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Toranomon Hills Forum

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Evaluations on Emission Reduction Efforts of Nationally Determined Contributions under the Paris Agreement

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Contents

1. Background and objectives

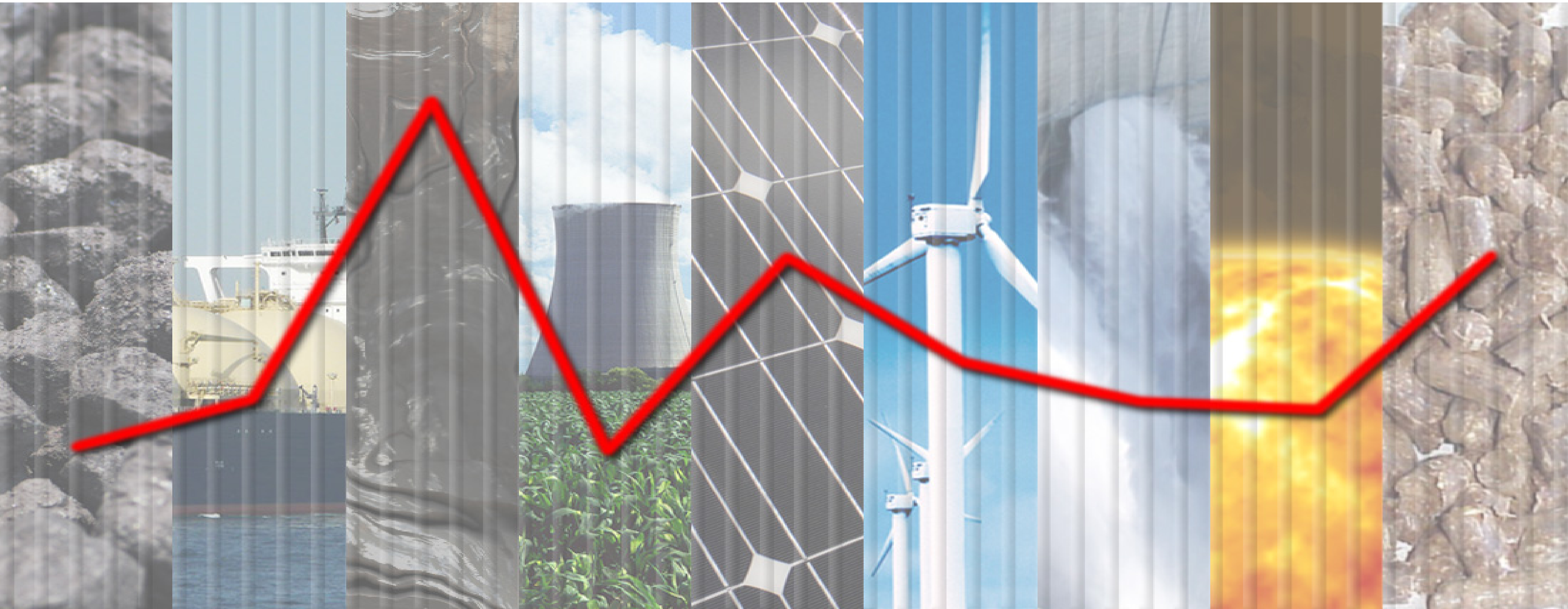
Background and objectives of ALPS project and its major topics

Climate change is a very complex issue. Effectiveness of response measures in the real world is important. The aim of the ALPS project is to support the developments of international frameworks to achieve green growth and effective response measures through better understandings of technologies, economics, policies etc. and quantitative analyses and evaluations.

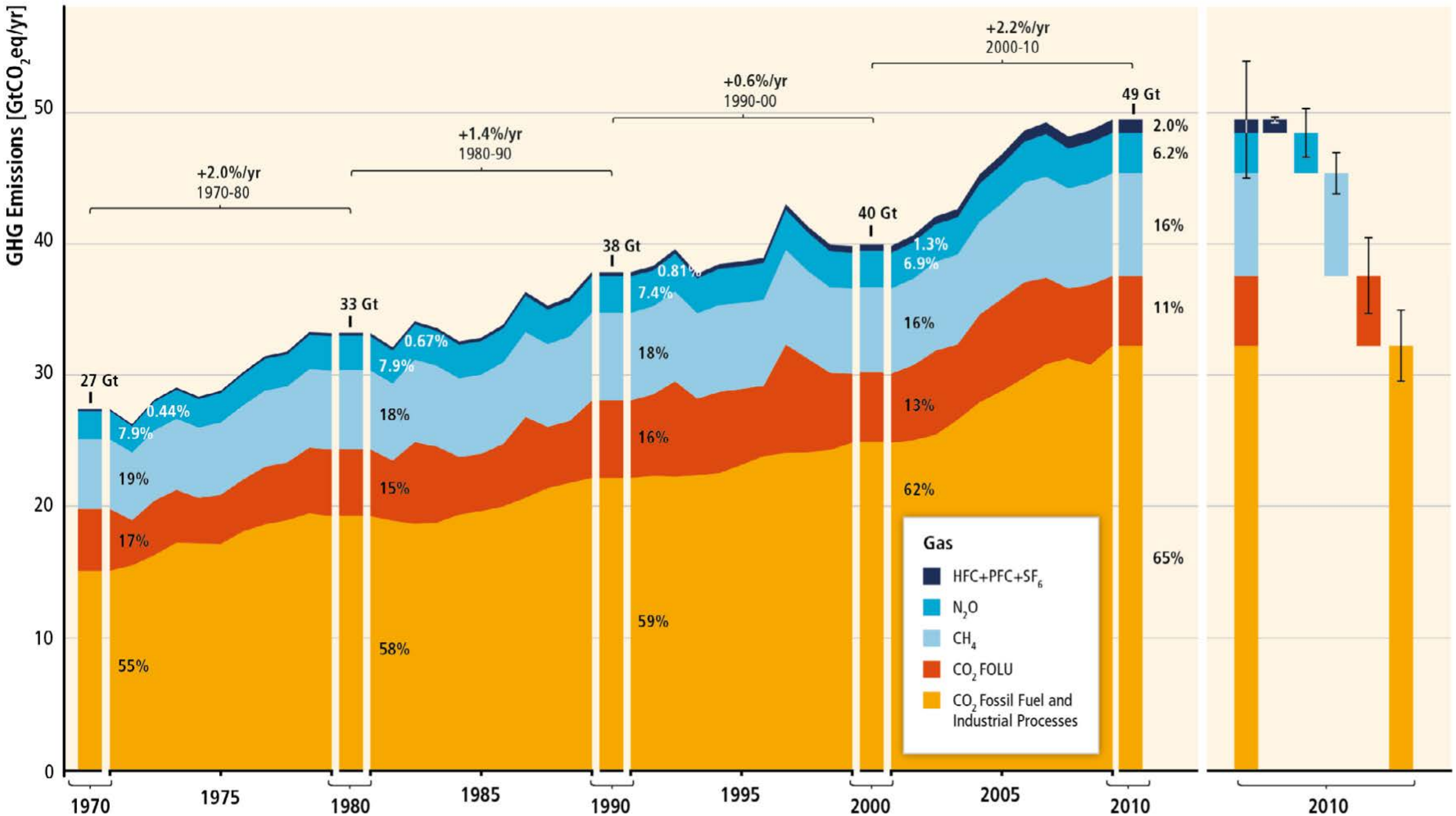
【major topics】

- **Risk management strategy for climate change responses**
  - Estimates of climate change damages, adaptations, and mitigation costs and their uncertainties
  - Long-term target and the corresponding emission pathways
  - Risk management strategy for climate change responses under uncertainties etc.
- **Better and deeper understandings of economics for real green growth**
  - Consideration of the possibilities and limitations of removing energy saving barriers, relationship between climate change and air pollution mitigation, etc., and evaluation based on model analyses
  - Estimations of international energy productivity gaps (comparisons between the U.S. and Japan)
  - Analyses for international financial constraint to coal power installation etc.
- **Climate change mitigation measures, particularly the integrated measures.**
  - hydrogen systems (total systems including supply, transport, consumption)
  - opportunities of integrated measures of building, and transportations etc.
- **Analyses regarding international frameworks, discussions and policy interests**
  - Evaluations of emission reduction targets of NDCs
  - Contributions to international model comparison projects etc.

2. Understanding on current global greenhouse gas emissions



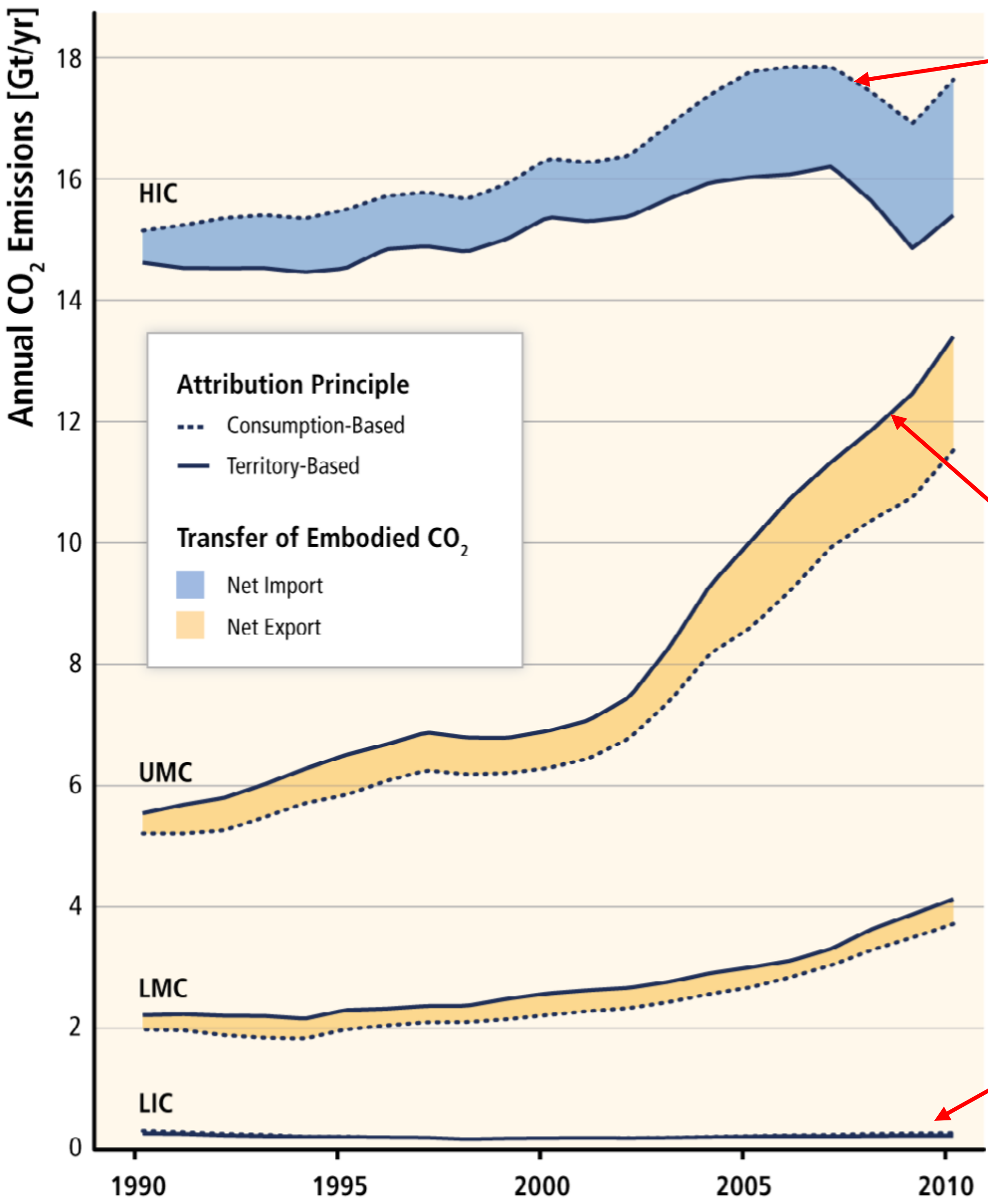
Trajectory of Global GHG Emission by Source



Source) IPCC AR5, 2014

The global emissions after 2000 increased more rapidly. The Kyoto Protocol was not able to exert large effects on emission reductions.

Trajectory of Global CO_2 Emission by Region



Consumption-based CO_2 emissions have not decreased even in HIC.

High income countries
($12,616 and more)

Upper middle income countries
($4,086 to $12,615)
(China, Brazil, Iran, Malaysia, South Africa etc.)

Rapid increase in CO_2 emissions

Lower middle income countries
($1,036 to $4,085)
(India, Indonesia, Philippine, Egypt etc.)

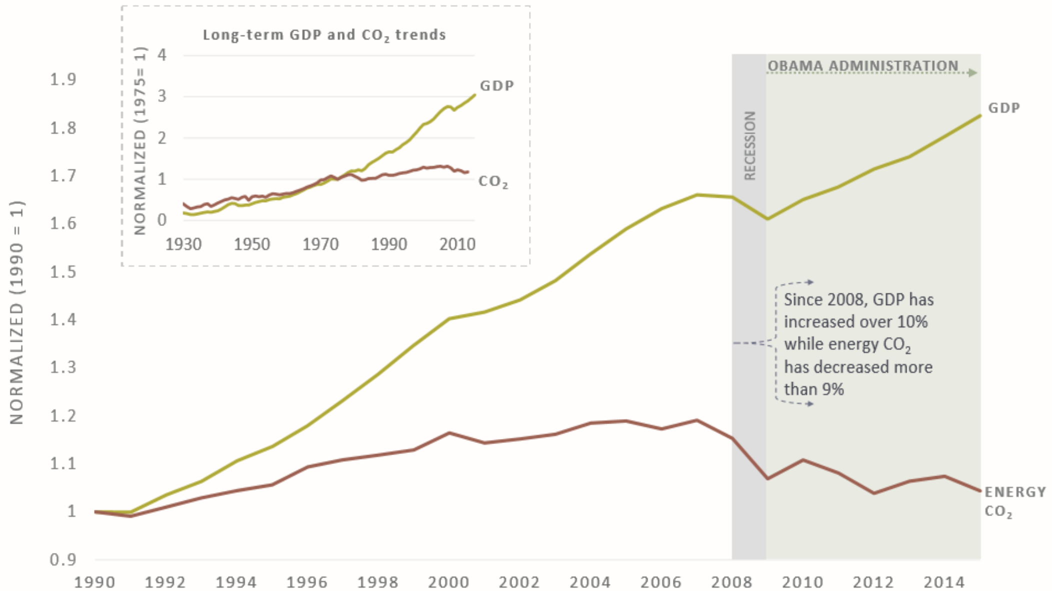
Tackling poverty; lower priority to CO_2 emission mitigation

Low income countries
($1,035 and less)

Source) IPCC AR5, 2014

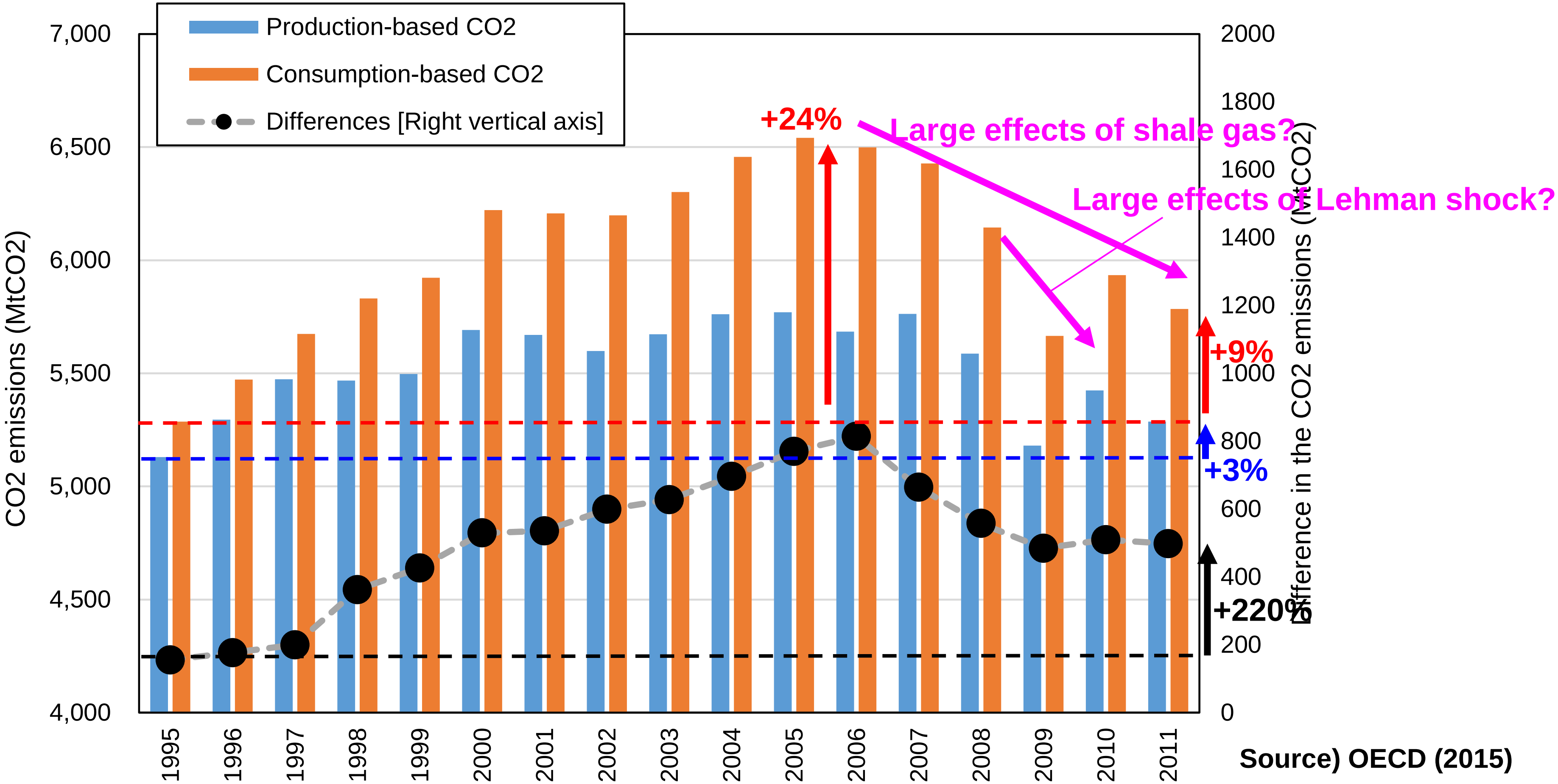
A paper by President Obama "The irreversible momentum of clean energy", Science, January 9, 2017

