wholeSEM 3rd Annual Conference (2016)

Energy Modelling Insights for Iterative Decision Making

July 4-5, 2016; Moller Centre, Cambridge

Evaluation of 2030 GHG emissions based on the submitted NDCs and their consistency with temperature rise target emission pathways considering scientific and policy uncertainties

Keigo Akimoto

Group Leader, Systems Analysis Group

Research Institute of Innovative Technology for the Earth (RITE)

RITE Research Institute of Innovative Technology for the Earth

Introduction

- Under the Paris Agreement, almost all nations tackle greenhouse gas (GHG) emission reductions for the post-2020 terms with internationally legal force.
- All of the member nations are required to submit their emission targets as the Nationally Determined Contribution (NDC), which are to be internationally and comparatively reviewed and evaluated from the viewpoint of meeting long-term targets constituting a form of "global stocktaking."
- 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."
- On the other hand, the emission pathway cannot be uniquely determined for a certain level of temperature target because of scientific and policy uncertainties; there still exists a large uncertainty in climate sensitivity; as to the temperature target, the target year, temperature profile (whether or not to allow overshoot), how large the achieving probability should be expected are not politically clarified.

Estimated allowable emissions for the 2 °C target considering scientific and policy uncertainties

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)**
Global mean temperature estimations for the long-term scenarios in the IPCC WG3 AR4 (employing MAGICC)	**No estimates with probability (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]**

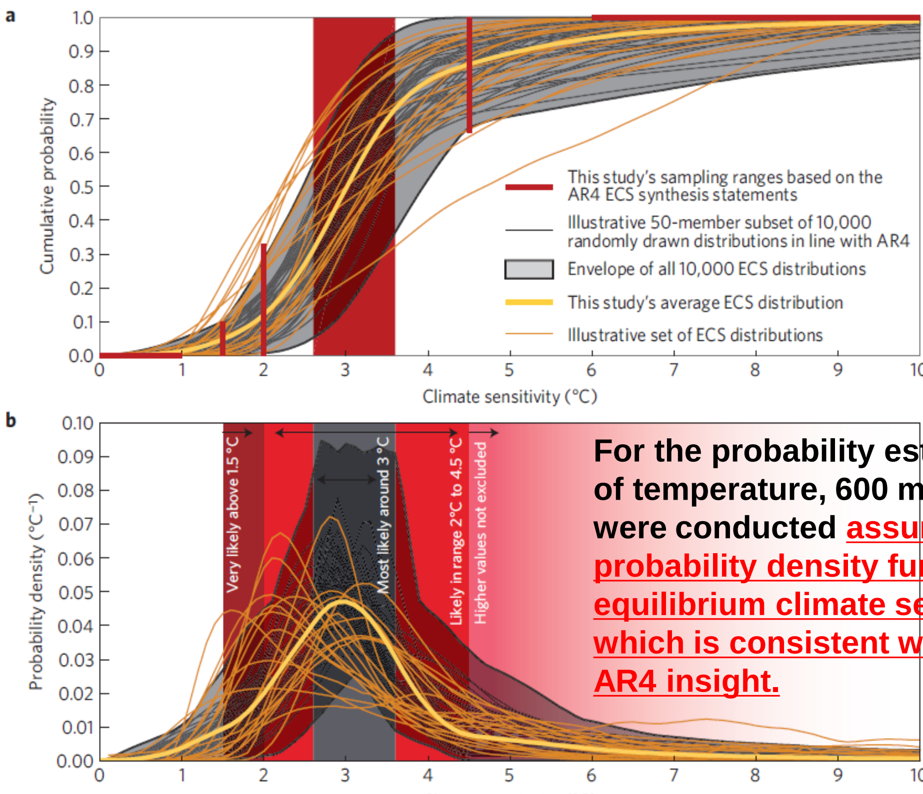
[The related descriptions of the SPM of WG1 AR5]

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 CIMP5 (AOGCM) results but also other study results.**
- **However, 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.**

The climate sensitivity of MAGICC model which was employed for the temperature change estimations in the long-term scenarios of IPCC WG3 AR5

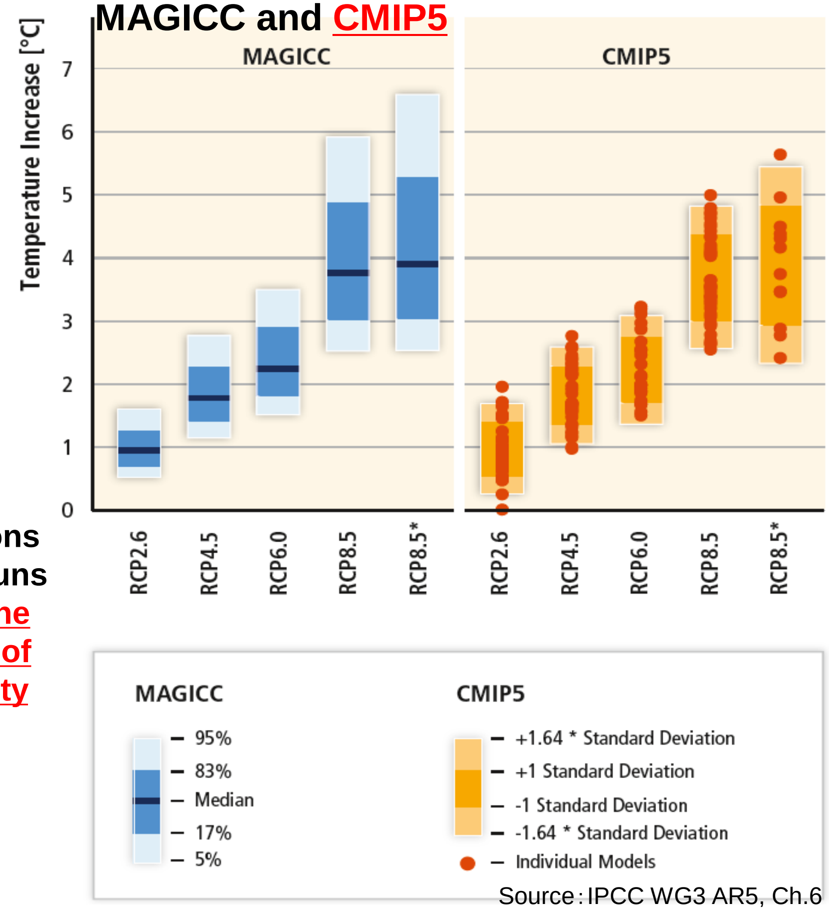
WG3 AR5 employed a simple climate change model MAGCC for the temperature estimates for long-term scenarios.



For the probability estimations of temperature, 600 model runs were conducted <u>**assuming the probability density function of equilibrium climate sensitivity which is consistent with the AR4 insight.**</u>

Source：J. Rogelj et al., 2012

The AR5 checked the differences between MAGICC and <u>**CMIP5**</u>



Source：IPCC WG3 AR5, Ch.6

- <u>**WG3 AR5 employed the climate sensitivity of AR4 (likely range: 2.0−4.5 °C, best estimate: 3.0 °C) for estimating the temperature of long-term scenarios.**</u> **This is almost consistent with the CMIP5 results but is inconsistent with the new judgment of WG1 AR5 considering other studies.**
- **Therefore, when the latest judgment for climate sensitivity of WG1 AR5 is employed, the temperature rise estimates of WG3 scenarios can be smaller than those shown in the WG3 AR5.**

Atmospheric GHG Concentration, Emission Reduction in 2050, and Expected Temperature Increase (IPCC WG3 AR5)

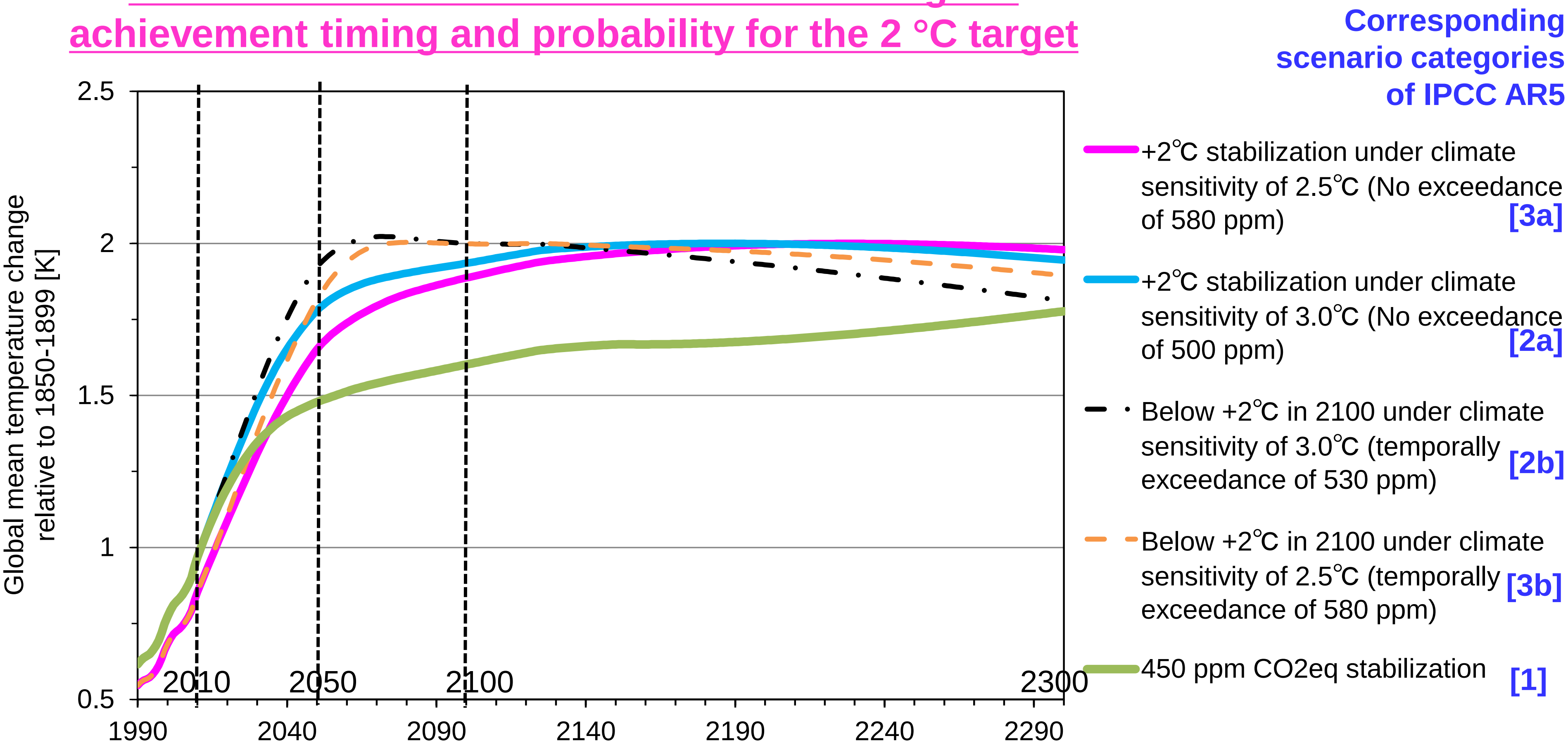
RITE Research Institute of Innovative Technology for the Earth

Category by concentration in 2100 (ppm CO2eq)	Sub-category	RCPs	Global GHG emissions in 2050 (relative to 2010)	Temperature in 2100 (°C, relative to 1850-1900)	Probability of exceeding the temperature rise over 21st century (relative to 1850-1900)		
					1.5 °C	2.0 °C	3.0 °C
[1] 450 (430-480)	—	RCP2.6	-72 to -41%	1.5–1.7°C (1.0–2.8)	49-86%	12-37%	1-3%
[2] 500 (480-530)	[a] No exceedance of 530 ppm CO2eq		-57 to -42%	1.7–1.9°C (1.2–2.9)	80-87%	32-40%	3-4%
	[b] Exceedance of 530 ppm CO2eq		-55 to -25%	1.8–2.0°C (1.2–3.3)	88-96%	39-61%	4-10%
[3] 550 (530-580)	[a] No exceedance of 580 ppm CO2eq		-47 to -19%	2.0–2.2°C (1.4–3.6)	93-95%	54-70%	8-13%
	[b] Exceedance of 580 ppm CO2eq		-16 to +7%	2.1–2.3°C (1.4–3.6)	95-99%	66-84%	8-19%
(580-650)	—	RCP4.5	-38 to +24%	2.3–2.6°C (1.5–4.2)	96-100%	74-93%	14-35%
(650-720)	—		-11 to +17%	2.6–2.9°C (1.8–4.5)	99-100%	88-95%	26-43%
(720-1000)	—	RCP6.0	+18 to +54%	3.1–3.7°C (2.1–5.8)	100-100%	97-100%	55-83%
>1000	—	RCP8.5	+52 to +95%	4.1–4.8°C (2.8–7.8)	100-100%	100-100%	92-98%

Source) IPCC WG3 AR5, 2014

Assumed temperature trajectories for the 2 °C target

There are several uncertainties concerning the achievement timing and probability for the 2 °C target



Estimated by RITE using MAGICC

The climate sensitivity assumes:
3.0 °C: according to the WG1 AR4 judgment, and
2.5 °C: according to the WG1 AR5 & before AR4 judgment

