COP24 side-event: Mitigation Policy Choices and Levels of Effort

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Evaluations on emission reduction efforts of NDCs and the Implications of Global Effectiveness on Climate Change Mitigation

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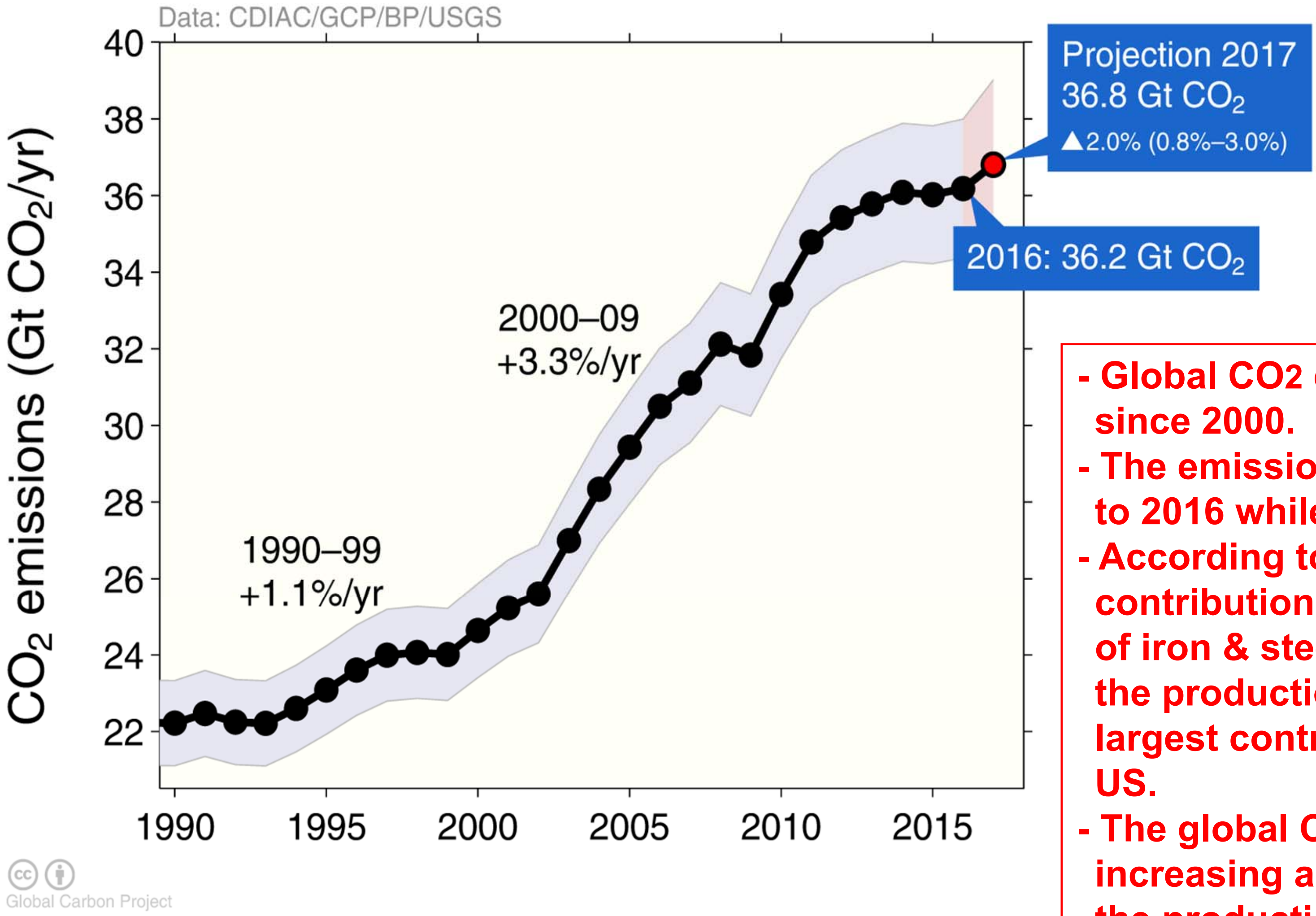
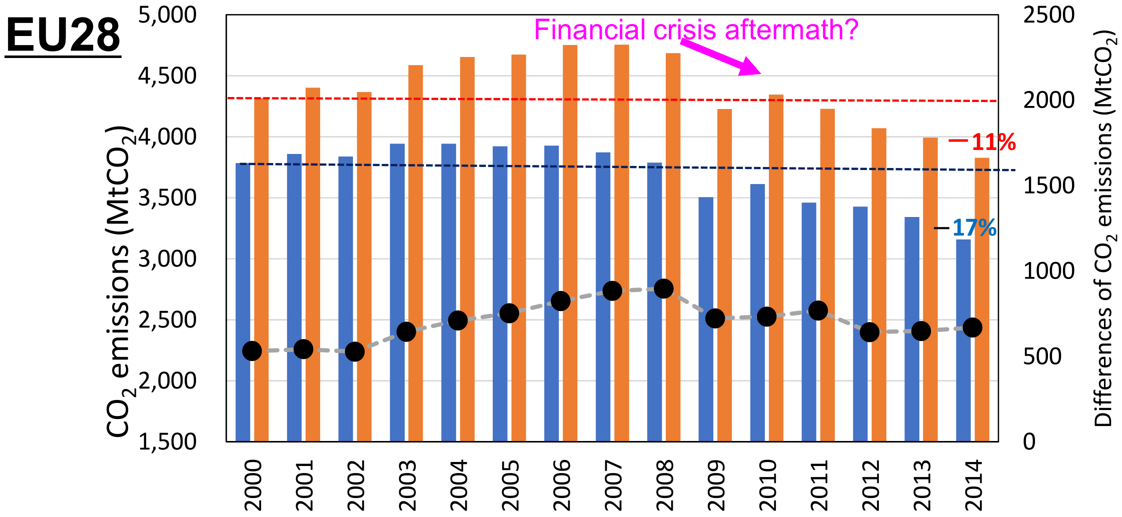
Global CO_2 Emissions Trajectory

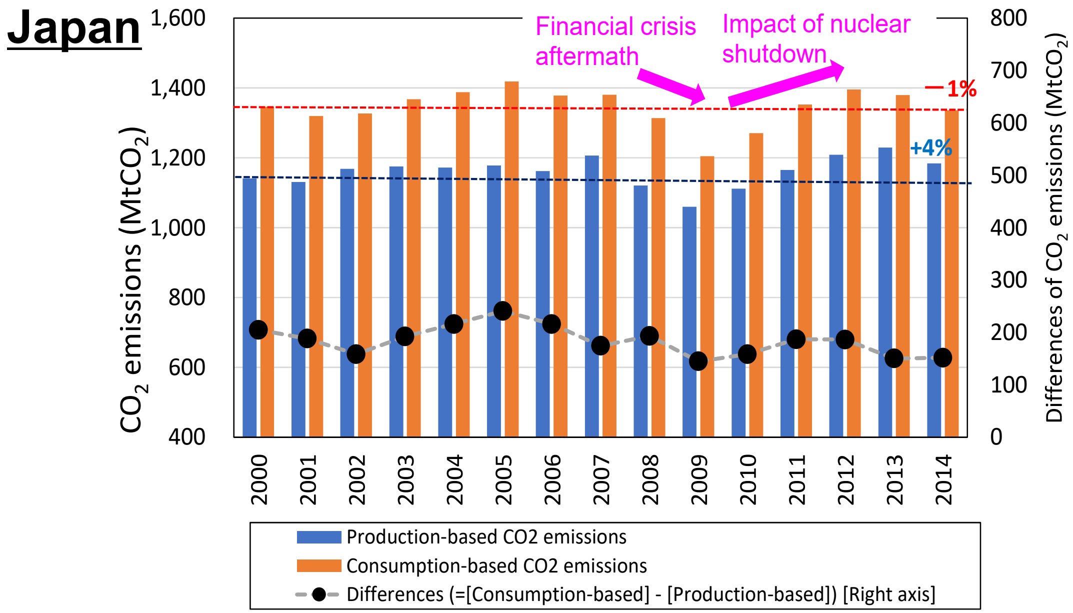


Source) Global Carbon Project

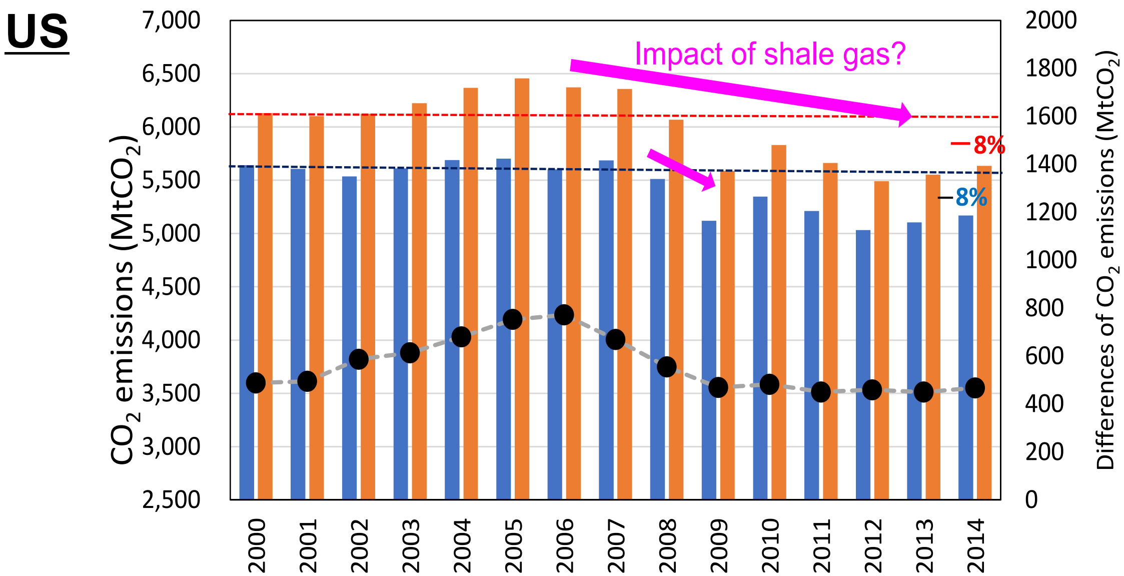
- Global CO_2 emissions increased more rapidly since 2000.
- The emissions were almost constant from 2013 to 2016 while the global GDP increased.
- According to our analysis, the largest contribution was due to production adjustments of iron & steel etc. mostly in China (since 2010, the productions were too large), and the second largest contribution was due to shale gas in the US.
- The global CO_2 emissions after 2016 are increasing again due to mainly mitigations of the production adjustments in China.

Production-based & Consumption-based CO2 emissions



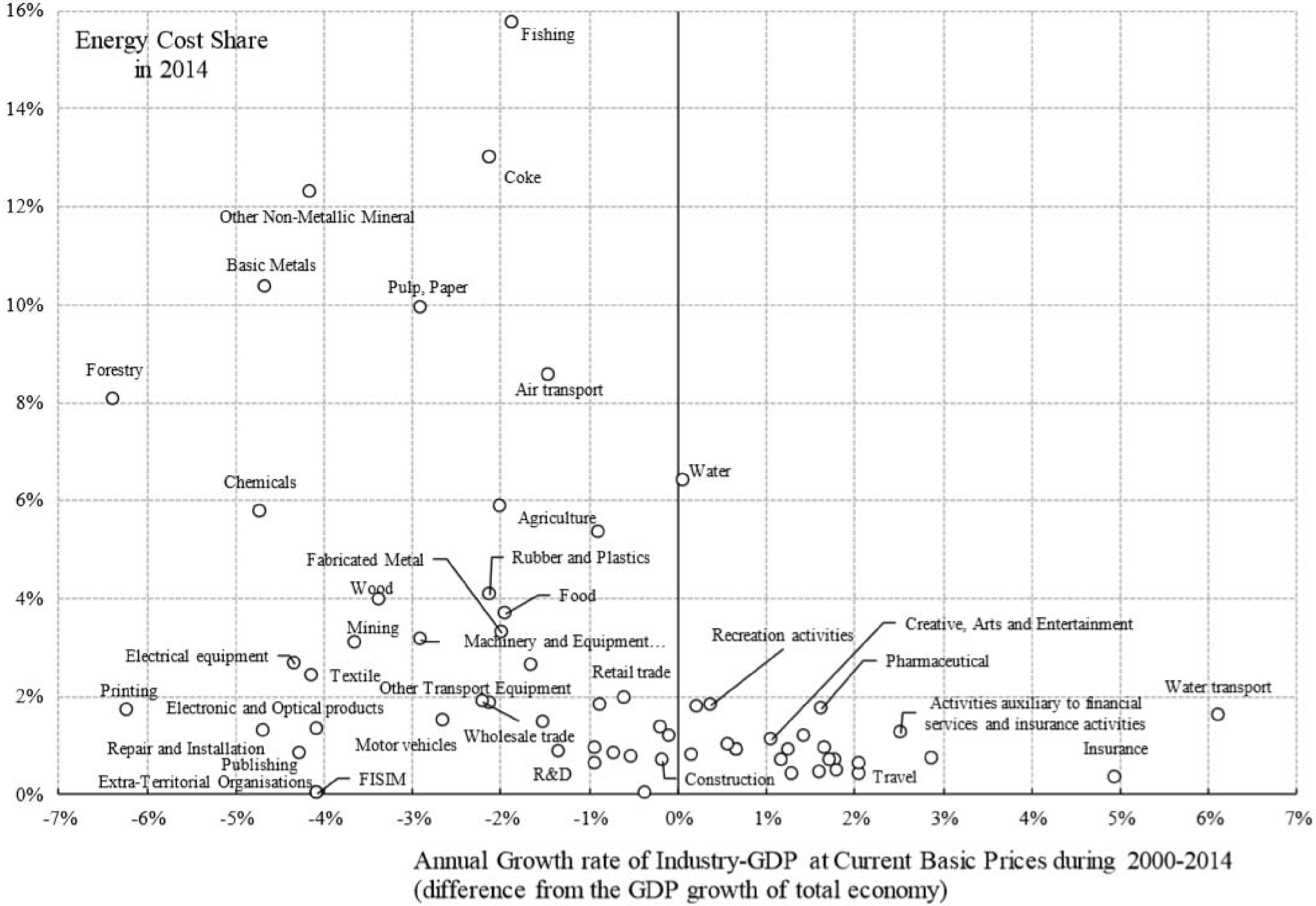


Source: estimated by RITE



- **The embodied emissions in trade (difference between Consumption-based CO2 and Production-based CO2) increased in EU, almost constant in the US, and slightly reduced in Japan between 2000 and 2014.**
- **Climate policies and other kinds of policies affect domestic emissions and also global emissions through international trade.**

