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Evaluation of CO_2 Reduction Potentials of Coal-fired Power Plants in Major Countries: the Effect of Operational Repair and New Construction

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1.1 Framework and features of this paper

Framework

1. Introduction
2. Main assumptions
3. The evaluation results of CO_2 reduction potentials
4. Summary

Appendix

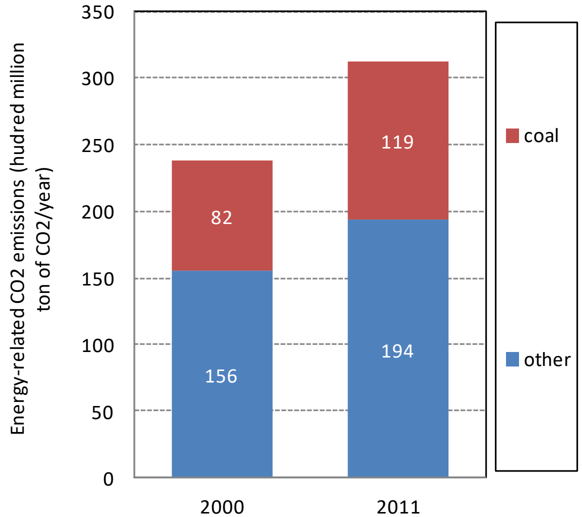
Features of this evaluation

- ✓ In many of the past CO_2 reduction potential evaluations, power generation facilities are often assumed to have (ideal) efficiency of all new technological level, including existing facilities
- ✓ This evaluation is featured to show the separated “effects of operational repair improvement” from “effects of new construction or replacement” in time series.
- ✓ Evaluations up to 2035
- ✓ Evaluated regions are OECD countries and Asian developing countries (see p.25)

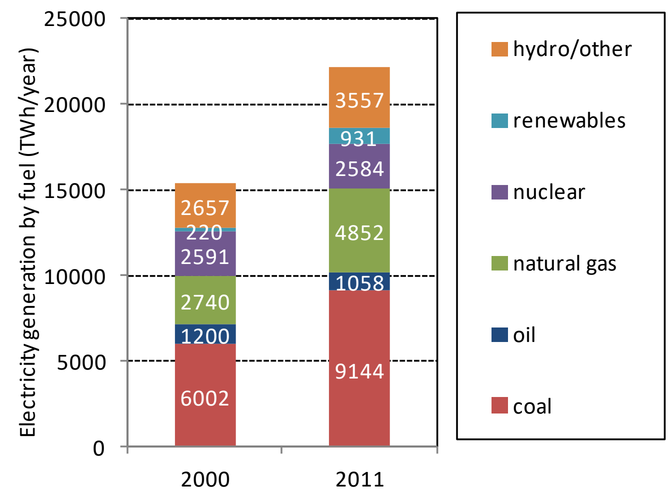
1.2 Issue awareness

- The global CO2 emissions have been increased continuously even after 2000.
- Power demand associated with the economic growth increases, including impact of new coal-fired power plants.

The global energy-related CO2 emissions



The global electricity generation by fuel



Source) Graphs by RITE, based on IEA (2013)

- As shown above, a number of coal-fired power plants are existing. It is crucial and basic information in advancing the specific CO2 reduction measures to figure out the CO2 reduction potentials by the efficiency improvement of power generation.
- In particular, it is also effective to quantify how much CO2 reduction can be expected by the "improvement in the operational repair" which is applicable to existing facilities, when considering the short and medium term measures

1.3 Overview of highly efficient coal-fired generation

Abbre-viation	Overview（Power generation efficiency is all based on LHV.）
USC	USC stands for Ultra Super Critical, which is referred to as ultra-supercritical pressure derivative coal-fired power plants. USC boasts the highest power generation efficiency among coal-fired power plants in commercial operation at the time of 2014 (except the IGCC below). The power generation efficiency of 700,000 kW class power generation end is 44.5 percent and sending end is 42% *1.
A-USC	A-USC stands for Advanced Ultra-Supercritical, which is referred to as advanced ultra-supercritical pressure derivative coal-fired power plants. A-USC is a power generation system for the next phase of USC. While USC uses 600 ℃ class boilers and steam turbines, A-USC uses 700 ℃ class. The target efficiency is 48% (sending end) *1.
IGCC	IGCC stands for Integrated Coal Gasification Combined Cycle, which is referred to as integrated coal gasification combined cycle. The gas gasified from coal turns the gas turbines by combusting gas. The steam generated by the exhaust gas after turning the gas turbine turns the steam turbine. The target efficiency is 49.2% (power generation end) *2.
IGCC2	GCC2 is the further developed 1700 ℃ class gas turbines of the 1500 ℃ class IGCC. GCC2 aims higher power generation efficiency than IGCC. The goal of the power generation efficiency is 51.3% (power generation end) * 2

*1 http://www.env.go.jp/policy/assess//4-6tpg/attach/130426a-3.pdf

*2 NEDO Technology Roadmap 2009

Supplement) The amount of power at the power generation end refers to the total amount of power generated by the power plants. The amount of power at the sending end refers to the net amount of power transmitted from the power plants. Self-consumed power by power plant house (the house loss) minus from power generation at the power generation end is the amount of power at the sending end. LHV (lower heating value, net calorific value) , compared with HHV (higher heating value, gross heating value) is smaller by the amount of latent heat (for vaporization). The numerical value of power generation efficiency based on LHV looks larger than power generation efficiency based on HHV.

2.1 Overview of the assumed 3 cases

Case	Transition of operational maintenance and repair and power generation efficiency (for more details pp.7, 8)	New construction and replacement types (for more details p.9)
Baseline case	• Operational maintenance and repair along the current trend • With the elapsed operation time, power generation efficiency is assumed to drop down.	• Introduction of ultra-supercritical pressure derivative coal-fired power plants from 2015 (USC) • Introduction of IGCC* equivalent from 2035
Strategic case	• Operational maintenance and repair will be more active than the current situation. • With the elapsed operation time, the power generation efficiency is assumed to be able to avoid the drop.	• The introduction of the IGCC * equivalent from an earlier stage than the baseline case
New technology case		• The introduction of the IGCC * equivalent from an earlier stage than the measure case

Please refer to p.4 for the overview of * IGCC and IGCC2.

2.2 Reference data for improvement potentials of operational maintenance and repair

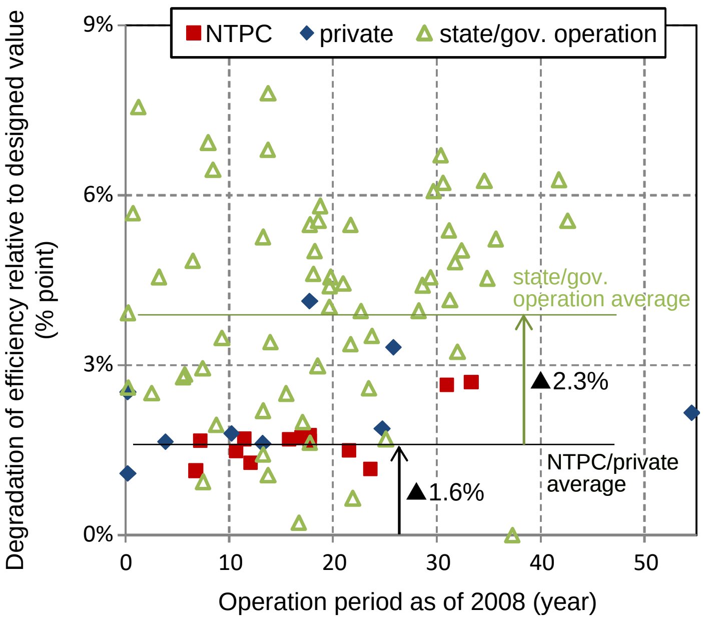
Setting of operational maintenance and repair improvement potentials

- For Asian developing countries, 1) questionnaire survey, 2) GSEP investigation, and 3) NEDO investigation, etc. are referred.
- For India, " The Perform, Achieve and Trade (PAT)", India's energy efficiency certification scheme which has been implemented and power generation efficiency by power plant has been released is referred in this paper.

