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Evaluations of climate change response measures considering several constraints and multi objectives in the real world

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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 to achieve the 2 ℃ or 1.5 ℃ target under the Paris Agreement?***

  - ***The climate sensitivity and its probability density function is still 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]**

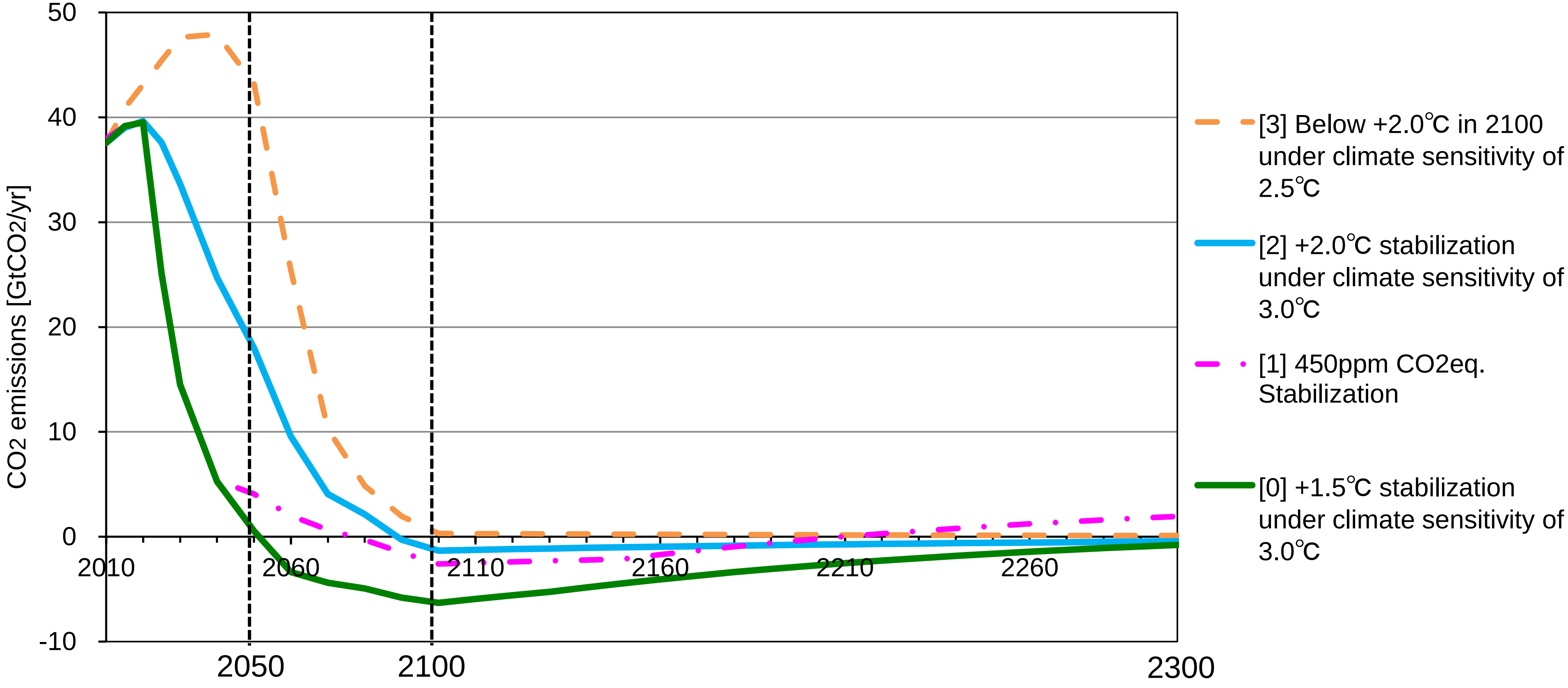
Same "likely" range

[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.**