- CO2 emissions from the energy sector fell by 9.5% from 2008 to 2015, while the economy grew by more than 10%.
- This "decoupling" of energy sector emissions and economic growth should put to rest the argument that combatting climate change requires accepting lower growth or a lower standard of living.
- The American electric-power sector—the largest source of GHG emissions in our economy—is being transformed, in large part, because of market dynamics. In 2008, natural gas made up ~21% of U.S. electricity generation. Today, it makes up ~33%, an increase due almost entirely to the shift from higher-emitting coal to lower-emitting natural gas.
- Renewable electricity costs also fell dramatically between 2008 and 2015: the cost of electricity fell 41% for wind, 54% for rooftop PV installations, and 64% for utility-scale PV.
- Public policy—ranging from Recovery Act investments to recent tax credit extensions—has played a crucial role, but technology advances and market forces will continue to drive renewable deployment.
- The latest science and economics provide a helpful guide for what the future may bring, in many cases independent of near-term policy choices, when it comes to combatting climate change and transitioning to a clean-energy economy.



Source: United States Mid-Century Strategy for Deep Decarbonization, Nov. 2016

Consumption-based CO2 emissions of the U.S.

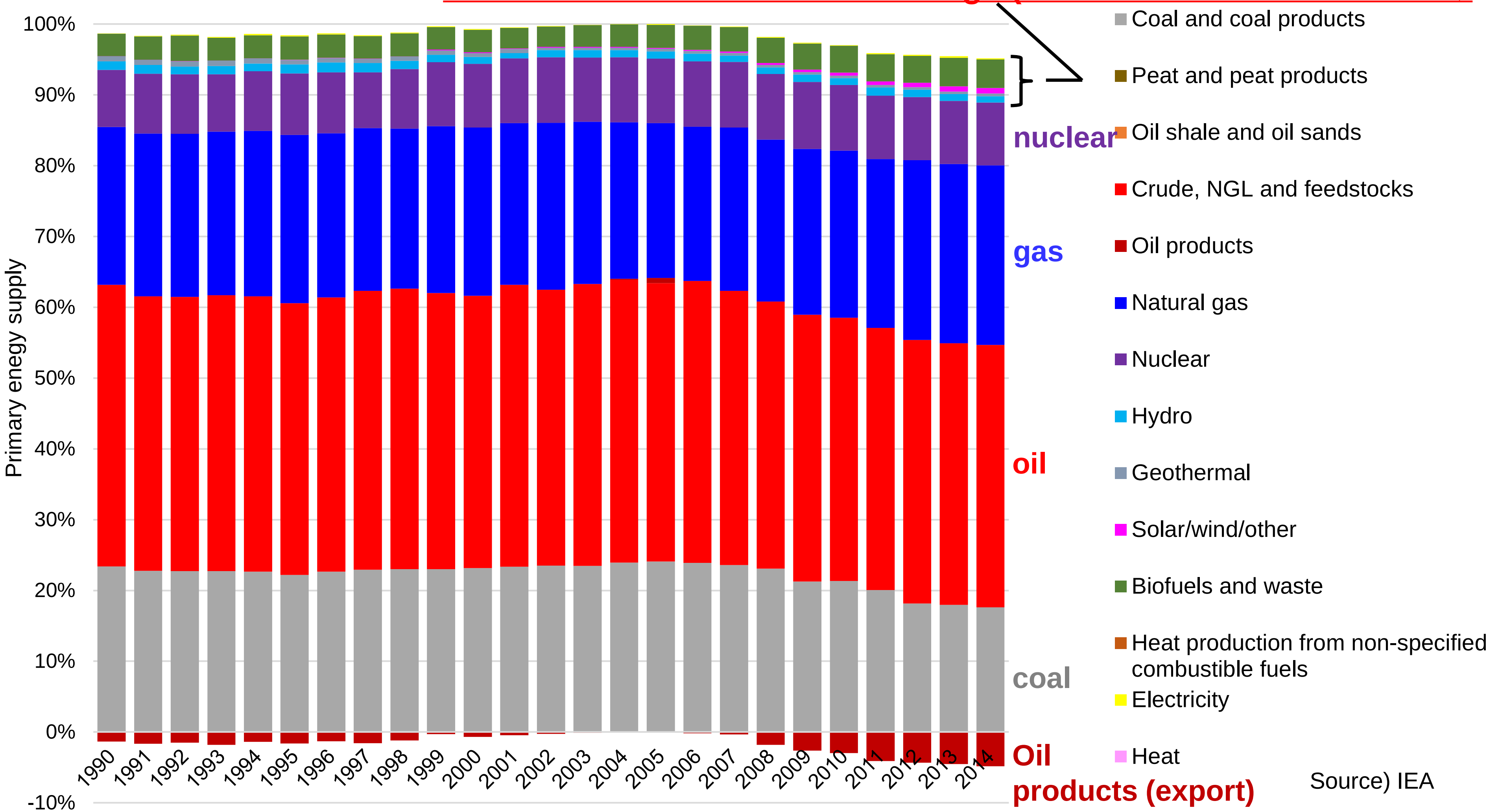


Source) OECD (2015)

- The difference between the consumption-based CO2 and the production-based CO2 had greatly increased by 2005 in the U.S. The consumption-based CO2 in 2005 was +24% compared to that in 1995.
- On the other hand, the difference became small from the 2006 in which shale gas expanded. However, the consumption-based CO2 in 2011 was +9% compared to that in 1995. (The production-based CO2 was +3%.)

The U.S. Primary Energy Supply

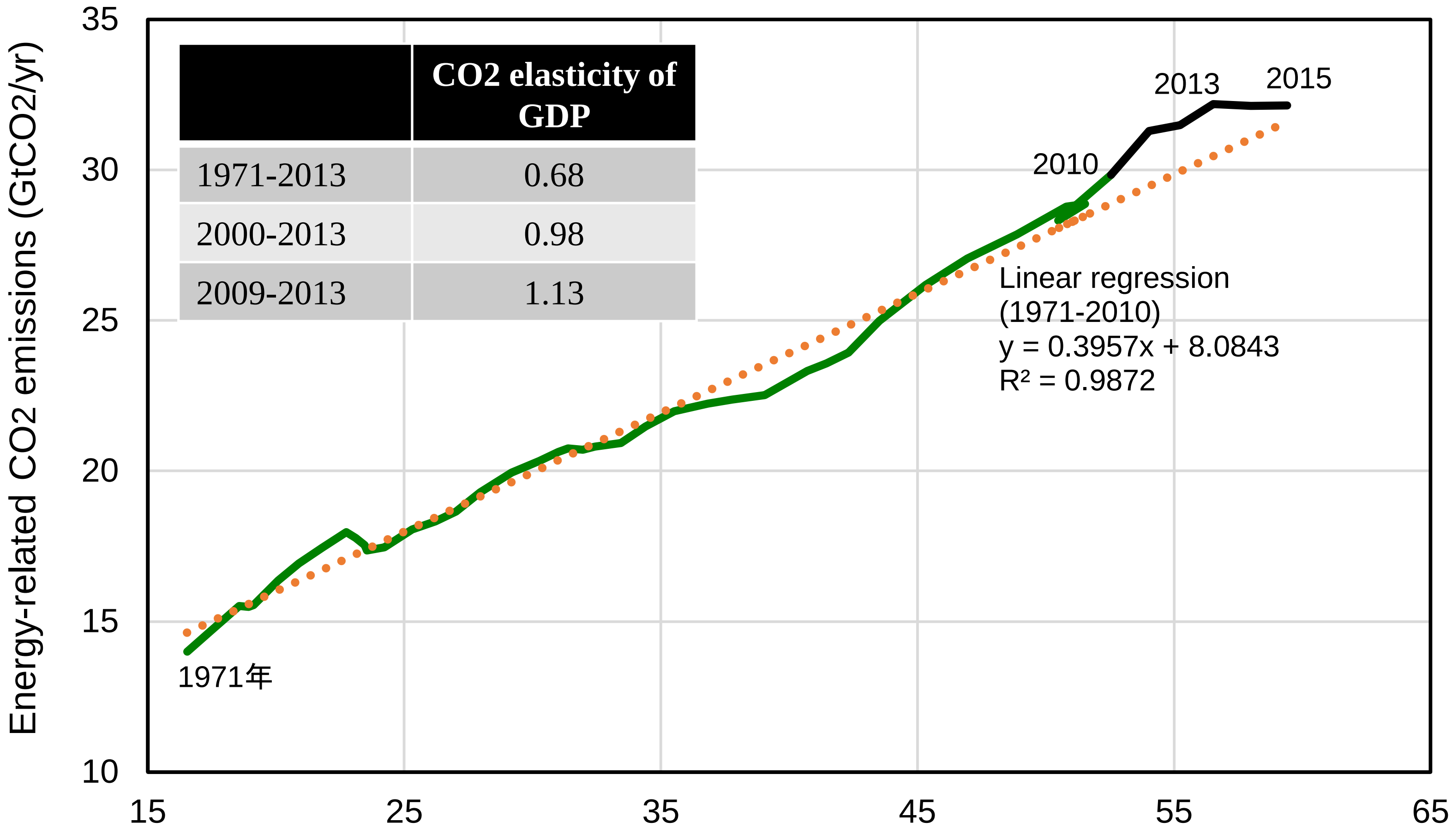
Renewable increase is not so large (4.8% in 2000⇒6.7% in 2014)



Source) IEA

Coal supply has decreased and gas share has increased since 2005 due to increases in shale gas productions, and this contributes to CO_2 emission reductions. Gas increase induced exports of oil products, which does not contribute to global CO_2 emission reductions. We should note that the shale gas expansions were not induced by climate policies.

The relationship between global GDP growth and global CO_2 emission **between 1971 and 2015**

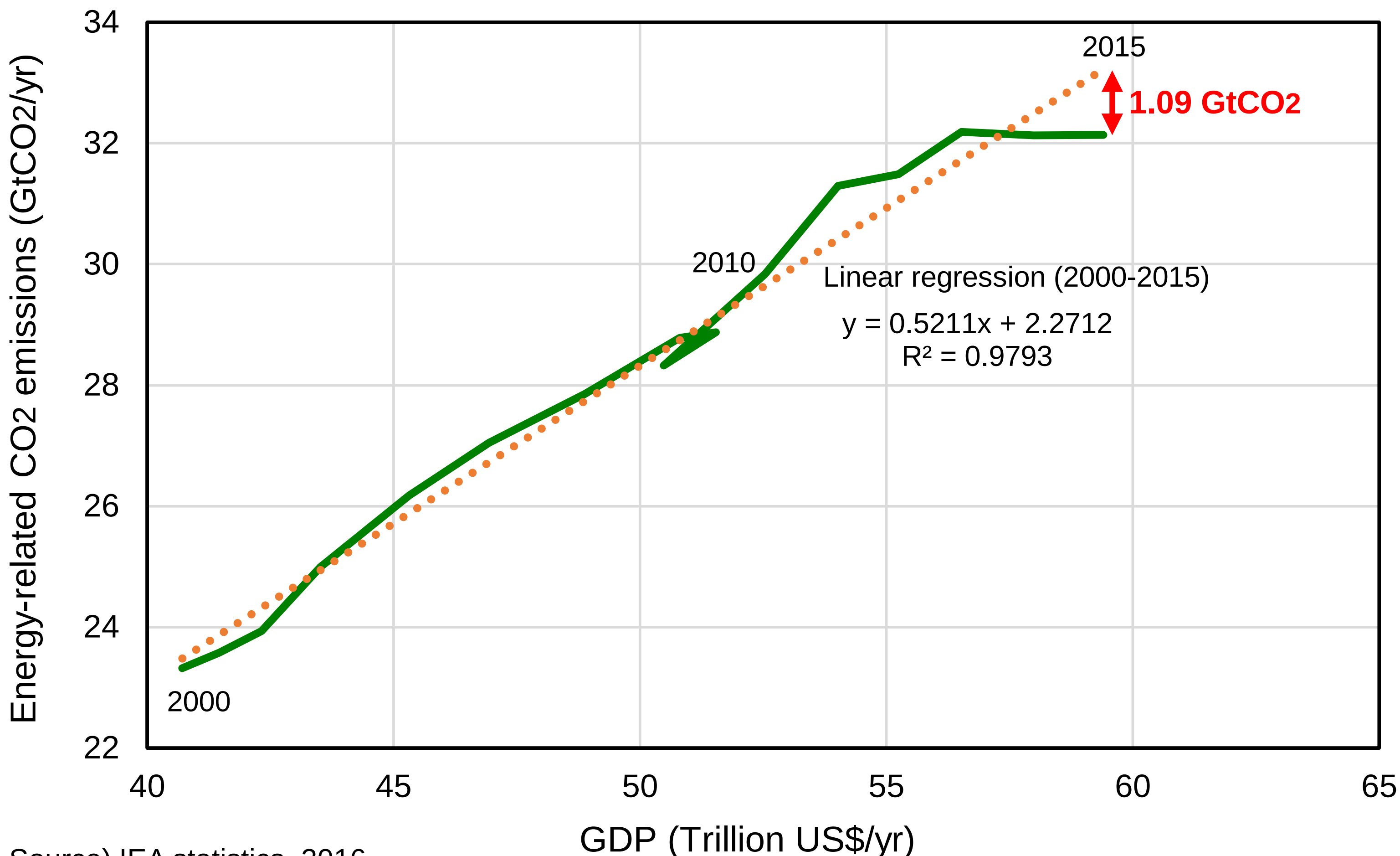


	CO2 elasticity of GDP
1971-2013	0.68
2000-2013	0.98
2009-2013	1.13

Source) IEA statistics, 2016

The strong positive relationship between global GDP and CO2 emissions was observed. On the other hand, global CO2 emissions from 2013 to 2015 were almost constant; however, compared to the long-term trend, the emission increase from 2009 to 2013 was too rapid, and the trend from 2013 to 2015 can be explained just as a return to the historical regression trend.