Expected effect by operational maintenance and repair improvement (reference values)

Country	Leading investigation institutes	Improvement potentials(%)
India	Data Organized based on PAT, India Ministry of Power (2012) *0	about 2% (refer to the lower right)
	NEDO investigation*1	1.9%~2.4%
	Hajime Murata (2013)*2	4.2%
China	Questionnaire survey	2.6%
Indonesia	Hajime Murata (2011)*3	1.2%
	Federation of Electric Power Companies of Japan, GSEP *4	more than 2%
(reference) Poland	Federation of Electric Power Companies of Japan, GSEP *5	about 3%
	Hitachi, GSEP *6	4.8%

India's PAT data(the average of 2007-2009) *0



Supplement) "Questionnaire survey " was conducted to power companies of coal-fired holdings in each country. GSEP stands for Global Superior Energy Performance which intends international partnership for energy efficiency improvement.
*1 Survey (2013) of coal composition of efficiency improvement project in India's coal-fired power plants *except for the coal preparation effects
*2 Assessment of Aged Power Plants to Improve the Efficiency, WEC * only in case of updated steam turbines
*3 Efficient and Clean Use of Coal (ECUC) Assessment of Suralaya Unit 7, WEC, 2011 http://www.worldenergy.org/documents/44b_assessment_of_suralaya_unit_7_murata_japan_.pdf
*4 GSEP Workshop in Indonesia http://www.fepc.or.jp/about_us/pr/sonota/__icsFiles/afieldfile/2013/01/28/20130128_GSEP.pdf
*5 GSEP Site Visit Activity in Poland http://www.pwc.com/jp/ja/japan-seminar/2013/assets/pdf/global-superior-energy131014-16-d5.pdf
*6 Hitachi Coal Fired Power Plant Technology (2013)

*0 RITE organized , based on BEE_PAT_Booklet_Final.pdf" (2012), Ministry of Power, Government of India

Supplement) If efficiency improvement of NTPC, the biggest national power utility and private utilities are assumed to be expected to achieve the designed efficiency level and efficiency improvement of state or other national utilities are assumed to be expected to achieve the private utilities level , the efficiency will be improved 1.6% and 2.3% , respectively,

2.2 Transitional operation maintenance/repair and generation efficiency （existing plants）

Setting of operational maintenance and repair improvement potentials

– 3 regions; “Japan”, “developed countries except Japan”, “developing countries”

Japan : Applying questionnaire results in Japan

Developed countries except Japan : Applying questionnaire results in US

Asian developing countries : Based on questionnaire results in China and India’s PAT data

<See page 6 and Appendix for details>

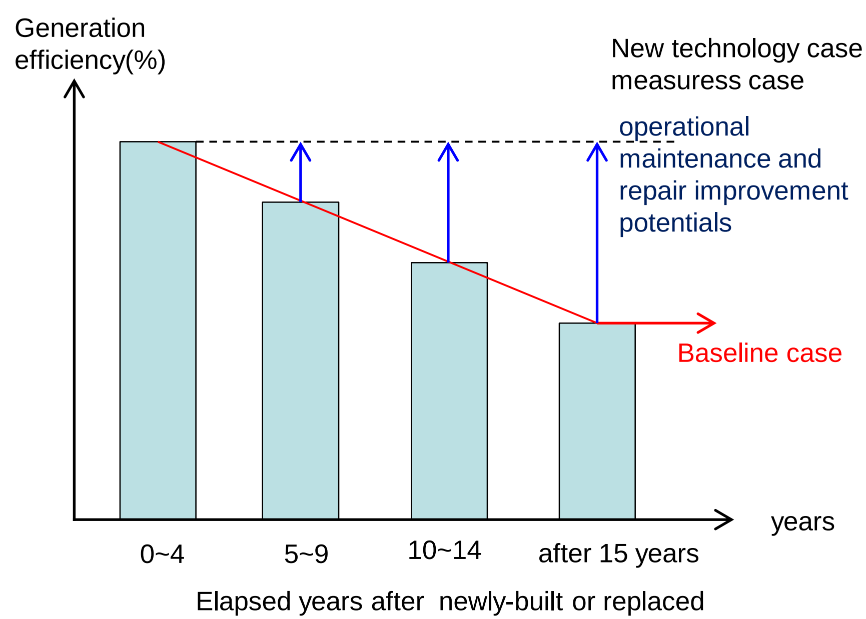
Supplement) The organized and consolidated questionnaire surveys which were conducted for the operators of coal-fired in each country provide “questionnaire results”. Power generation efficiency and operational repair room for improvement of the current situation, in many cases, is the data to be confidential for companies. On the other hand, Some power plants have evaluated these observed data. Therefore how to ensure the number of valid responses and response ratio of the questionnaire is the key.

– Power generation efficiency is assumed to reduce in linear up to 15 years after the start of operation, and then to remain at a constant level.

Operational maintenance and repair improvement potentials at constant generation efficiency (%)

Evaluated regions		Steam conditions	Operational maintenance and repair improvement potentials (%)	
			Existing equipment	New equipment
Developed countries	Japan	Subcritical pressure (PC)	0.48%	0.40%
		Super critical pressure (SC)	0.40%	
		Others	-	
	Except Japan	Subcritical pressure (PC)	0.62%	0.40%
		Super critical pressure (SC)	0.59%	
		Others	-	
Asian developing countries		No classification	2.0%	2.0%

Transitional generation efficiency and operational maintenance and repair improvement potentials



2.2 Transitional operation maintenance/repair and generation efficiency （newly-built /replaced equipments）

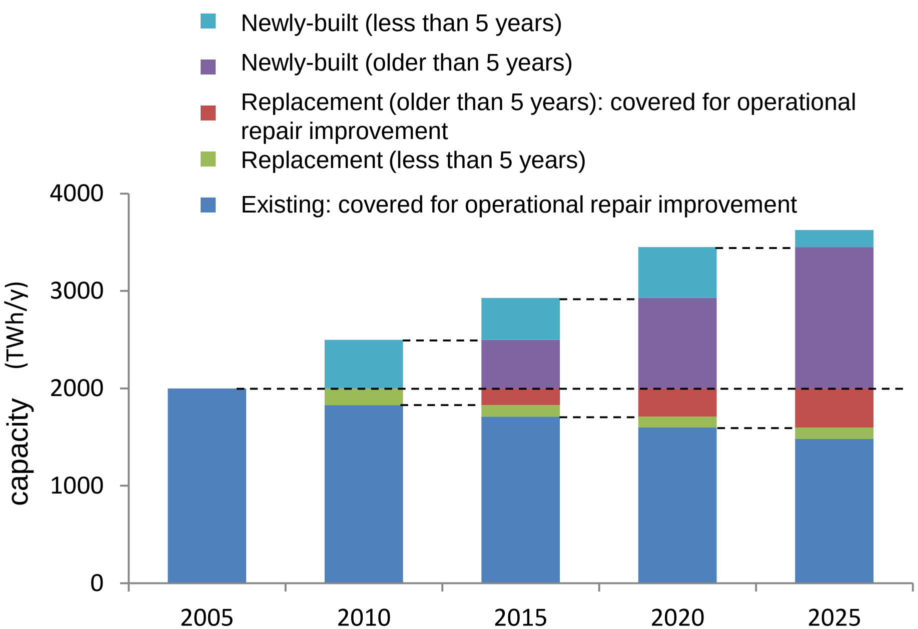
Newly-built or replaced equipments elapsed more than 5 years are covered for operational repair improvement

- In the reference case, power generation efficiency is assumed for both newly-built and replaced equipments to decrease over the operational course, which are covered for operational repair improvement

Setting of operational repair improvement potentials

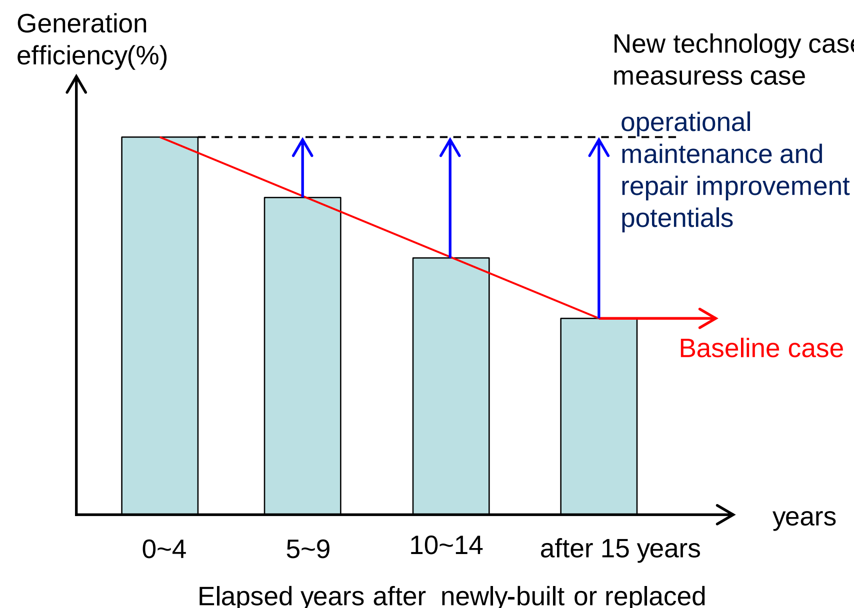
- Setting equivalent to the potentials of the existing equipment

Transitional image of the existing, newly-built and replacement equipments



Note) capacity expansion and operate rate change over time by replacement are not assumed.

Transitional generation efficiency and operational maintenance and repair improvement potentials



2. Major Assumptions

2.3 Generation efficiency improvement by new construction and replacement

- The generation amount of newly-built coal-fired power plants is based on the Current Policies scenarios of IEA "World Energy Outlook 2013"
- Replacement installed capacity is calculated from the capacity of coal-fired power plants elapsed 50 years (40 years for developing countries). (The time point of operation start is based on the Platts data.)
- Facilities shown in the table below (facilities that have the substantial power generation efficiency) are assumed to be introduced into both newly-built and replaced plants.