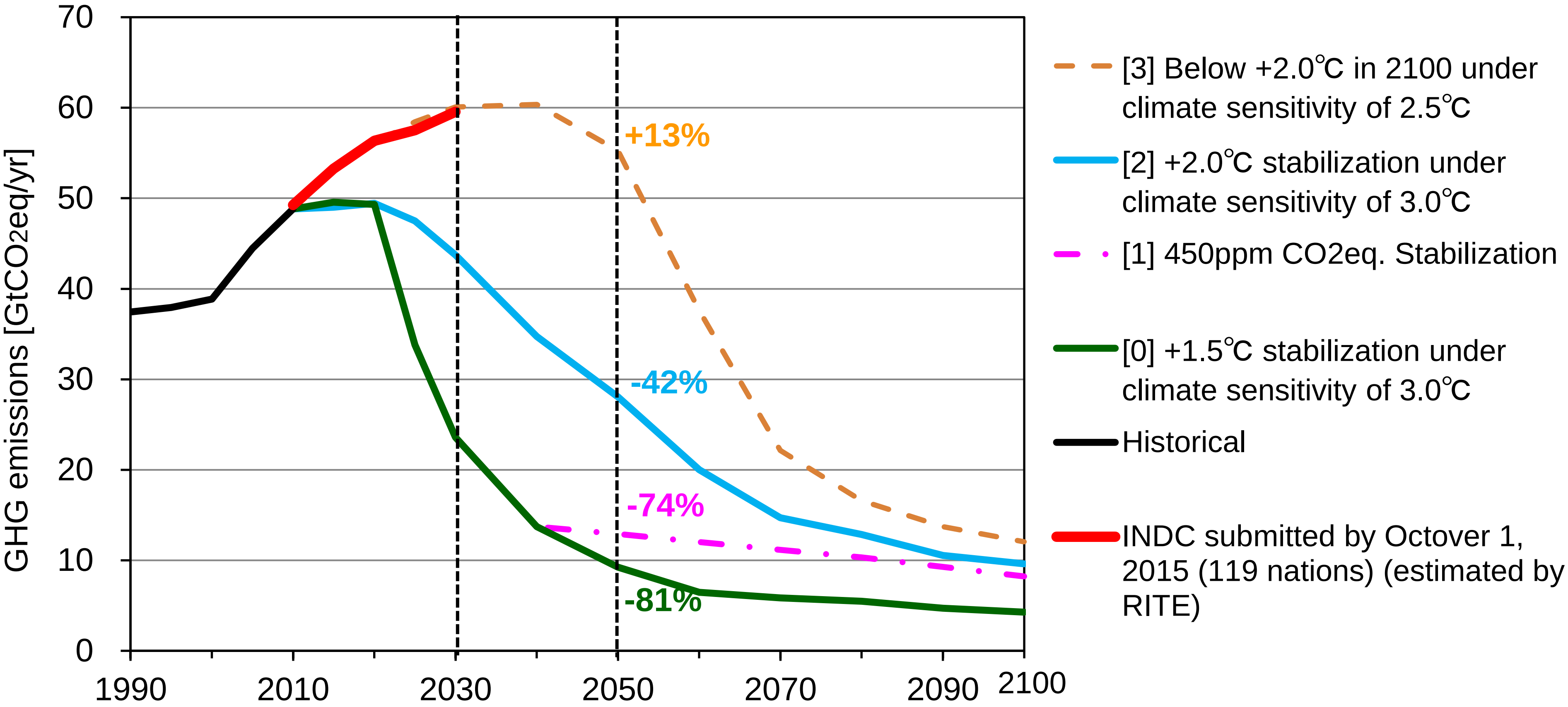
Global CO_2 emission profiles toward 2300 for the 2 °C and 1.5 °C targets



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 after 2050 are required for the 1.5 °C scenario.

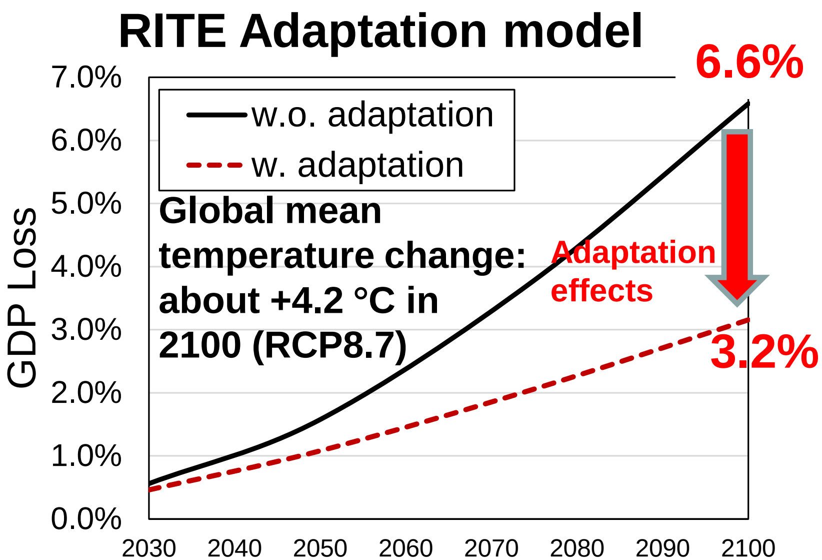
Global GHG emission profiles toward 2100 for the 2 °C and 1.5 °C targets



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

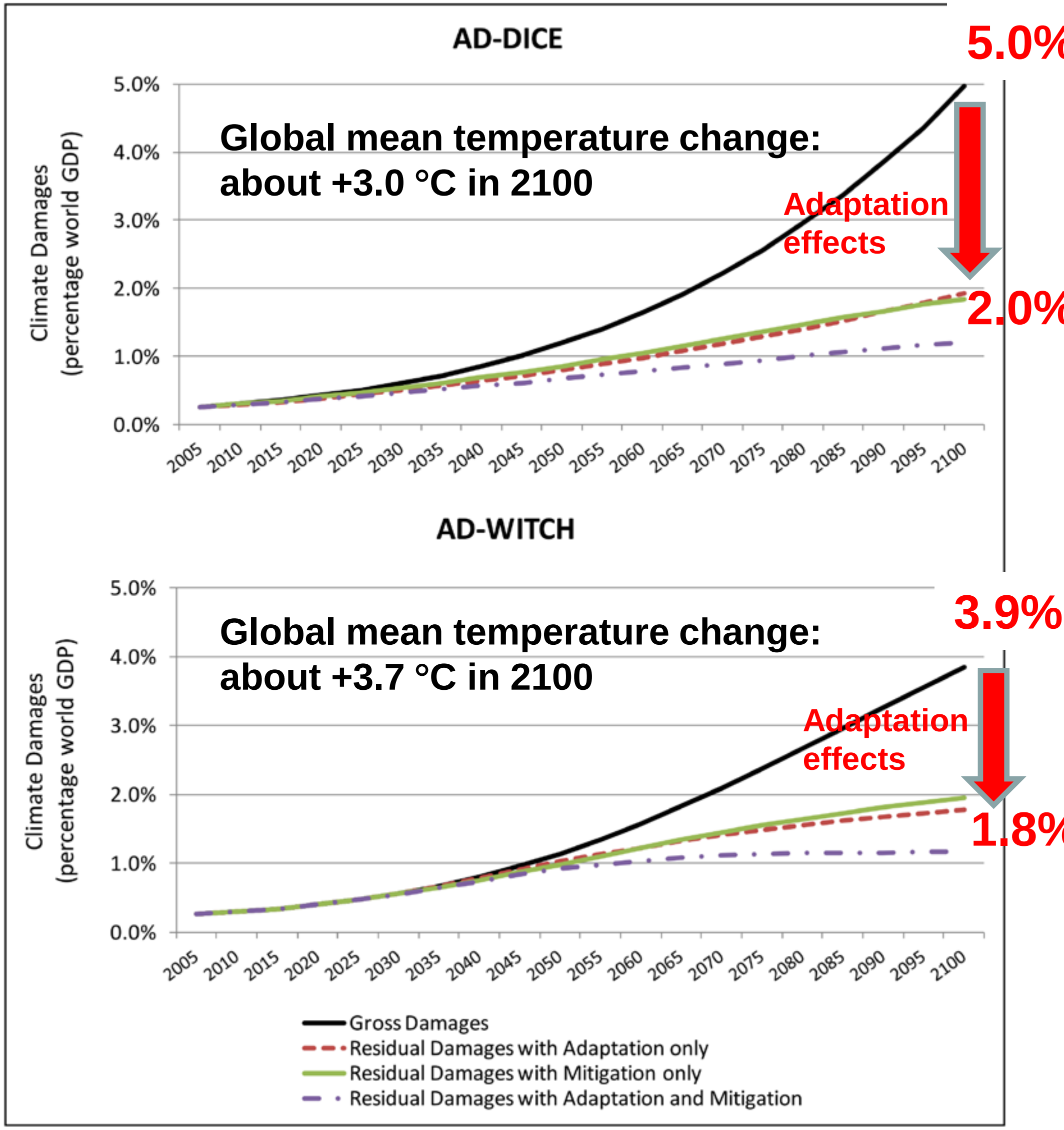
- The corresponding GHG emission trajectories for the 2 °C target vary widely particularly before 2050.
- There are large gaps between the expected emissions under the submitted NDCs and the 2 °C target.