The relationship between global GDP growth and global CO_2 emission between 2000 and 2015

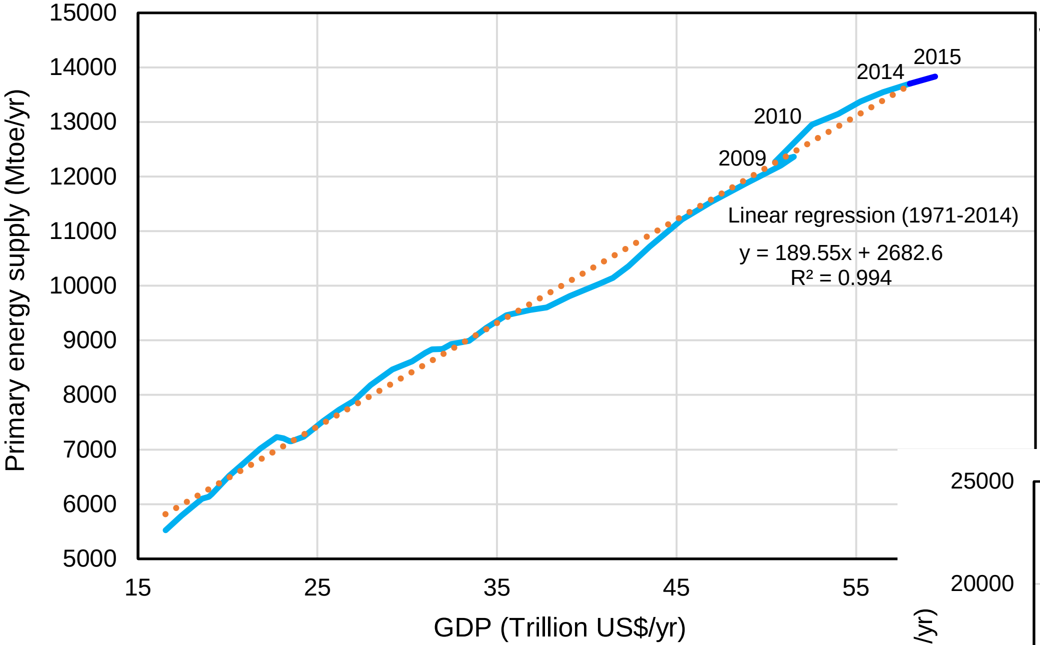


Source) IEA statistics, 2016

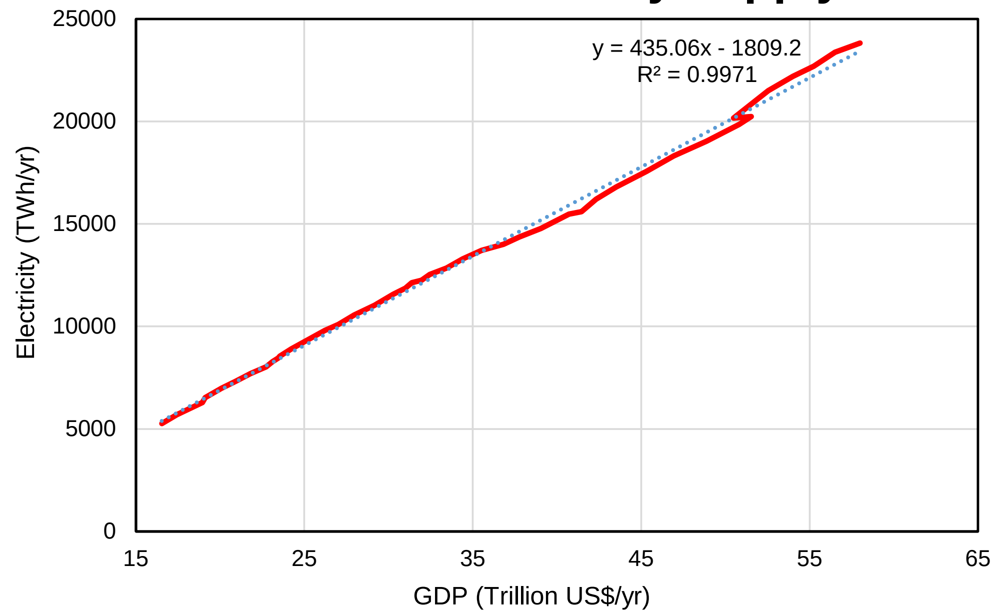
While the emission in 2013-15 is regarded just as a return to the long-term trend (1971-2015), the gap between the emission expected from the linear regression for a shorter term trend (2000-2015) and the actual emission in 2015 was estimated to be about 1090 MtCO2/yr in 2015.

Global GDP growth v.s. primary energy and electricity

World primary energy supply



World electricity supply



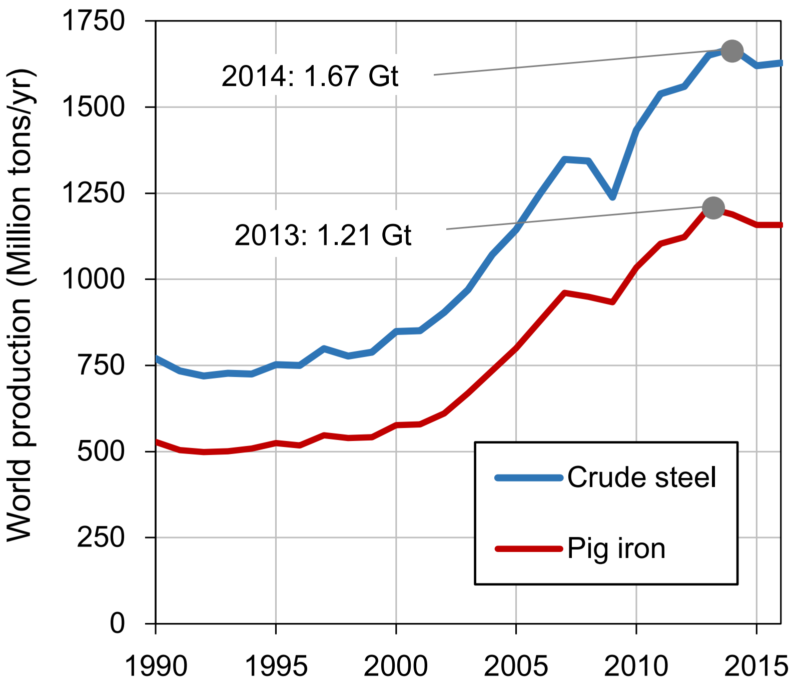
1971～2014

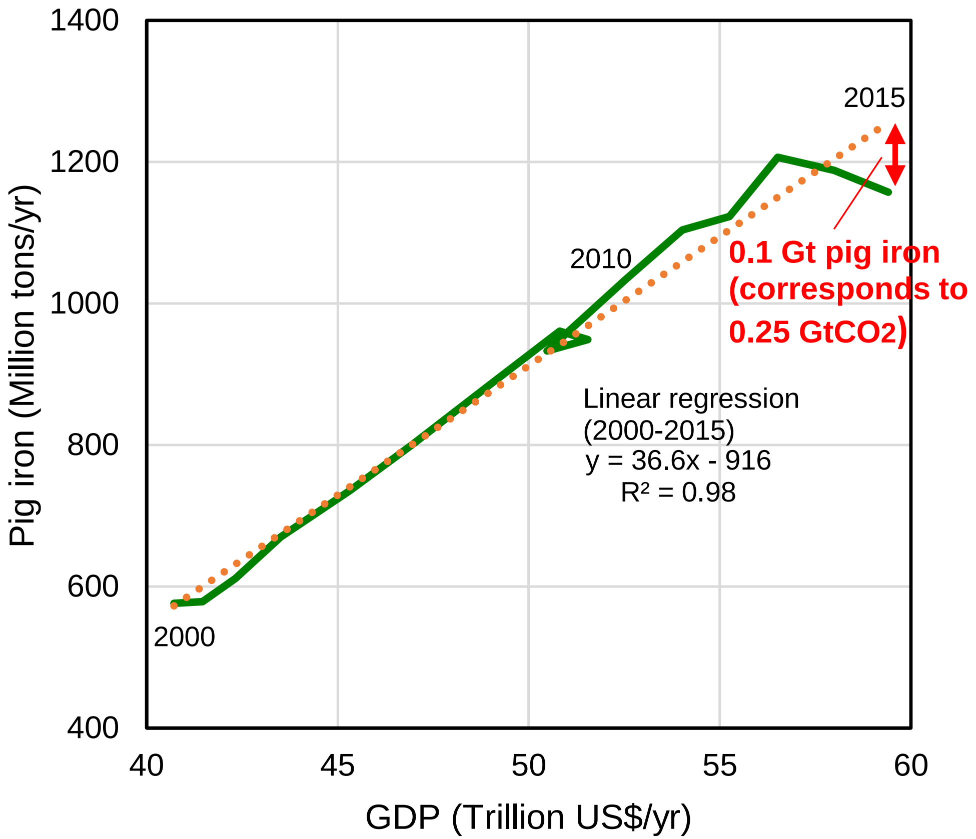
Source) IEA, 2016

The relationship between the global GDP and the primary energy supply or electricity consumption shows a stronger linearity than that between the GDP and CO2 emissions. With respect to primary energy and electricity supply, no decoupling with GDP is observed.

The relationship between global GDP growth and global iron and steel productions

Note: Production data in 2016 is based on preliminary figures released by worldsteel.





Global productions of pig iron in 2013 was about 1.2 Gton and decreased toward 2015 due to decrease in demands of China. From the trend of global GDP and pig iron productions between 2000 and 2015, the production decreased by about 0.1 Gton in 2015, and this corresponds to CO_2 emission reductions of about 0.25 $GtCO_2$.

Rough estimations of global emission reduction effects in 2015

Emission reduction factors	Emission reduction effects in 2015	Specific factors
Reductions in global iron production	about 250 MtCO2/yr	Decrease in global iron production of about 100 ton (particularly in China)
Reductions in global cement production	about 50 MtCO2/yr	Decrease in global cement production of about 170 ton (particularly in China)
Emission reductions due to increase in shale gas in the U.S.	about 220 MtCO2/yr	Shifts from coal to gas (shale gas) economically in the U.S.
Expansion of renewable energies	about 160 MtCO2/yr	Higher expansions by 1.2%/yr point compared with the average annual expansion rate between 2000 and 2015
Reduction in CO2 emissions of Japan	about 40 MtCO2/yr	Due to Fukushima-daiichi nuclear power accident, the emission in Japan increased by about 110 $MtCO_2$ from 2011 to 2013, but by about 70 $MtCO_2$ from 2011 to 2015
sub-total	about **720** MtCO2/yr	
Total emission reductions	about **1090** MtCO2/yr	

- The emission reduction effects due to reductions in iron and cement productions were observed as only temporary effects because of the decrease in China, and global productions of iron and cement will increase to meet growing demands in India etc.
- For renewables, the expansions are considered as the effects of political support such as FiT. This is not necessarily regarded as an example of “decoupling”.

3. Evaluations on the NDCs (emission reductions) for the Paris Agreement

The Paris Agreement; significance and concern

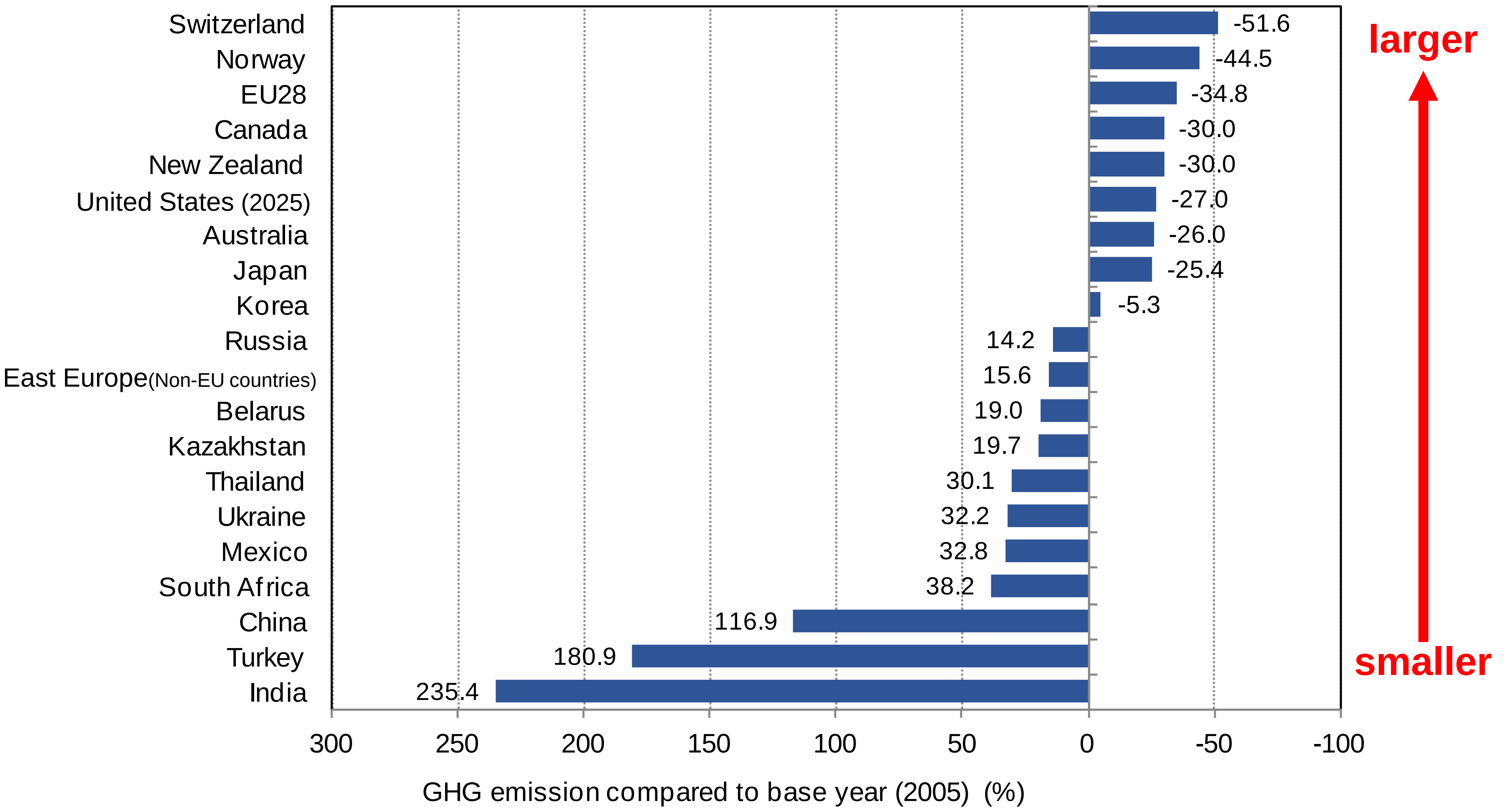
- **Almost all nations participated in the Paris Agreement and are expected to tackle emission reductions continuously, and the Paris Agreement is welcomed as a first step to achieve the green growth.**
- **However, appropriate reviews of NDCs are crucially important, measuring emission reduction efforts.**
- **If marginal abatement costs of emission reduction targets vary largely across nations, leakages of industries and carbon and consequent ineffectiveness in emission reductions will be a great concern.**

How to measure the comparability of efforts

The submitted NDCs are expressed using various kinds of targets; the targets of emissions reduction from different base years, CO_2 intensity, and CO_2 emission reductions from baseline (w/w.o. clear definition of baseline). We need to interpret them through comparable metrics to measure the efforts:

- **Simple metrics (easily measurable and replicable)**
  - **Emissions reduction from the same base year**
  - **etc.**
- **Advanced metrics (more comprehensive, but require forecasts)**
  - **Emission reduction ratios from baseline emissions**
  - **Emissions per unit of GDP**
  - **etc.**
- **More advanced metrics (most comprehensive, but require modeling)**
  - **Energy price impacts**
  - **Marginal abatement cost (per ton of CO_2)**
  - **Abatement costs as a share of GDP**
  - **etc.**

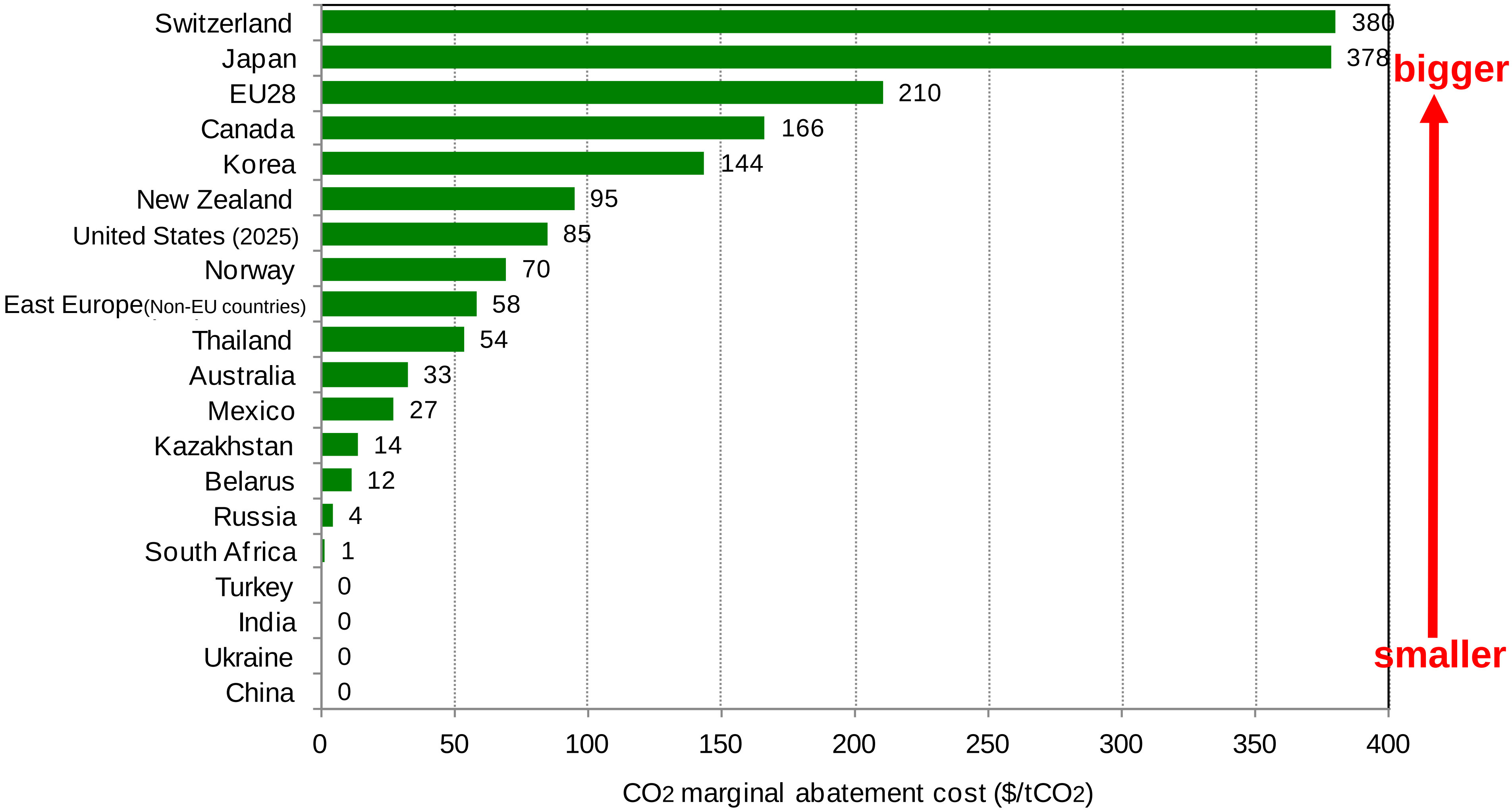
International comparison of emission reduction ratios in 2030 (in 2025 for the U.S.) from the base year of 2005



* The average values are shown for the countries submitted the NDC with the upper and lower ranges.