Assumption of newly-built and replaced facilities by time point

<table>
<tr><th>Scenarios</th><th>Regions</th><th>2010</th><th>2015</th><th>2020</th><th>2025</th><th>2030</th><th>2035</th></tr>
<tr><td rowspan="2">Baseline case</td><td>Developed countries</td><td rowspan="2">Equivalent to PC</td><td rowspan="2" colspan="4">Equivalent to USC</td><td rowspan="2">Equivalent to IGCC</td></tr>
<tr><td>Asian developing countries</td></tr>
<tr><td rowspan="2">Measures case</td><td>Developed countries</td><td>Equivalent to USC</td><td rowspan="2" colspan="3">Equivalent to USC</td><td rowspan="2" colspan="2">Equivalent to IGCC</td></tr>
<tr><td>Asian developing countries</td><td>Equivalent to PC</td></tr>
<tr><td rowspan="2">New technology case</td><td>Developed countries</td><td rowspan="2">Equivalent to USC</td><td rowspan="2">Equivalent to USC</td><td rowspan="2" colspan="2">Equivalent to IGCC</td><td rowspan="2" colspan="2">Equivalent to IGCC2</td></tr>
<tr><td>Asian developing countries</td></tr>
</table>

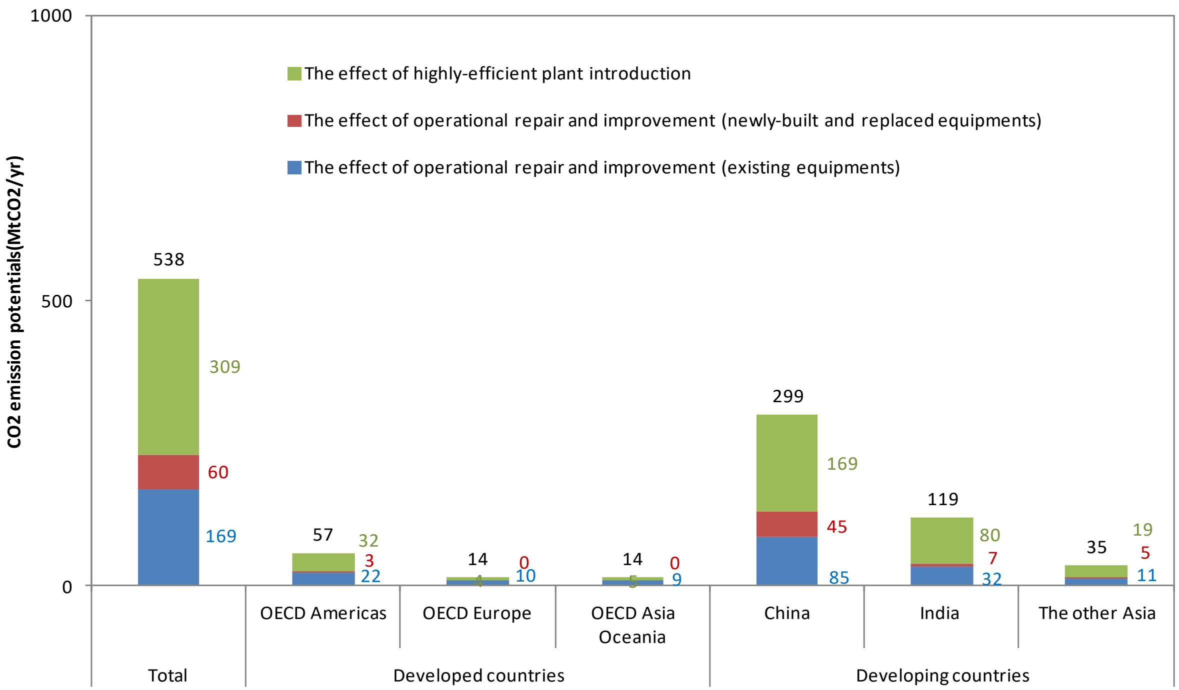
<table>
<tr><th></th><th>coal-fired power plants</th><th>Generation efficiency (generation end/ LHV)</th><th>Remarks/sources</th></tr>
<tr><td rowspan="4">New construction/ replacement</td><td>Subcritical pressure derivative coal-fired power plants (PC) [new construction]</td><td>-</td><td>Existing power generation efficiency by region + Operation repair improvement potentials</td></tr>
<tr><td>Ultra-supercritical pressure derivative coal-fired power plants (USC)</td><td>43.1%</td><td rowspan="3">NEDO Technology Roadmap 2009</td></tr>
<tr><td>Integrated coal gasification combined cycle (IGCC) [1500℃]</td><td>49.2%</td></tr>
<tr><td>〃 (IGCC2) [1700℃]</td><td>51.3%</td></tr>
</table>

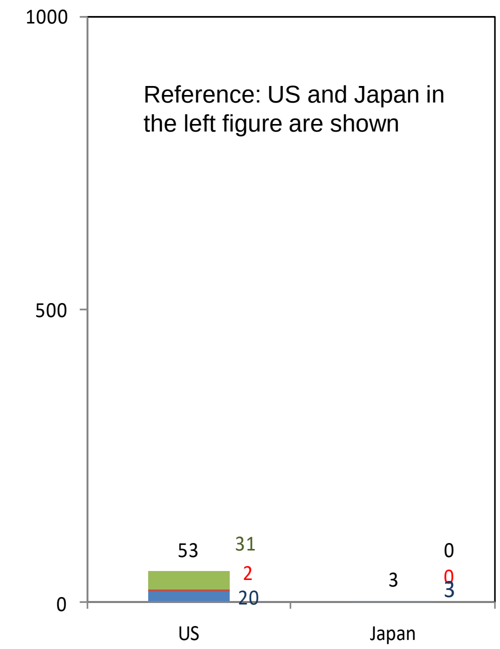
Note) In addition to the supercritical pressure derivative coal-fired power plants (SC), the introduction of A-USC is not explicitly considered. However, A-USC is considered to be explicit by the combination of PC, USC and IGCC. See p.4 for an overview of the power generation system.

3.1 Evaluation: 2020 CO2 reduction potentials by region: measures cases

- ✓ "① CO2 reductions by the operational repair and improvement (existing, newly-built and replaced equipments) " and "② CO2 reductions by introduction of highly-efficient plants" are evaluated separately.
- ✓ The evaluation results of CO2 reductions in the measures cases (compared to the 2020 baseline case) shows the following:
  - The total CO2 reduction in the evaluated regions is 538 million (tCO2/year).
  - Operational repair is really effective, as ① accounts for about 43%, 229 million (tCO2/year).

CO2 reductions in measures cases (compared to the 2020 baseline) case)



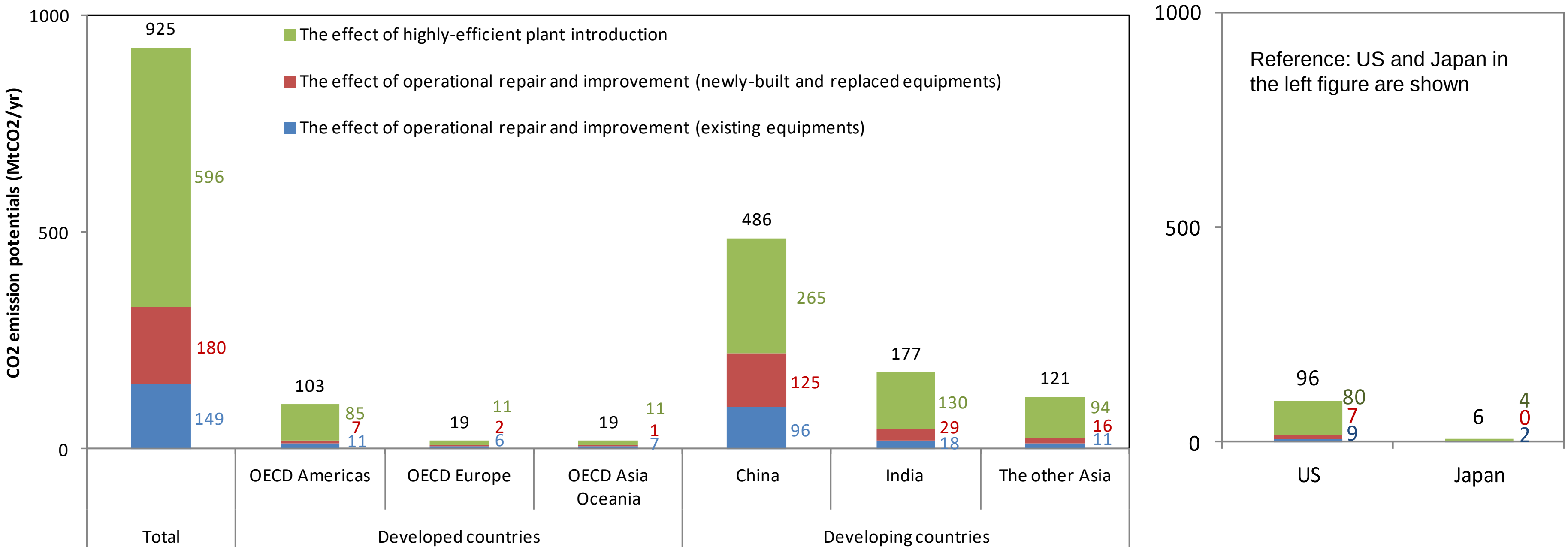


3.2 2030 CO2 reduction potentials evaluation by region: measures cases

✓ From the evaluation results of CO2 reductions in the measures cases (compared to the 2030 baseline case), mainly we can say the following:

- CO2 reduction of evaluation regions' total is 925 (million tCO2 / year)
- The red parts of 2030, the effect of operational repair improvement (newly-built and replaced equipment), grow significantly compared with the results of the 2020 figure
- As the green parts of the figure, the highly-efficient plant introduction is accelerated by Japan's contribution, reduction of the red parts of the figure can be expected in the long-term with Japan involving operational repair

CO2 reductions in measures cases (compared to the 2030 baseline case)



