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Long-term strategy toward deep emission reductions under several kinds of uncertainties

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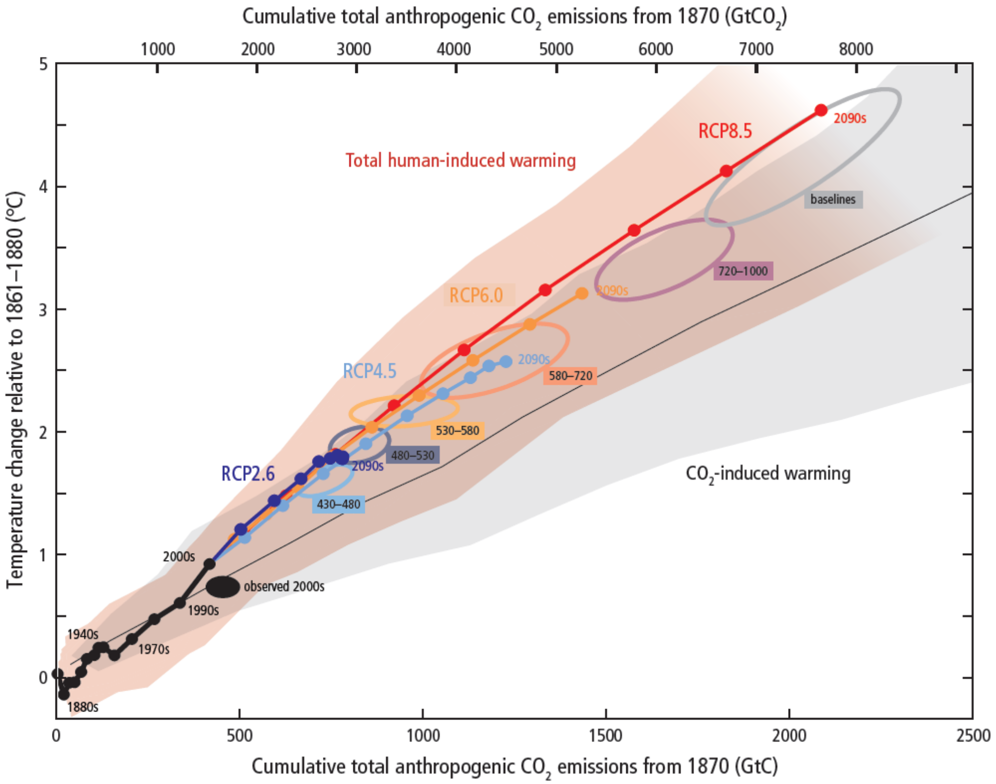
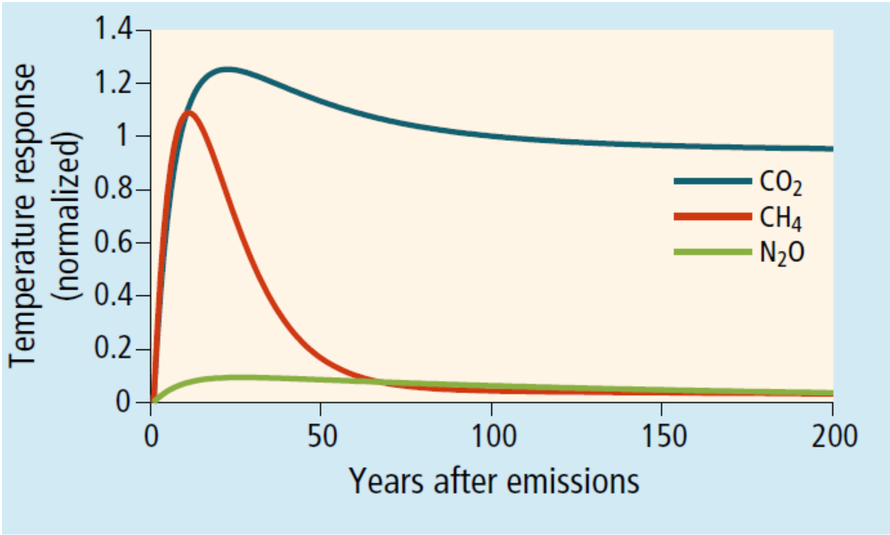
1. Required long-term goals and uncertainties in short/mid-term pathway

Relationship between cumulative CO2 emissions and temperature rise



Source) Synthesis report of IPCC AR5



Temperature response to emissions in 2010; the responses are normalized by the amount of contribution of CO2 emission after 100 years past

- **Approximately linear relationship between cumulative CO2 emissions and temperature rise can be observed.**
- **Nearly net zero CO2 emissions are necessary for the stabilization of global temperature at any level.**

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]**

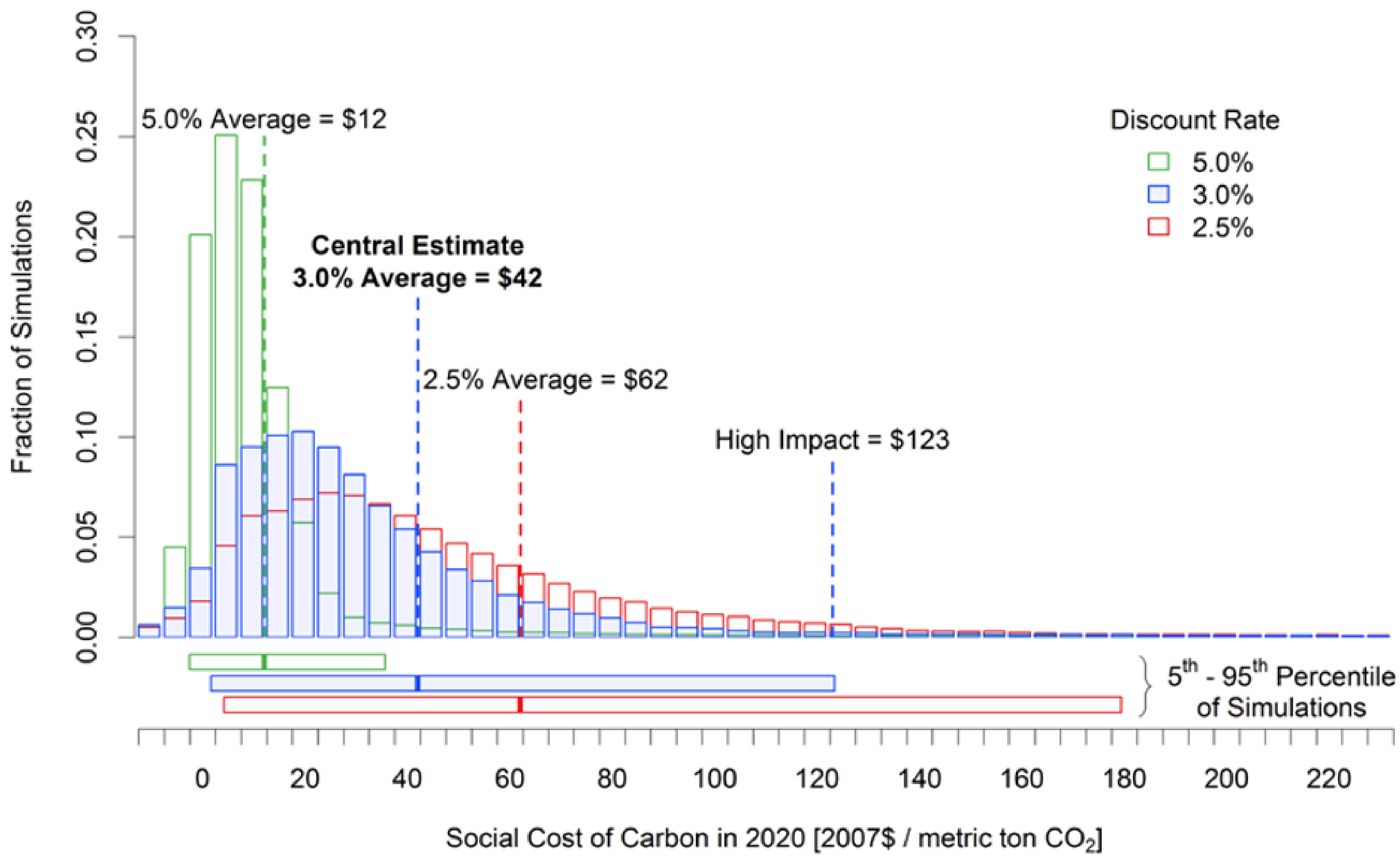
Same "likely" range

[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.**

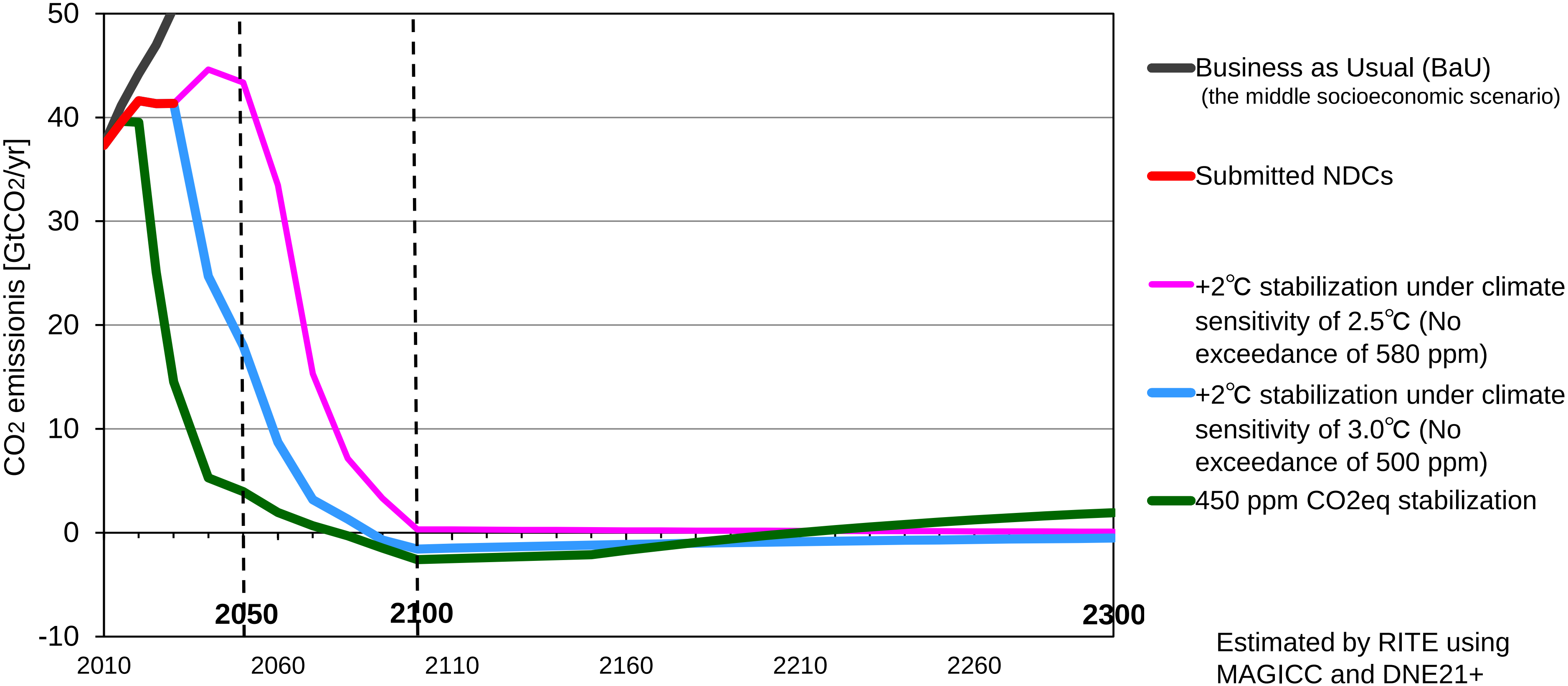
Social Cost of Carbon (SCC)



Source) Interagency working group on social cost of carbon, 2016

- Social cost of carbon is the marginal damage costs of CO2 emissions.
- The estimation methods are very debatable, and the estimated distributions of the damage costs vary widely depending on the estimated models, climate sensitivity, discount rate etc. Therefore, it is not easy to determine the optimal temperature level.