It is not easy to measure 'emission reduction efforts' by using the emission reduction ratios from a certain base year due to large differences across countries in future economic growth and historical achievements of energy saving and emission reductions, for example.

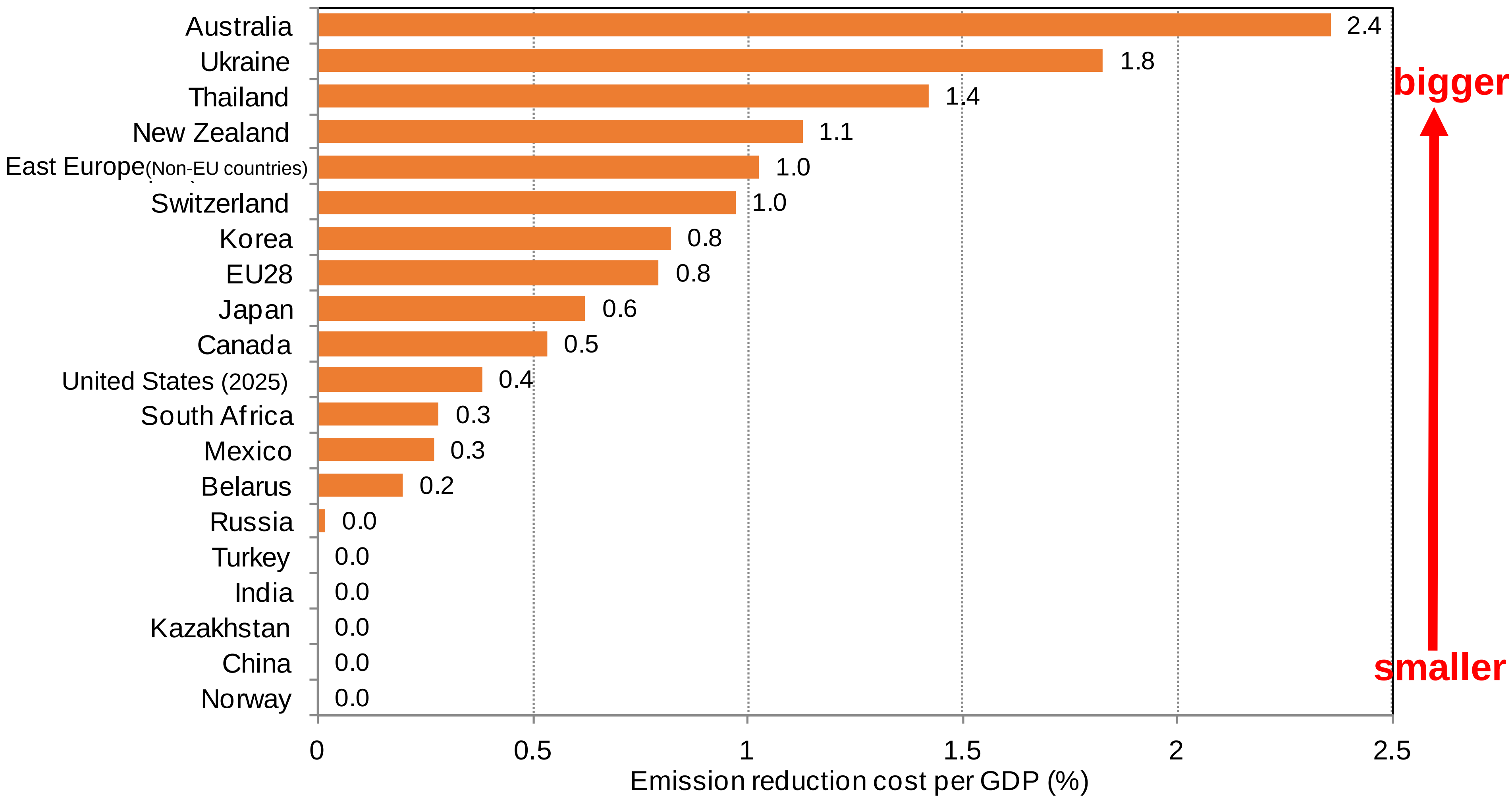
International comparison of CO_2 marginal abatement costs in 2030 (in 2025 for the U.S.) (RITE DNE21+ model)



* The average values are shown for the countries submitted the NDC with the upper and lower ranges.

Large differences in marginal abatement costs are estimated across countries. The large differences raise concern about inducing the carbon leakage and the ineffectiveness of global emission reductions.

International comparison of emission reduction costs per GDP in 2030 (in 2025 for the U.S.) (RITE DNE21+ model)

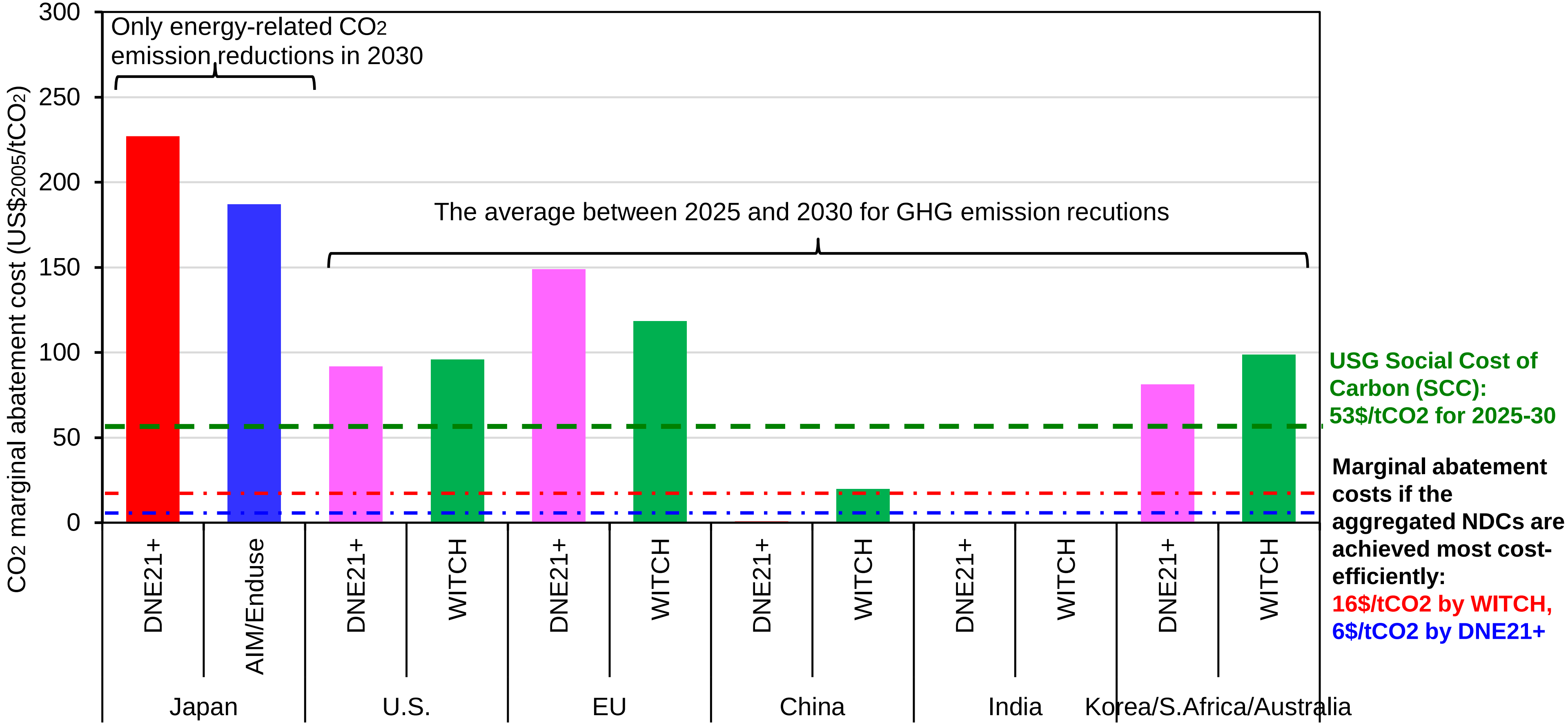


* The average values are shown for the countries submitted the NDC with the upper and lower ranges.

Note: The emission reduction costs include the net cost changes due to changes of energy import and export.

This indicator is a metric in terms of the economy's capability of emission reductions.

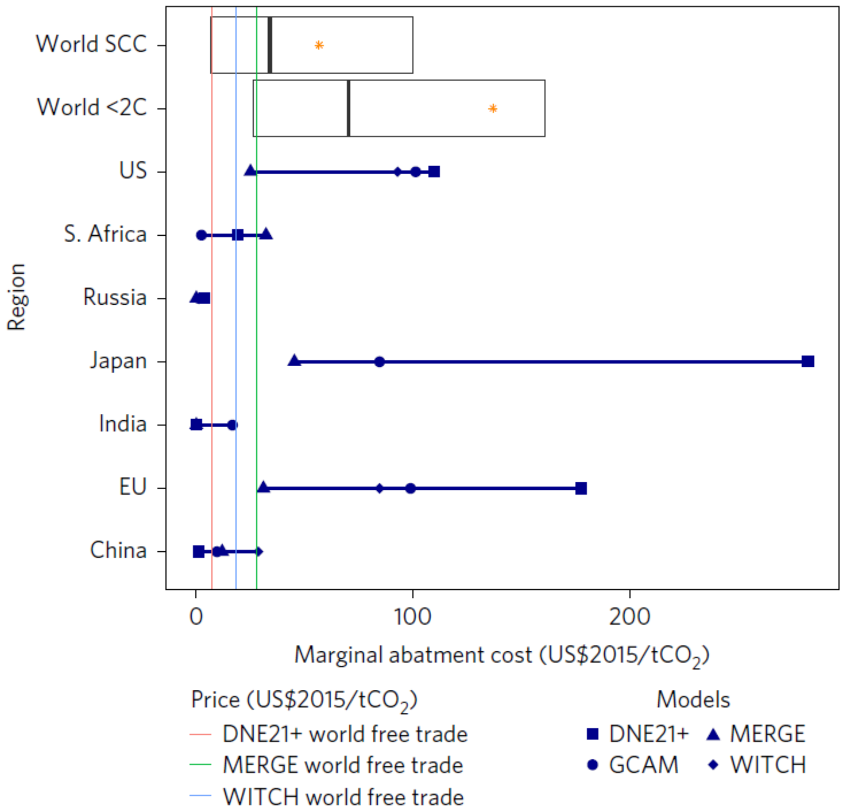
Marginal abatement costs estimations across models (RITE DNE21+, FEEM WITCH and NIES AIM)



Source: B. Pizer, J. Aldy, R. Kopp, K. Akimoto, F. Sano, M. Tavoni, COP21 side-event; MILES project report for Japan

- The marginal abatement costs vary across models for some countries, but can be comparable for many countries/regions.
- The CO_2 marginal abatement costs of the NDCs of OECD countries are much higher than the uniform marginal cost for achieving the aggregated NDCs most cost-efficiently (globally uniform marginal abatement cost).

CO_2 marginal abatement costs of the NDCs



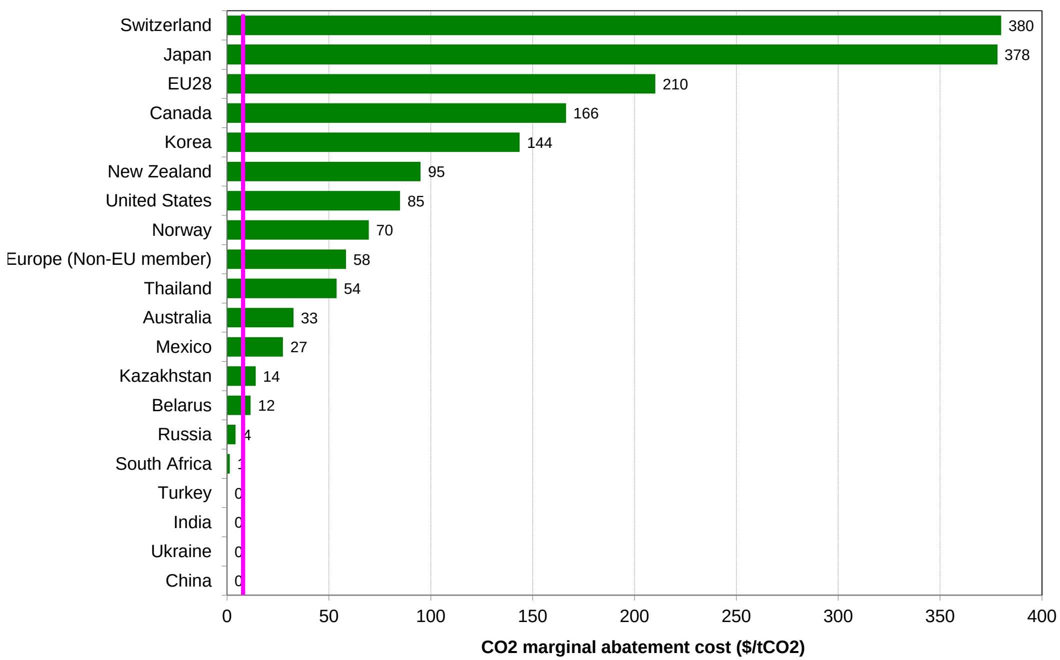
Source: J. Aldy et al., Nature Climate Change, 2016

Average of 2025-2030

2030 (2025 for the U.S.)

【World GDP loss due to mitigation】
NDCs:0.38%; the global least cost：0.06%

The least cost (equal marginal abatement costs)：6$/tCO2



Source: K. Akimoto et al., Evol. Inst. Econ. Rev., 2016

- The marginal abatement costs for NDCs are greatly different across nations.
- The global costs are estimated to be about 6.5 times as large as the least cost for the same amount of global reductions.
- The mitigation costs in the real world will be much higher than those of the ideal case.

