421st Forum on Research Works

Asia/World Energy Outlook 2015

– Analyses of oil pricing and climate change measures under new circumstances –

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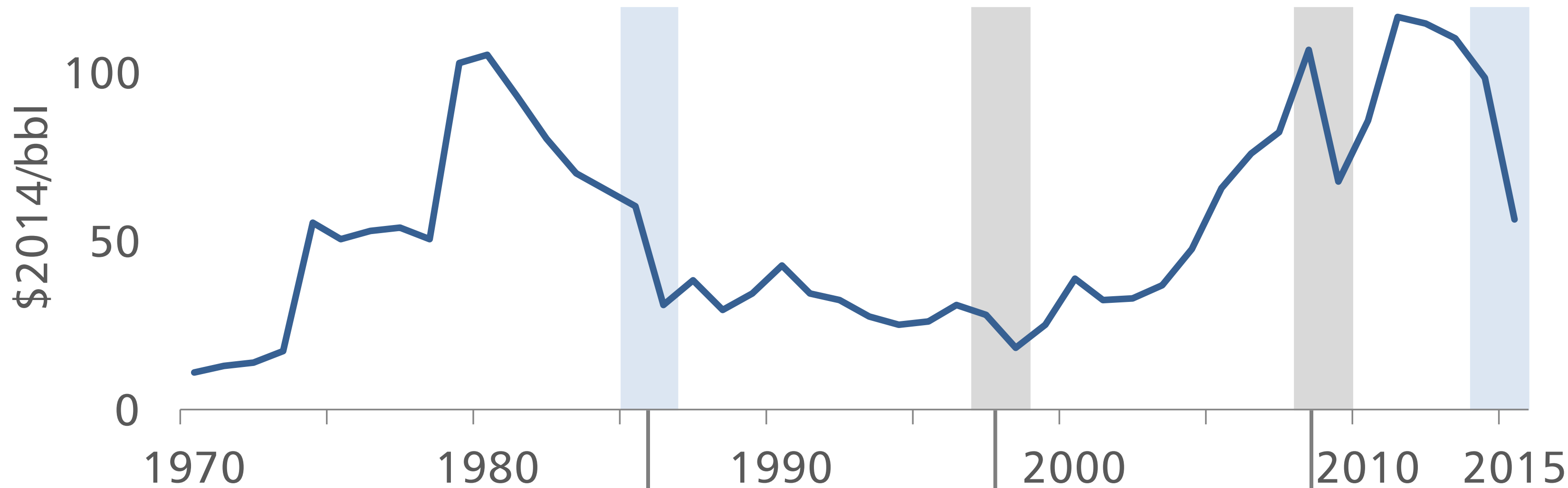
"History doesn't repeat itself, but it does rhyme" Mark Twain

❖ Oil price



Source: BP

- Decreases in demand and increases in supply by non-OPEC countries following high price after the oil crises
- Severer competition in OPEC
- Easy supply-demand balance affected by the Netback pricing

- Decreases in emerging economies' demand on the Asian financial crisis
- Expansion of OPEC production quota and excess production by the members over their quota

- Sharp drop of demand on the Lehman shock
- Expansion of production capacity by Saudi Arabia and others

- Increases in supply by non-OPEC and OPEC countries
- Slow growth of global demand

Various factors involve oil price

❖ Factors related with oil price

Supply
- OPEC's policy
- Fiscal break-even price
- OPEC's spare capacity
- Increases in production of unconventional oil

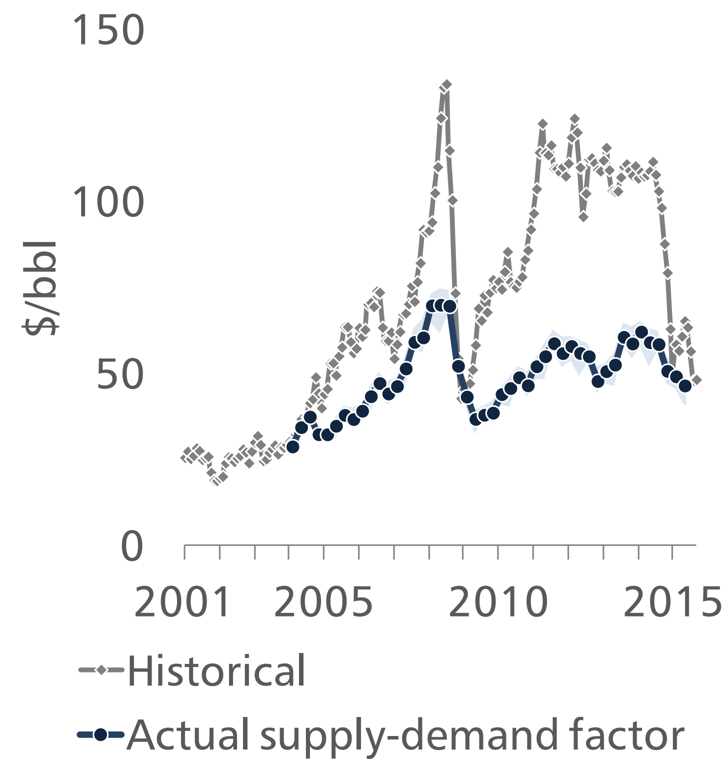
Demand
- Economic growth
- Stock in developed countries
- Oil use policy in developing countries
- Car ownership and fuel economy

Expectation in market

Money
- Stock prices and exchange rates
- Expected inflation
- Money supply
- Risk appetite
- New investment commodity and technology

Risk
- Political situation in producing countries
- Foreign policy
- Terror acts on related facilities
- Unusual weather, disasters and accidents
- Strikes, etc.

❖ Historical and actual supply-demand factor prices



Oil price is found by expectation in the futures market affected by supply and demand, risk and money.

Oil price was much higher than what was indicated by actual supply-demand factor.

Highlights

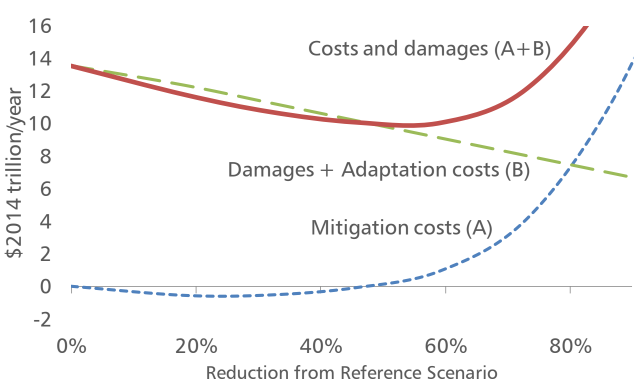
❖ Outlook for World/Asia energy and measures against climate change

- Global energy demand continues to increase led by Asian emerging economies, etc.
- Huge effect is expected by energy conservation and mitigating climate change measures. The target of halving CO_2 emissions by 2050, however, is hardly progressing.
- Mitigating measures expected from major emitters' INDCs very likely fail to sufficiently reduce GHG emissions.
- Balancing among mitigation, adaptation and damage and assessing various emission reduction trajectories with a long-term view are essential.

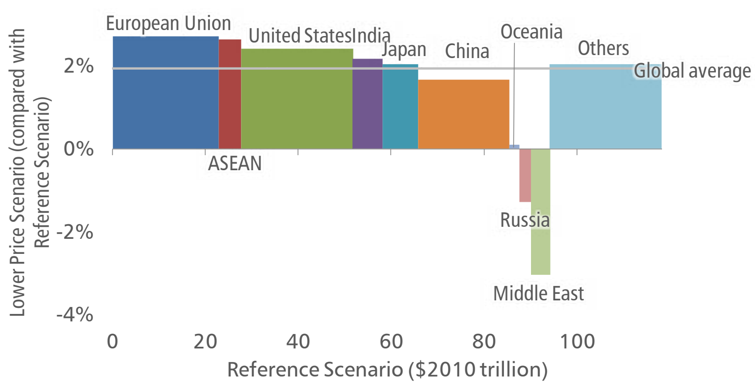
❖ Analysis of lower prices by easy energy supply and demand balance

- Production of the Middle East grows by only 1.0 Mb/d if development of unconventional resources, strong energy conservation and decarbonisation progress simultaneously.
- While lower prices are a great boon to energy importing countries, exporters will inevitably face damage unless they reform the current economic structure.
- There is risk of supply-demand imbalance in the future due to the absence of proper investment under extreme unstable prices.
- Dialogue and cooperation between producers and consumers and among consumers themselves play a important role.

❖ Mitigation and adaptation costs and damage [2100]



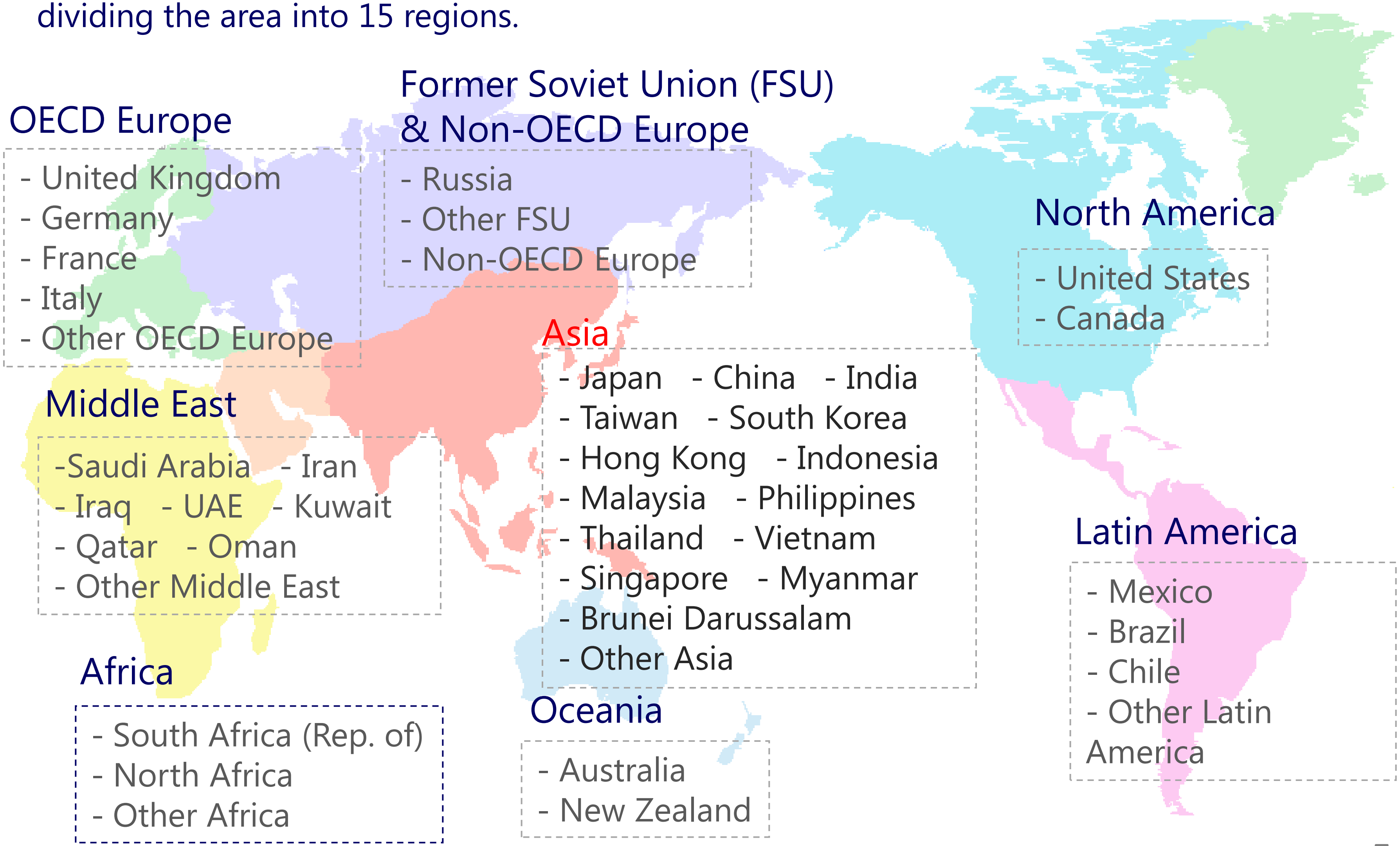
❖ Economic impact of lower prices [2030]



Asia/World Energy Outlook through 2040

Geological Coverage

- The world is geographically divided into 42 regions.
- Especially the Asian energy supply/demand structure is considered in detail, dividing the area into 15 regions.



Modeling Framework

Major assumptions

GDP, Population, Energy prices, Exchange rates, Global 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 forecast future energy supply and demand by regression analysis of historical trends based on the energy balance tables data of the International Energy Agency (IEA).
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.

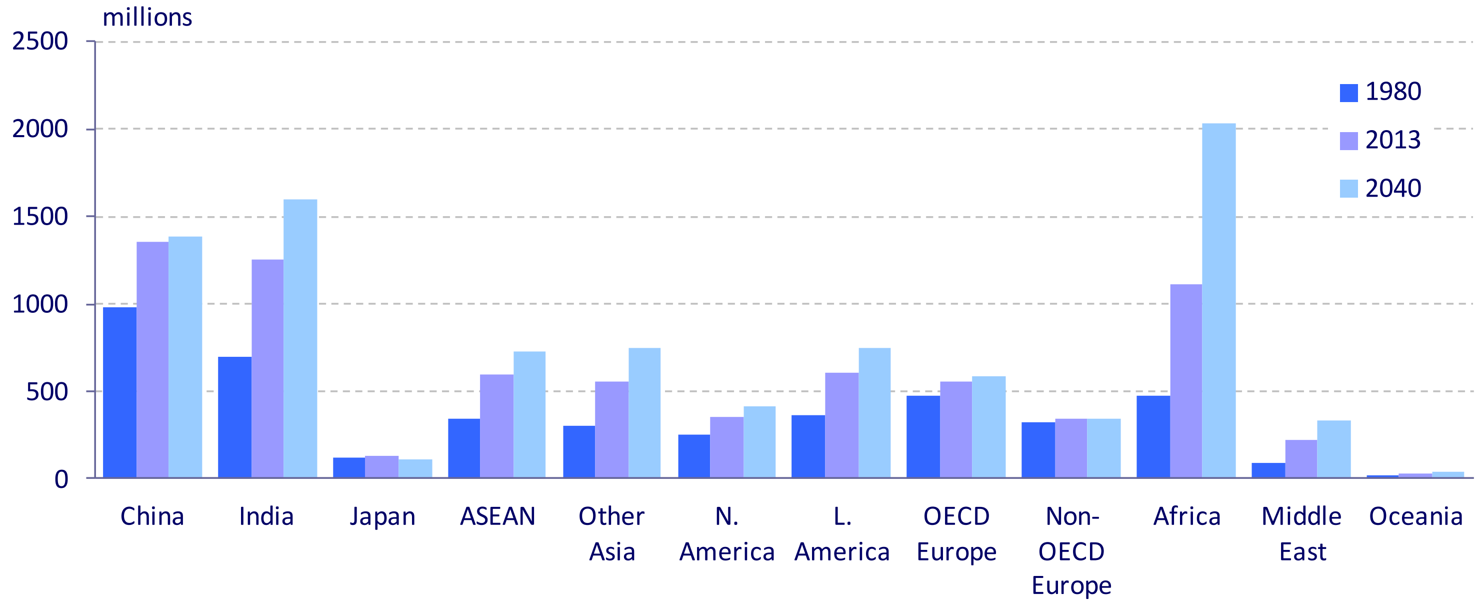
Computable general equilibrium model

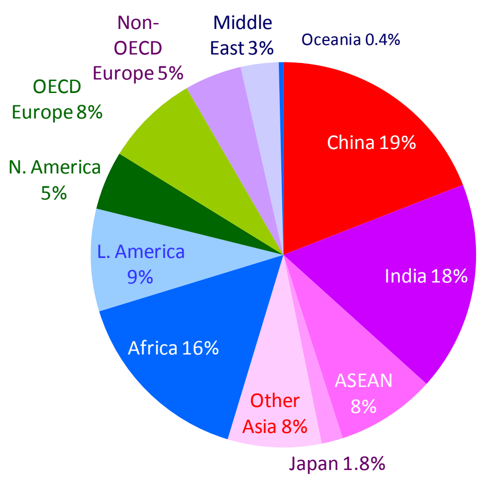
Estimate the economic impacts induced by the changes in energy supply and demand, based on input-output data.

Climate change model

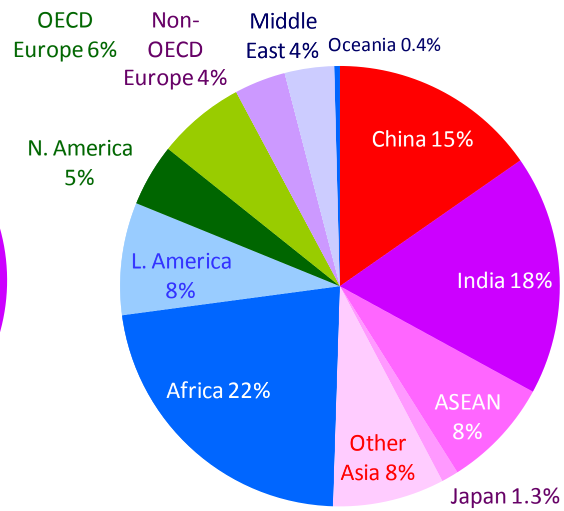
Calculate future GHG concentration in the atmosphere, temperature rise, damage caused by climate change, etc.