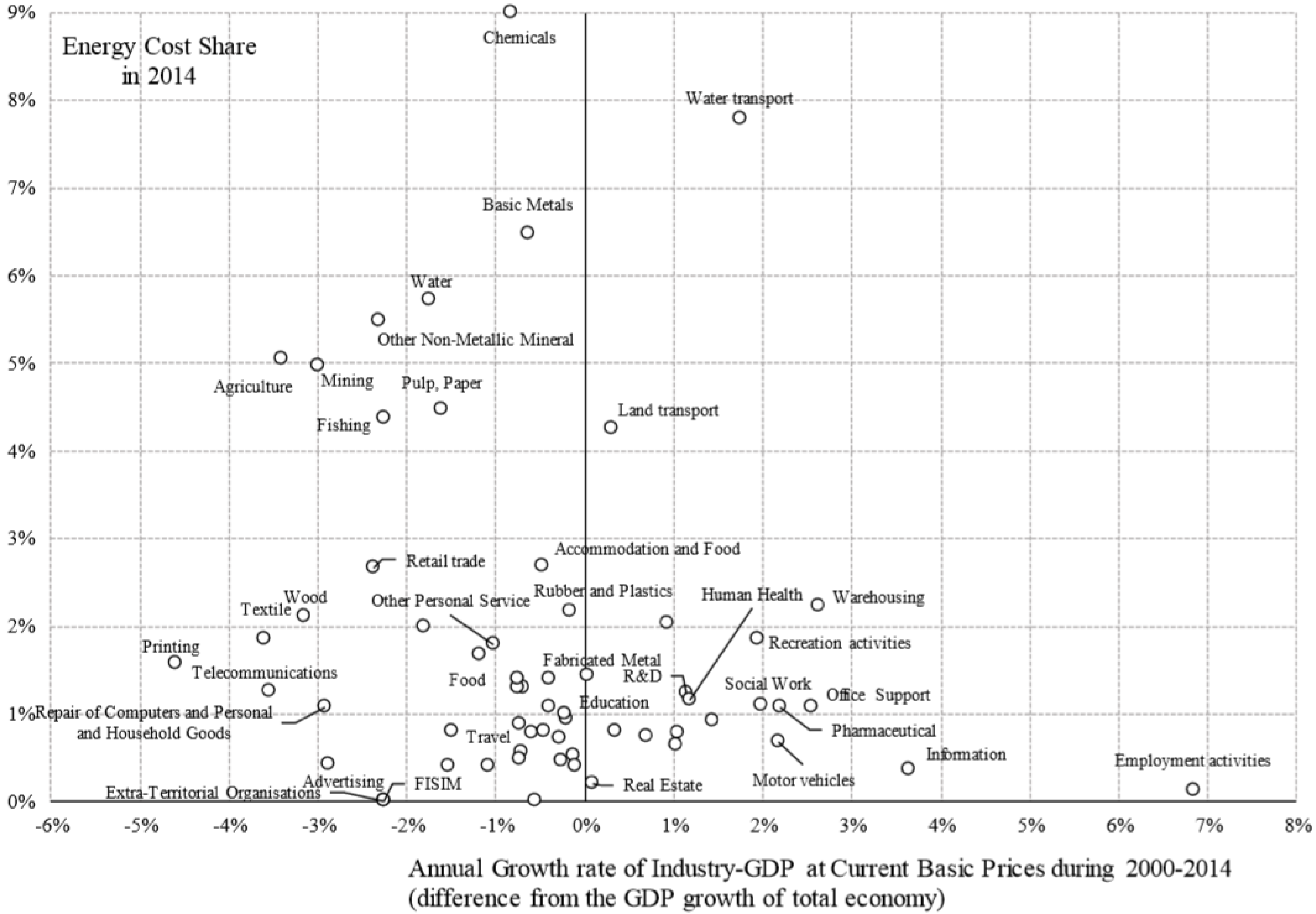
Energy cost share (2014) vs Economic growth (2000-14) of industrial sectors in UK



Source: K. Nomura,
https://www.dbj.jp/ricf/pdf/research/DBJ_RCGW_DP60.pdf
(in Japanese)

The industrial sectors having high share of energy costs in the total costs showed relatively small growth rate between 2000 and 2014. These sectors shifted outside the UK according to the analyses of consumption-based CO2 emissions.

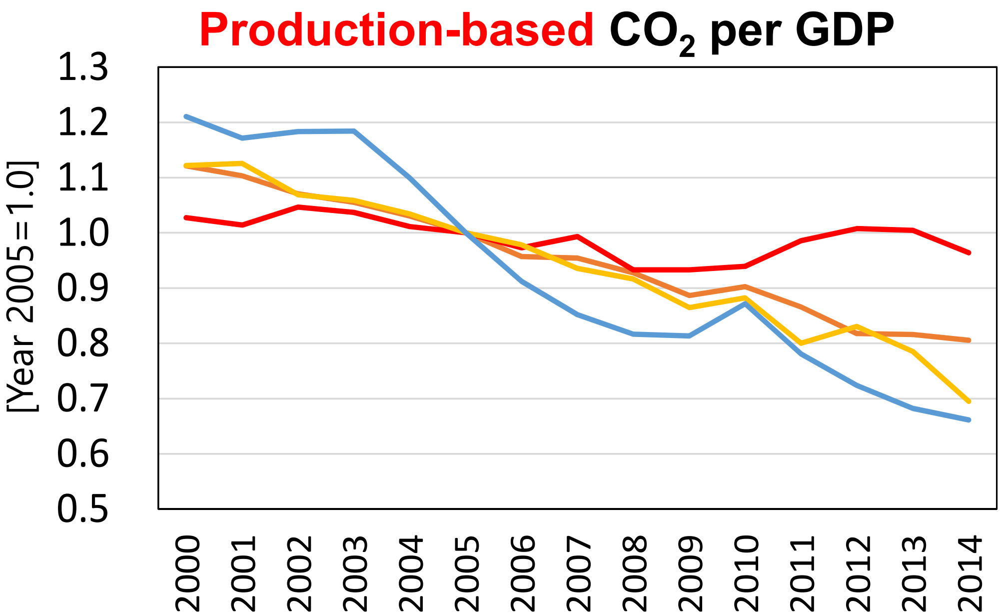
Energy cost share (2014) vs Economic growth (2000-14) of industrial sectors in Germany

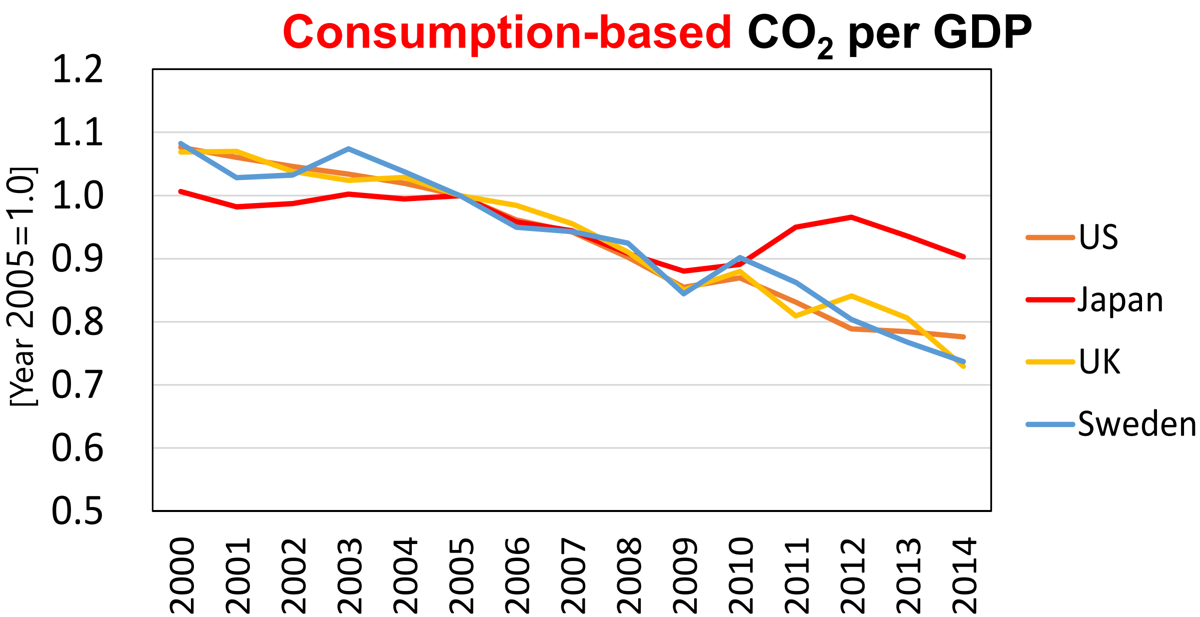


Source: K. Nomura, https://www.dbj.jp/ricf/pdf/research/DBJ_RCGW_DP60.pdf (in Japanese)

Employment activities and information service sectors whose share of energy cost are relatively small achieved relatively high economic growth between 2000 and 2014 in Germany. Relatively cheap Euro compared with the industry competitiveness of Germany helped motor vehicle sectors to achieve relatively high growth.

Per-GDP CO2 Emission in US, UK, Sweden and Japan: Production-base v.s. Consumption-base





Note: 2010 local currency base

Source: estimated by RITE

- In terms of the production-based CO2 emissions per GDP, the degrees of improvement of the four countries differs greatly.
- However, concerning the consumption-based emissions, the improvement rates of the four countries do not differ that much when excluding the impact of Japan's emission increase due to the shutdown of nuclear power generation after the Fukushima Daiichi nuclear power accident during the Great East Japan Earthquake.
- Focusing only on production-based emissions may lead to wrong interpretation of emission reduction efforts of individual nation.

How to measure the comparability of efforts of NDCs

The Paris Agreement allows pledges of various type emission reduction targets and adopts a review process for them.

The submitted Nationally Determined Contributions (NDCs) include 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 ratios 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)
  - Final energy prices
  - Marginal abatement cost (per ton of CO_2)
  - Abatement costs as a share of GDP etc.

and the effects on international competitiveness of the NDCs are significant for sustainable measures.

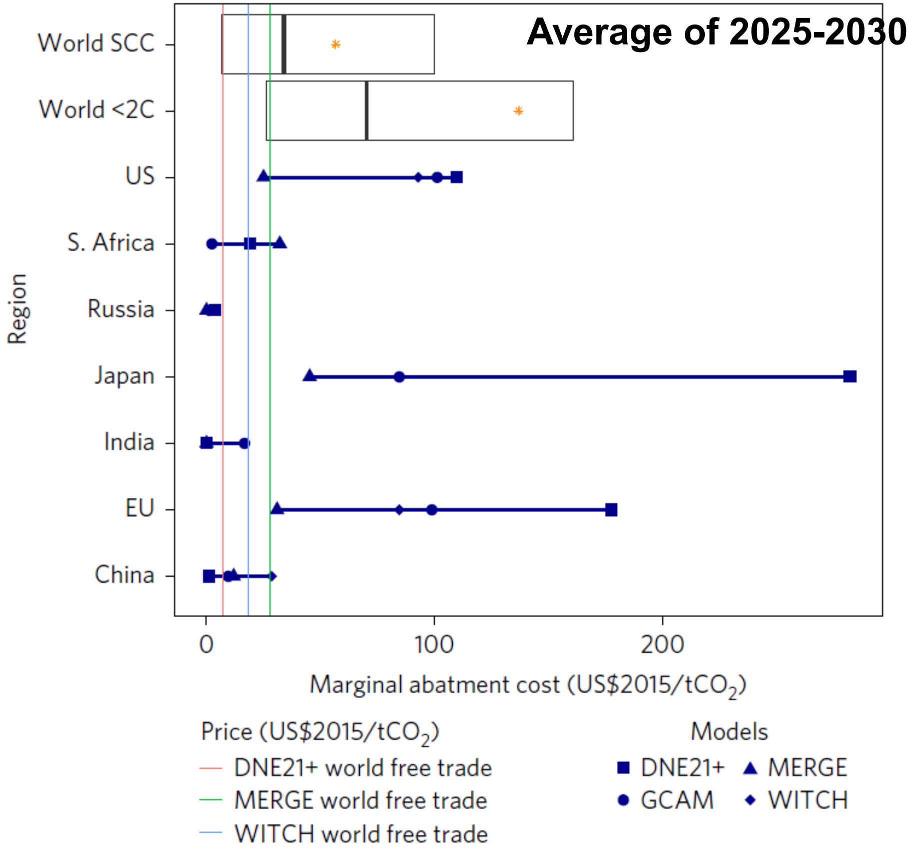
Emissions reduction ratio from base year of NDCs for major countries

	Emissions reduction ratio from base year		
	From 1990	From 2005	From 2013
Japan: in 2030, -26% from 2013 levels	-17.8%	-24.3%	**-26.0%**
US: in 2025, about -26 to -28% from 2005 levels	-15 to -17%	**-26 to -28%**	-19 to -21%
EU28: in 2030, -40% from 1990 levels	**-40%**	-35%	-24%
Russia: in 2030, -25% to -30% from 1990 levels	**-25 to -30%**	+13 to +6%	+7 to 0%
China: in 2030, CO_2 intensity of -60% to -65% from 2005 levels	+406 to +343%	**+96 to +72%**	+17 to +2%

Underlined: official NDCs, Others: estimated by RITE

Emission reduction ratios vary depending on the base year. The emission reduction ratios of NDCs cannot be used directly for comparison of emission reduction efforts, mainly because the base years are different across the nations.

