August 19, 2014

International efficiency comparison of thermal power plants: up to 2011

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1. Calculation frame of generation efficiency （Overview）

Overview of calculation

- ✓ Calculating energy efficiency, based on the fuel input and power output described in “Energy Balances of OECD/Non-OECD Countries 2013” (power generation end/LHV)
- ✓ Applied the same methods as Oda et al. (2012)*, up to the 2011 data

*Oda et al., International comparisons of energy efficiency in power, steel, and cement industries, *Energy Policy*, **44**, pp.118-129, 2012.

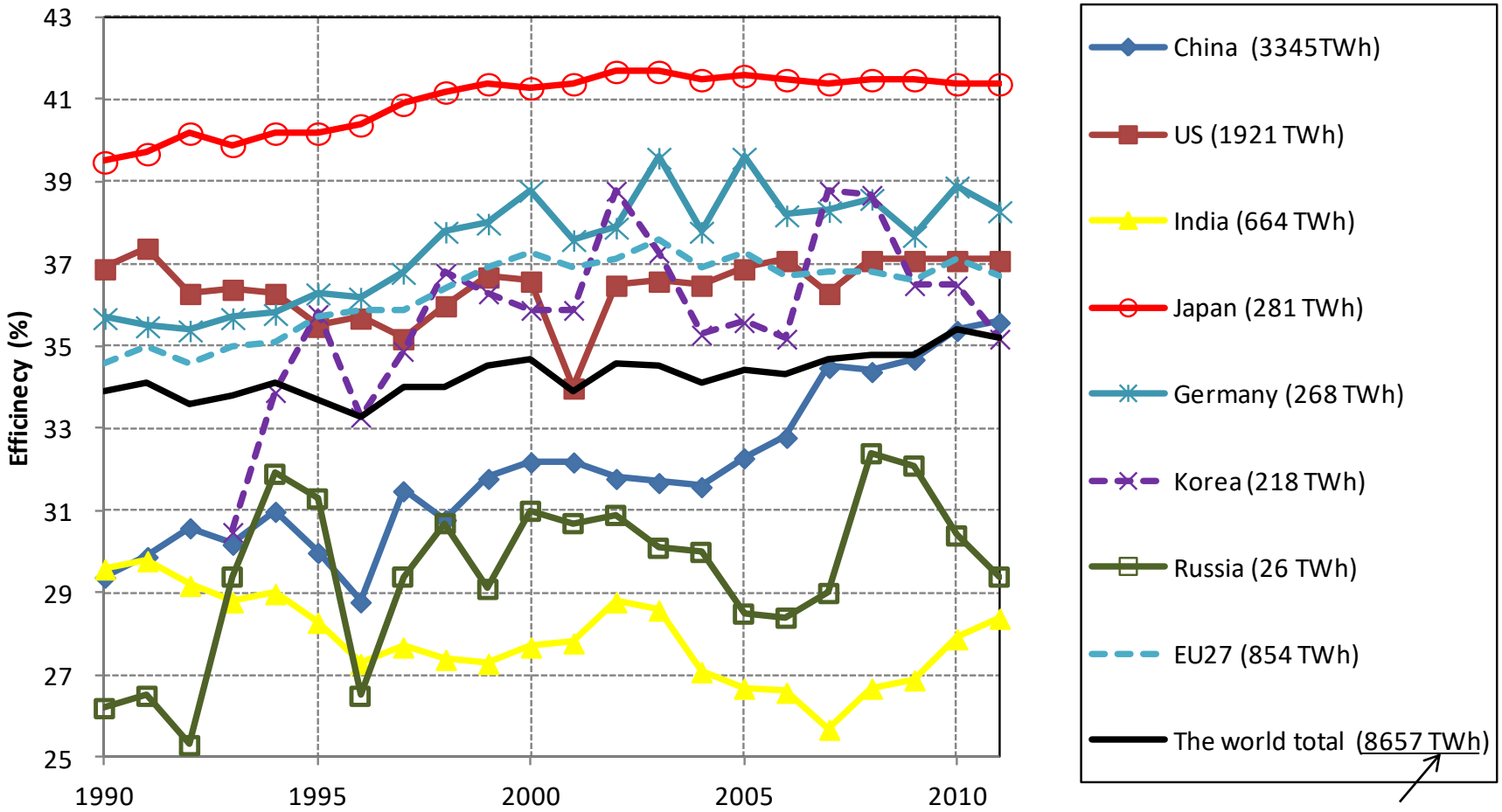
Evaluated power generation

✓ Basically evaluated all the thermal power plants (including private power generation and CHP)

（〇 = evaluated power generation）	Electric power supplier	Private power generation
Power generation only	〇	〇
Combined heat and power (CHP)	〇	〇

Note: In many cases, private power generation is excluded in the analyses of Ecofys, which is different from this paper basically including private power generation facilities.