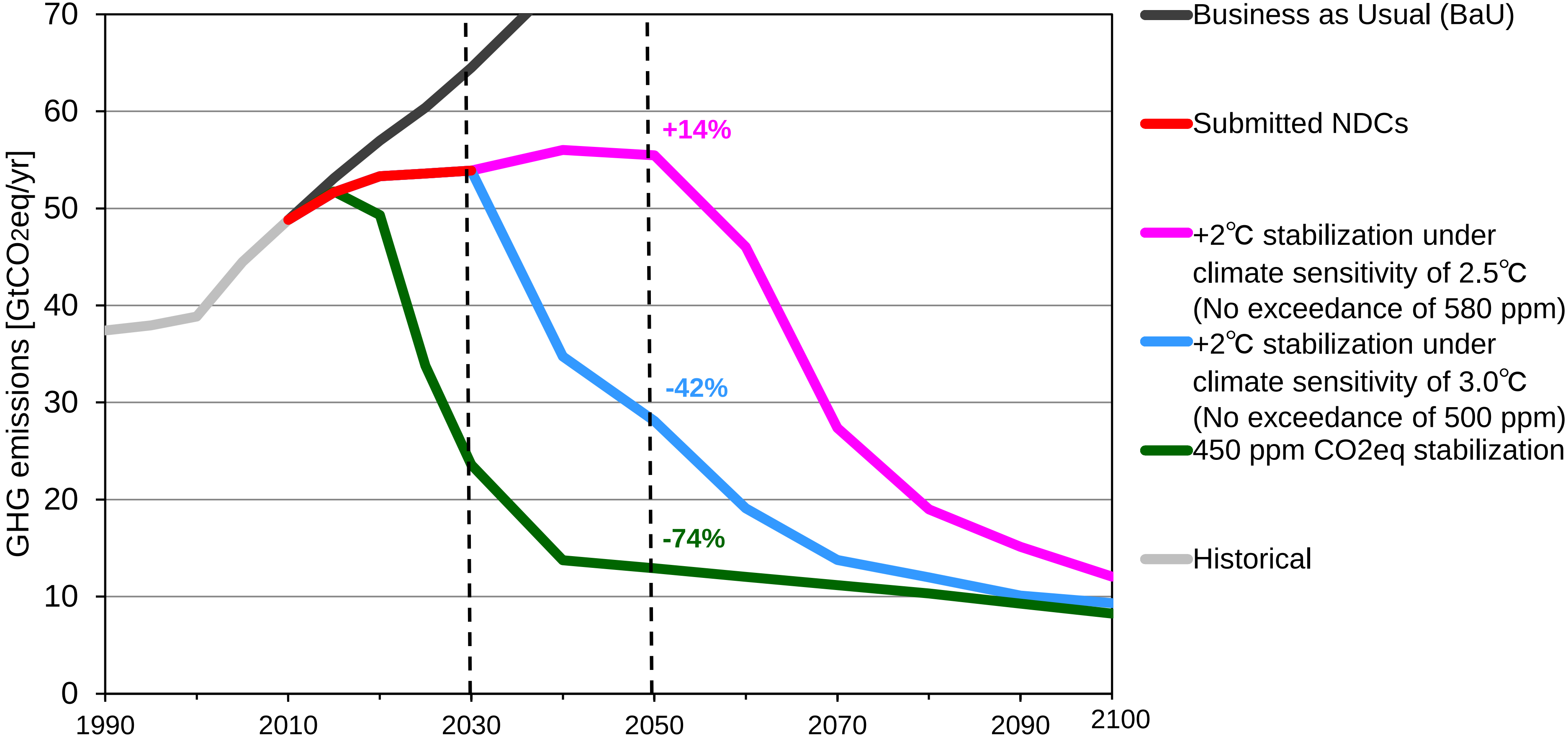
Global CO_2 emission profiles toward 2300 for the 2 °C targets



Estimated by RITE using MAGICC and DNE21+

- The global CO_2 emissions should be nearly zero for a long-term period in the far future in any pathway to achieve temperature stabilization.
- On the other hand, the allowable global CO_2 emissions toward the middle of this century have a wide range according to the uncertainties in climate sensitivity (or achieving probability) even when the temperature target level is determined as a 2 °C. We should use this flexibility to develop several kinds of innovative technologies and societies.

Global <u>GHG emission</u> profiles toward 2100 for the 2 °C target

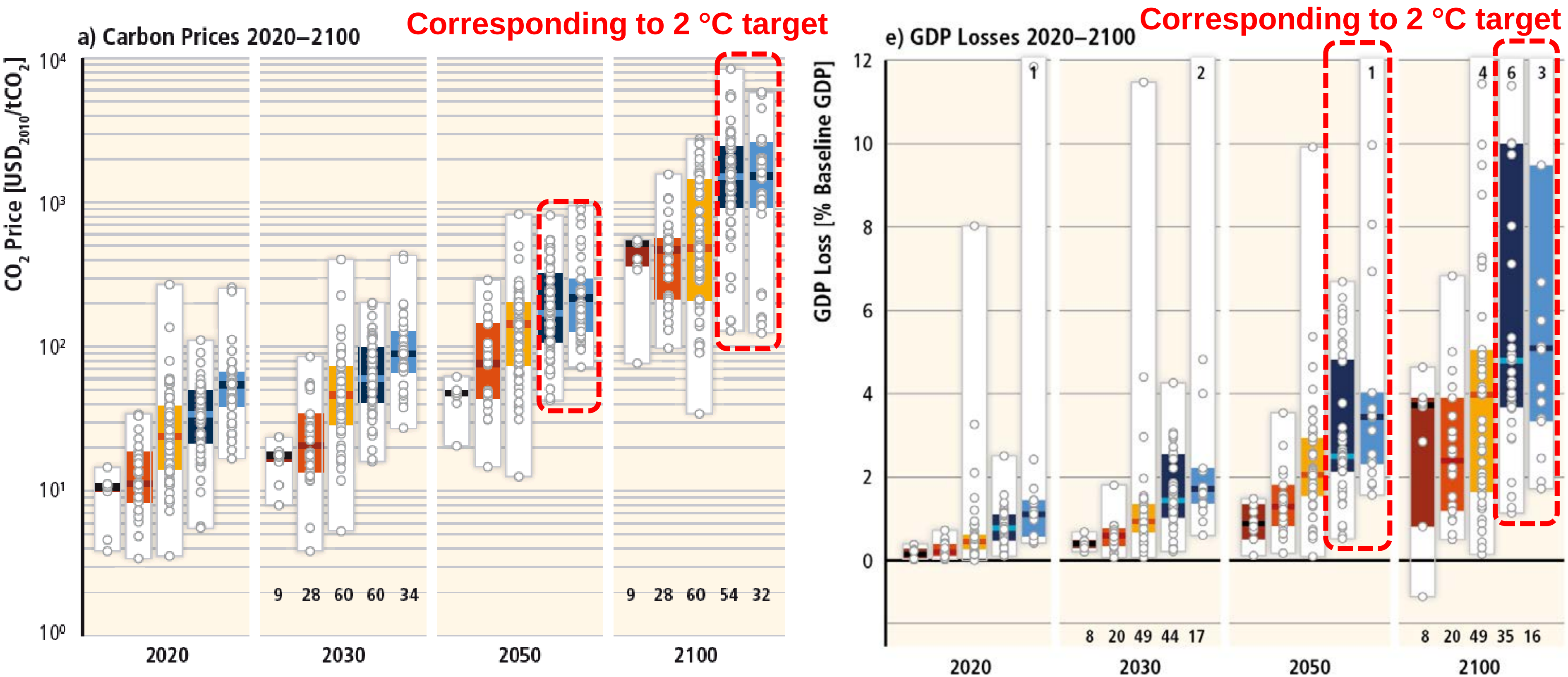


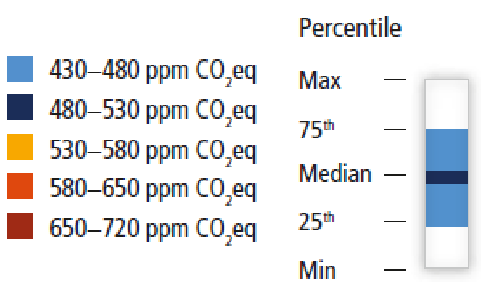
Estimated by RITE using MAGICC, DNE21+ and non-CO2 GHG models

- The corresponding GHG emission trajectories for the 2 °C target vary widely particularly in 2050.
- There are large gaps between the expected emissions under the submitted NDCs and the 450 ppm CO2eq pathway.

2. Mitigation costs – the gaps between the idealistic mitigation costs and real costs

Huge costs are estimated for achieving the 2 °C target

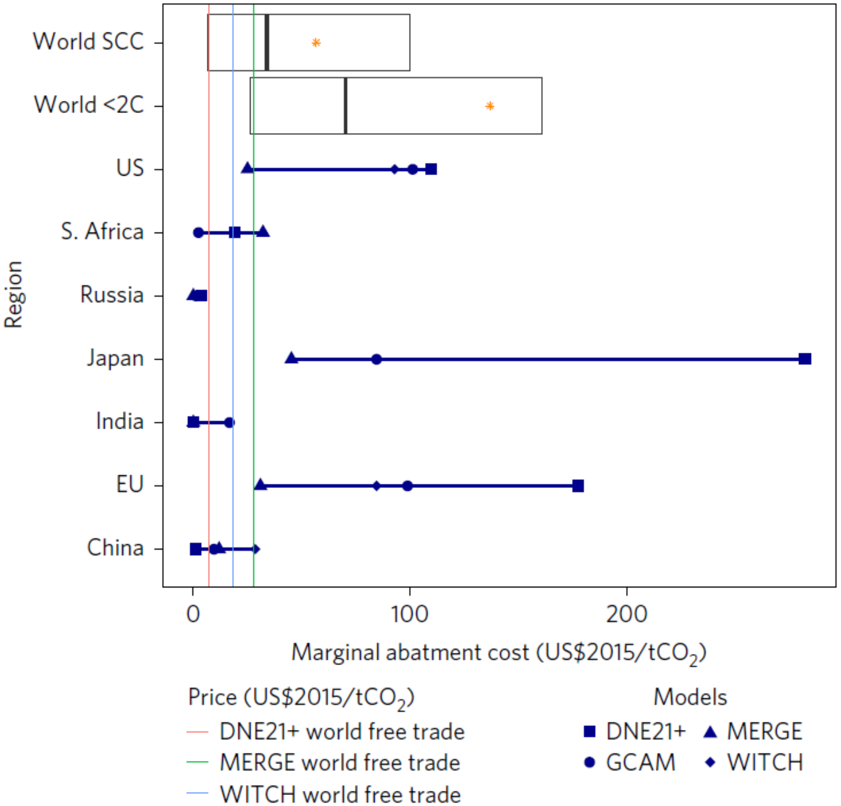




Source) IPCC WG3 AR5

- According to the IPCC AR5, the CO2 marginal abatement costs (carbon prices) for the 430-530 ppm CO2eq (which are consistent with the 2 °C target) are about 1000-3000 $/tCO2 (25-75 percentile) and 150-8000 $/tCO2 (full range) in 2100.
- About 25% of the analyzed scenarios estimate global GDP losses of over 10%.
- The feasibility of such scenarios should be carefully examined in terms of various constraints in the real world.