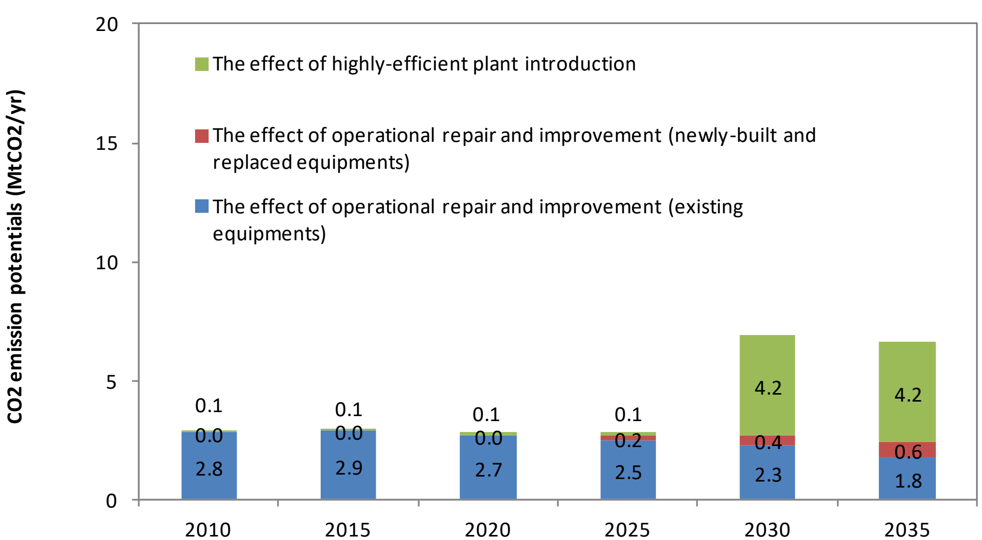
3.3 CO2 reduction potentials in Japan

- CO2 emission potentials by operational repair and improvement is equal to about 2.7 (MtCO2/yr).
- Since the proper operational repair has been doing in Japan, this reduction potential has already been achieved.[*1]
- It should be interpreted that emissions equal to the figure would potentially increase, if proper operational repair could not be carried out

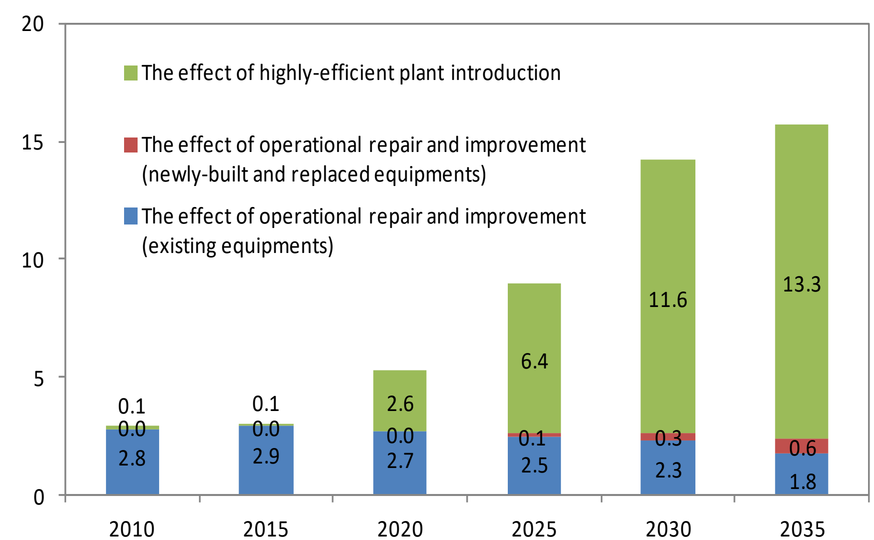
[*1] Germany and South Korea are considered as the region s that have made an effort at operational repair and already achieved some of the blue parts in the figure

- To ensure greater reductions, the introduction of highly efficient power generation equipments assumed in the new technology case is required.

Measures case (compared to the baseline case)



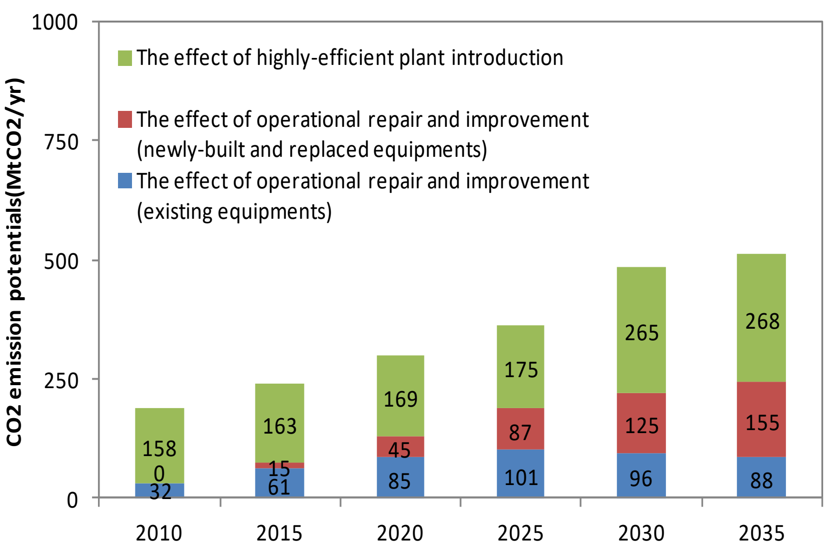
New technology case (compared to the baseline case)



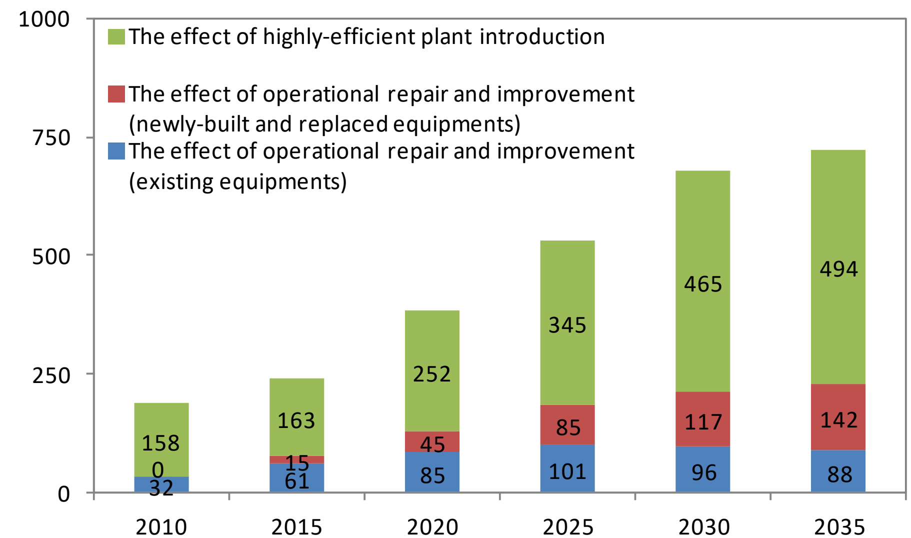
3.4 CO2 reduction potentials in China

- As well as holding a number of coal-fired power plants, China is estimated that the scale of the future new-built plants would be large.
- In 2030, "① CO2 reduction by operational repair and improvement is 221 or 213 (million tCO2 / year) "② CO2 reductions by highly efficient plant introduction" is 265 or 465 (million tCO2 / year). Both ① and ② show large reductions.
- Just ① above is close to the total of CO2 emission level of Japanese coal-fired power plants (see p.16).

Measures case (compared to the baseline case)



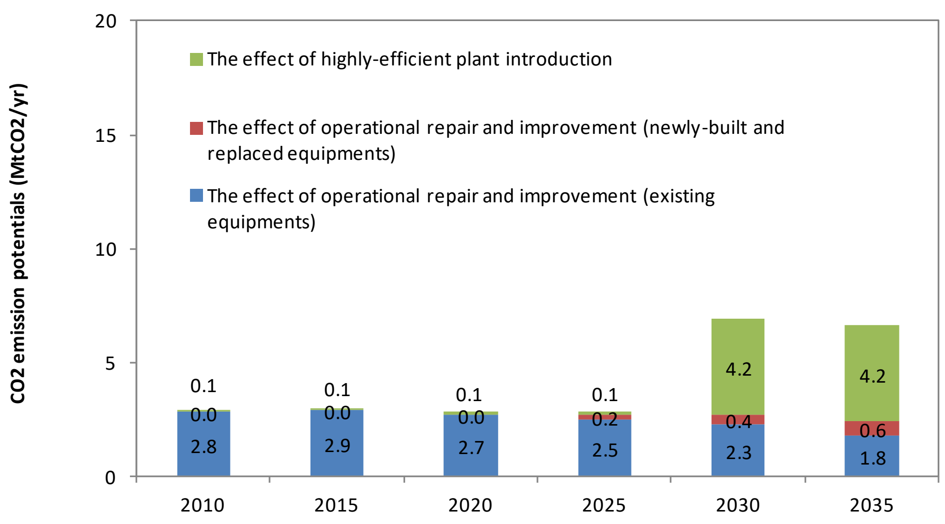
New technology case (compared to the baseline case)



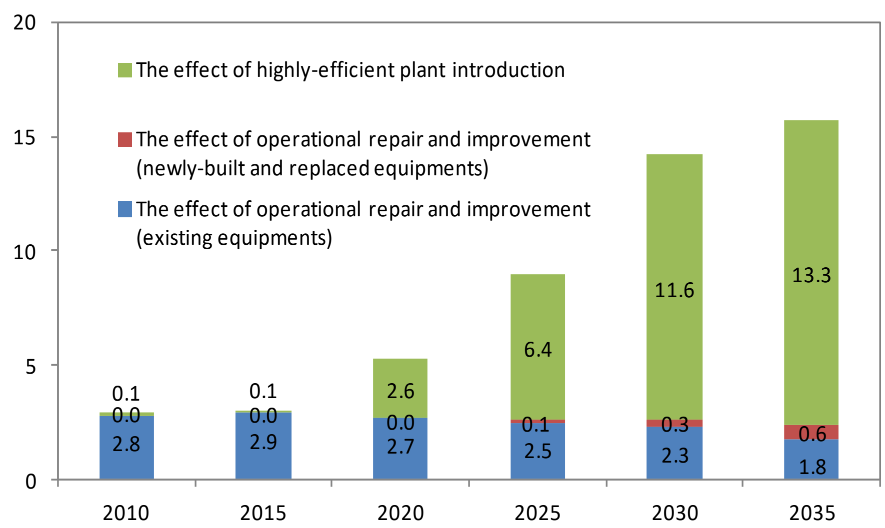
3.5 CO_2 reduction potentials in India

- In the future, India is expected to build a number of new plants and highly-efficient plant introduction is effective, if you look at the ratio
- "② CO_2 reductions by highly efficient plant introduction" is 130 or 227 (million tCO_2 / year) in 2030.
- CO_2 reduction potentials by operational repair and improvement of newly-built and replaced equipments 29 or 26 (million tCO_2 / year) in 2030, which is a key point.