2.1 Efficiency of coal power generation (power generation end/LHV) [figure]



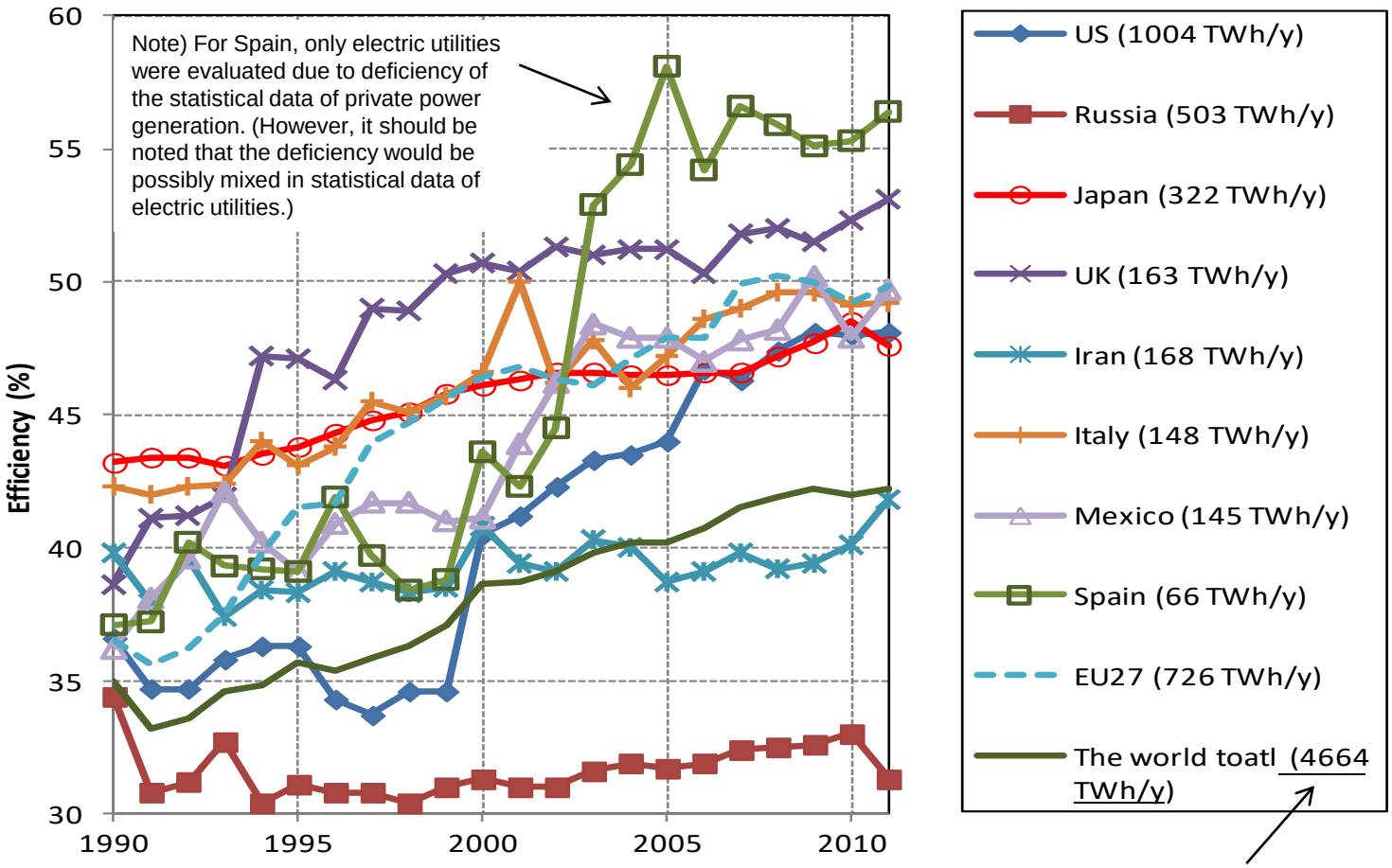
- ✓ **Japan has maintained the excellent energy efficiency in the world (with both hardware and software improved)**
- ✓ **Germany, EU27 countries, and the United States follow Japan**
- ✓ **China has slowly improved energy efficiency**
- ✓ **India and Russia are relatively inferior in energy efficiency**