CO_2 marginal abatement costs of the NDCs



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

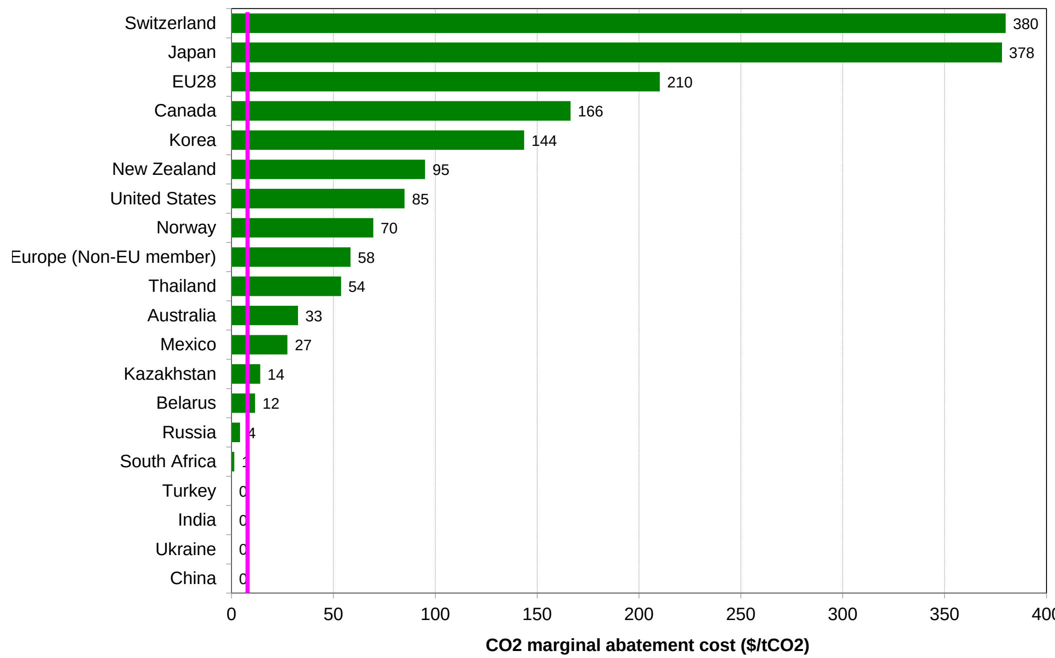
Average of 2025-2030

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

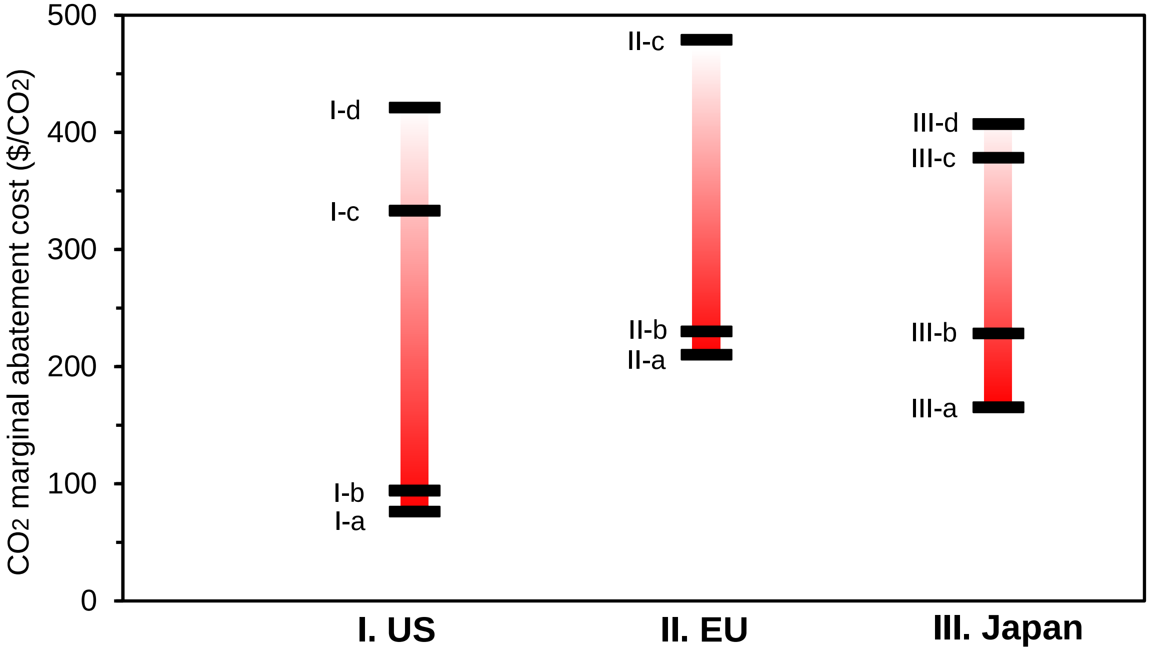


Source: K. Akimoto et al., Evol. Inst. Econ. Rev., 2016

- The estimated marginal abatement costs of NDCs are largely different among countries, and the mitigation costs are much larger than those under the least cost measures due to such large difference in marginal abatement costs.

- The difference will induce carbon leakages, and the leakages will reduce the effectiveness of global emission reductions.

CO_2 marginal abatement cost for the U.S, EU and Japan considering several kinds of policy constraints



I. US

I-a: -26%; the least cost
I-b: -28%; the least cost
I-c: -26%; power sector according to CPP
I-d: -28%; power sector according to CPP

* CPP: Clean Power Plan

II. EU

II-a: the least cost
II-b: Brexit (-40% for UK)
II-c: splitting into ETS and non-ETS sectors

III. Japan

III-a: the least cost under nuclear of maximum 20%
III-b: the least cost under nuclear of maximum 15%
III-c: following the NDC including the energy mix (nuclear of 20%)
III-d: following the NDC including the energy mix but nuclear of 15%

Source: estimated by RITE DNE21+

- It is not easy to achieve the least cost measures because there are several kinds of social and political constraints in each nation.
- The mitigation costs constrained by other policies can be much higher than those under the least cost measures.

3. Climate change mitigation measures under different socioeconomic conditions

Overview of Shared Socioeconomic Pathways (SSPs)

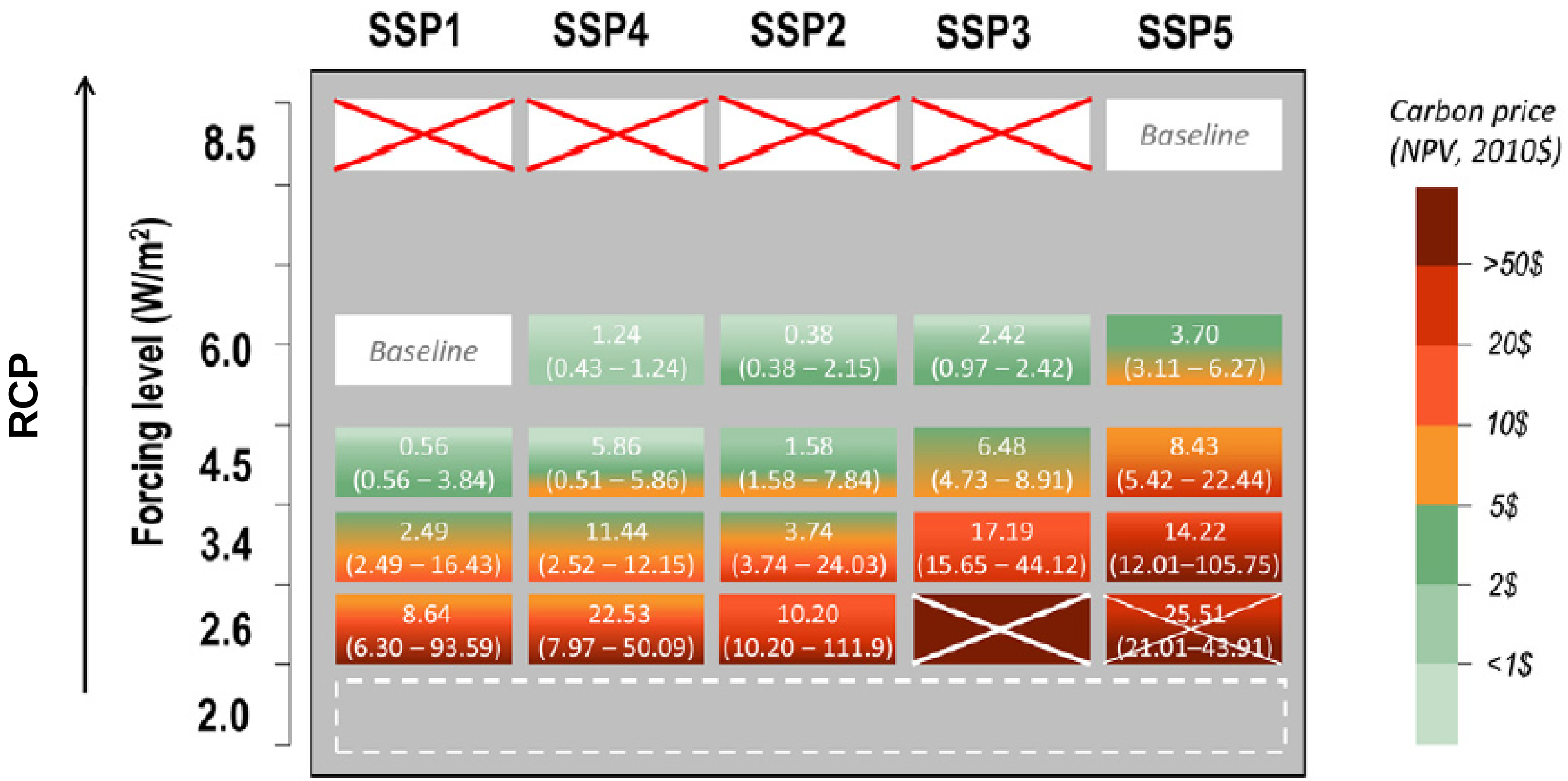
Fossil fuel price: low;
Fossil fuel resources: high;
GDP: very high

Tech. improve: low;
Population: low;
GDP: low

Tech. improve.：high;
Public acceptability of large-scale tech.: low;
Population: low;
GDP: high