4. Detailed evaluations on emission reduction costs of Japan's NDC

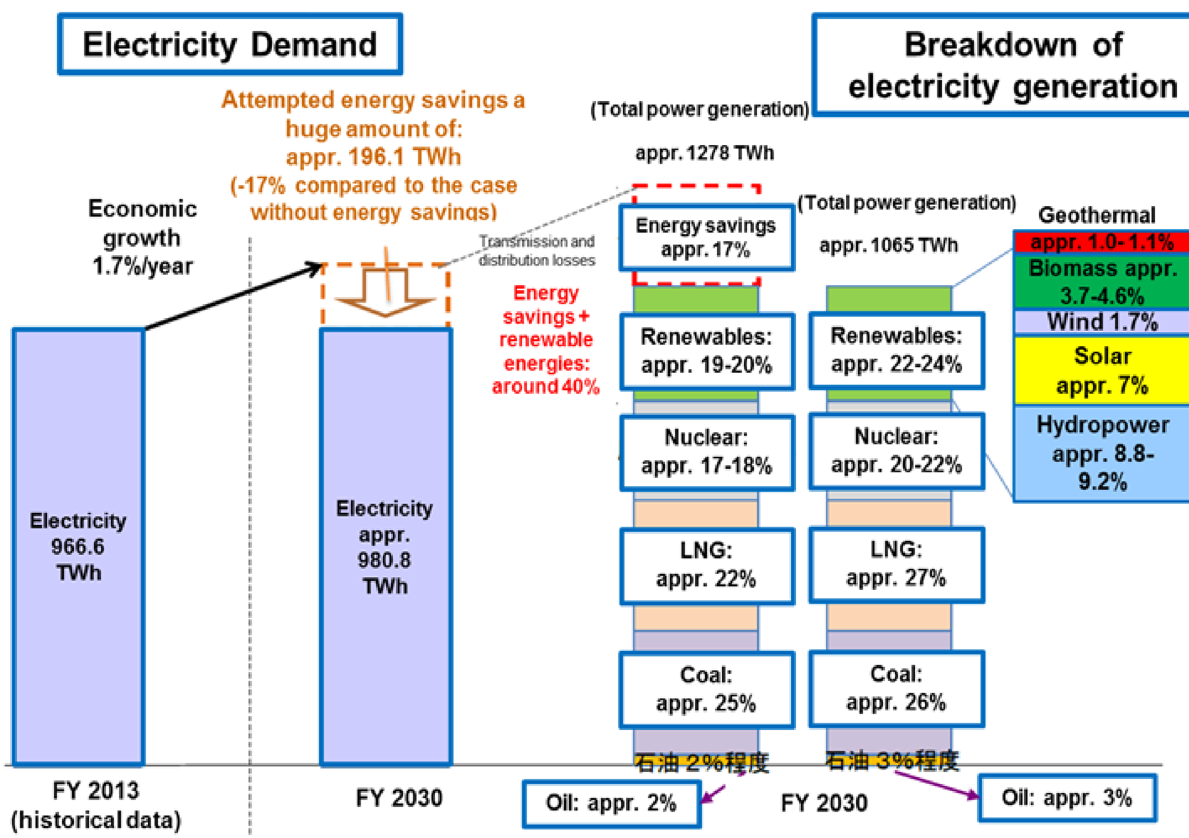
Consideration of country's political and social situations in evaluation of the cost metrics

Cost metrics are comprehensive and good indicators for measuring emission reduction efforts, but …

- **How should we treat the considerations of social constraints for implementing climate policies? ⇒ public acceptance of nuclear power, CCS etc.; considerations of energy security**
- **How should we treat the considerations of political constraints for implementing climate policies? ⇒ For example, in the U.S. it is not easy to establish a new climate policy act due to the political systems.**
- **When the governments make/implement inefficient policies, how should we treat them for measuring the costs for the emission reduction efforts? ⇒ FIT policies can be inefficient, and how should we treat them for the mitigation costs?**

2030 Emission Target of Japan's NDC and the Energy Mix (Electricity)

	2030; Compared to 2013（compared to 2005）
Energy-related CO_2	**-21.9%（-20.9%）**
Other GHGs	-1.5%（-1.8%）
Reduction by absorption	-2.6%（-2.6%）
Total GHGs	**-26.0%（-25.4%）**



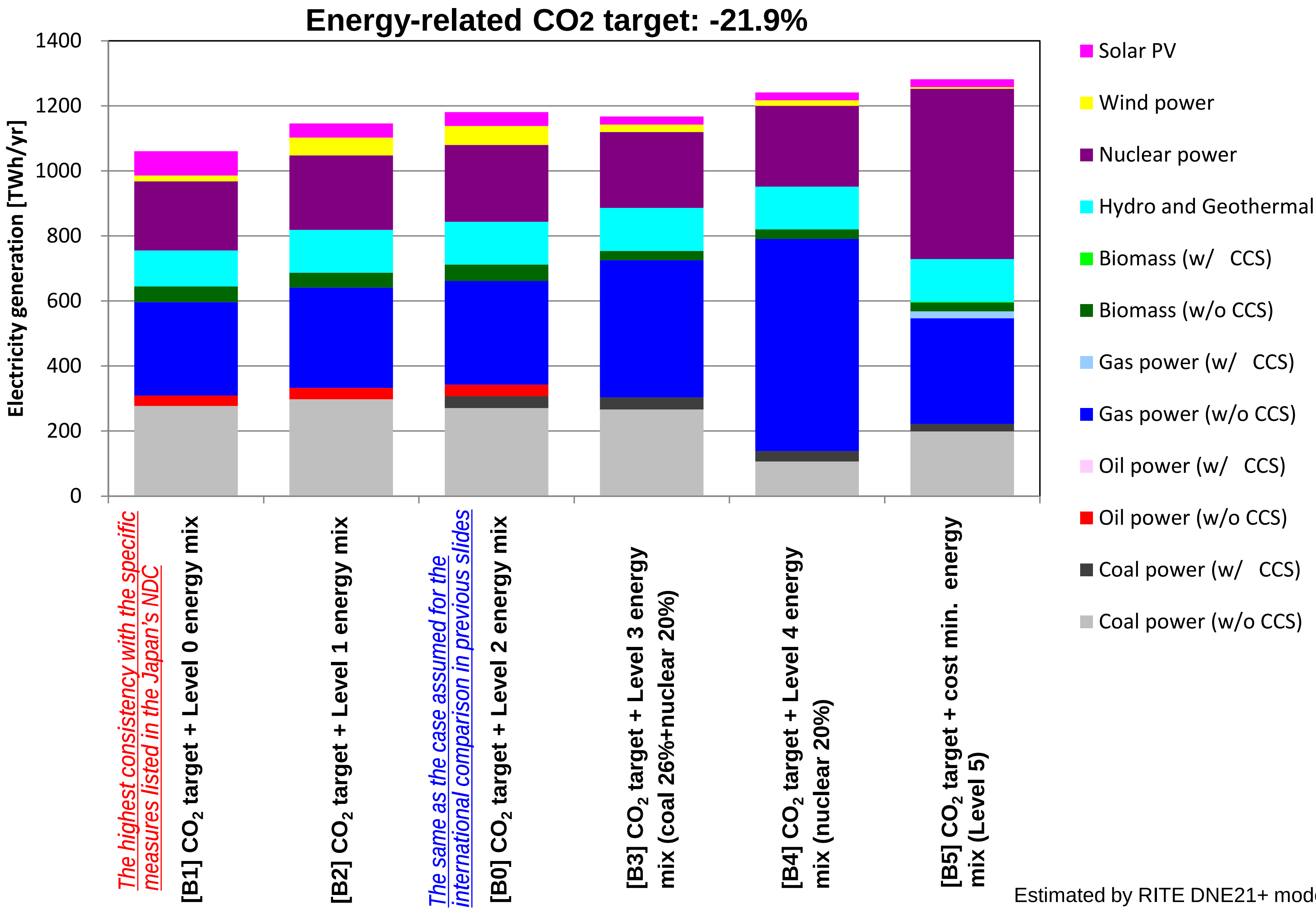
The Japanese government, July 2015

The analysis cases for Japan's NDC

	GHG emis. target	Energy related CO2 emission target	Electricity share			w./w.o. CCS option	Electricity saving
			Fossil fuel	Nuclear power	Renewables		
[A0] GHG target + Level 2 energy mix [A] *(The same as the case assumed for the international comparison in previous slides)*	-26%	Cost min.	Coal: 26% LNG: 27% Oil: 3%	20%	24% (cost min. within renewable sources)	Cost min.	Cost min.
[B0] CO_2 target + Level 2 energy mix	-	[B] -21.9%	Coal: 26% LNG: 27% Oil: 3%	20%	24% (cost min. within renewable sources)	Cost min.	Cost min.
[B1] CO_2 target + Level 0 energy mix ***(The highest consistency with the specific measures listed in the Japan's NDC)***	-	-21.9%	Coal: 26% LNG: 27% Oil: 3%	20%	24% (PV: 7%, wind: 1.7% etc.)	w.o. CCS	Total elec. supply: 1065 TWh/yr
[B2] CO_2 target + Level 1 energy mix	-	-21.9%	Coal: 26% LNG: 27% Oil: 3%	20%	24% (cost min. within renewable sources)	w.o. CCS	Cost min.
[B3] CO_2 target + Level 3 energy mix (coal 26% + nuclear 20%)	-	-21.9%	Coal: 26% LNG: cost min. Oil: cost min.	20%	Cost min.	Cost min.	Cost min.
[B4] CO_2 target + Level 4 energy mix (nuclear 20%)	-	-21.9%	Cost min.	20%	Cost min.	Cost min.	Cost min.
[B5] CO_2 target + cost min. energy mix (Level 5)	-	-21.9%	Cost min.	Cost min.	Cost min.	Cost min.	Cost min.

Note: Higher level of energy mix provides more flexibility.

Evaluations of Japan's NDC in Electricity in 2030



Estimated by RITE DNE21+ model

Evaluations of Japan's NDC in Mitigation Cost in 2030

Estimated by RITE DNE21+ model

	Marginal abatement cost of CO2 ($2000/tCO2)	Mitigation cost increase (billion $2000/yr)	Mitigation cost increase per reference GDP (%)
[A0] GHG target (-26%) + Level 2 energy mix *The same as the case assumed for the international comparison in previous slides*	378	99	1.41
[B0] CO_2 target (-21.9%) + Level 2 energy mix	227	28	0.40
[B1] CO_2 target (-21.9%) + Level 0 energy mix *The highest consistency with the listed specific measures in the Japan's NDC*	242	38	0.55
[B2] CO_2 target (-21.9%) + Level 1 energy mix	272	32	0.46
[B3] CO_2 target (-21.9%) + Level 3 energy mix (coal 26% + nuclear 20%)	277	24	0.34
[B4] CO_2 target (-21.9%) + Level 4 energy mix (nuclear 20%)	165	20	0.28
[B5] CO_2 target (-21.9%) + cost min. energy mix (Level 5)	50	10	0.15

4.1% GHG reductions by non-energy CO2 is much more expensive than 21.9% GHG reductions by energy related CO2 (A0 vs B0)

Energy-related CO2 target (-21.9%) (B0–B5)

Electricity saving target , CCS constraint (B0 vs B1)

Renewable energy target etc. (B2 vs B3)

Considering energy security issue (B3 vs B4)

Considering social constraint of nuclear power (B4 vs B5)

Note: it should be noted that the orders of between marginal cost and mitigation cost are different. The constraints for specific measures could reduce the CO2 marginal abatement cost while total mitigation cost increases.

Which constraints should we consider as appropriate or inevitable?

Other sensitivity analyses —The cases of unachievement of the GDP growth rate and nuclear power target

- **The future government targets are also uncertain in terms of achievement, and some sensitivity studies were conducted as follows;**

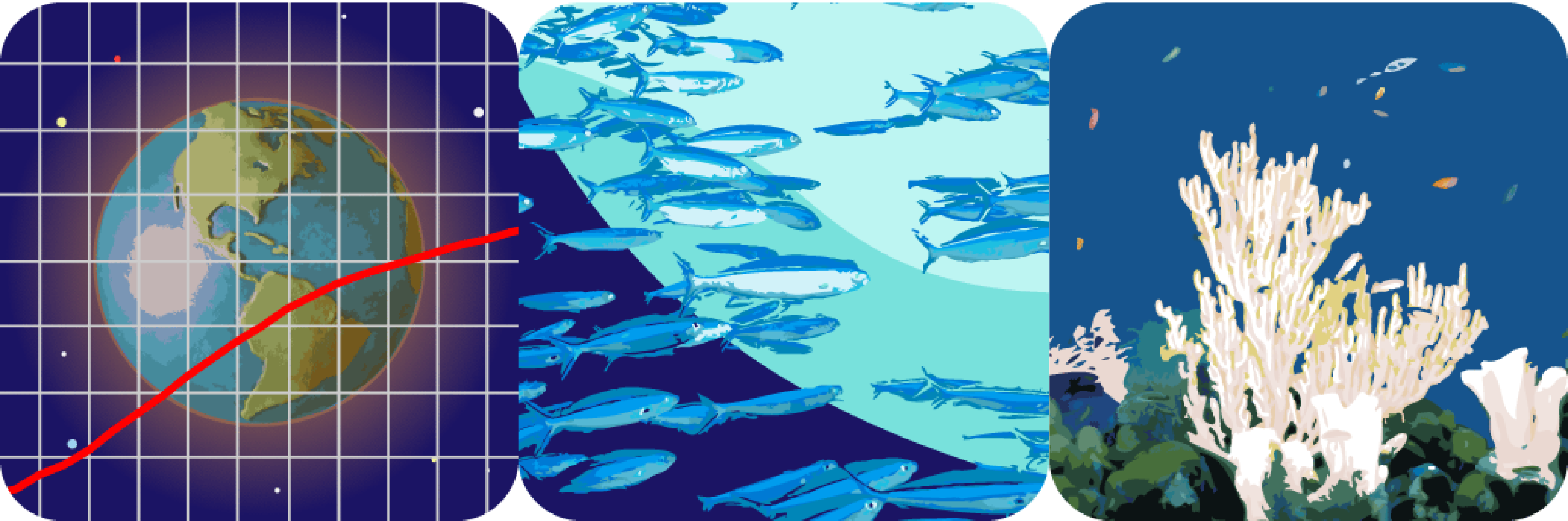
a) **GDP growth rate assumed in the NDC and energy mix: 1.7%/yr ⇒ 0.9%/yr**

b) **Nuclear power share assumed in the NDC and energy mix: 20-22% ⇒ 15%**

	Marginal abatement cost of CO_2 ($2000/t$CO_2$)	Mitigation cost increase (billion $2000/yr)	Mitigation cost increase per reference GDP (%)
[B0] CO_2 target (-21.9%) + Level 2 energy mix (GDP：1.7%/yr, nuclear power: 20%)	227	28	0.40
[B0-a] Low GDP growth (0.9%/yr)	151	18	0.31
[B0-b] Nuclear power share: 15%	228	36	0.51
[B0-c] Low GDP growth (0.9%/yr) + Nuclear power share: 15%	142	24	0.40

Estimated by RITE DNE21+ model

5. Toward a better management of climate change risks



Temperature targets under the Paris Agreement and their Political and Scientific Uncertainties

- **Regarding the long term targets, the Paris Agreement contains: "To hold the increase in the global average temperature to well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C above pre-industrial levels."**

  - ***When should the temperature goal be achieved below +2 ℃ or +1.5 ℃ under the Paris Agreement?***
  - ***How high probability should be assigned for the achievement of the 2 ℃ or 1.5 ℃ target under the Paris Agreement?***
  - ***The climate sensitivity and its probability density function are still greatly uncertain scientifically.***

History of climate sensitivity judgment by IPCC and the sensitivity employed in the scenario assessments of the IPCC WG3 AR5

	Equilibrium climate sensitivity Likely range ("best estimate" or "most likely value")
Before IPCC WG1 AR4	**1.5–4.5°C (2.5°C)**
IPCC WG1 AR4	**2.0–4.5°C (3.0°C)**
IPCC WG1 AR5	**1.5–4.5°C (no consensus)**
Global mean temperature estimations for the long-term scenarios in the IPCC WG3 AR5 (employing MAGICC)	**2.0–4.5°C（3.0°C）** **[Based on the AR4]**

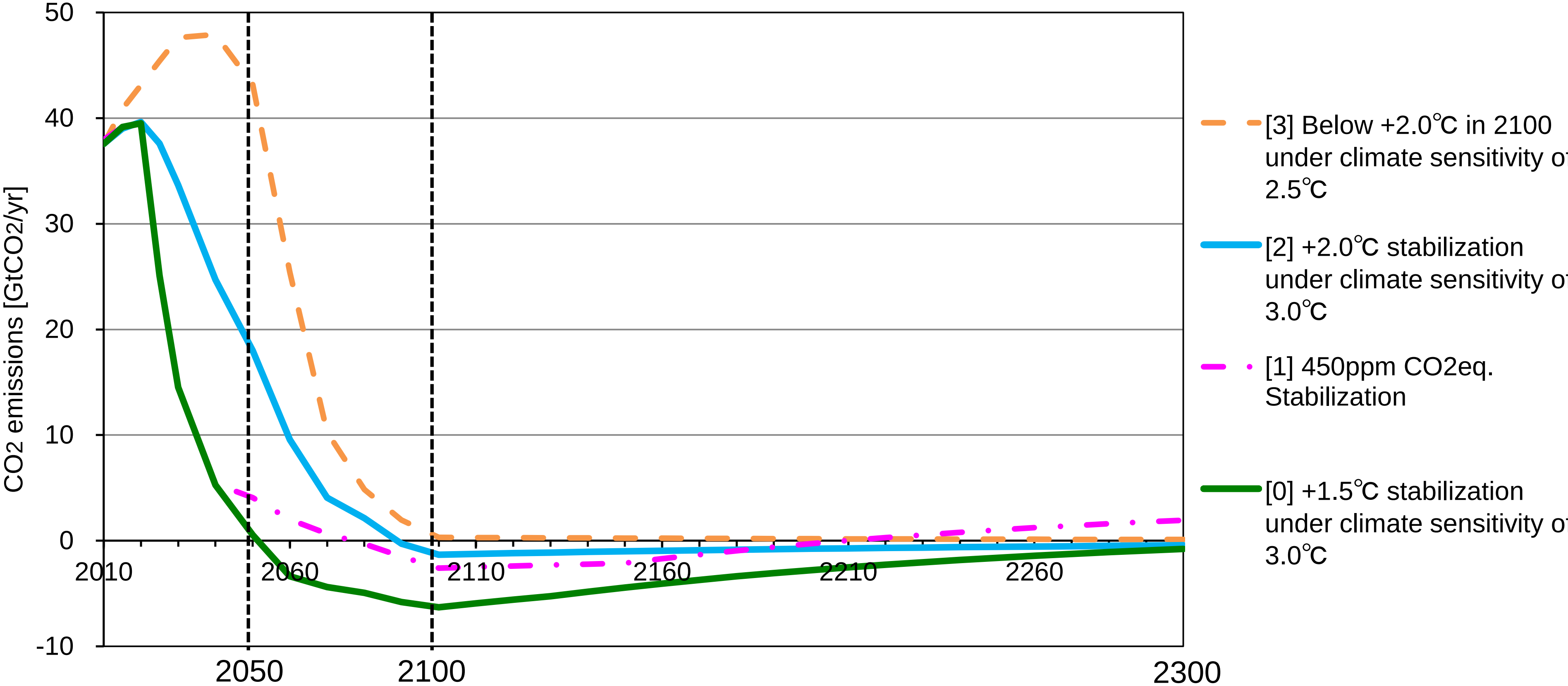
Same "likely" range

[The related descriptions of the SPM of WG1 AR5]

Likely in the range 1.5 °C to 4.5 °C (high confidence)
Extremely unlikely less than 1 °C (high confidence)
Very unlikely greater than 6 °C (medium confidence)
No best estimate for equilibrium climate sensitivity can now be given because of a lack of agreement on values across assessed lines of evidence and studies.