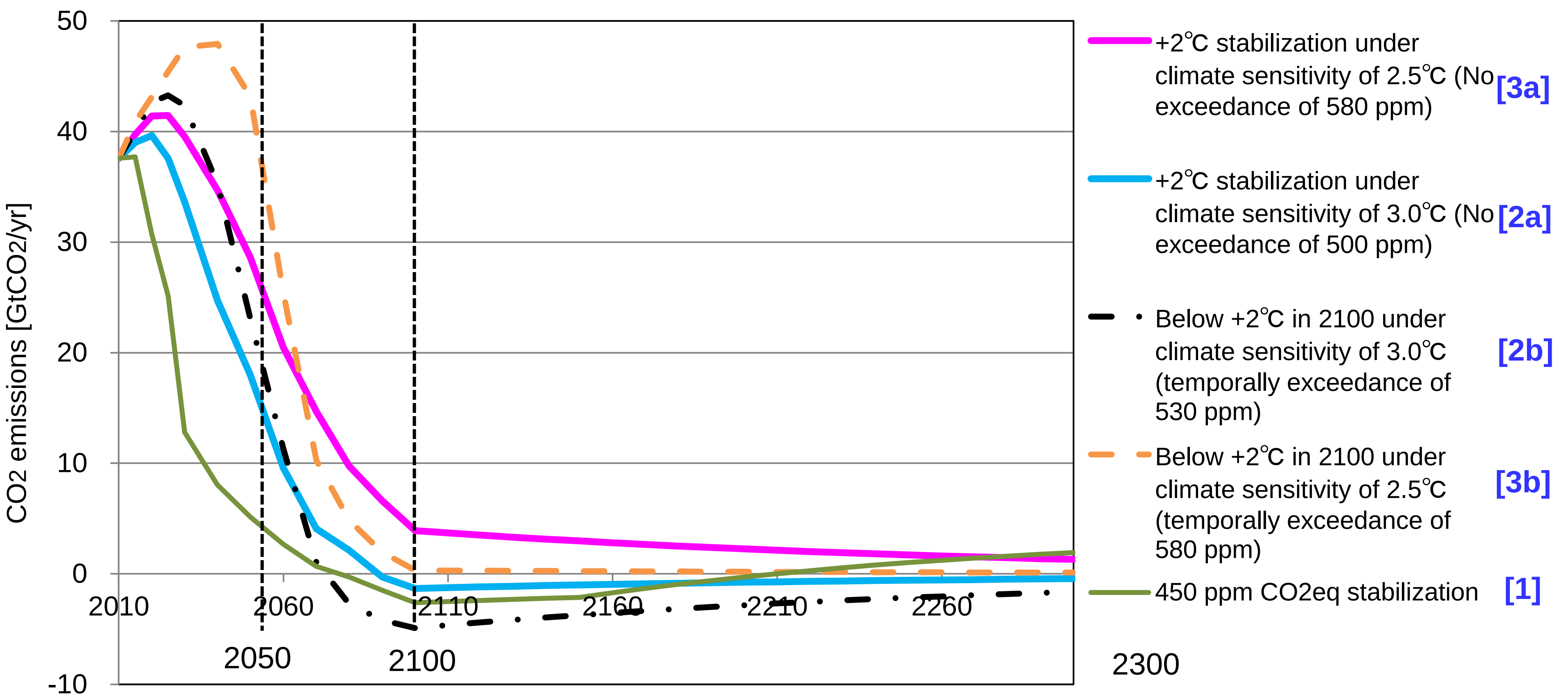
Five kinds of temperature trajectories including CO_2 concentration stabilization, temperature stabilization, temperature overshoot are assumed.

Energy Assessment Model: DNE21+

- Linear programming model (minimizing world energy system cost)
- Evaluation time period: 2000-2050
  Representative time points: 2000, 2005, 2010, 2015, 2020, 2025, 2030, 2040, 2050
- World divided into 54 regions
  Large area countries are further divided into 3-8 regions, and the world is divided into 77 regions.
- Bottom-up modeling for technologies both in energy supply and demand sides (about 300 specific technologies are modeled.)
- Primary energy: coal, oil, natural gas, hydro&geothermal, wind, photovoltaics, biomass and nuclear power
- Electricity demand and supply are formulated for 4 time periods: instantaneous peak, peak, intermediate and off-peak periods
- Interregional trade: coal, crude oil, natural gas, syn. oil, ethanol, hydrogen, electricity and CO_2
- Existing facility vintages are explicitly modeled.

- The model has regional and technological information detailed enough to analyze sectoral measures. Consistent analyses among regions and sectors can be conducted.

Global CO2 emission profiles toward 2300 for the 2 °C target

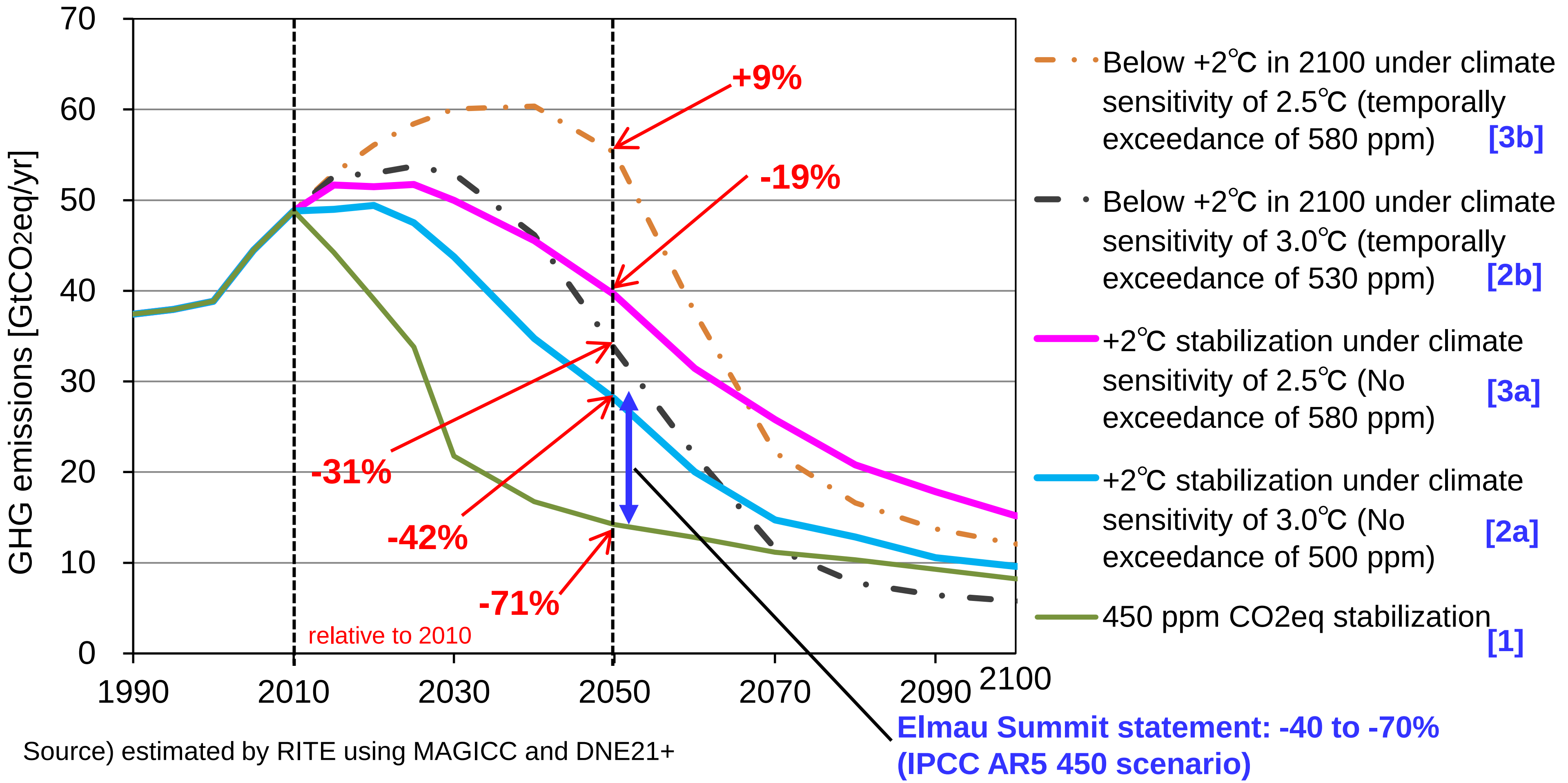


Source) estimated by RITE using MAGICC and DNE21+

- The corresponding CO2 emission profiles vary widely particularly when the climate sensitivity uncertainty is considered even within 0.5 °C difference of the climate sensitivity.

- On the other hand, the CO2 emissions should be nearly zero by 2300 in any pathways for the 2 °C target.

Global GHG emission profiles toward 2100 for the 2 °C target

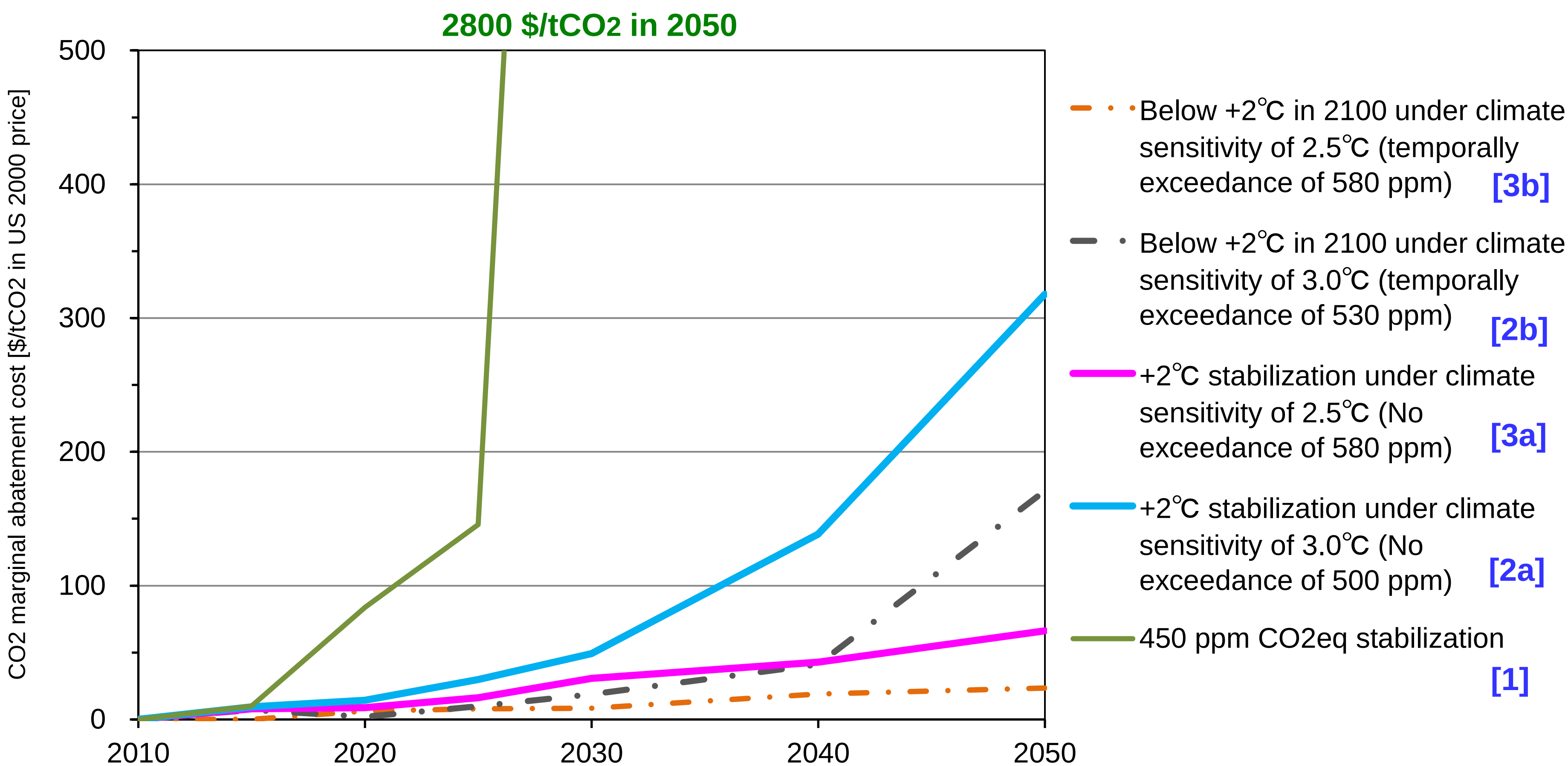


Source) estimated by RITE using MAGICC and DNE21+

- The corresponding GHG emission profiles also vary widely particularly before 2050. (e.g., +9 to -71% in 2050 compared to 2010)

- The Paris Agreement states the 2 °C target politically; however, the emission pathways and reduction measures vary widely. We need to seek a better strategy for the 2 °C target considering other kind of risks than climate change as well.