Governance: low;
Price distribution of fossil fuel energy prices: big

Relationship between SSPs and RCPs

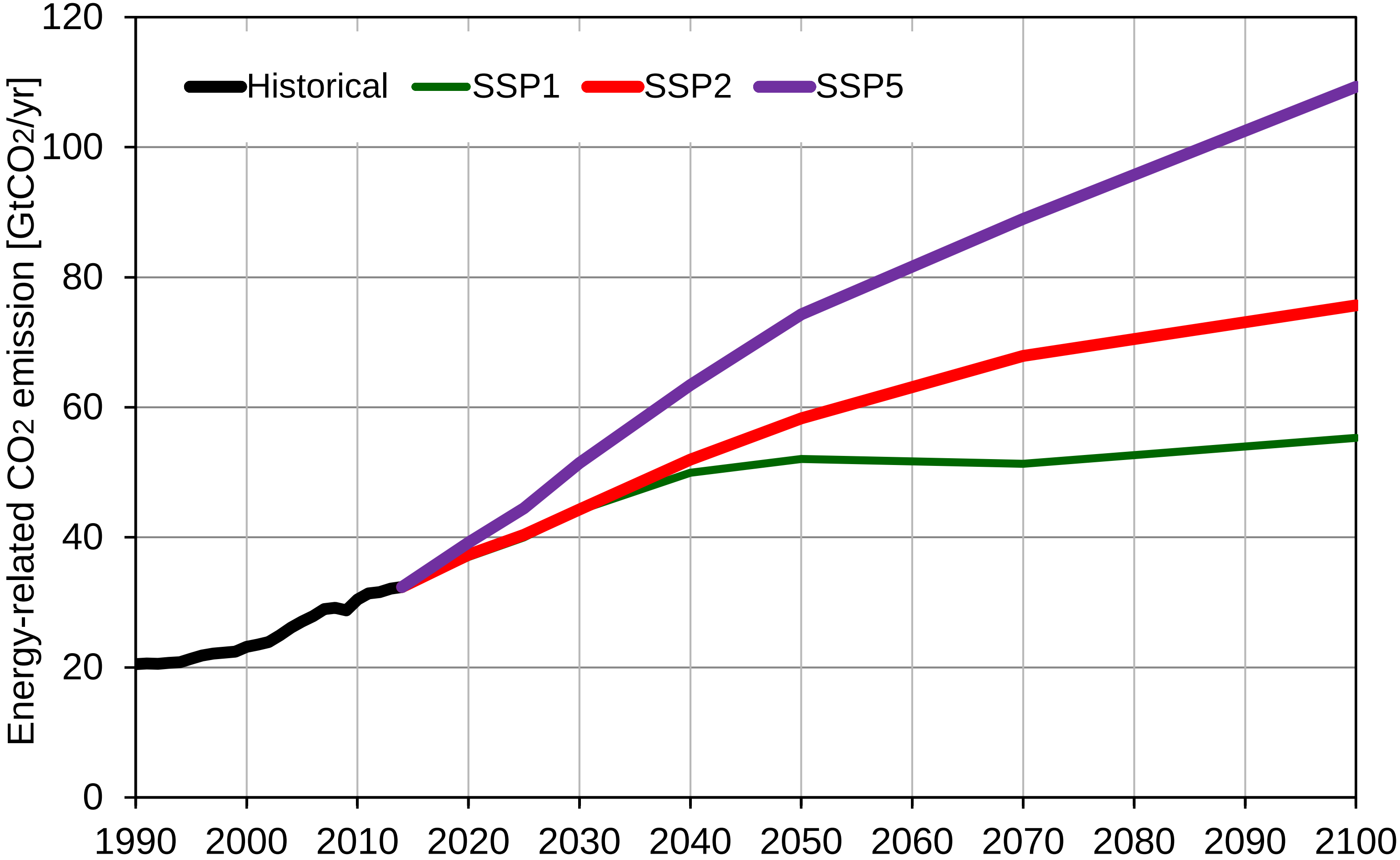


Note 1) 2.6 W/m2 corresponds to below 2 °C in 2100 with >66% achieving probability; 3.4 W/m2 corresponds to below 2 °C in 2100 with >50% probability, and 4.5 W/m2 corresponds to below about 2.5 °C with >50% probability.
Note 2) Carbon prices are shown as the converted values in 2010 by employing discount rate of 5%/yr. The carbon price of 20 $/tCO2 as the 2010 value corresponds to about 1800 $/tCO2 for 2100.

K.Riahi et al., Global Environmental Change 42 (2017) 153–168

Global CO_2 emissions in Baseline

Estimated by RITE DNE21+ model



- Baseline emissions are very different depending on the future socioeconomic conditions including technology improvements.

Marginal CO2 abatement costs (Carbon prices) for the 2 °C target

SSP: "Shared Socioeconomic Pathways"

	SSP2 (Middle of the Road)			SSP1 (Sustainability)		
	+2°C stab. under climate sensitivity of 2.5°C	+2°C stab. under climate sensitivity of 3.0°C	450 ppm CO2eq stab. (climate sensitivity of 3.4°C)	+2°C stab. under climate sensitivity of 2.5°C	+2°C stab. under climate sensitivity of 3.0°C	450 ppm CO2eq stab. (climate sensitivity of 3.4°C)
2050	12	135	604	14	117	518
2100	408	427	457	134	140	143

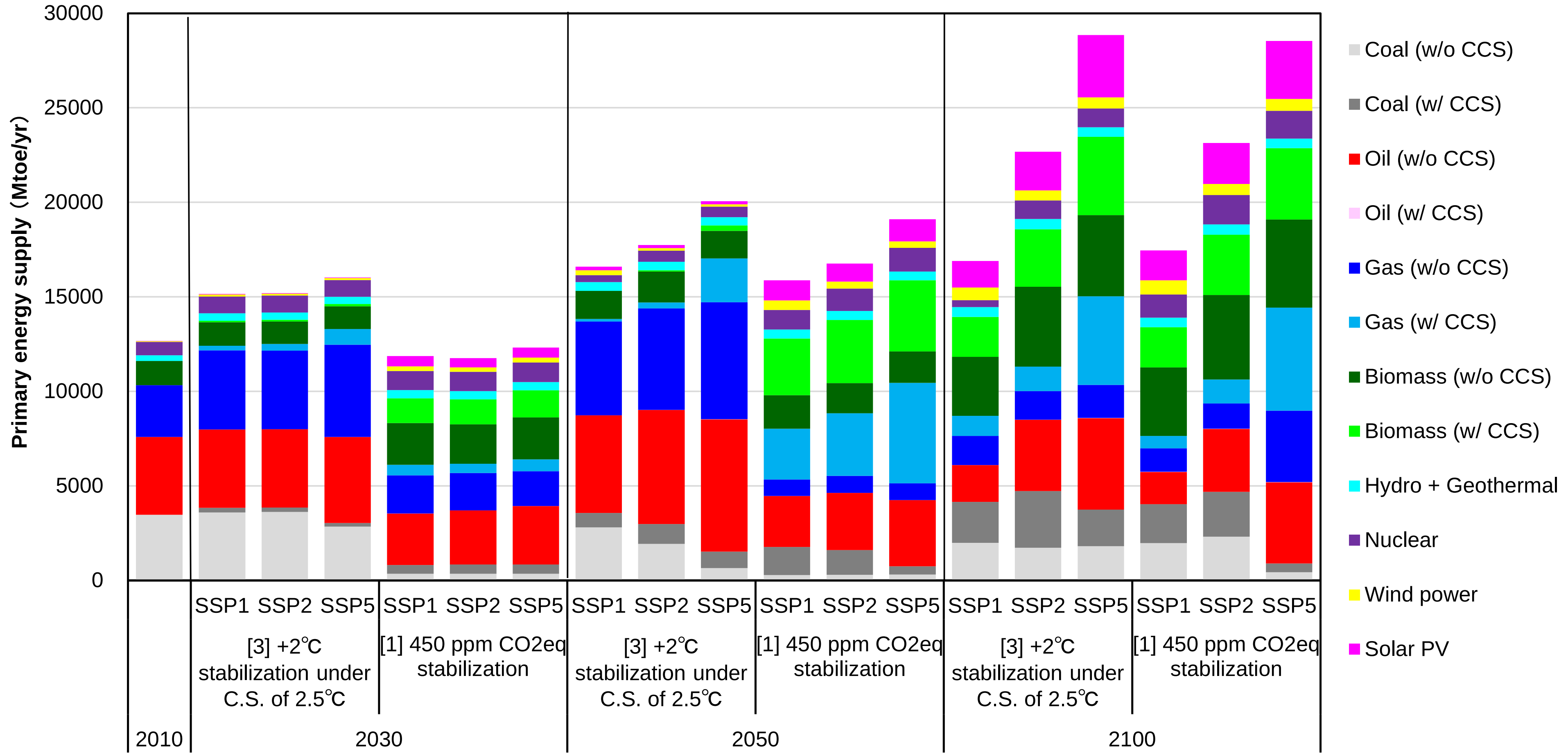
Unit: $/tCO2 (real price); Uniform carbon prices among all nations are assumed.

Source) estimated by RITE DNE21+

- **The marginal abatement costs (carbon prices) for the 2 °C target are huge even under the global least cost measures (uniform carbon prices) except in the case of low climate sensitivity (2.5 °C) and by 2050.**
- **The carbon price in SSP1 in which energy demands in the end-use sectors are much smaller than in SSP2 is much lower than that in SSP2.**
- **Technological and social innovations are definitely required for the 2 °C target to be achieved in harmony with other SDGs. (Newly emerging technologies such as AI, IoT etc. will induce social changes which may lower the energy demand.)**

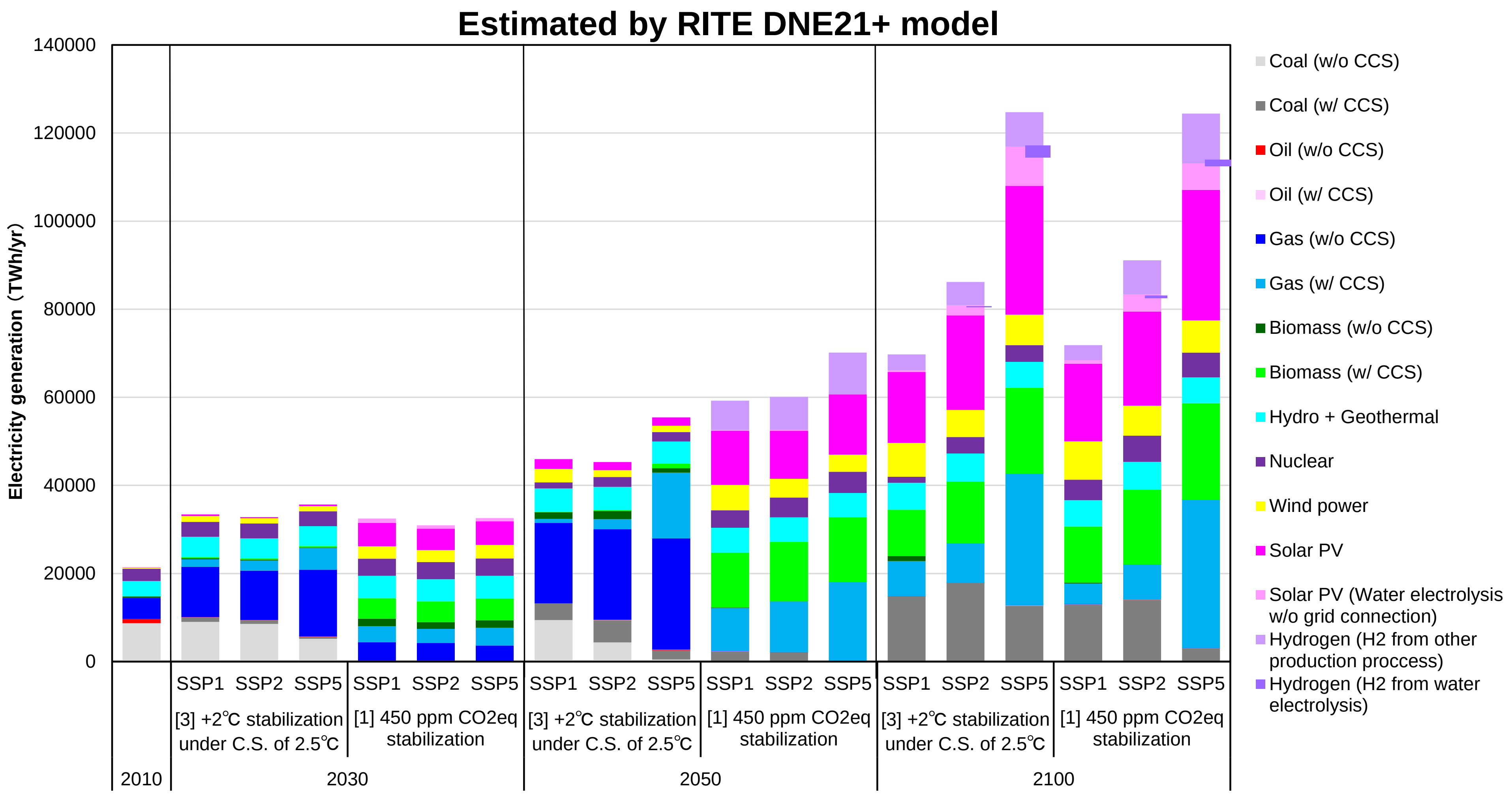
Global primary energy supply

Estimated by RITE DNE21+ model



- The energy supply is very different in 2050 according to the uncertainty in the climate sensitivity and different socioeconomic scenarios.
- The total amount of energy supply in the SSP1 world in 2100 is much smaller than that in the SSP2 and SSP5.

