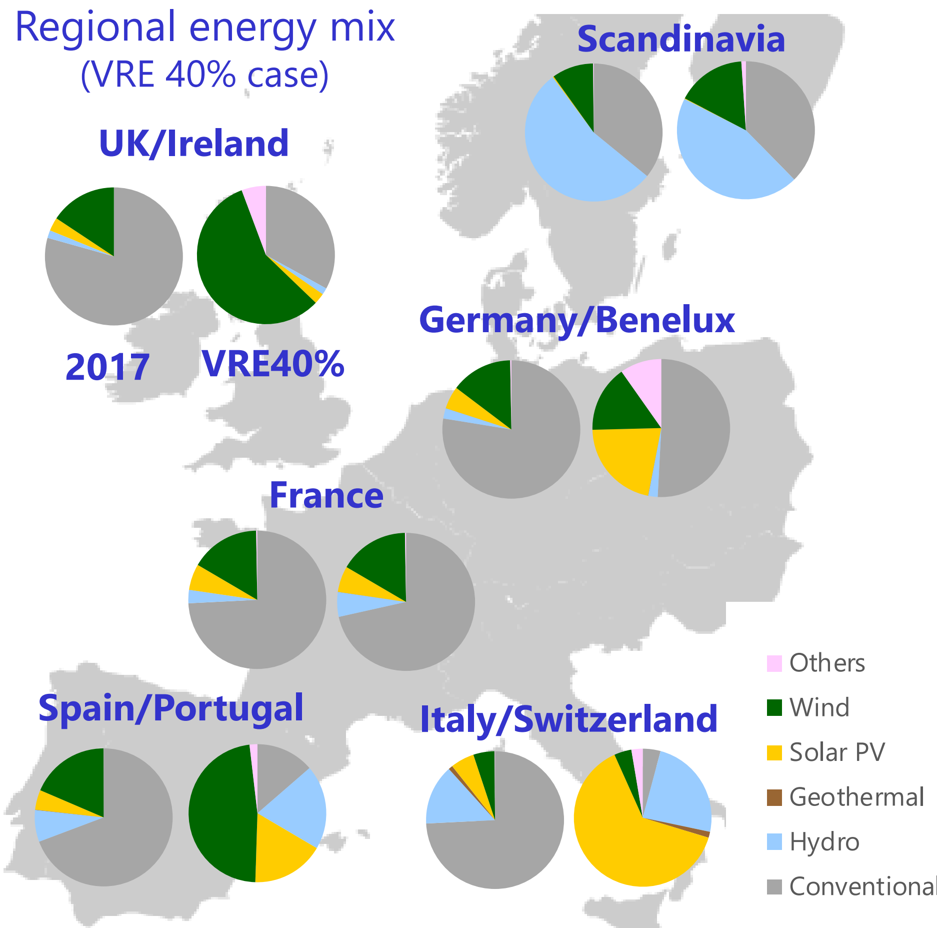


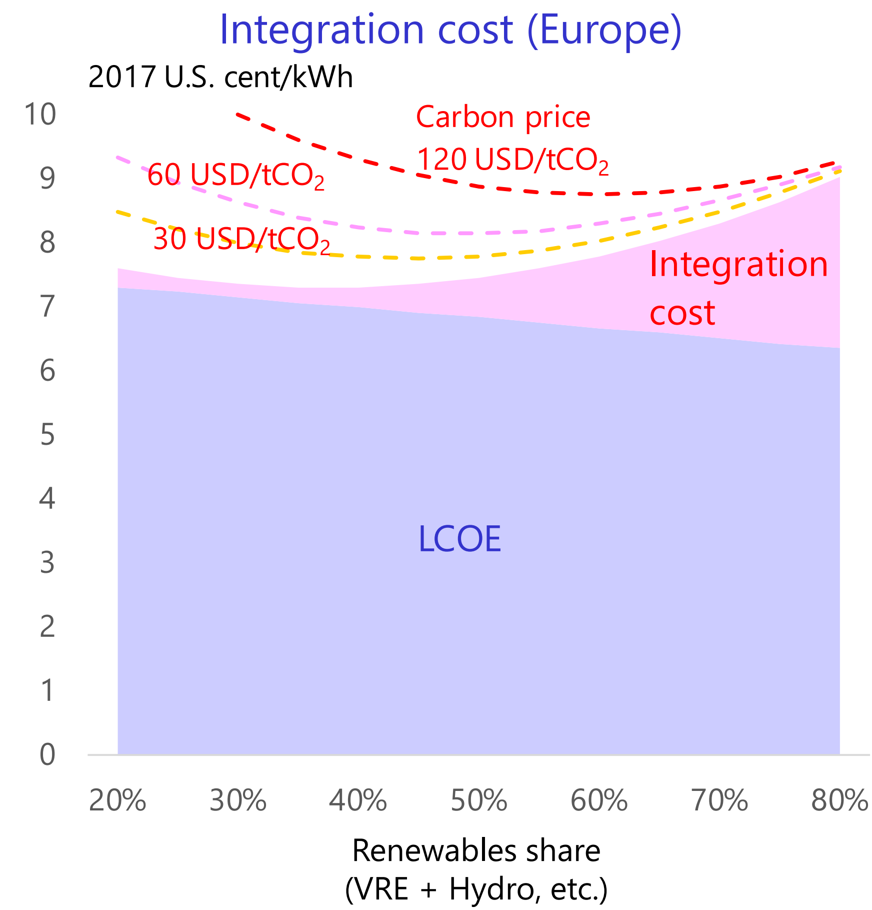
- If the LCOE of VRE is smaller than that of conventional power sources, the “traditional” power generation cost, which represents the costs proportional to the LCOEs, shown as $C_{conv}+C_{VRE}$ in the above figure, declines with increasing share of VRE.

- However, high penetration of VRE requires additional cost related to the necessity of power storage, VRE output curtailment, and grid extension, etc., known as ***system integration costs***, indicated by C_{INT} as illustrated above.