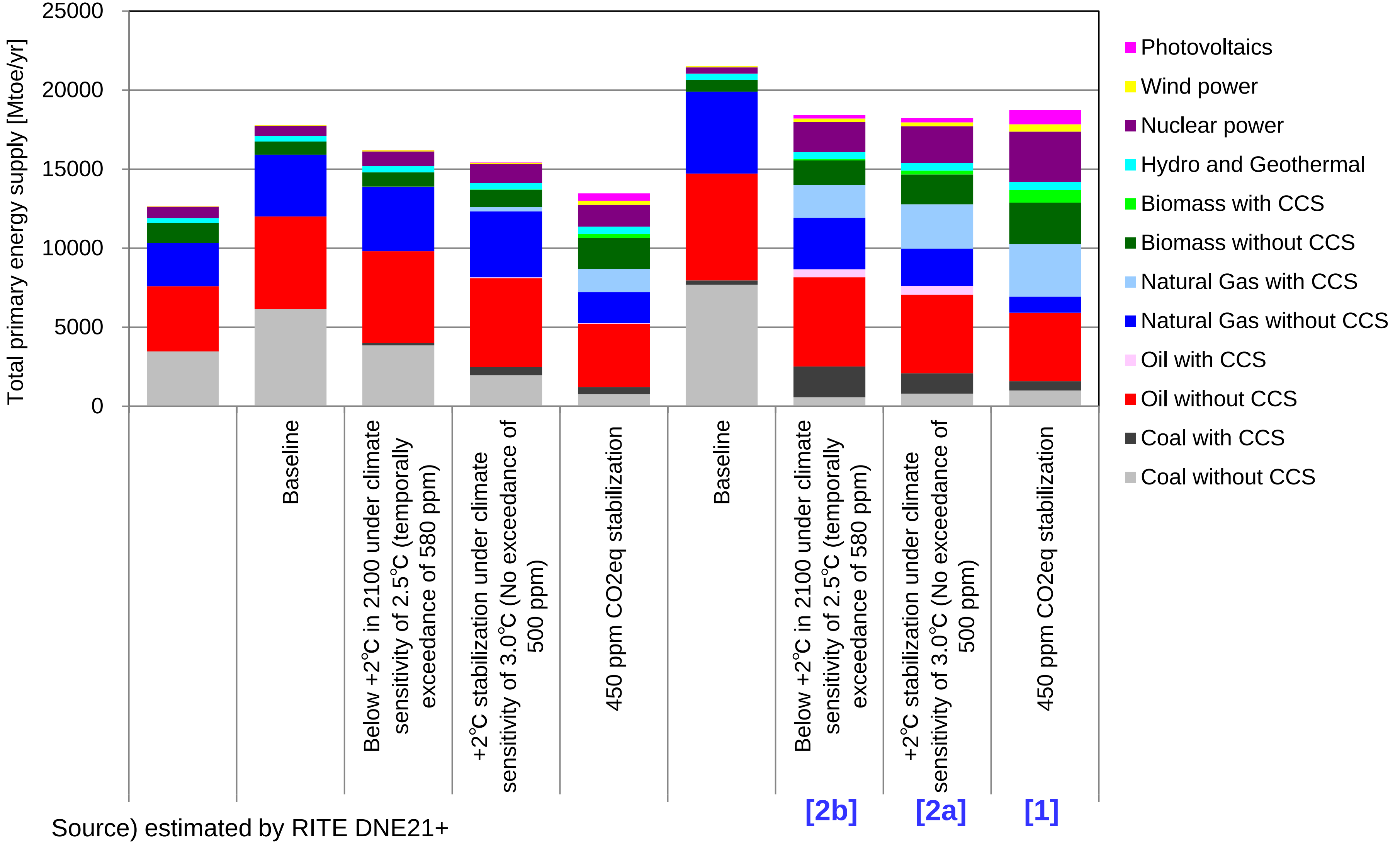
CO_2 Marginal Abatement Cost for the 2 °C target



Source) estimated by RITE DNE21+

- The marginal abatement costs for the 2 °C target also vary widely. For the assessed five emission pathways, the costs in 2050 are between 24 and 2800 $/tCO2 even under the globally least-cost measures.
- Risks of not only climate change damages but also mitigation costs are also large. Management of mitigation costs are important in the total risk management strategy.

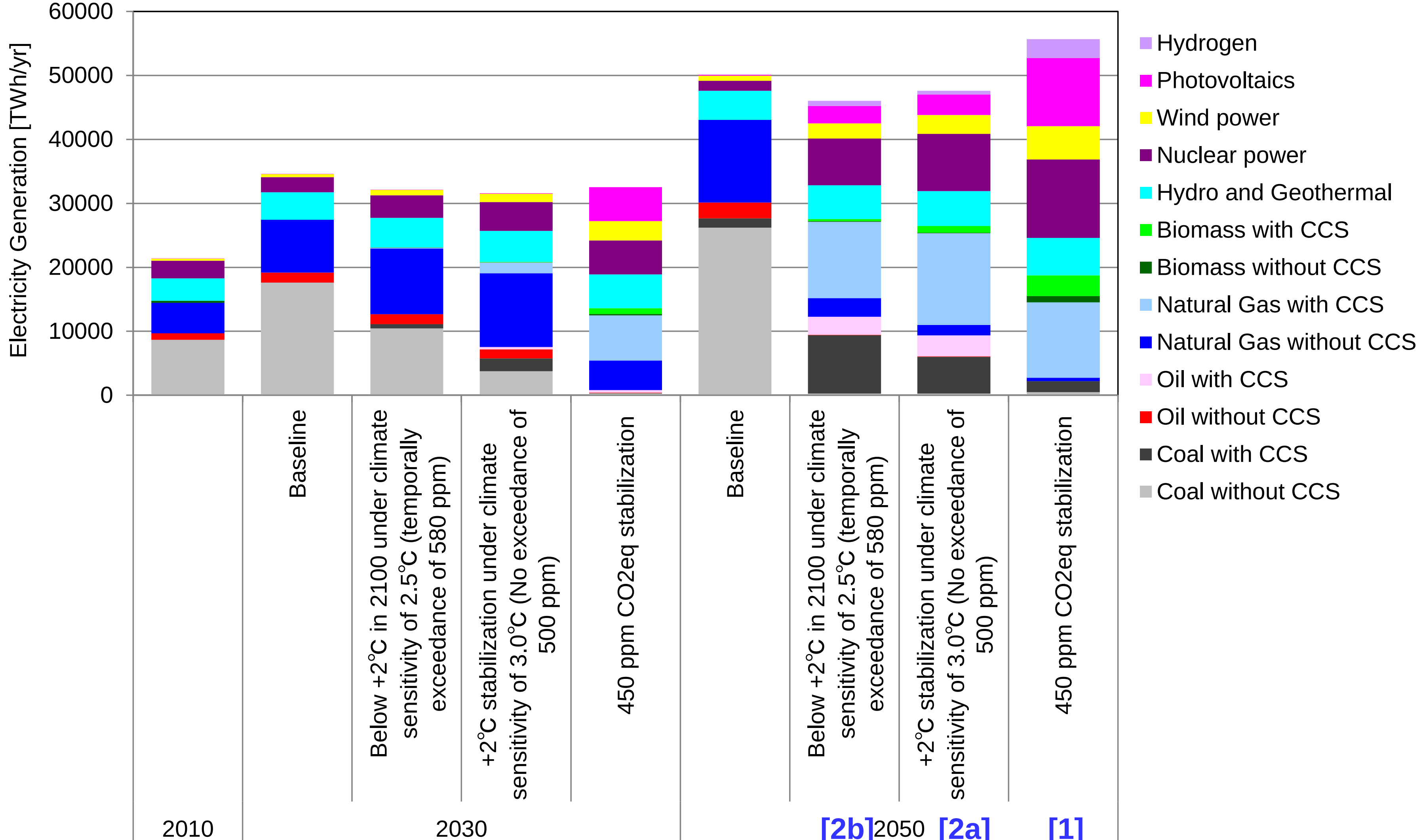
Global Primary Energy Supply



Source) estimated by RITE DNE21+

- The total amounts of primary energy for the 2 °C target will decrease compared with those in Baseline.
- Coal should be small by 2050, but these scenarios require high emission reduction costs.

Global Electricity Generation



Source) estimated by RITE DNE21+

- CO_2 emissions from power sector in most of the scenarios for the 2 °C target are nearly zero.
- The total amounts of electricity for the 2 °C target will increase with deeper emission reductions due to substitution for fossil fuel use in other sectors.

Evaluation of the comparability of emission reduction efforts of NDCs, and the expected emissions until 2030 and the consistency with the emission pathways for the 2 °C target

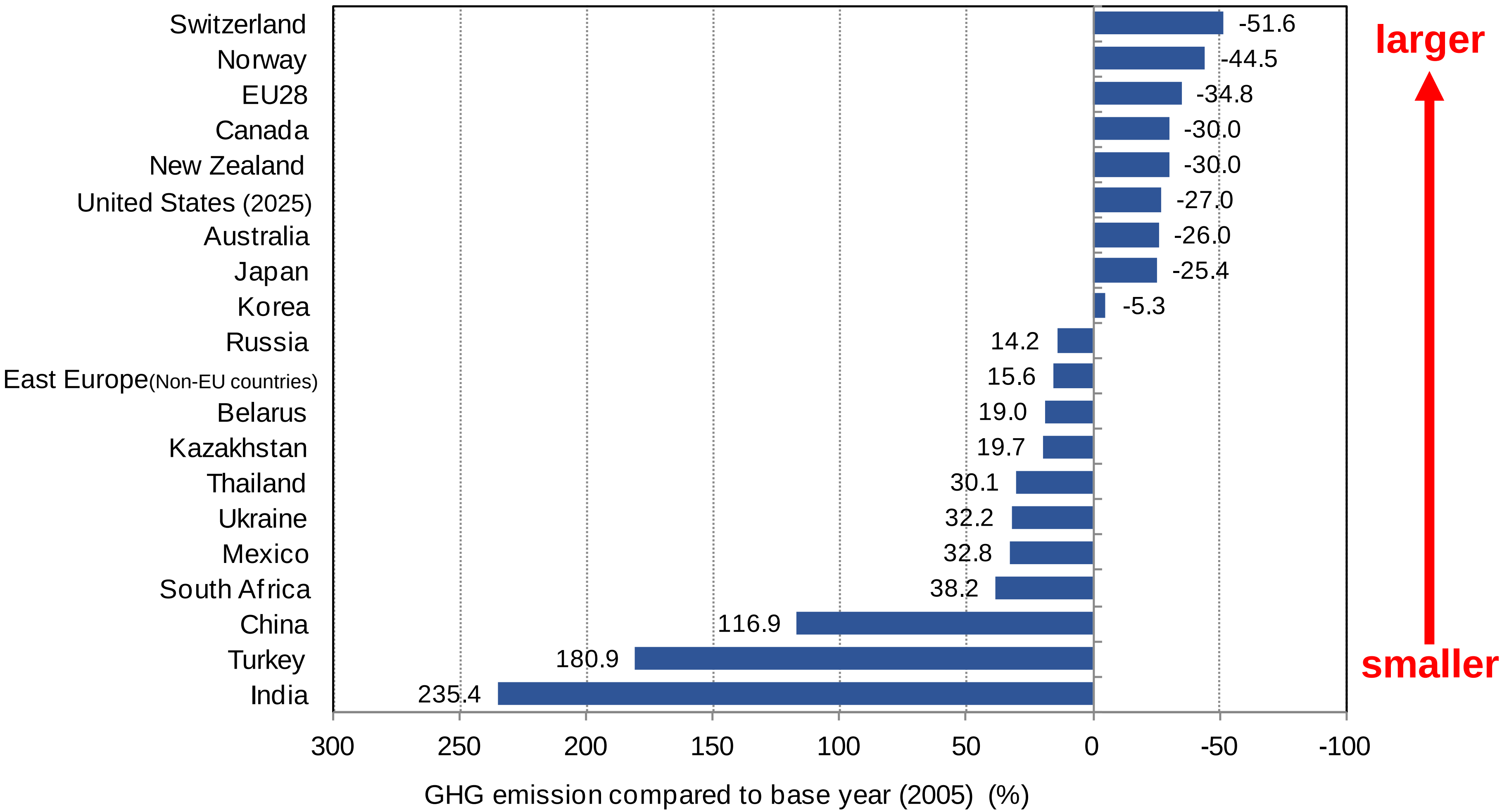
Evaluated NDCs for the expected emissions until 2030 and the comparability of emission reduction efforts across nations

- **The submitted INDCs include the targets of emissions 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.**
- **The 119 INDCs submitted as of October 1st, 2015 were evaluated. Their emissions account for about 88 per cent of global emissions in 2010.**
- **Here, comprehensive evaluations of emission reduction efforts were only for 20 countries due to the limited regional resolution of the model.**

Note: More ambitious emission reduction targets had been submitted as “conditional“ targets from some countries, but they are not considered in this evaluation.

DNE21+ model was employed for the analyses of mitigation costs for the INDCs.

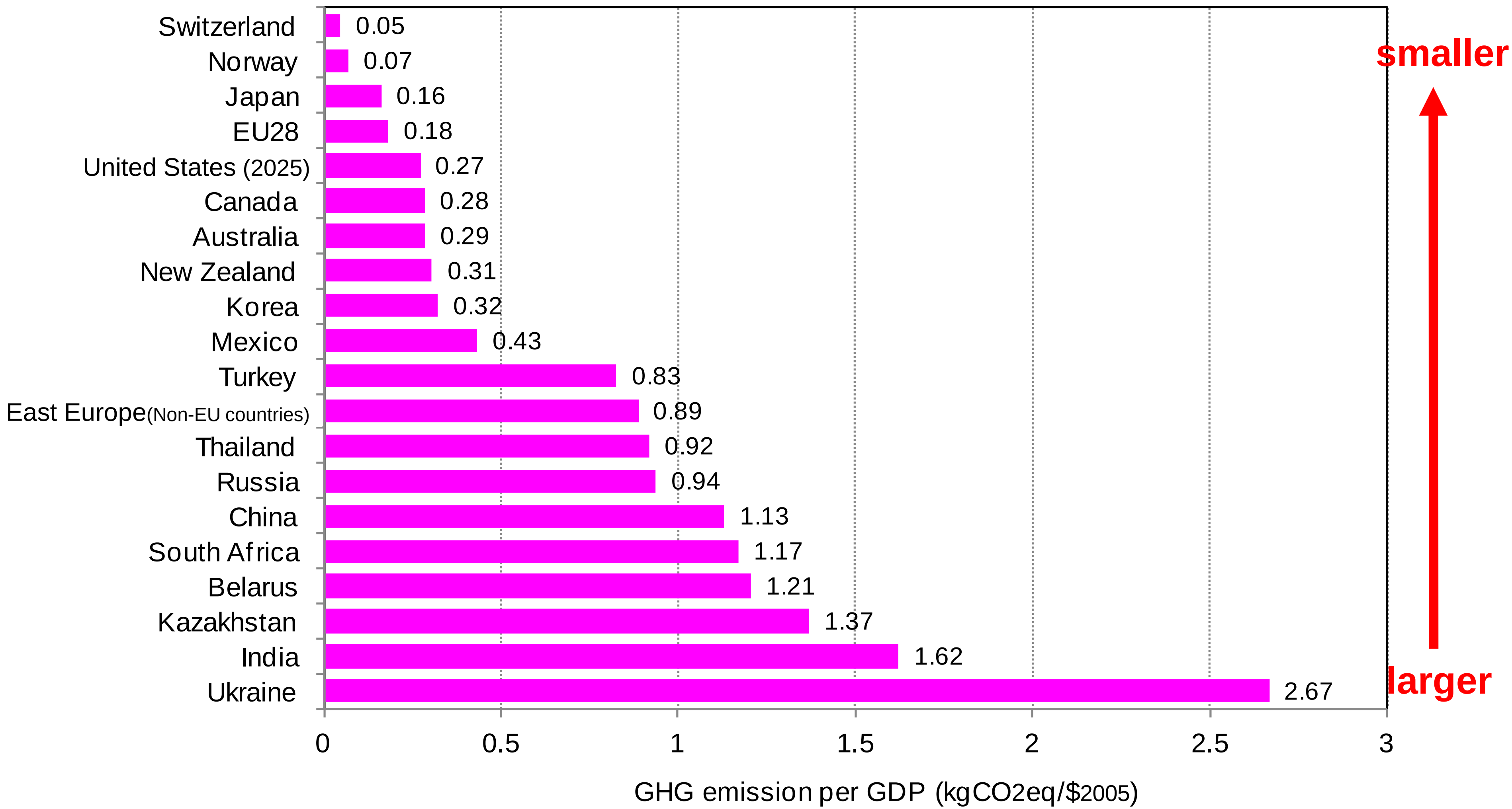
International comparison of emission reduction ratios from the base year of 2005



* The average values are shown for the countries submitted the INDC 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 in future economic growth and historical achievements of energy saving improvements and emission reductions, for example.