Measures case (compared to the baseline case)



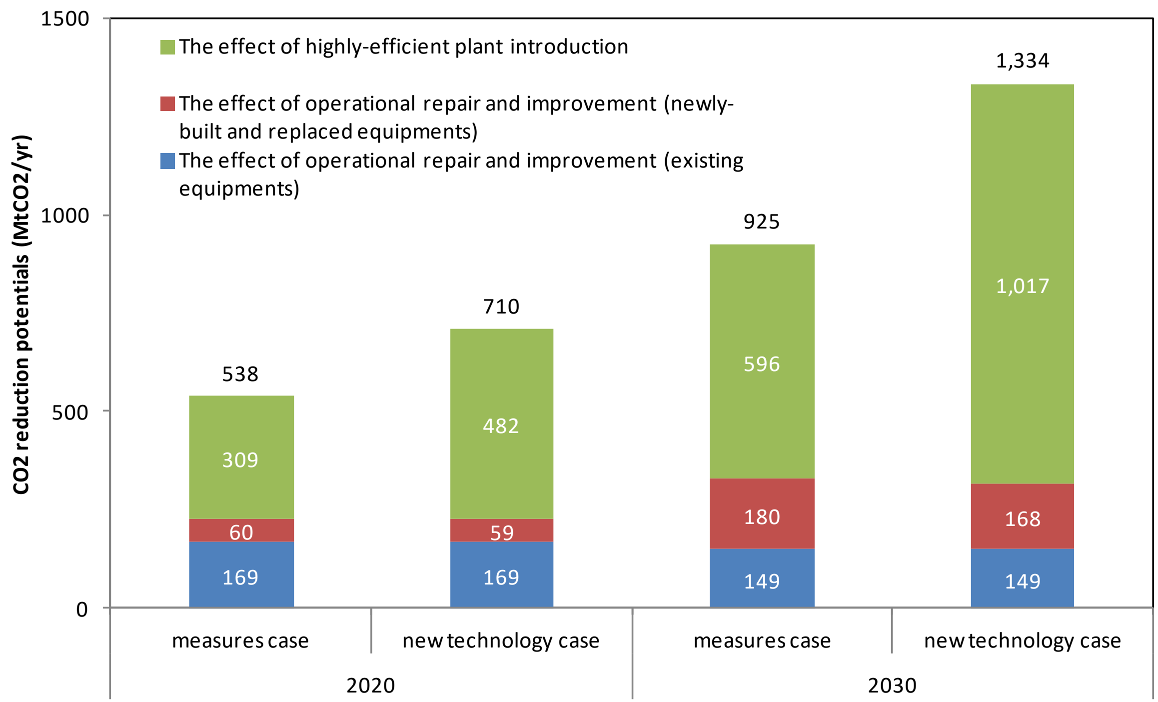
New technology case (compared to the baseline case)



3.6 Comparison of measures cases and new technology cases

✓ From the results of the CO2 reduction potential evaluation by region, we can generally say the following:
- If we consider the time axis of 2020, operational repair and improvement which poses relatively fewer impediment than plant construction is considered to be crucial and noteworthy measures in the future (the blue parts in the figure which direct CO2 emission reduction)
- In the long term, the importance of the development and diffusion of highly-efficient plants will increase. Japan should contributed to spread highly-efficient plants worldwide (green parts of the figure) and it is also important for Japan to be involved in the subsequent operational repair (the red parts in the figure which direct further CO2 emission reduction).

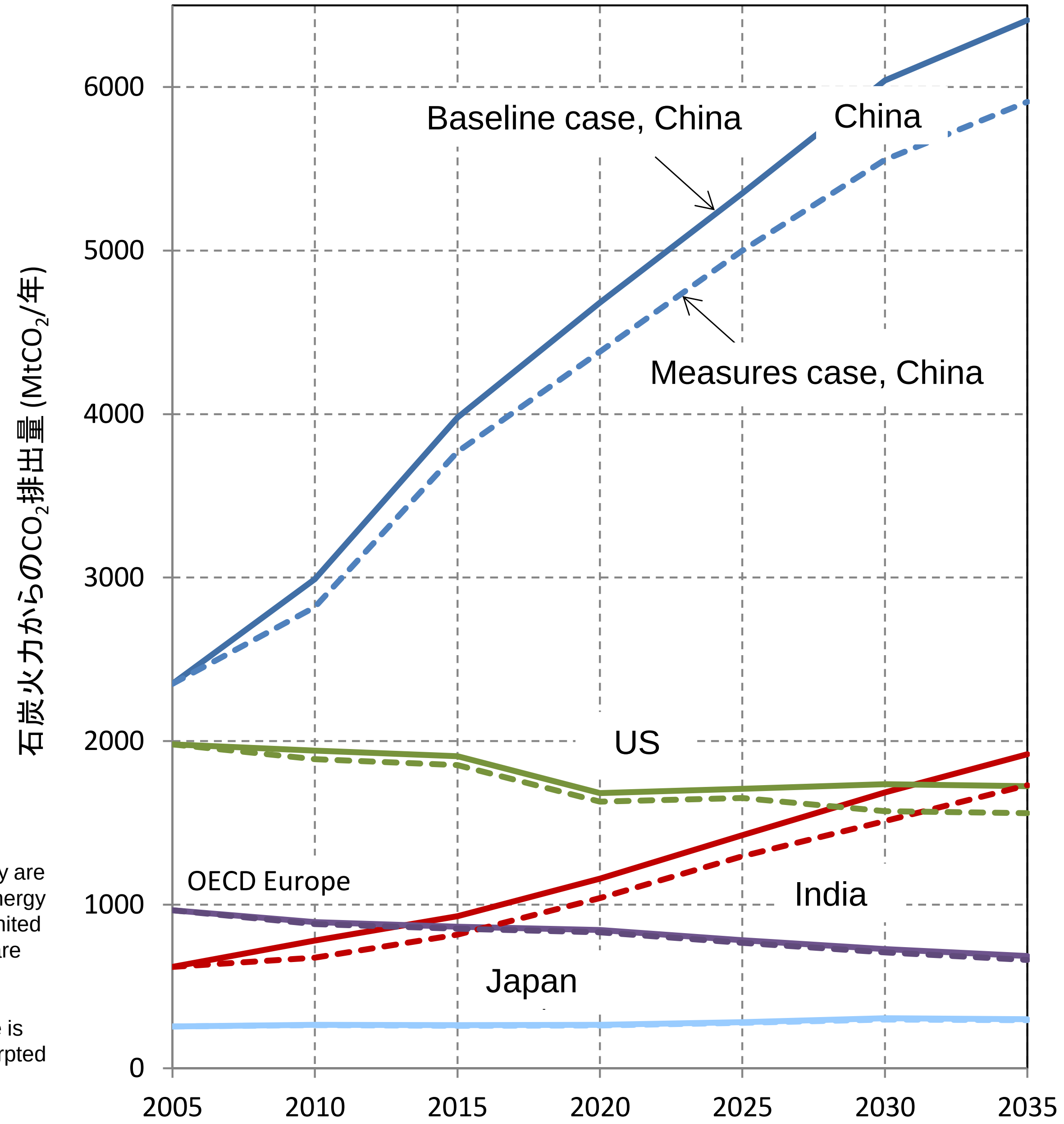
Total of all regions (OECD, Asian developing countries)



3.7 CO_2 emission prospects from the coal-fired power plants

Baseline case and measures case

- ✓ Coal-fired power plants in China and India are potential to increase which may result in CO2 emission increases
- ✓ Reduction potential of China is larger than the total CO2 emissions from coal-fired power plants in Japan. (see p.13)
- ✓ For climate change mitigation, it is important to share CO2 emissions and CO2 reduction potentials on a global scale.



Supplement) Coal-fired power generation and equipment capacity are based on the Current Policies scenario of the IEA "World Energy Outlook 2013". Therefore, for example, in the case of the United States, the proposed regulations by US EPA in June 2014 are different from WEO 2013.

Note) The solid line in the figure is reference case, the dotted line is the transition of measures case. Only major regions are excerpted in this figure.