Power output for coal power generation in the period average 2009-2011 (power generation end, TWh/y)

2.2 Efficiency of coal power generation [numeric value]

Coal-fired power output (power generation end)		Efficiency of coal power generation (power generation end/LHV)																				
2009-2011 average (TWh/y)		1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
3,345	China	29.4%	29.9%	30.6%	30.2%	31.0%	30.0%	28.8%	31.5%	30.8%	31.8%	32.2%	32.2%	31.8%	31.7%	31.6%	32.3%	32.8%	34.5%	34.4%	34.7%	35.4%	35.6%
1,921	US	36.9%	37.4%	36.3%	36.4%	36.3%	35.5%	35.7%	35.2%	36.0%	36.7%	36.6%	34.0%	36.5%	36.6%	36.5%	36.9%	37.1%	36.3%	37.1%	37.1%	37.1%	37.1%
664	India	29.6%	29.8%	29.2%	28.8%	29.0%	28.3%	27.3%	27.7%	27.4%	27.3%	27.7%	27.8%	28.8%	28.6%	27.1%	26.7%	26.6%	25.7%	26.7%	26.9%	27.9%	28.4%
281	Japan	39.5%	39.7%	40.2%	39.9%	40.2%	40.2%	40.4%	40.9%	41.2%	41.4%	41.3%	41.4%	41.7%	41.7%	41.5%	41.6%	41.5%	41.4%	41.5%	41.5%	41.4%	41.4%
268	Germany	35.7%	35.5%	35.4%	35.7%	35.8%	36.3%	36.2%	36.8%	37.8%	38.0%	38.8%	37.6%	37.9%	39.6%	37.8%	39.6%	38.2%	38.3%	38.6%	37.7%	38.9%	38.3%
239	S. Africa	37.1%	37.1%	36.8%	36.3%	36.2%	35.3%	36.2%	35.6%	33.2%	34.9%	34.8%	37.7%	38.5%	37.0%	36.0%	37.1%	38.0%	38.4%	33.2%	34.7%	34.0%	36.0%
218	Korea	–	–	–	30.5%	33.9%	35.8%	33.3%	34.9%	36.8%	36.3%	35.9%	35.9%	38.8%	37.3%	35.3%	35.6%	35.2%	38.8%	38.7%	36.5%	36.5%	35.2%
180	Australia	36.2%	36.1%	36.1%	36.5%	37.2%	36.8%	36.7%	36.7%	35.4%	35.0%	35.6%	35.5%	31.9%	32.6%	33.3%	34.6%	34.6%	34.6%	34.6%	34.4%	34.5%	33.3%
164	Russia	26.2%	26.5%	25.3%	29.4%	31.9%	31.3%	26.5%	29.4%	30.7%	29.1%	31.4%	30.7%	30.9%	30.1%	30.0%	28.5%	28.4%	29.0%	32.4%	32.1%	30.4%	29.4%
138	Poland	30.1%	30.3%	30.6%	31.1%	31.5%	34.0%	34.1%	34.2%	34.8%	35.0%	35.5%	35.4%	35.7%	35.8%	36.4%	36.3%	36.3%	36.2%	36.1%	36.2%	36.3%	36.3%
108	UK	37.2%	37.9%	36.3%	37.8%	38.2%	38.4%	38.5%	37.0%	36.7%	37.1%	37.4%	37.2%	37.5%	37.7%	37.1%	36.8%	36.9%	36.8%	37.0%	36.9%	37.0%	37.0%
854	EU	34.6%	35.0%	34.6%	35.0%	35.1%	35.7%	35.9%	35.9%	36.4%	36.9%	37.3%	36.9%	37.1%	37.6%	36.9%	37.3%	36.7%	36.8%	36.8%	36.6%	37.1%	36.7%
8,657	The world total	33.9%	34.1%	33.6%	33.8%	34.1%	33.7%	33.3%	34.0%	34.0%	34.5%	34.7%	33.9%	34.6%	34.5%	34.1%	34.4%	34.3%	34.7%	34.8%	34.8%	35.4%	35.2%