Major Assumptions: Population





2013：7.1 billion

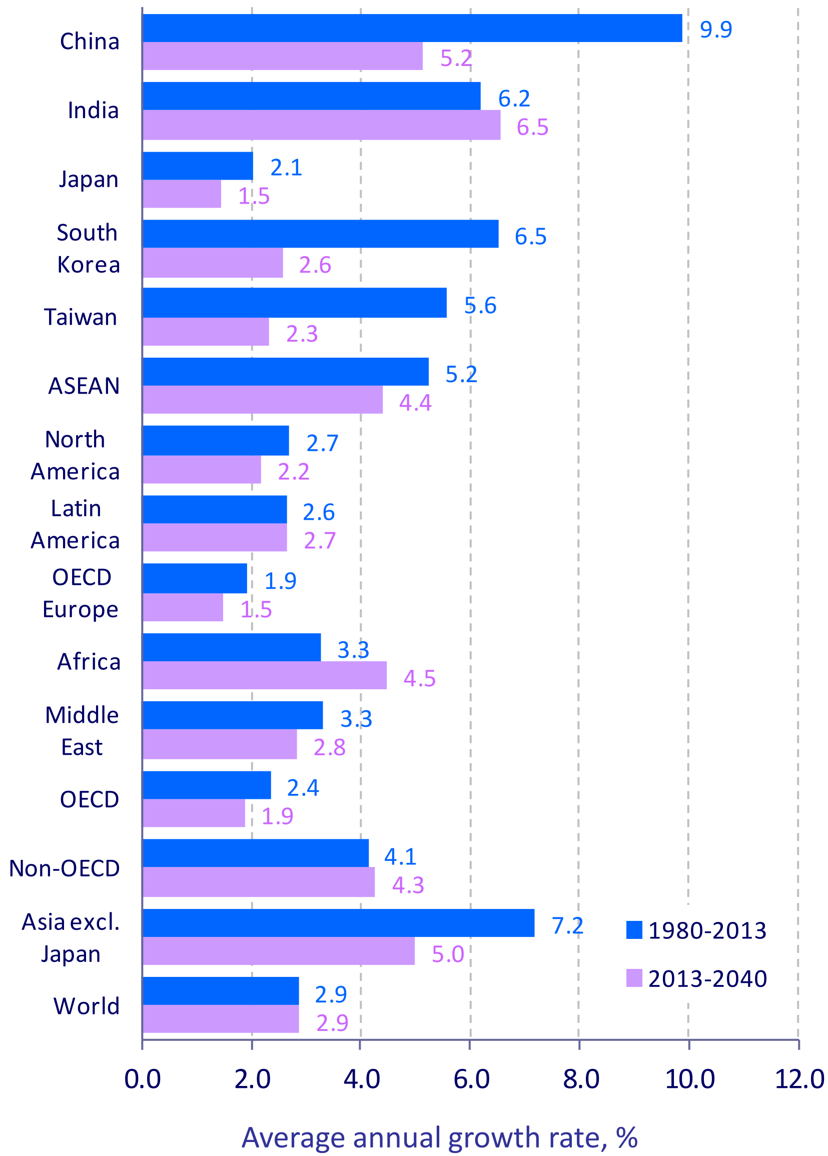


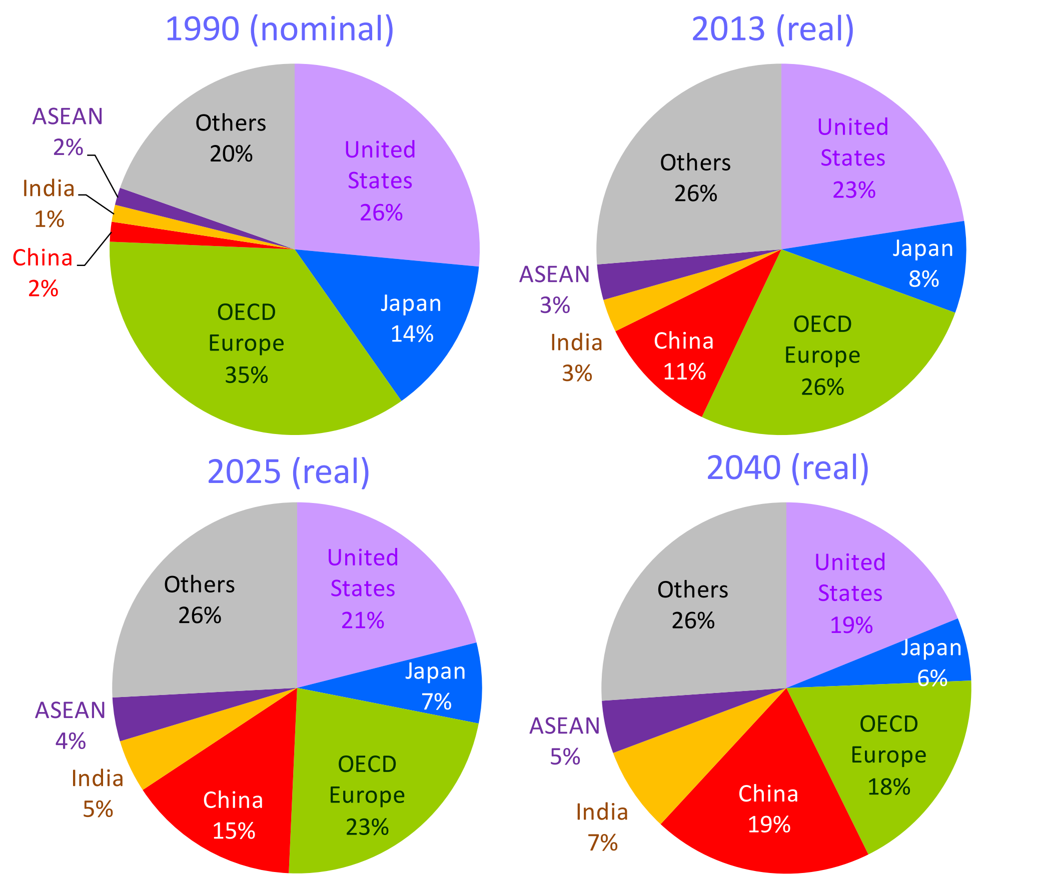
2040：9.1 billon

- Population is expected to increase mainly in developing (non-OECD) countries.
- China's population gradually ages and peaks out around 2030. Meanwhile, population rapidly increases in India and Africa, thanks to medical technology and food nutrition improvement.
- India replaces China as the most populated country in Asia (and the world) around 2025; population should reach 1.6 billion in 2040.

Major Assumptions: Economic Growth

Note: Real values are in 2010 USD





- While the world economy is facing a variety of challenges, it is assumed to achieve strong growth over the medium to long term.
- In the Reference Scenario, China's real GDP in 2040 is ahead of the United States and is 3.5 times that of Japan. India also overtakes Japan in the late 2030s; it is 1.4 times that of Japan in 2040.

Major Assumptions: Primary Energy Prices

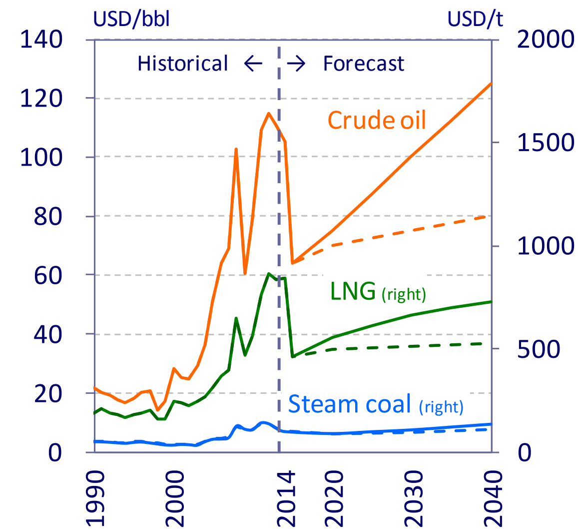
			Reference				Lower Price		
			2014	2020	2030	2040	2020	2030	2040
Crude oil	USD/bbl	Real	105	75	100	125	70	75	80
		Nominal	105	84	137	209	79	103	134
Natural gas	Japan USD/t	Real	842	554	663	730	498	507	528
		Nominal	842	624	909	1,221	561	696	883
	Japan USD/MBtu	Real	16.3	10.7	12.8	14.1	9.6	9.8	10.2
		Nominal	16.3	12.0	17.6	23.6	10.8	13.5	17.1
	Europe USD/MBtu	Real	8.2	8.5	9.8	11.7	6.8	7.3	8.1
		Nominal	8.2	9.6	13.5	19.6	7.7	10.0	13.6
	USA USD/MBtu	Real	4.4	4.5	5.6	6.8	3.4	3.7	3.9
		Nominal	4.4	5.1	7.7	11.4	3.8	5.1	6.5
Steam coal	USD/t	Real	98	89	106	132	86	96	108
		Nominal	98	100	145	221	97	132	181

- Prices are for calendar years. Real prices are in 2014 dollars.
- Japan's energy prices are on a CIF import basis.

- In the Reference Scenario, crude oil prices rise gradually again to $100/bbl by 2030 due to robust demand growth in non-OECD countries, emerging geopolitical risks and financial factors, oil supply constraints reflecting rising depletion rates for oil fields, etc. LNG prices will rise accordingly, with the existing price disparity shrinking due to expanding interregional trades.

- In the Lower Price Scenario, energy prices remain lower due to the dull growth in demand in accordance with the diffusion of energy saving technologies, as well as further promotion of unconventional resources development.

CIF import prices for Japan



Solid line: Reference, Dashed line: Lower Price

Scenarios

Reference Scenario

This scenario reflects past trends as well as energy and environment policies that have been introduced so far. This scenario does not reflect any aggressive policies for energy conservation or low-carbon measures.

Advanced Technologies Scenario

In this scenario, energy conservation and low-carbon technologies are promoted for maximum impacts, as each country is assumed to implement powerful policies to enhance energy security and address climate change issues.

Lower Price Scenario

In this scenario, it is assumed that energy savings will be pursued as stringently as in the Advanced Technologies Scenario, while assuming large increases in unconventional oil and natural gas production, resulting in considerable relaxation of supply and demand.

Assumptions for the Advanced Technologies Scenario

In this scenario, each country further enhances policies on energy security and addresses global warming. Technological developments and international technology transfers are promoted to further expand the diffusion of innovative technologies.

Introducing and Enhancing Environmental Regulations and National Targets

Environment Tax, Emissions Trading, RPS, Subsidy Provisions, FIT, Efficiency Standards, Automobile Fuel Efficiency Standard, Low Carbon Fuel Standard, Energy Efficiency Labeling, National Targets, etc.

Promoting Technology Development and International Technology Cooperation

R&D Investment Expansion, International Cooperation on Energy Efficient Technology (steelmaking, cement and other areas), Support for Establishing Energy Efficiency Standards, etc.

【Demand Side Technology】

■ Industry

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

■ Transport

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

■ Building

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

【Supply Side Technology】

■ Renewable Energy

Wind power generation, photovoltaic power generation, CSP (Concentrated Solar Power) generation, biomass power generation and bio-fuel will diffuse further.

■ Nuclear Energy Promotion

Nuclear power plant construction will be accelerated with operating rates improved.

■ Highly Efficient Fossil-fired Power Plant Technology

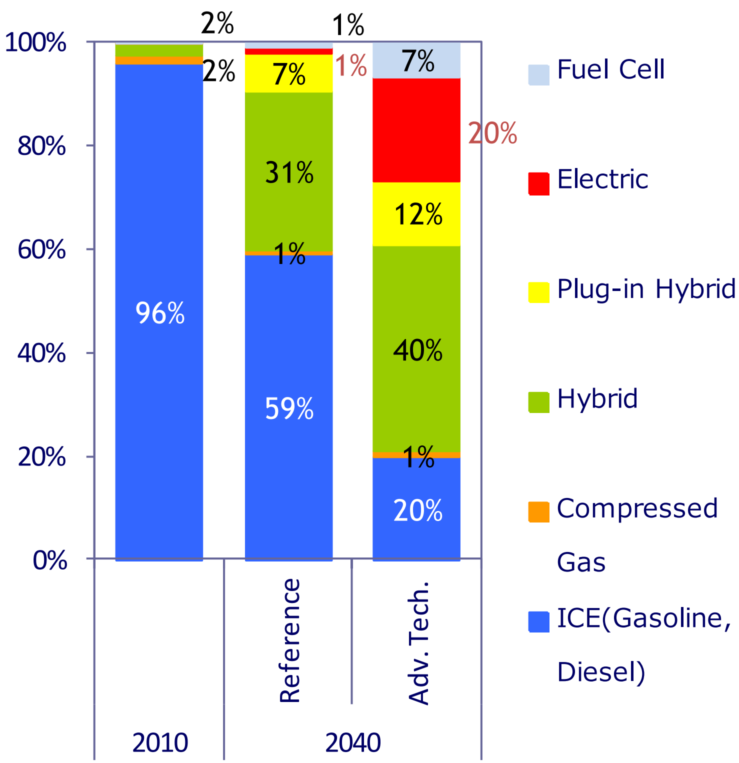
Coal-fired power plants (USC, IGCC, IGFC) and natural gas MACC (More Advanced Combined Cycle) plants will diffuse further.

■ CCS

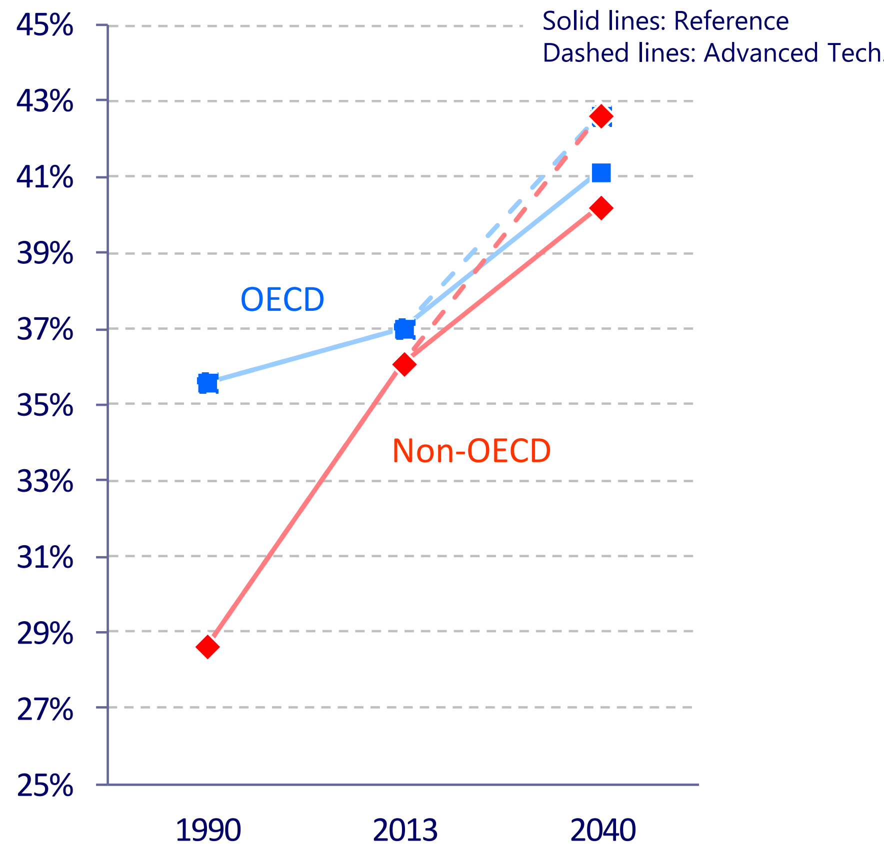
CCS deployment will expand in the power generation sector (new and old coal-fired and gas-fired plants) and the industrial sector (steelmaking, cement and other plants that emit massive GHGs).

Assumptions for the Advanced Technologies Scenario

The share of vehicle sales by type (world)



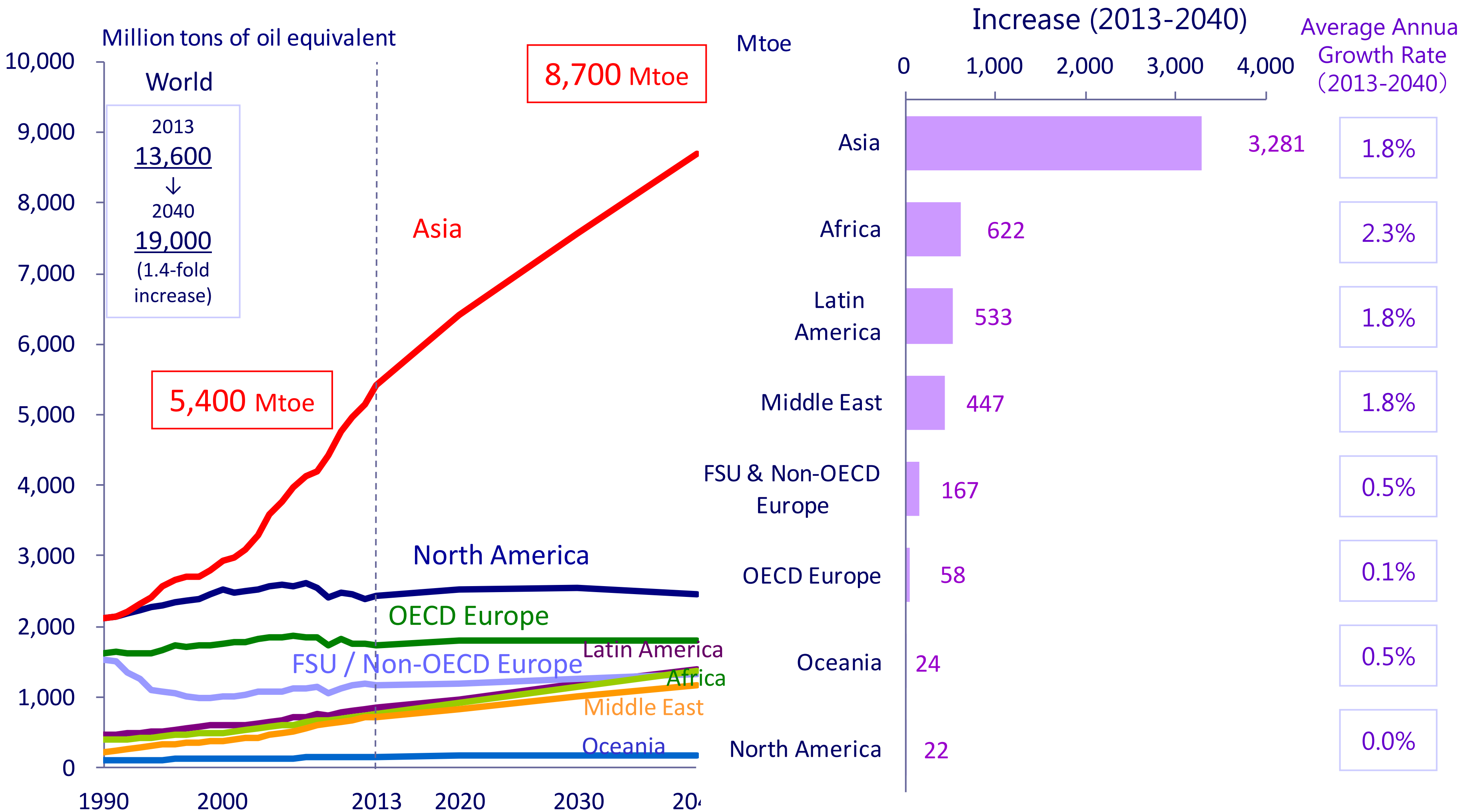
Thermal efficiencies of coal-fired power plants



- In the Advanced Technologies Scenario for the transport sector, clean energy vehicles diffuse drastically and fuel efficiency is improved. In the power sector, low carbon technology diffuses and highly efficient fossil-fired power plant technology are introduced.
- In the industrial, residential and commercial sectors, the technologies that become available in the near future are heavily introduced.