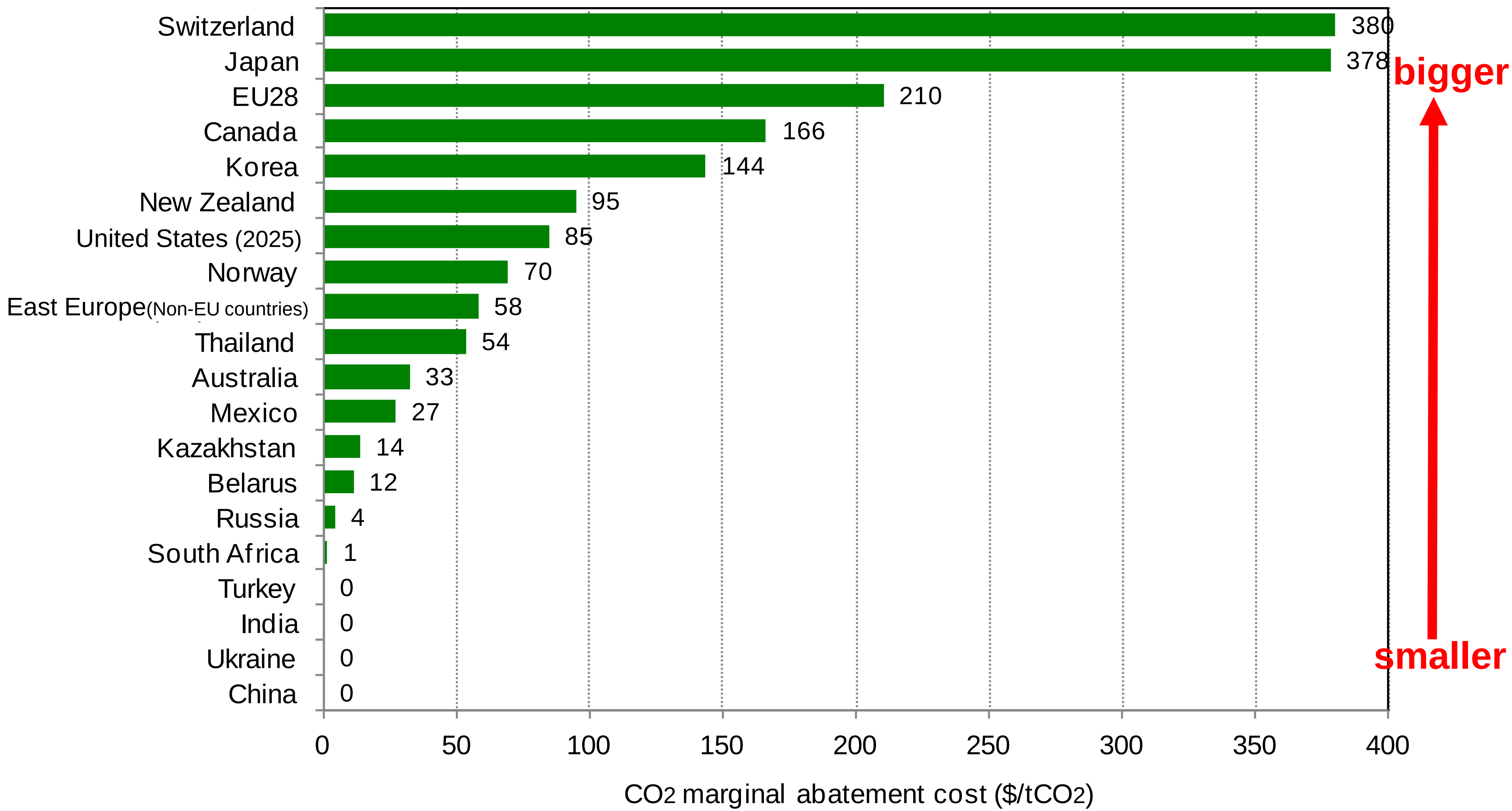
International comparison of GHG emissions per GDP



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

GHG emission per GDP indicates economic efficiency of GHG emission in general, but it depends on the industrial structures and low-carbon energy supply potentials.

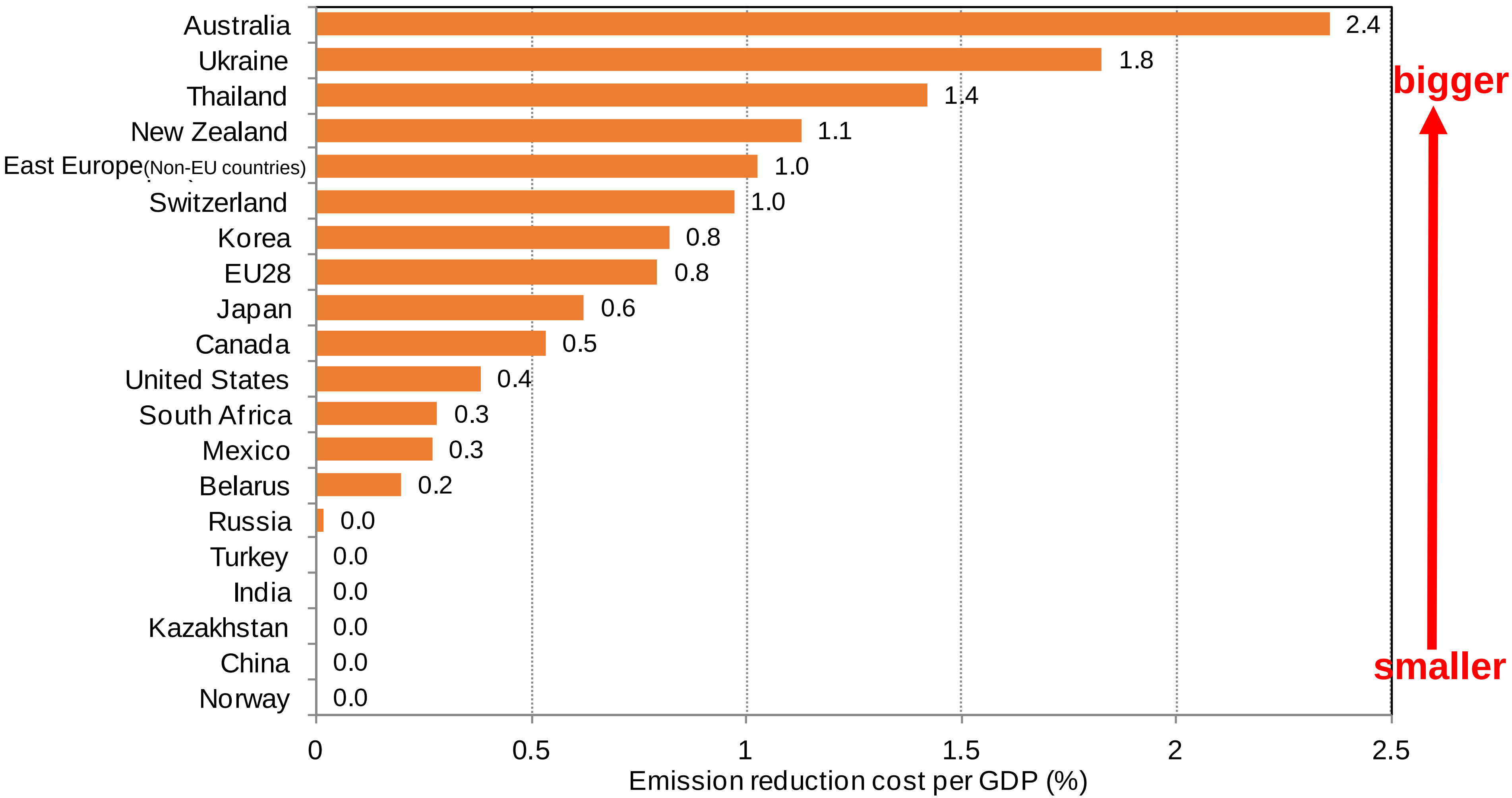
International comparison of CO_2 marginal abatement costs (RITE DNE21+ model)



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

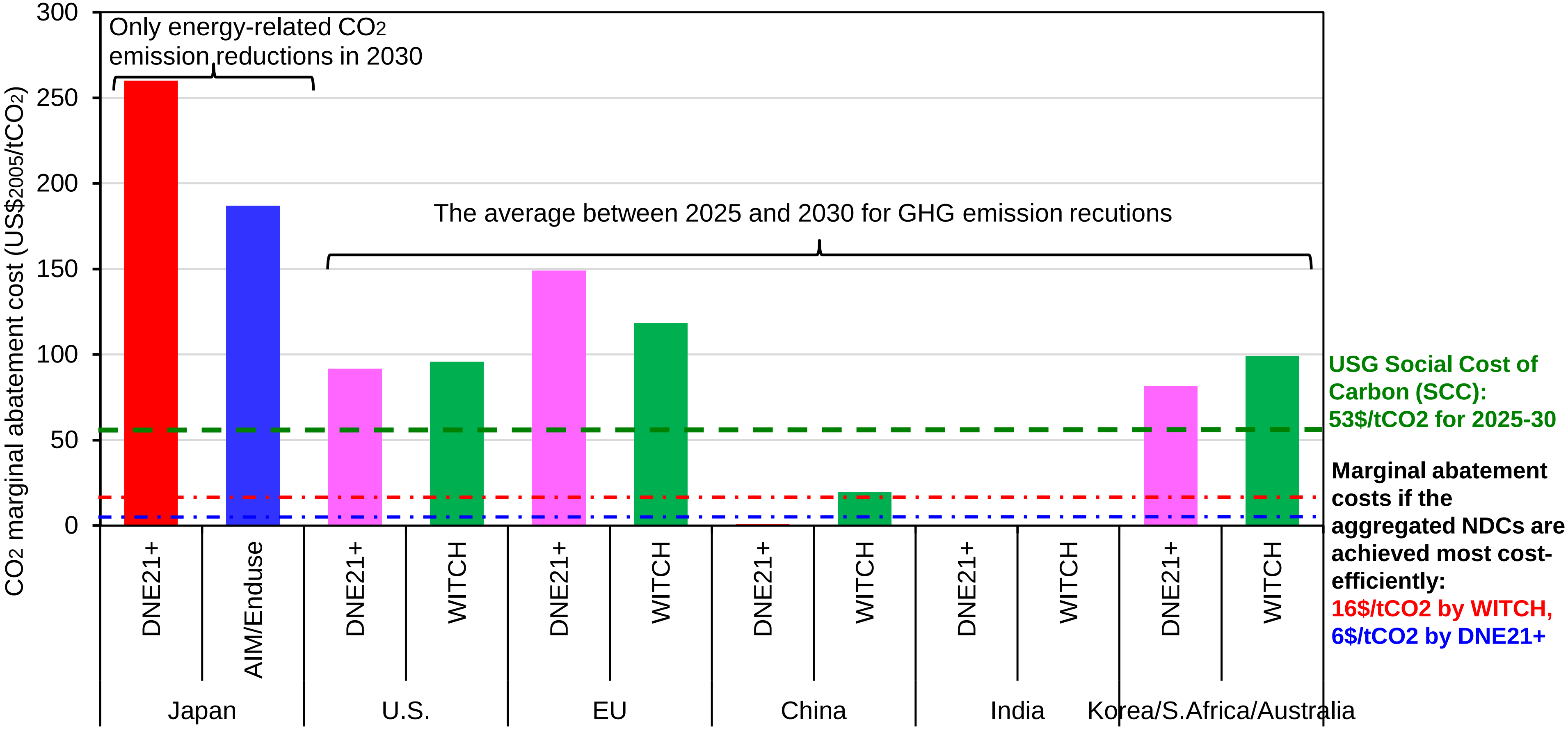
Large differences in marginal abatement costs are estimated across countries. The large differences raise concern about inducing the carbon leakage and the ineffectiveness of global emission reductions.