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



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 reduced by adaptation measures. (Reductions in GDP loss due to adaptation measures: 2.1 to 3.4% points in 2100)



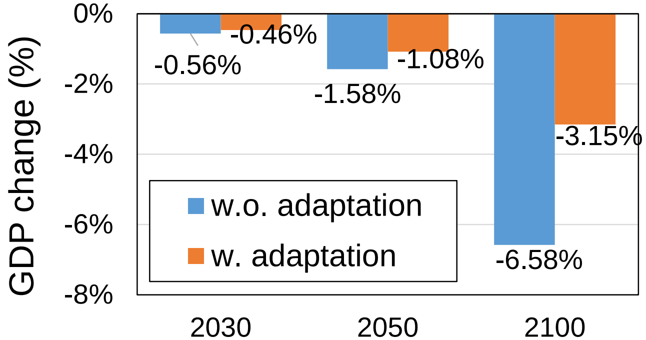
Source: Agrawala et al.2010, Fig13

Climate Change Damages, Adaptation and Mitigation Costs

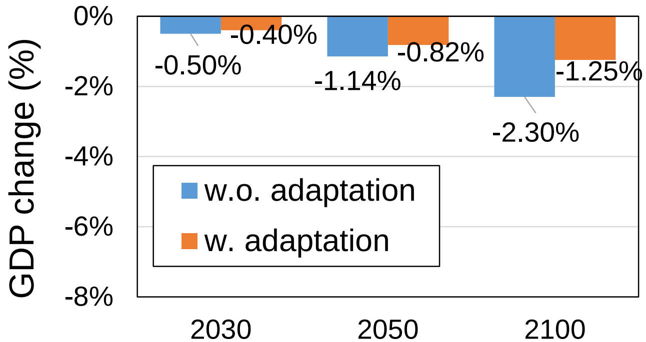
World GDP damages w.o./w. adaptation

(compared to the case without consideration of climate change)