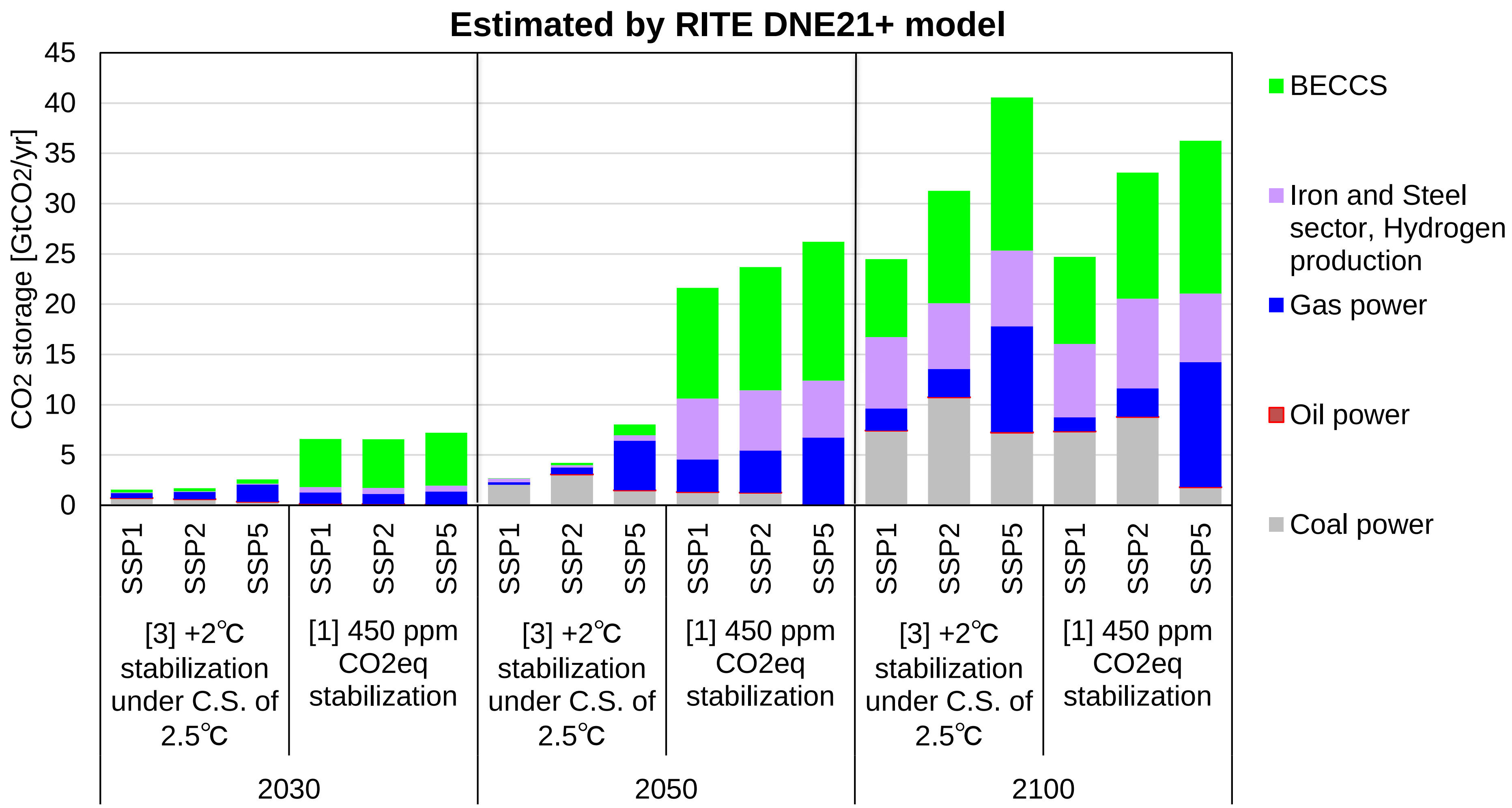
Global electricity generation



- CO_2 emissions from power sector in most of the scenarios for the 2 °C goals are nearly zero.

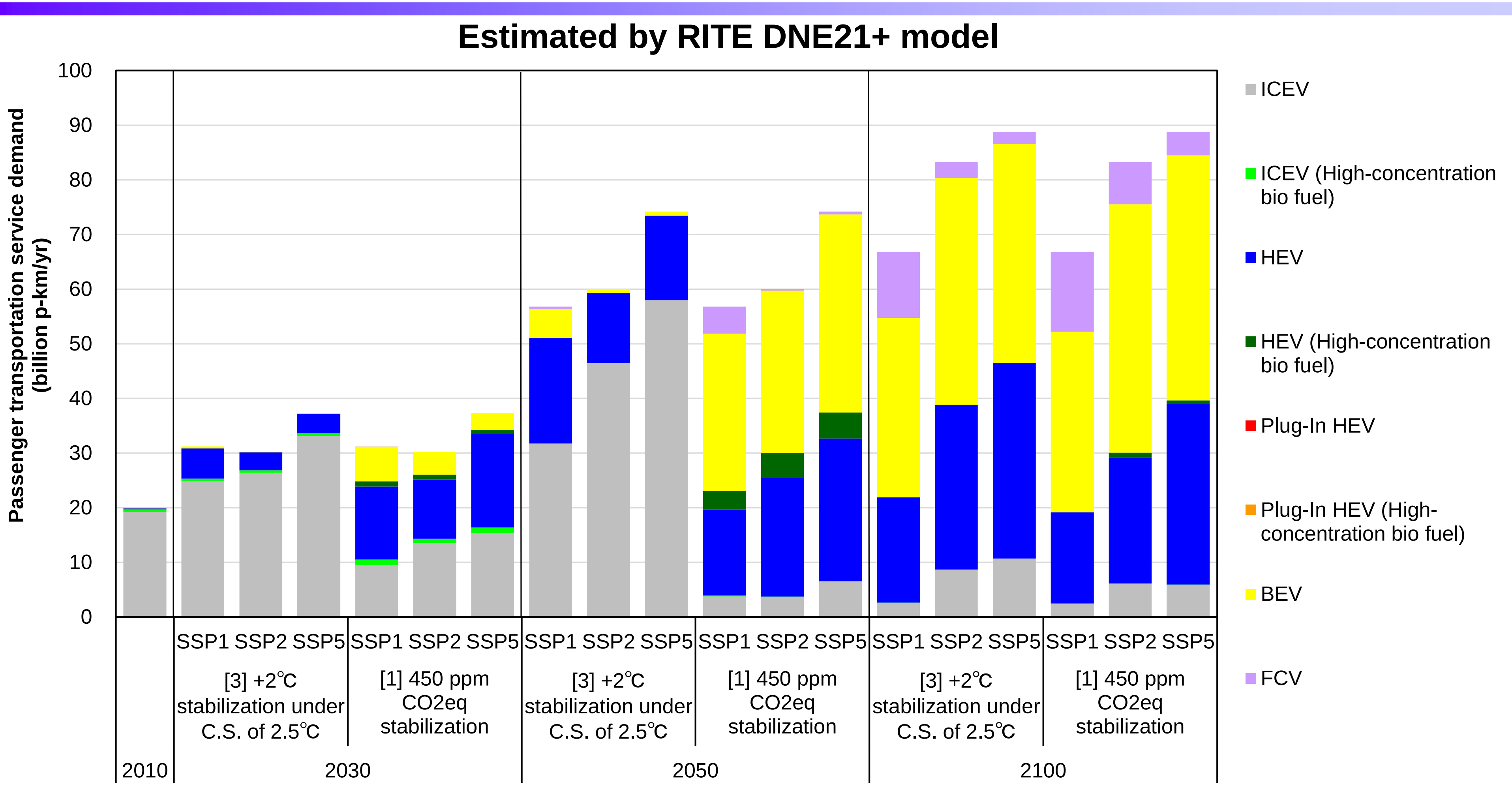
- The total amounts of electricity for the 2 °C target will increase with deeper emission reductions due to substitution of fossil fuel use in other sectors.

Global CO2 capture and storage (CCS)



- The total amount of CO2 storage by CCS is also very different in 2050 according to the uncertainty in the climate sensitivity and different socioeconomic scenarios.
- In 2100, large amounts of CCS including BECCS are required for all of the emission pathways for 2 °C goal.

Global transportation (automobile)



- The technology options in automobile are also very different in 2050 according to the uncertainty in the climate sensitivity.
- In 2100, large shares of EVs and FCVs are required as well as HVs for all of the emission pathways for 2 °C goal.

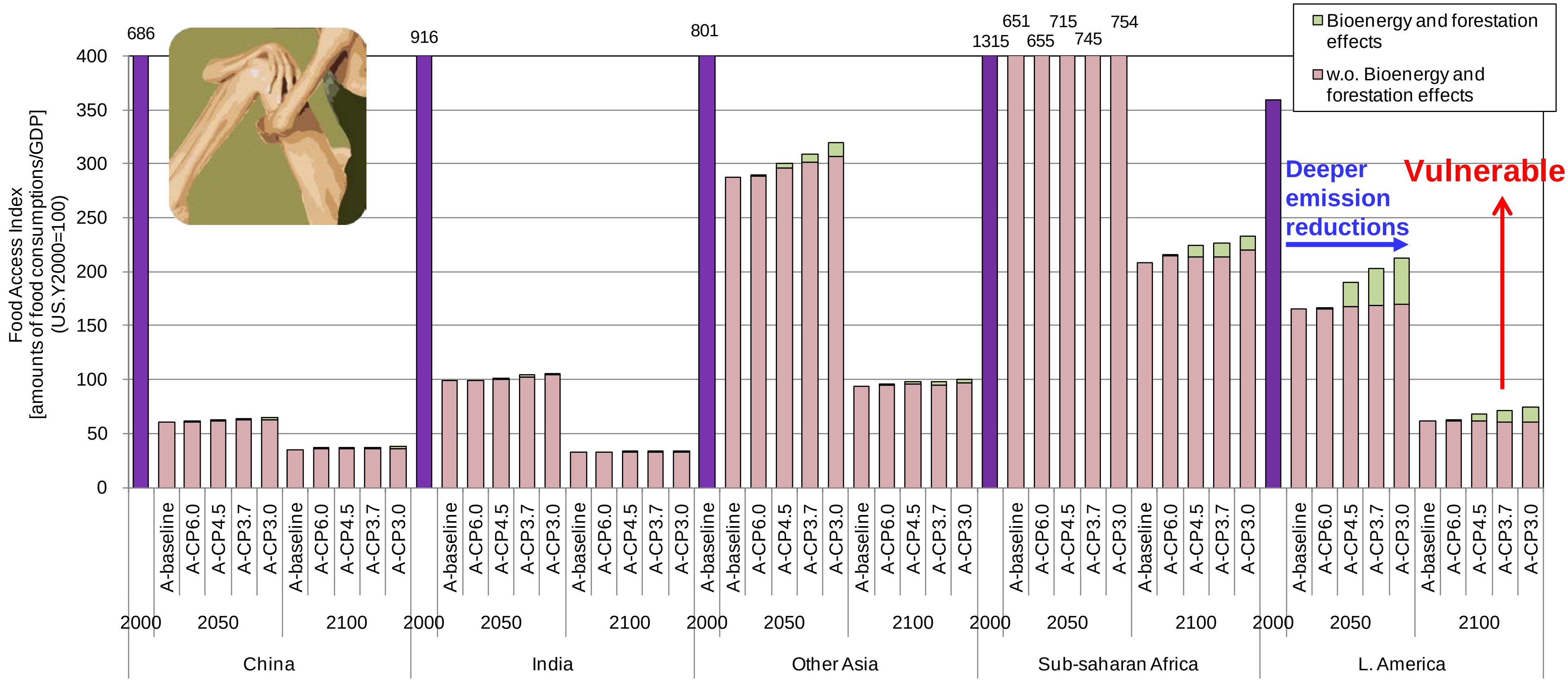
4. Co-benefit and trade-off between climate change and other sustainable development goals