International comparison of emission reduction costs per GDP (RITE DNE21+ model)



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

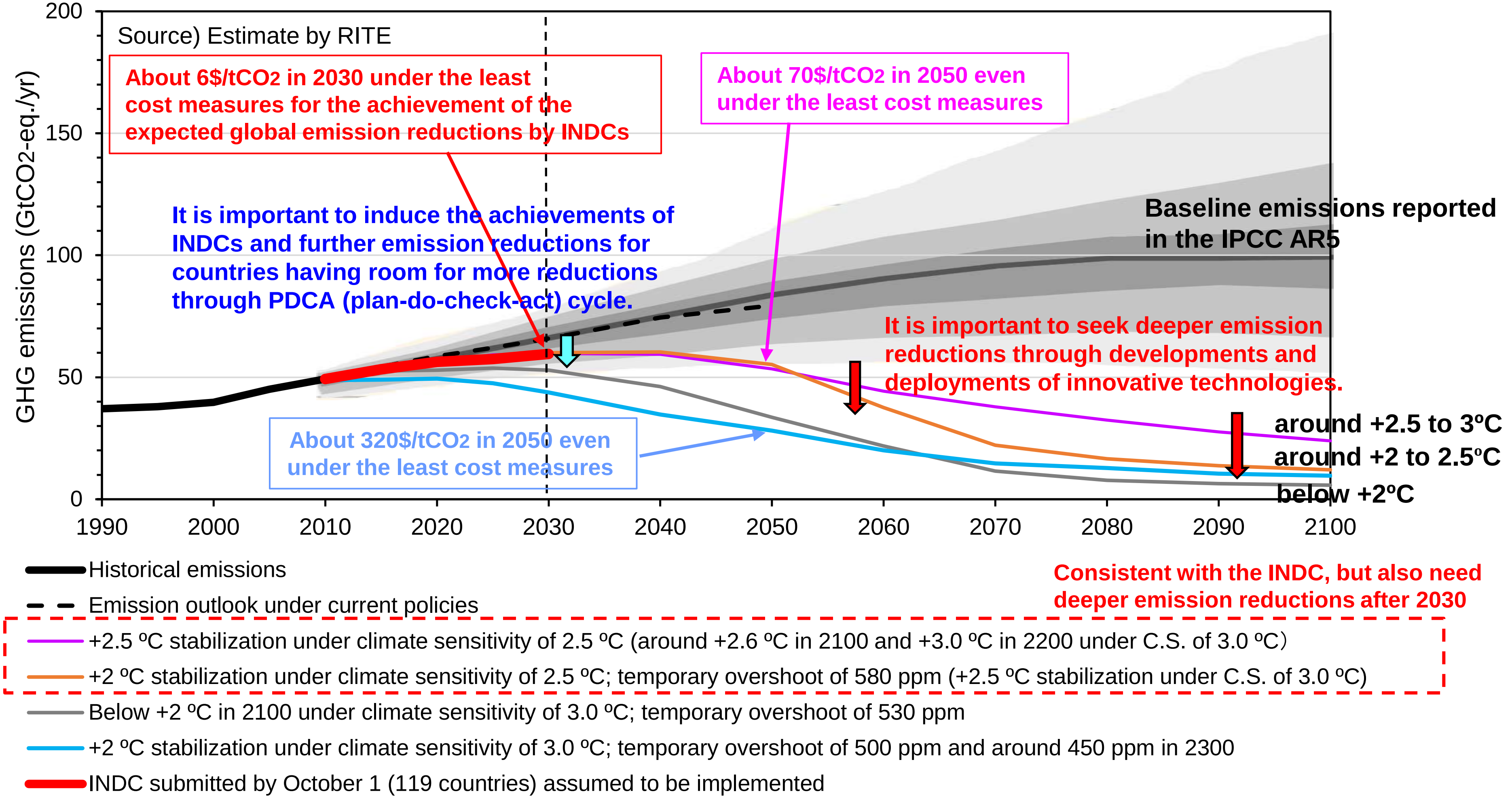
Marginal abatement costs estimations across models (RITE DNE21+, FEEM WITCH and NIES AIM)



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 marginal cost for the case that the total reductions are achieved most cost-efficiently (globally uniform marginal abatement cost).

Expected global GHG emissions of the aggregated INDCs and the corresponding emission pathways up to 2100 toward +2 °C goal



- The expected global GHG emission in 2030 is about 59.5 GtCO2eq. when all the submitted INDCs are successfully achieved. Emissions reductions from the baseline are estimated to be about 6.4 GtCO2eq, in which about 0.5 GtCO2eq reductions are offset due to carbon leakages from nations with INDCs of high marginal abatement costs to those with zero or low costs through induced lower fossil fuel prices.

- The expected temperature change in 2100 is +2 to +3 °C from preindustrial levels. The range depends on the uncertainties of climate sensitivity, and on future deep emission reductions through developments and deployments of innovative technologies.

Analysis on the Option Value of SRM under uncertain climate sensitivity

Effectiveness, Affordability, and Risk of SRM and CDR

carbon dioxide removal

Stratospheric injection of sulfur aerosols is a cost-effective and can be useful particularly under large uncertainty in temperature increase, while potentially risky technique, and such side effects of SRM should be evaluated together with SRM's option values.

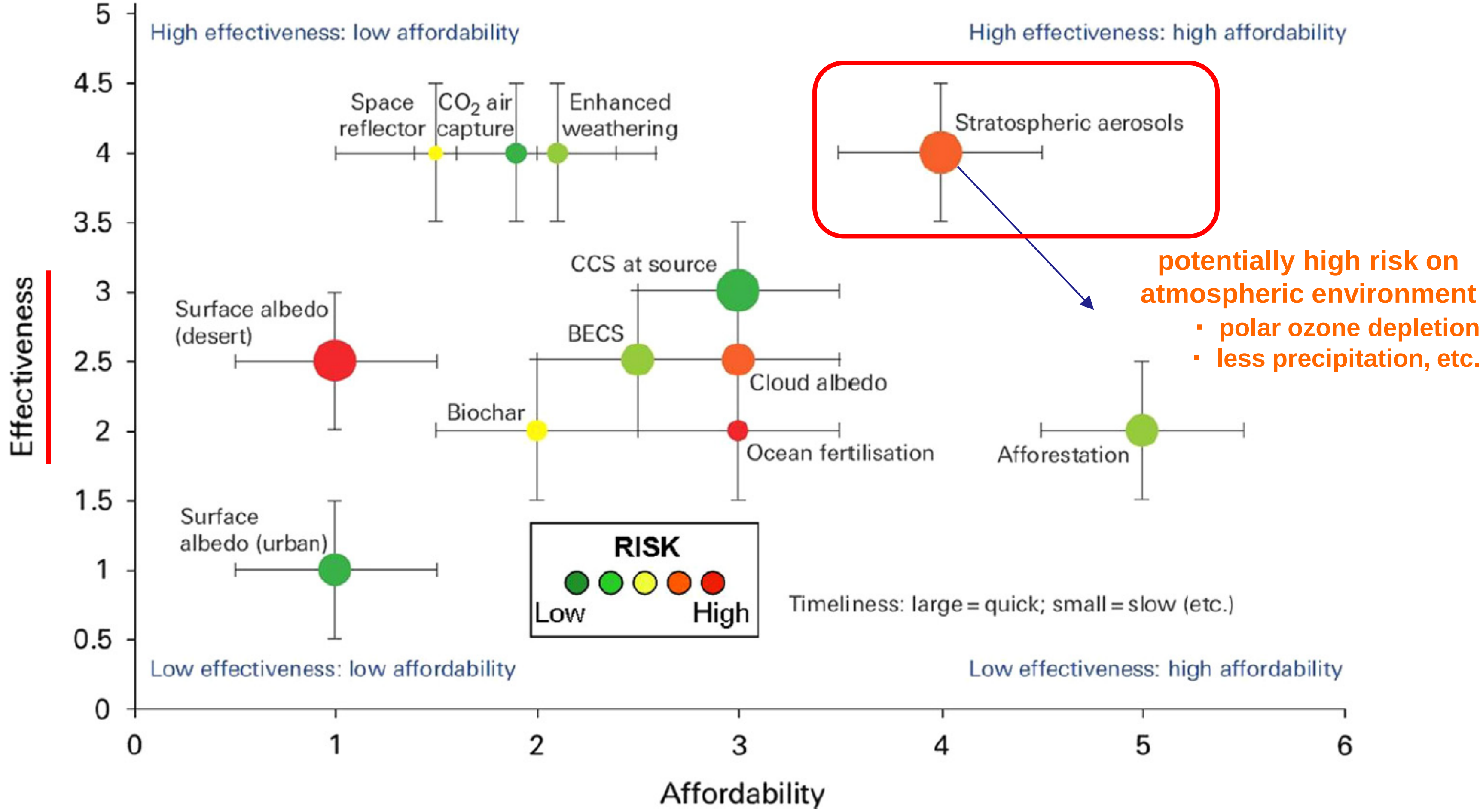


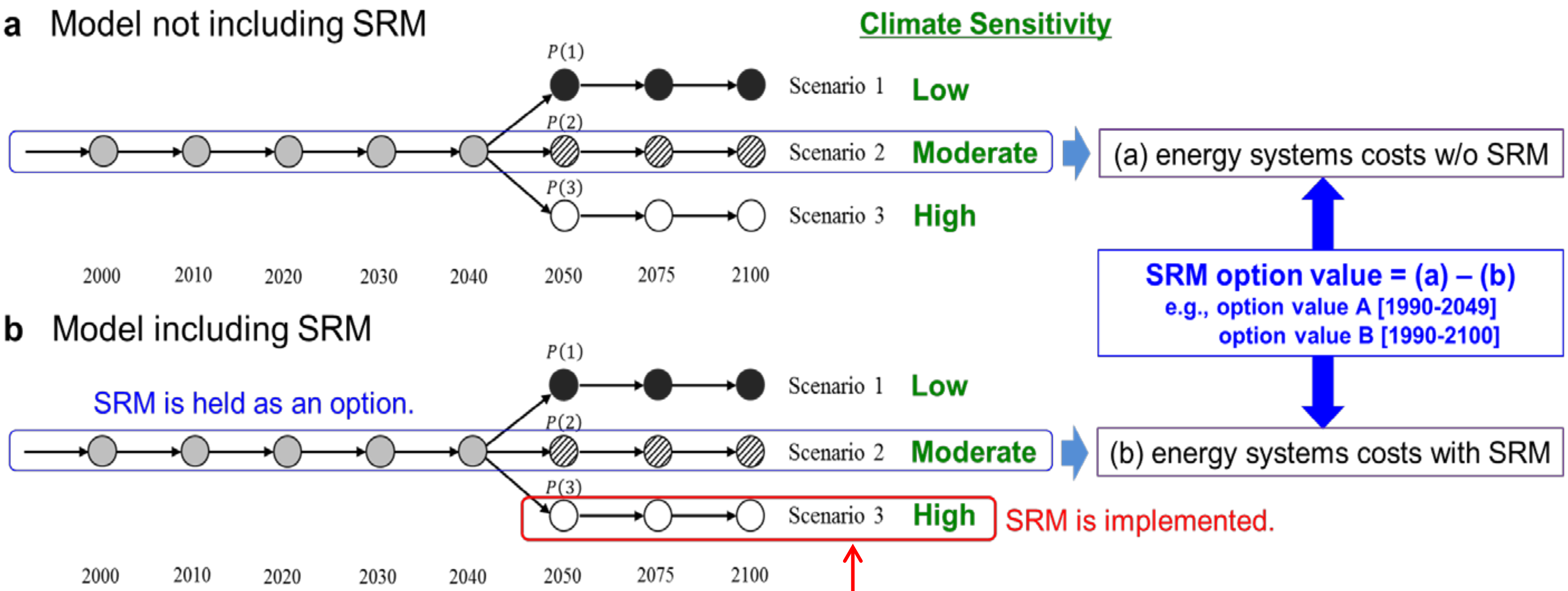
Fig. 3. Geoengineering proposals classified in the Royal Society report [16] for their safety, effectiveness and affordability.

Source: Ming and de Richter et al. 2014, Fighting global warming by climate engineering: Is the Earth Radiation Management and the solar radiation management any option for fighting climate change? Renewable and Sustainable Energy Reviews 31, 792–834.

Framework on evaluating the option value of SRM

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

- **The option value of SRM under a temperature target with uncertainty in climate sensitivity is evaluated by using the DNE21 model* with a "decision tree analysis" framework having simplified three scenarios regarding climate sensitivity.**
  - * DNE21: a simpler model than DNE21+; 10 divided regions; but up to 2100



【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

- DNE21 model seeks CO_2 emission pathways with the expected least-cost for a certain level of temperature increase target.

The probability density function of the climate sensitivity provided by Rogelji et al. (2012) which is based on the IPCC AR4 is employed.