Primary Energy Demand by Region

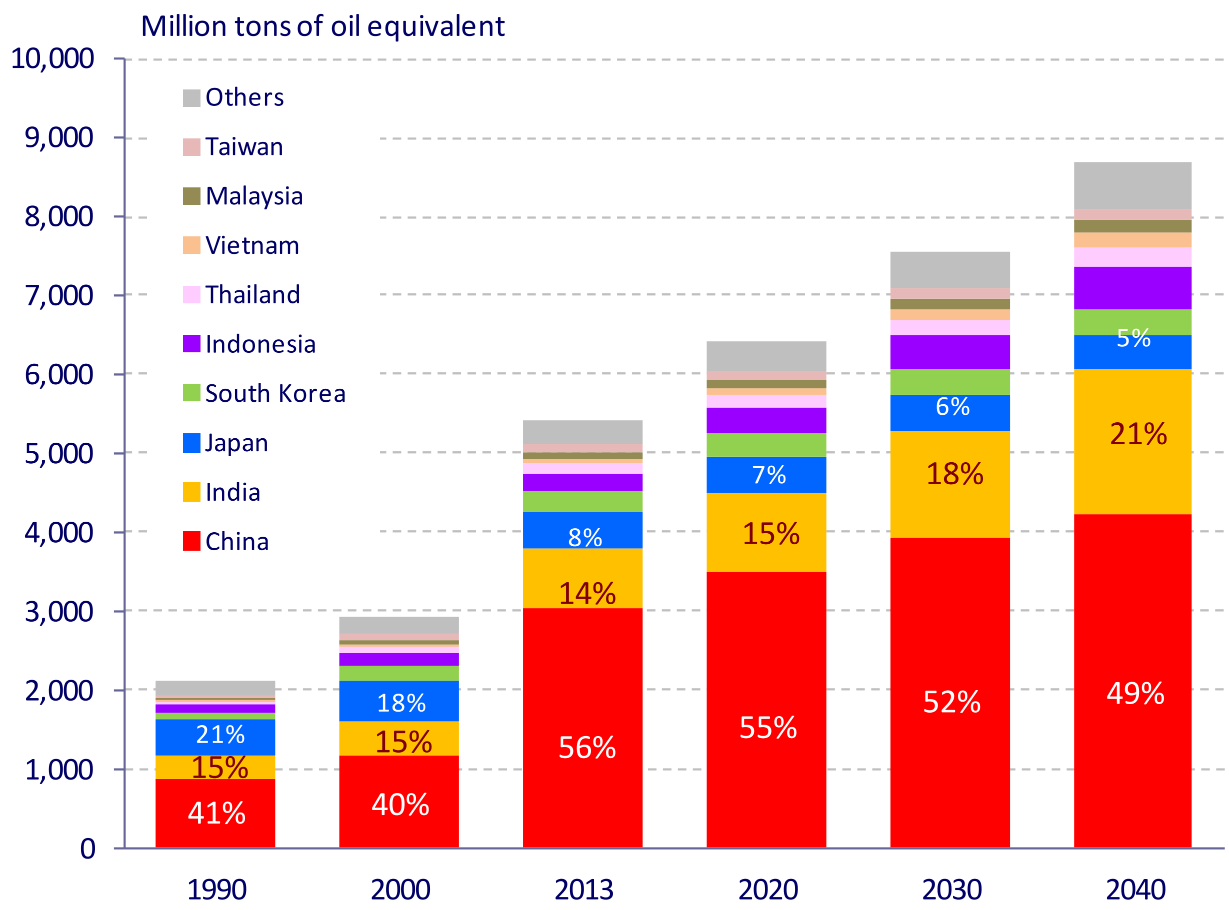
Reference Scenario



- Under the steady economic growth assumption, Asian energy consumption in 2040 increases 1.6-fold from the present level (from 5.4 billion tons in 2013 to 8.7 billion tons in 2040).
- Non-OECD countries account for about 90% of global energy consumption increase between 2013 and 2040.

Primary Energy Demand (Asia)

Reference Scenario



Asia

2013
5,400
↓
2040
8,700
(1.6-fold increase)

China & India

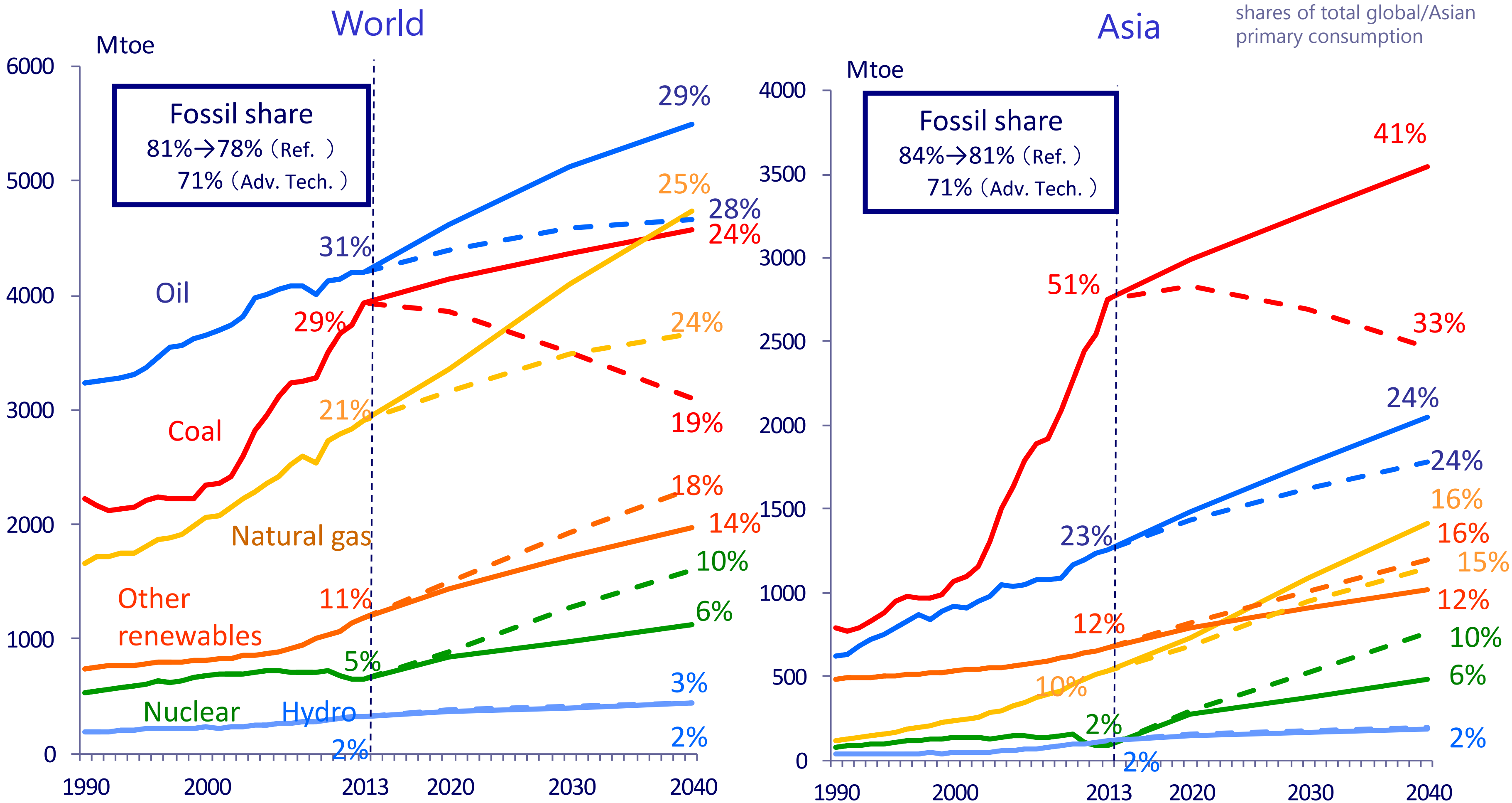
2013
3,000 780
↓
2040
4,200 1,800
(1.4-fold inc.) (2.3-fold inc.)

- Energy demand in China and India increase rapidly in line with economic growth. Their share of Asian energy demand expands 70% in 2040.
- Japan's energy consumption declines as a result of progress in energy efficiency combined with a maturing economy and a decreasing population. Its share of Asian energy consumption shrinks from 8% to 5%.

Primary Energy Consumption by Source

Solid lines: Reference
Dashed lines: Adv. Tech.

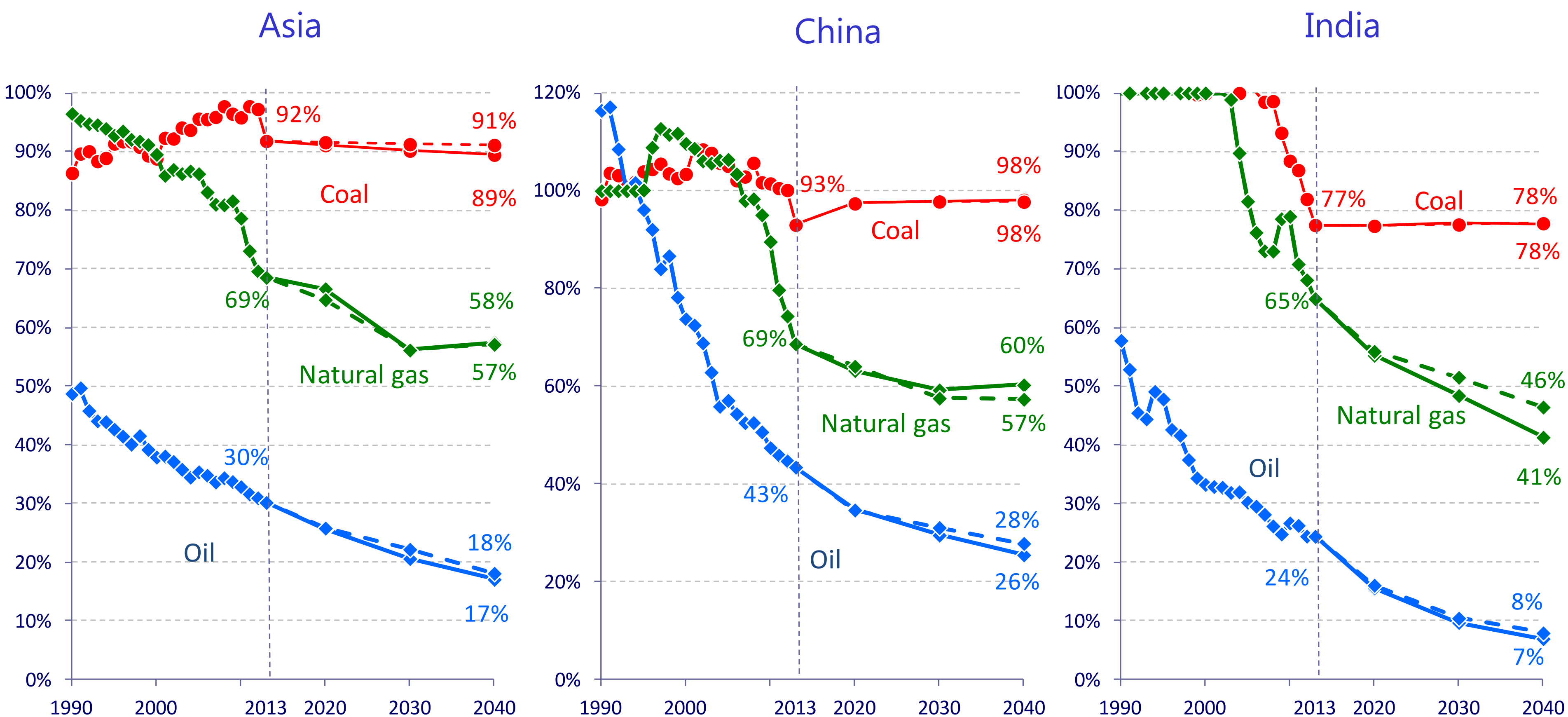
The percentages indicate the shares of total global/Asian primary consumption



- In both the Reference and Advanced Technologies Scenarios, oil continues to be the largest share of primary energy consumption and remains a major energy source up to 2040.
- In Asia, coal remains the largest share among energy sources. In the Advanced Technologies Scenario, coal consumption declines substantially while retaining the largest share among energy sources.
- Share of fossil fuel declines until 2040, while maintaining the 70% in the Advanced Technologies Scenario

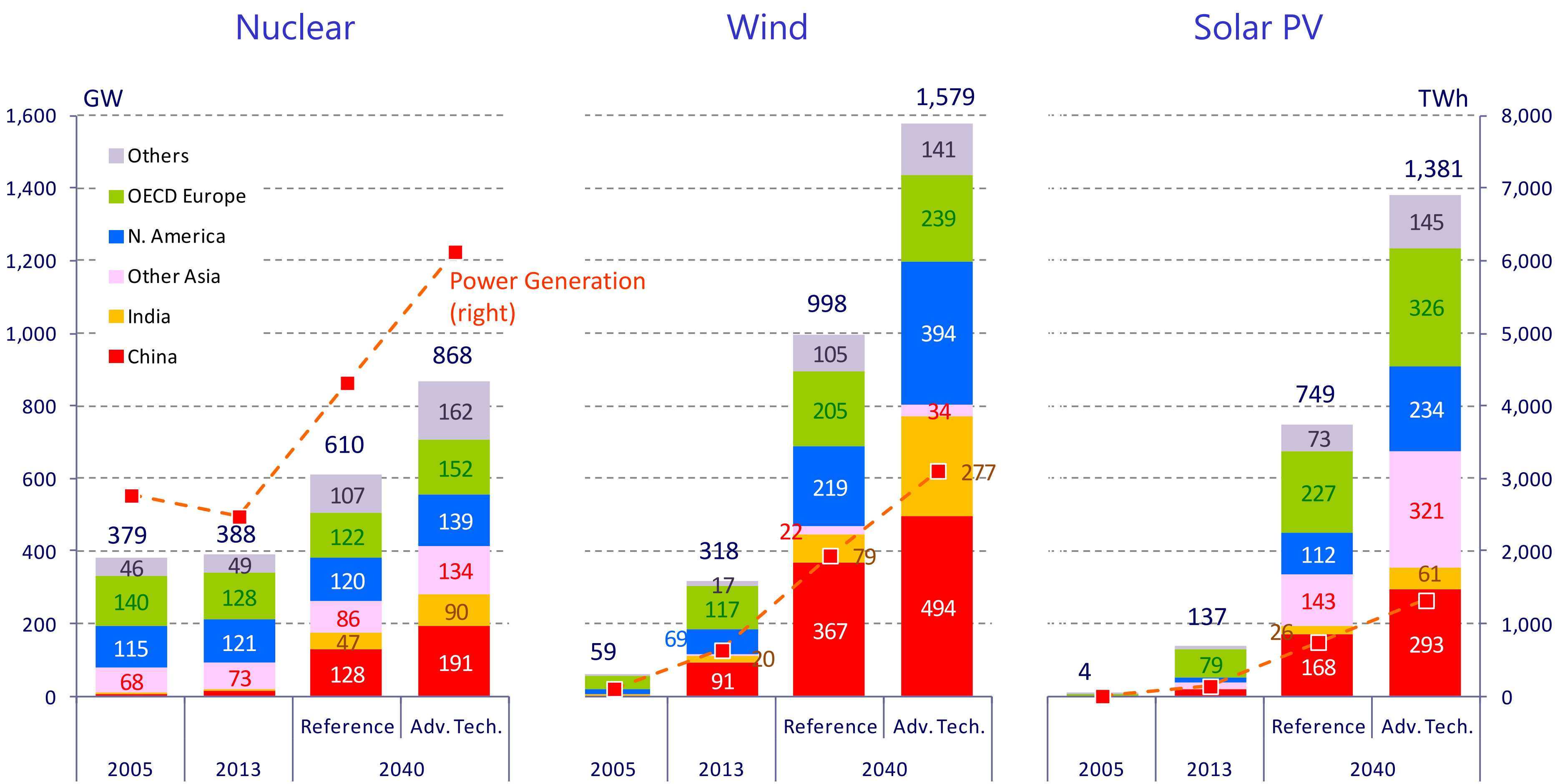
Energy self-sufficiency in Asia

Solid lines: Reference
Dashed lines: Adv. Tech.



- While Asia including China and India have scarce oil and natural gas resources, coal resource are abundant and this contributes to stabilize energy self-sufficiency.
- Asian fossil fuel self-sufficiency rate has been decreasing and it keeps decreasing not only in the Reference Scenario where demand rapidly increases but also in the Advanced Technologies Scenario where energy saving technologies are heavily introduced.

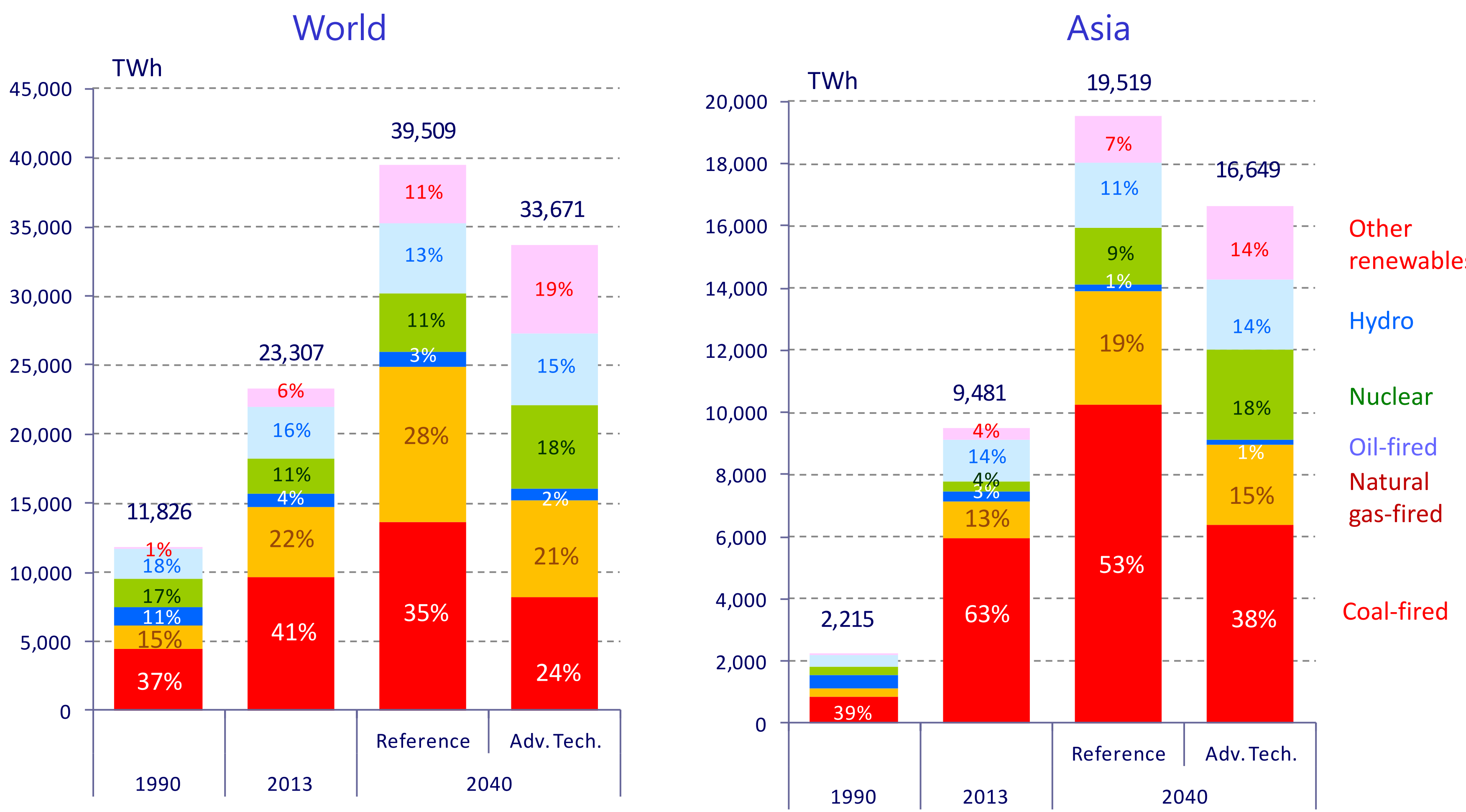
Outlook for nuclear and renewable power generation capacities



· In the Reference Scenario, global nuclear, photovoltaic generation capacity, and wind power expand 1.6-fold, 3.1-fold, and 5.5-fold, respectively, from 2013 to 2040. In the Advanced Technologies Scenario they are 2.2-fold, 5.0-fold, and 10.1-fold, respectively.