Harmonization among climate change issues and other SDGs needed

- We have multiple agendas to be tackled. Harmonization among climate change issues and other SDGs are necessary.

Climate Change Mitigation & Food Access

Food access index (Amounts of food consumption／GDP)



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

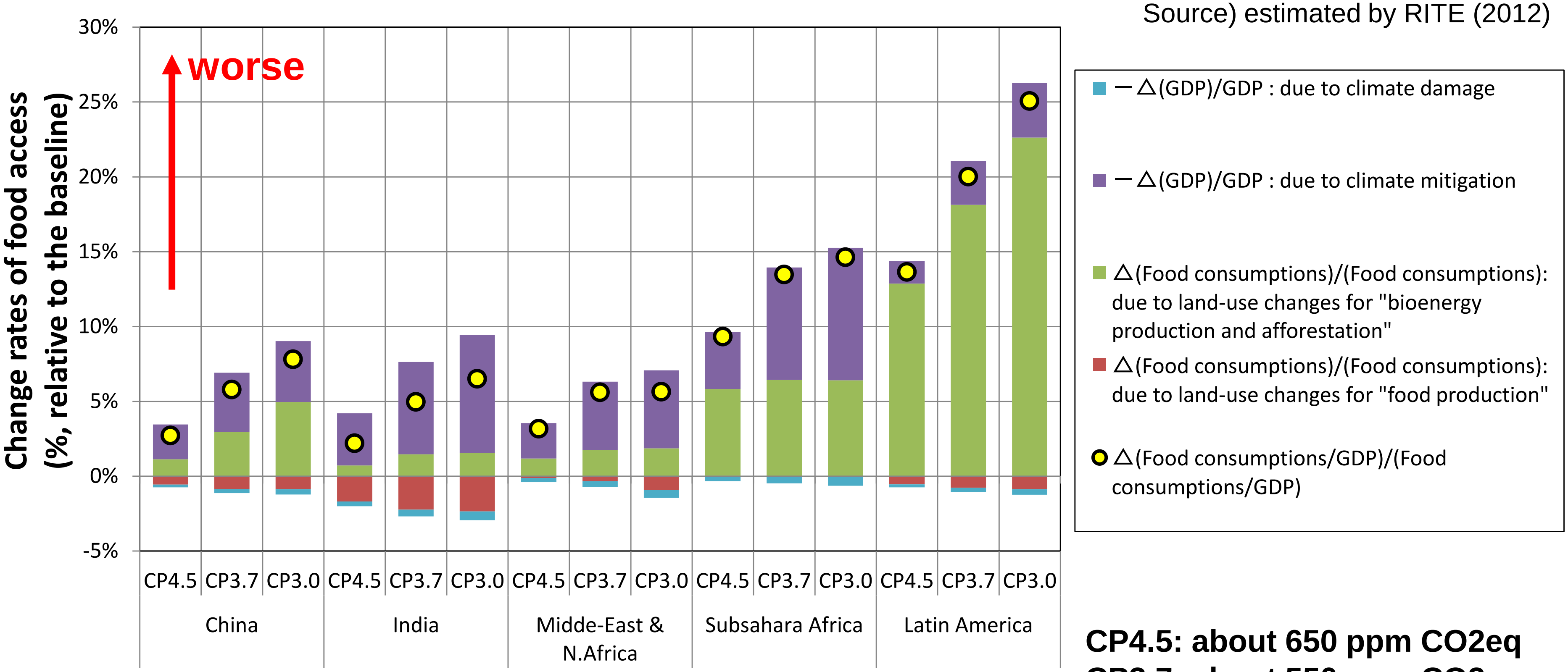
- Vulnerabilities of food access will decrease in most countries and regions in the long-term under any emission scenarios, because future incomes are expected to increase.

- Large-scale forestation and bioenergy use slightly increase vulnerabilities of food access.

An example of the synergy and trade-off among SDGs: Climate Change Mitigation and Food Access

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

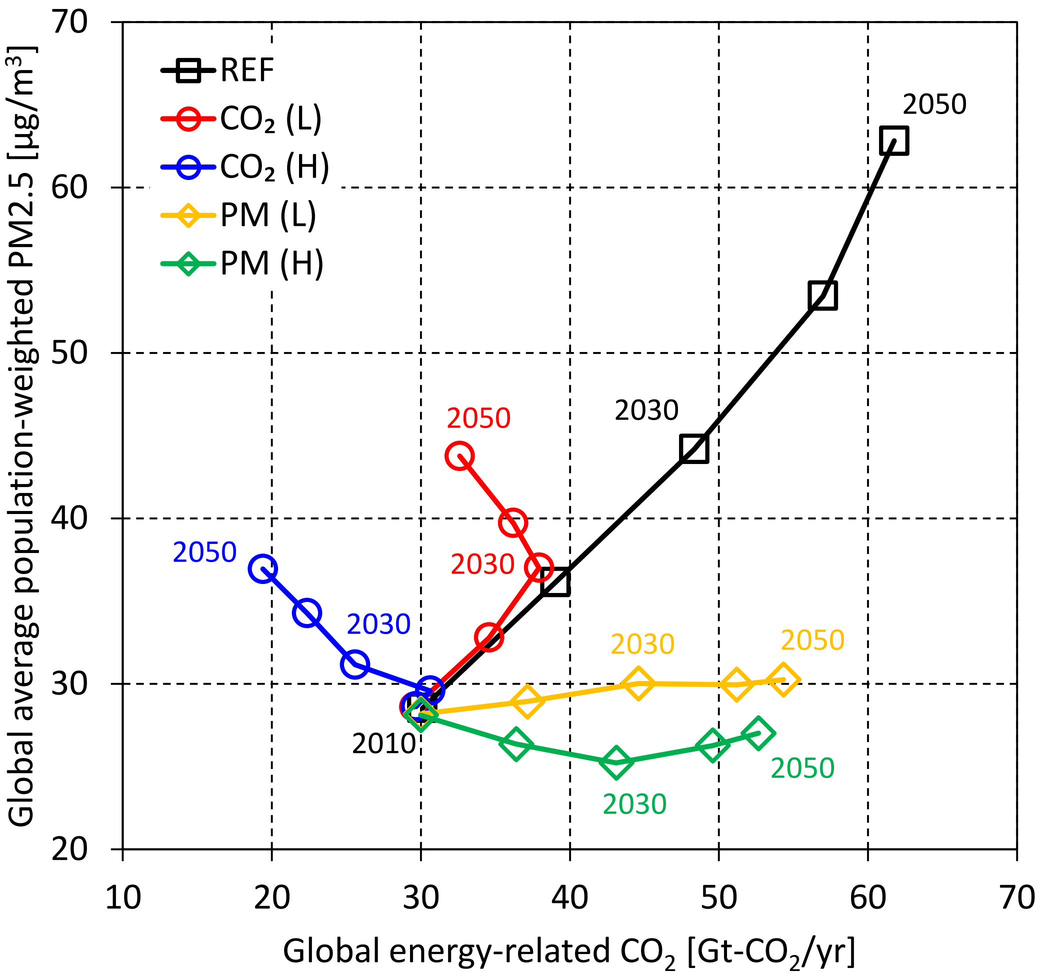
Source) estimated by RITE (2012)



CP4.5: about 650 ppm CO2eq
CP3.7: about 550 ppm CO2eq
CP3.0: about 450 ppm CO2eq

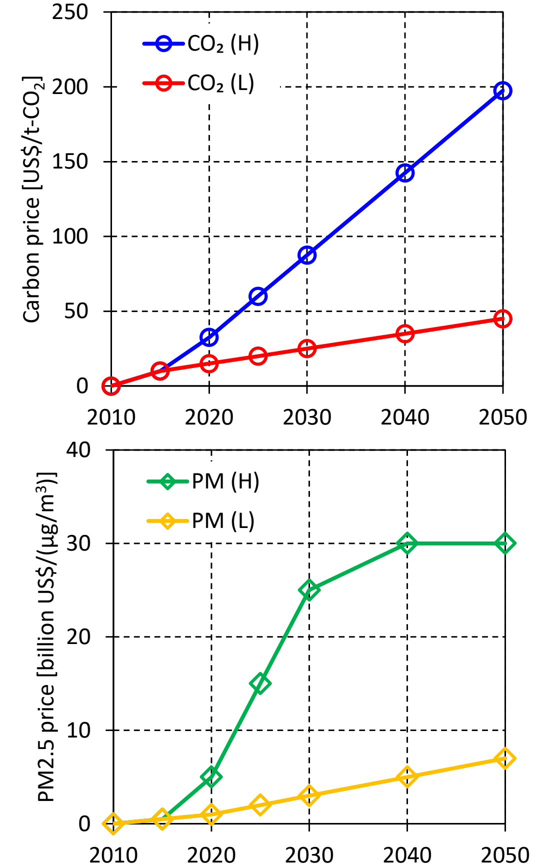
- Factor decomposition shows that climate change mitigation brings about small positive impacts on the food access index in certain aspects, but worsens the index in total.

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



Estimated by RITE DNE21+

Scenario assumptions*



***The emission factors by region and sector are assumed not to increase after 2010 than those in 2010.**

- Co-benefits of CO2 emission reduction by PM2.5 concentration reduction measures saturates as the level of PM2.5 mitigation deepens in the light of significant difference in the measure costs between PM(L) and PM(H).

- Taking into account the sufficiently high measure costs for PM(H), the co-benefit of CO2 reduction by PM2.5 measures is limited to be about 9 Gt-CO2/yr within the realistic range of measure costs.