CO2 marginal abatement costs of the NDCs

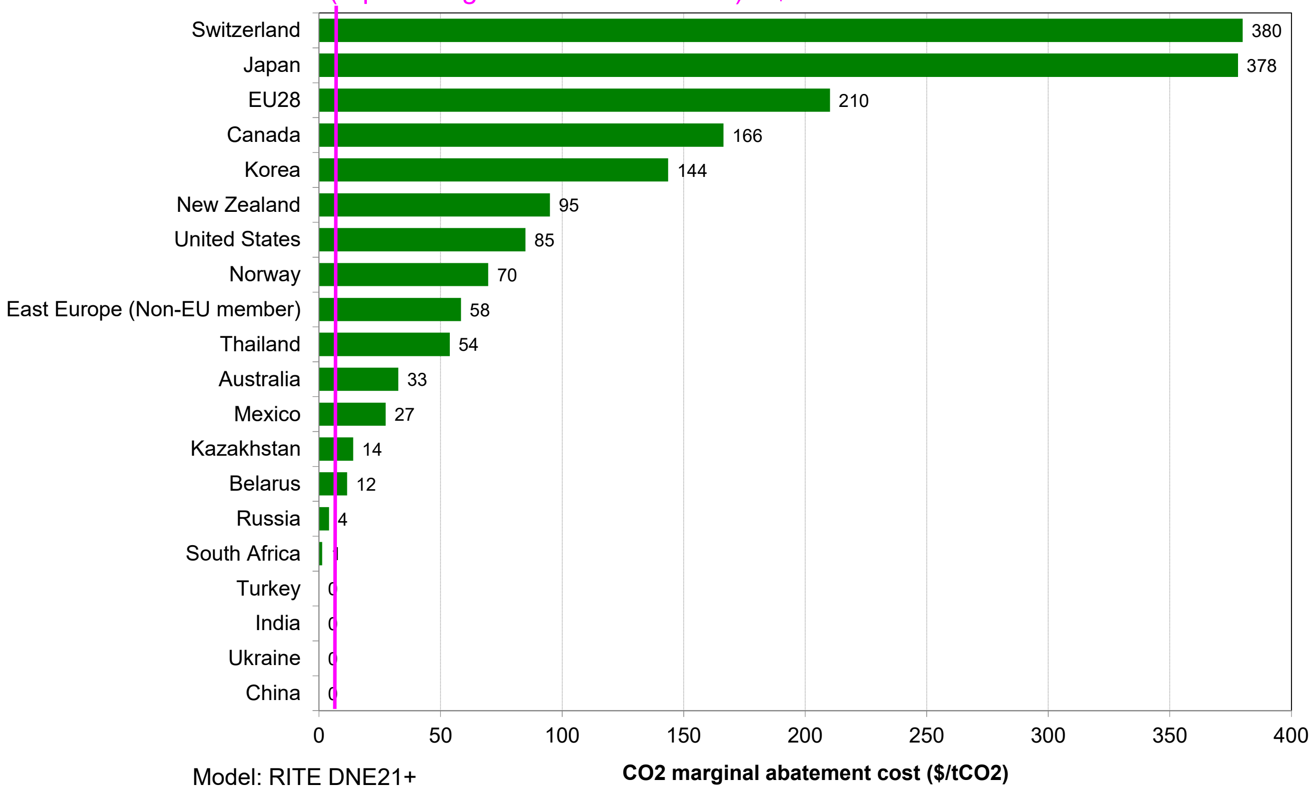


Source: J. Aldy et al., Nature Climate Change, 2016

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



Model: RITE DNE21+

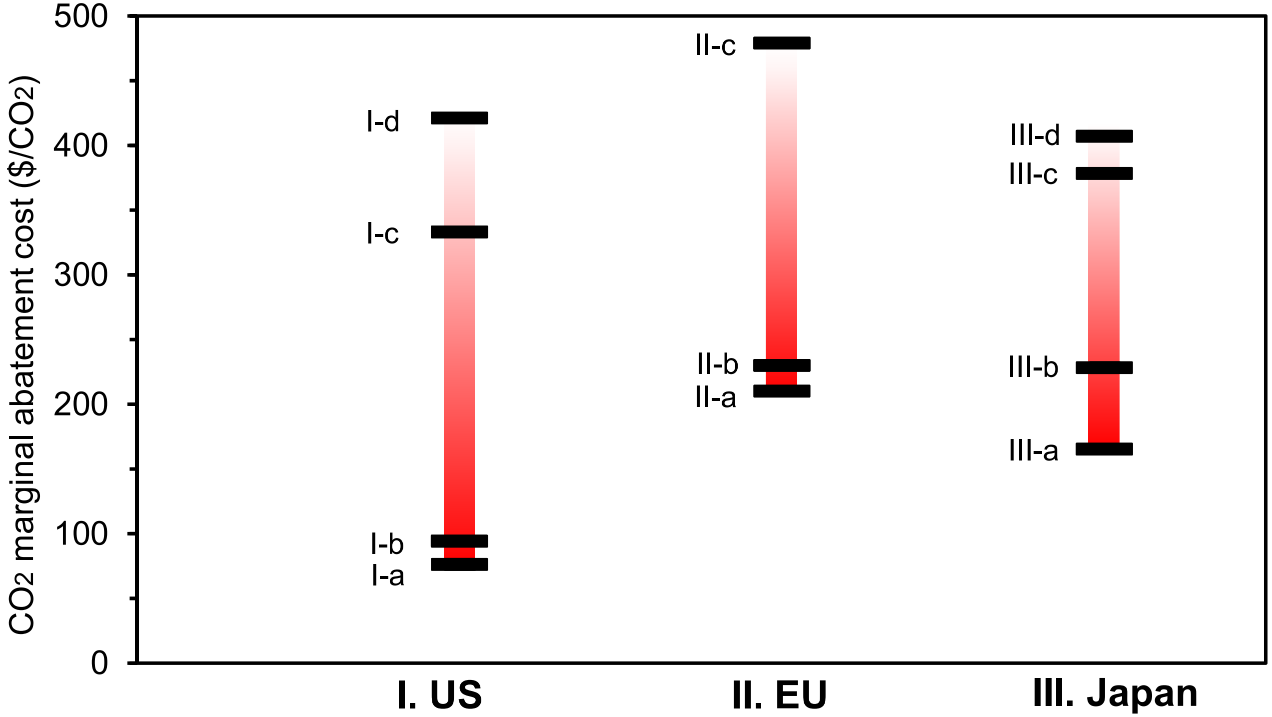
Source: K. Akimoto et al., Evol. Inst. Econ. Rev., 2016

The estimated marginal abatement costs of NDCs are largely different among countries, and therefore the world total mitigation costs are much larger than those for achieving the aggregated emission reductions under the least cost measures, i.e., under globally uniform MAC.

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

		Assumptions
United States	I-a	26% reductions relative to 2005 with least cost measures
	I-b	28% reductions relative to 2005 with least cost measures
	I-c	26% reductions relative to 2005. The amount of emission reductions in power sector proceeds according to the estimates for the Clean Power Plan by EPA.
	I-d	28% reductions relative to 2005. The amount of emission reductions in power sector proceeds according to the estimates for the Clean Power Plan by EPA.
EU28	II-a	40% reductions relative to 1990 with least cost measures
	II-b	40% reductions relative to 1990 for both the UK and non-UK EU nations
	II-c	The emission reductions for EU-ETS sectors are determined by the planned emission allowances, and the non-ETS sectors fill the rest of reductions to meet the 40% reductions relative to 1990.
Japan	III-a	26% reductions relative to 2013 with least cost measures. Maximum share of nuclear power in electricity generation is assumed to be 20%.
	III-b	26% reductions relative to 2013 with least cost measures. Maximum share of nuclear power in electricity generation is assumed to be 15%.
	III-c	26% reductions relative to 2013. Electricity share assumed to be same as the energy mix of Japanese governmental plan.
	III-d	26% reductions relative to 2013. Electricity share assumed to be nuclear: 15%, renewables: 29%, others: same as the energy mix of Japanese governmental plan.

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



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

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+

The annual total emission reduction cost ;

US: the cost for I-c is about 5.1 times larger than that for I-a.

EU: the cost for II-c is about 1.5 times larger than that for II-a.

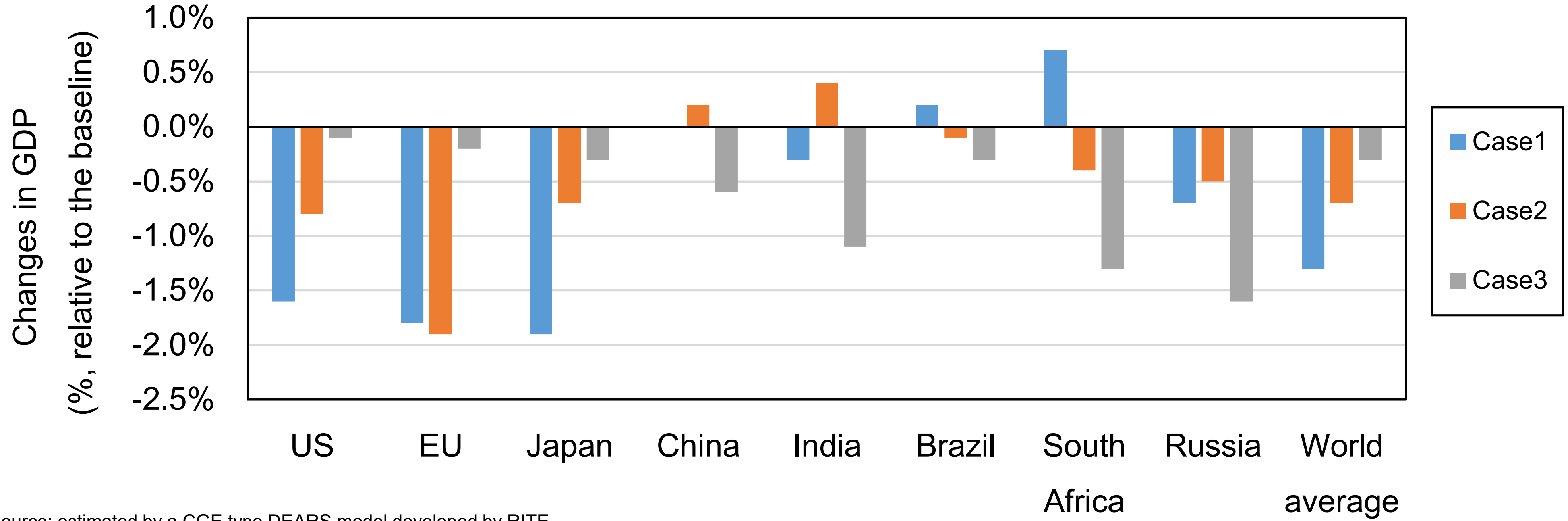
Japan: the cost for III-c is about 2.2 times larger than that for III-a.

- **It is not easy to achieve the least cost measures because there are various 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.**

Analyzed three cases for evaluating economic impacts of NDCs for major nations/regions

	Case 1: NDCs		Case 2: Equal MACs among sectors within each nation (Autarky)	Case 3: Equal MACs among nations and sectors (Global trade)
	National emission reduction targets in 2025/2030 without CO2 emission trading	**Other related policies**	**Individual achievement of national emission reduction targets without CO2 trading**	**Global achievement of aggregated emission reduction targets**
U.S.	26% GHG emission reduction in 2025 relative to 2005	CO_2 intensity of power generation: 462[gCO_2/kWh], & 27% renewables in TPES	Same emission reduction target as those in Case 1 without CO2 emission trading	National emission reduction targets in Case 1 are aggregated globally, with global CO2 emissions trading
EU	40% GHG reduction relative to 1990	20% renewables in TPES		
Japan	26% GHG reduction relative to 2013 (energy-related CO_2 emissions: 927$MtCO_2$)	Electricity share same as the energy mix of Japanese governmental plan.(22% renewables, 26% coal, 20% nuclear)		
China	65% reduction of CO_2/GDP relative to 2005	20% renewable in TPES		
India	35% reduction of GHG/GDP relative to 2005	40% non-fossil in power generation		
Brazil	43% GHG reduction relative to 2005	45% renewables in TPES		
South Africa	398-614 [$MtCO_2$eq.] GHG emissions	–		
Russia	27.5% GHG reduction relative to 1990	–		

Impacts of the NDCs on GDP for the major countries in 2030

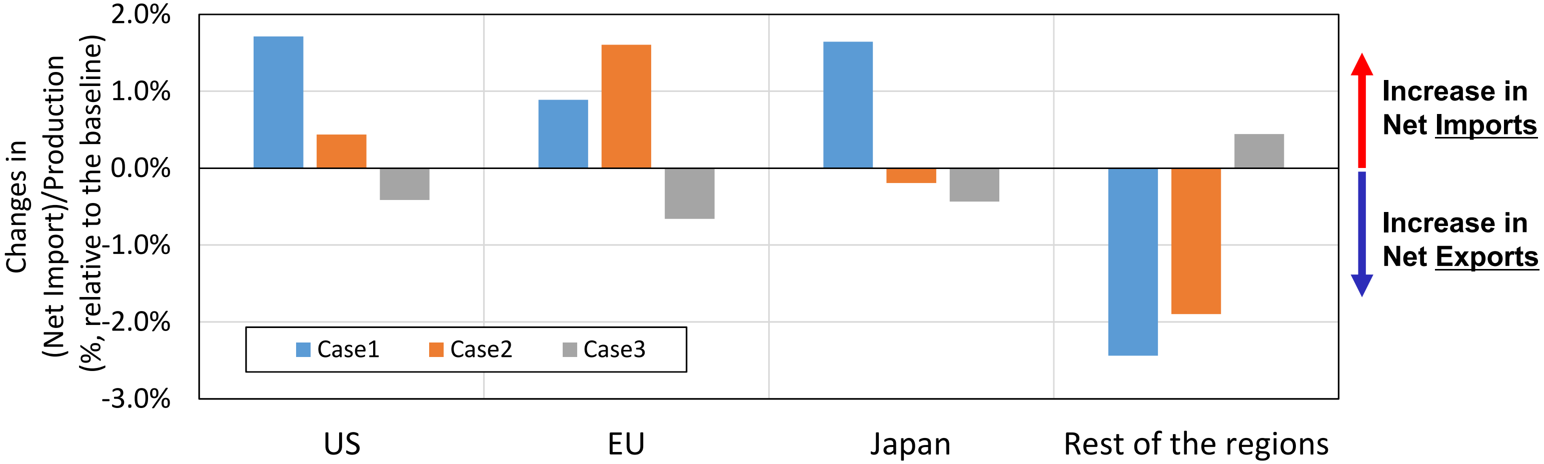


Source: estimated by a CGE type DEARS model developed by RITE

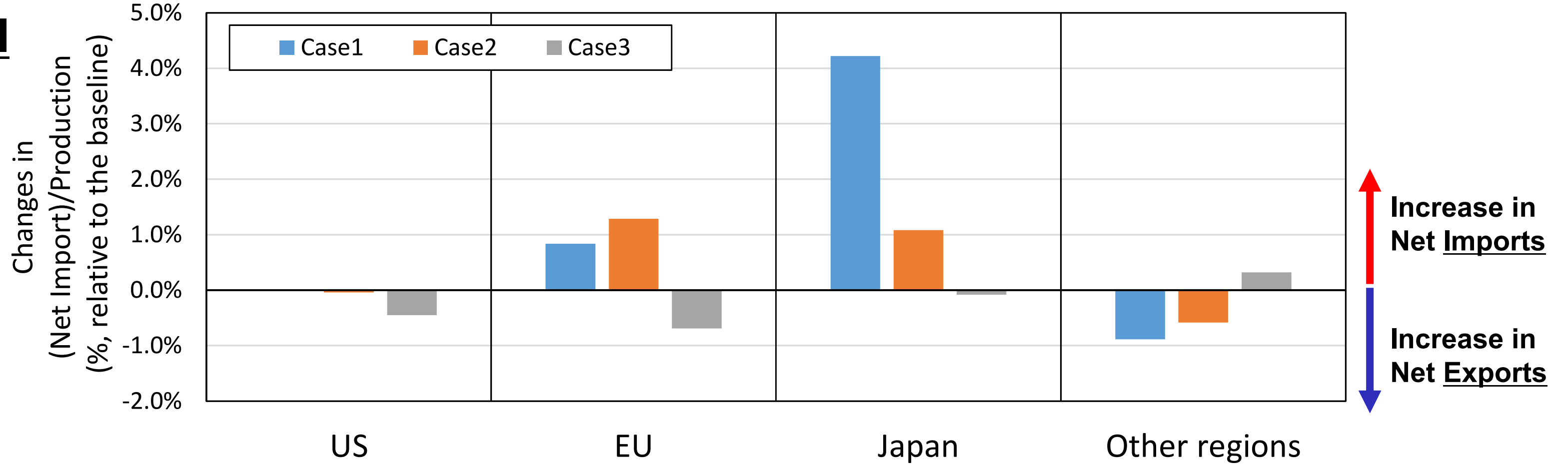
- For the U.S., the decreases in GDP in Cases 1 and 2 are 1.6% and 0.8% relative to the baseline, respectively. The estimated GDP loss in Case 1 is much higher than that in Case 2, mainly due to the constraints on carbon intensities of the power sector assumed in the proposed CPP.
- For EU, the decreases in GDP in Cases 1 and 2 are almost the same, because the renewable target is cost efficient for the 40% emission reduction target.
- For Japan, the decreases in GDP in Cases 1 and 2 are 1.9% and 0.7%, respectively. The energy mix of the Japanese governmental plan results in larger decreases in GDP and sectoral productions (the energy mix is determined not only by cost efficient emission reductions but also by energy security issues etc.).