Source: “IEEJ Outlook 2020” (IEEJ, October 2019)

High penetration of renewables in Europe: VRE 40%



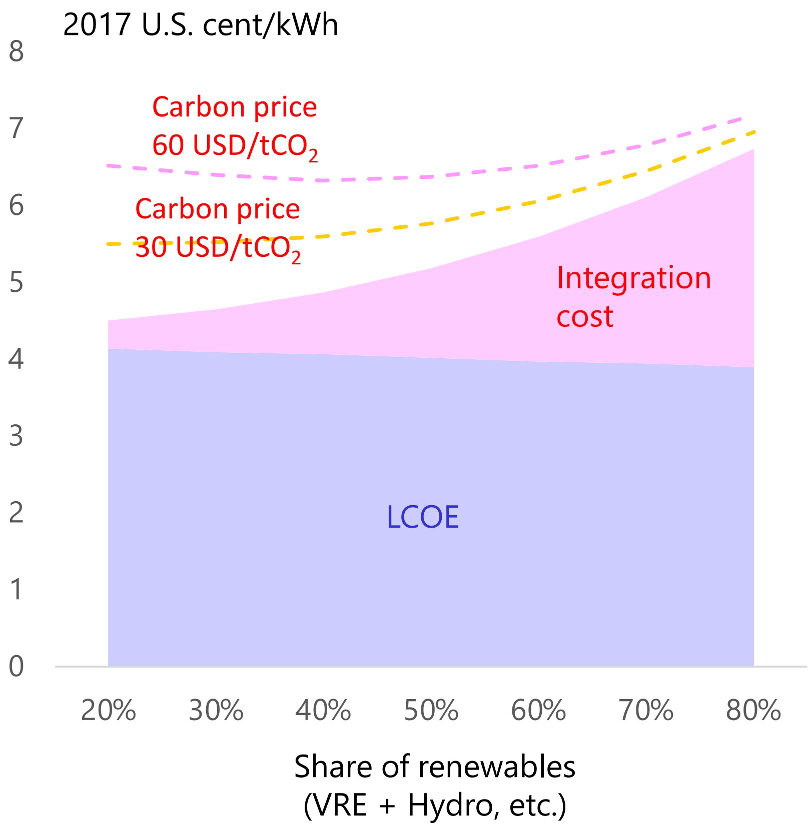


- Renewable energy resources are unevenly distributed also in Europe. Hydropower is utilized largely in Scandinavian countries, while wind power is abundant in UK and in Spain. Italy can take advantage of high solar irradiation.
- The total system cost moderately increases as VRE share rises. In comparison with ASEAN, the optimal share of VRE is higher due to higher costs of conventional technologies, while the effects of carbon prices are smaller because of low carbon intensities.

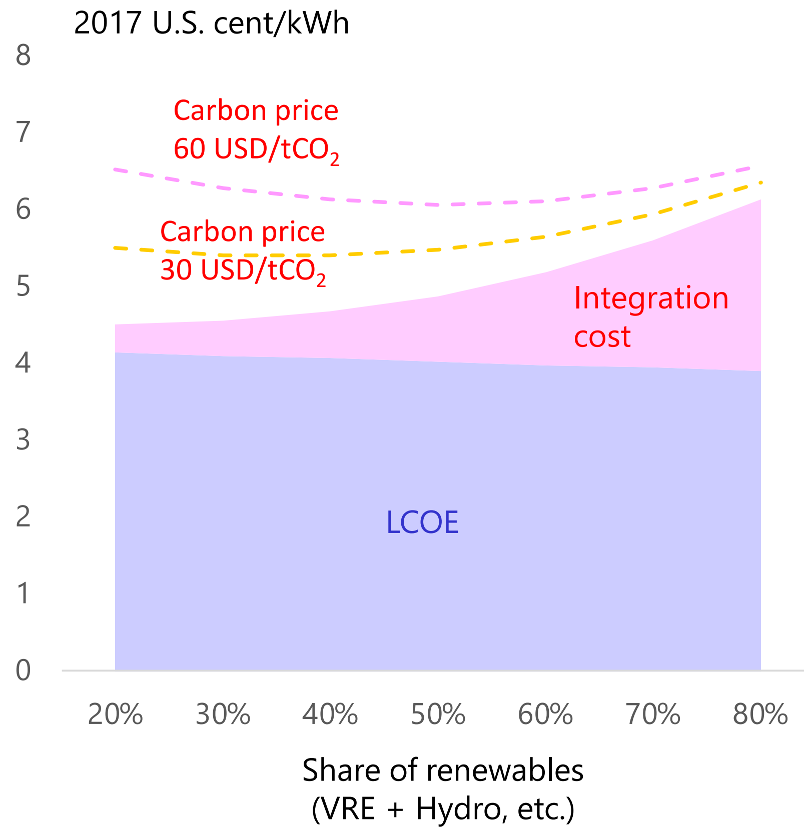
Source: "IEEJ Outlook 2020" (IEEJ, October 2019)

Integration cost with high shares of VRE: ASEAN

Without grid interconnection Hydropower share: 11%



With grid interconnection Hydropower share: 22%



- Integration costs increase along with higher shares of VRE, although the rise can somewhat be mitigated if grid interconnection is implemented, due to efficient use of hydropower potentials that are distributed unevenly across regions.
- ***Strong policy measures need to be implemented*** to cover the cost increases with higher shares of VRE.

Source: "IEEJ Outlook 2020" (IEEJ, October 2019)

Challenges related to higher penetration of VRE

1. "Cannibalization" effect: Decline in market values

Once VRE power generating facilities are deployed, they produce electricity with very small marginal costs. This results in very low wholesale electricity prices, which undermines the "values" of the VRE facilities.

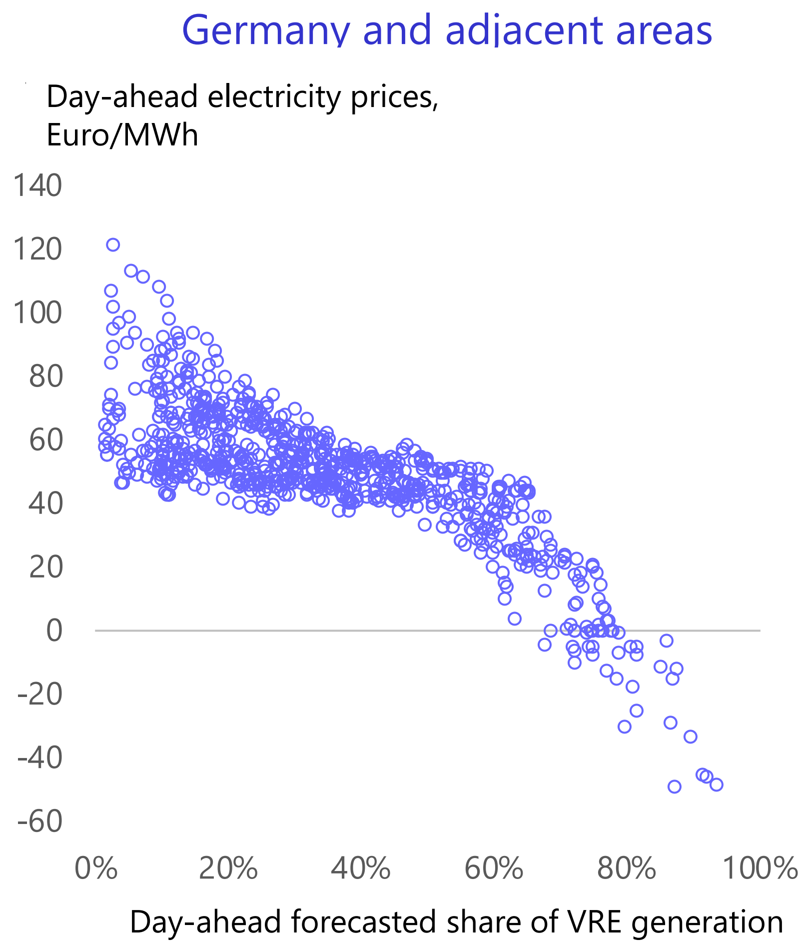
2. Supply disruption due to extreme weather conditions

