Comparative Analysis on Japan's CO_2 Emission Computation -- Gaps between Japanese GHG Inventory Report and IEA Statistics and Their Factor Decomposition --

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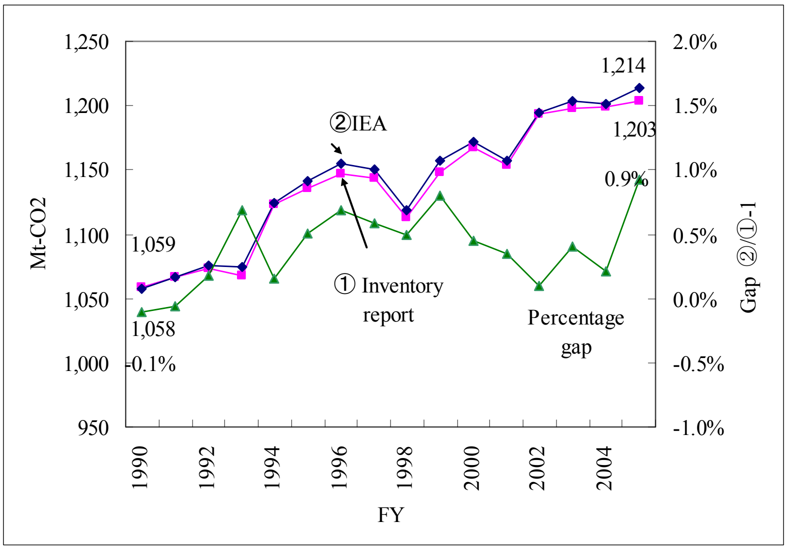
1. Introduction

Being used as Japan's energy-originated carbon dioxide emission data are estimates by two agencies. They are the greenhouse gas inventory report by the Ministry of the Environment and the CO_2 Emissions from Fuel Combustion by the International Energy Agency. Under the U.N. Framework Convention on Climate Change and the Kyoto Protocol, the GHG inventory report specifying GHG emission and absorption data is submitted by the Japanese government to the UNFCCC Secretariat. The IEA uses Japan-submitted energy consumption data for estimating CO_2 emissions based on the IPCC (Intergovernmental Panel on Climate Change) guidelines as revised in 1996. But the two CO_2 emission estimates do not match each other. The IEA's sector-by-sector estimates are largely different from those in the Japanese GHG inventory report.

GHG emission data are used for a wide range of areas as the first commitment period under the Kyoto Protocol begins. However, emission data users have little recognized gaps between the Japanese government and IEA data. The data are in a state of contradiction. In order to allow GHG emission data to be used properly for many analyses with right recognitions, the reporter would like to compile the gaps between the Japanese government and IEA data from a statistical viewpoint.

2. Comparison of Energy-originated CO_2 Emission Data in Japanese GHG Inventory Report and IEA Statistics

For fiscal 1990, energy-originated CO_2 emissions in the Japanese GHG inventory report were given at 1.059 billion t-CO_2, close to 1.058 billion t-CO_2 in the IEA statistics. For years after fiscal 1990, however, IEA data tended to exceed Japanese GHG inventory report data. For fiscal 2005, the Japanese GHG inventory report gave CO_2 emissions at 1.203 billion t-CO_2 against 1.214 billion t-CO_2 in the IEA statistics. While the average gap has been 0.5%, the fiscal 2005 gap came to some 1%. The Japanese GHG inventory report has estimated Japan's CO_2 emission growth between fiscal 1990 and 2005 at 12.0% against 13.6% in the IEA statistics. The deviation is large, given that it is difficult for Japan to achieve its 6% emission reduction goal under the Kyoto Protocol.