4. Summary

Short- and mid-term（2020）

1. 2020 CO_2 reduction potential of coal-fired power plants (total of all regions) is 538 (million tCO_2 / year) in the measures case [compared to the baseline case].
2. The reduction potential of operational repair and improvement is 229 (million tCO_2 / year), accounting for approximately 40% of the reduction potential
3. It is important for Japan to play a good role, leading operational repair and improvement for the global coal-fired power plants.

Mid- and long-term（2030）

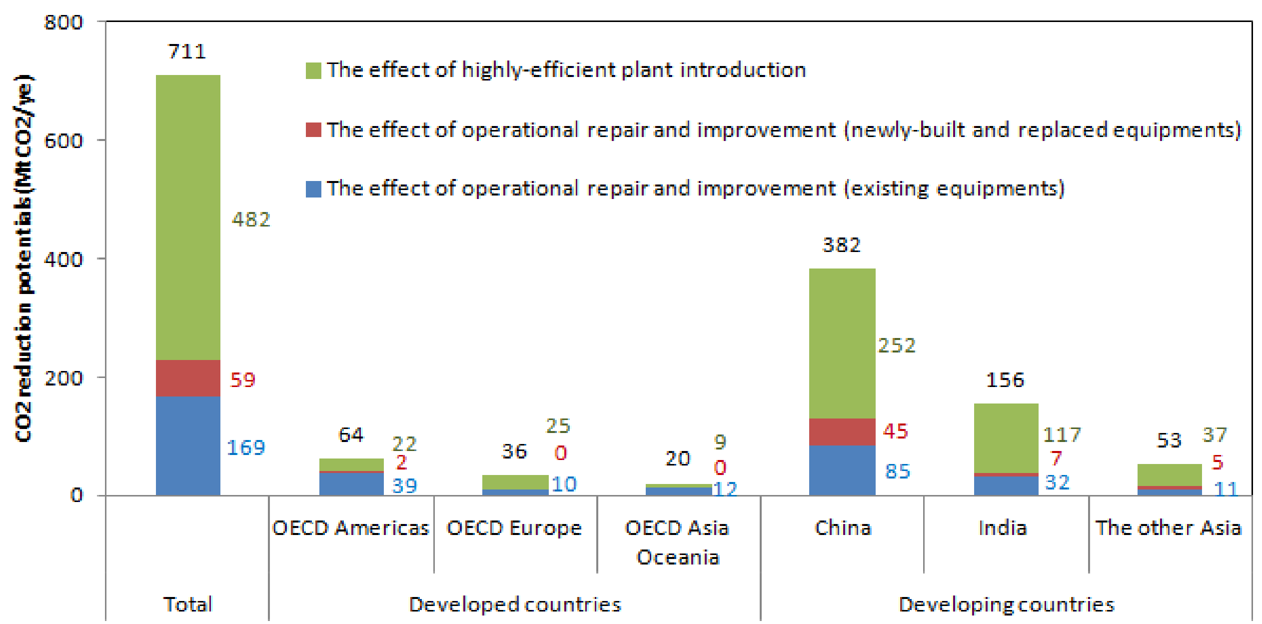
4. 2030 CO_2 reduction potential of coal-fired power plants (total of all regions) is 925 (million tCO_2 / year) in the measures case and 1334 (million tCO_2 / year) in the new technology case [compared to the baseline case].
5. After all, for the medium- and long-term, direct effects of highly-efficient plant introduction is large.
6. For the medium- and long-term, Japan is expected to play a good role, promoting the development and global diffusion of superior coal-fired power plants with efficient generation (for example, A-USC * and IGCC *)

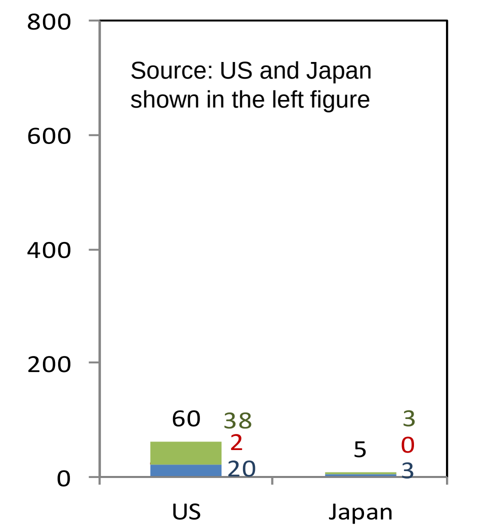
Please refer to p.4 about the overview of * A-USC and IGCC.

Appendix 1. 2020 CO2 reduction potentials evaluation by region: New technology case

- ‘①CO2 reductions by operational repair and improvement (existing/newly built /replacement equipment) ‘and ‘②highly efficient plant introduction’ are evaluated separately.
- Results from the evaluation of CO2 reductions in the new technology case compared to 2020 baseline case, we can say following;
  - The total of CO2 reductions in the evaluated regions is 711($MtCO_2$ / yr).
  - ①CO2 reductions by operational repair and improvement (existing/newly built /replacement equipments) account for 229 (MtCO2 / yr), 32% and very effective.
  - By region, while China, India and the United States have a large share, Japan accounts for less than 1% of the total.

CO2 reductions in the new technology case (compared to the 2020 baseline case)



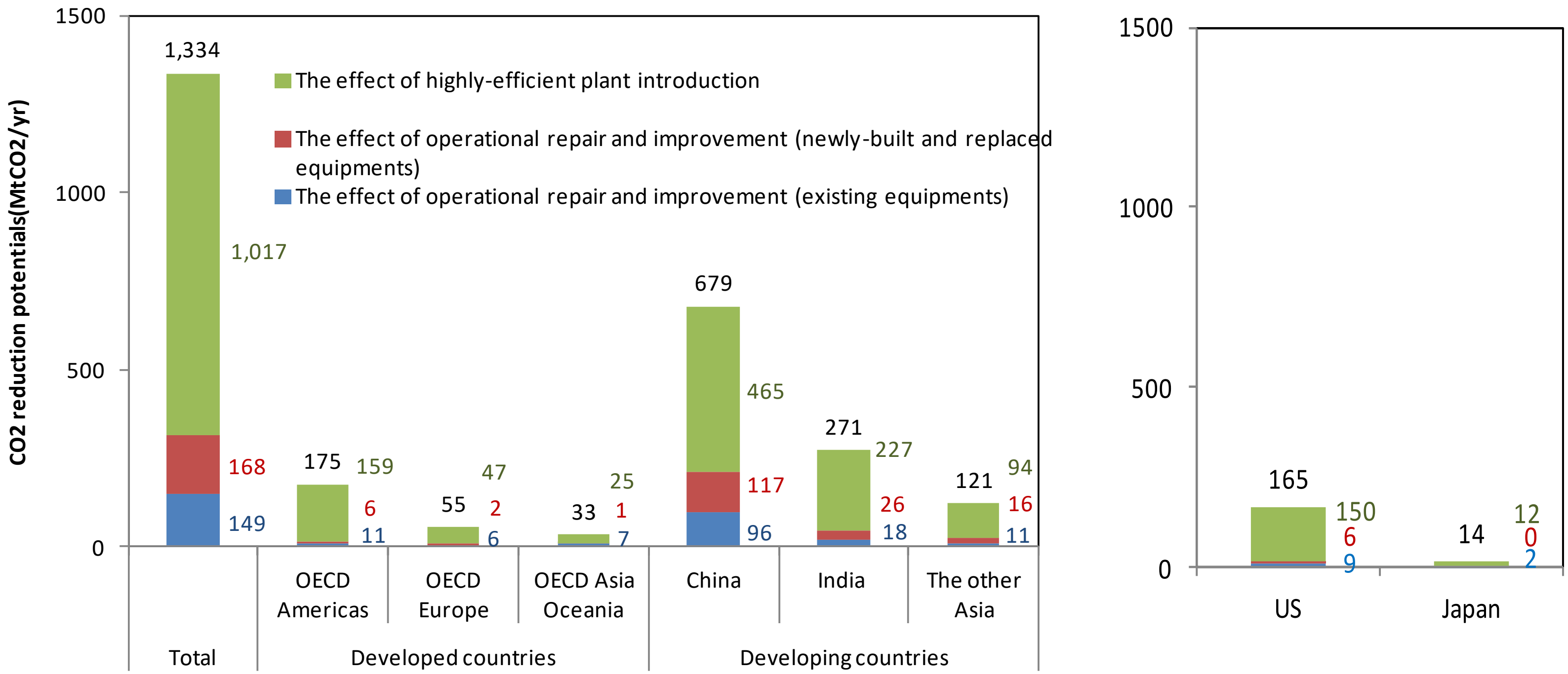


Appendix 1. 2030 CO2 reduction potentials evaluation by region: New technology case

✓ Results from the evaluation of CO2 reductions in the new technology case compared to 2030 baseline case, we can say following;