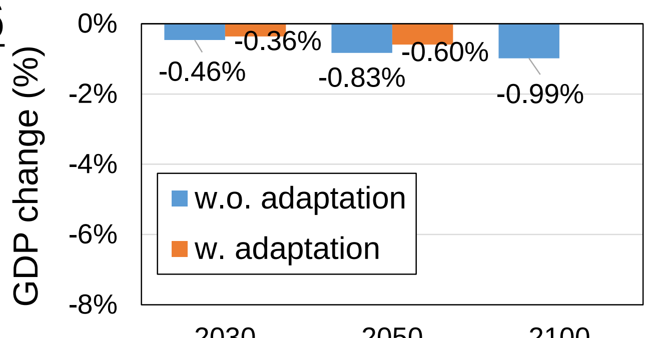
RCP8.5



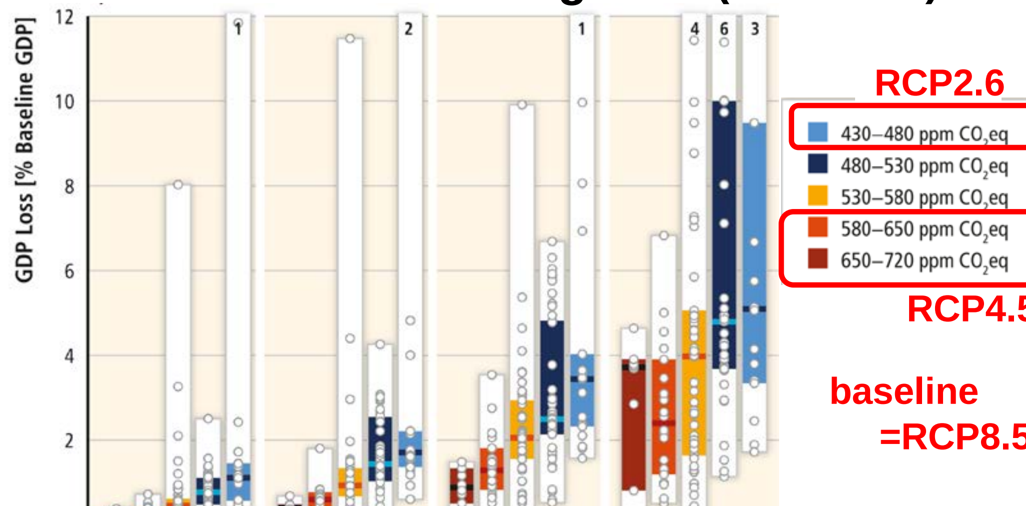
RCP4.5



RCP2.6



GDP loss due to mitigation (IPCC AR5)



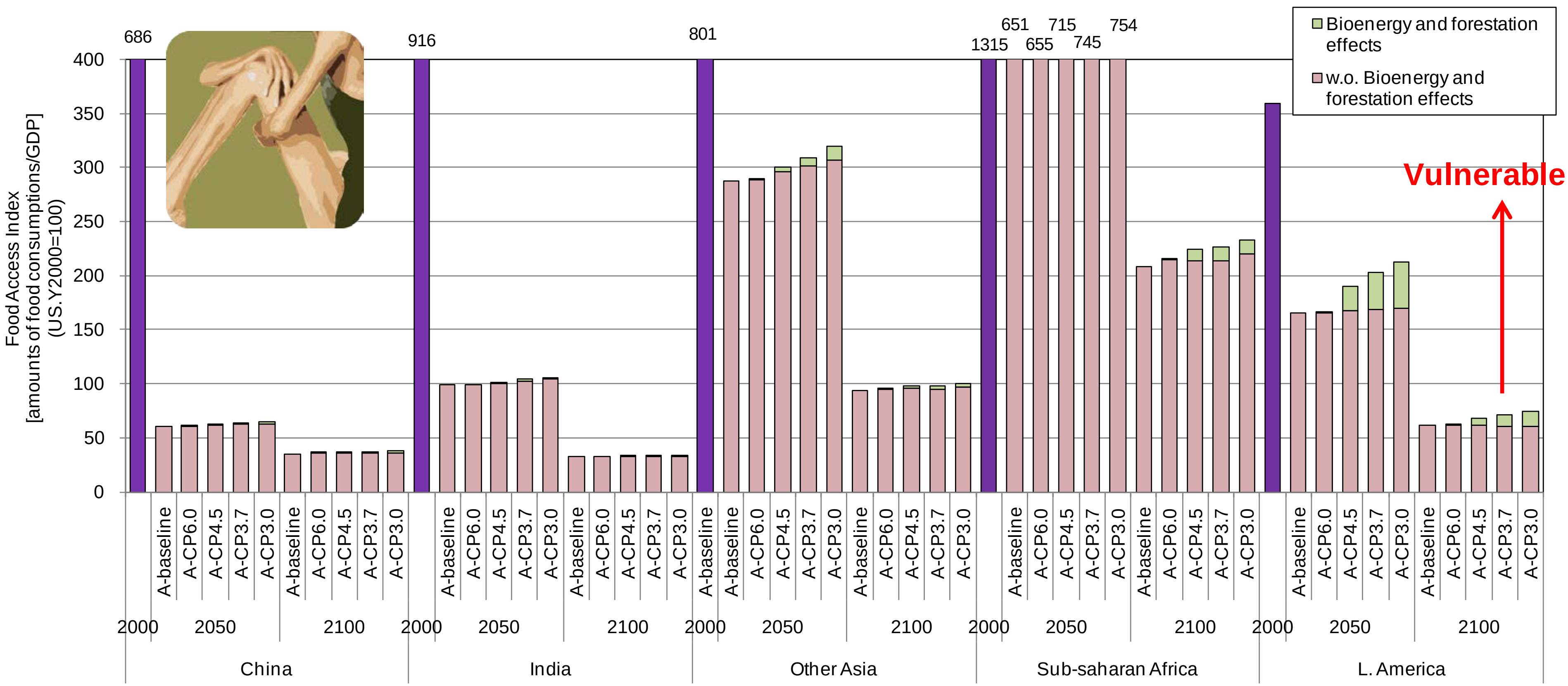
Note) The costs are estimated under the least global cost measures.

% 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 such large damages due to climate change, and the mitigation costs are large, the long-term targets, such as the 2 °C target like RCP2.), should be considered more flexibly.

Climate Change Mitigation & Food Access (1/2)

Food access index (Amounts of food consumption／GDP)