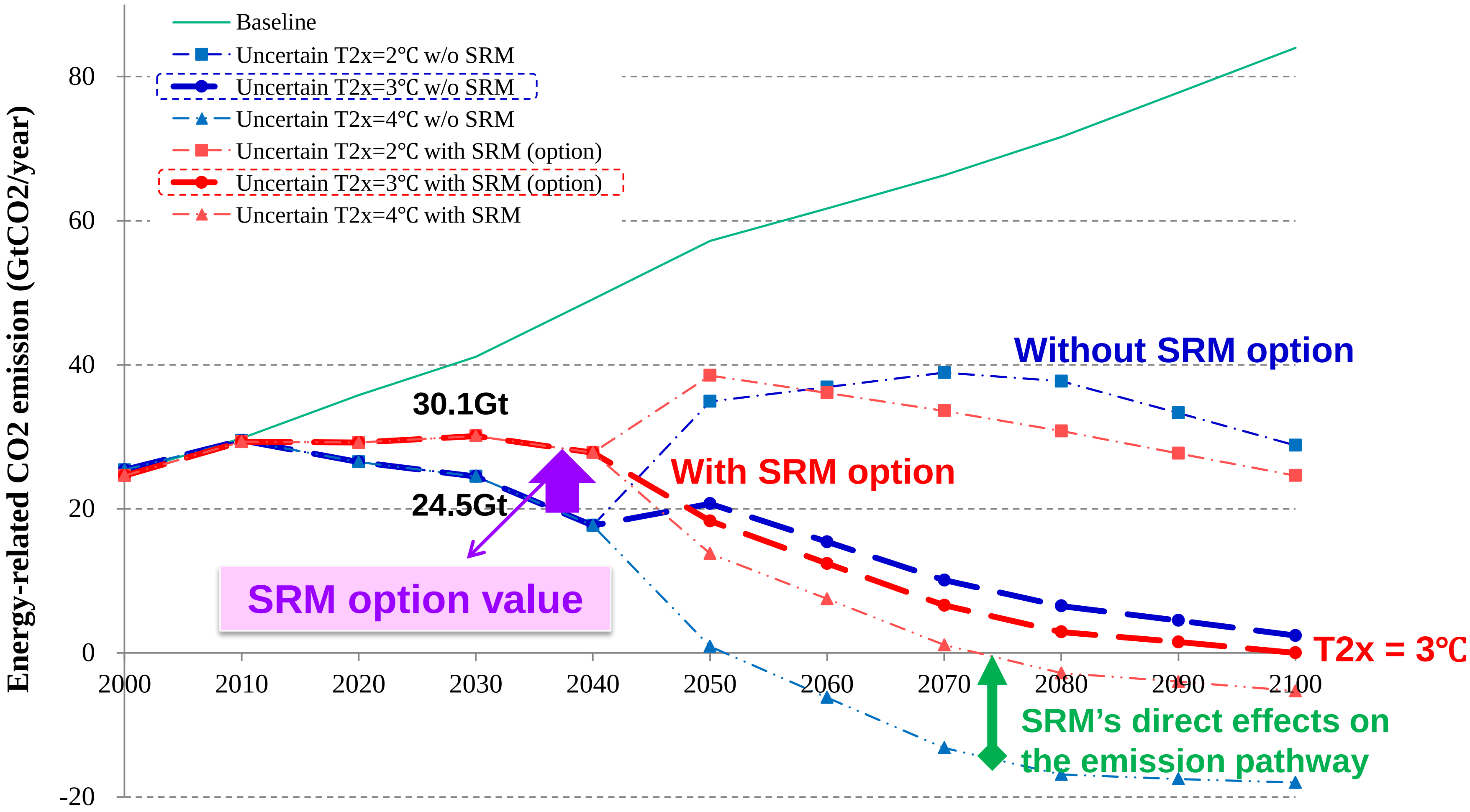
[Scenarios]

	Climate sensitivity (T2x)	Occurrence probability	SRM implementation *
Scenario 1	2.0℃	10%	×
Scenario 2	3.0℃	71%	×
Scenario 3	4.0℃	19%	○

* This study assumed that SRM can be introduced only after 2050 in Scenario 3 (climate sensitivity: high) with its cooling capacity limited to -0.5℃.

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

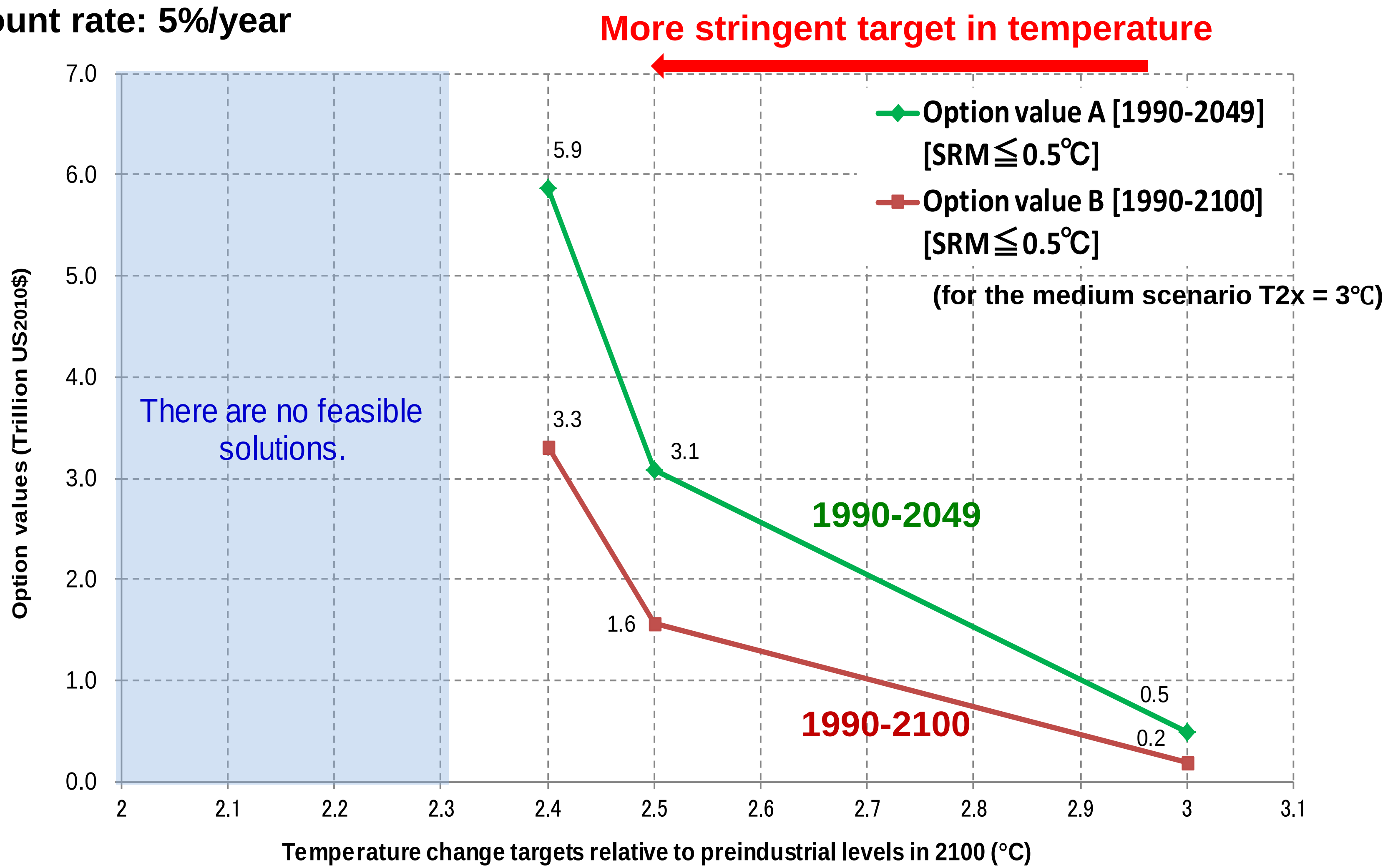


Y. Arino, K. Akimoto et al., PNAS, 113(21), 2016

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 option values

Discount rate: 5%/year



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

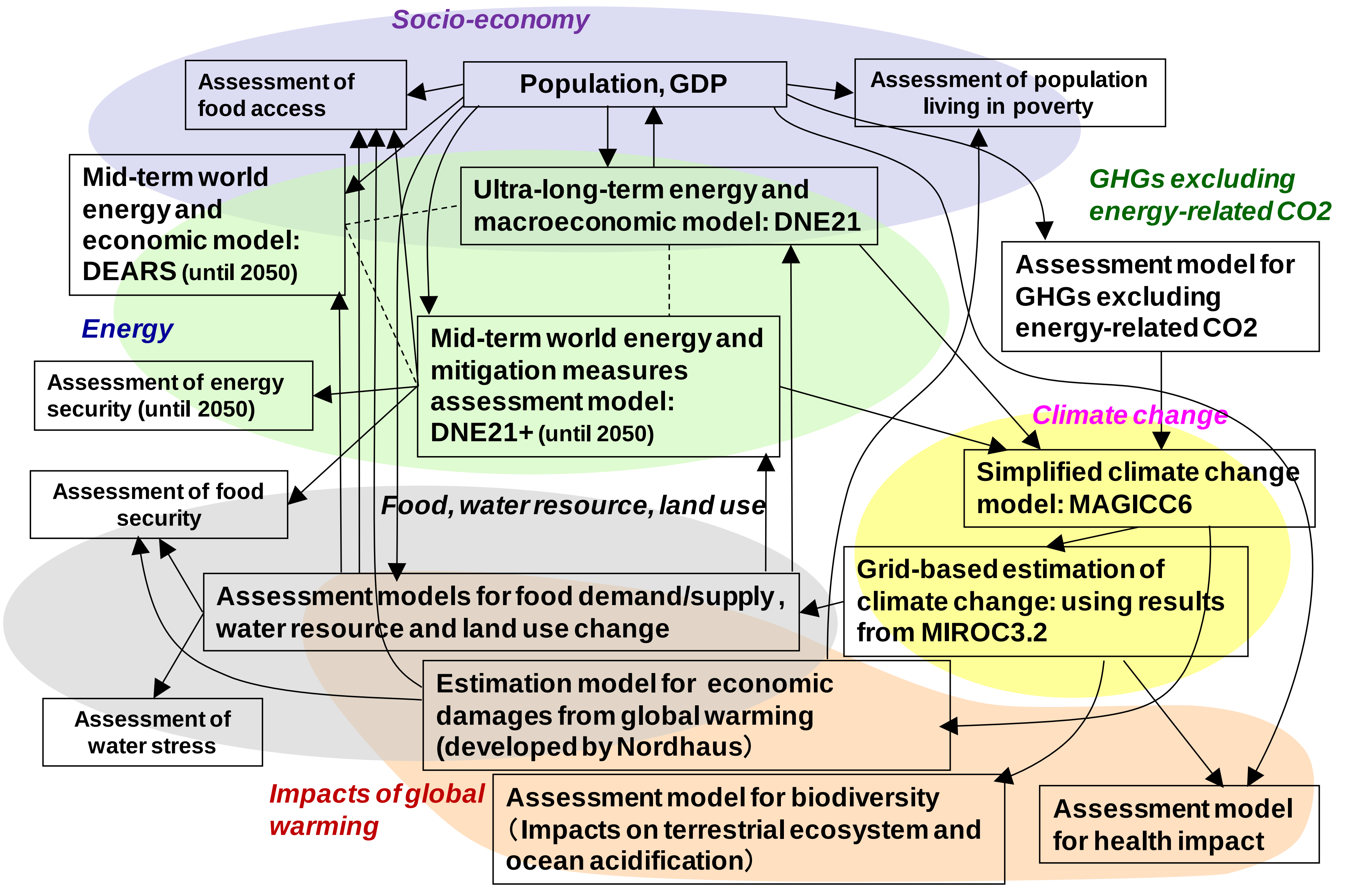
The SRM option values increase with the stringency of temperature change targets, reaching US$ 5.9 trillion when accumulated during 1990-2049.

Conclusion

- **The COP21 successfully adopted the Paris Agreement, which requires all nations to submit the nationally determined contributions (NDCs), and states long-term targets including the 2 ºC target.**
- **However, there are several scientific and policy uncertainties even for the 2 ºC target.**
- **A better emission reduction strategy should be implemented considering other kind of risks than climate change as well.**
- **There are still large uncertainty in climate sensitivity, and the allowable emissions vary widely even for a specific level of temperature rise target, e.g., the 2 ºC target.**
- **The 2030 global emission expected by the submitted NDCs has large gaps from the emission pathways for the 2 ºC target with a high achieving probability, but is consistent with those under a low climate sensitivity.**
- **On the other hand, geoengineering method, e.g., SRM, can be useful as an option in preparation for the case that the true climate sensitivity is high from the holistic viewpoint of climate change risk management.**

Appendix

Relationships among Models for Consistent Scenario Analysis



Overview of the Model

DNE21+ Model

- Assessment model for energy-related CO2 emissions
- 54 regions in the world
- Bottom-up modeling (200-300 specific technologies are modeled)

LULUCF Model

- Assessment model for Land use (land area for food production, energy crops, and afforestation)
- CO2 emission from LULUCF
- 15-minute-grid model
- Crop productivity is estimated based on the GAEZ model

Non-Energy CO2 Emissions Scenario

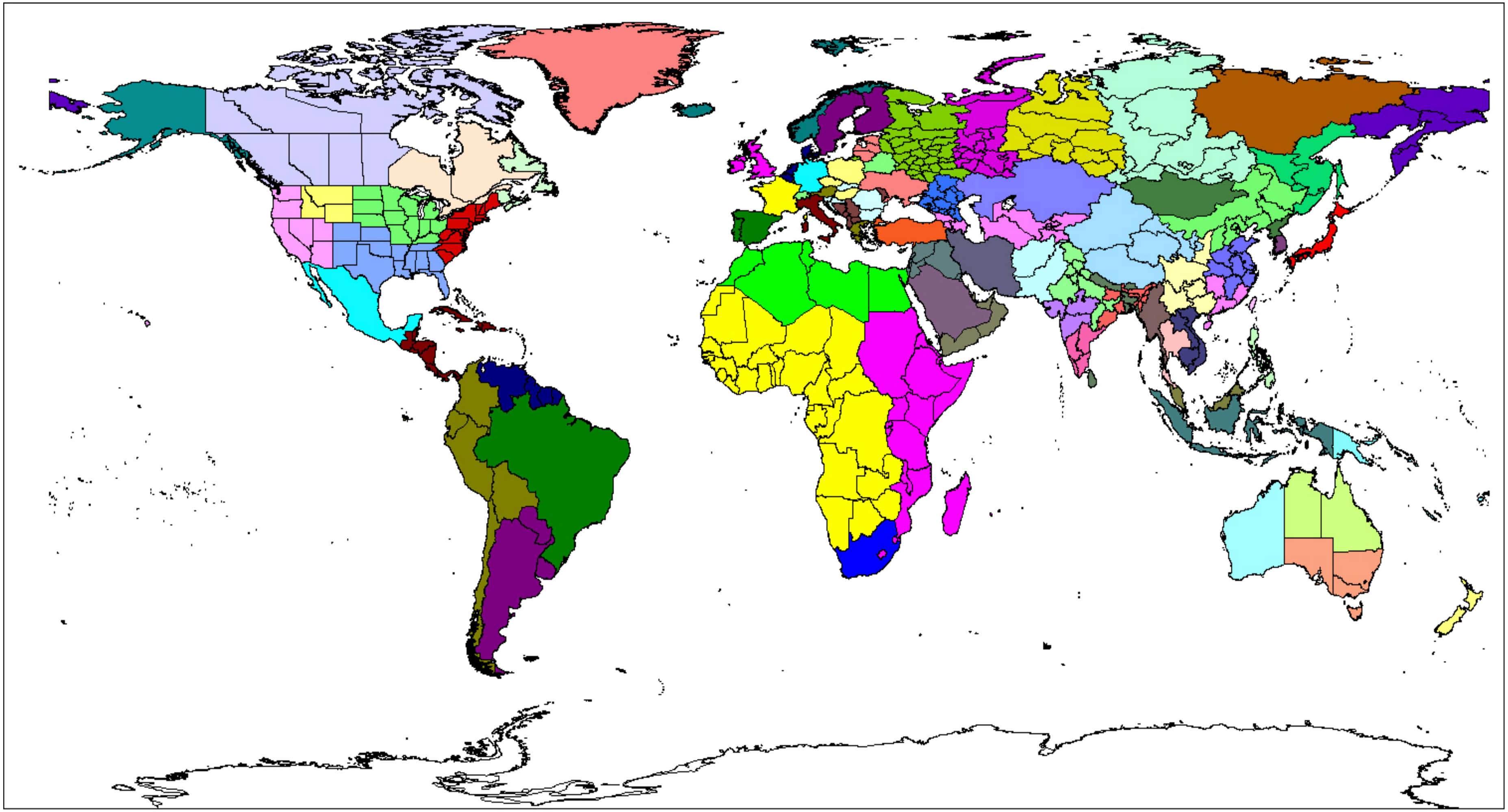
- Projection module for non-energy CO2 emissions
- 54 regions in the world
- Estimates of sectoral non-energy CO2 emissions to be consistent with GDP and production activities