2.3 Efficiency of gas power generation (power generation end/LHV) [figure]



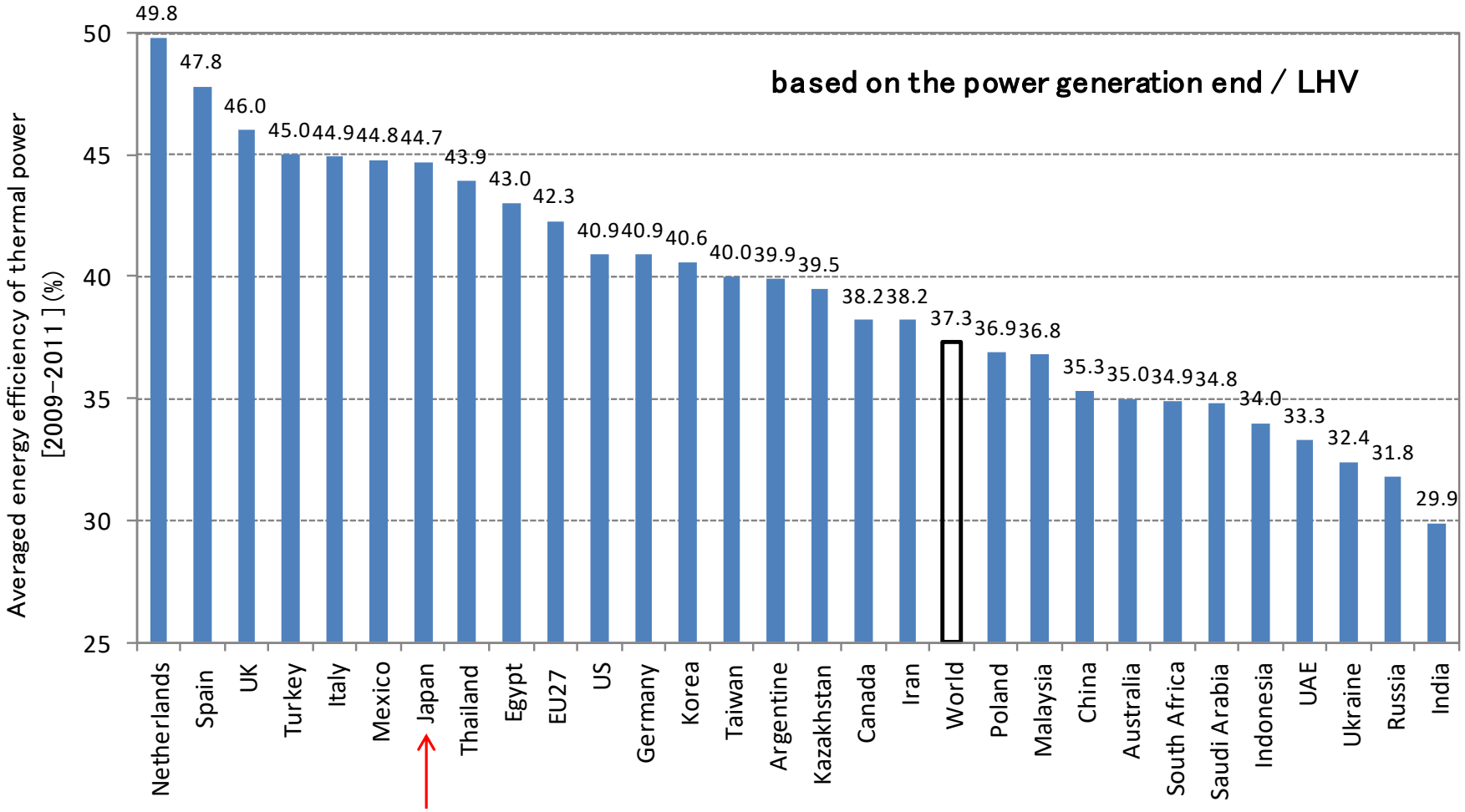
- ✓ **1990 or later combined-circle gas turbines have been installed in Spain and the United Kingdom, where energy efficiency is superior**
- ✓ **Before 1990 a number of gas power plants were built in Japan, where the ratio of combined-circle gas turbines is lower than Spain and the UK**