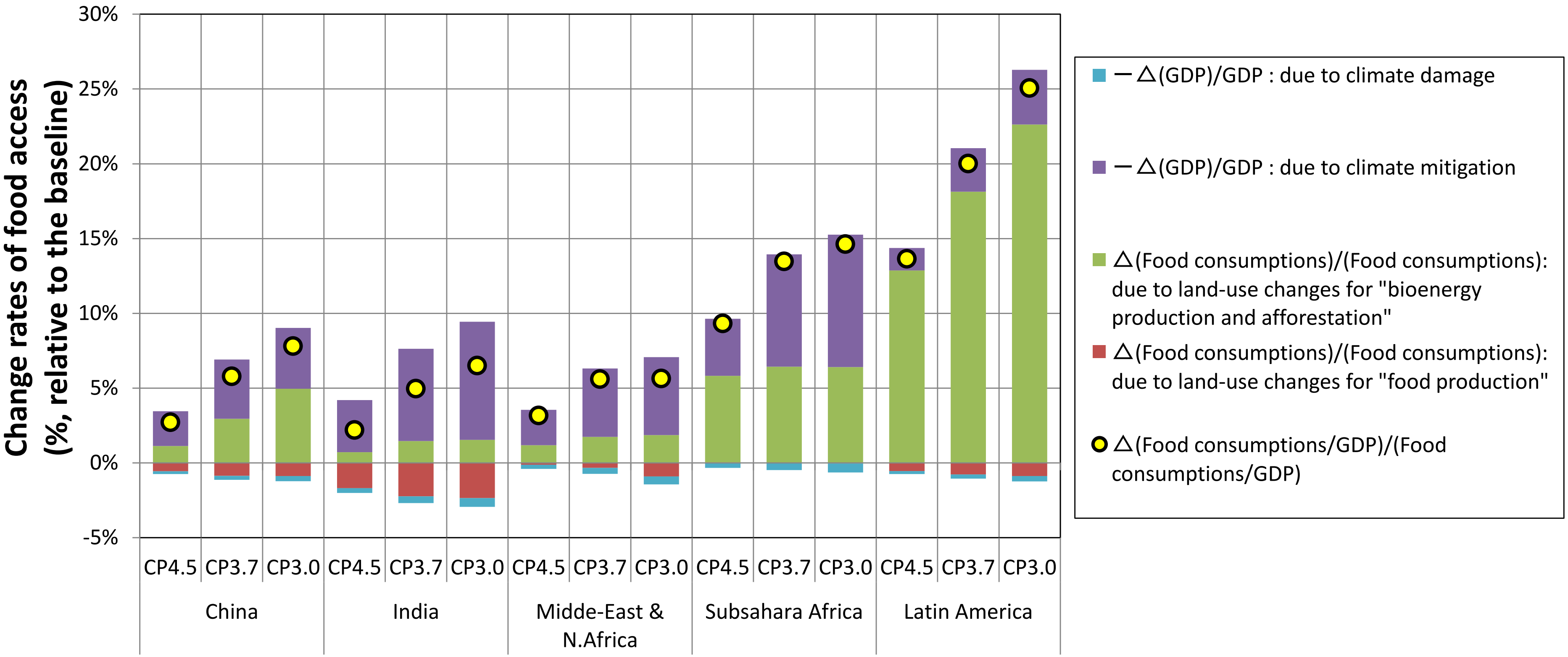
Source) K. Akimoto et al., Natural Resources Forum, 36(4), 231-244, 2012

- Vulnerabilities of food access will decrease in most countries and regions in the long-term under any emission scenarios, because future incomes are expected to increase in the future.

- Global warming counter-measures of large scale of forestation and bioenergy use slightly increase vulnerabilities of food access.

Climate Change Mitigation & Food Access (2/2)

Food access index (amounts of food consumption/GDP) in 2050 by factor



- The impacts of increase in vulnerability on food access due to climate change (synergy effects) can be seen but are not large.
- Food access can be significantly more vulnerable to large deployments of forestation and bioenergy use and large mitigation costs in the case that the emission reductions are large (adverse side effects).

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

Kaya identity

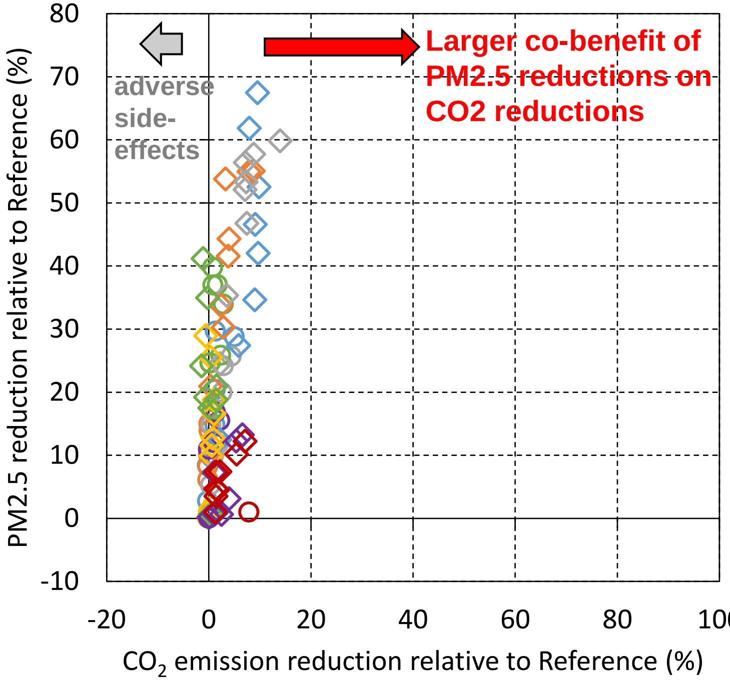
End-of-pipe measures (CCS) | Co-benefit measures