- **The equilibrium climate sensitivity, which corresponds to global mean temperature increase in equilibrium when GHG concentration doubles, is still greatly uncertain.**
- **AR5 WG1 judged the likely range of climate sensitivity to be 1.5–4.5 °C, in which the bottom range was changed to a smaller number than that in the AR4, based not only on CMIP5 (AOGCM) results but also other study results.**
- **AR5 WG3 adopted the climate sensitivity of AR4, which has the likely range of 2.0–4.5 °C with the best estimate of 3.0 °C, for temperature rise estimates of long-term emission scenarios.**

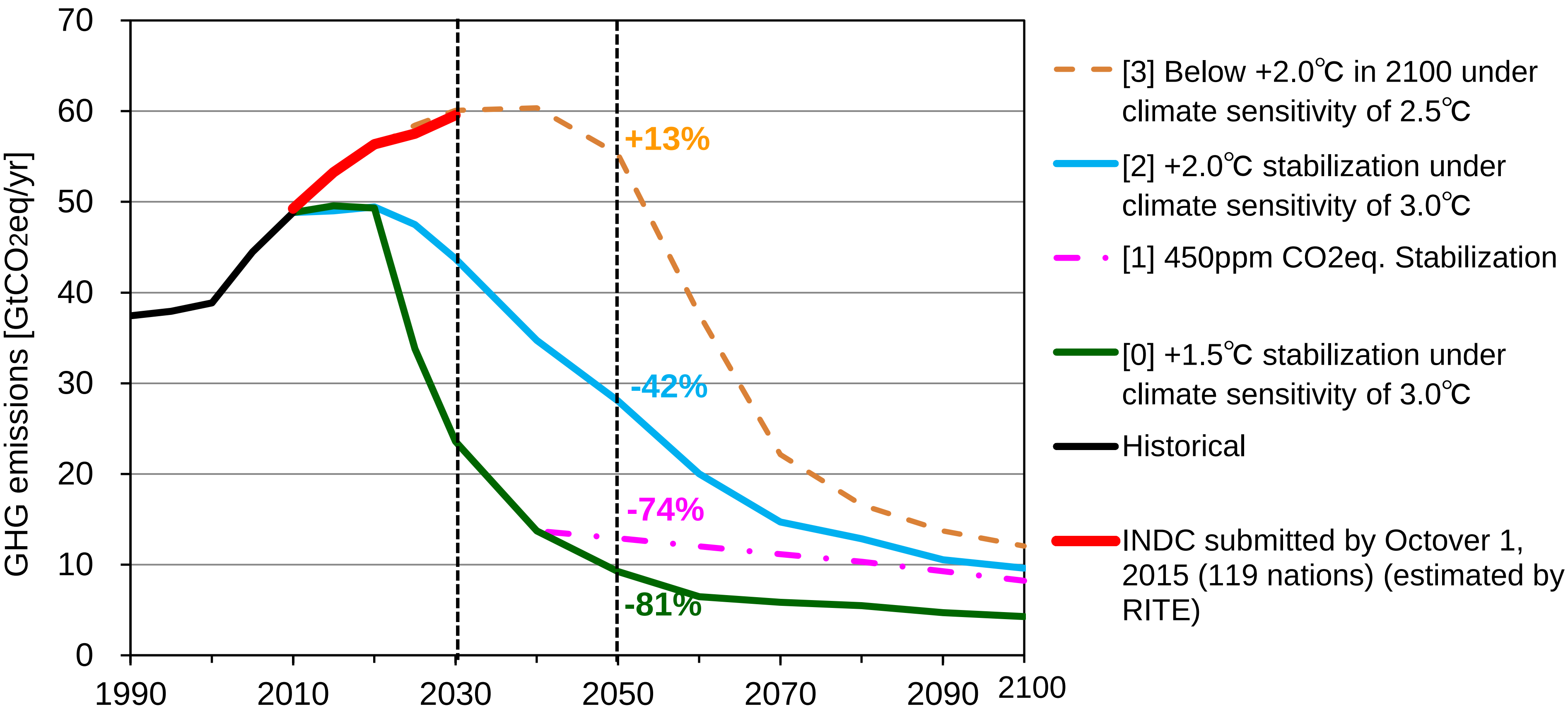
Global CO_2 emission profiles toward 2300 for the 2 °C and 1.5 °C targets



Estimated by RITE using MAGICC and DNE21+

- The CO2 emissions should be nearly zero for long future in any pathways for the temperature stabilization.
- Large amounts of negative CO2 emissions are required after 2050 for the 1.5 °C scenario.

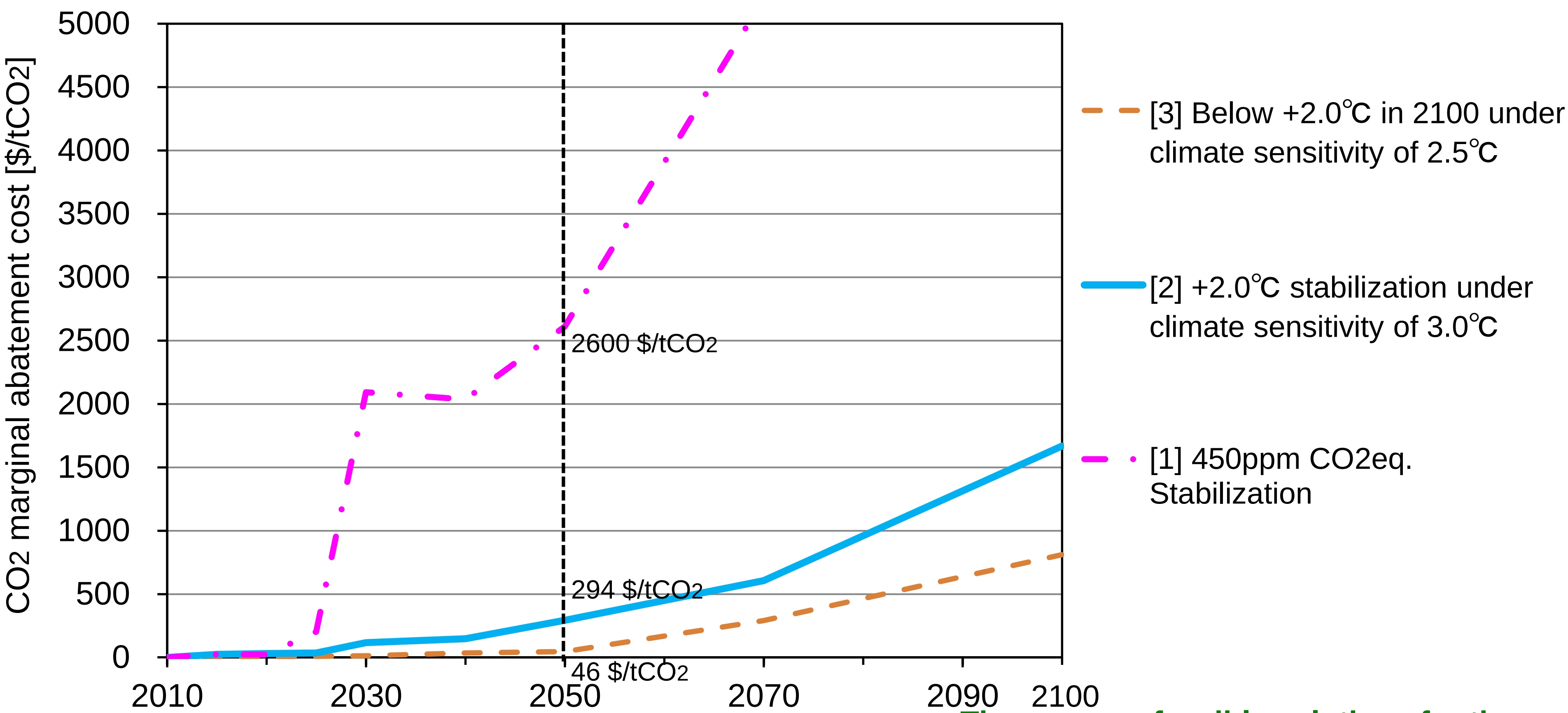
Global GHG emission profiles toward 2100 for the 2 °C and 1.5 °C targets



Estimated by RITE using MAGICC, DNE21+ and non-CO2 GHG models

- The corresponding GHG emission trajectories for the 2 °C target vary widely particularly before 2050.
- There are large gaps between the expected emissions under the submitted NDCs and most of the pathways for the 2 °C target.

CO_2 Marginal Abatement Costs for Achieving the Emission Pathways



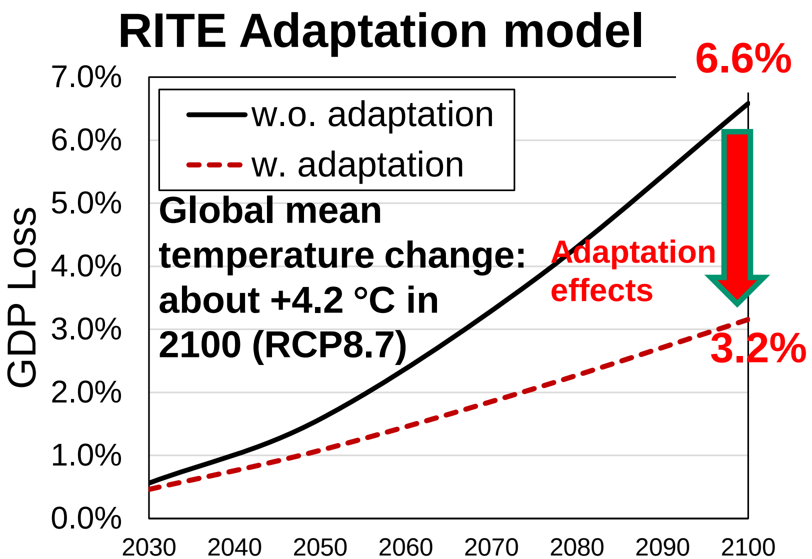
Estimated by RITE using DNE21+ model

There are no feasible solutions for the scenario of [0] +1.5℃ stabilization under climate sensitivity of 3.0℃

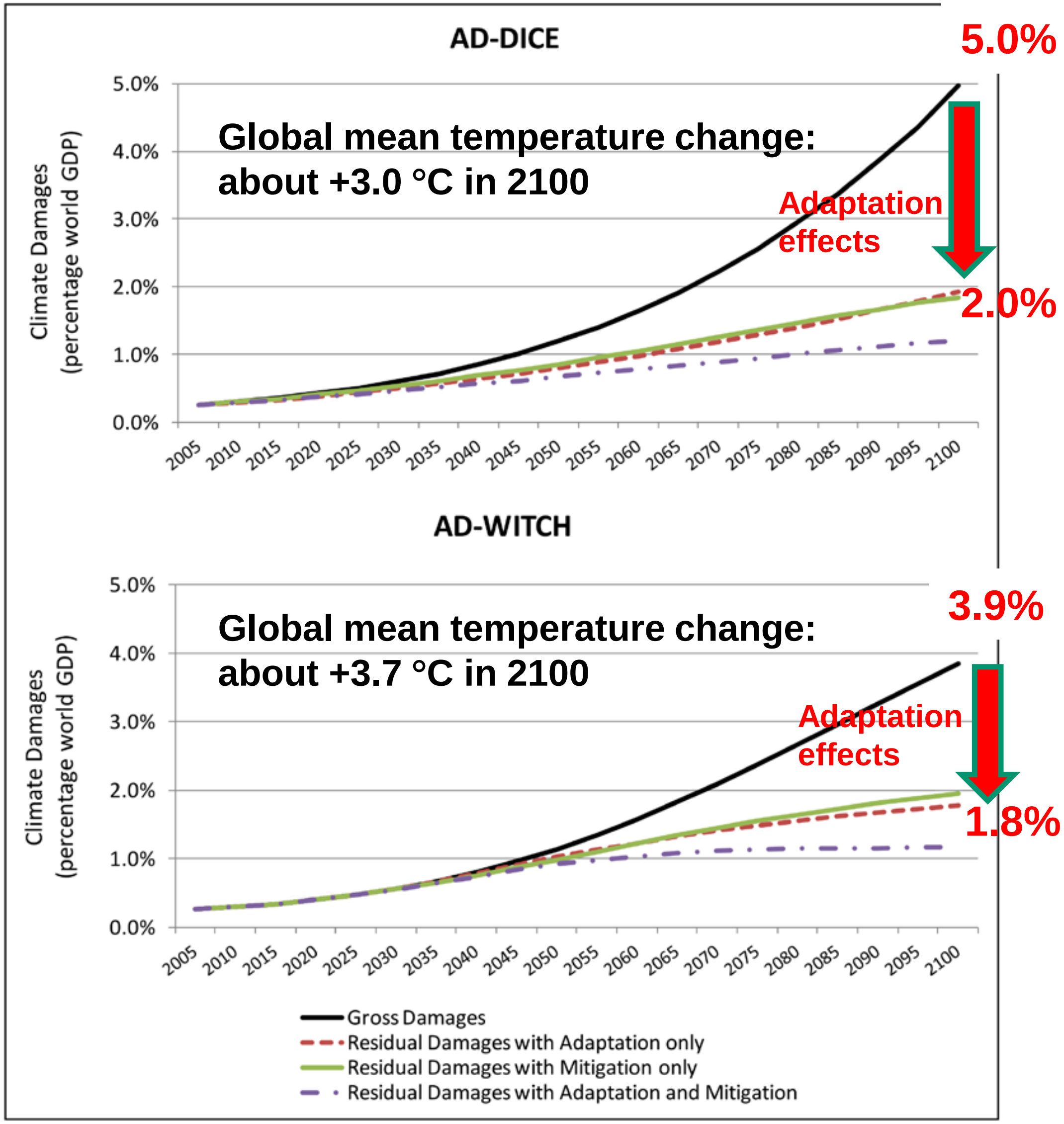
- The marginal abatement cost for the case of [1] 450 ppm stabilization is extremely high even in 2030, and it will be difficult to achieve it in reality.
- The costs for the [2] and [3] scenarios in 2100 are around 1000 $/tCO2 or larger, and innovations, especially technological ones, are necessary even for these scenarios.

Climate Change Damages and Adaptation (GDP impacts) —Comparison of the estimates by three models—

RIT Research Institute of Innovative Technology for the Earth



Note 1) RITE adaptation model does not cover broad adaptation measures but consider only coastal dike in coastal sector as adaptation measures
Note 2) The estimates of all the models are highly uncertain in the damage and adaptation costs.