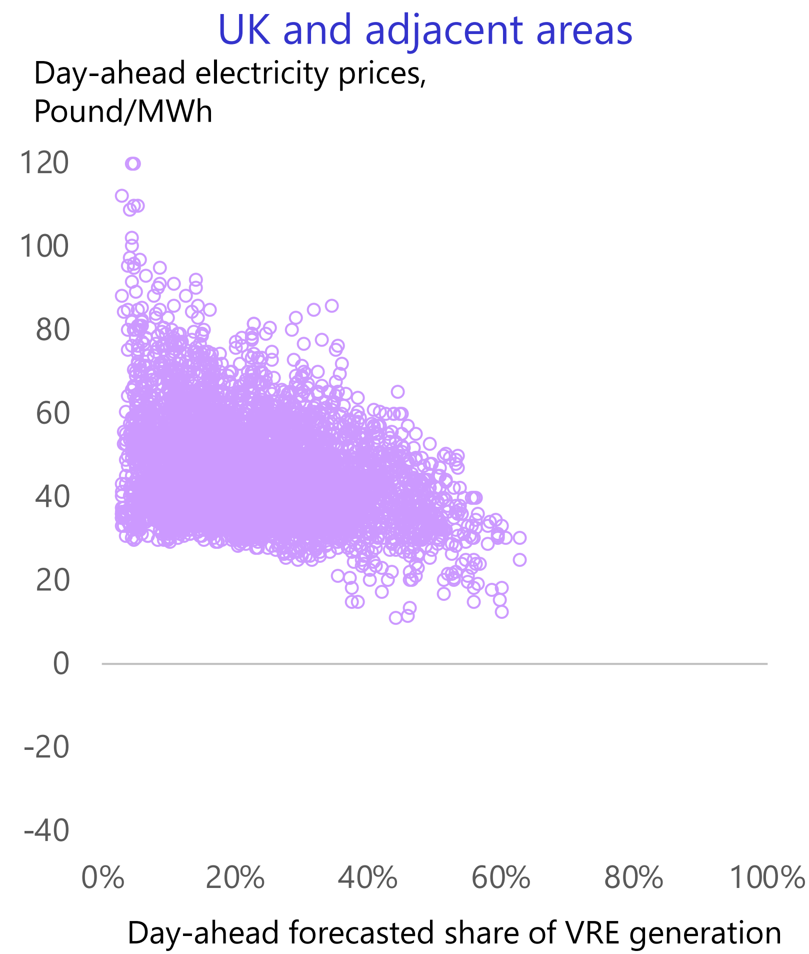
VRE outputs, as well as hydropower outputs, vary significantly depending on meteorological conditions in the short-, mid- and long-term.

The risk of supply disruption due to long-term fluctuations with extreme weather conditions is one of the major challenges with very high shares of renewable energies.

Source: "IEEJ Outlook 2020" (IEEJ, October 2019)

Declines in market values of VRE: Actual data for the period from Jan. to Jul. 2019





Source: Entso-E Transparency Platform

- Historical data exhibit low electricity prices with large VRE outputs.
- The prices can take negative values in Germany, when the VRE share exceeds 80%.

No “Silver Bullet” energy option

Oil
- Convenience, competitiveness in transport, etc.
- Middle East dependence, CO_2 emission, etc.

Gas
- Clean fuel, supply stability, etc.
- Price competitiveness, etc.

Coal
- Supply stability, price competitiveness
- CO_2 emission, air pollution, etc.

Renewable energy
- Domestic energy, CO_2 free, etc.
- Higher costs, supply intermittency, etc.

Nuclear
- Quasi domestic energy, CO_2 free, baseload power
- Safety concern, PA, etc.

Energy saving/efficiency
- Contribution to ３E+S
- Economic burden in case of excessive push for saving