Climate Change Mitigation & Air Pollution (PM2.5) Reduction Measures – Co-benefits

Kaya identity

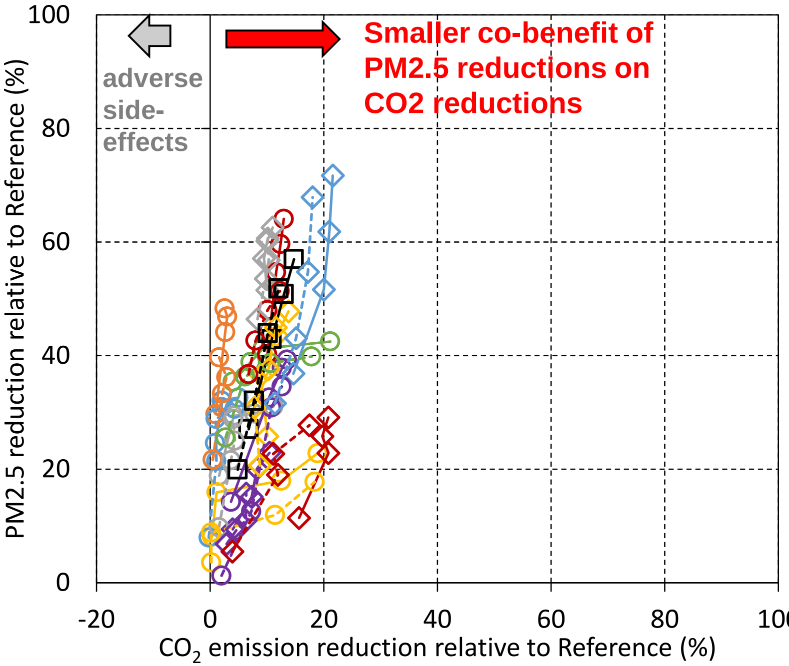
End-of-pipe measures (CCS) | Co-benefit measures

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

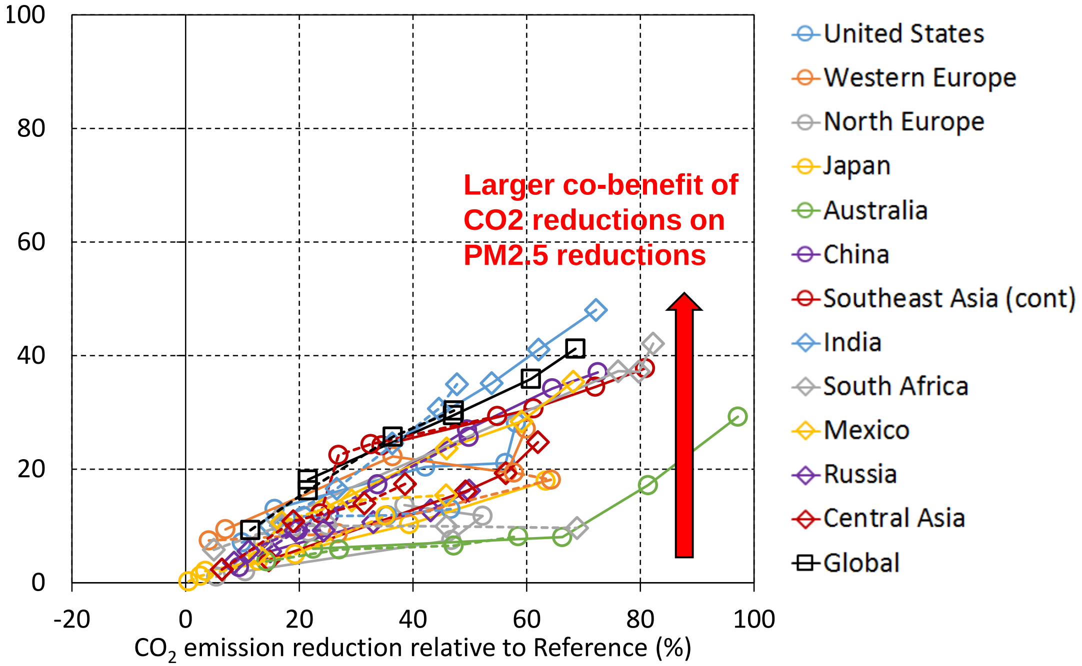
PM2.5 = (PM2.5／Gross PM2.5) × (Gross PM2.5／PE) × (PE／GDP) × (GDP)

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

PM2.5 concentration reduction cases



CO_2 emission reduction cases



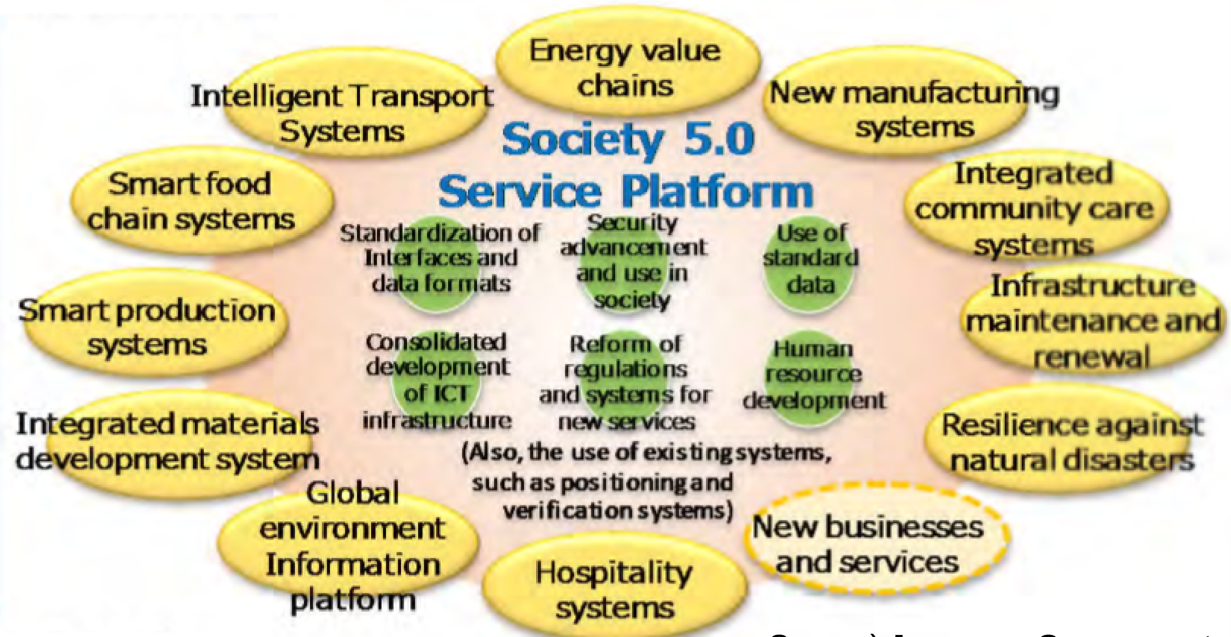
Estimated by RITE DNE21+

- 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 and China.
- 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.

5. Innovations and emission pathways

5th Science and Technology Basic Plan of Japan - “Society 5.0” (“Super Smart Society”) -

What is Society5.0?
It is a society that can be expected to facilitate human prosperity. Such a society is capable of providing the necessary goods and services to the people who need them at the required time and in just the right amount; a society that is able to respond precisely to a wide variety of social needs; a society in which all kinds of people can readily obtain high-quality services, overcome differences of age, gender, region, and language, and live vigorous and comfortable lives.



Source) Japanese Government

AI + IoT + big data + ….

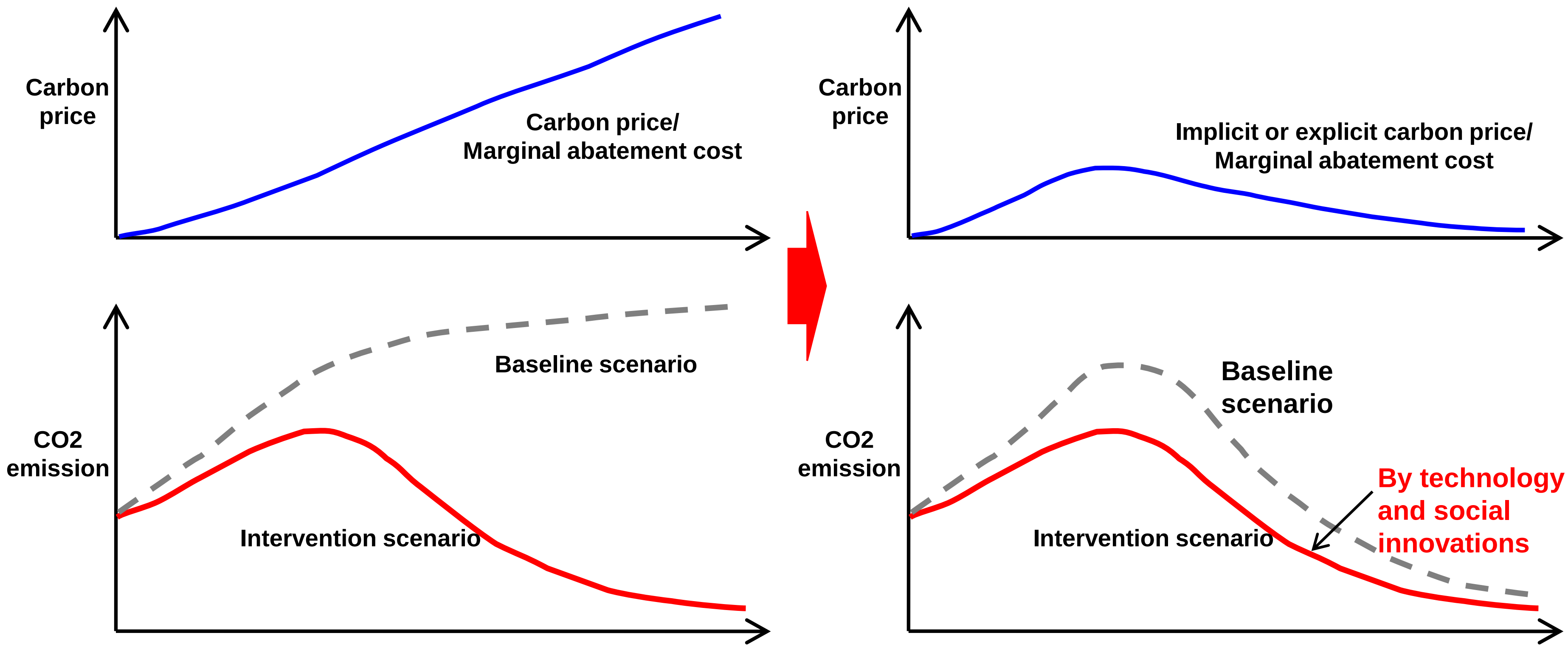
Operation ratio of automobiles is about 4%, for example. The large room for the improvement exists.

- Wide range of innovations of technologies and their integrations are required for improving our welfare and sustainable development.
- AI, IoT, big data etc. will be able to stimulate such innovations.

Image of standard scenario by models and real world scenarios for deep cuts

Model world:
Ordinary technology progress

Realistic world requirement:
Innovations stimulated & implemented



Explicit high carbon prices of such as over 100$/tCO2 in real price are unlikely in a real world. Technology and social innovations resulting in low (implicit or explicit) carbon prices (including coordination of secondary energy prices) are key for deep emission cuts to be implemented.