2.4 Efficiency of gas power generation [numeric value]

Energy efficiency of gas power generation (power generation end/LHV）

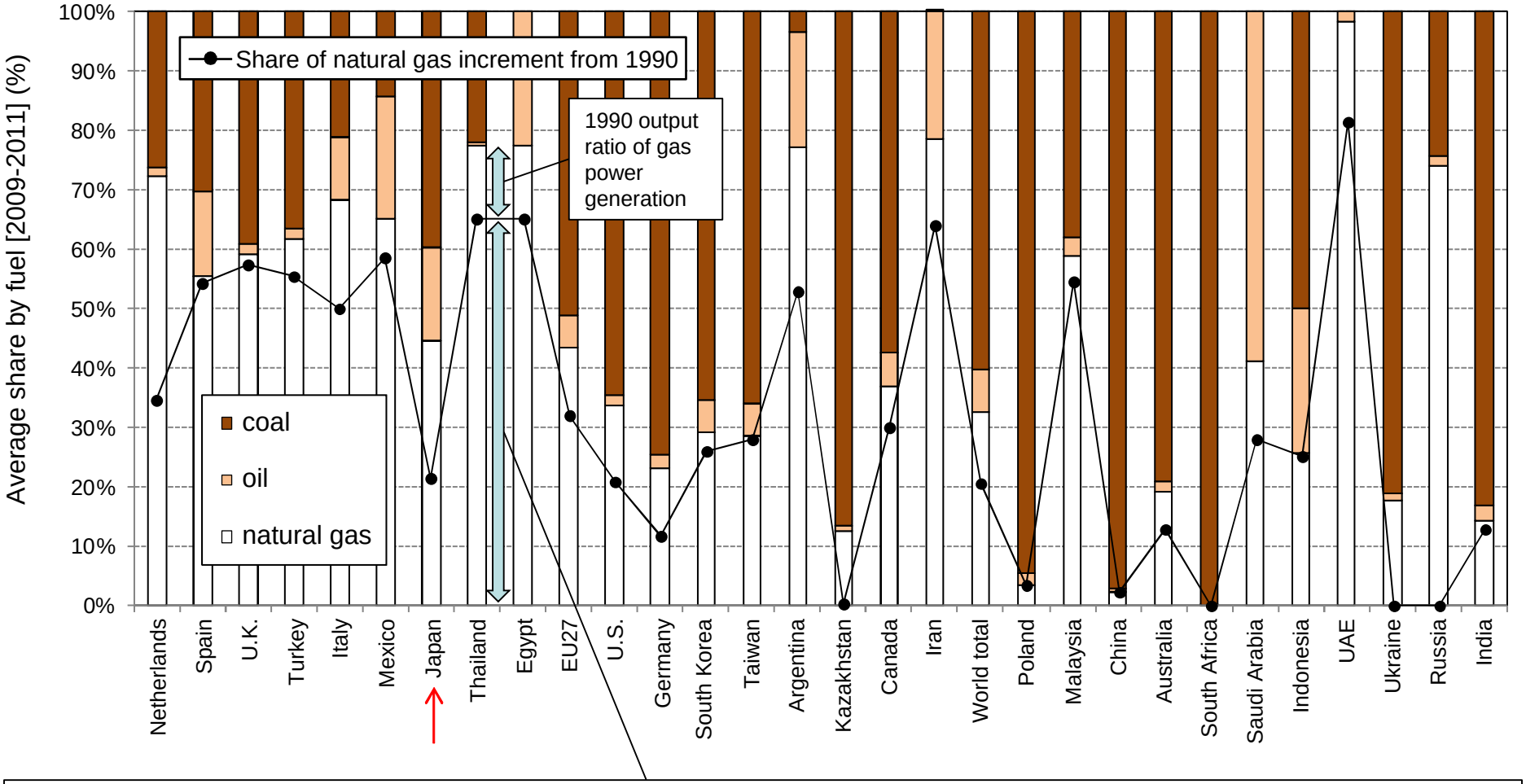
Output power for Gas power generation (power generation end) 2009-2011 average (TWh/y)		1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
1,004	US	36.6%	34.7%	34.7%	35.8%	36.3%	36.3%	34.3%	33.7%	34.6%	34.6%	40.5%	41.2%	42.3%	43.3%	43.5%	44.0%	46.7%	46.3%	47.4%	48.1%	48.0%	48.1%
503	Russia	34.4%	30.8%	31.2%	32.7%	30.4%	31.1%	30.8%	30.8%	30.4%	31.0%	31.3%	31.0%	31.0%	31.6%	31.9%	31.7%	31.9%	32.4%	32.5%	32.6%	33.0%	31.3%
322	Japan	43.2%	43.4%	43.4%	43.1%	43.5%	43.8%	44.3%	44.8%	45.1%	45.8%	46.1%	46.3%	46.6%	46.6%	46.5%	46.5%	46.6%	46.6%	47.2%	47.7%	48.5%	47.6%
163	UK	38.6%	41.1%	41.2%	41.9%	47.2%	47.1%	46.3%	49.0%	48.9%	50.3%	50.7%	50.4%	51.3%	51.0%	51.2%	51.2%	50.3%	51.8%	52.0%	51.5%	52.3%	53.1%
168	Iran	39.8%	37.9%	39.6%	37.4%	38.4%	38.3%	39.1%	38.7%	38.3%	38.5%	40.8%	39.4%	39.1%	40.3%	40.0%	38.7%	39.1%	39.8%	39.2%	39.4%	40.1%	41.8%
148	Italy	42.3%	42.0%	42.3%	42.4%	44.0%	43.1%	43.8%	45.5%	45.1%	45.7%	46.6%	50.0%	46.2%	47.8%	46.0%	47.2%	48.6%	49.0%	49.6%	49.6%	49.1%	49.2%