Reference material

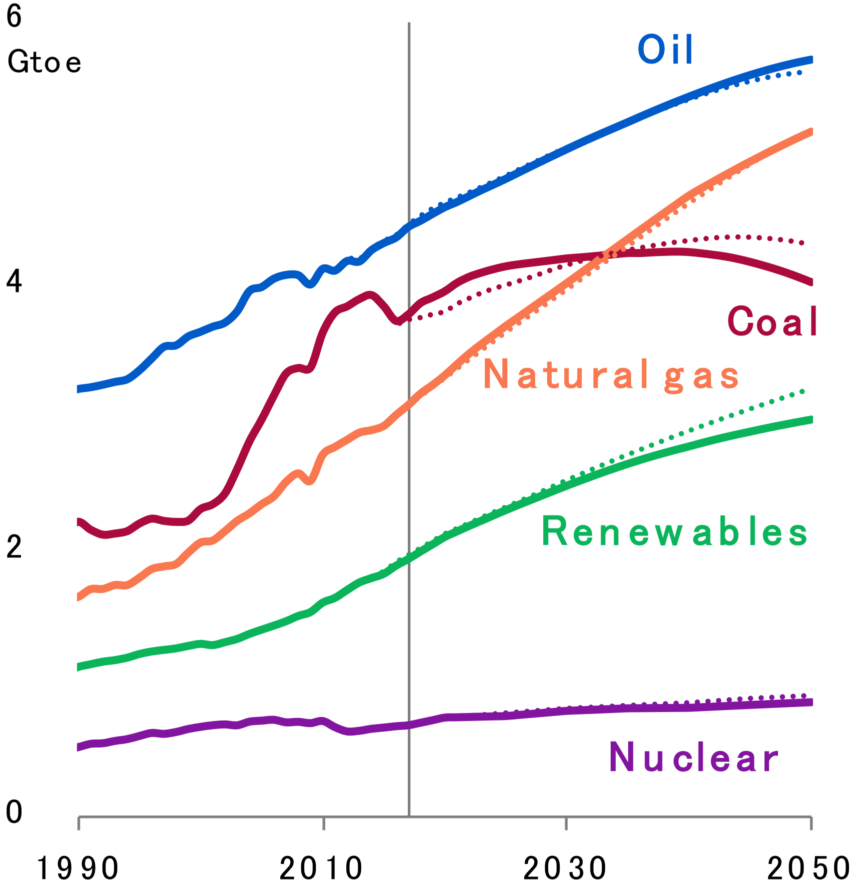
Examples of technology assumptions

		2017	2050 Reference	2050 Advanced Technologies	Assumptions for Advanced Technologies Scenario
Improving energy efficiency					
Industry	Intensity in steel industry (ktoe/kt)	0.284	0.250	0.220	100% penetration of Best Available Technology by 2050.
	Intensity in non-metallic minerals industry	0.092	0.066	0.058	
Transport	Electrified vehicle share in passenger car sales	3%	56%	86%	Cost reduction of electrified vehicles. Promotion measures including fuel supply infrastructure. *electrified vehicle includes hybrid vehicle, plug-in hybrid vehicle, electric vehicle and fuel-cell vehicle
	Average fuel efficiency in new passenger car (km/L)	14.1	23.9	33.8	
Buildings	Residential total efficiency (Y2017=100)	100	154	188	Efficiency improvement at twice the speed for newly installed appliance, equipment and insulation.
	Commercial total efficiency	100	186	220	Electrification in space heating, water heater and cooking (clean cooking in developing regions).
Power	Thermal generation efficiency (Power transmission end)	38%	46%	47%	Financial scheme for initial investment in high-efficient thermal power plant.
Penetrating low-carbon technology					
Biofuels for transport (Mtoe)		84	128	253	Development of next generation biofuel with cost reduction. Relating to agricultural policy in developing regions.
Nuclear power generation capacity (GW)		409	480	717	Appropriate price in wholesale electricity market. Framework for financing initial investment in developing regions.
Wind power generation capacity (GW)		515	1,810	3,065	Further reduction of generation cost. Cost reduction of grid stabilization technology. Efficient operation of power system.
Solar PV power generation capacity		386	2,954	4,434	
Thermal power generation capacity with CCS (GW)		0	0	1,270	Installing CCS after 2030 (regions which have storage potential except for aquifer).
Zero-emission generation ratio (incl. CCS)		35%	41%	79%	Efficient operation of power system including international power grid.