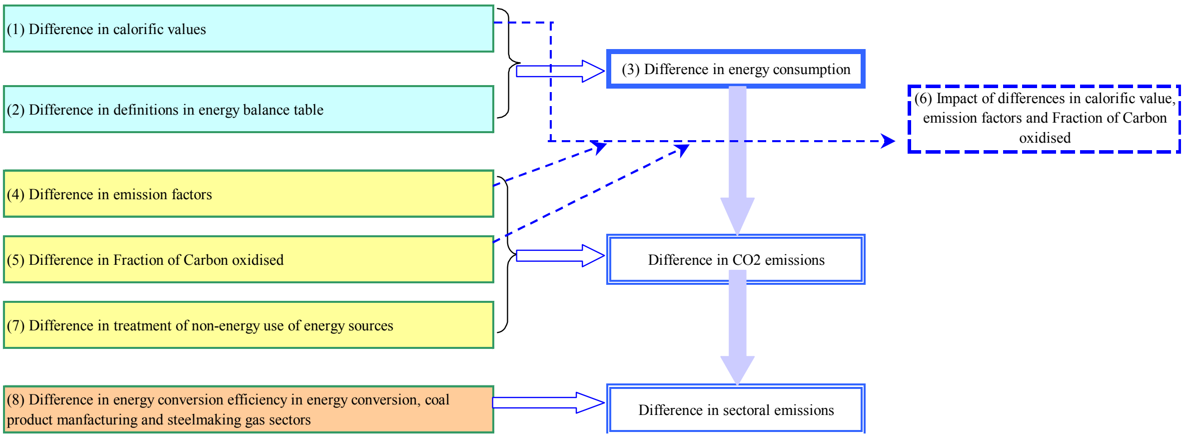


Sources: "Japan's Greenhouse Gas Emission Data," Greenhouse Gas Inventory Office; "CO_2 Emission from Fuel Combustion 2007," IEA

Figure 1 Comparison of Energy-originated CO_2 Emission Data

3. Putting in Order Statistical Differences between Japanese GHG Inventory Report and IEA Statistics

Both the Japanese GHG inventory report and IEA statistics have based energy-originated CO_2 emission estimates on Japan's energy balance table that overviews the nation's energy supply and demand. The reporter would like to put in order their gaps based on the energy balance table.



(Note) The numbers in the figure correspond to item numbers (1) to (8) in this section.

Figure 2 Outline of Statistical Differences between Japanese GHG Inventory Report and IEA Statistics

(1) Difference in calorific values

The Japanese GHG inventory report is based on the comprehensive energy statistics of the Agency for Natural Resources and Energy. The agency has adopted both the Japanese standard calorific values revised every five years in principle and the real calorific values revised every year. The calorific values for the IEA energy balance table as the source of the IEA CO_2 emission statistics are estimated by the IEA. IEA-estimated calorific values for petroleum products are universal in principle.

The calorific values for the ANRE comprehensive energy statistics are gross calorific values[1]. But the calorific values for the IEA energy balance table are net calorific values. Generally, net calorific values are 5% less than gross calorific values for coal and coil and 10% less for gas.

Calorific values in the ANRE comprehensive energy statistics are 2% less than in the IEA energy balance table for coal, 5-14% less for oil and 12% less for gas.

Table 1 Comparison of Calorific Values

	ANRE comprehensive energy statistics	IEA energy balance table	Calorific value ratio
	(A)	(B)	(B/A)
Coking coal	6,928 kcal／kg	6,777 kcal／kg	0.978
Steaming coal	6,139 kcal／kg	6,194 kcal／kg	1.009
Crude oil	9,126 kcal／L	8,671 kcal／L	0.950
Gasoline	8,266 kcal／L	7,886 kcal／L	0.954
Naphtha	8,027 kcal／L	7,923 kcal／L	0.987
Diesel oil	9,006 kcal／L	8,725 kcal／L	0.969
Fuel oil C	10,009 kcal／L	8,640 kcal／L	0.863
Natural gas	10,392 kcal／m^3	9,111 kcal／m^3	0.877

(Note) Standard calorific values are for the ANRE comprehensive energy statistics. Gross calorific values are adopted for the ANRE comprehensive energy statistics and net calorific values for the IEA energy balance table.
Sources: ANRE Comprehensive Energy Statistics, IEA Energy Balance Table