145	Mexico	36.2%	38.1%	39.6%	42.1%	40.2%	39.1%	40.9%	41.7%	41.7%	41.0%	41.1%	43.9%	46.2%	48.4%	47.9%	47.9%	47.0%	47.8%	48.2%	50.2%	47.9%	49.7%
111	Thailand	40.0%	34.8%	38.0%	41.0%	40.8%	42.9%	42.2%	39.3%	41.1%	41.9%	41.6%	39.9%	40.4%	42.5%	43.2%	43.6%	43.9%	43.7%	45.2%	45.9%	46.1%	48.1%
66	Spain (only electric utilities)	37.1%	37.2%	40.2%	39.3%	39.2%	39.1%	41.9%	39.7%	38.4%	38.8%	43.6%	42.3%	44.5%	52.9%	54.4%	58.1%	54.2%	56.6%	55.9%	55.1%	55.3%	56.4%
105	Saudi Arabia	24.3%	24.4%	24.4%	25.3%	25.5%	25.4%	25.7%	25.8%	25.9%	26.6%	27.8%	29.0%	29.2%	29.4%	30.2%	30.4%	29.6%	29.7%	29.8%	30.2%	31.6%	31.4%
96	Korea	40.5%	40.6%	40.3%	42.3%	42.3%	42.2%	44.8%	45.2%	49.3%	47.1%	46.7%	45.4%	50.1%	50.9%	50.1%	50.4%	51.1%	50.8%	50.8%	50.8%	51.0%	51.2%
83	Germany	36.6%	33.4%	34.4%	36.0%	35.7%	40.0%	38.0%	38.6%	40.8%	40.1%	43.2%	42.2%	39.6%	44.2%	44.1%	44.8%	45.8%	45.4%	46.2%	45.4%	47.2%	48.5%
726	EU27	36.5%	35.6%	36.2%	37.5%	39.8%	41.5%	41.7%	43.9%	44.7%	45.6%	46.4%	46.8%	46.3%	46.1%	47.1%	47.9%	47.9%	49.9%	50.2%	50.0%	49.2%	49.8%
4,664	The world total	35.0%	33.2%	33.6%	34.6%	34.8%	35.7%	35.4%	35.8%	36.3%	37.1%	38.6%	38.7%	39.1%	39.8%	40.2%	40.2%	40.7%	41.5%	41.9%	42.2%	42.0%	42.2%