• In particular, expansions in Asia are significant and China and India account for nearly half in all technologies in the Advanced Technologies Scenario.

Power generation mix in 2040

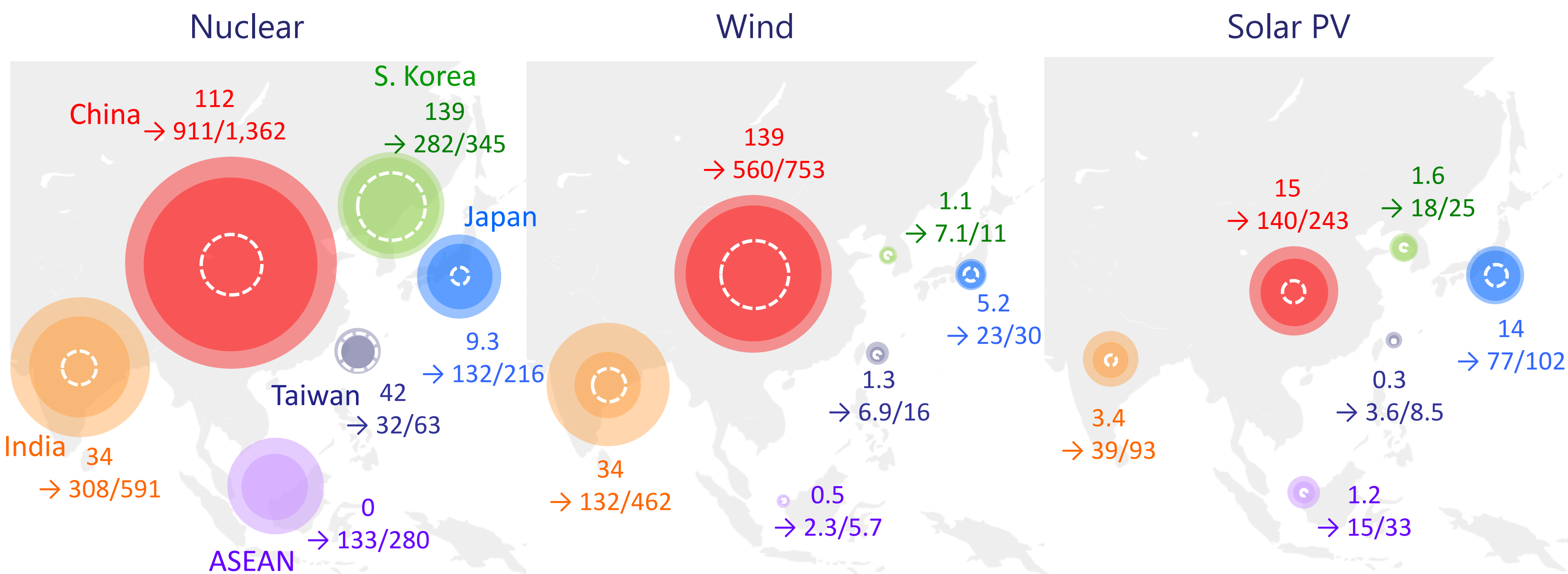


- In 2040, coal still accounts for the largest share of power generation. Natural gas-fired power plants globally increase on the introduction of natural gas combined cycle plants. Renewable energy sources including wind and solar energy also expand their share of power generation.
- In the Advanced Technologies Scenario, coal's share of power generation declines to 24%, while nuclear, hydro and other renewable energy sources expand their respective shares.

Nuclear and renewables power generation expansion in Asia

Unit: TWh

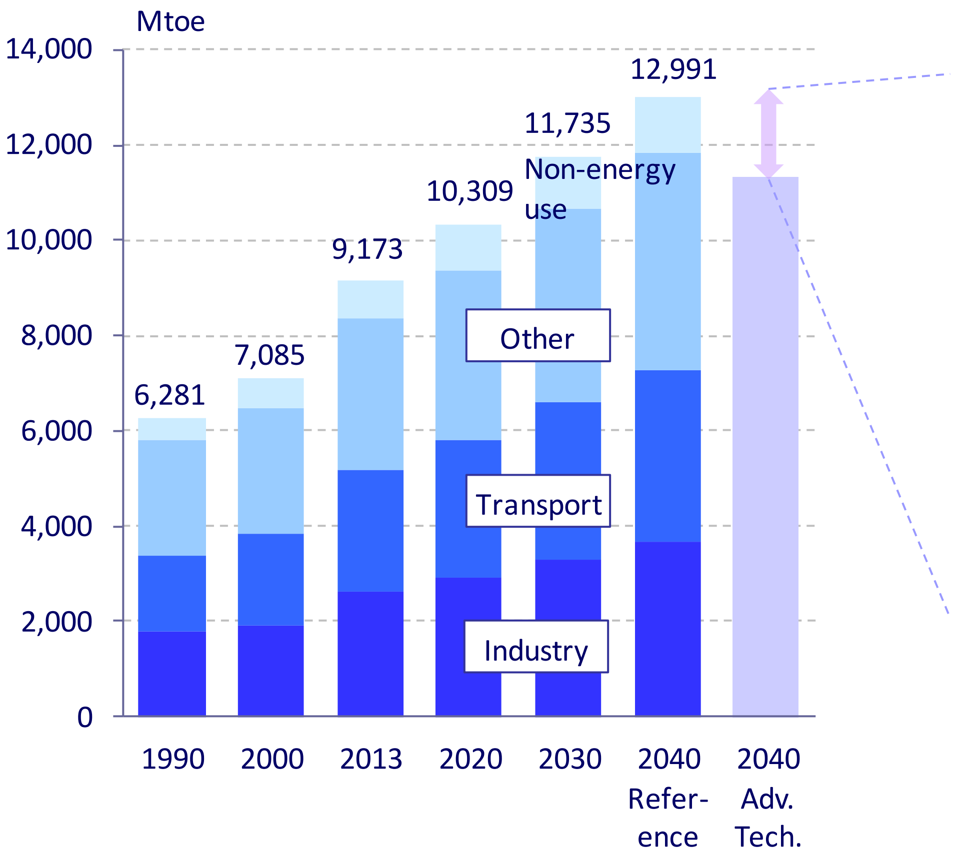
2013 (dashed line)
→2040 Reference (inner circle)
/ 2040 Adv. Tech. (outer circle)



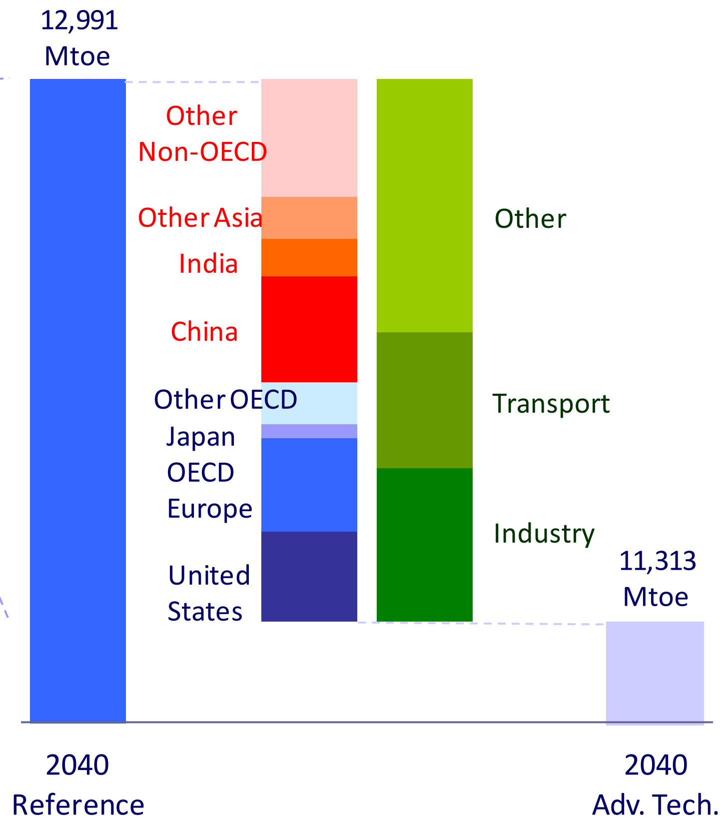
- Nuclear power generation will continue to increase in China, India and Korea. Vietnam becomes the first country to operate a nuclear power plant in Southeast Asia, followed by other ASEAN countries.
- Wind power expands in China and India. Its diffusion in ASEAN will be limited because of the complex topography.
- Solar power grows at the highest rate. Due to the low load factors, however, it falls behind wind power in terms of power output.

Energy saving in 2040 by region and by sector

Global final energy demand



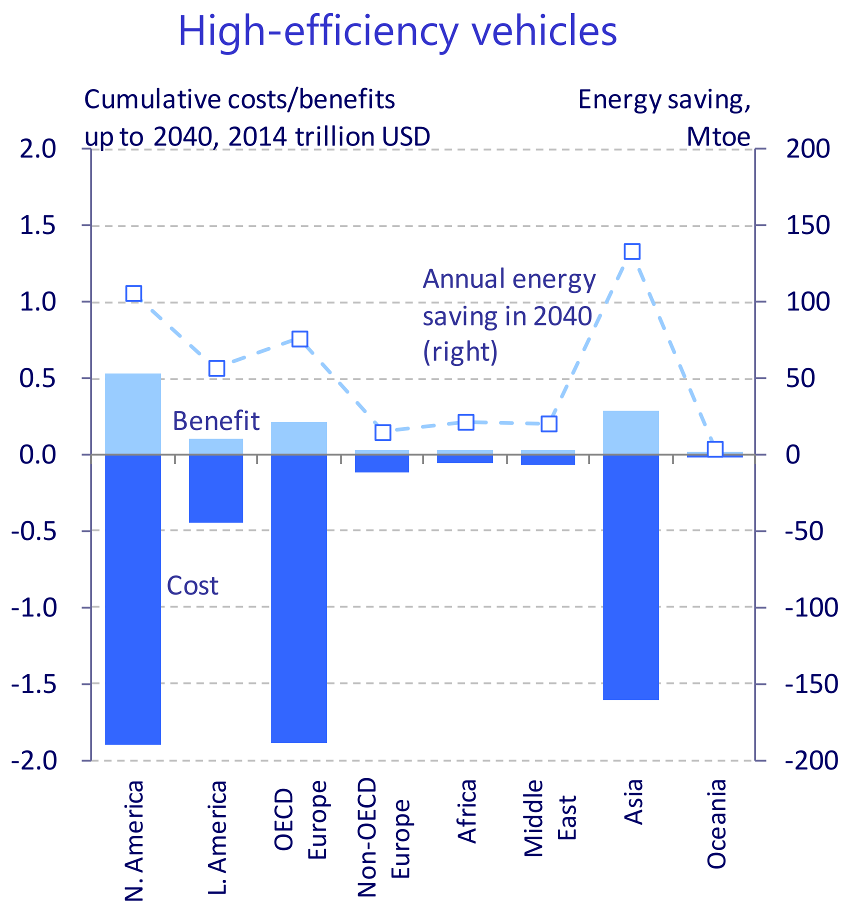
Energy saving by region and by sector

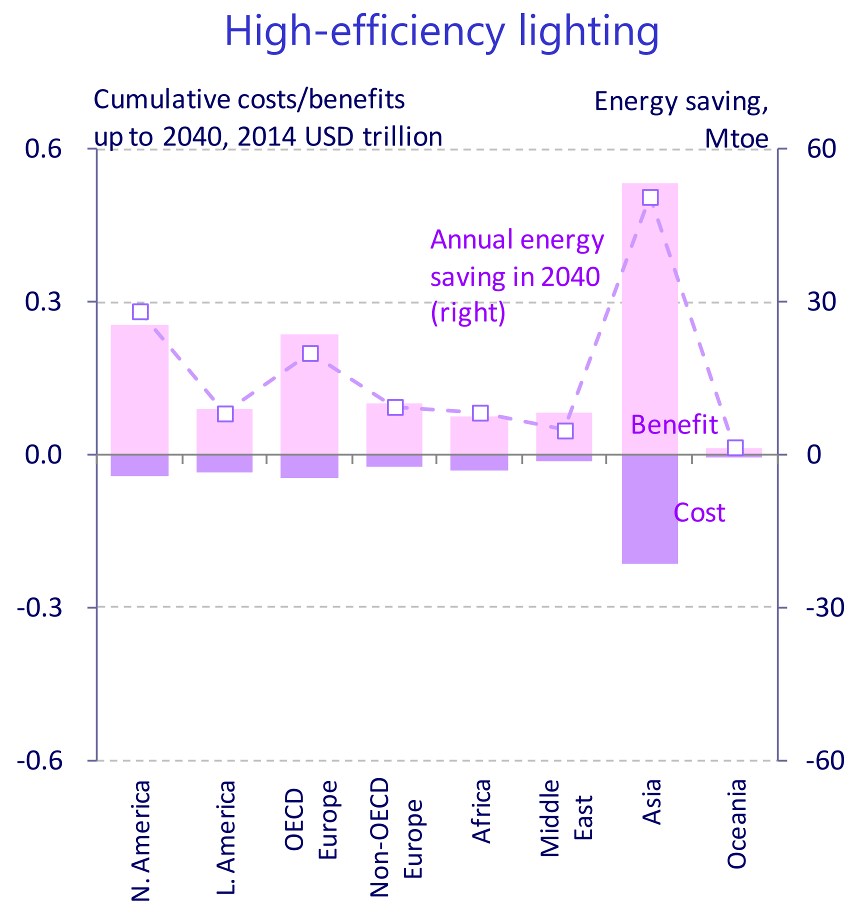


- Global final energy demand expands 1.4-fold from 9,173 Mtoe in 2013 to 12,991 Mtoe in 2040 in the Reference Scenario.

- In the Advanced Technologies Scenario, final energy demand in 2040 is reduced by 13% to 11,313 Mtoe. 60% of the energy saving is attributable to non-OECD countries. By sector, “other” sector including residential and commercial sectors accounts for nearly half (47%) of total energy saving.

Costs and benefits of energy saving technologies

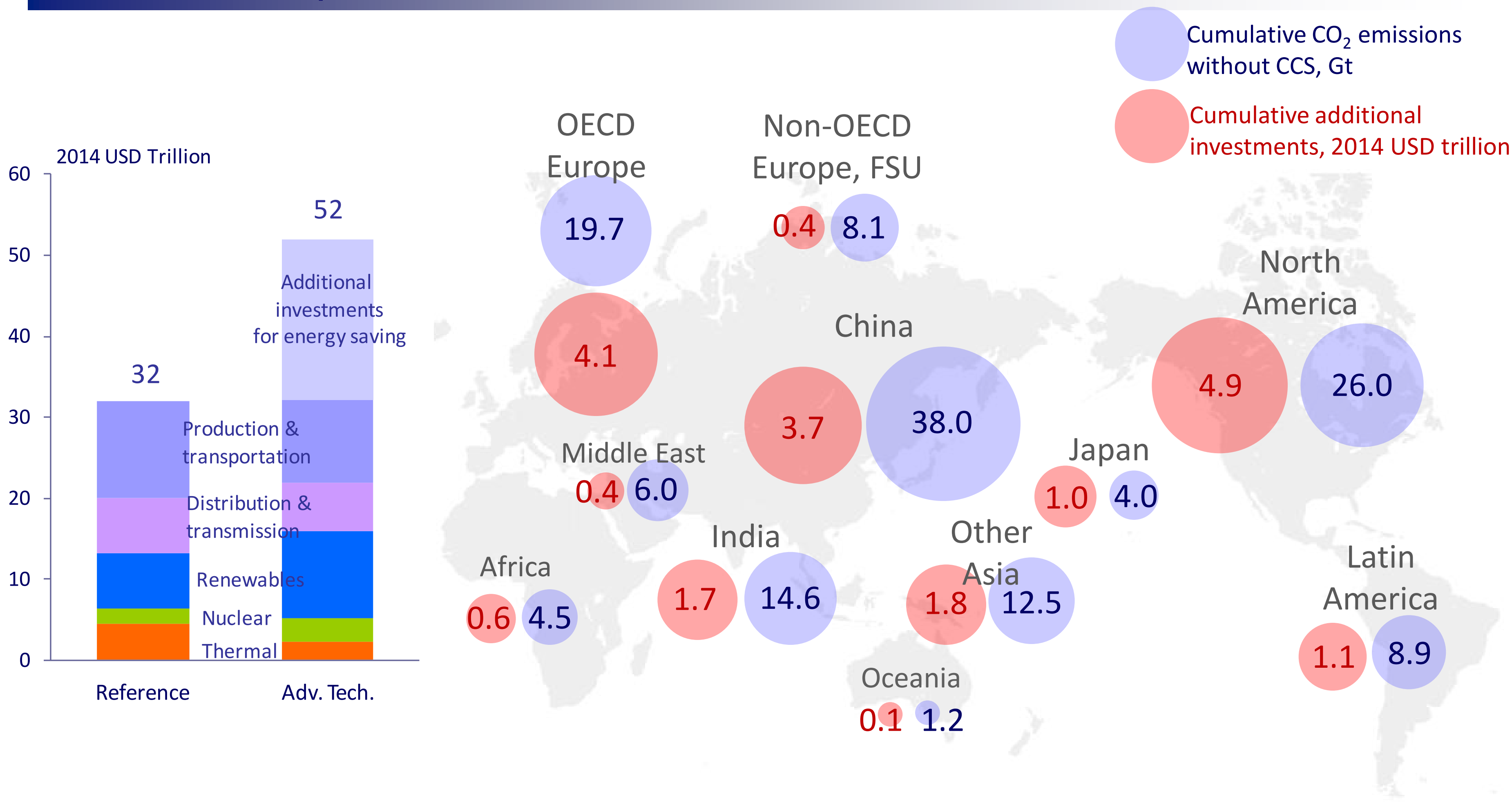




- In the case of high-efficiency lighting such as light-emitting diodes (LED), the benefits induced by energy saving outweigh the costs, resulting in net positive benefits. On the other hand, in many cases the energy saving measures that need huge initial investments bring net negative benefits, because the investments cannot be recouped by energy saving. In these cases, vigorous policies including subsidies and tax incentives are needed to promote energy saving.