Non-CO2 GHG Assessment Model

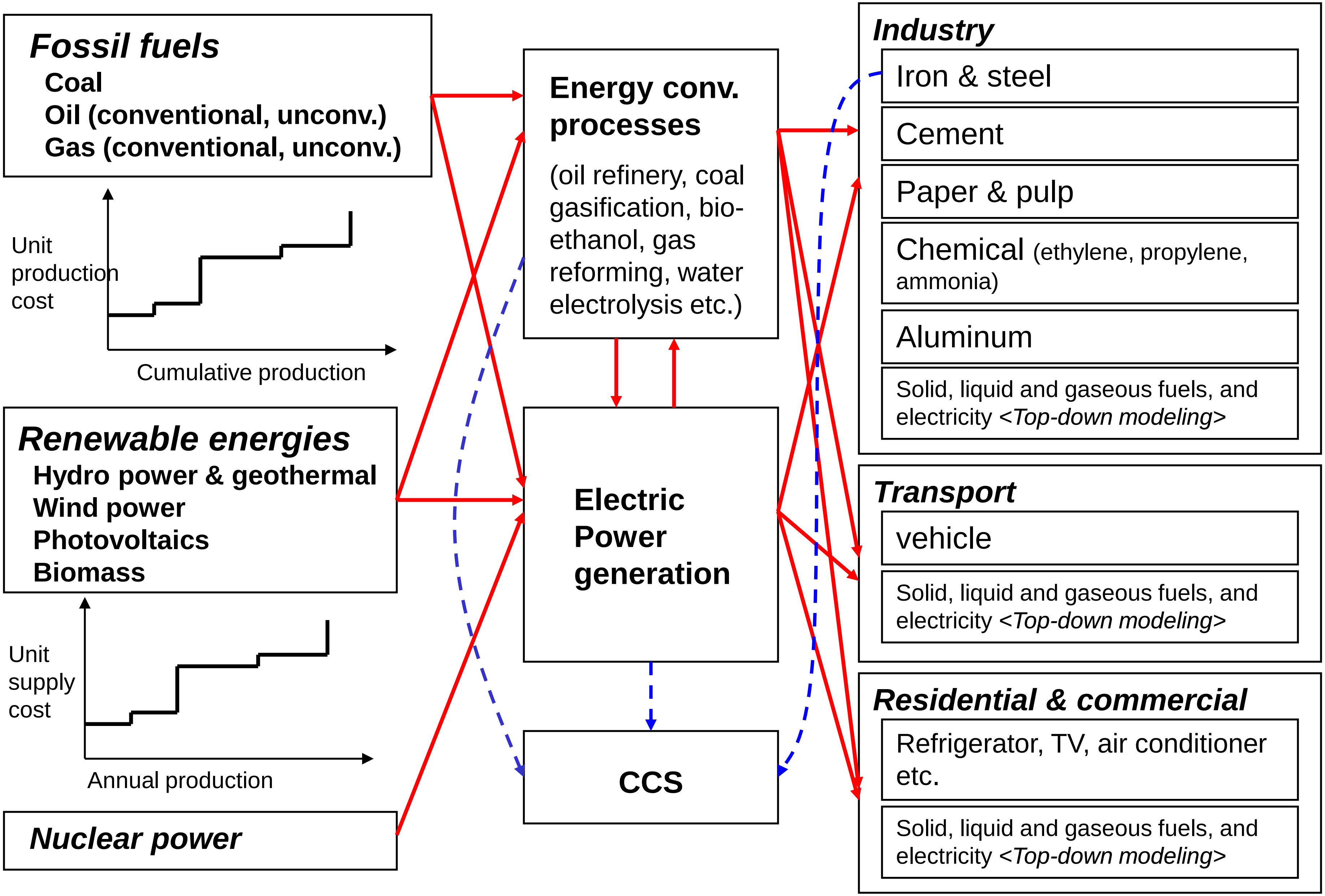
- Assessment model for the five types of non-CO2 GHG emissios (CH4, N2O, HFCs, PFC, SF6)
- 54 regions in the world
- The methodology is similar to the USEPA assessment

Integrated Assessment Framework covers 6 GHGs emissions, emission reduction costs and potentials, and cost-effective mitigation measures/technologies

Region divisions of DNE21+

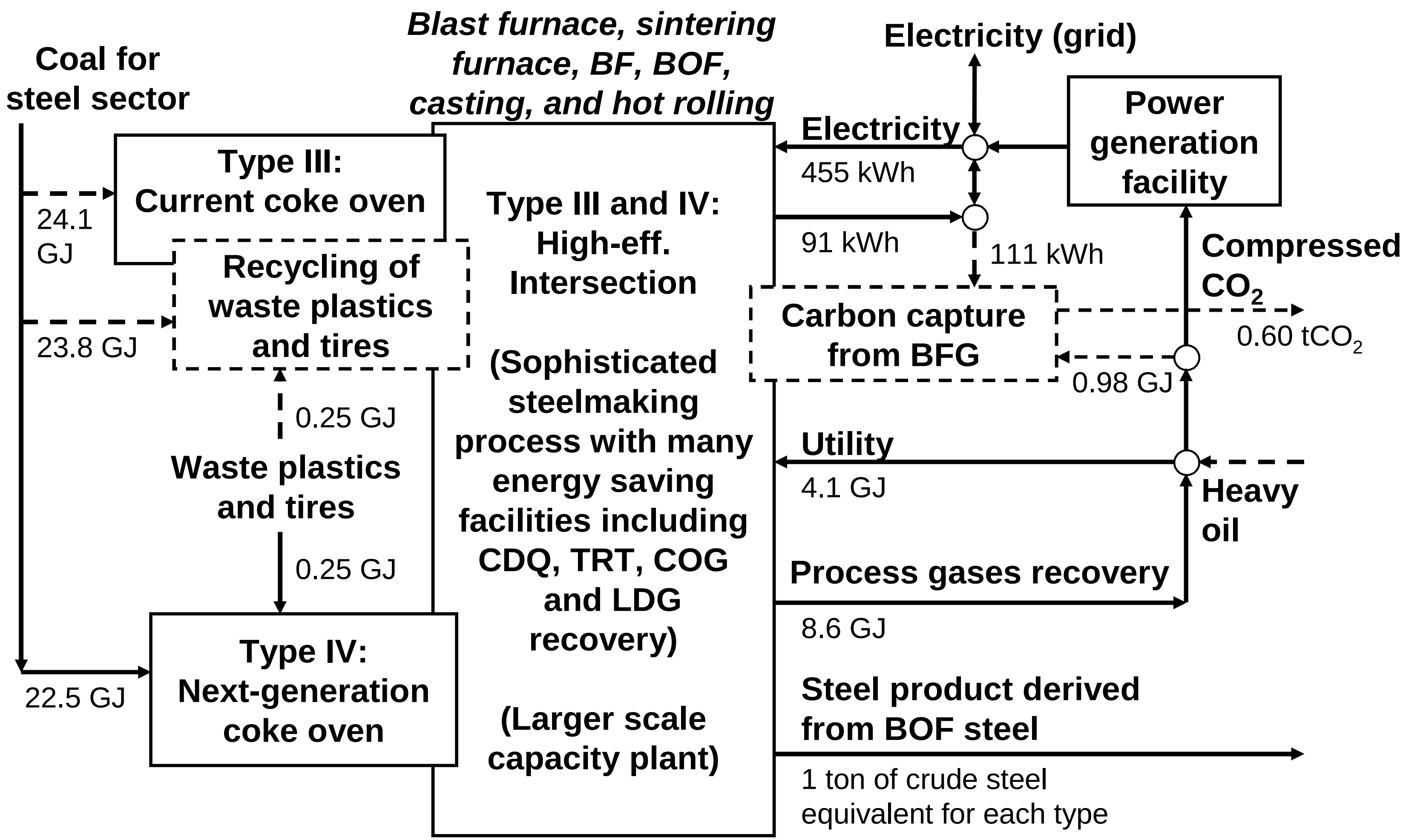


Technology Descriptions in DNE21+ (1/2)



Technology Descriptions in DNE21+ (2/2)

–An Example for High Energy Efficiency Process in Iron & Steel Sector–



BF: blast furnace, BOF: basic oxygen furnace, CDQ: Coke dry quenching, TRT: top-pressure recovery turbine, COG: coke oven gas, LDG: oxygen furnace gas

The allowable cumulative emissions expected when the climate sensitivity is lower by 0.5 °C

Estimates based on CMIP5: 2−4.5°C (mean: 3.2°C)

Cumulative CO_2 emissions from 1870 in $GtCO_2$									
Net anthropogenic warming [a]	<1.5°C			<2°C			<3°C		
Fraction of simulations meeting goal [b]	66%	50%	33%	66%	50%	33%	66%	50%	33%
Complex models, RCP scenarios only [c]	2250	2250	2550	2900	3000	3300	4200	4500	4850
Simple model, WGIII scenarios [d]	No data	2300 to 2350	2400 to 2950	2550 to 3150	2900 to 3200	2950 to 3800	n.a. [e]	4150 to 5750	5250 to 6000
Cumulative CO_2 emissions from 2011 in $GtCO_2$									
Complex models, RCP scenarios only [c]	400	550	850	1000	1300	1500	2400	2800	3250
Simple model, WGIII scenarios [d]	No data	550 to 600	600 to 1150	750 to 1400	1150 to 1400	1150 to 2050	n.a. [e]	2350 to 4000	3500 to 4250
Total fossil carbon available in 2011 [f]: 3670 to 7100 $GtCO_2$ (reserves) and 31300 to 50050 $GtCO_2$ (resources)									

IPCC Synthesis report, Table 2.2

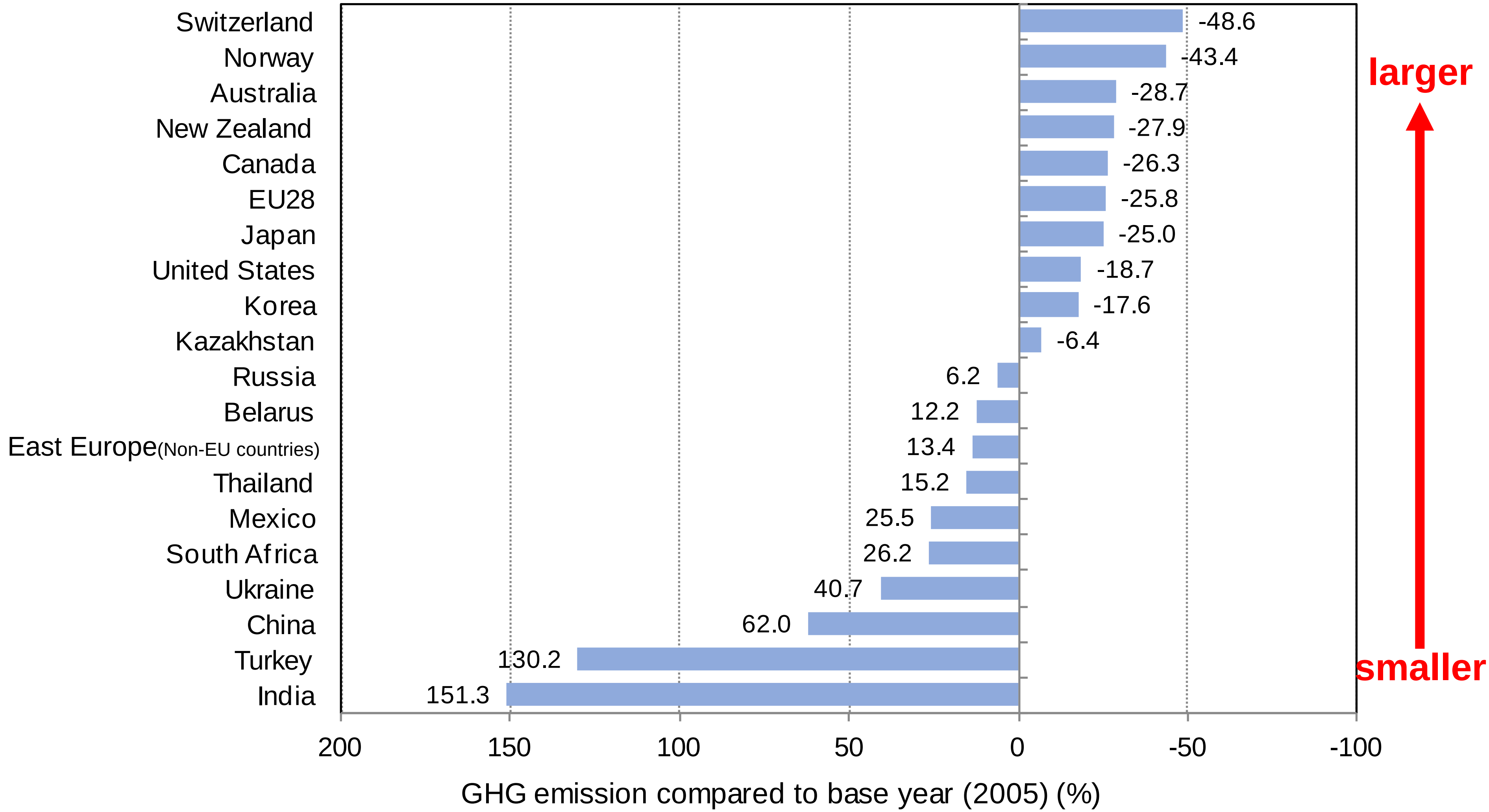
The difference is 750 Gt for the temperature difference of 0.5 °C.