6. Conclusions

Conclusions

- **Nearly zero CO_2 emissions are required in the long-term.**
- **But there are lots of uncertainties, and we should recognize these uncertainties to manage the risks in a better way.**
- **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)**
- **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.**
- **Innovations are significant for achieving zero emissions. The demand side revolutions induced by IT, AI etc. will be highly expected as one of the innovations for reducing energy consumptions and toward deep emission reductions (but currently uncertain) .**
- **Total risk management with flexibilities reserved is critically important rather than pursuing rigid targets.**

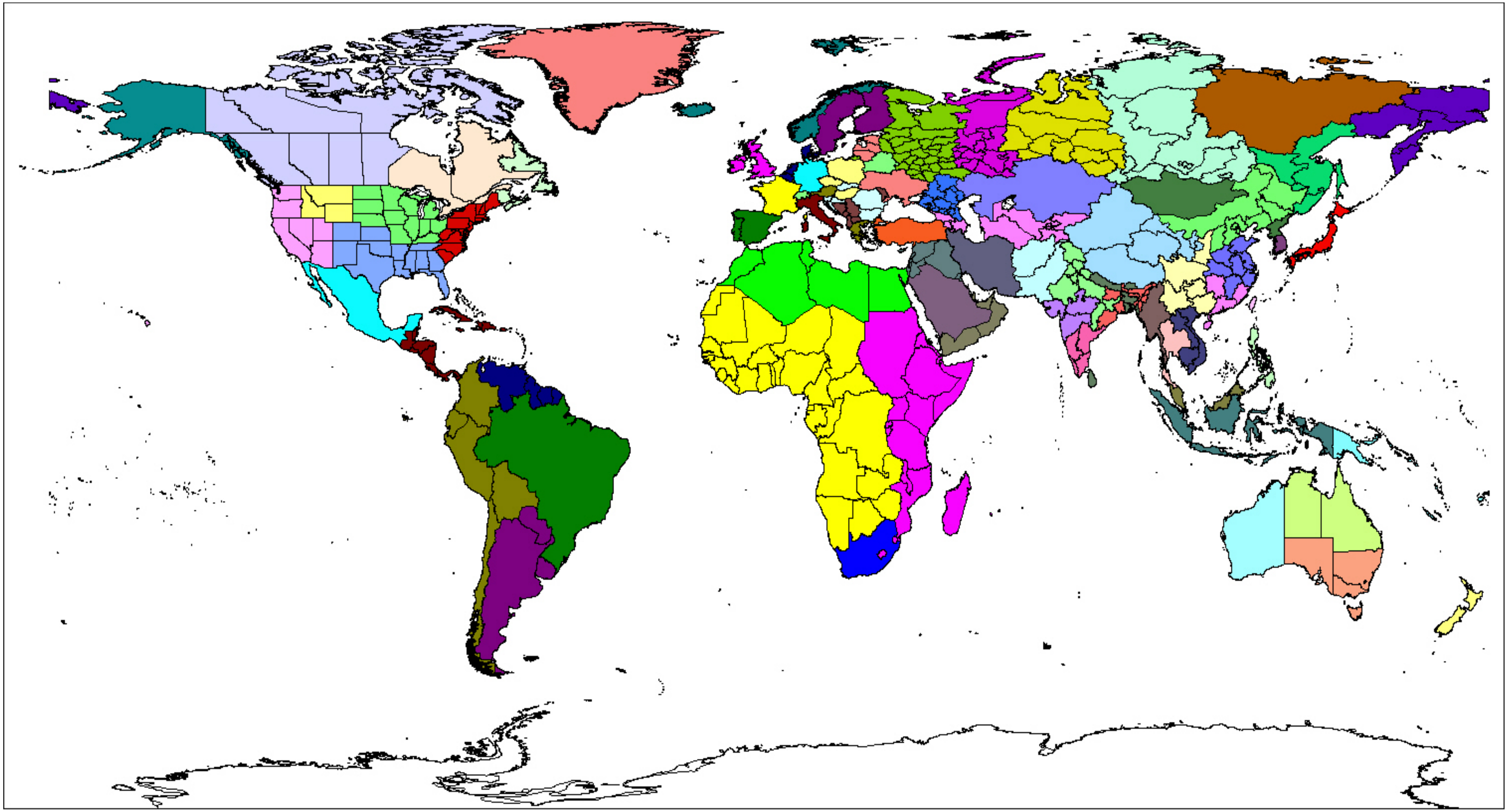
Appendix

Energy Assessment Model: DNE21+

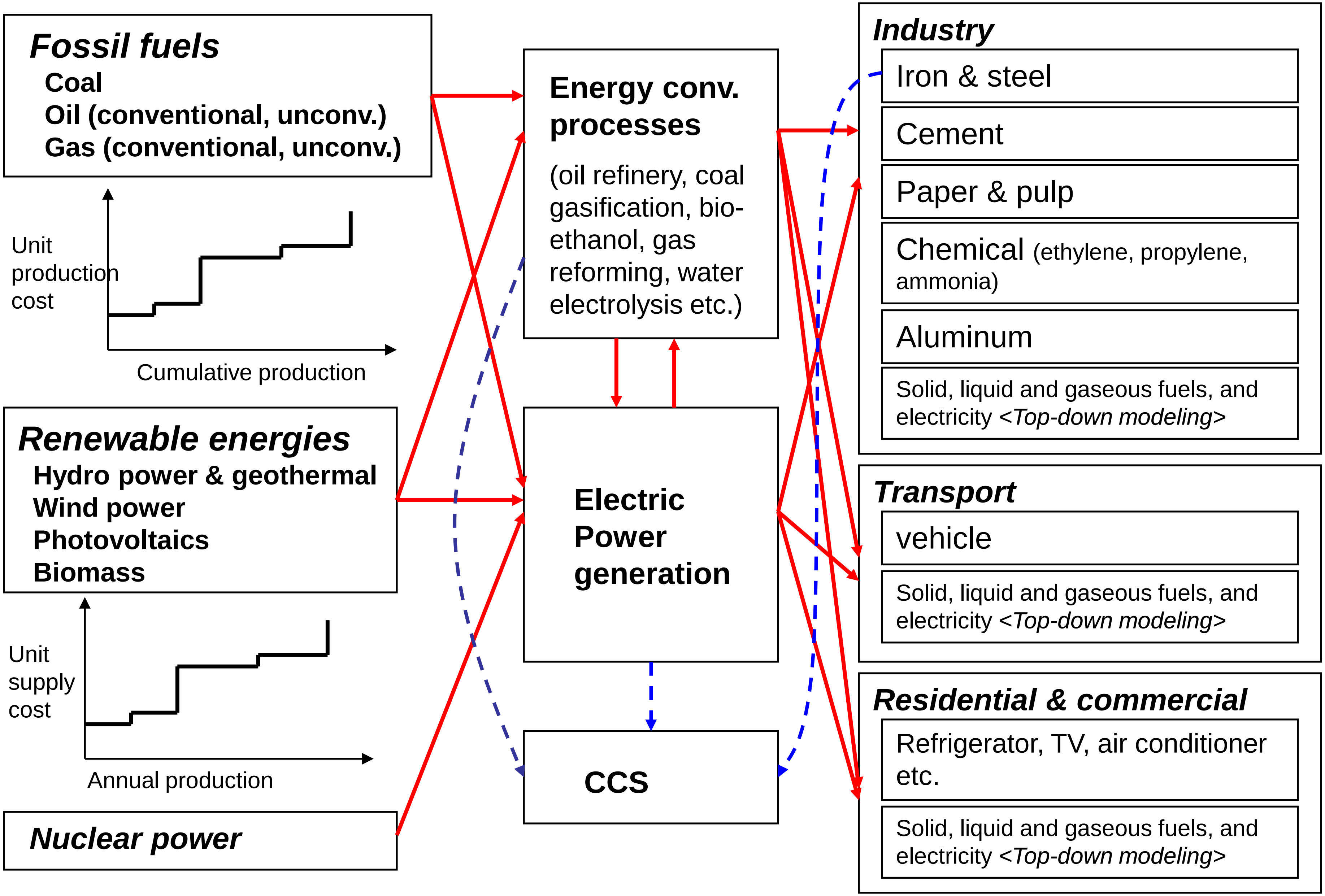
- Linear programming model (minimizing world energy system cost)
- Evaluation time period: 2000-2100
  Representative time points: 2000, 2005, 2010, 2015, 2020, 2025, 2030, 2040, 2050, 2070, 2100
- World divided into 54 regions
  Large area countries are further divided into 3-8 regions, and the world 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.

Region divisions of DNE21+



Technology Descriptions in DNE21+ (1/2)

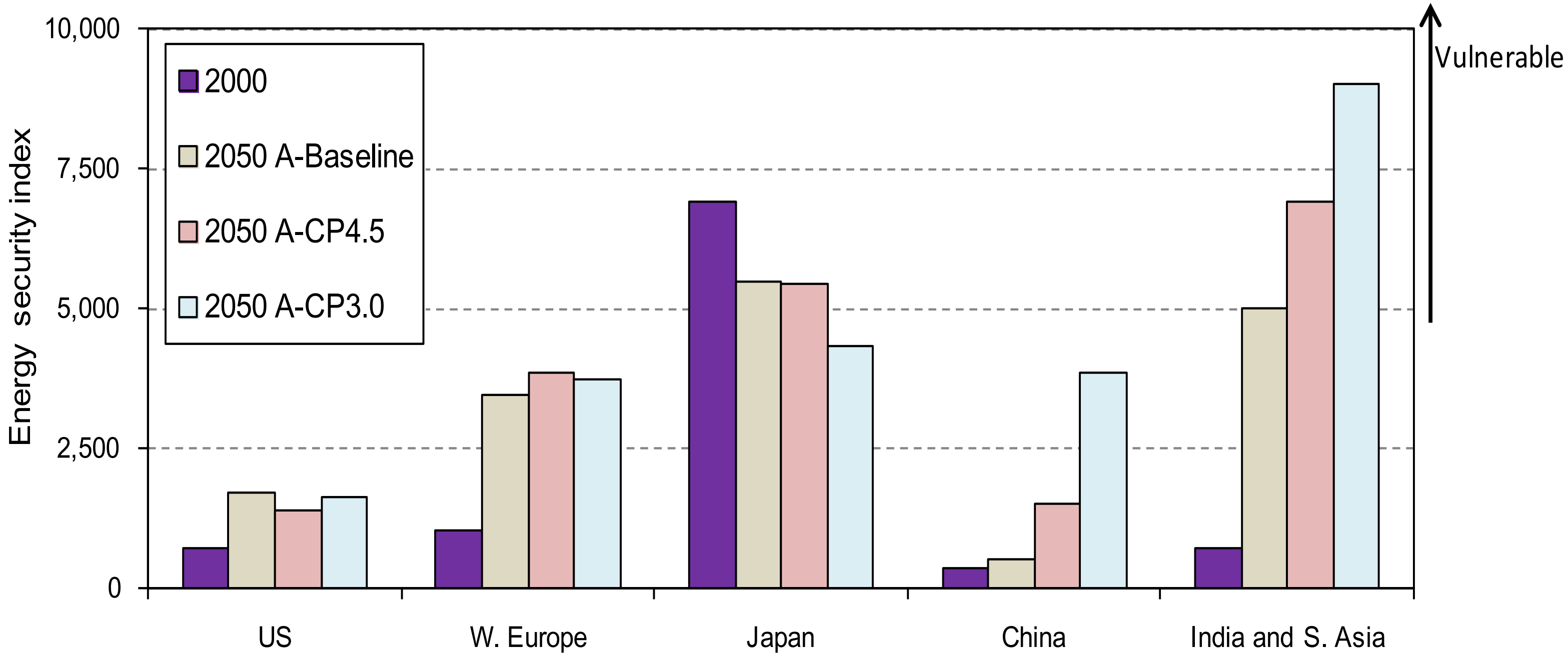


Climate Change Mitigation & Energy Security

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

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), those of China and India increase (more vulnerable) for deeper emission reductions due to increase in imported gas shares (adverse side effects).