- Taking only the “beneficial” energy saving actions is not sufficient to achieve ambitious CO_2 reduction targets. Maximum deployment of energy saving technologies, including the more “costly” ones, is indispensable.

Additional investments in the Advanced Technologies Scenario (cumulative up to 2040)



- On the supply side, while energy supply decreases in the Advanced Technologies Scenario, investments on renewable energy (etc.) expand and the cumulative investments up to 2040 are the same level as the Reference Scenario.
- On the demand side, additional investments of over 20 trillion USD are required for energy savings. Asian countries, including China and India, account for 42% of the additional investments.

Conclusion: Asia/World Energy Outlook through 2040

- Global and Asian primary energy consumption increase 1.4-fold and 1.6-fold, respectively, through 2040. As energy demand expands rapidly, Asia's energy self-sufficiency rate continues to fall and that change may destabilize the world energy markets. It also results in increasing global CO_2 emissions, causing severe damages to the environment.

- The key to solving these problems are energy saving and the decarbonization of energy use. Energy saving measures include the penetration of the technologies that bring more benefits than costs. With only these "beneficial" technologies, however, it would not be possible to achieve a sufficient level of energy saving. Every effort should be made to realize the maximum possible saving of energy consumption, taking more "costly" measures as well.

- Asian emerging countries, including China and India, hold the key to reducing CO_2 and GHG emissions. Without their cooperation, the international community is not able to address the climate change problem. All countries and regions have to adopt maximum measures of efficiency, while maintaining sustainable economic growth.

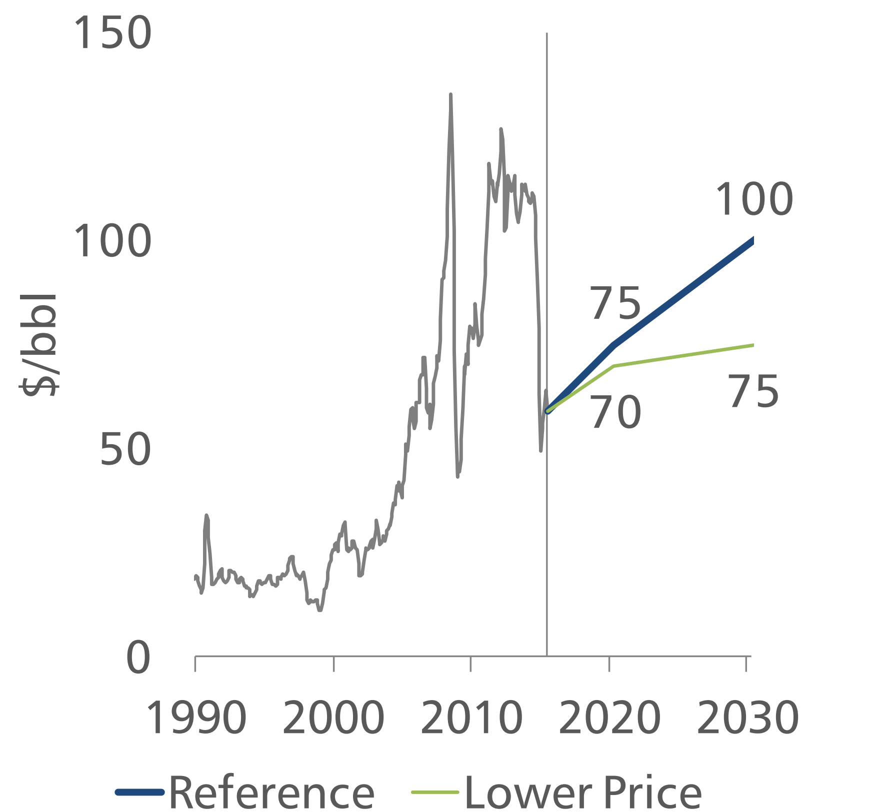
What do lower prices produce?

We may see lower prices than in the Reference Scenario

❖ Background of the scenarios

	Reference	Lower Price
Demand	Energy conservation and fuel switching in transport sector progress along with the trend.	Strong energy conservation and fuel switching by non-fossil fuel progress.
Supply	**Conventional resources** Development in each country follows its historical trend. **Unconventional resources** Production growth in the United States declines in and after 2020s. Slow development is seen in other countries.	**Conventional resources** Competition among low-cost producers such as OPEC, Russia, etc. continues. OPEC effectively loses its power as a cartel organisation. **Unconventional resources** Reach the highest levels both inside and outside the United States.

❖ Assumption of oil price

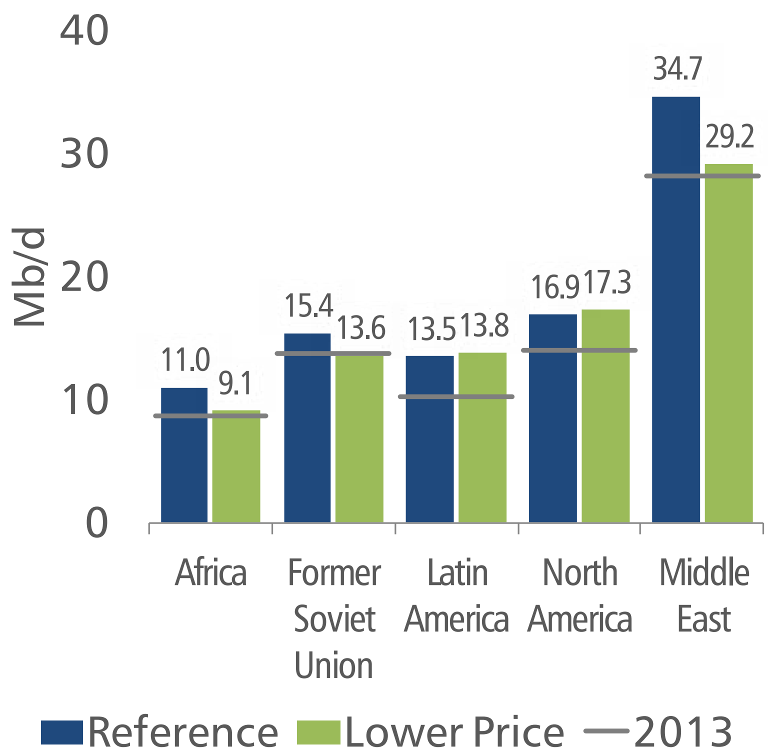


Note: Future prices are in $2014.

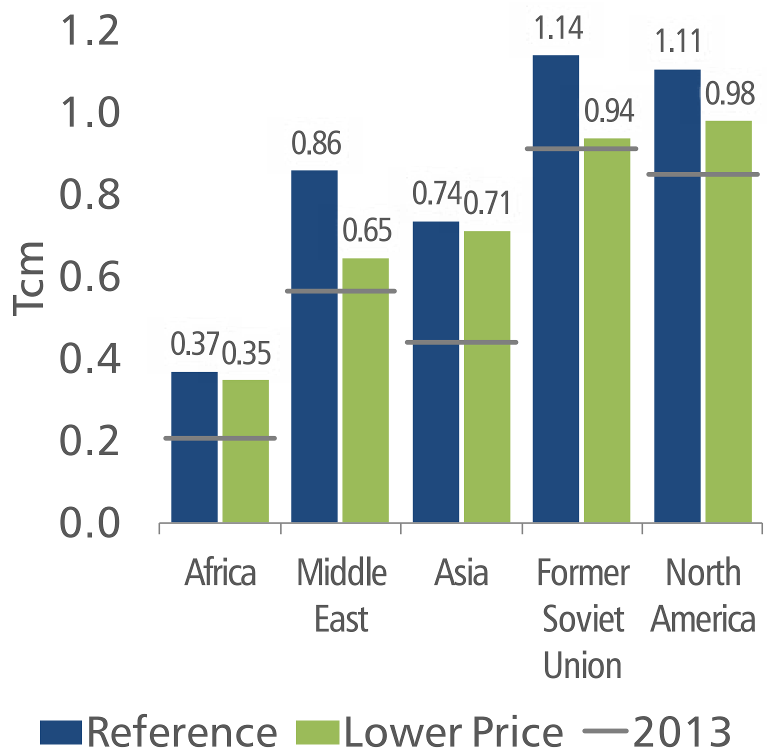
Easy supply-demand balance due to factors in supply and demand sides is assumed in the Lower Price Scenario. Real oil price in 2030 in the scenario is premised to be cheaper by 25% than in the Reference Scenario.

Depressed production in traditional exporting regions

❖ Crude oil production in selected regions [2030]



❖ Natural gas production in selected regions [2030]

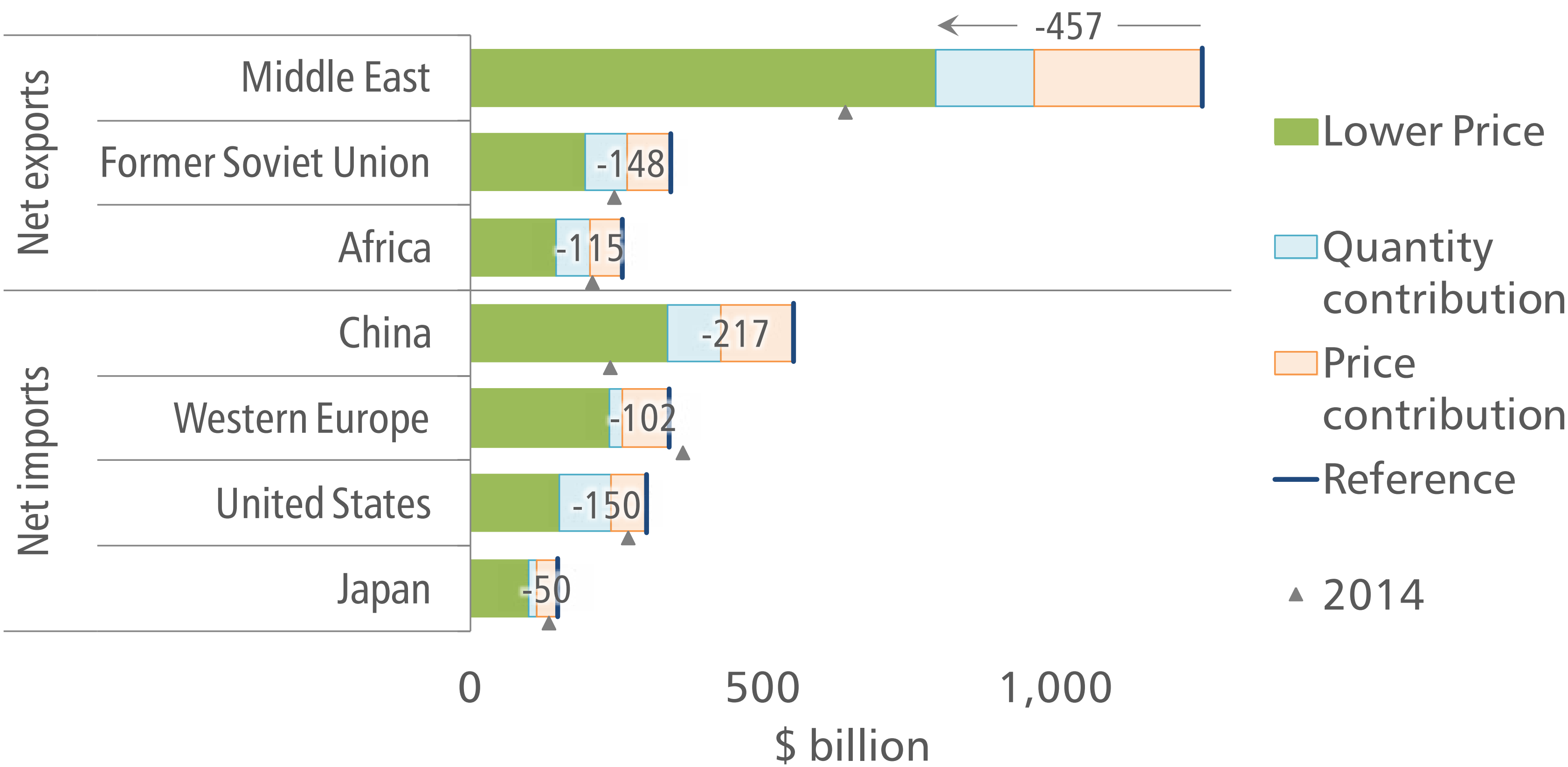


Global oil supply in 2030 is 96.5 Mb/d, increased by just 7.7 Mb/d from today, due to the assumed strong energy conservation and fuel switching to other energies.

Production growth in the Middle East is only 1.0 Mb/d, squeezed by large increases in unconventional oil production in North America and others. Russia faces production reduction by 0.8 Mb/d.

Benefit for importing countries thanks to lower imports and price

❖ Crude oil net imports/exports in selected regions [2030]

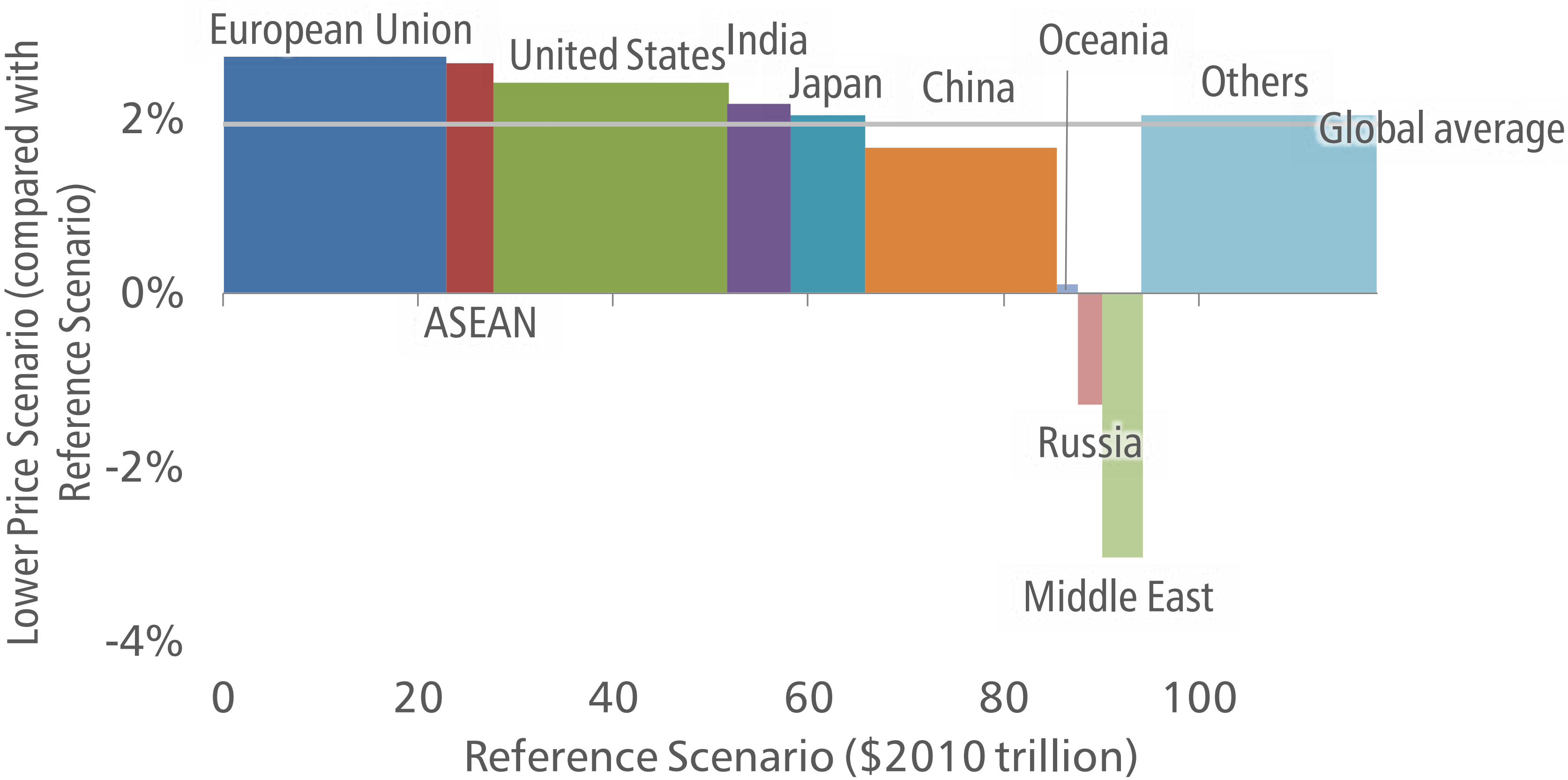


Oil saving, lower oil price and wider use of unconventional resources make international trade of crude oil* 36% less, to $2.8 trillion from $4.4 trillion, in the Reference Scenario. * Among the modelled 15 regions. Nominal value.

China is the biggest winner in terms of saving of net import spending, acquiring $217 billion. The United States follows with $150 billion. Net export earning of the Middle East decreases by $457 billion.

Lower prices support the global economy varying by region

❖ Changes in real GDP [2030, compared with the Reference Scenario]

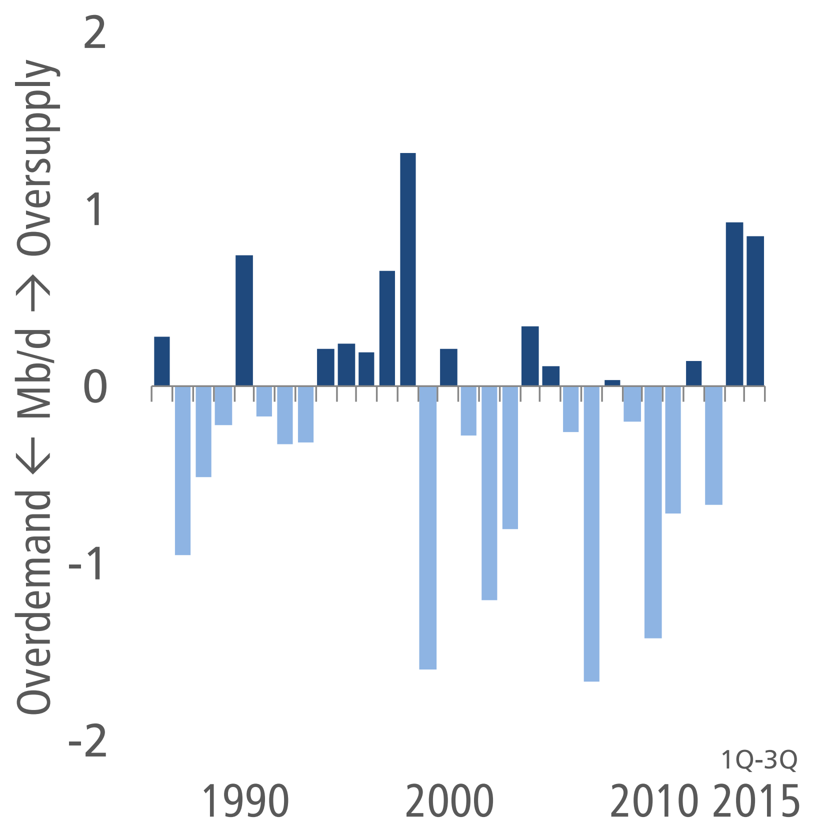


Lower prices and consumption of oil and natural gas vitalise importing countries' economies through less outflow of national welfare and improvement of real purchasing power. The global economy expands by 1.9%.