Impacts on Trade in Chemical and Iron & steel sector in 2030

Chemical



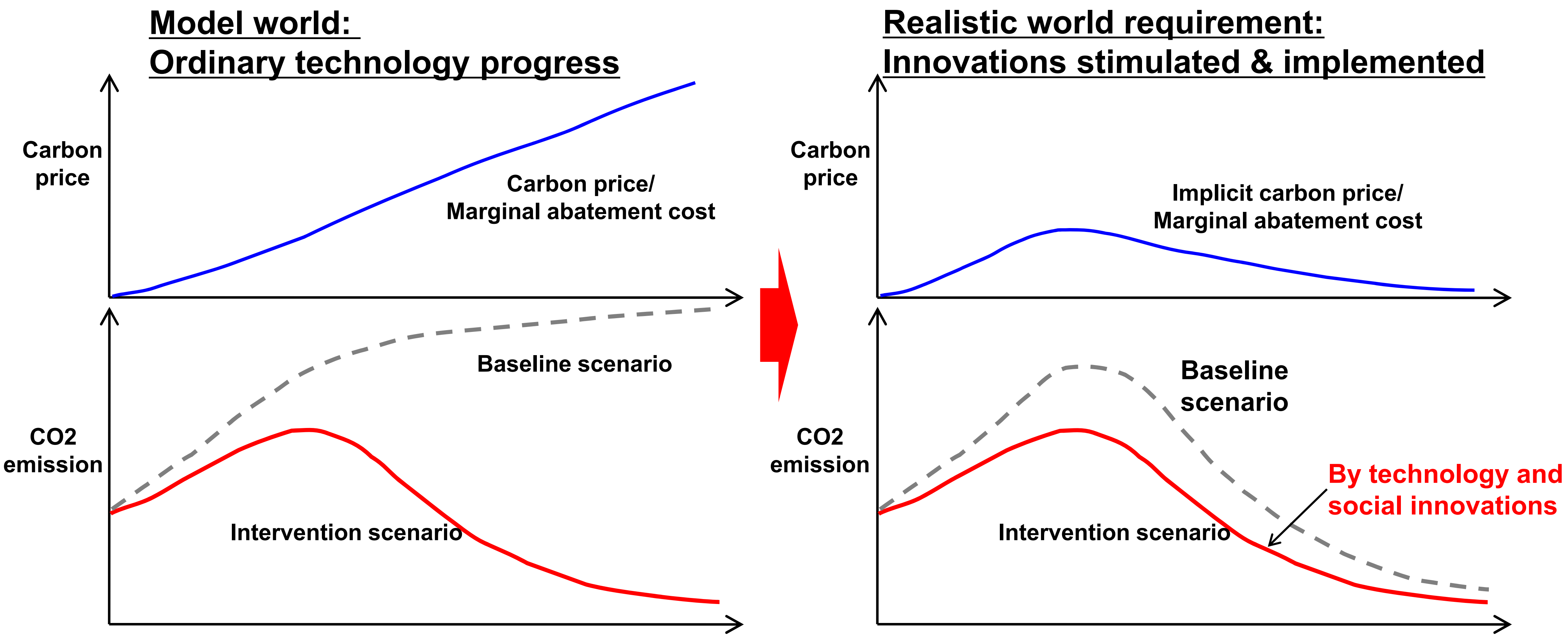
Iron & steel



Source: estimated by a CGE type DEARS model developed by RITE

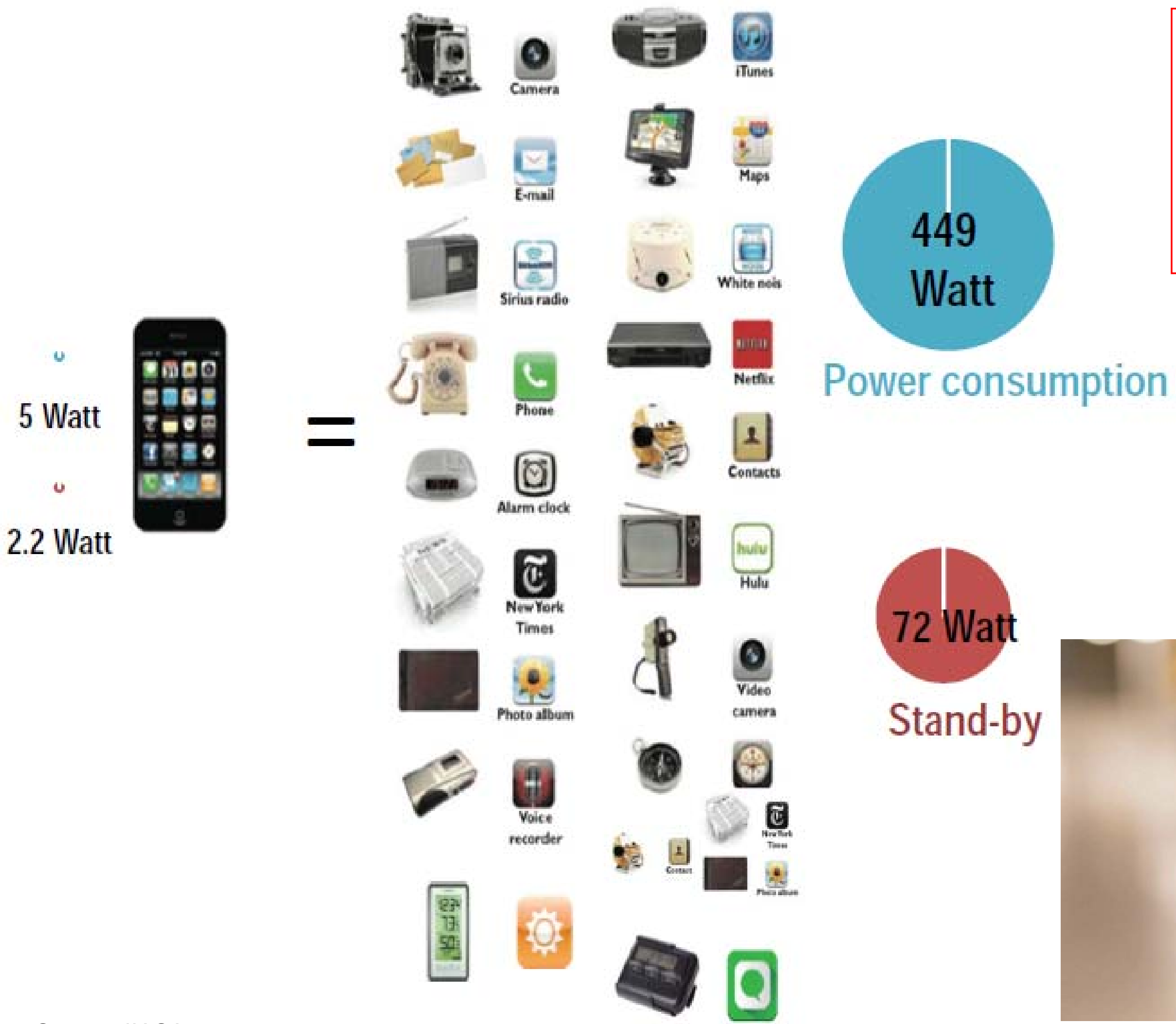
- The NDCs will make a large impacts on the potential international trade balances in Chemical sector in the US, EU and Japan, and in Iron & steel sector in Japan and EU. (Cases 1 and 2)
- Under the global emission trade case (equal MACs), the impacts will be relatively small. (Case 3)

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



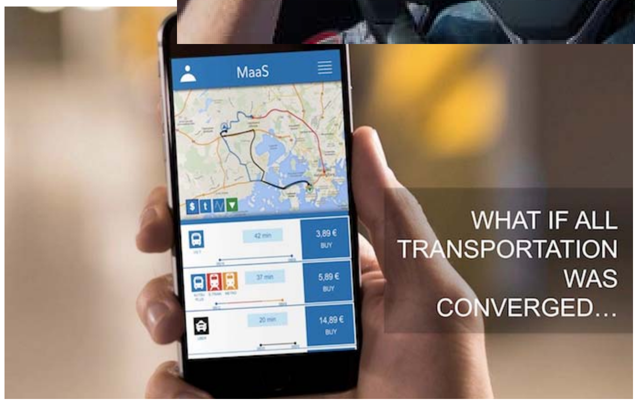
Explicit high carbon prices of such as over 100$/tCO2 in real price are unlikely to be accepted in a real world. Technology and social innovations resulting in low (implicit or explicit) carbon prices (including coordination of secondary energy prices) are key for deep emission cuts to be implemented.

Innovations of end-use technologies and the induced social changes



Source: IIASA

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



Source: Finland

Operation ratio of automobiles is about 4%, for example. The large room for the improvement exists by the achievement of complete autonomous cars.

CO_2 marginal abatement cost in 2050 for 2 °C goal under the middle energy demand scenario vs low energy demand scenario with car- & ride-sharing

The global emissions in 2050: -40% compared to 2010
(corresponding to below 2 °C in 2100 with 50% probability)

CO_2 marginal abatement cost (MAC) in 2050

Middle energy demand scenario: SSP2	Low energy demand scenario: SSP1 with car- & ride-sharing
180 $/tCO_2$	100 $/tCO_2$

Unit: $/tCO_2$ (real price);
Equal marginal abatement costs among all nations are assumed.
SSP: Shared Socioeconomic Pathway

Source: estimated by RITE DNE21+ model

MAC in SSP1 with car- and ride-sharing assumptions is much smaller than in the standard scenario, SSP2, due to achievement of low energy demands even in non-climate policies through the achievement of an economically efficient society induced by energy demand side innovations, such as IT, IoT and AI.

Conclusions

- **Increasing trend of global CO_2 emissions continues.**
- **In some developed nations, a relatively long decreasing trend of the emission can be observed, but it was induced mainly by industrial structure change, and the consumption-based CO_2 emissions were not reduced in most of the nations. High energy cost burden induced the leakage of industries. The international competitiveness issue is very important.**
- **The marginal abatement costs for the currently submitted NDCs are greatly different among nations. Such large differences will hinder global efficiency of emission reductions and sustainable efforts of participating nation.**
- **Several social and political conditions hindering the least cost mitigation measures exist in each nation. Cheaper emission reduction measures should be pursued, but some of the realistically unavoidable constraints should also be considered.**
- **According to the assessments for the macro economic impacts, some developing nations/regions with almost zero marginal abatement costs will have positive impacts on GDP and on outputs of some energy-intensive sectors as carbon leakages take place through international trade. The coordination of the NDCs through the review process will be important.**
- **On the other hand, the coordination based on high carbon prices is unrealistic in the real world. The opportunities for decreasing energy demand, particularly through further improvements in IT, IoT or AI, will be expected for deep reductions with much lower mitigation costs.**

Appendix

Introduction: International Competitiveness and the Global Effectiveness of Climate Change Mitigation

- The historical trends in emissions in some developed nations where their emissions have greatly reduced have been induced mainly by industrial structure change under globalization.
- The Paris long-term goals, such as 2 °C goal, require large global emission reductions. According to many research studies, the emission gap between the aggregated NDCs and the pathways for the goal is large.
- For sustainable measures of climate change mitigation, harmonized efforts of emission reductions among all nations are the key.
- This presentation includes:

  1) historical CO_2 emission trends including consumption-based CO_2 emissions and the factor analyses