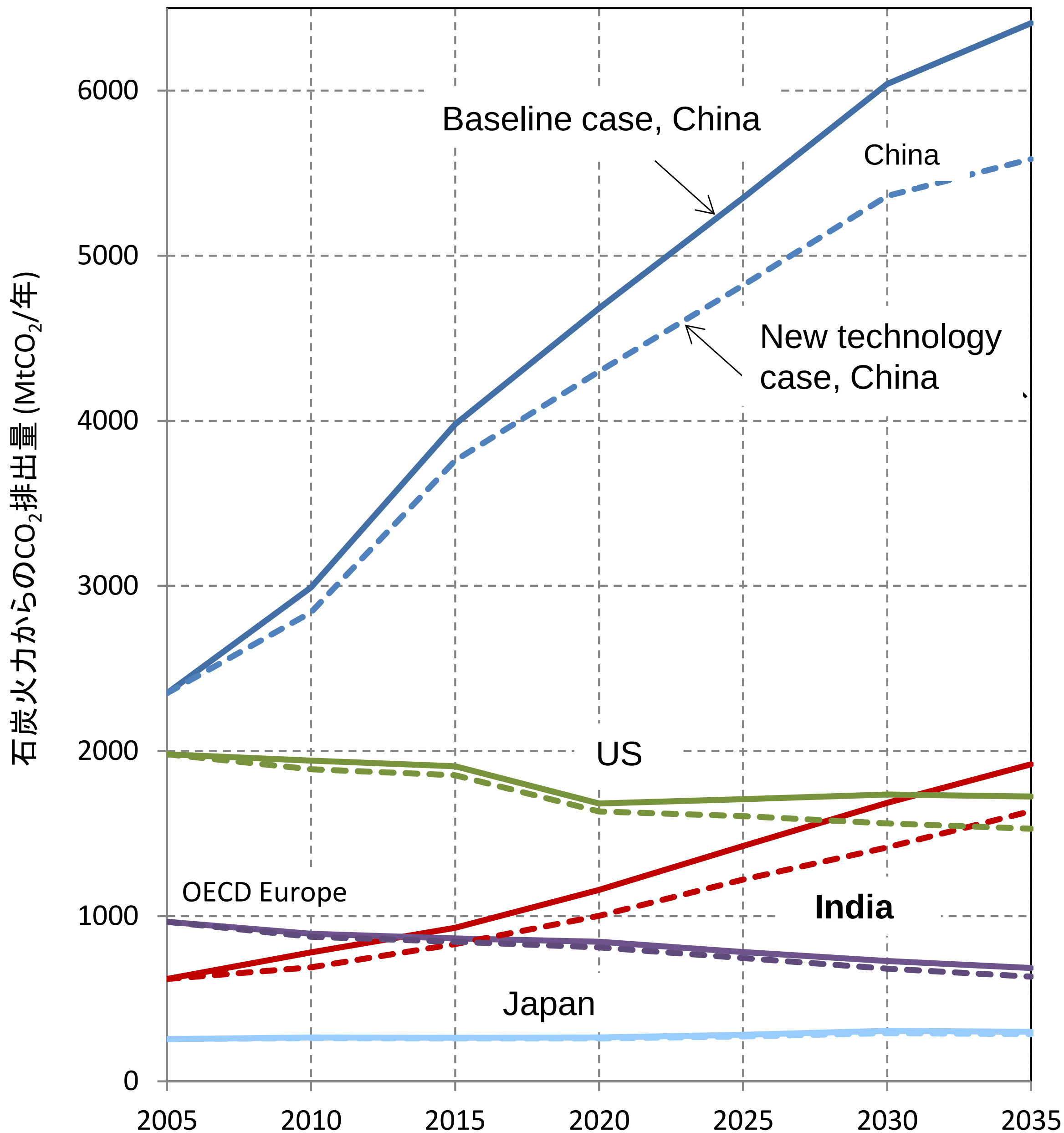
- The total of CO2 reductions in the evaluated regions is 1,334($MtCO_2$ / yr).
- CO2 reductions by operational repair and improvement (existing/newly built /replacement equipments) account for 317 (MtCO2 / yr), 24%.
- Compared with 2020, in 2030 the percentage of CO2 reductions by "② highly-efficient plant introduction rises along with increases in newly-built plants.
- Highly-efficient plant introduction is more effective in the long term.

CO2 reductions in the new technology case (compared to the 2030 baseline case)



Appendix 2. CO2 emission prospects from the coal-fired power plants

Baseline case and measures case

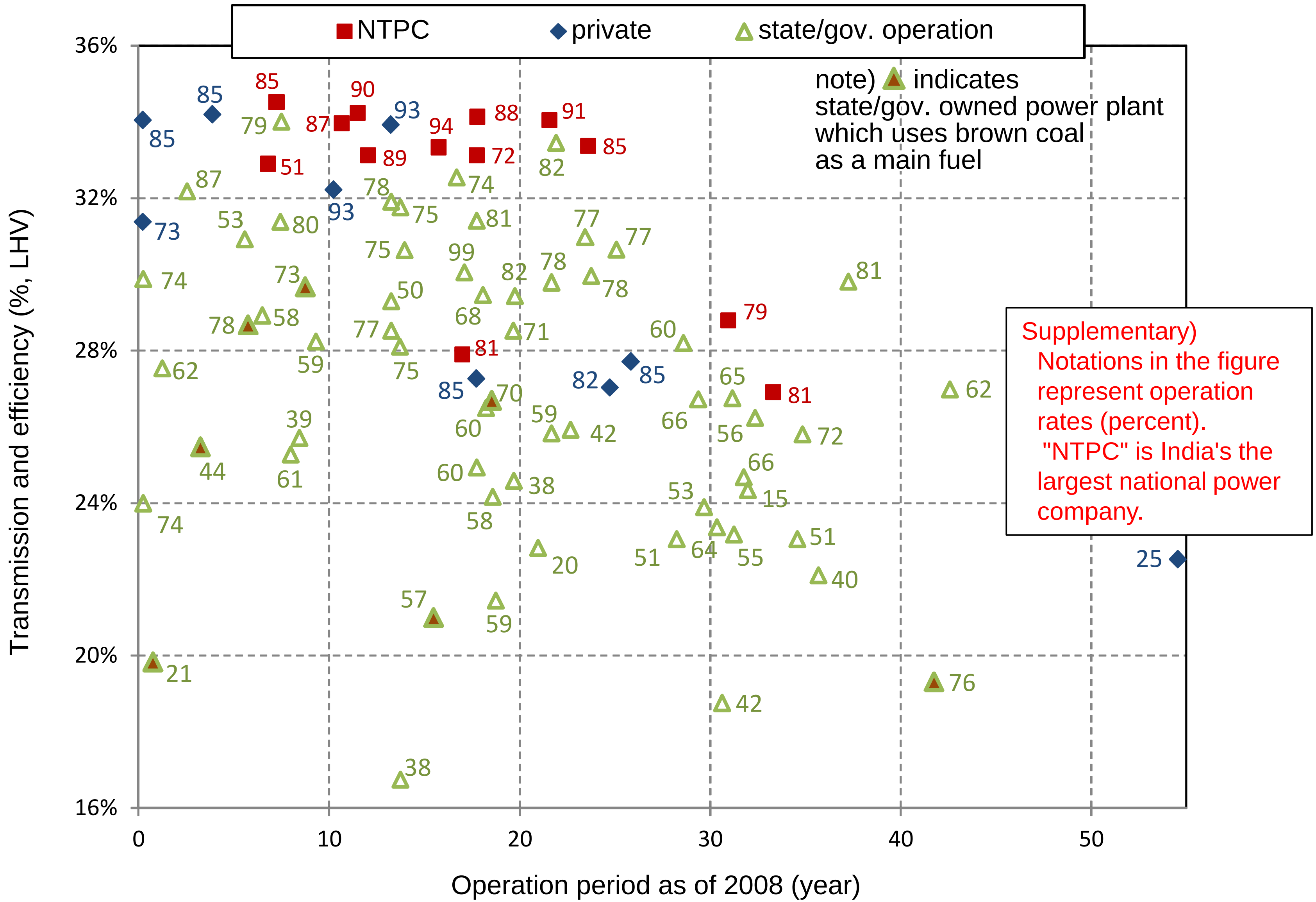


Supplement) Coal-fired power generation and equipment capacity are based on the Current Policies scenario of the IEA "World Energy Outlook 2013". Therefore, for example, in the case of the United States, the proposed regulations by US EPA in June 2014 are different from WEO 2013.

Note) The solid line in the figure is reference case, the dotted line is the transition of new technology case. Only major regions are excerpted in this figure.

Appendix 3. India's Performance, Achieve and Trade (PAT) scheme for power generation efficiency (real values in statistics)

Real values of India's coal-fired power generation efficiency (averaged PAT data of 2007-2009 fiscal year by power plant)



Source) Organized by RITE , based on "BEE_PAT_Booklet_Final.pdf" (2012), Ministry of Power（N = 82 power plants）

Appendix 3. India's Performance, Achieve and Trade (PAT) scheme for power generation efficiency (real values in statistics)

- ✓ Real values of generation efficiency at the sending end (2007- 09 fiscal year average)
  - Evaluating what elements have a linkage with real values of generation efficiency by multiple regression (N = 82 power plants)
  - Although a number of regression equations are identified to be effective in terms of the statistical significance and logical explanation force, two equations out of them are shown.