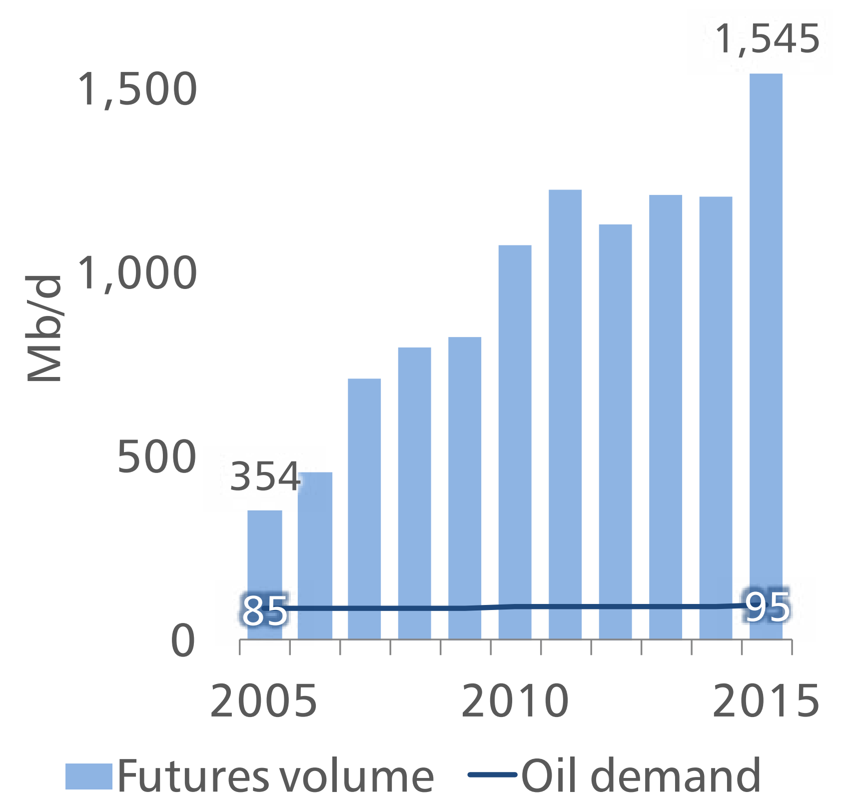
The situation exerts downward pressure on oil producing countries in the Middle East and others, whose revenue depends heavily on energy exports.

Lurking risks of high price and volatility

❖ Global oil supply-demand balance



❖ Global oil demand and volumes of futures



Note: Futures of WTI at NYMEX and Brent at ICE. Source: IEA, CME, ICE

Oversupply since 2014 is as much as 1 Mb/d, the largest in the last 16 years. We, however, have no experience that oversupply at such a scale continues for three or more years in the last three decades.

The crude oil futures market has grown much faster than actual oil supply and demand. We cannot deny that money and geopolitical factors have a huge influence on oil price again.

Summary: Lower energy prices

❖ How do we see the current oil price?

- Similarities can be found between fall of oil price this time and in 1980s:
  1. Huge contribution by increases in supply from new sources,
  2. Independent from demand factor caused by economic shock, and
  3. Competition among OPEC members.
- Oil market fundamentally has a nature that draws cycles. Therefore, oil price turns to rise sooner or later. The similarities, however, suggest possibility that current low price does not end in short term.
- Oil price was much higher than indicated by actual supply-demand factor since 2011. We cannot deny that money and geopolitical factors have huge influence on oil price again.
- There is risk of supply-demand imbalance in future due to absence of proper investment under extreme unstable prices. Dialogue and cooperation between producers and consumers and among consumers themselves play an important role for sustainable development.

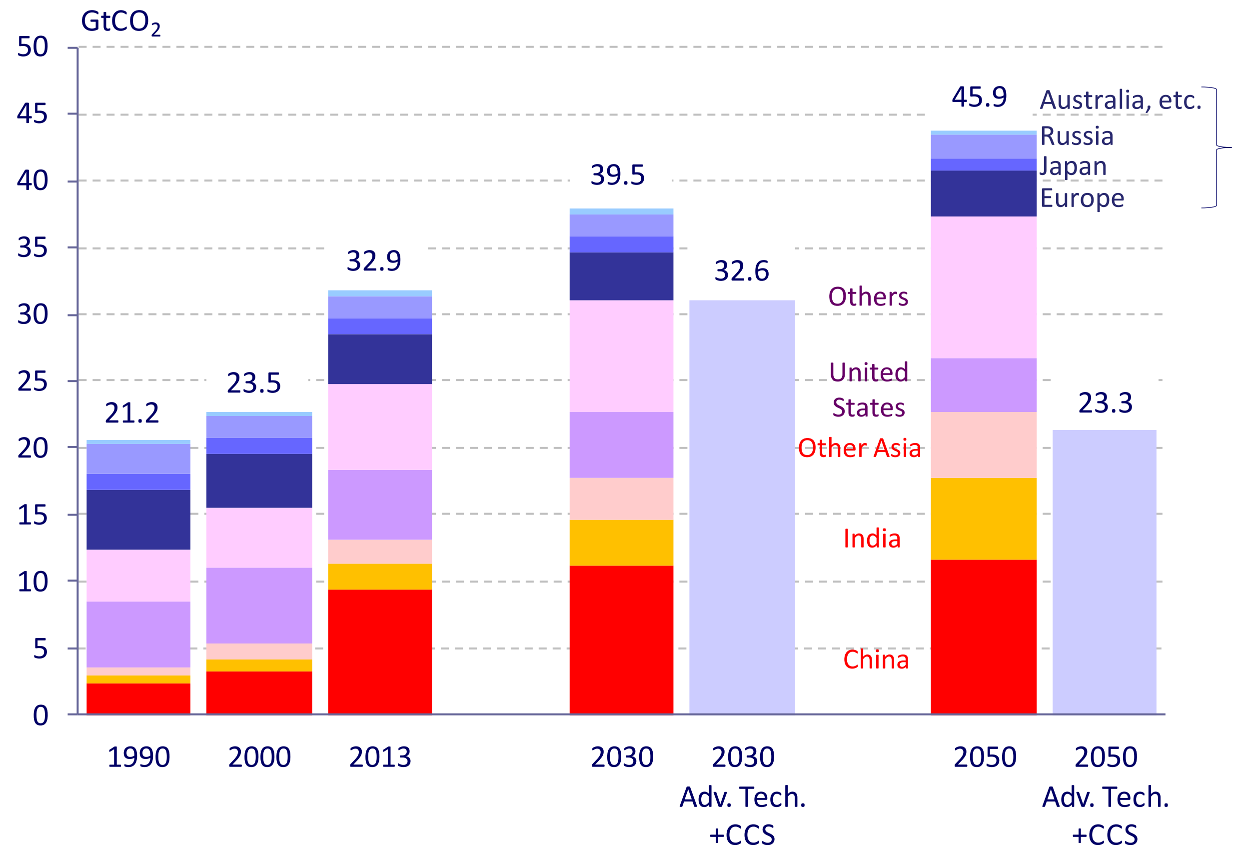
❖ Impact by lower prices [2030]

- We can assume $75/bbl or lower oil price if policy-driven fossil fuel saving and wider utilisation of unconventional resources by technology development ease supply-demand balance.
- Global oil supply in 2030 is 96.5 Mb/d, increased by just 7.7 Mb/d from today, due to assumed strong energy conservation and fuel switching. Production growth in the Middle East is only 1.0 Mb/d squeezed by large increases in unconventional oil production in North America, etc. Russia faces production reduction by 0.8 Mb/d.
- Lower import quantity and price result in substantial low import spending for crude oil. Largest fruits are in hands of China.
- Reduction in energy import spending supports global economy with 1.9% of expansion, especially for importing countries. Situation exerts downward pressure on oil producing countries in the Middle East and others, whose revenue depends heavily on energy exports.

Addressing climate change issues

CO_2 Emissions by region

Note: Total figures include international bunkers.

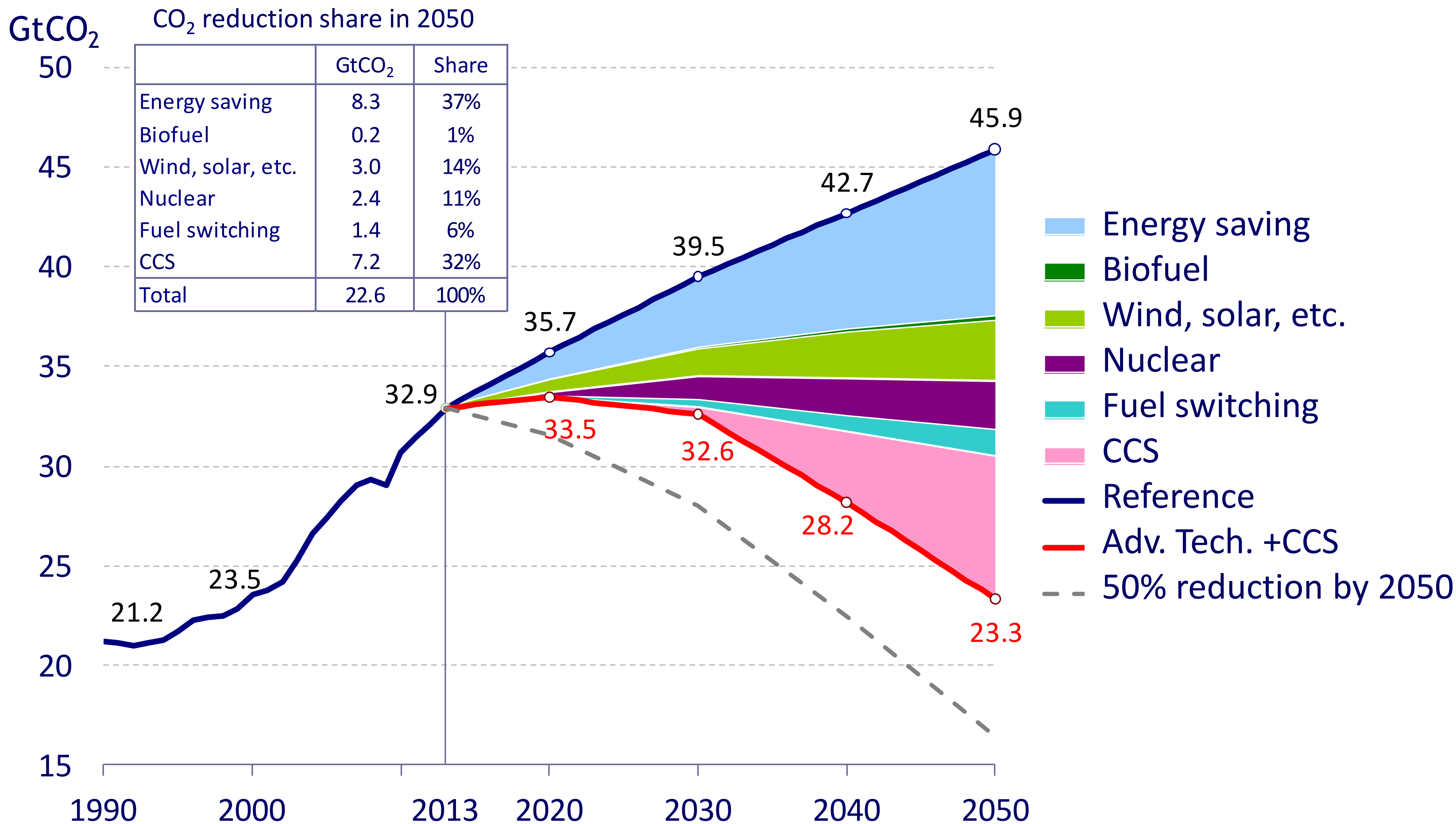


- Global energy-related CO_2 emissions will increase 1.4 times from 2013 to 2050. The expansion is especially rapid in India and other Asian countries, as well as Africa, the Middle East and Latin America.
- The share of the ANNEX I countries with reduction obligations under the Kyoto Protocol was 40% in 1990. It declined to 22% in 2013, and will decline further to 15% by 2050.

CO_2 Emissions Reduction by Technology (World)

CO_2 reduction share in 2050

	$GtCO_2$	Share
Energy saving	8.3	37%
Biofuel	0.2	1%
Wind, solar, etc.	3.0	14%
Nuclear	2.4	11%
Fuel switching	1.4	6%
CCS	7.2	32%
Total	22.6	100%



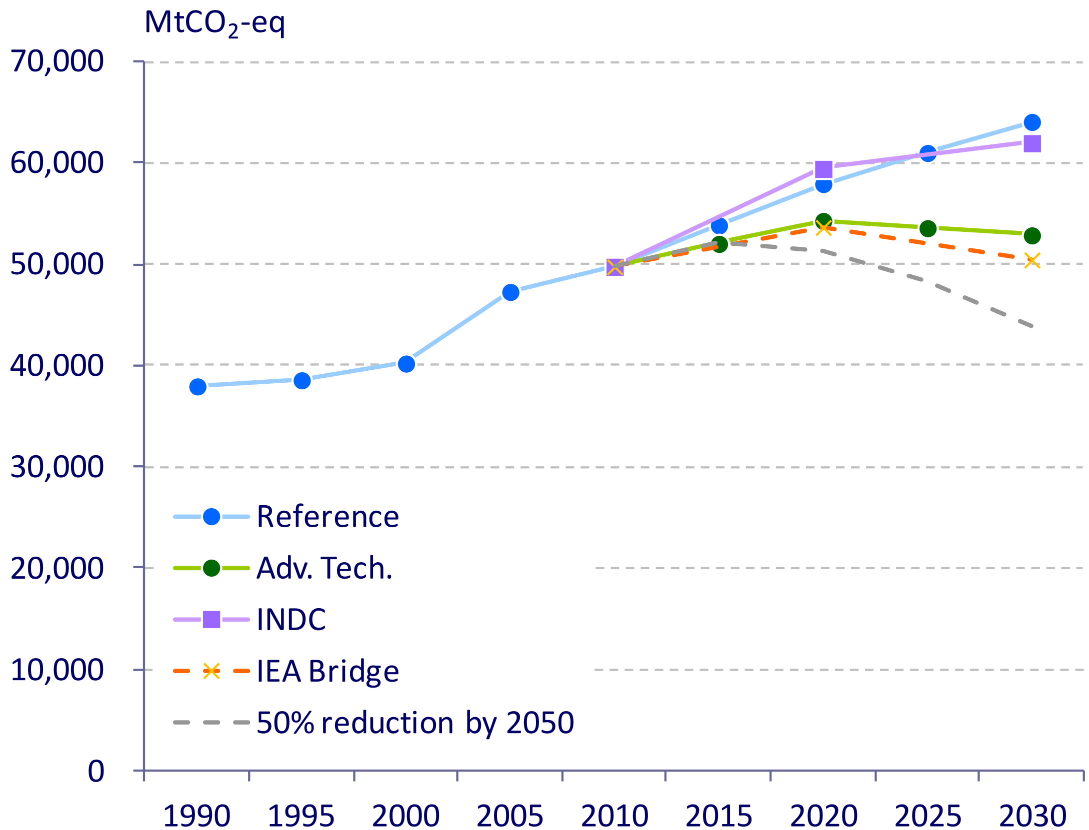
- In the Advanced Technologies Scenario, the global CO_2 emissions are reduced by various technological options, including energy saving, enhancement of power generation efficiency, renewables, nuclear and CCS. Altogether these options contribute to large CO_2 emissions reduction.
- To achieve halving global CO_2 emissions from current levels, additional measures such as innovative technological development and eco-friendly urban development are required in the long-term.

Intended Nationally Determined Contributions (INDCs) of major countries

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

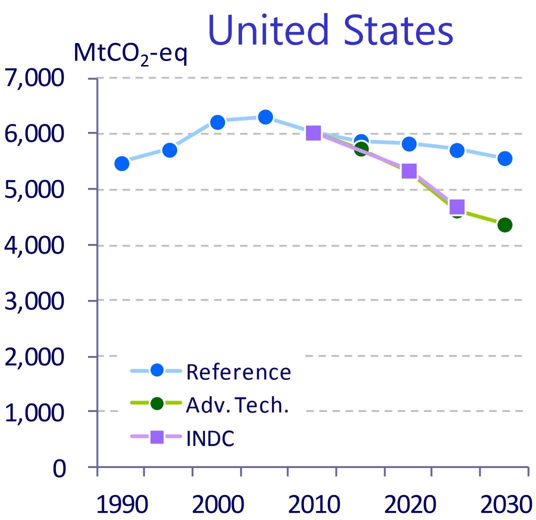
- In advance of the United Nations Climate Change Conference (COP21) in Nov. 2015, the participating countries have submitted the Intended Nationally Determined Contributions (INDCs) which present the post-2020 climate actions each country intends to take.
- By Oct 1st, 117 countries and regions (totaling 144 countries) have submitted their INDCs.
- The 8 major countries and regions shown above cover 65% of global GHG emissions in 2010.