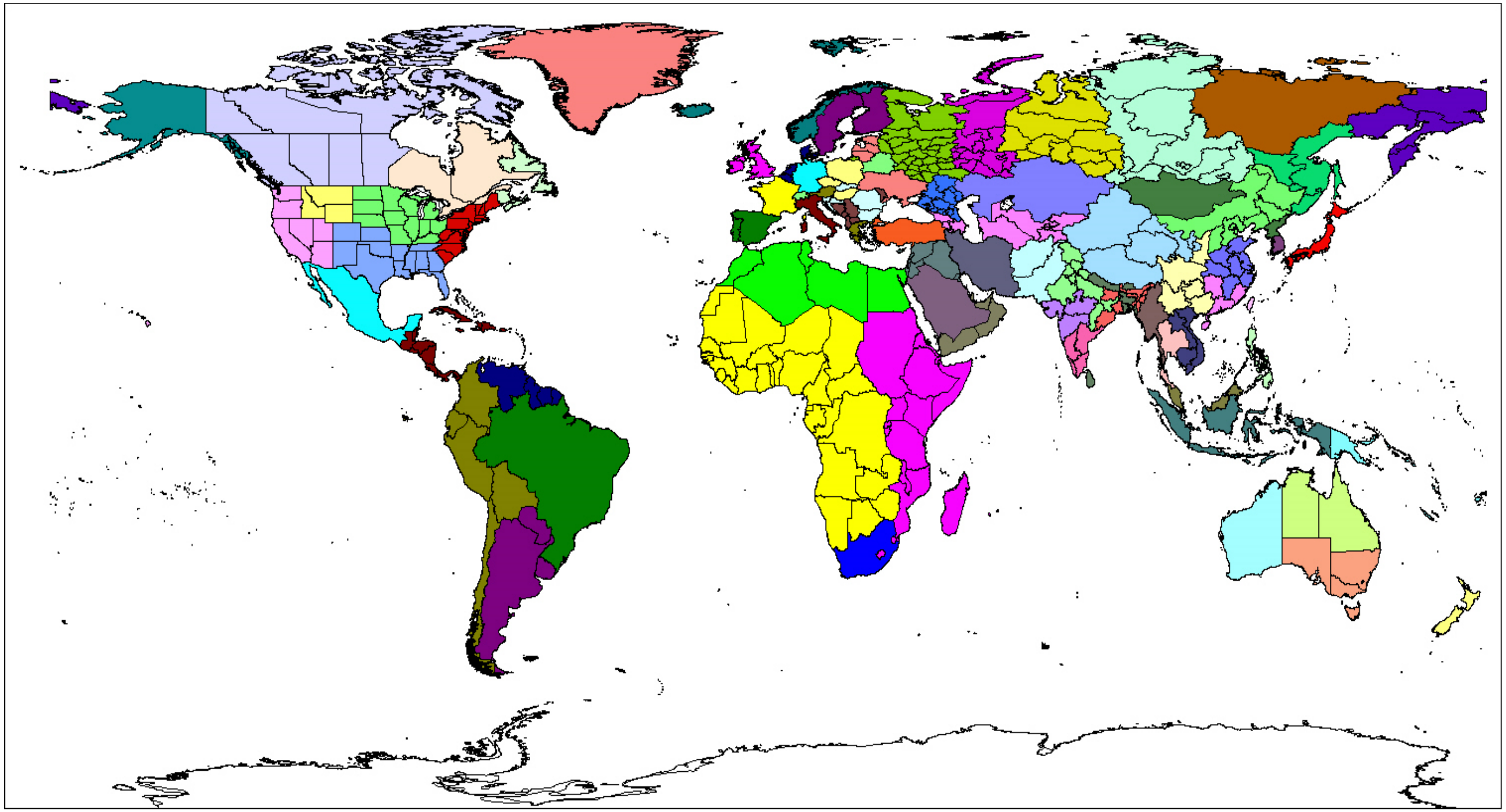
  2) measuring emission reduction efforts of Nationally Determined Contributions (NDCs) and the assessments on international competitiveness

  3) In order to avoid the global ineffectiveness of climate change mitigation measures, the possible pathways of end-use innovations with green growth will be provided.

Employed indicators for measuring emissions reduction efforts

	Indicators for emissions reduction efforts		Framework	Notes
Simple metrics	**Emissions reduction ratio from base year** (only for OECD countries or Annex I countries)	Compared to 2005	When baseline emissions are expected to stagnate, it is more relevant to simply compare the projected reduction rates (all the more since there are uncertainties regarding the BAU). This is why we use the reduction ratio compared to BAU for OECD countries only - on the other hand, such an approach would be irrelevant for countries where emissions are expected to grow substantially.	Most countries use 2005 as their base year (as a matter of fact, 1990 seems too far in the past to be used as a base year to evaluate the emissions reduction effort for upcoming emissions)
		Compared to 2012 (or 2010)		Adopting a recent base year may enable appropriate comparison of future efforts.
	Emissions per capita (only for non-OECD countries or non-Annex I countries)	Absolute value	For non-OECD countries, we adopt the absolute value of emissions per capita instead of the reduction ratio from base year.	As this indicator (absolute value) is very dependent on country's situations such as economic development stage, industry structure, climate etc., not appropriate to measure reduction efforts.
Advanced metrics	**CO_2 intensity (GHG emissions per GDP)**	Absolute value	Reveals what level of CO_2 emissions corresponds to what degree of economic activity	It can easily reach bad values for countries with a low GDP; it is also highly dependent on the country's industry structure.
		Improvement rate (compared to 2012 or 2010)	It will be better to measure emission reduction efforts because the bias due to differences in economic growth rate can be removed compared with the indicator of emission reduction ratio from base year.	The value may change greatly for low GDP countries with high GDP growth rate.
	Emissions reduction ratio compared to BAU		The differences in economic growth etc. can be cancelled.	Efforts already made in the past for energy saving etc. are neglected and future abatement potential as well.
More advanced metrics	**CO_2 marginal abatement cost (carbon price)**		This is a particularly relevant indicator to assess reduction efforts as it contains countries' differences in terms of economic growth, energy savings efforts, abatement potential of renewables.	Past efforts made for energy saving etc. may lead to high marginal abatement costs for additional reduction efforts.
	Retail prices of energy (electricity, city gas, gasoline, diesel)	Employing historical data of 2012 or 2010 for weighted average	While marginal abatement costs reflect the frontier effort, this indicator corresponds to the efforts made in the baseline as a whole.	Market data is available for ex-post evaluation, but for ex-ante evaluation, only model-based estimates are available which makes uncertainties rather high.
	Emission reduction costs per GDP		This indicator corresponds to the economy's capability to bear efforts for the whole reduction.	Uncertainties are high as this is a model-based estimation.

Region divisions of DNE21+



Population prospects (millions)

	2010	2020	2030
Japan	127	124	118
United States	312	340	364
EU28	507	515	515
Switzerland	8	8	8
Norway	5	6	6
Australia	22	25	27
New Zealand	4	5	5
Canada	34	37	40
Russia	144	139	132
China	1367	1445	1477
Korea	48	49	49
Mexico	118	128	135
Ukraine	46	44	41
Belarus	9	9	8
Kazakhstan	16	17	17
East Europe (Non-EU countries)	23	23	22
Thailand	66	70	72
India	1206	1357	1474
Turkey	72	80	86
South Africa	51	54	56
The World Total	***6916***	***7679***	***8308***

Source) RITE estimates based on the 2008 UN population prospects in the medium variants. For statistical values up to 2010, The UN World Population Prospects 2012 are used.

GDP Prospects (MER, %/yr)

	2010—2020	2020－2030
Japan	1.4	1.9
United States	2.6	2.0
EU28	1.2	1.3
Switzerland	1.4	1.2
Norway	1.8	1.6
Australia	2.7	1.8
New Zealand	2.4	1.6
Canada	2.1	1.7
Russia	4.3	6.3
China	7.7	5.6
Korea	3.0	1.9
Mexico	3.2	3.0
Ukraine	3.2	5.3
Belarus	3.2	3.4
Kazakhstan	5.4	5.0
East Europe (Non-EU countries)	2.2	3.8
Thailand	4.3	4.0
India	6.5	5.9
Turkey	4.0	2.8
South Africa	2.5	3.4
The World Average	***3.0***	***2.9***

Source) RITE estimates. Our estimates are not so different form USDOE/EIA International Energy Outlook and IEA World Energy Outlook. (In consideration of the differences between PPP and MER)

Evaluated INDCs (1/2)

The 119 INDCs submitted as of October 1st, 2015 were evaluated.
As of October 1st, 2015, 119 INDCs had been submitted, and representing about 88 per cent of global emissions in 2010.
Comprehensive evaluations of emission reduction efforts were only for 20 countries (see below) due to the limited regional resolution of the model.

	2020 (Cancun Agreements)	Post-2020 (INDCs)
United States	-17% compared to 2005	**-26% to -28% by 2025 compared to 2005**
Canada	-17% compared to 2005	**-30% by 2030 compared to 2005**
EU28	-20% compared to 1990	**-40% by 2030 compared to 1990**
Switzerland	-20% compared to 1990	**-50% by 2030 compared to 1990 (-35% by 2025 compared to 1990)**
Norway	-30% compared to 1990	**-40% by 2030 compared to 1990**
Japan	-3.8% compared to 2005*	**-26% by 2030 compared to 2013**
Australia	-5% compared to 2000	**-26% to -28% by 2030 compared to 2005**
New Zealand	-5% compared to 1990	**-30% by 2030 compared to 2005**
Russia	-15 to -25% compared to 1990	**-25% to -30% by 2030 compared to 1990**

Note: More ambitious emission reduction targets had been submitted as “conditional “ targets from some countries, but they are not included in this table.
* Emission reduction target assuming zero nuclear power

Evaluated INDCs（2/2）

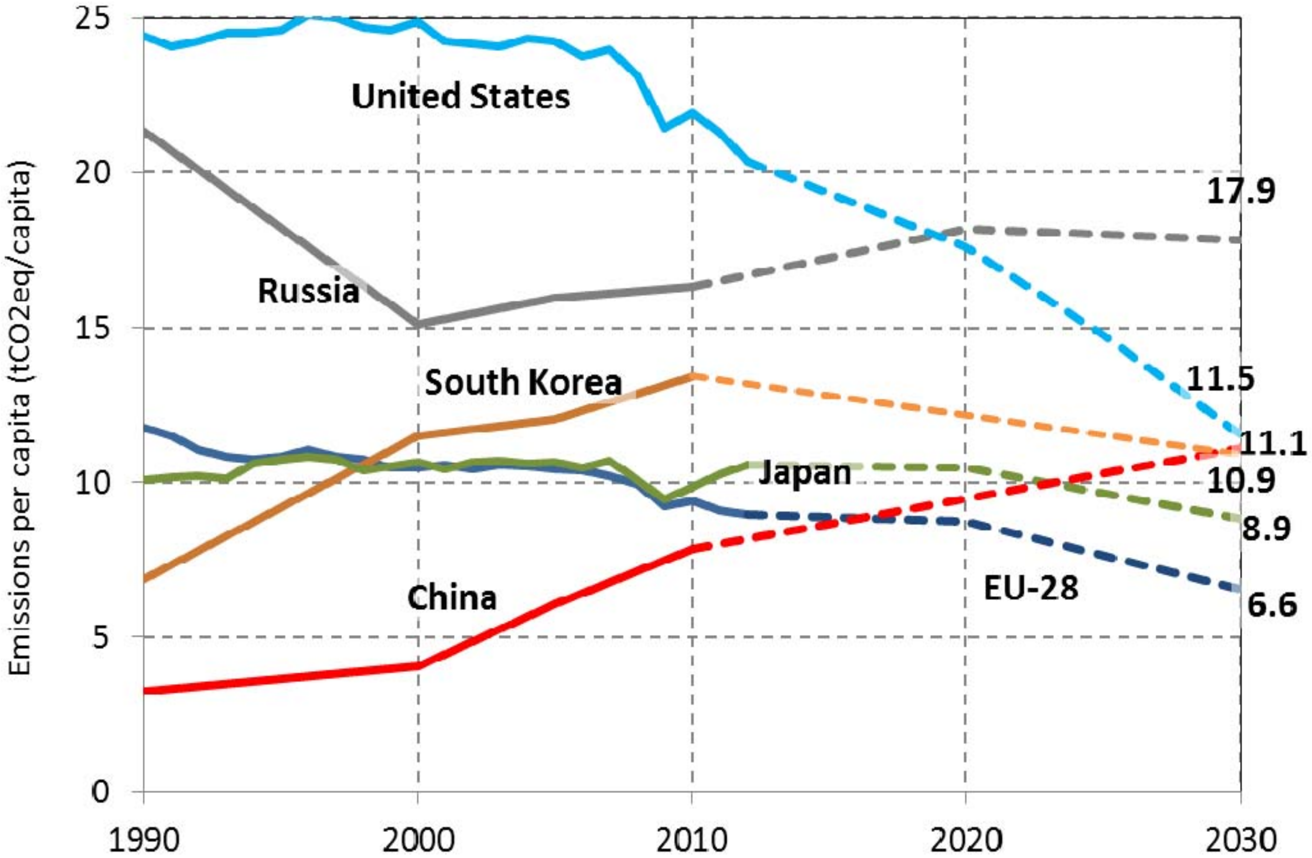
	2020 (Cancun Agreements)	Post-2020 (INDCs)
Non-EU Eastern Europe	—	**-19% by 2030 compared to 1990***
Ukraine	-20% compared to 1990	**-40% by 2030 compared to BAU**
Belarus	-5 to -10% compared to 1990	**-28% by 2030 compared to 1990**
Kazakhstan	-15% compared to 1992	**-15% by 2030 compared to 1990**
Turkey	—	**-21% by 2030 compared to BAU**
Korea	-30% compared to BAU	**-37% by 2030 compared to BAU**
Mexico	-30% compared to BAU	**-25% by 2030 compared to BAU** **(-22% by 2030 compared to BAU in GHG)**
South Africa	-34% compared to BAU	**614MtCO_2eq/yr by 2030**
Thailand	-7 to -20% compared to BAU (Energy and transportation sectors)	**-20% by 2030 compared to BAU**
China	To reduce CO_2/GDP by -40 to -45% compared to 2005	**To reduce CO_2/GDP by -60 to -65% by 2030 compared to 2005 (To achieve the peaking of CO_2 emissions around 2030 and making best efforts to peak early)**
India	To reduce GHG/GDP by -20 to -25% compared to 2005	**To reduce GHG/GDP by -33 to -35% by 2030 compared to 2005**

* The reduction rate was estimated from the total emissions by the INDCs of Albania, Makedonia, Moldova, and Serbia.
** Emission reduction target of Mexico includes black carbon.