In all of the model analyses, the GDP losses due to climate change damages can be significantly reduced by adaptation measures. (Reductions in GDP loss due to adaptation measures: 2.1 to 3.4% points in 2100)

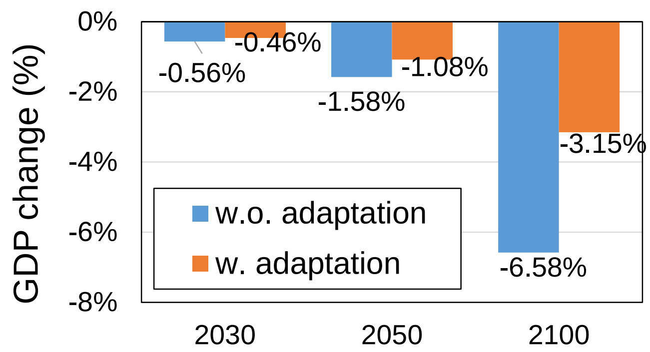
Source: Agrawala et al.2010, Fig13

Climate Change Damages, Adaptation and Mitigation Costs

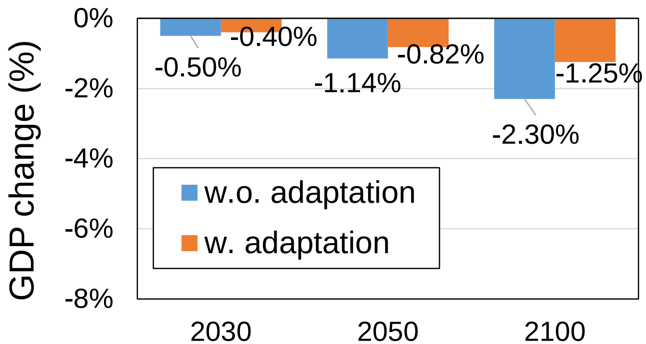
World GDP damages w.o./w. adaptation

(compared to the case without consideration of climate change)

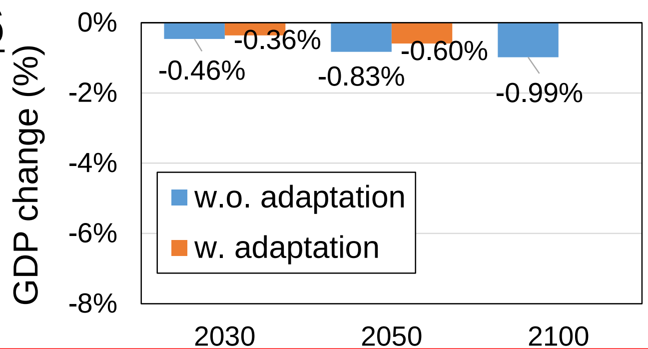
RCP8.5



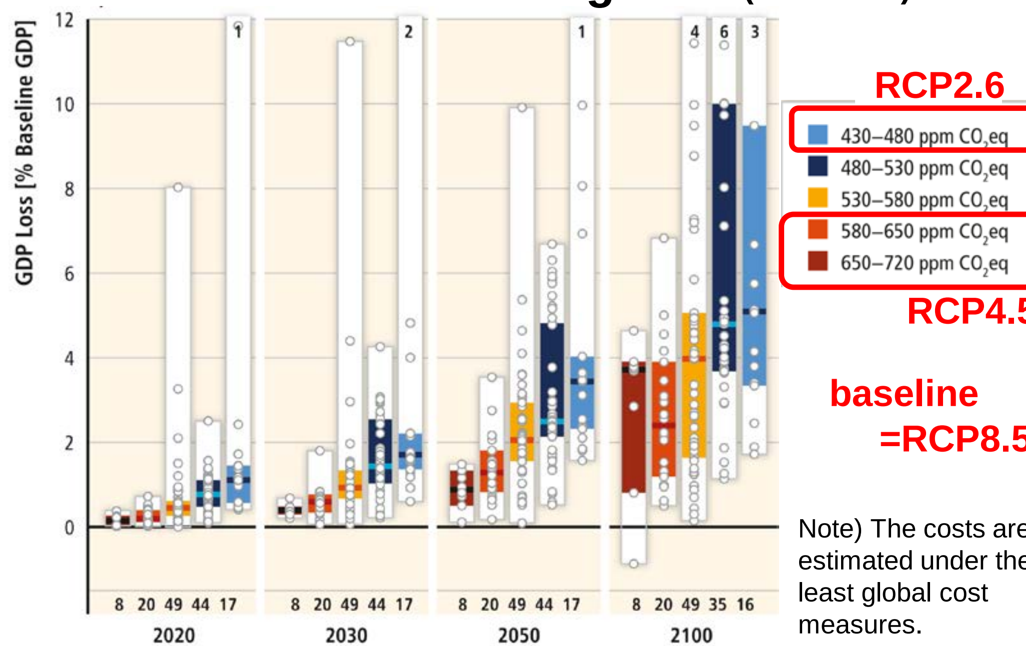
RCP4.5



RCP2.6



GDP loss due to mitigation (IPCC AR5)



Note) The costs are estimated under the least global cost measures.

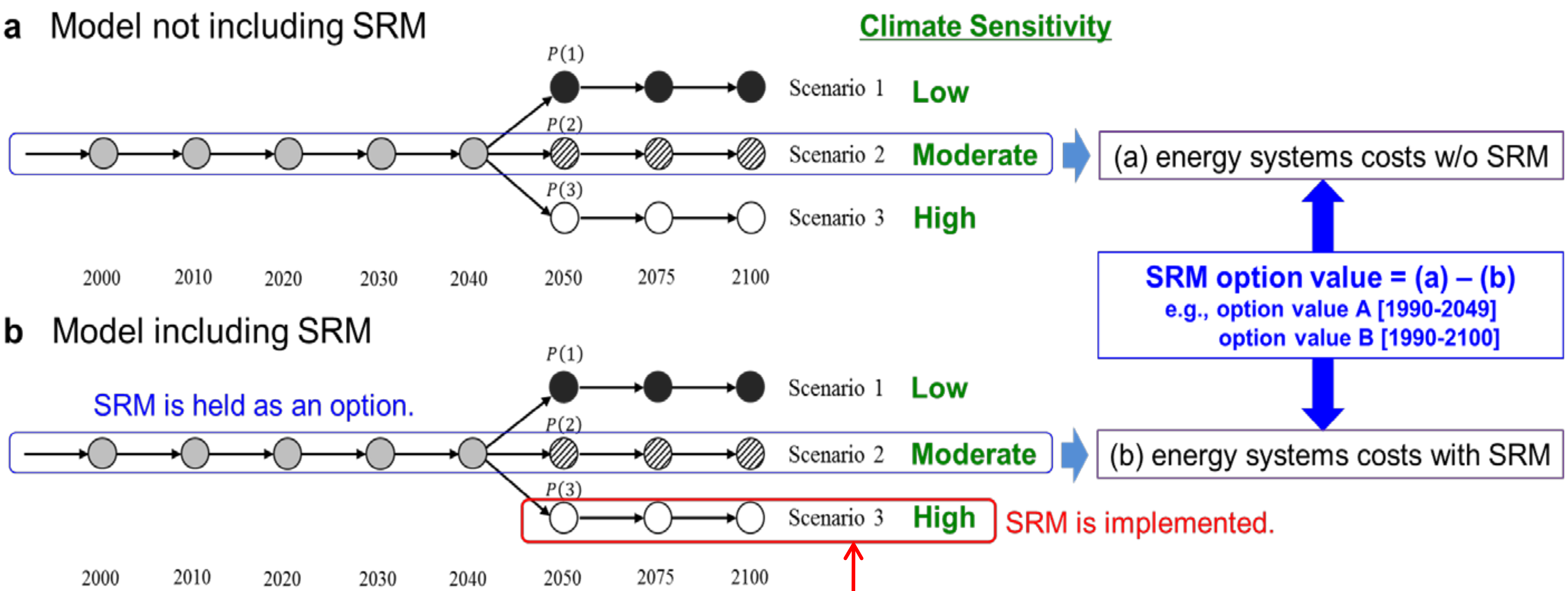
% of GDP		Damage & adaptation	Mitigation	Total
RCP8.5	w.o. adapt.	6.6%	0%	6.6%
	w. adapt.	3.2%		**3.2%**
RCP4.5	w.o. adapt.	2.3%	2.5%	4.8%
	w. adapt.	1.3%		**3.8%**
RCP2.6	w.o. adapt.	1.0%	5.2%	6.2%
	w. adapt.	0%		**5.2%**

There are large uncertainties in estimates on climate change damages and adaptation costs; however, if adaptation measures can reduce climate damages significantly, and the mitigation costs are large, then stringent long-term targets, such as the 2 °C like RCP2.), will be debatable.

Climate risk management strategy for the case of high climate sensitivity –Framework on evaluating the option value of SRM–

- **Solar radiation management (SRM) is proposed as a geoengineering method. The option value of SRM under a temperature target with uncertainty in climate sensitivity was evaluated.**
- **DNE21 model which is simplified from DNE21+ evaluated the option value by employing a decision tree having simplified three scenarios regarding climate sensitivity.**

Y. Arino, K. Akimoto et al., PNAS, 113(21), 2016



【Assumptions】

(1) **Climate sensitivity is uncertain before 2050,**
(2) **Climate sensitivity uncertainty would be resolved in 2050, and**
(3) **SRM would be implemented (a) to a limited extent of cooling (-0.5°C), (b) only after 2050, and (c) only when true climate sensitivity would turn out to be high.**

Scenarios after the learning of uncertain climate sensitivity

- CO_2 emission pathways were estimated with the expected least-cost for a certain level of temperature increase target.

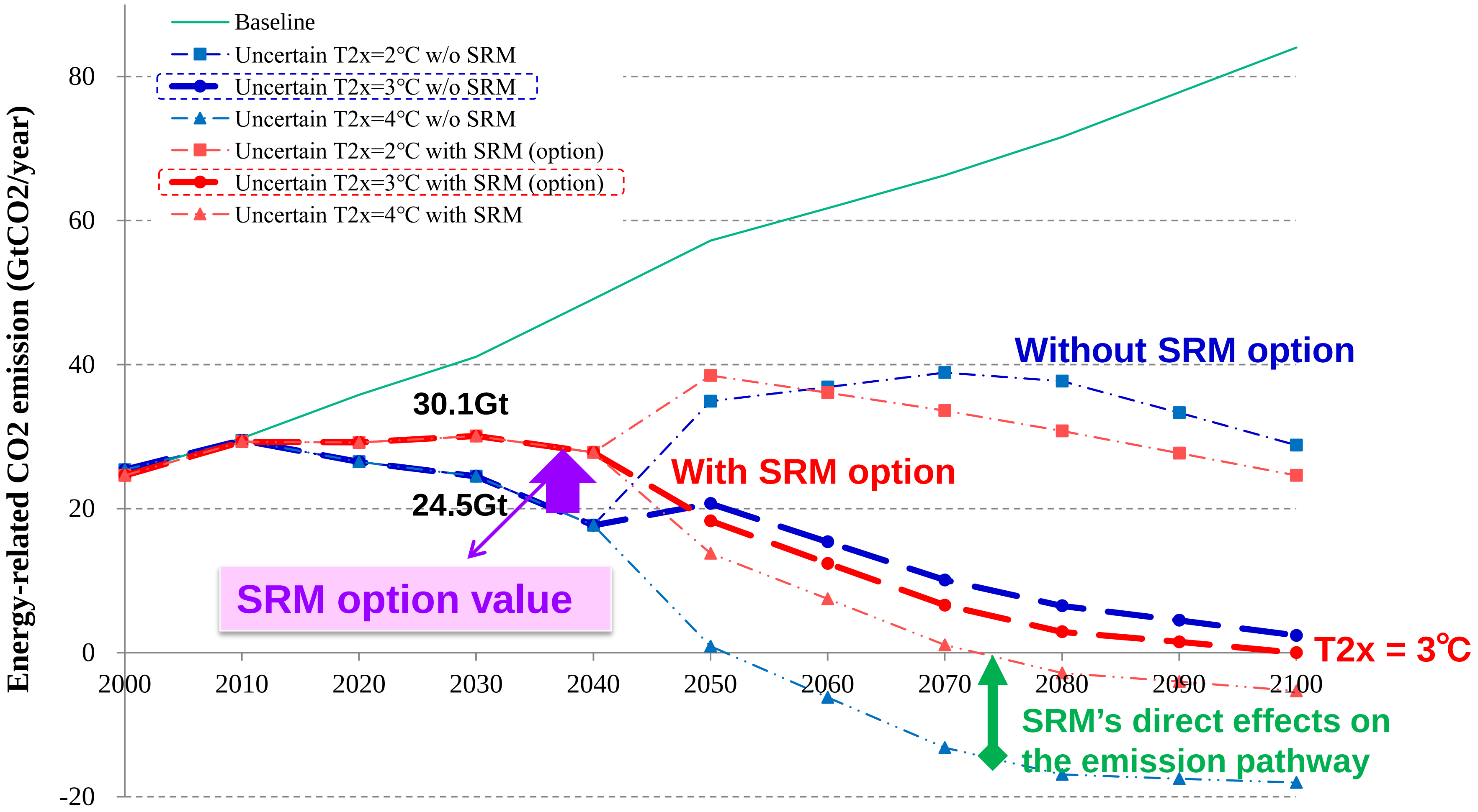
The probability of climate sensitivity was assumed based on the Rogelji et al. (2012) which is consistent with the IPCC AR4 (2.0-4.5 °C: likely; 3.0 °C: mean).

[Scenarios]

	Climate sensitivity (T2x)	Occurrence probability	SRM implementation
Scenario 1	2.0℃	10%	No SRM
Scenario 2	3.0℃	71%	No SRM
Scenario 3	4.0℃	19%	SRM implementation (cooling capacity limited to -0.5 °C)

Y. Arino, K. Akimoto et al., PNAS, 113(21), 2016

The CO_2 emission pathways for the 2.5 °C target with and without SRM option



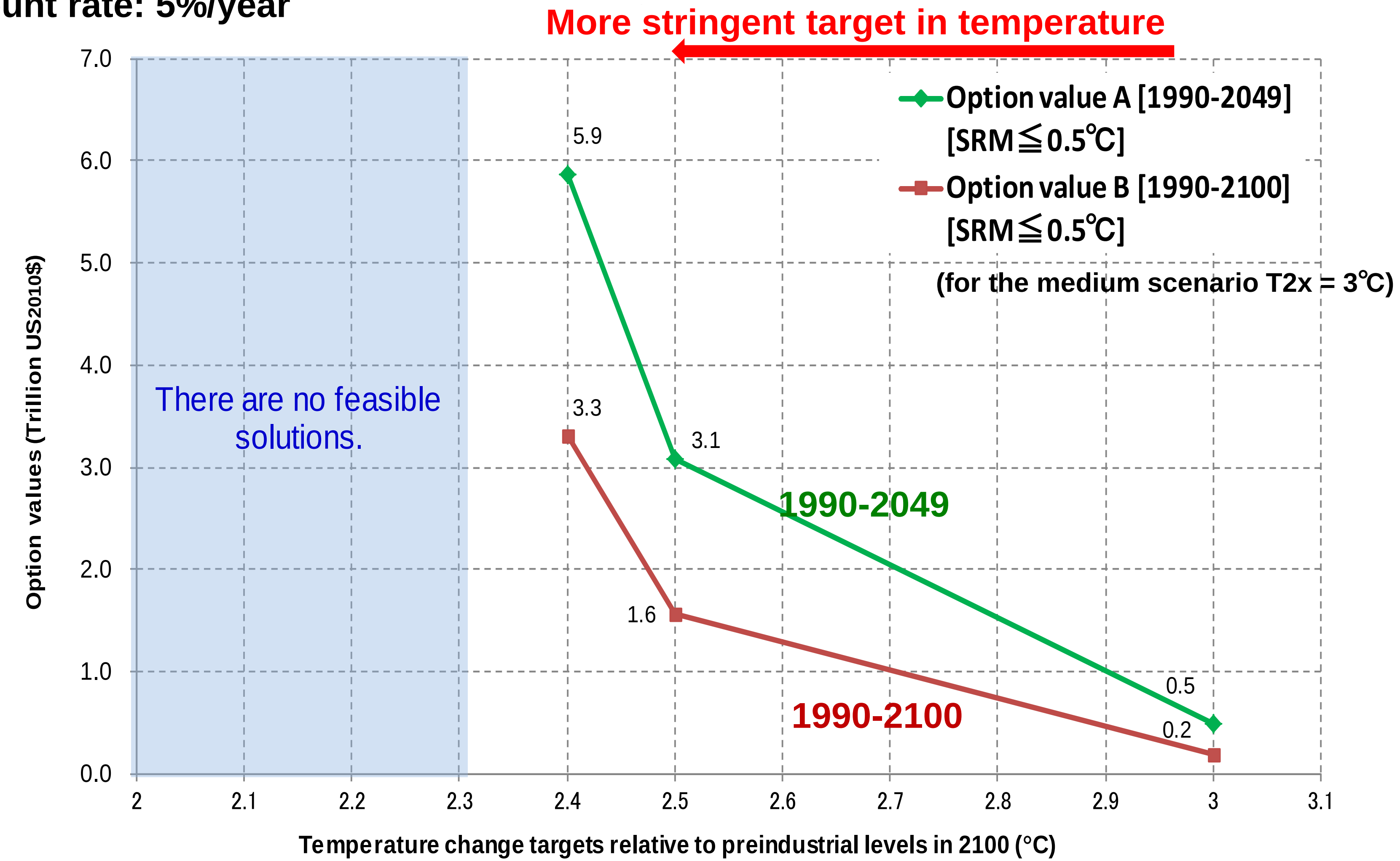
Y. Arino, K. Akimoto et al., PNAS, 113(21), 2016

Holding SRM options during the uncertain periods (2000-2040) alleviates the stringency of emission reduction in the short to medium term even though SRM is not truly deployed.