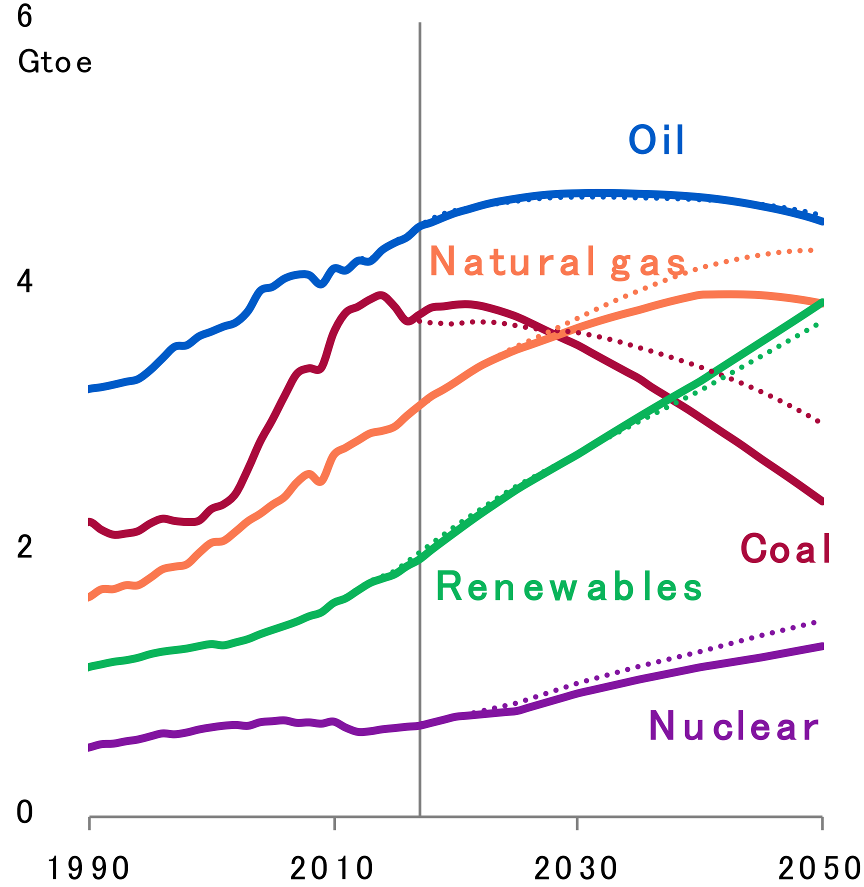
Reference material

Comparison with IEEJ Outlook 2019

❖ Reference Scenario



❖ Advanced Technologies Scenario

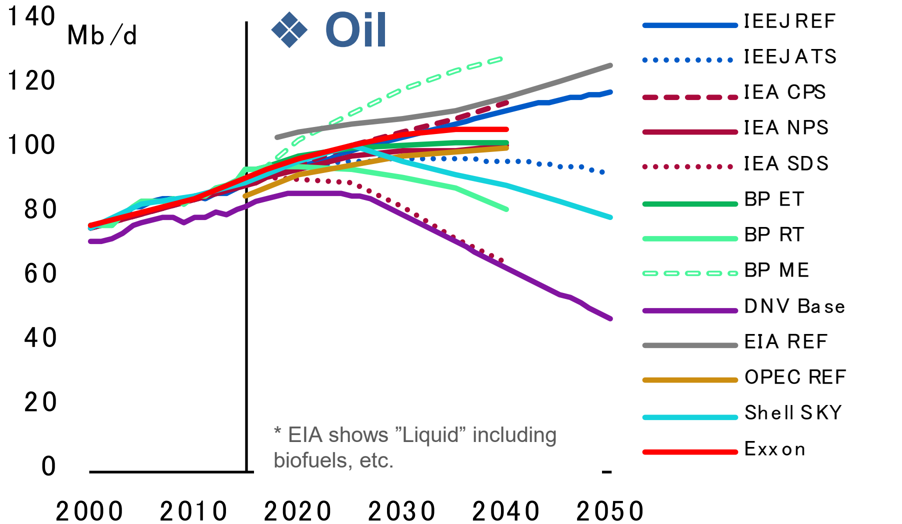


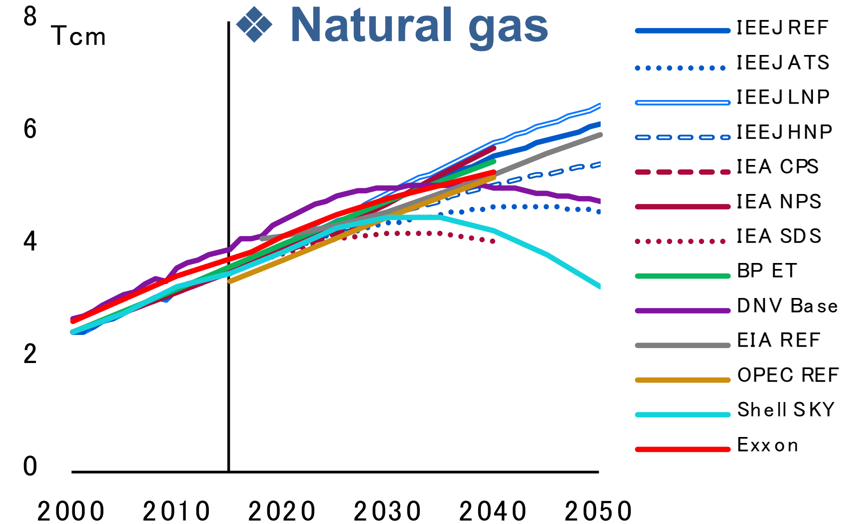
* Primary energy demand
Solid lines: IEEJ Outlook 2020
Dotted lines: IEEJ Outlook 2019

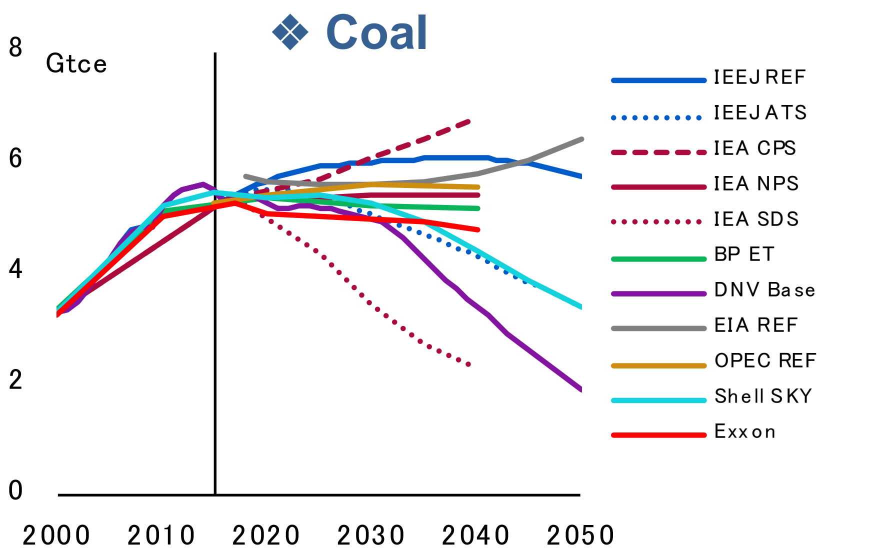
Source: "IEEJ Outlook 2020" (IEEJ, October 2019)

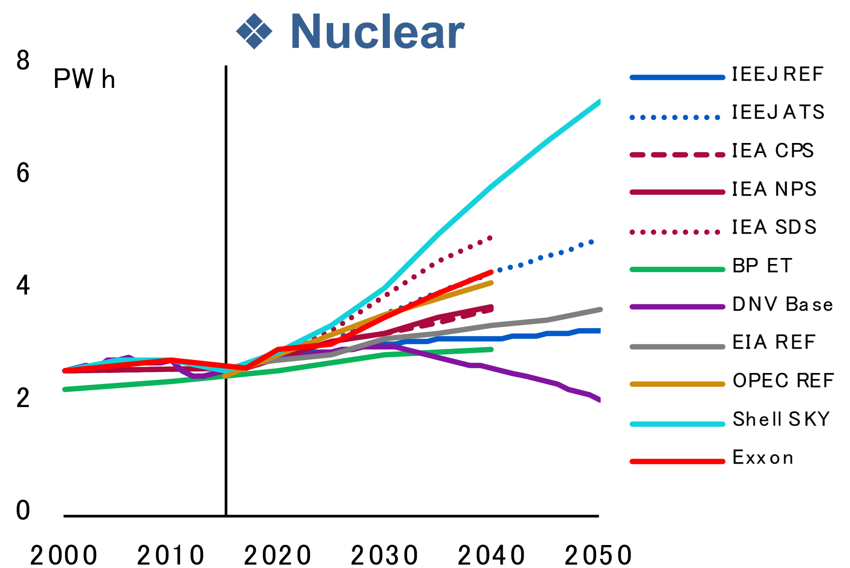
Reference material

Comparison with other outlooks (1)