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

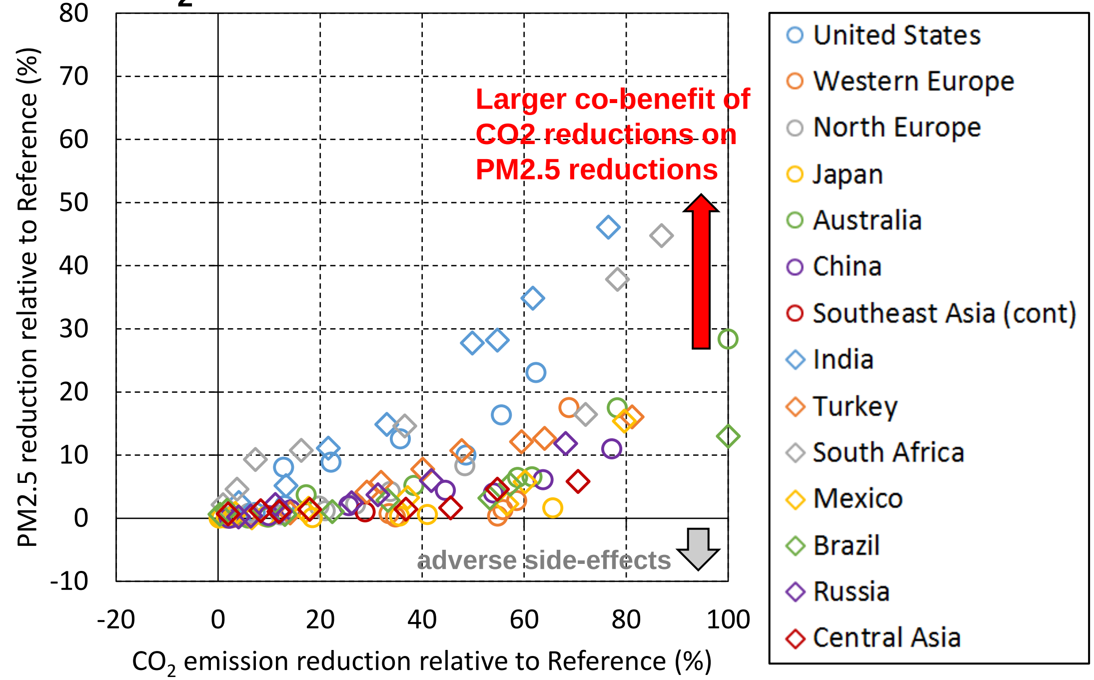
PM2.5 = (PM2.5／Gross PM2.5) × (Gross PM2.5／PE) × (PE／GDP) × (GDP)

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

PM2.5 concentration reduction cases



CO_2 emission reduction cases

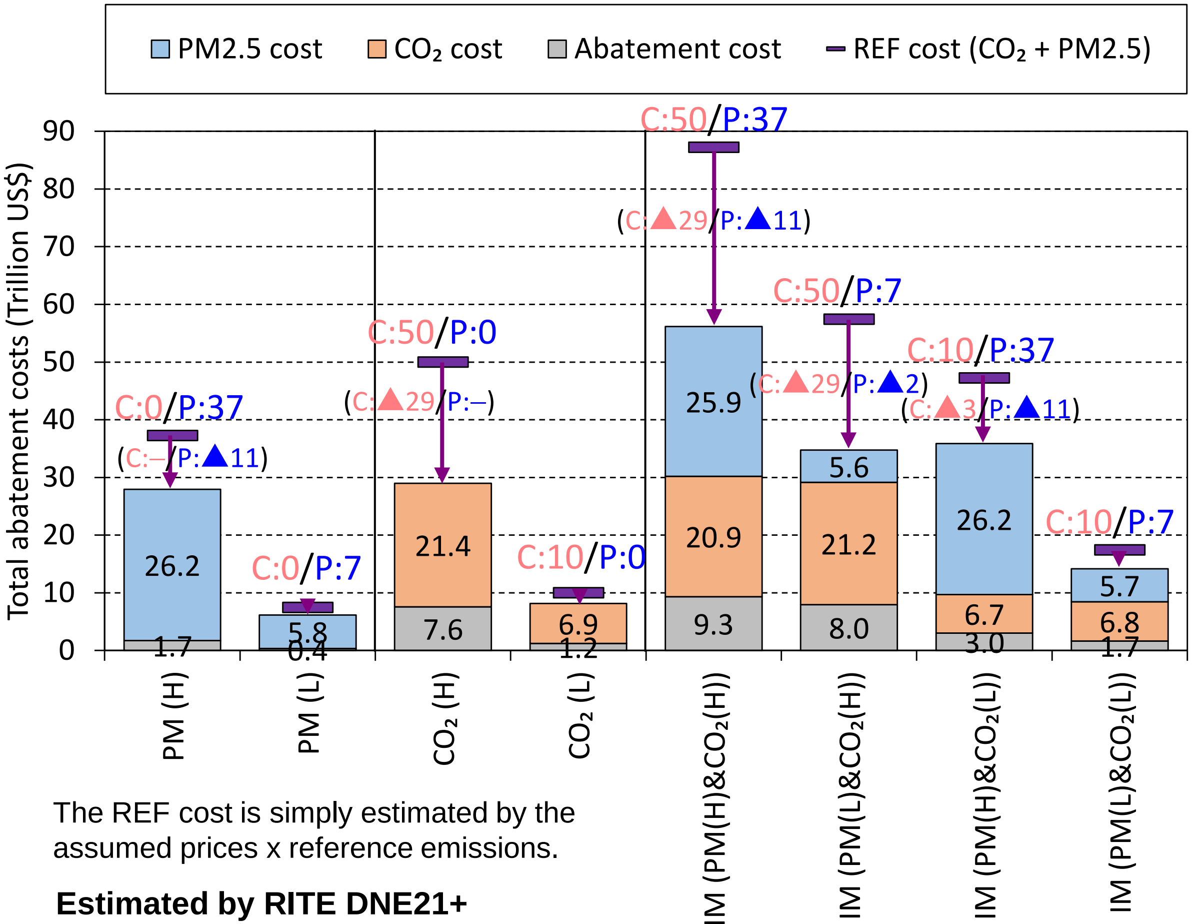


Estimated by RITE DNE21+ model (up to 2050)