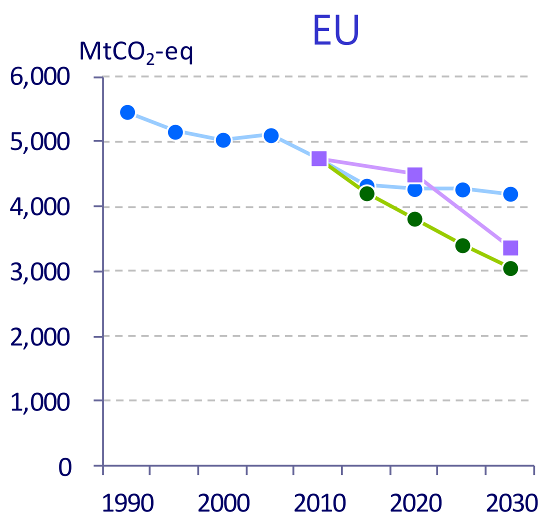
Comparison of INDCs with the Reference/Adv. Tech. Scenarios

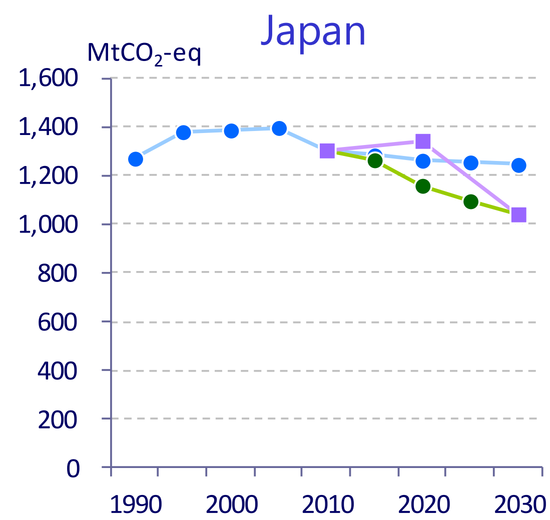


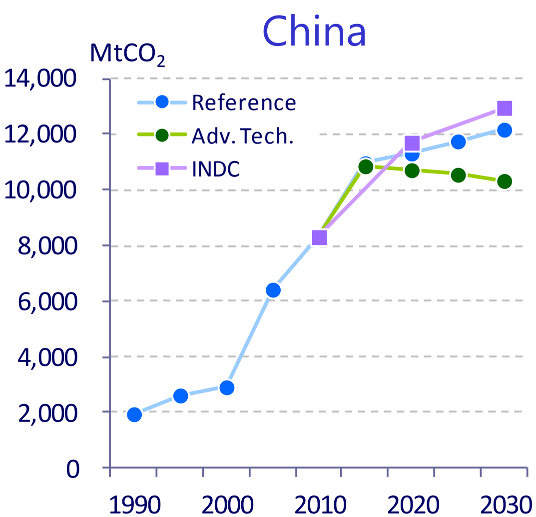
- The future evolution of global GHG emissions suggested by the INDCs of the 8 parties traces a path similar to that of the Reference Scenario. Thus, climate actions based on the INDCs are not sufficient to reach the Advanced Technologies Scenario, being far behind the target of “50% reduction by 2050.”

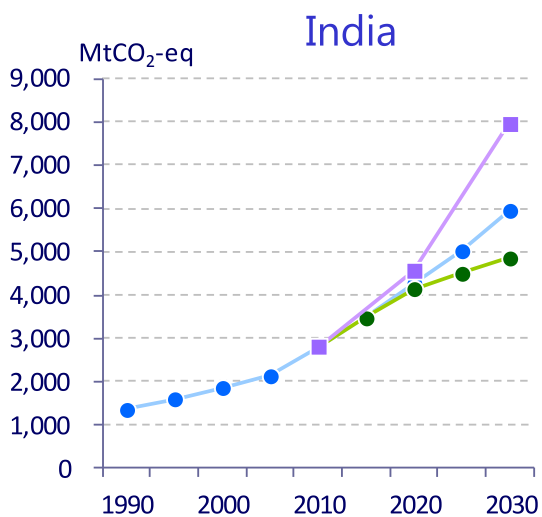
Comparison of INDCs with the Reference/Adv. Tech. Scenarios by country

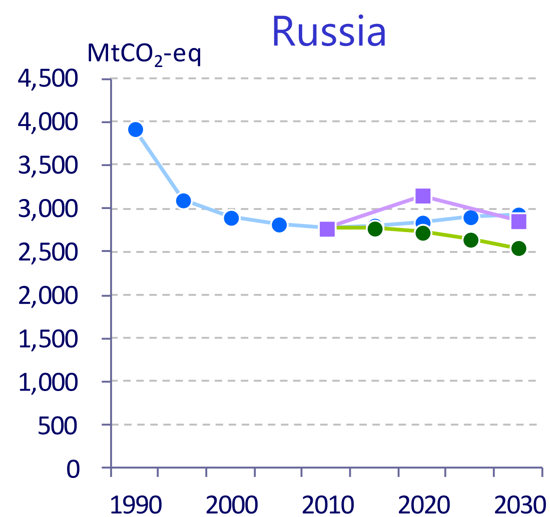












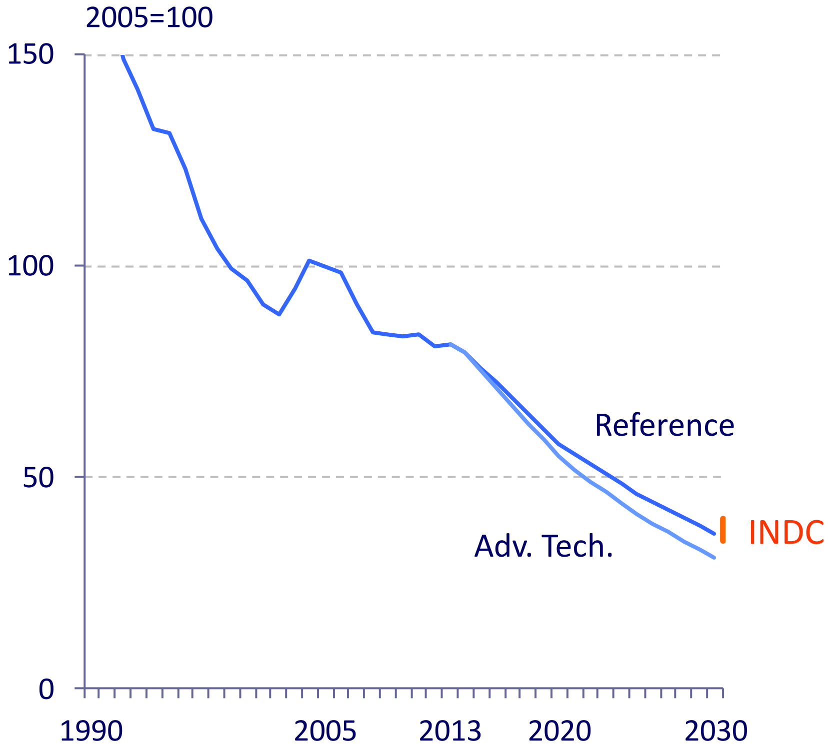
- The INDC targets of the United States and Japan are as ambitious as the Advanced Technologies Scenario. The target of EU is also positioned near the ATS.
- The targets of China and India exceed the Reference Scenario in terms of CO_2/GHG emissions.

Note: Japan's 2020 target does not include reduction by nuclear power. China's target is for CO_2, while others are for GHG.

Comparison of CO_2/GHG intensities (China and India)

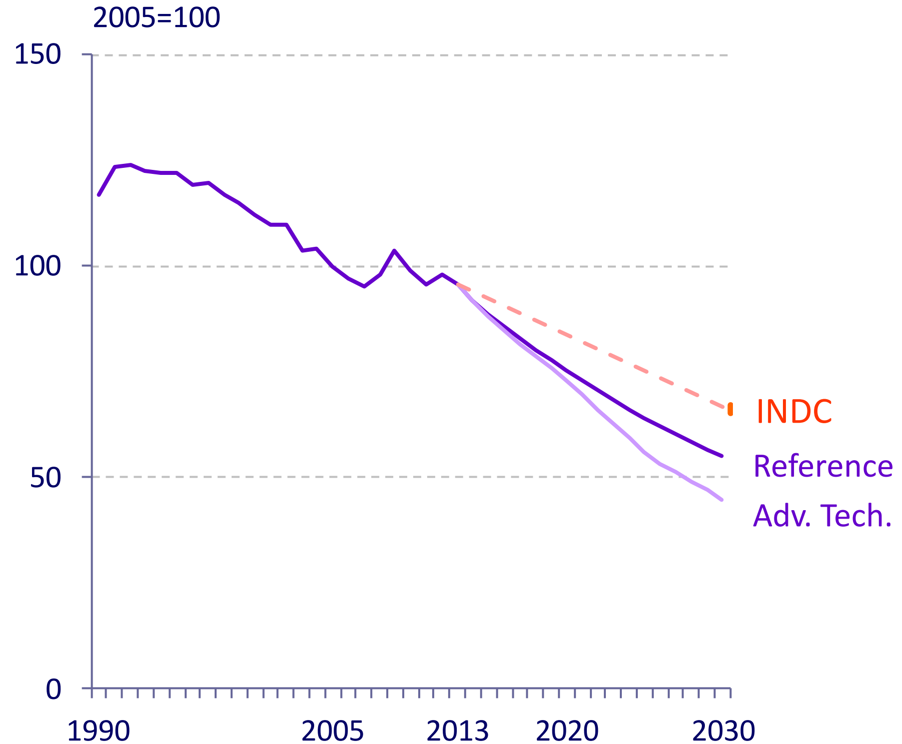
China

INDC：60 to 65% reduction from 2005



India

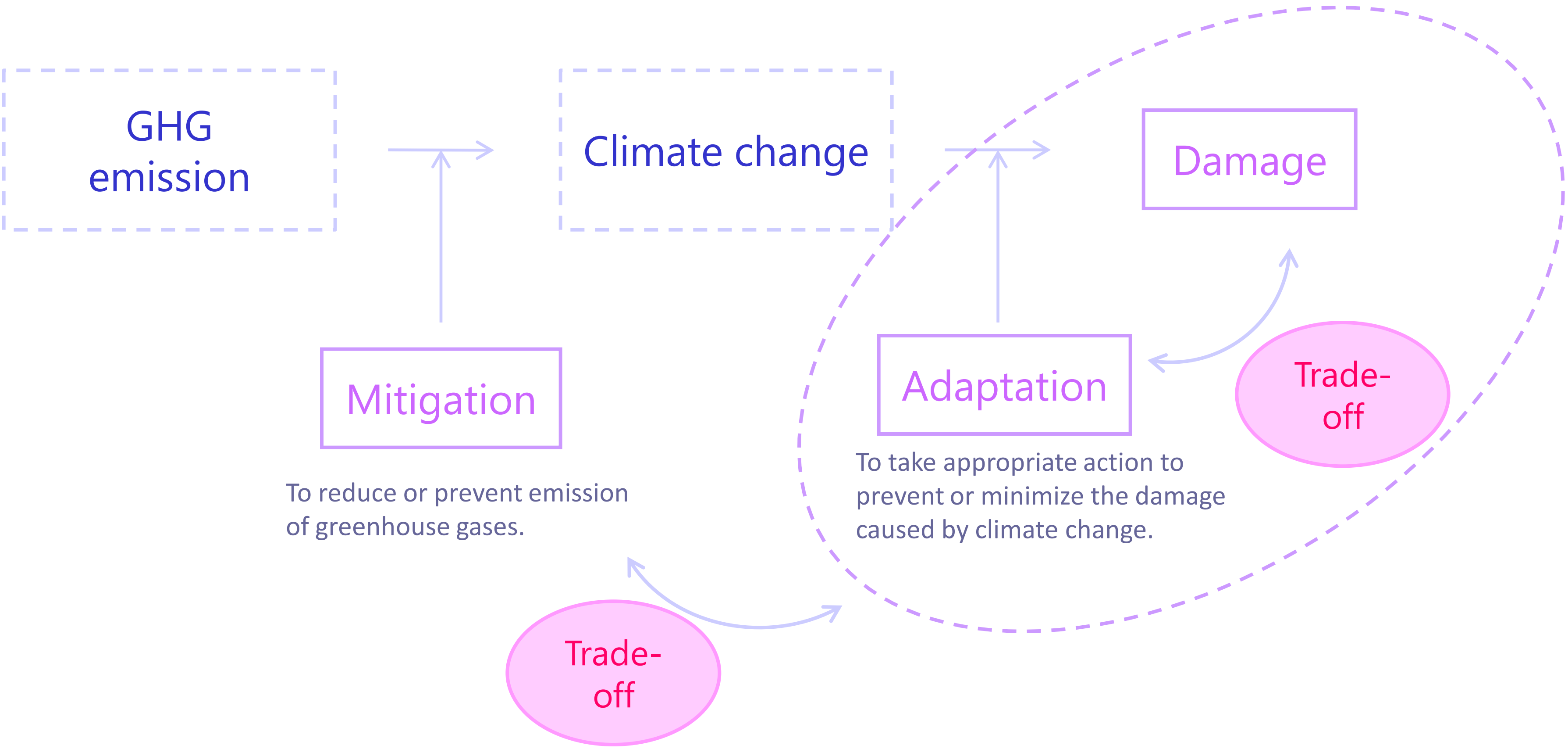
INDC：33 to 35% reduction from 2005



Assumed the reduction rate of CO_2 intensity as identical to that of GHG intensity.

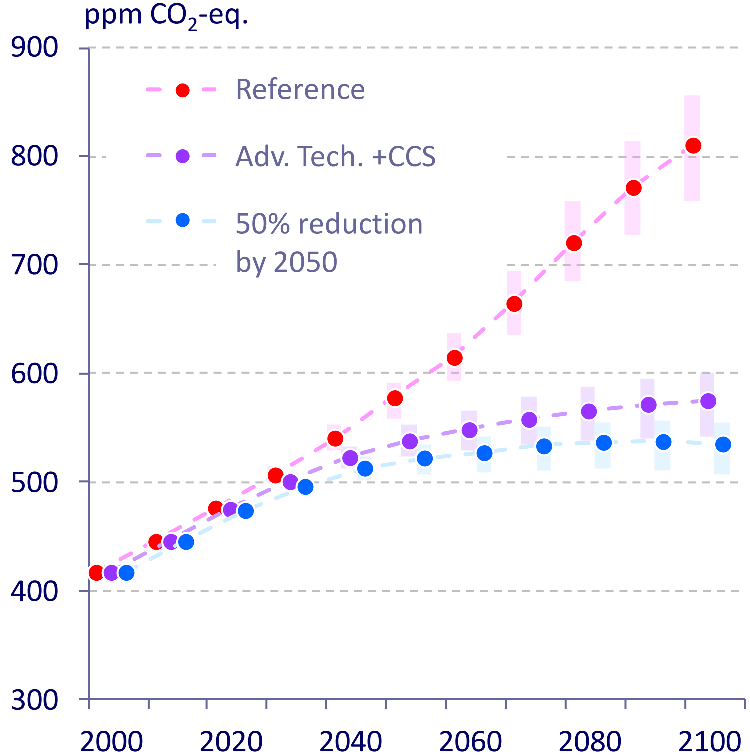
- In most countries including emerging nations, the GHG intensity (i.e. GHG emission divided by real GDP) has rapidly been declining, even though total GHG emission has been increasing.
- The continuation of the historical trends (the Reference Scenario) shows that the targets are hardly challenging.

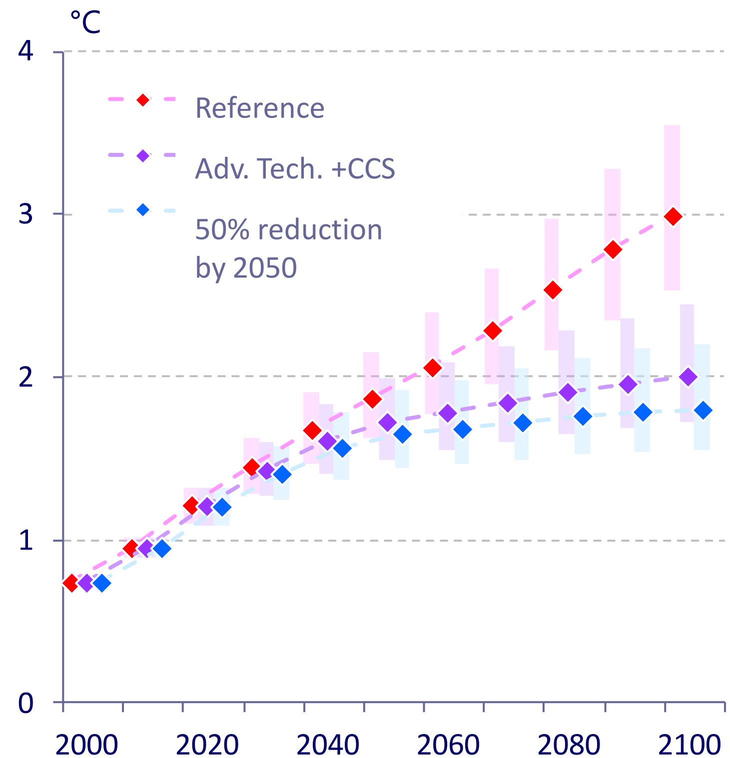
Mitigation, adaptation and damage costs



- There is a trade-off relationship among the mitigation, adaptation and damage costs. It is impossible to reduce all three costs at the same time.
- It would be realistic to expect a balance among the three, while minimizing the total cost.

Reference, Adv. Tech. and “50% reduction by 2050” scenarios





* The “CO_2-equivalent concentration” includes the forcing of all GHGs, as well as aerosols and albedo change.

- The results of the Reference Scenario correspond to a level of CO_2-eq. concentration in 2100 in the range of 760-860 ppm, with the average temperature rise from 1850-1900 reaching 2.8-4.0° C in the same year.
- On the other hand, the Advanced Technologies Scenario is comparable to CO_2-eq. concentrations in 2100 of 540-600 ppm, with the average rise in temperature between 1.7 and 2.4° C. This is lower than 2.5° C and possibly lower than 2° C in 2100.

450 ppm category in IPCC 5th Assessment Report

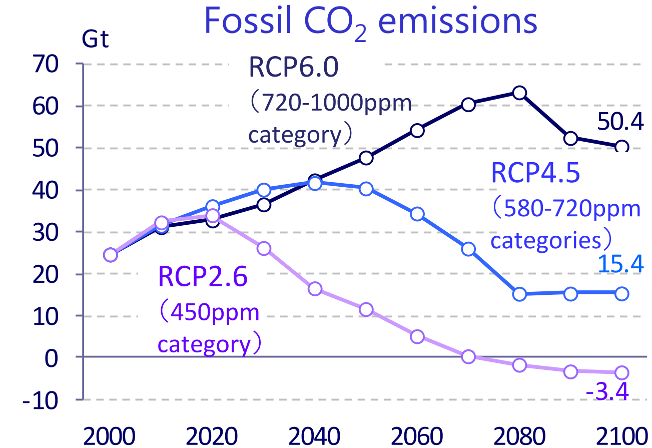
Scenarios in IPCC AR5 WG3

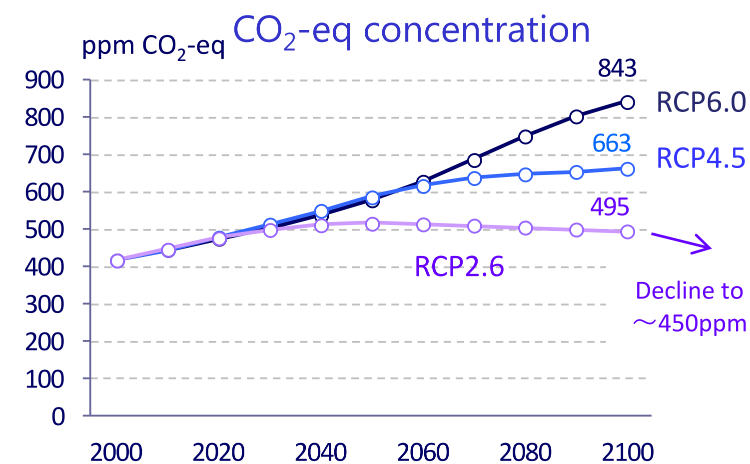
CO_2-eq Concentration* in 2100, ppm	Sub-category	Change in GHG emissions from 2010 to 2050, %	2100 temperature change relative to 1850-1900 (℃)**
450 (430-480)	Overshoot (vast majority)	-72 to -41	1.5 - 1.7 (1.0 - 2.8)
500 (480-530)	No overshoot	-57 to -42	1.7 - 1.9 (1.2 - 2.0)
	Overshoot	-55 to -25	1.8 - 2.0 (1.2 - 3.3)
550 (530-580)	No overshoot	-49 to -19	2.0 - 2.2 (1.4 - 3.6)
	Overshoot	-16 to +7	2.1 - 2.3 (1.4 - 3.6)
(580-650)		-38 to +24	2.3 - 2.6 (1.5 - 4.2)
(650-720)		-11 to +17	2.6 - 2.9 (1.8 - 4.5)
(720-1000)		+18 to +54	3.1 - 3.7 (2.1 - 5.8)

* The "CO_2-equivalent concentration" includes the forcing of all GHGs, as well as aerosols and albedo change.