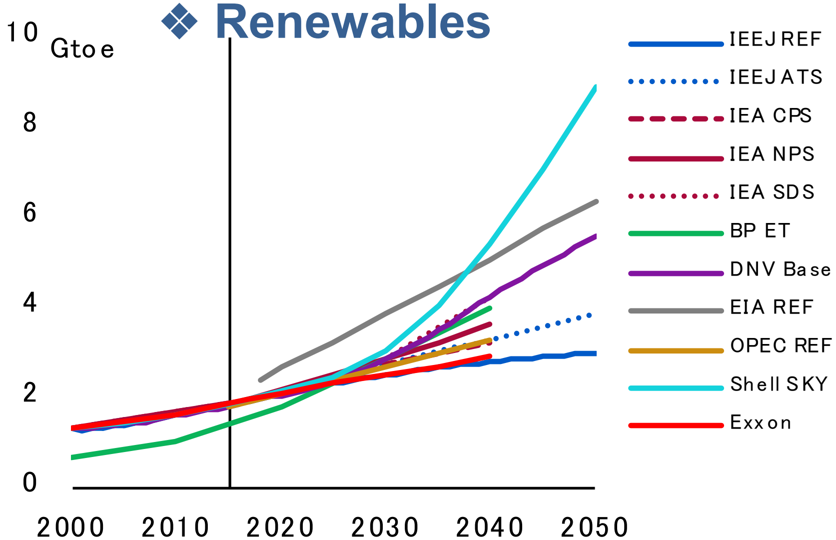




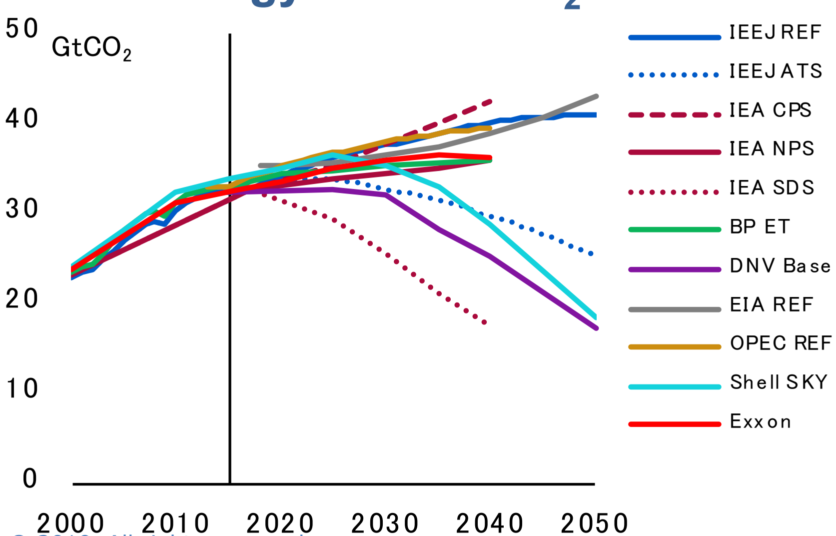
Source: "IEEJ Outlook 2020" (IEEJ, October 2019)

Comparison with other outlooks (2)

❖ Renewables



❖ Energy-related CO_2



Source

IEEJ "IEEJ Outlook 2020", Oct. 2019
- REF: Reference Scenario
- ATS: Advanced Technologies Scenario
- LNP: Low Price Case
- HNP: High Price Case

IEA "World Energy Outlook 2018", Nov. 2018
- CPS: Current Policies Scenario
- NPS: New Policies Scenario
- SDS: Sustainable Development Scenario

BP "BP Energy Outlook 2019", Feb. 2019
- ET: Evolving transition
- RT: Rapid transition demand
- ME: More energy demand

DNV GL "Energy Transition Outlook 2019", Sep. 2019
- Base: Base Scenario

US EIA "International Energy Outlook 2019", Sep. 2019
- REF: Reference Scenario

OPEC "World Oil Outlook 2040", Oct. 2018
- REF: Reference Scenario

Shell "Shell Scenarios", May 2018
- SKY: Sky Scenario

ExxonMobil "Outlook for Energy", Aug. 2019

Source: "IEEJ Outlook 2020" (IEEJ, October 2019)

Reference material

IEE JAPAN

Innovative Technology for ultra long-term

Technologies		Description	Challenges
Technologies to reduce CO_2 emissions	Next Generation Nuclear Reactors	Fourth-generation nuclear reactors such as ultra-high-temperature gas-cooled reactors (HTGR) and fast reactors, and small- and medium-sized reactors are now being developed internationally.	Expansion of R&D support for next generation reactors
	Nuclear fusion reactor	Technology to extract energy just like the sun by nuclear fusion of small mass number such as hydrogen. Deuterium as fuel exists abundantly and universally. Spent nuclear fuel as high-level radioactive waste is not produced.	Technologies for continuously nuclear fusion and confining them in a certain space, energy balance, cost reduction, financing for large-scale development and establishment of international cooperation system, etc.
	Space Photovoltaic Satellite (SPS)	Technologies for solar PV power generation in space where sunlight rings abundantly above than on the ground and transmitting generated electricity to the earth wirelessly via microwave, etc.	Establishment of wireless energy transfer technology, reduction of cost of carrying construction materials to space, etc.
Technologies to sequestrate CO_2 or to remove CO_2 from the atmosphere	**Hydrogen production and usage**	Production of **carbon-free hydrogen** by steam reforming of fossil fuels and by CCS implementation of CO_2 generated.	Cost reduction of hydrogen production (**fossil and RE basis**), efficiency improvement, infrastructure development (**#1&2 Hydrogen Energy Ministerial Meeting/Tokyo Statement**), etc.
	CO_2 sequestration and usage (**carbon recycling**)	Produce carbon compounds to be chemical raw materials, etc. using CO_2 as feedstocks by electrochemical method, photochemical method, biochemical method, or thermochemical method. **CO_2 can be removed from the atmosphere**.	Dramatic improvement in quantity and efficiency, etc. (**International Conference on Carbon Recycling**).
	Bio-energy with carbon capture and storage (BECCS)	Absorption of carbon from the atmosphere by photosynthesis with biological process and CCS.	It requires large-scale land and may affect land area available for the production of food etc.

Source: "IEEJ Outlook 2020" (IEEJ, October 2019)