Relationship between temperature targets and SRM option values

Y. Arino, K. Akimoto et al., PNAS, 113(21), 2016

Discount rate: 5%/year



The SRM option values increase with the stringency of temperature change targets, and the values of US$ 3.1 and US$ 5.9 trillion for the 2.5 and 2.4 °C targets when accumulated during 1990-2049.

Climate Change Mitigation & Air Pollution (PM2.5) Reduction Measures

Kaya identity

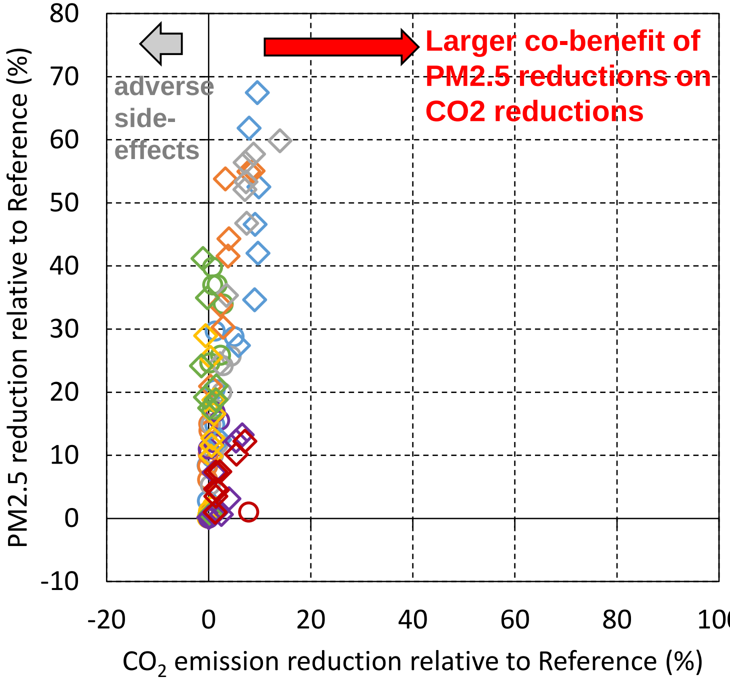
End-of-pipe measures (CCS) | Co-benefit measures

Net CO2 = (Net CO2／Gross CO2) × (Gross CO2／PE) × (PE／GDP) × (GDP)

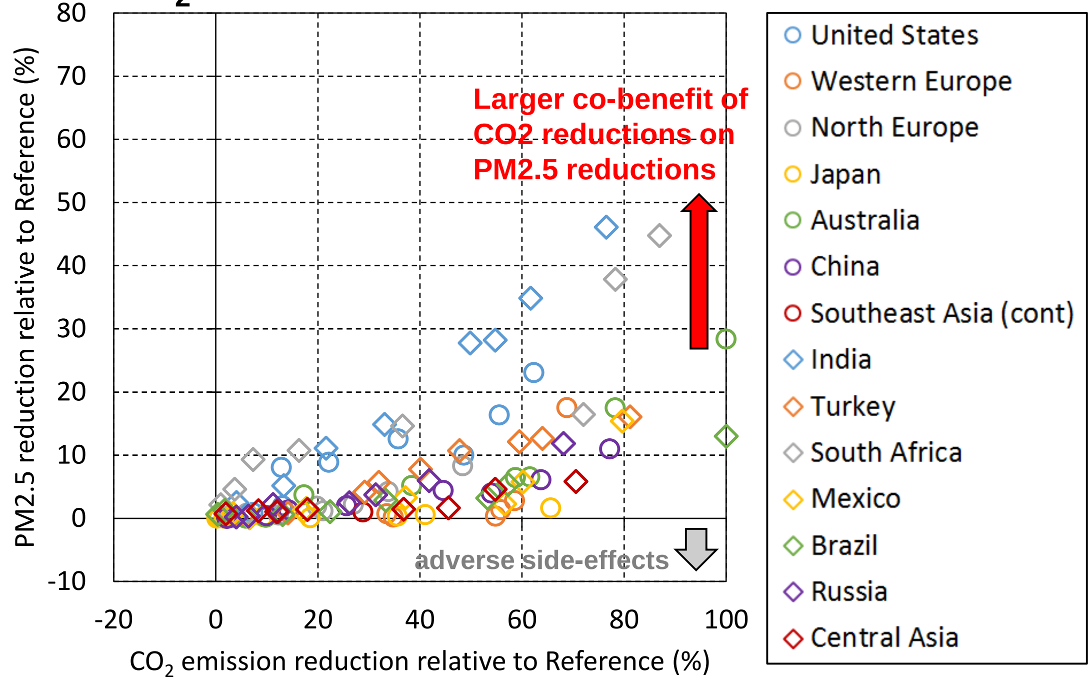
PM2.5 = (PM2.5／Gross PM2.5) × (Gross PM2.5／PE) × (PE／GDP) × (GDP)

End-of-pipe measures (de-Sulfer, de-NOx etc.) | Fuel switching | Energy saving

PM2.5 concentration reduction cases



CO_2 emission reduction cases

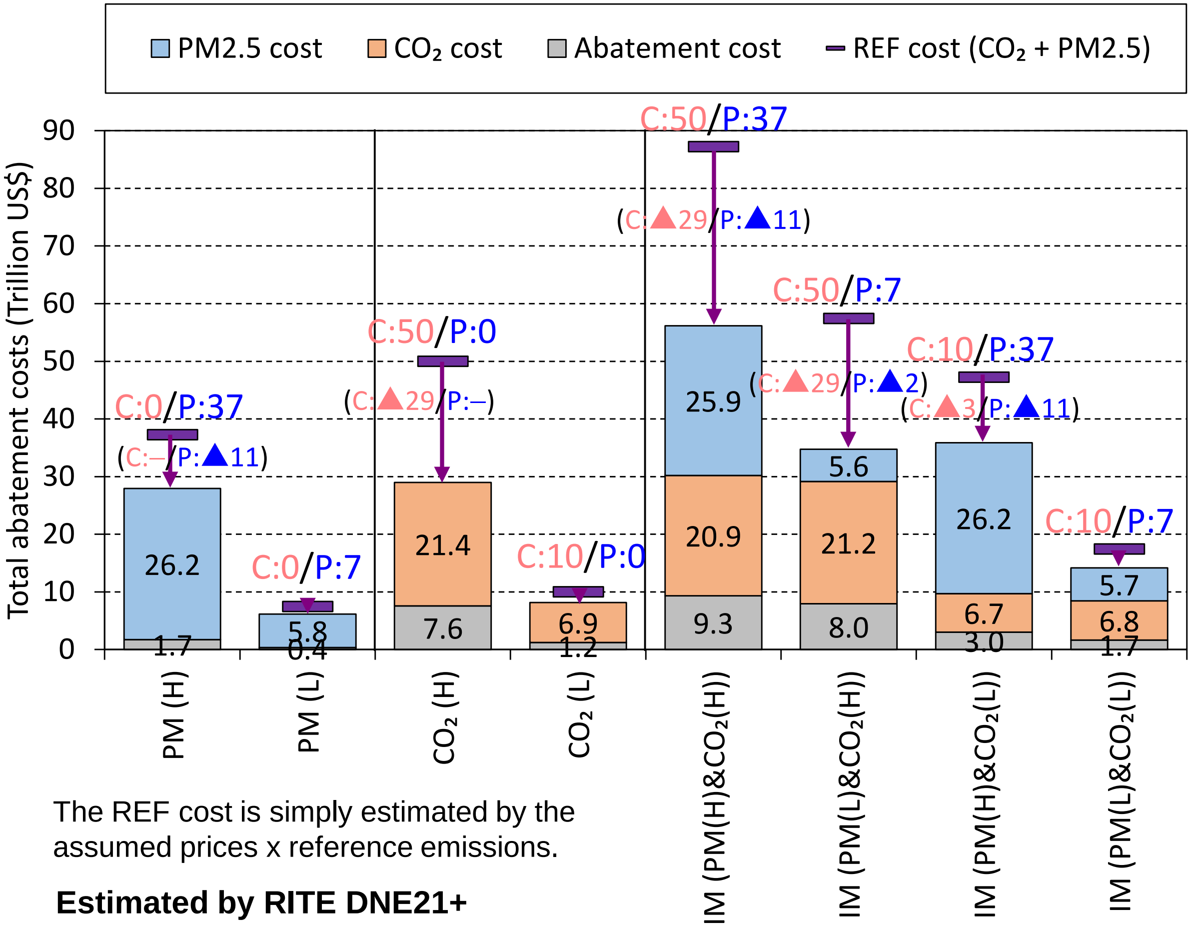


Estimated by RITE DNE21+ model (up to 2050)

- The co-benefit of CO2 emission reductions on PM2.5 reductions are larger than that of PM2.5 reductions on CO2 emission reductions. Large co-benefits are not necessarily observed for all countries but are observed particularly in India, South Africa, and the U.S.
- For PM2.5 reductions, relatively cheap end-of-pipe type measures exist (e.g., de-Sulfer, de-NOx); but for CO2 reductions, the end-of-pipe type measures (e.g., CCS) are relatively expensive.

Climate Change Mitigation & Air Pollution (PM2.5) Reduction Measures – Costs

Total costs of 2010-50 (discount rate: 5%/yr)



The REF cost is simply estimated by the assumed prices x reference emissions.

Estimated by RITE DNE21+

CO_2, PM2.5 price assumptions (in 2030)

	Low (L)	High (H)
PM2.5 (M$/(μg/m3))	500	2500
CO2 ($/tCO2)	10	50

The price increase of +10%/yr is assumed between 2010 and 2050. The CO2 price scenarios of "Low" and "High" correspond to RCP4.5 and RCP2.6, respectively.

Total cost [Trillion US$]

(Parenthesis: total mitigation costs)

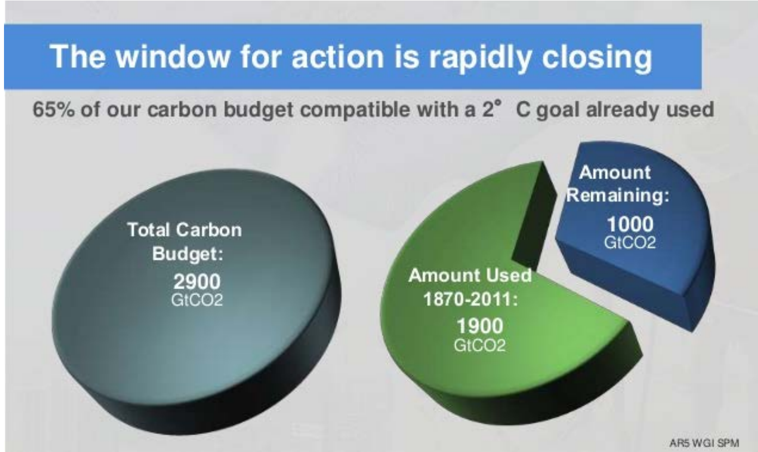
PM (H) + CO_2 (H) 57 (9.3)	>>	IM (H&H) 46 (8.9)
PM (L) + CO_2 (H) 35 (7.9)	≈<	IM (L&H) 35 (8.0)
PM (H) + CO_2 (L) 34 (3.0)	>≈	IM (H&L) 33 (3.0)
PM (L) + CO_2 (L) 14 (1.6)	>≈	IM (L&L) 13 (1.6)

- Relatively large co-benefits are estimated in the case that both CO_2 and PM2.5 reduction levels are large (both CO2 and PM2.5 emission damages are large). ⇒ In this case, large scales of energy saving and fuel switching are cost-effective.

- On the other hand, large co-benefits are not observed in other cases. ⇒ In the case that the human health impacts of PM2.5 are large and the resources for the mitigation measures are limited, the end-of-pipe type measures for PM2.5 reductions are cost effective in early stages.

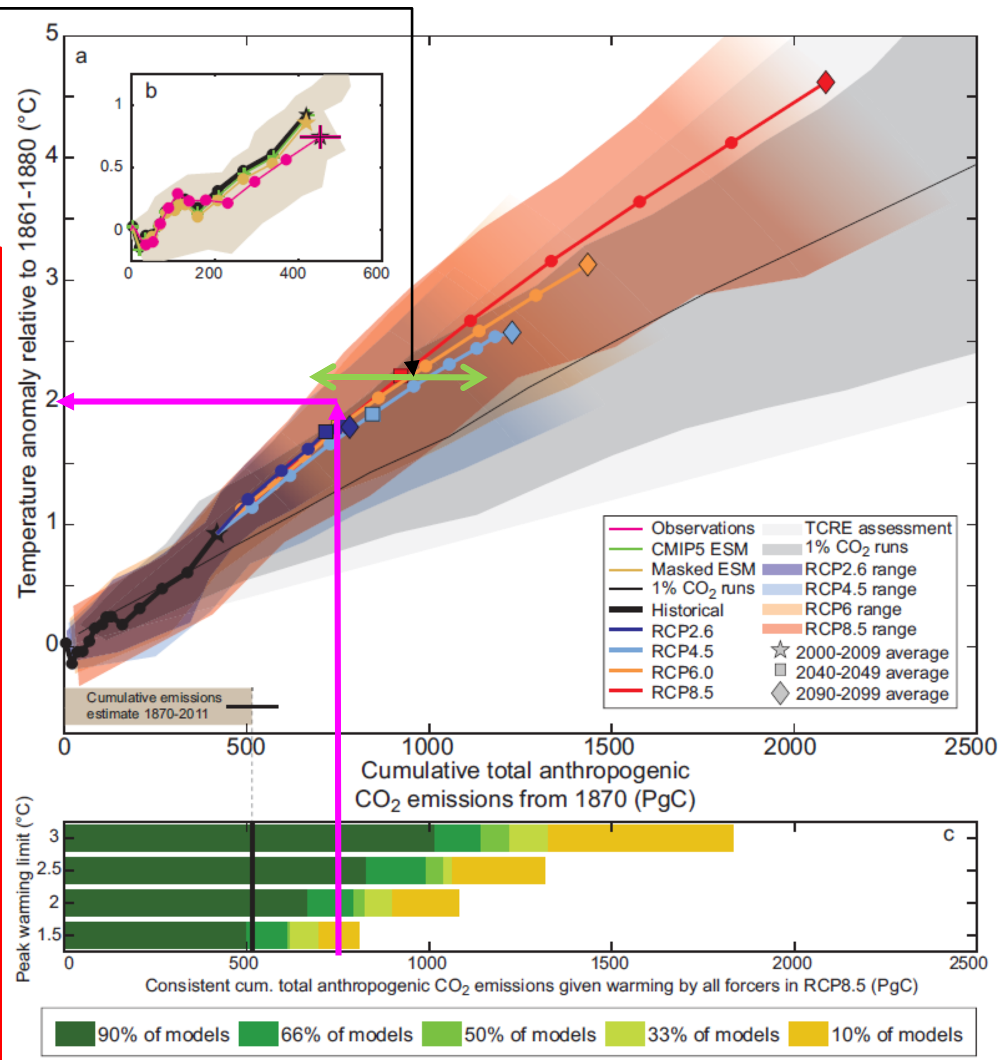
6. Conclusions

Climate Change Risk Management to be Considered



IPCC bureau sometimes simply explains that the remaining carbon budget is only1000 $GtCO_2$ for the 2 °C target; however there are large uncertainties in the budget.

(This IPCC figure shows the uncertainties, but it is drawn only by GCM results; wider ranges exist if climate sensitivity ranges 1.5-4.5 °(likely value of IPCC AR5))



- Scientific uncertainties: risk management recognizing various uncertainties is prerequisite.
- CO2 zero emissions are required in the long-term ⇒ technology innovation is essential.
- The potentials of adaptation to reduce climate change damages significantly
- Potential increase in mitigation costs: political factors (large differences in MAC across nations, Trump Administration etc.), social constraints of technology deployment, inefficient policies etc.
- Potential decrease in mitigation costs (future unknown innovations)
- High climate sensitivity case: increase in costs if it is tackled only by mitigation measures ⇒ potential response by SRM as an option
- Pursuing co-benefits in line with several objectives of sustainable development including PM2.5 reductions. But some are trade-offs. Our resources are limited and total risk management is required.

Conclusions

- The Paris Agreement is an international framework where all nations tackle climate change, and is welcomed.
- It is a key to appropriately compare and review NDCs, measuring emission reduction efforts for the effective achievement of deeper reductions.
- The marginal abatement costs of NDCs vary widely across nations, and the global costs are estimated to be over six times as large as the least cost for the same amount of global reductions. This big difference will hinder effective global emission reductions.
- Even within a nation, there are lots of other policies, social constraints etc. to be considered and they will increase the emission reduction costs greatly compared to the ideally least cost.
- The Paris Agreement aims the 2 °C target (also pursuing the 1.5 °C target), but the nominal temperature target has a wide range of global emission pathways.
- We should recognize such various uncertainties, and manage not only climate change risks but also total risks of society in order to achieve a better sustainable development in a better way.