Notes of the assessments of INDCs in this study

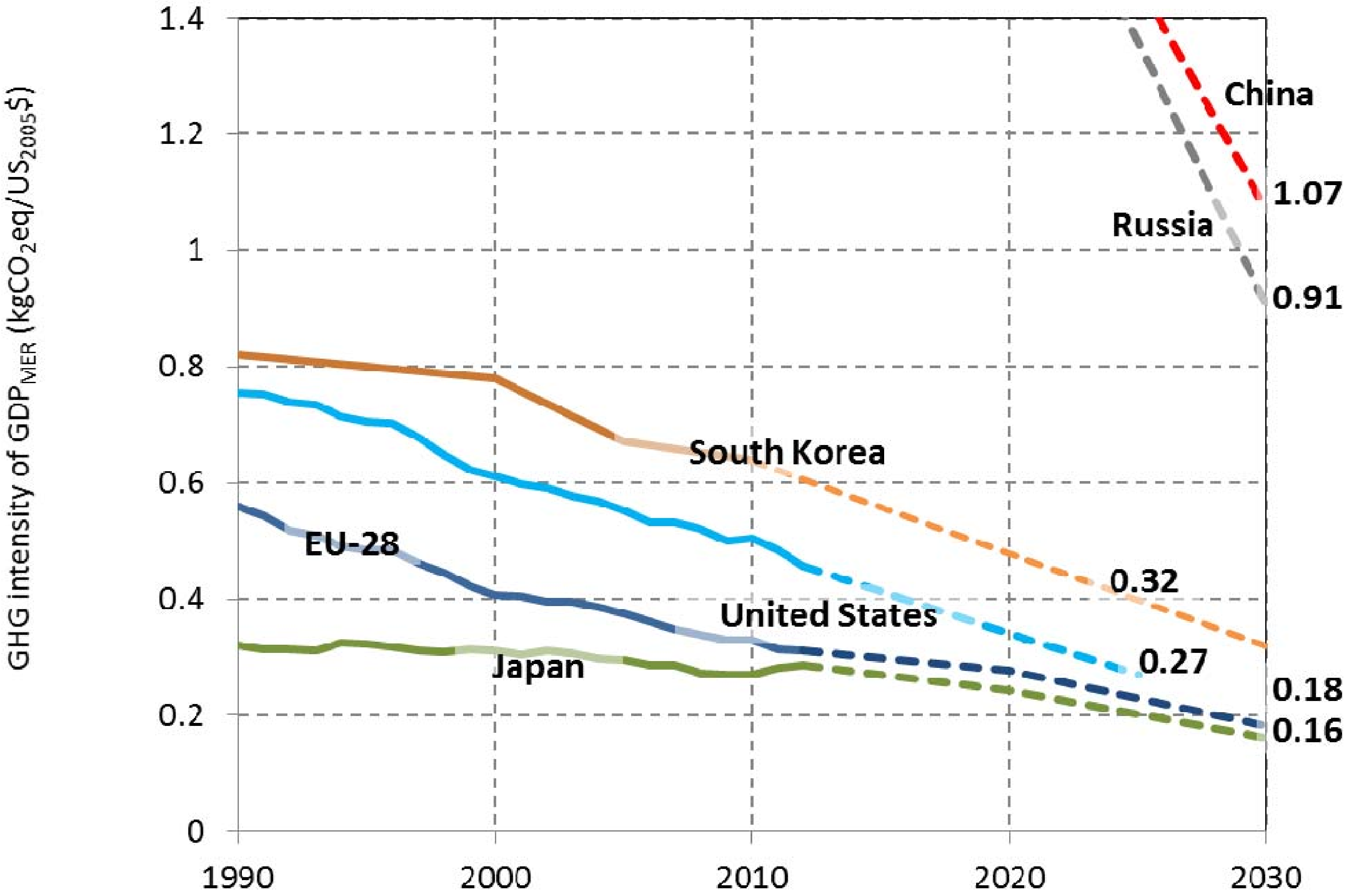
- LULUCF emissions are not taken into account for international comparison of mitigation efforts, because they have large uncertainty and their appropriate evaluation is difficult. (LULUCF emissions are taken into account for the aggregated INDCs evaluation with respect to 2°C target.)
- For the countries with emission reduction targets compared to the base year, the emissions in the target year are calculated based on historical emissions excluding LULUCF. Historical emissions are derived from Greenhouse Gas Inventory Office of Japan for Japan, UNFCCC for other Annex I countries, and IEA for other countries.
- For the countries with emission intensity improvements targets, the emissions in the target year are calculated based on historical emissions and our GDP scenario.
- For the countries with emission reduction ratio targets to BAU, if BAU emissions in target year are stated in their INDCs, the values of INDCs are adopted for calculation of emissions in the target year. If not, their INDCs are not evaluated in the international comparison of mitigation efforts in this study. (For the aggregated INDCs evaluation with respect to 2°C target, their carbon prices are assumed to be zero until 2030.)
- Other countries with policies and actions targets are omitted from this assessment.
- Most of the countries set 2030 as the target year, but the United States and Brazil chose 2025. For these countries, indicators concerning emission reduction efforts in 2025 are evaluated and compared with the other countries' indicators in 2030.
- Evaluation of all of the adopted indicators was carried out for twenty regions.
- For Brazil and Indonesia who are large emitters from LULUCF, only the three indicators (emission reductions compared to base year, emissions per capita, and emissions per GDP) are evaluated including LULUCF.

GHG emissions per capita of NDCs



Note) The lower range of emission targets are shown for the countries submitting their INDCs with ranges.
Source) estimate by RITE

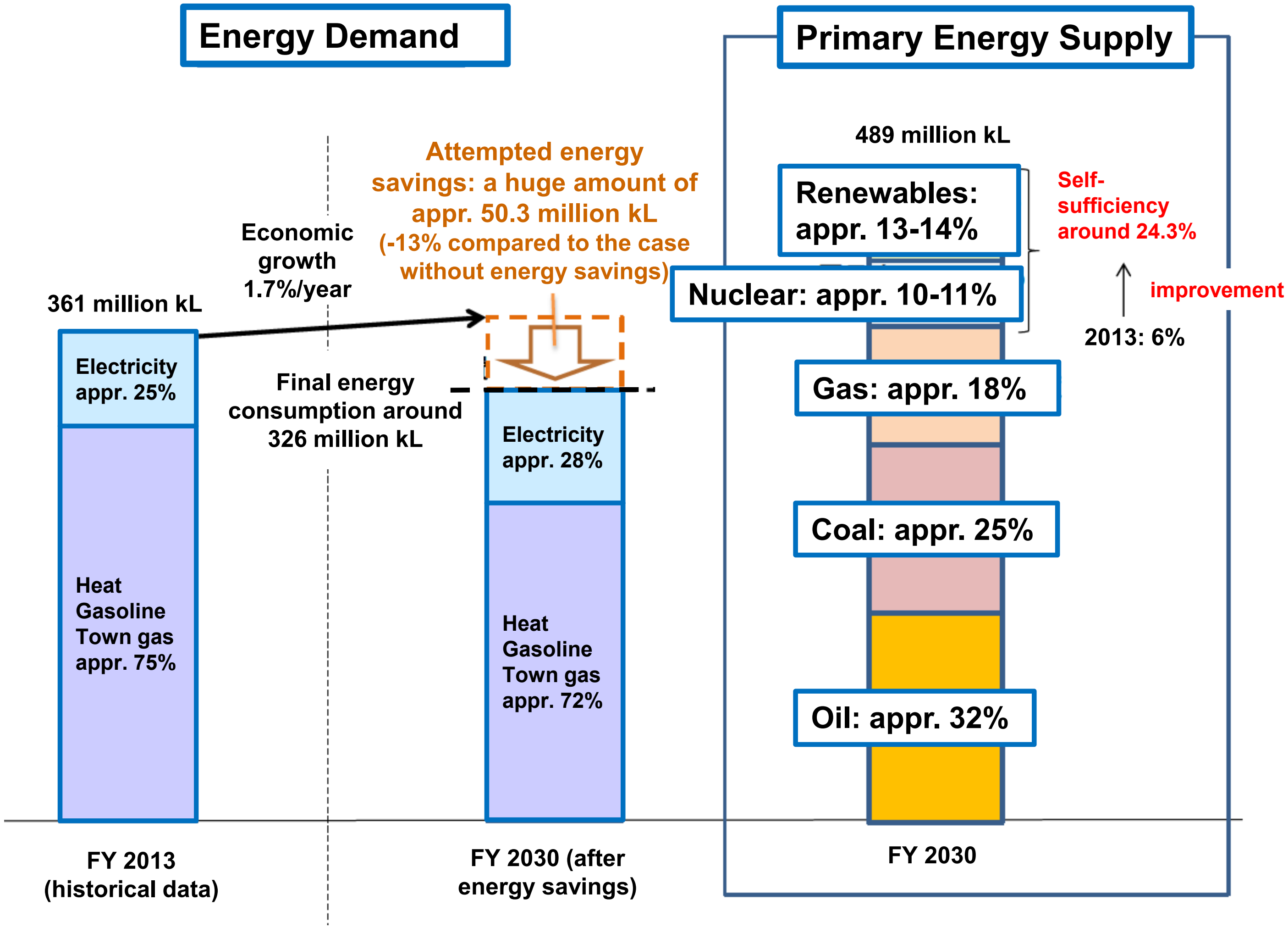
GHG intensity of GDP (MER)



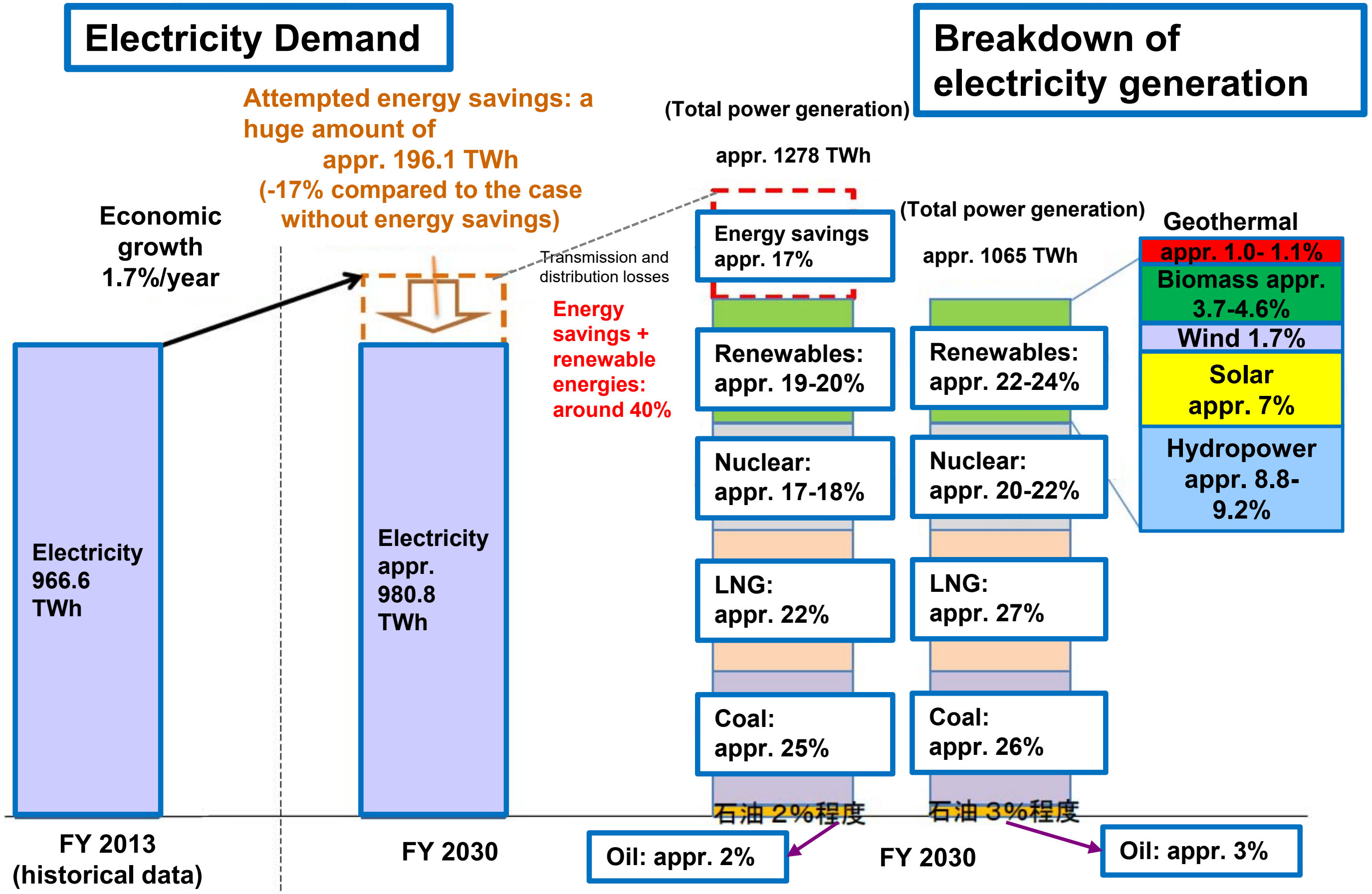
The standings of current GHG intensity among major nations will keep toward 2030 under the pledged NDCs.

Note) The lower range of emission targets are shown for the countries submitting their NDCs with ranges.
Source) estimated by RITE

The drafted energy mix of Japan for 2030



The energy mix target in 2030
– The composition of the power generation mix –



In the standard case without energy savings, the GDP elasticity of electricity demand is 0.68. This elasticity is consistent with the one assessed in the RITE analysis, which is around 0.8 for the 2013-2020 period, and 0.6 for 2020-2030, and also consistent with that of the 'Current Policies' scenario in IEA WEO2014. As a result, the estimate by the government seems a reasonable one. However, in the energy savings case, a significant reduction of electricity demand (17%) is assumed (the elasticity then being 0.05), this point will be further examined in our analysis.

2030 Emission Target of Japan's NDC

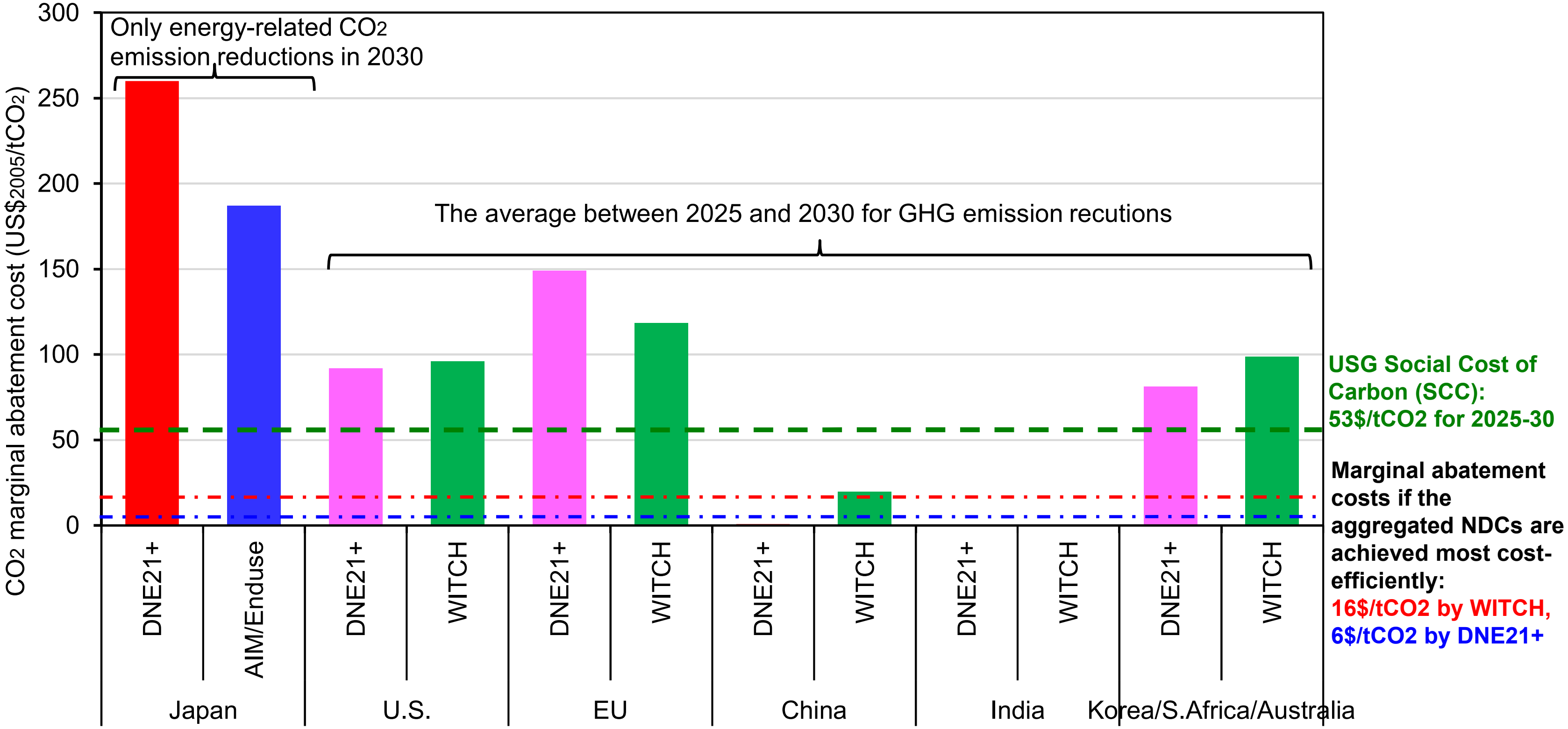
Since GHG emissions are strongly dependent on energy mix issues, policy making and technology development for post-2020 targets need to take careful consideration of technology availability and costs in order to set achievable goals. Based on this, the Japanese NDCs commit to reduce emission levels in 2030 by 26% compared to 2013 (which corresponds to 25.4% compared to 2005), including CO_2 sink (GHG emissions in 2030 would be about 1,042 million tCO_2 in total).