Estimates by MAGICC: 2.0−4.5°C (median: 3.0°C)

Note: The ranges in the table are generated by differences in non-CO2 GHG emission scenarios.

Although there are differences between temperature estimate and equilibrium climate sensitivity, a rough estimation can be conducted: 1300-550=750 GtCO2. According to this estimate, the rest of the allowable cumulative emission will be about <u>2000 GtCO2 even for the 2 °C target</u>, <u>when the achieving probability of 50%> and the climate sensitivity of 2.5 °C are employed</u>. (This is consistent with the cumulative emissions of 530-580 ppm scenarios provided by the IPCC WG3 AR5.)

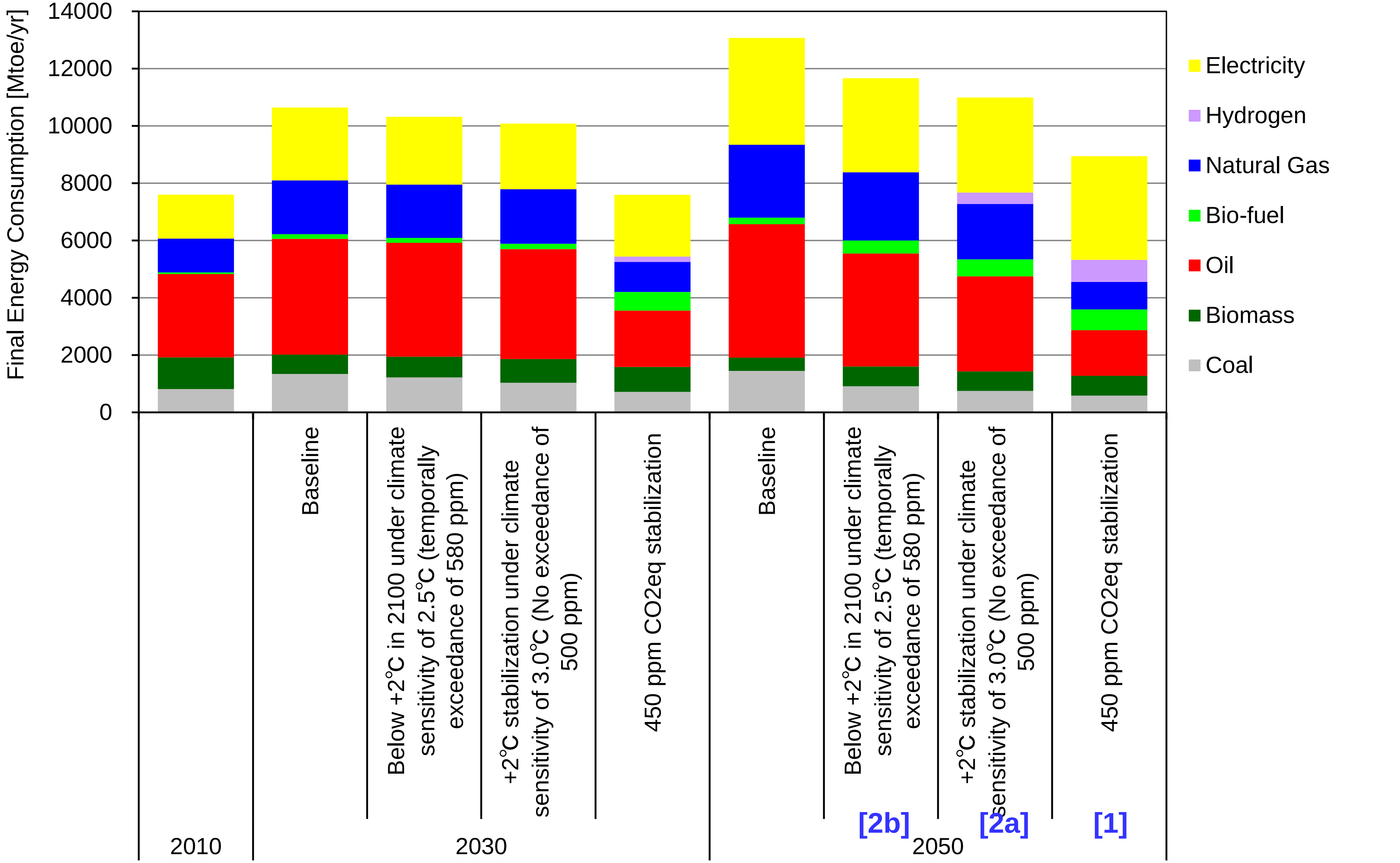
International comparison of emission reduction ratios from the base year of 2012 (or 2010)



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

Note) This indicator was employed only for OECD countries or Annex I countries for the integrated ranking.

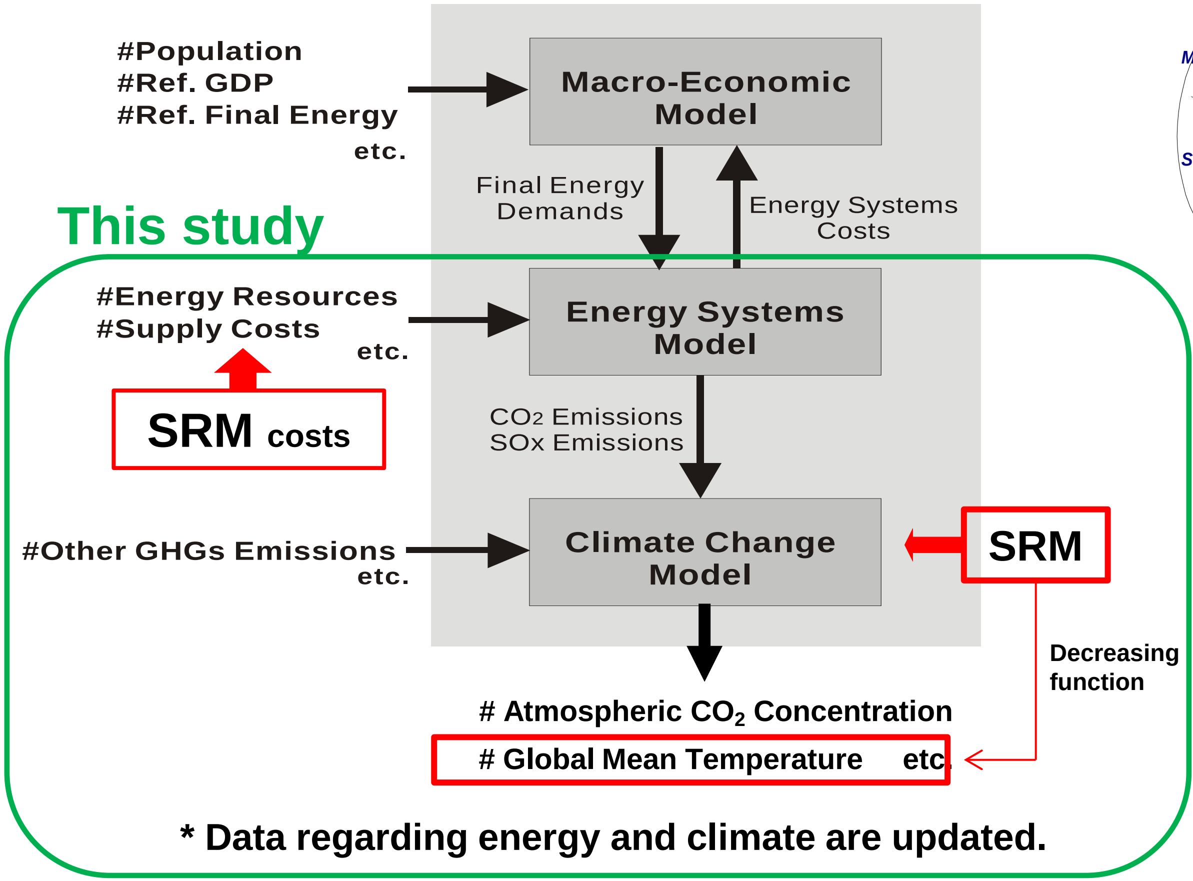
Global Final Energy Consumption

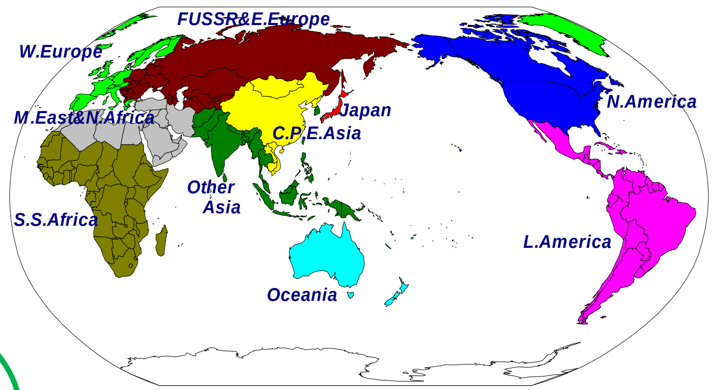


Source) estimated by RITE DNE21+

DNE21 (Dynamic New Earth 21) model

Overview of DNE21





10 regions in DNE21 model

Intertemporal nonlinear optimization model

Bottom-up fashioned energy supply system with about 50 mitigation technologies

Time horizon: 1990-2100

- **An SRM option is incorporated into the energy systems model and climate change model, and we examined SRM's effects on CO_2 emission pathways and energy systems costs in 1990-2100.**

SRM deployment cost

- The SRM cost is assumed to be **US＄10/kg-S（= US＄ 10 billion/ Mt-S）,** which represents the higher order of estimates in the preceding literature.
- The cost assumption above is equivalent to **US＄ 15 billion/ 0.5 °C**.

Sulphur injection 1.5Mt-S/yr ⇔ Radiative Forcing 0.75W/m² ⇔ Global mean temperature change 0.5℃

10 Billion＄/Mt-S → 15 Billion＄/Mt-S/yr → Annual cost of SRM : 15 Billion＄/0.5℃

This study: RITE (2015)
Komatsu et al. (2012)
Broecker (1985)
NRC (1992)
Kosugi (2013)

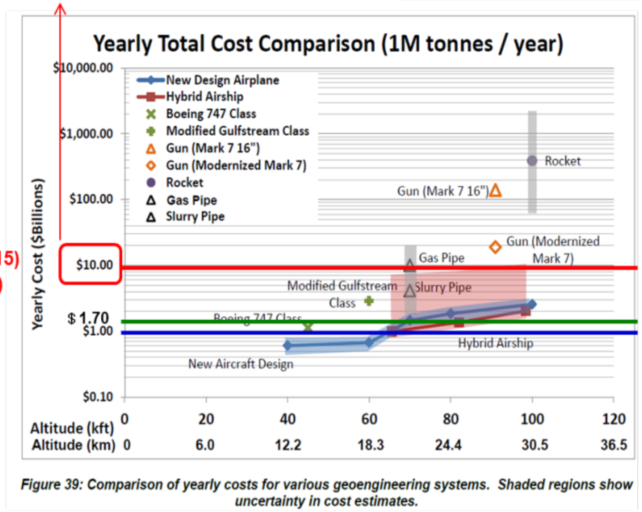
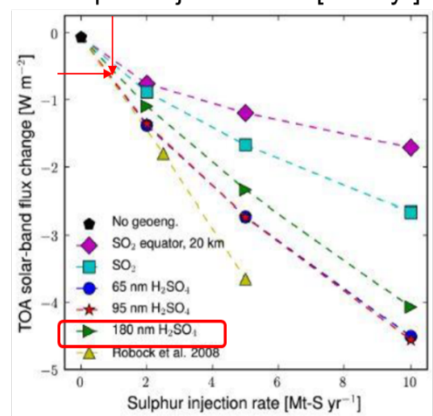


Figure 39: Comparison of yearly costs for various geoengineering systems. Shaded regions show uncertainty in cost estimates.

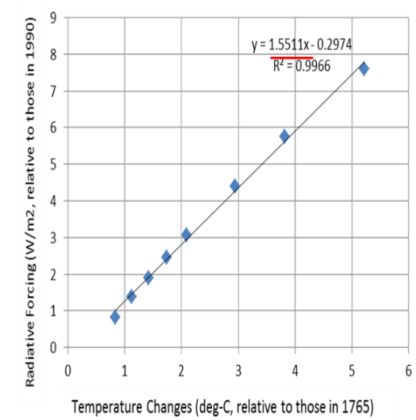
Source ）McClellan et al. (2010)

Relationship between radiative forcing and sulphur injection rate [Mt-S/yr]



Source）McClellan et al. (2010)

Relationship between temperature changes and radiative forcing in DNE21 model



As sulfate aerosol delivery systems, aircraft and airship are considered.