- 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+

CO2, 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$]

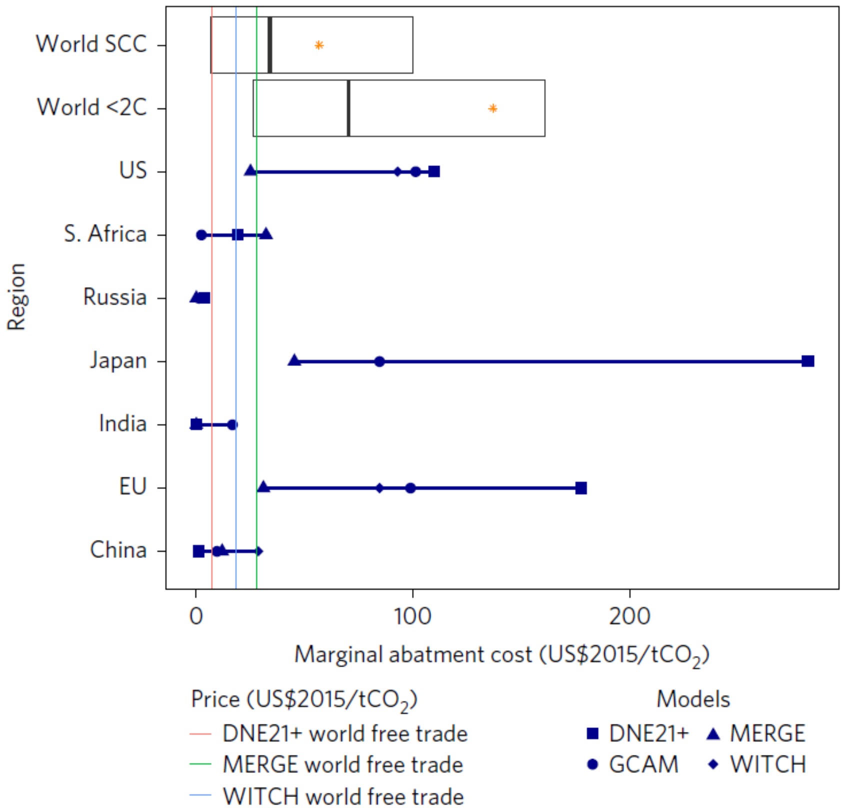
(Parenthesis: total mitigation costs)

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.

CO_2 marginal abatement costs of the NDCs



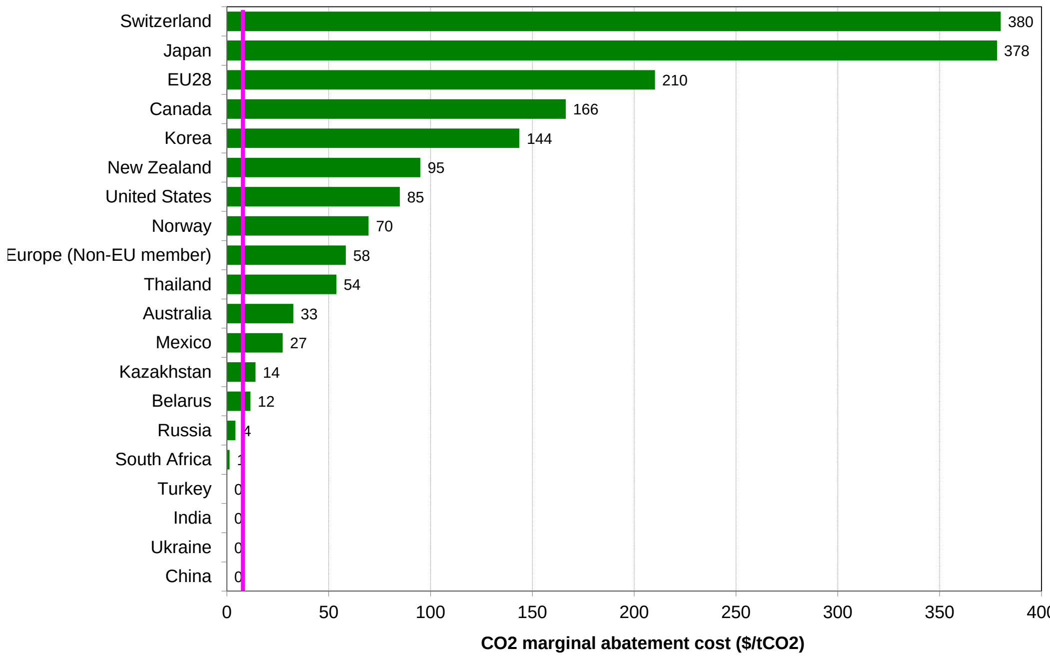
Source: J. Aldy et al., Nature Climate Change, 2016

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

Emission reduction costs are an important indicator for measuring emission reduction efforts. The marginal abatement cost of Japan's NDC is estimated to be high across countries. However, the estimated marginal costs of NDCs are largely different among countries, and such large difference will induce carbon leakages, and the leakages will reduce the effectiveness of global emission reductions.

Issues of IPCC

- The IPCC assessment reports are written basically based on the scientifically reviewed articles.
- In addition, the principle of IPCC is “not policy prescriptive but policy relevant”.
- Under the conditions, the IPCC reports have the dilemma that it is valuable in practice but not easily accepted to the realistic solutions considering economic, social and political constraints in the real world.