3.1 Energy efficiency in average thermal power (2009-2011)



✓ **The Japanese average of thermal power, in spite of the low ratio of combined-cycle gas turbines (see next page), is excellent to a certain degree in energy efficiency.**

3.2 Power output share for thermal power during the period from 2009-2011



the output ratio of gas power generation increment later than 1990 (Many combined-cycle gas turbines are assumed to contribute to the increment, as there is a general tendency for energy efficiency that the higher this ratio is, the higher energy efficiency average of thermal power is.)

✓ **Before 1990 a number of gas power plants were built in Japan and the ratio of combined-cycle gas turbines is not so high. (However, the average energy efficiency of thermal power is excellent to a certain extent.)**

4. Summary

1. **Japan's coal power generation is excellent in energy efficiency even in the world**
2. **Both hardware including excellent coal power facilities such as steam conditions to be built and possessed and software including continued efforts such as operational repair and improvement are considered to contribute to efficiency**
3. **In the world, a number of coal power plants that are inferior in energy efficiency are required to improve efficiency from the viewpoint of CO2 emission reduction**
4. **The efficiency of gas power generation is strongly dependent on whether a combined-cycle gas turbines are installed or not***
5. **Many plants with combined-cycle gas turbines have been newly built or expanded over the past 15 years and Spain and the UK with the high ratio of combined-cycle gas turbines are excellent in energy efficiency**
6. **As Japan launched and started to operate gas power generation before 1990, the ratio of combined-cycle gas turbines is not so high. However, the averaged gas power or thermal generation efficiency shows the constant level**

* Please refer to p.12 for energy efficiency examples of combined cycle.

Appendix 1.a Energy efficiency of calculation frame (details)

Fuels

- ✓ Lignite is included in “coal", but peat is excluded.

The case of concrete deficiencies of IEA statistics

- ✓ The Spanish data of private power is excluded from evaluation due to explicit deficiencies, so only electric utilities are evaluated
- ✓ For some countries such as South Korea, data deficiencies are found in the first half of 1990s, the results are not shown in the figure during the period. (see p.4)

Appendix 1.b Energy efficiency of calculation frame (details)

Heat provided by CHP

- ✓ In an attempt to increase the heat supply in the CHP, there is a trade-off between the heat and power such as decrease in power supply [for the providers' position].
- ✓ In general, the heat is less accessible (relatively compared with power) such as large loss up to reach the consumers [for both positions of providers and consumers].
- ✓ Among the above, particularly considering both positions of providers and consumers, the heat times 0.175 is converted to the power in this analysis (*)
- ✓ In other words, 1 GJ heat provided by CHP is calculated equivalent to the power supply amount of (1000 / 3.6) * 0.175 = 48.611 kWh.

* The conversion factor "0.175 times" has been used worldwide, included in the conventional Ecofys analyses (e.g.,the following literature). Graus, W., Voogt., M., Worrell, E., International comparison of energy efficiency of fossil power generation. *Energy Policy*, **35**, pp.3936–3951, 2007.

Appendix 2. Generating-end / Sending-end and Impacts of LVH / HHV

Criteria in this paper

- ✓ This paper shows the generation efficiency, based on generation-end and LVH.

References

- ✓ In general, as the coal-fired has a high house rate compared to the gas-fired, from the sending end, a reduction in the percentage of coal-fired efficiency is apparently large.
- ✓ In general, LHV:HHV=0.95:1 in the coal (bituminous coal)-fired and LHV:HHV=0.90:1 in the gas-fired

600 thousand kW class coal-fired power plants (state-of-the-art, pulverized coal-fired and ultra-supercritical (USC)

(designed value)	LHV criteria	HHV criteria
generating-end	44%	42%
sending-end	41%	39%

400 thousand kW class gas-fired plants（a state-of-the-art combined cycle gas turbine）

(designed value)	LHV criteria	HHV criteria
generating-end	58%	52%
sending-end	57%	51%

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

Supplementary) LHV (lower heating value, net calorific value), compared to HHV (higher heating value, the total calorific value) is small due to the latent heat (used to water evaporation).