	2030; Compared to 2013（compared to 2005）
Energy-related CO2	-21.9% （-20.9%）
Other GHGs	-1.5% （-1.8%）
LULUCF	-2.6% （-2.6%）
Total GHGs	**-26.0%** （**-25.4%**）

	2005	2013	2030
Industry	457	429	**401**
Commercial and other	239	279	**168**
Residential	180	201	**122**
Transport	240	225	**163**
Energy conversion	104	101	**73**
Energy-related CO2 Total	1219	1235	**927**

Unit: Mt-CO2

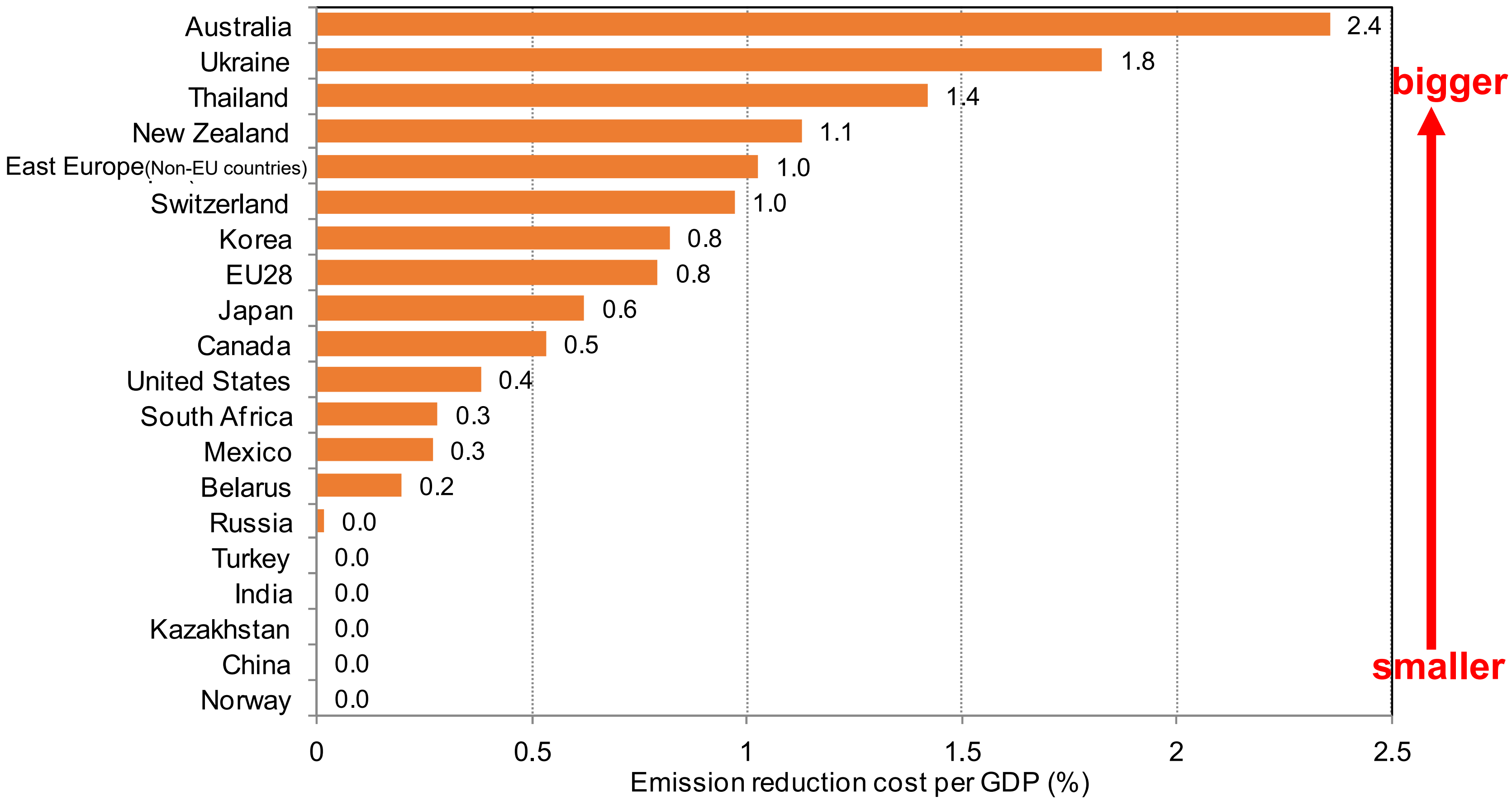
Marginal abatement costs estimations across models (RITE DNE21+, FEEM WITCH and NIES AIM)



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

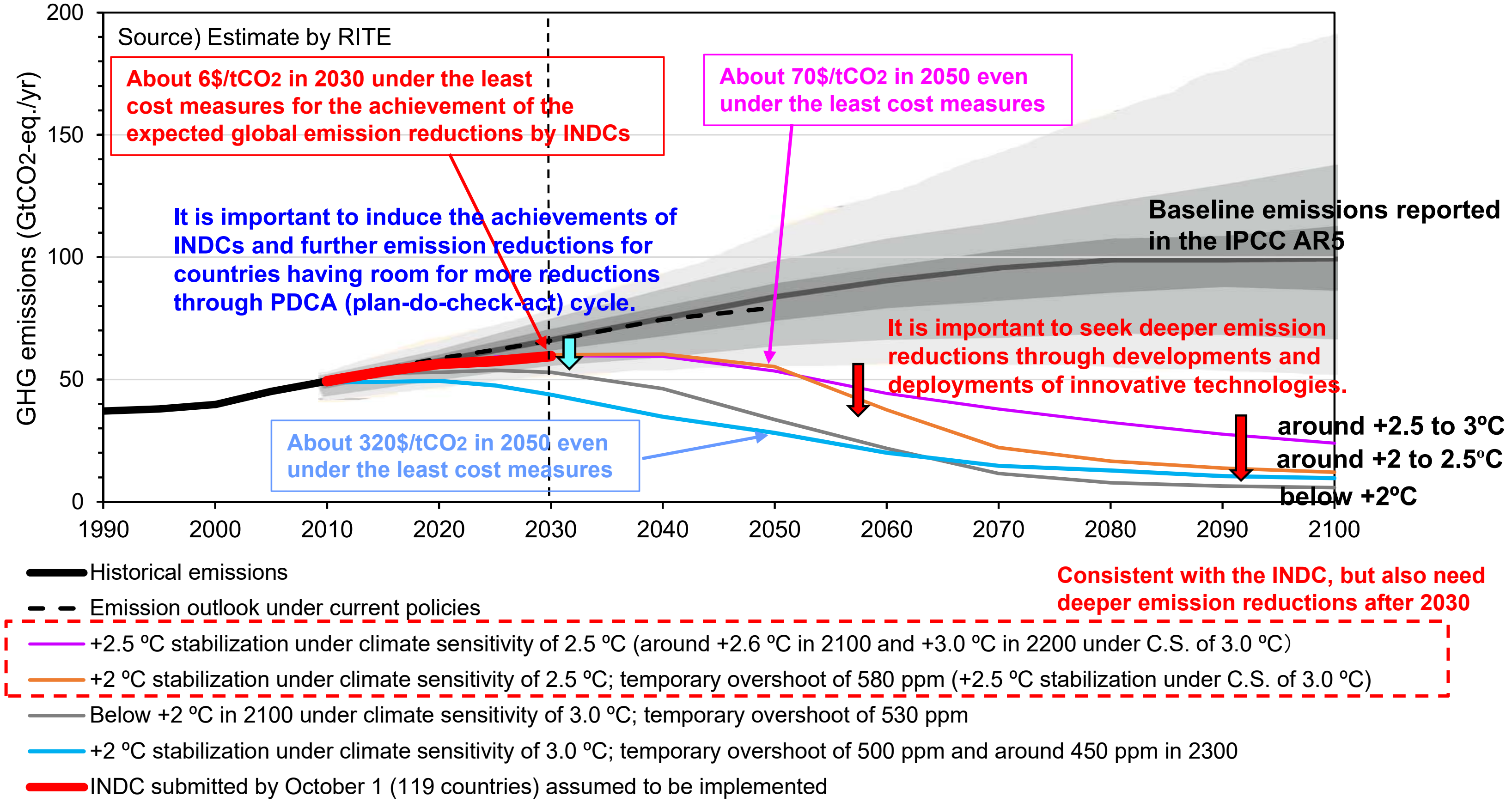
- The marginal abatement costs vary across models for some countries, but can be comparable for many countries/regions.
- The CO_2 marginal abatement costs of the NDCs of OECD countries are much higher than the marginal cost for the case that the total reductions are achieved most cost-efficiently (globally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

Per-GDP emission reduction costs of NDCs



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

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



- The expected global GHG emission in 2030 is about 59.5 $GtCO_2eq$. when all the submitted INDCs are successfully achieved. Emissions reductions from the baseline are estimated to be about 6.4 $GtCO_2eq$, in which about 0.5 $GtCO_2eq$ reductions are offset due to carbon leakages from nations with NDCs 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 more so on the effects of future developments and deployments of innovative technologies.

A technology-oriented climate change mitigation model: DNE21+

Overview of Tech.-oriented Assessment Model: DNE21+

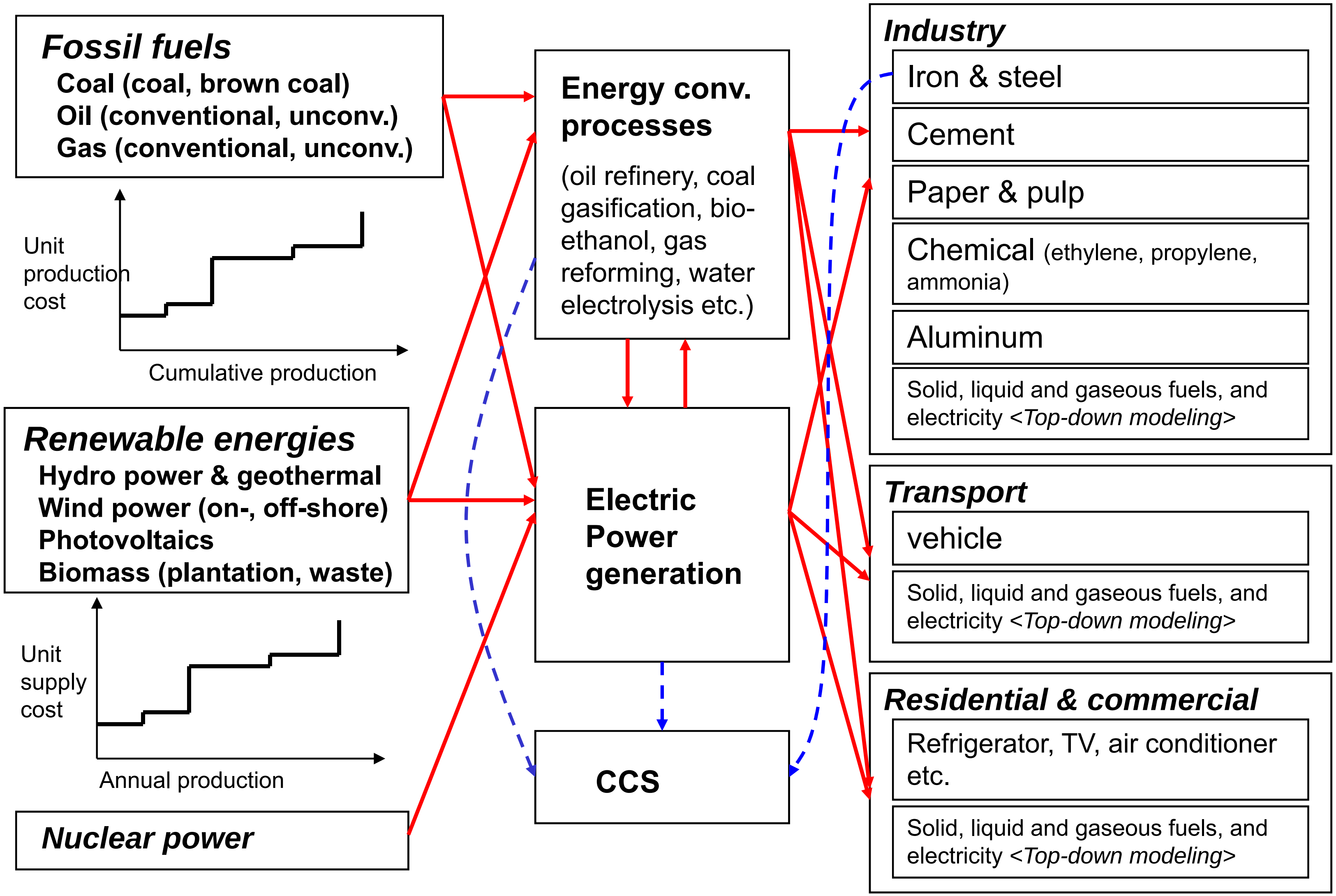
- Intertemporal linear programming model (minimizing world energy system cost)
- Evaluation time period: 2000-2100

  Representative time points: 2000, 2005, 2010, 2015, 2020, 2025, 2030, 2040, 2050, 2070, 2100
- World divided into 54 regions