Reference material

Example of attempts to refine the damage function

Spatial distribution of projected damages

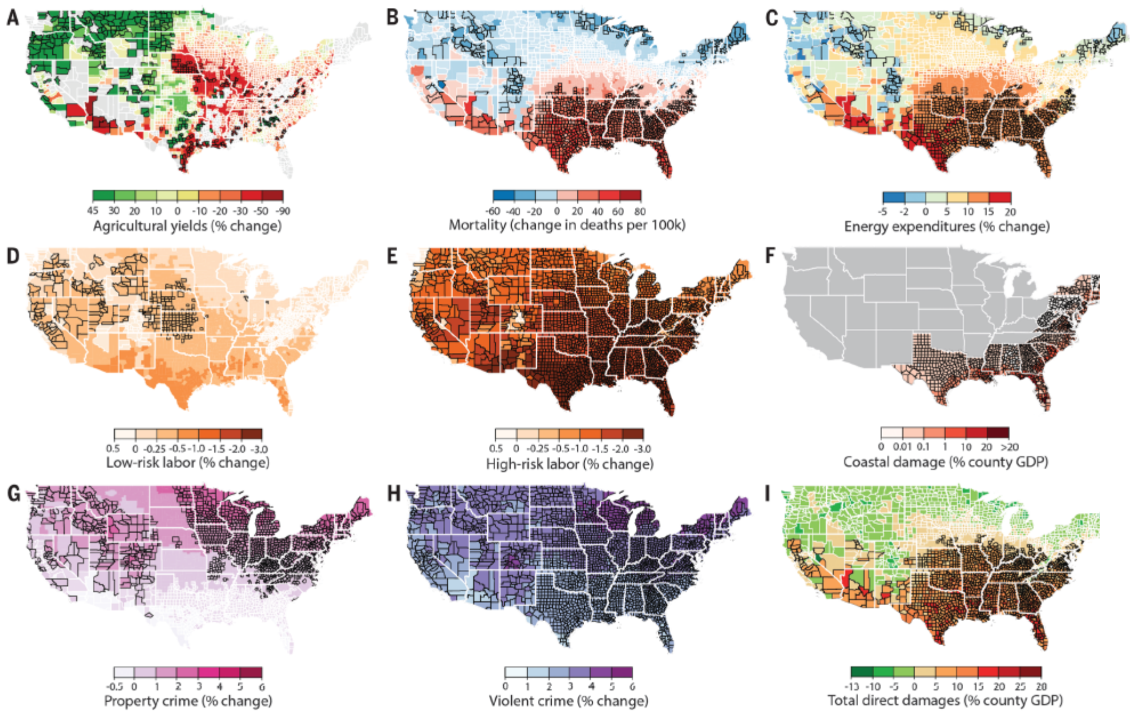
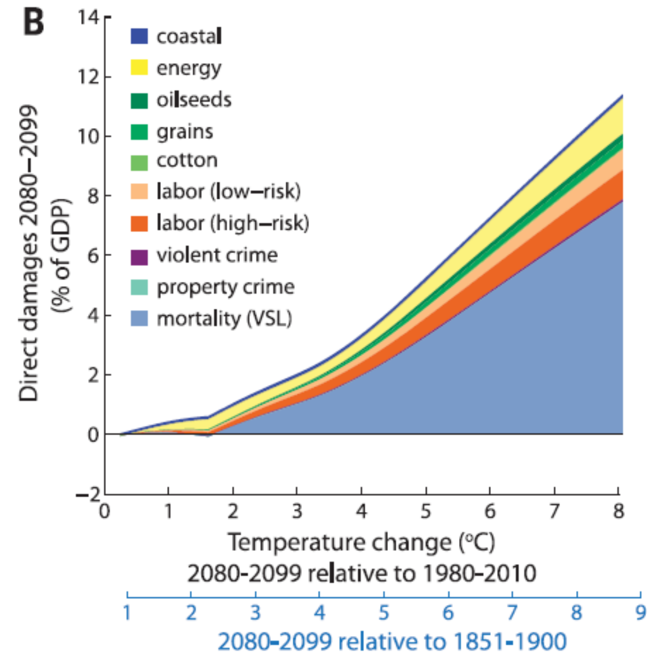


Fig. 2. Spatial distributions of projected damages. County-level median values for average 2080 to 2099 RCP8.5 impacts. Impacts are changes relative to counterfactual "no additional climate change" trajectories. Color indicates magnitude of impact in median projection; outline color indicates level of agreement across projections (thin white outline, inner 66% of projections disagree in sign; no outline, ≥83% of projections agree in sign; black outline, ≥95% agree in sign; thick white outline, state borders; maps without outlines shown in fig. S2). Negative damages indicate economic gains. (**A**) Percent change in yields, area-weighted average for maize, wheat, soybeans, and cotton. (**B**) Change in all-cause mortality rates, across all age groups. (**C**) Change in electricity demand. (**D**) Change in labor supply of full-time-equivalent workers for low-risk jobs where workers are minimally exposed to outdoor temperature. (**E**) Same as (D), except for high-risk jobs where workers are heavily exposed to outdoor temperatures. (**F**) Change in damages from coastal storms. (**G**) Change in property-crime rates. (**H**) Change in violent-crime rates. (**I**) Median total direct economic damage across all sectors [(A) to (H)].

Total damage (as a percentage of GDP)

About 2 to 3% at 4 °C
and about 10 to 11% at 8 °C



- The efforts to refine the damage function are being promoted in the United States, although the sophisticated results do not always differ significantly from previous estimations.

Hsiang et al., 2017. Estimating economic damage from climate change in the United States. *Science*, 356, 1362-1369.

Source: "IEEJ Outlook 2020" (IEEJ, October 2019)

Reference material

Estimation of integrated costs: Cases of Europe and ASEAN

Methodology

- Simulates electricity supply and demand for 2050 with hourly time resolution (24 hours×365 days = 8,760 time slices) based on historical data for 2014.
- Calculates supply-demand balances for the year, also estimating the required investments, using the Linear Programming method.
- Considers the costs of power storage systems, interregional transmission lines, VRE output curtailment, declines in the load factors of conventional power generating facilities, and the load frequency control (LFC) constraints.
- Possibly underestimates the total costs, without some elements being considered explicitly: Increases in the start and stop numbers of thermal facilities, declines in the efficiencies due to partial load operation, and the inertia of the power systems.
- Considers batteries and pumped hydro power generation as electricity storage systems, additionally estimating the use of hydrogen storage.

Batteries: Assumes that the average cost declines to USD 80/kWh by 2050.

Hydrogen storage: Although the costs of storage facilities (hydrogen tanks) are much cheaper than batteries at USD 13/kWh, additional expenses are required for electrolysis, etc.

Regional divisions

- Europe: 6 subregions, ASEAN: 10 countries

Source: "IEEJ Outlook 2020" (IEEJ, October 2019)

Reference material

Breakdown of the integration cost

1. Balancing cost

・ Costs related to the uncertainty of power generation due to unforeseen plant outages or forecasting errors.

2. Grid-related cost

・ Costs related to locational constraints, which can be further divided into two categories: grid reinforcement costs and connection costs.