Appendix

The Assumed Scenarios for Obtaining the Emission Pathways Meeting the 2 °C and 1.5 °C targets

Category by concentration in 2100 (ppm CO2eq)	Sub-category	Global GHG emissions in 2050 (relative to 2010)	Temperature in 2100 (°C, relative to 1850-1900)	Probability of not exceeding the temp. rise over 21st century (relative to 1850-1900)* — C.S. likely: 2.0-4.5°C, most likely:3.0°C by IPCC AR4 (=WG3 AR5)		Probability of not exceeding the temp. rise over 21st century (relative to 1850-1900)* — C.S. likely: 1.5-4.5°C, Most likely: 2.5°C by IPCC WG1 AR5+ TAR	
				1.5℃	2.0℃	1.5℃	2.0℃
[0] <430	Only a limited number of studies exist. (There are no scenarios in the AR5 DB.)			50%以上*		66%以上	
[1] 450 (430-480)	—	-72～-41%	1.5～1.7℃ (1.0～2.8)		66%以上	50%以上	
[2] 500 (480-530)	[2a] No exceedance of 530 ppm CO2eq	-57～-42%	1.7～1.9℃ (1.2～2.9)		50%以上		66%以上
	[2b] Exceedance of 530 ppm CO2eq	-55～-25%	1.8～2.0℃ (1.2～3.3)				
[3] 550 (530-580)	[2a] No exceedance of 580 ppm CO2eq	-47～-19%	2.0～2.2℃ (1.4～3.6)				50%以上
	[2b] Exceedance of 580 ppm CO2eq	-16～+7%	2.1～2.3℃ (1.4～3.6)				

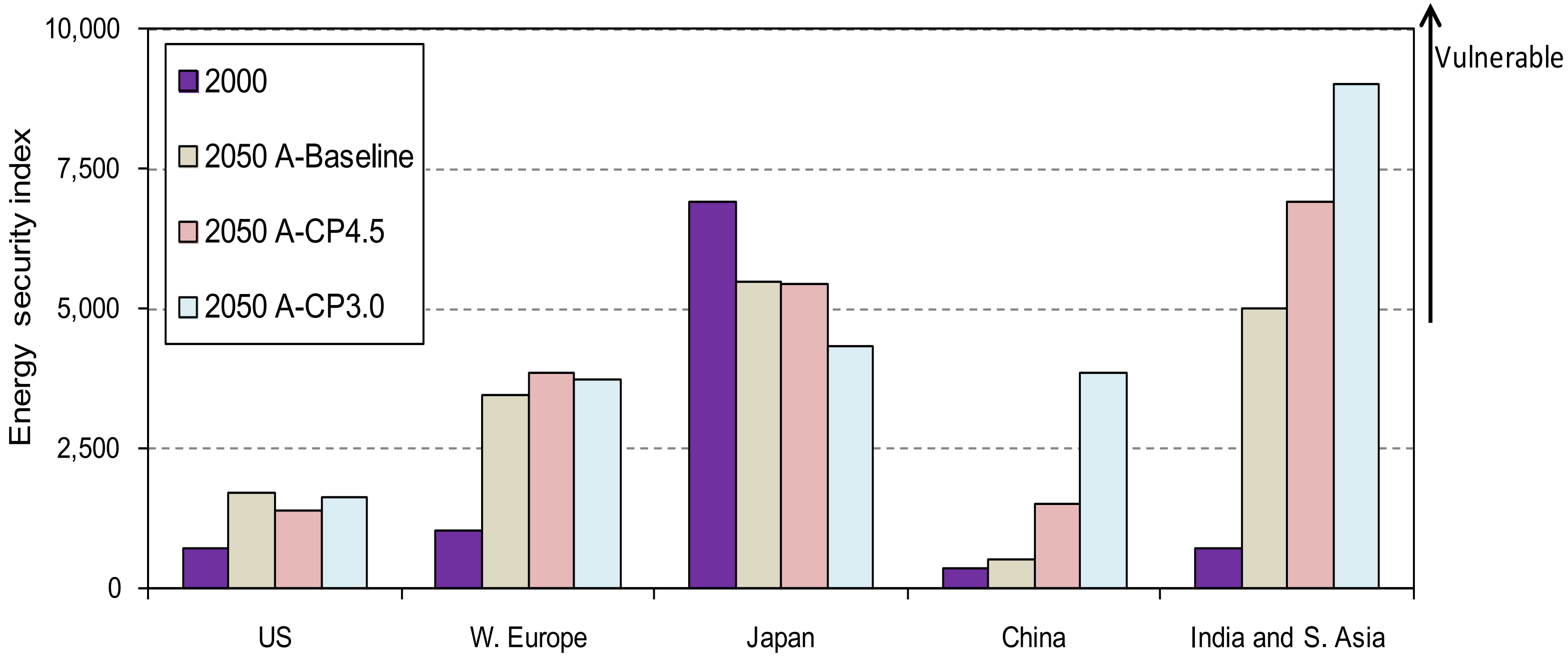
Source) IPCC AR5; * simply estimated by RITE

Climate Change Mitigation & Energy Security

$$ESI = \frac{C_{oil}}{TPES}\sum_i \left(r_i \cdot S_{i,oil}{}^2\right) + \frac{C_{gas}}{TPES}\sum_i \left(r_i \cdot S_{i,gas}{}^2\right)$$

Share of imported oil in TPES — Political risks of region i — Dependence on region i

ESI : energy security index, TPES: total primary energy supply
Note: index based on IEA, 2007



Source) K. Akimoto et al., Natural Resources Forum, 36(4), 231-244, 2012

While the energy security index of Japan decreases (less vulnerable) for CP3.0 (synergy effects), that of China, India increases (more vulnerable) for deeper emission reductions due to increase in imported gas shares (adverse side effects).