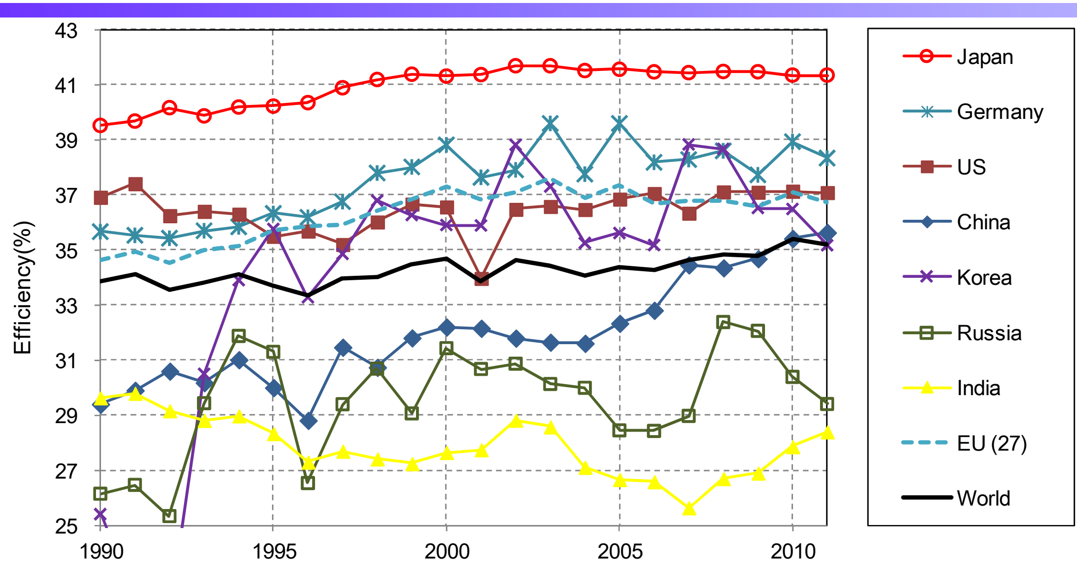
  Large area countries are further divided into 3-8 regions, and the world is divided into 77 regions.
- Bottom-up modeling for technologies both in energy supply and demand sides (about 300 specific technologies are modeled.)
- Primary energy: coal, oil, natural gas, hydro&geothermal, wind, photovoltaics, 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 about 6 million decision variables.

- The model has detailed information in regions and technologies.
- Consistent analyses among regions and sectors can be conducted.

Technology Descriptions in DNE21+



Comparison of energy efficiencies in major energy sectors (1/2)

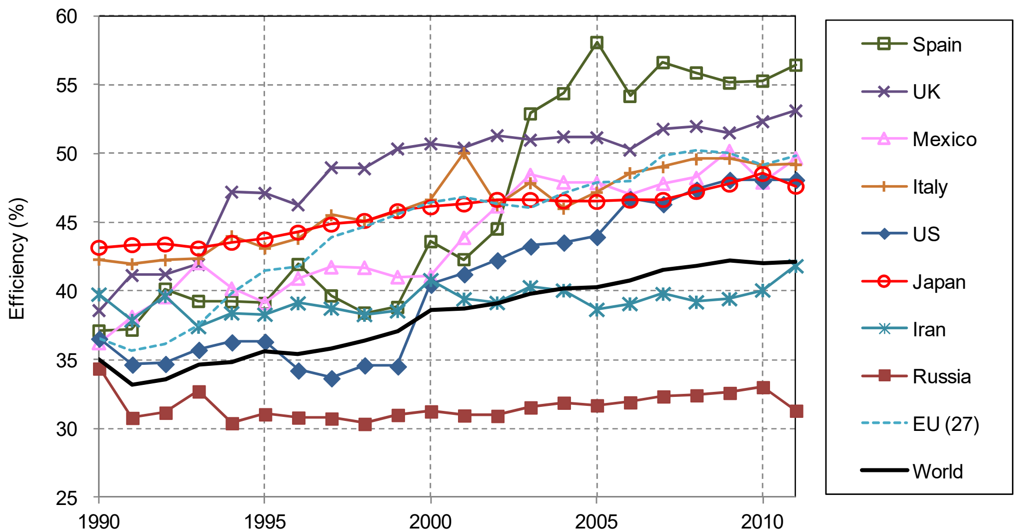


Coal power generation

Source: RITE, 2014 (estimation based on IEA data, 2013)

Gas power generation

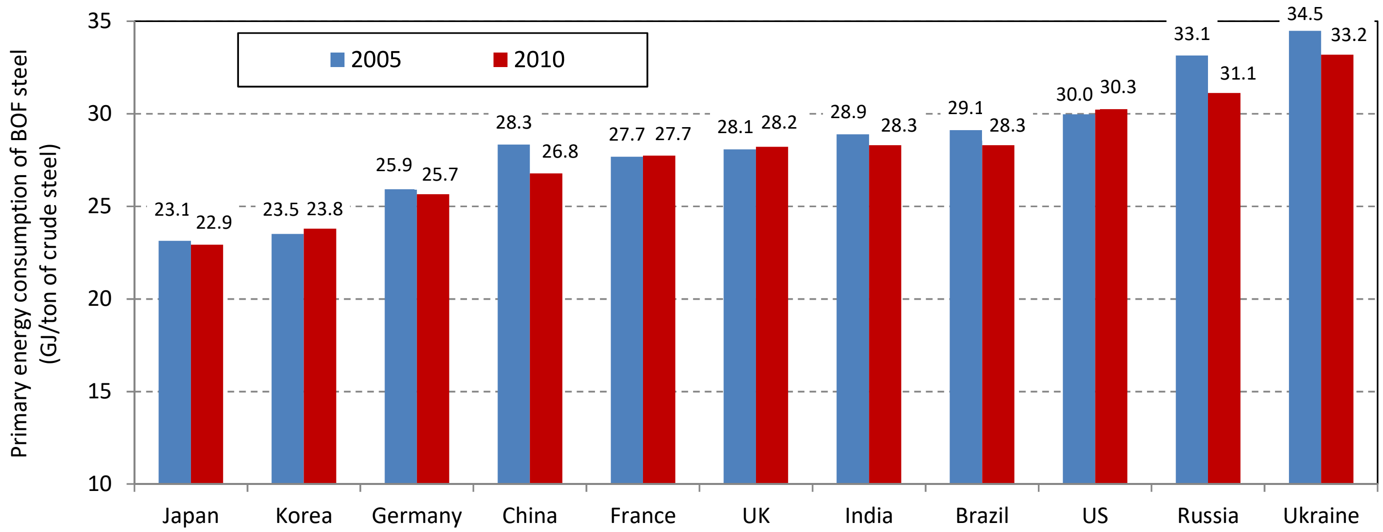
Source: RITE, 2014 (estimation based on IEA data, 2013)



The differences in existing facilities with different levels of energy efficiency by technology including their vintages are explicitly considered in the model.

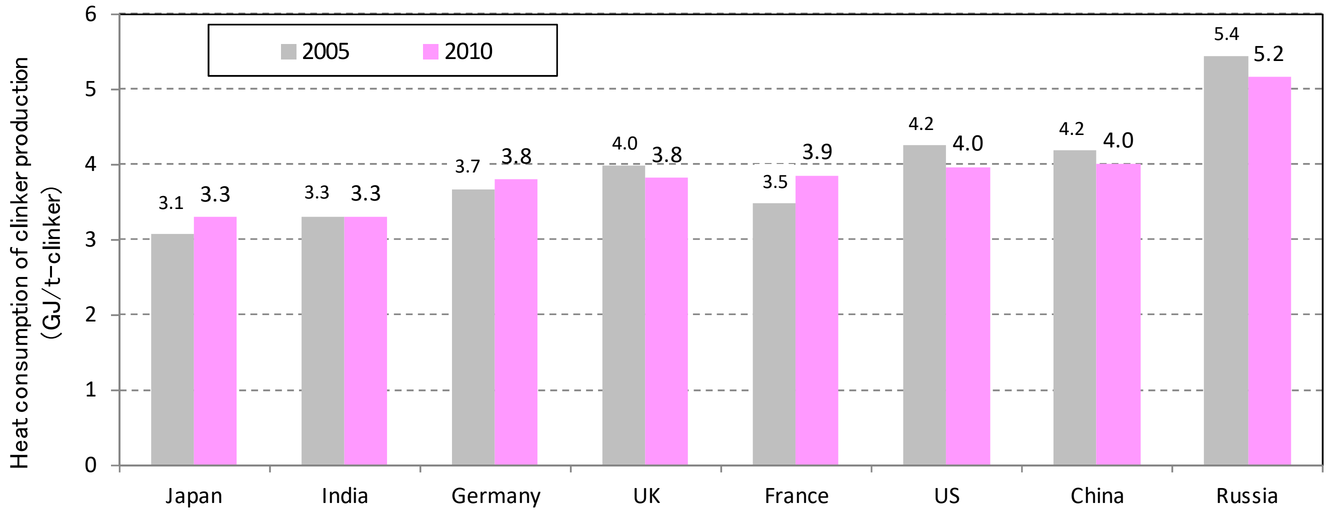
Comparison of energy efficiencies in major energy sectors (2/2)

Iron and steel (BOF steel)



Source: Oda et al. 2012; RITE, 2012

Cement (Clinker)



Source: RITE estimate based on WBCSD/CSI data

A CGE-type energy-economic model: DEARS

Overview of Global Energy-Economic Model: DEARS*

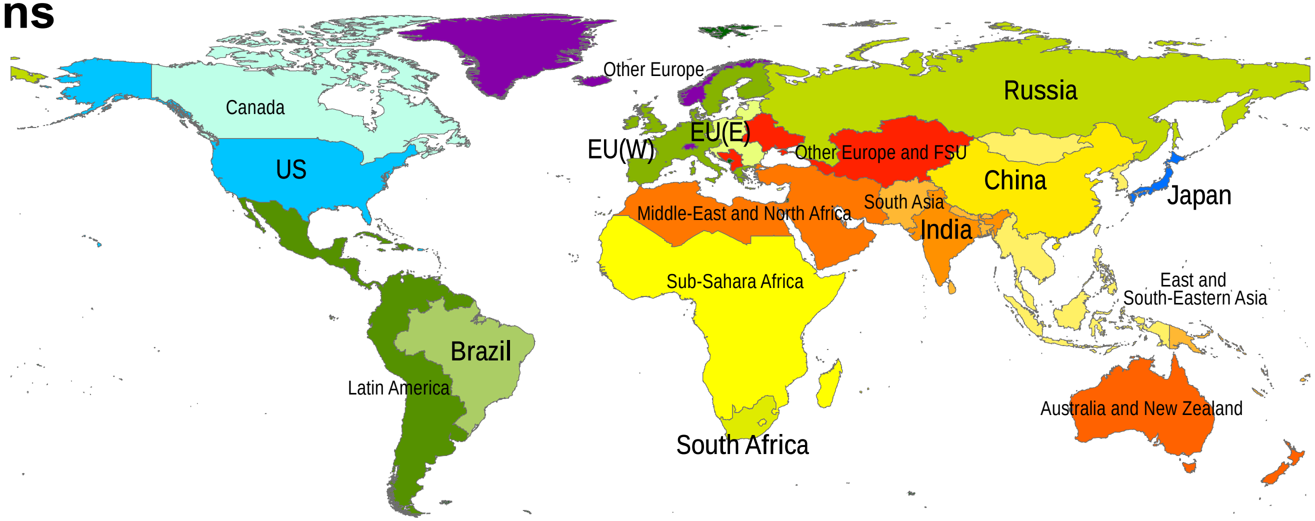
(Dynamic Energy-economic Analysis model with multi-Regions and multi-Sectors)

- **Integration model of top-down-typed economic module and bottom-up-typed energy systems module**
- **Dynamic non-linear optimization model (Maximization of global consumption utility)**
- **Evaluation time period: up to middle of this century (10 years steps)**
- **World divided into 18 regions**
- **Non-energy sectors: 18 sectors**
- **Energy: 8 types of primary energy and 4 types of secondary energy**
- **Economic module that represents international economic structures based on input-output tables of GTAP (Global Trade Analysis Project) database.**
- **Simplified energy systems module**
  - ✓ **Bottom-up modeling for technologies in energy supply (e.g. , power generation) and CCS (carbon capture and storage)**
  - ✓ **Primary energy (8 types): coal, crude oil, natural gas, hydro & geothermal, wind, photovoltaics, nuclear and others**
  - ✓ **Top-down modeling for energy demand (price and income elasticities of demand for energy and income, linked to economic module)**
  - ✓ **Final energy (4 types): solid, liquid and gaseous fuels and electricity**

** T. Homma & K. Akimoto,” Analysis of Japan's energy and environment strategy after the Fukushima nuclear plant accident “, Energy Policy 62 (2013) 1216–1225*

Regions and Industries in DEARS

- **18 regions**



- **18 non-energy sectors**

energy-intensive sectors

I_S	Iron and steel	LUM	Lumber
CRP	Chemical	CNS	Construction
NFM	Non-ferrous metal	TWL	Textile
NMM	Non-metal mineral	OMF	Other manufacturing
PPP	Paper and pulp	AGR	Agriculture
TRN	Transport equipment	ATP	Aviation
OME	Machinery	T_T	Other transport
OMN	Mining	BSR	Business service
FRP	Food processing	SSR	Social service

DEARS Model Details

♦ Objective function（Utility maximization consumption）

$$\sum_t \sum_r d_t \cdot L_r \cdot \sum_i \theta_{i,r,t} \cdot \log \frac{C_{i,r,t}}{L_{r,t}} \rightarrow \max .$$

$C_{i,r,t}$: **consumption amount in period t, region r, sector i (endogenous)**

$L_{r,t}$: **population in period t, region r (exogenous)**

d_t : **discount factor in period t (exogenous)**

$\theta_{i,r,t}$: **consumption-utility weights in period t region r and sector i (exogenous)**

♦ Capital accumulation function

$$K_{r,t} = (1 - dep_{r,t})K_{r,t-1} + \sum_i I_{r,i,t}$$

$I_{r,i,t}$: **investment amount in period t, region r, sector i (endogenous)**

$K_{r,t}$: **capital stock in period t, region r (endogenous)=**

$dep_{r,t}$: **Depreciation rate of capital in period t, region r (exogenous)**

♦ Modeling the production in non-energy sector

The model has a structure that goods are produced and exported only in the regions where production of goods is efficient, assuming the production function in the inter-industry structure under the consumption utility maximization. However, taking into account that products and consumption of agriculture and food are different in nature from those of industry and services, products and consumption of agriculture and food are modeled, using the food production and demand scenario as a constraint so that the variation would be reduced.

DEARS Model: Inter-industry
-Integration of energy and non-energy sectors-