** Temperatures in parentheses include carbon cycle and climate system uncertainties.

Source: IPCC AR5 WG3





※Calculated using MAGICC 6.0

Meinshausen, M., S. C. B. Raper and T. M. L. Wigley (2011). "Emulating coupled atmosphere-ocean and carbon cycle models with a simpler model, MAGICC6: Part I – Model Description and Calibration." Atmospheric Chemistry and Physics 11: 1417-1456.

- For the Representative Concentration Pathway (RCP) 2.6, which is a typical scenario for the "450ppm" category, the GHG concentration is estimated around 500 ppm CO_2-eq in 2100. In a longer term, the concentration declines to some 450 ppm.
- This scenario assumes 64% reduction of fossil CO_2 from 2010 to 2050, and negative emissions after 2070. It is much more ambitious than the "50% reduction by 2050" target.

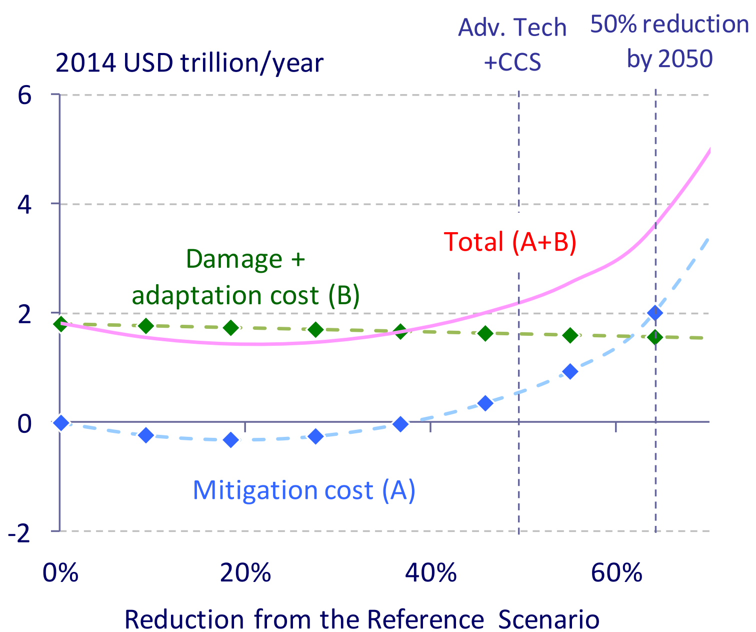
Mitigation vs. adaptation and damage

Mitigation cost: estimated by IEEJ
Damage + adaptation cost: calculated using the formula in the DICE 2013R model
Equilibrium Climate Sensitivity assumed at 3° C.

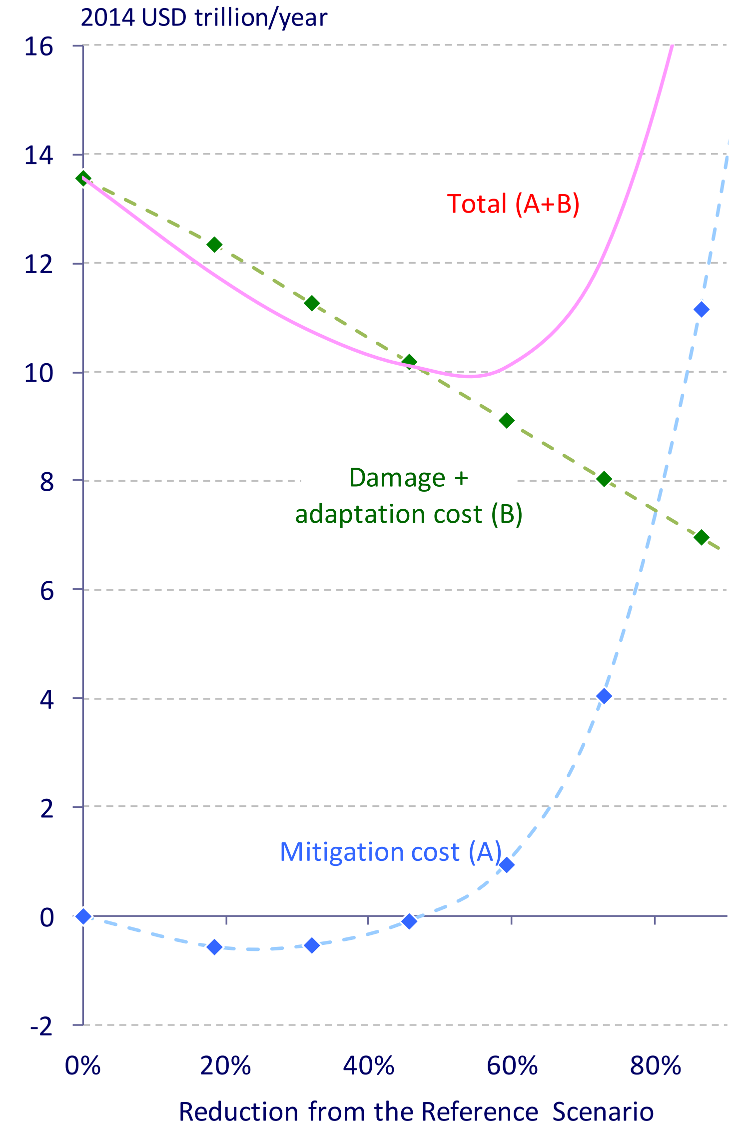
- In 2050 the temperature rise is relatively small (less than 2° C from the latter half of the 19th century), resulting in smaller damage.

- CO_2 reduction brings benefits (negative costs) to a certain extent due to the savings of fossil fuel consumption. If the reduction ratio exceeds that of the Advanced Technologies Scenario, however, the cost increases enormously.

- The damage costs also become tremendous after 2100. Thus a long-term perspective is indispensable to address the problem of climate change.

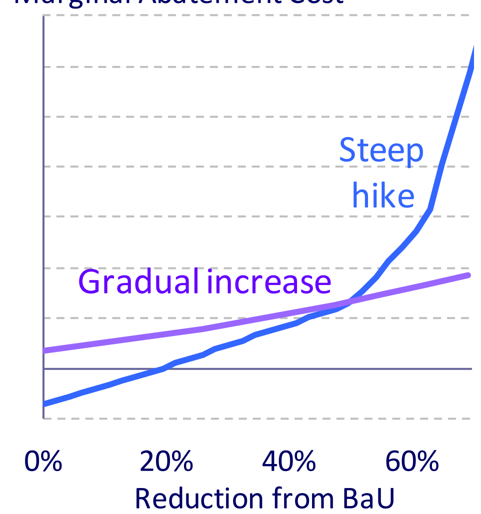


2050



2100

Uncertainty in estimating the long-term optimal path



Mitigation, adaptation and damage costs

- The estimation of these costs and damages are still at a very early stage. The uncertainty is extremely large.
- The mitigation cost hike with larger reduction ratio makes the achievement of “zero emission” or “negative emission” extremely difficult. Future R&D should aim to reduce this cost hike.

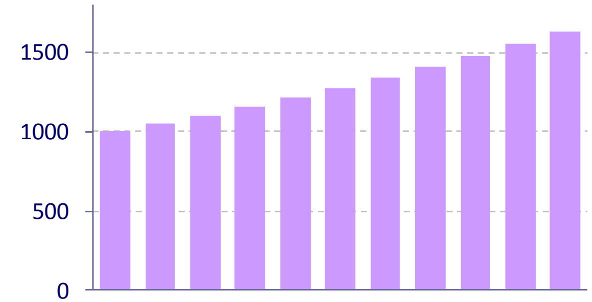
Equilibrium Climate Sensitivity (ECS)

- The temperature change in response to the changes in the radiative forcing is called the Equilibrium Climate Sensitivity (ECS).
- In IPCC AR4, it was estimated at 2.0 – 4.5°C with the best estimate at 3.0°C. However, recent studies tend to estimate ECS lower. In IPCC AR5, it was estimated at 2.0 – 4.5°C without any agreement on the best estimate.
- With lower ECS, damage caused by climate change becomes smaller, resulting in a less ambitious mitigation path being optimal.

Discount rate (social discount rate)

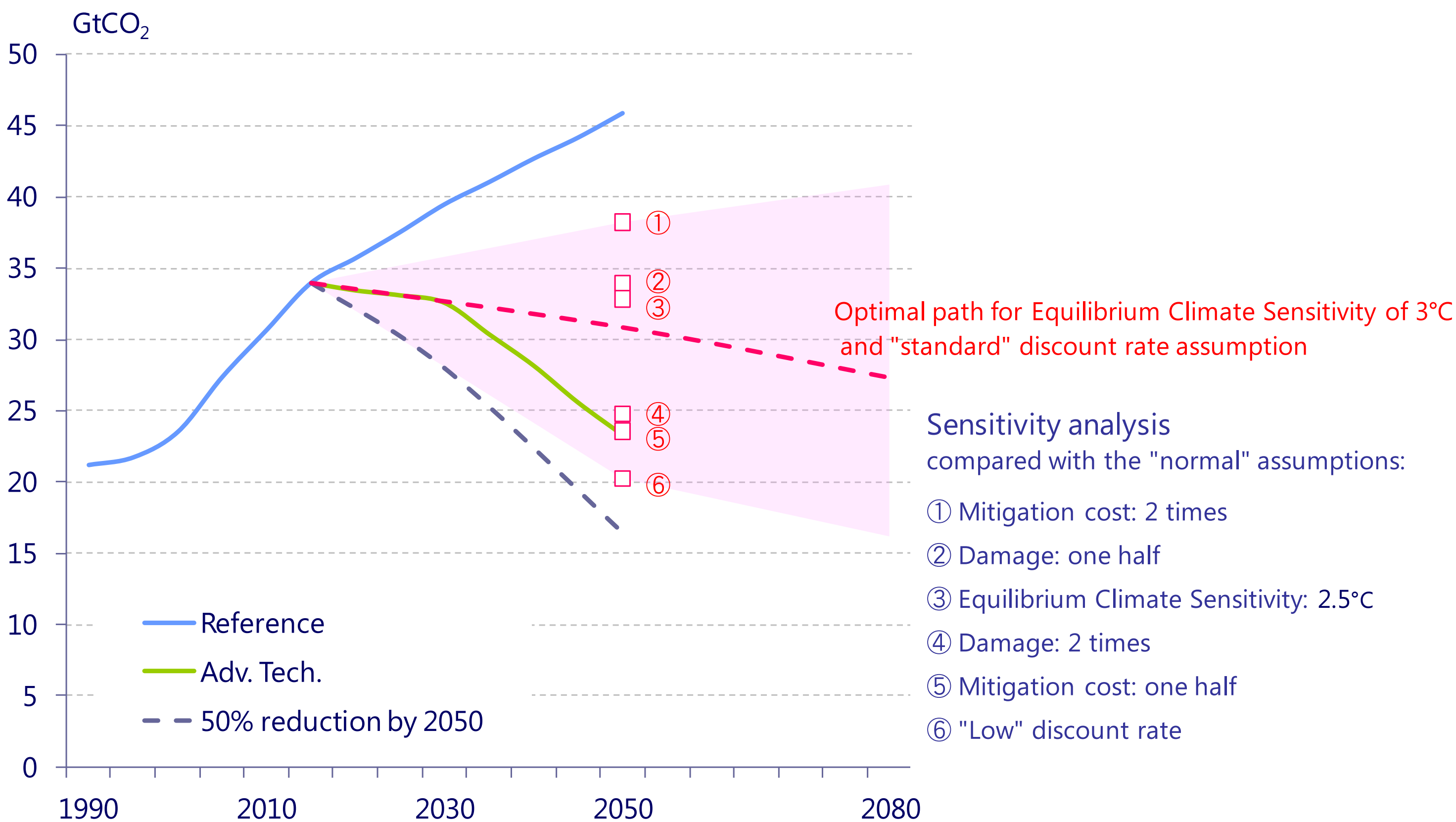
- An annual ratio used to convert a future value to the present value.
- When a certain rate of interest is expected for sure, the interest rate can be regarded as the discount rate.
- With higher discount rates, future climate damages are valued less, resulting in smaller mitigation being optimal.
- This study assumes the “normal” discount rate at around 4% in 2050, and the “low” discount rate at around 2% in 2050, under the assumptions as described later.

Case of discount rate at 5%



$1,000 of today worth $1,630 of 10 years from now. $1,000 in the future is equivalent to $610 today.

Example of the calculation of the long-term optimal path



- The optimal path considering mitigation and adaptation costs and climate damage shows a downward trend of CO_2 emission from the current level, although the uncertainty is very large.
- These calculations suggest that the paths to reduce 50% or more from current levels by 2050 result in enormous mitigation costs compared with the damage, and cannot be regarded as optimal, even assuming lower discount rates.
- In order to achieve zero or negative emissions in a longer term, technological innovation would be needed to reduce the cost hike with larger CO_2 reduction ratios.

Social discount rate

The "social discount rate" ρ can be formulated as follows (Ramsey's formula):

$$\rho = \delta + \eta g$$

δ: Pure rate of time preference

g: Growth rate of per capita consumption η: Elasticity of marginal utility with respect to consumption

If the economic (and consumption) growth rate declines in the future, the discount rate also declines according to this formula.

"Standard" assumption

Calibrate the parameters to match the observed market interest rates.

Example： $\delta = 1.5\%$、$\eta = 1.45$ (DICE 2013R model)

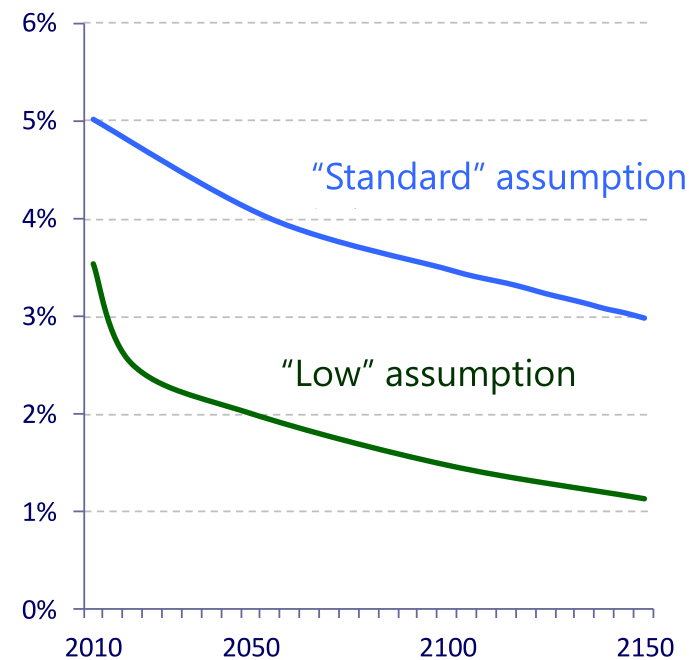
⇒ Discount rate: 5% in 2010, 4% in 2050 and 3.5% in 2100

"Low" assumption

Set the parameters normatively irrespective of the observed interest rates, from the viewpoint of intergenerational justice.

Example： $\delta = 0.1\%$、$\eta = 1.0$ (Stern review)

⇒ Discount rate: 3.5% in 2010, 2% in 2050 and 1.5% in 2100



Innovative technology development towards the future

Technology		Overview and challenges
Reducing the production of CO_2	**Next generation nuclear power**	Advanced nuclear technologies under development worldwide, including fast breeder reactors, high temperature gas-cooled reactors, molten salt reactors and small modular reactors.
	Nuclear fusion	Unlike the conventional nuclear technologies that exploit the energy released by the fission of heavy nuclei, nuclear fusion makes use of the energy released during the reaction (fusion) of light nuclei. This technology could possibly result in a almost limitless supply of energy, without producing spent fuels as high-level radioactive wastes.
	Space Solar Power System (SSPS)	A system that transmits energy from space-based solar power plants to the ground in the form of microwaves or laser beams. It can generate power stably with almost no influence from the weather. Reducing the costs of mass transition through space is one of the major challenges.
Preventing the release of CO_2 to the atmosphere	**Bioenergy and Carbon Capture and Storage (BECCS)**	The technology to capture and store the carbon dioxide released by burning biofuels. If the biofuel can be regarded as carbon neutral, this technology makes it possible to achieve negative emissions. Barriers to large-scale deployment of BECCS include risks related to transport and provision of biomass feedstock.
Utilizing the produced CO_2	**Carbon Capture and Utilization (CCU)**	The technologies to capture and use carbon dioxide as industrial materials, etc. Large-scale processing of CO_2 is one of the major challenges.
	Artificial photosynthesis	A chemical process to convert sunlight, water and carbon dioxide into carbohydrates and oxygen. As with the BECCS technology, it could realize negative emissions. Major challenges include the development of the catalysis to split water into hydrogen and oxygen.

Conclusion: Addressing climate change issues

・ With the climate actions suggested by the INDCs of major countries, it would not be possible to curb GHG emissions to sufficient levels. It is strongly expected that each party tries its best to reduce GHG emissions further.

・ At the same time, we should note that there is a trade-off relationship among the mitigation, adaptation and damage costs. It would be realistic to expect a balance among the three, while minimizing the total cost. Otherwise no international agreements would be obtained.

・ From this point of view, it is necessary to take actions against climate change considering various scenarios and options other than only the "450ppm" scenario.

・ Long-term measures have to be taken beyond 2050 to reduce global CO_2 emissions drastically. In addition to existing technologies, innovative technologies including CCS, CCU and artificial photosynthesis have to be developed to accomplish the target.

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