Regression equation 1
Real values of generation efficiency at the sending end (%)
= 20.2% + 1.9% * total capacity (GW) -0.09% * operating period (years) + 0.12 * utilization (%) -2.5% * dummy lignite + 0.041 * overseas coal ratio%
(4.4) (-3.7) (7.3) (-2.6) (1.9)
value t in parentheses, R^2=0.71

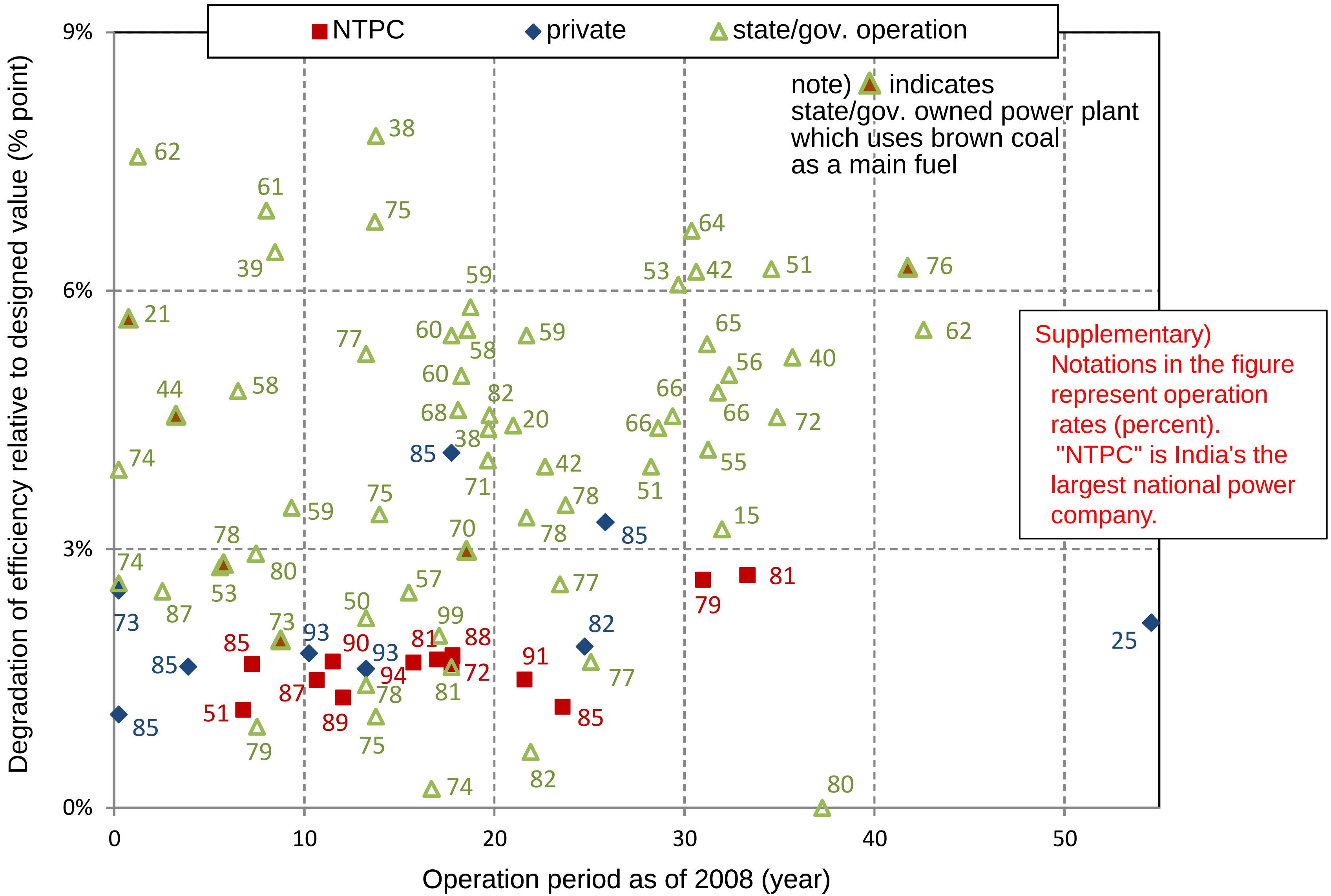
Regression equation 2
Real values of generation efficiency at the sending end (%)
= 20.7% + 1.7% * total capacity (GW) -0.10% * operating period (years) + 0.11 * utilization (%) -2.6% * dummy lignite + 1.2% * NTPC/dummy private plants
(3.9) (-4.1) (6.8) (-2.7) (1.9)
value t in parentheses, R^2=0.71

- ✓ The results of multiple regression analysis
  - Total capacity (total installed capacity of the power plant), operating period and utilization have a strong linkage with the power generation efficiency.
  - The power generation efficiency of power plants that use lignite is evaluated relatively 2.5% inferior
  - The power generation efficiency of power plants that use imported coal or are managed by NTPC/private company is superior to the other plants
  - This is because NTPC /private plants are considered to have tendency to take advantages of overseas coal whose ash content is less than the Indian domestic coal [the correlation coefficient of overseas coal ratio and NTPC /dummy private plants is 0.3].

Source) RITE organized , based on "BEE_PAT_Booklet_Final.pdf" (2012), Ministry of Power（N = 82 power plants）

Appendix 4. India's Performance, Achieve and Trade (PAT) scheme for power generation efficiency (versus designed values)

The differences between designed values and real values of India's coal-fired power plants (averaged PAT data of 2007-2009 fiscal year by power plant)



Source) RITE organized , based on "BEE_PAT_Booklet_Final.pdf" (2012), Ministry of Power（N = 82 power plants）

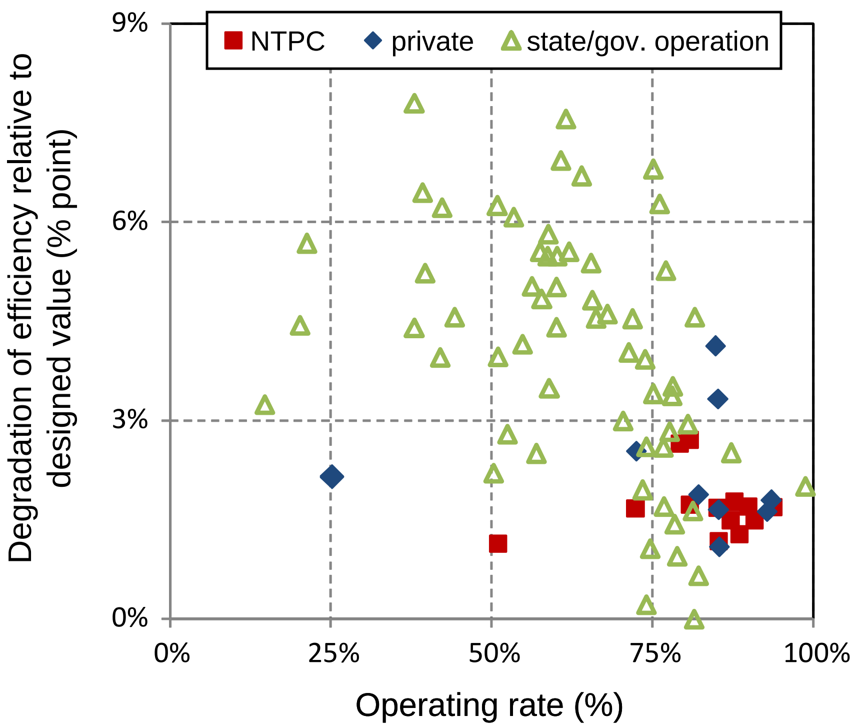
Appendix 4. India's Performance, Achieve and Trade (PAT) scheme for power generation efficiency (versus designed values)

- ✓ Reduction (divergence) % of real values of generation efficiency to the designed values (2007-09 fiscal year average).
  - Evaluating what elements have a linkage with the differences between designed values and real values by multiple regression (N = 82 power plants)
  - The number of samples (N) = 82 power plants
  - The following multiple regression equation is selected in terms of statistical significance, and multiple regression equation selected in terms of the statistical significance and logical explanation force

The difference between the design value and the actual value (%)
= 6.5% -0.039 * occupancy rate (%) -1.5% * (NTPC/dummy power plants)
(-3.8) (-3.5) value t in parentheses, R^2=0.71

- ✓ The results of multiple regression analysis
  - Power plants of high utilization rate are excellent in power generation efficiency closer to the higher design value (or, preferentially running the equipment of superior power generation efficiency) .*1
  - India's largest and national power company, NTPC and the private coal-fired plants have 1.5% smaller divergence from the designed value than state or other national plants, even taking into account the utilization rate differences compared to the other state or national plants . (This could be due to relatively superior operational repair of NTPC and private power plants). * 2

The differences between designed values and real values of India's coal-fired power plants
(averaged PAT data of 2007-2009 fiscal year by power plant)



Source) Organized by RITE, based on "BEE_PAT_Booklet_Final.pdf" (2012)
*1 Power generation efficiency is technically effected by the low utilization rate. In addition, if the power generation efficiency is significantly as low as output reduction, the utilization rate in this paper calculated from the electric power generation per MW would be lower. (even if the operating time is long)
*2 State coal-fired power plants may use coal with high ash content. The typical ash content of the Indian domestic coal is from 36% to 44%. Refer to CEA, Review of Performance of Thermal Power Stations, 2013.

Appendix 5 Evaluated regions and specific countries

Analyzed regions	Specific countries
OECD Americas	US, Canada, Mexico, Chile
OECD Europe	EU-15, Czech Republic, Estonia, Hungary, Iceland, Poland, Slovakia, Turkey, Norway, Switzerland, Slovenia, Israel
OECD Asia Oceania	Japan, Australia, New Zealand, Korea
China	China
India	India
The other Asian countries	Taiwan, Singapore, Philippines, Mongolia, Vietnam, Laos, Cambodia, Brunei, Indonesia, Malaysia, Thailand, Myanmar, Bangladesh, Sri Lanka, Bhutan, Nepal, Pakistan, Afghanistan, North Korea, Cook Islands, East Timor, Fiji, French Polynesia, Kiribati, Macao, Maldives, New Caledonia, Palau, Papua New Guinea, Samoa, Solomon Islands, Tonga, Vanuatu