3. Profile cost

・ Costs related to the temporal variability of power generation,

3-1. Adequacy cost / Backup cost

3-2. Overproducion cost

3-3. Full-load hour reduction

3-4. Flexibility effect

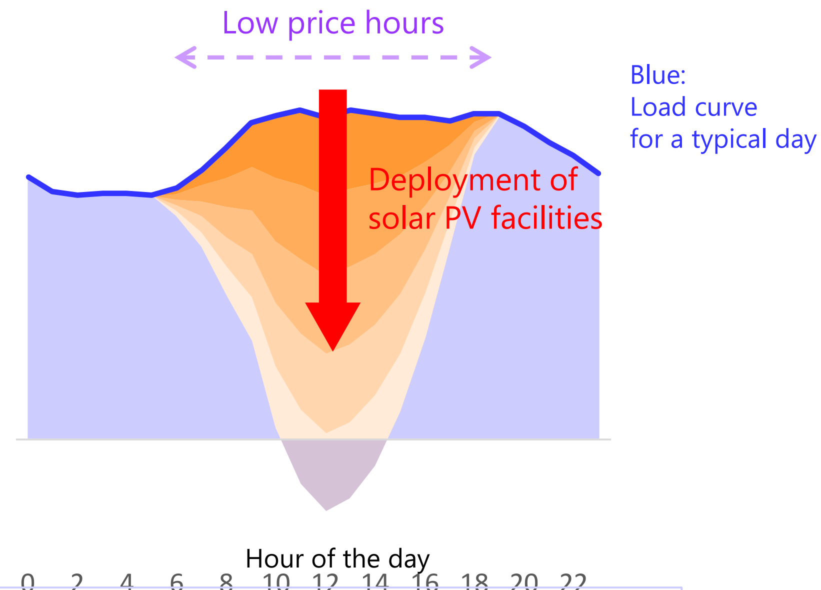
Sources: Ueckerdt F. et al., 2013. System LCOE: What are the costs of variable renewables?, *Energy*, 63, pp.61-75.
OECD/NEA, 2018. *The full costs of electricity provision*.

Challenges for high penetration of VRE (1) Cannibalization effect

◎ With large deployment of solar PV power generating facilities, …

→ Massive electricity is supplied with very low marginal costs, during the daytime on a sunny day.

→ Wholesale electricity prices take very low values during those hours.



Under such situations, ….

Solar PV power facilities:

- Generate electricity only during low-price hours.

  → ***"Market values" of solar power facilities decline significantly*** in line with solar power deployment.

- If the "value" falls below the LCOE, further deployment of solar PV facilities becomes difficult.

Conventional power facilities:

- Generate electricity during higher price hours as well.

  → Limited declines in market values.

- However, ***recovering the initial costs becomes more difficult*** due to lower wholesale market prices.

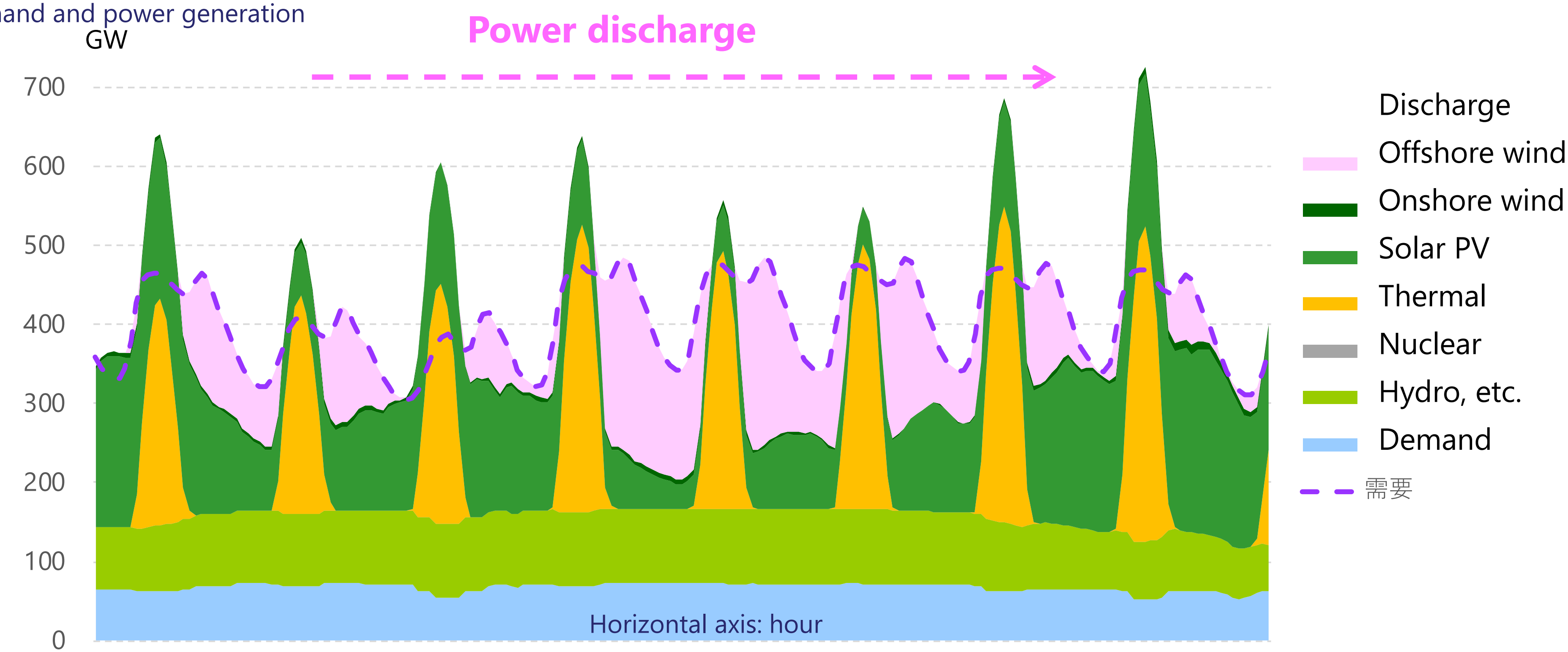
- Similar situations take place, although in a somewhat milder manner, also for large deployment of wind power facilities.

Source: "IEEJ Outlook 2020" (IEEJ, October 2019)

Reference material

Challenges for high penetration of VRE (2) "Windless" periods

Vertical axis:
Demand and power generation



・ ***Windless (and sunless) periods***, also known as ***dark doldrums***, in which wind and solar power output is exceptionally small, can take place once or twice in a year. The above figure illustrates an extreme case with zero thermal power generation during these periods, in which massive power discharge is required to meet the demand.

・ To achieve very high shares of VRE, it would be required to assess the largest risks related to supply disruptions during windless periods, using multiannual meteorological data, and to implement energy storage capacities large enough to meet electricity demands.

Source: "IEEJ Outlook 2020" (IEEJ, October 2019)