(2) Difference in definitions in energy balance table

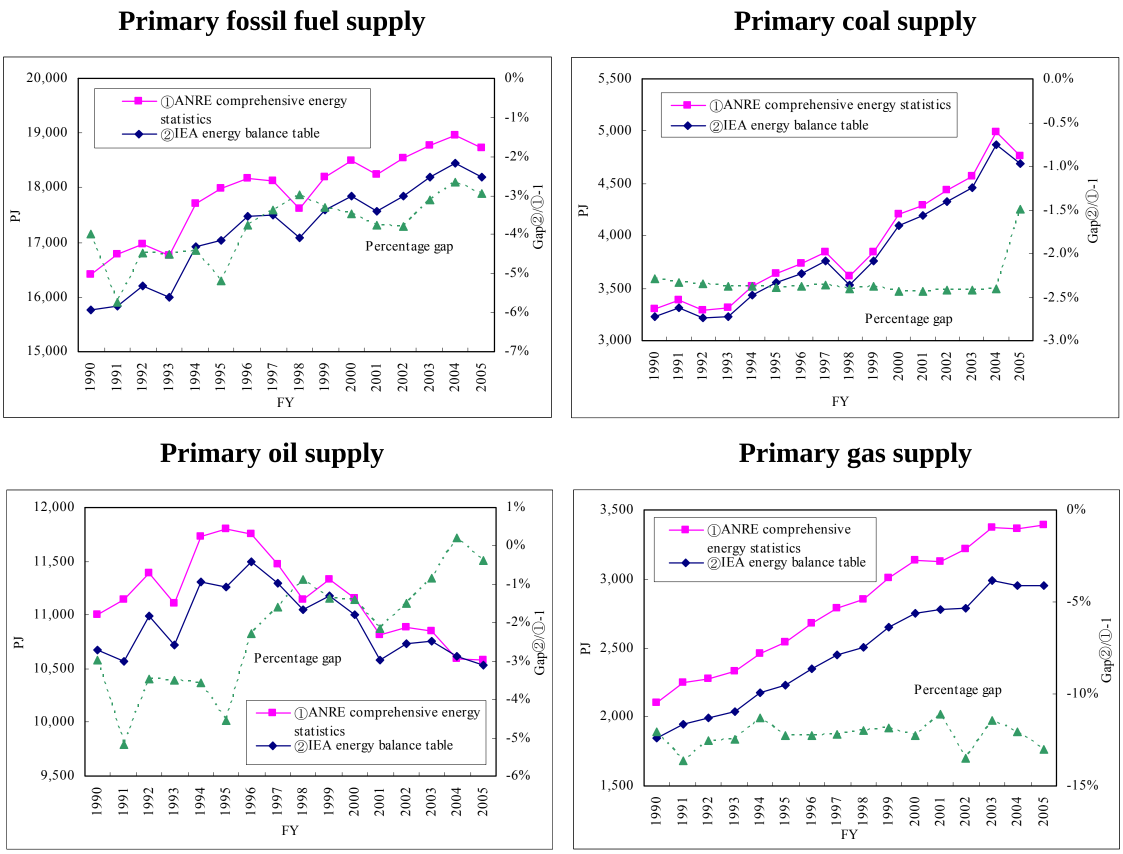
The IEA bases its energy balance table as the source of its CO_2 emission statistics on annual energy consumption questionnaires answered by the Japanese government.

The ANRE fills out the annual questionnaires in cooperation with the IEEJ. Basic data for filling out the questionnaires are from the ANRE comprehensive energy statistics. In order to adapt data to statistical definitions of the IEA annual questionnaires, however, the ANRE uses data other than those in the comprehensive energy statistics and make estimates for some questions. Therefore, energy consumption in the ANRE comprehensive energy statistics does not necessarily match IEA energy balance table data, even after adjustment for calorific value differences.

[1] One calorific value measure covers the evaporative latent heat that is lost due to evaporation and the other measure does not. The lower (net) calorific value does not cover the evaporative latent heat, while the higher (gross) calorific value does so.

(3) Difference in energy consumption

The differences in (1) calorific values and (2) energy balance table definitions have caused gaps between calorie-based energy consumption data in the ANRE comprehensive energy statistics and the IEA energy balance table. Fossil fuel consumption in the IEA table is 3-6% less than in the ANRE statistics. Consumption in the IEA table is some 3% less than in the ANRE statistics for coal among energy sources, 1-5% less for oil and over 10% less for gas. The wide difference in gas consumption is attributable to the large gap between gross and net calorific values.

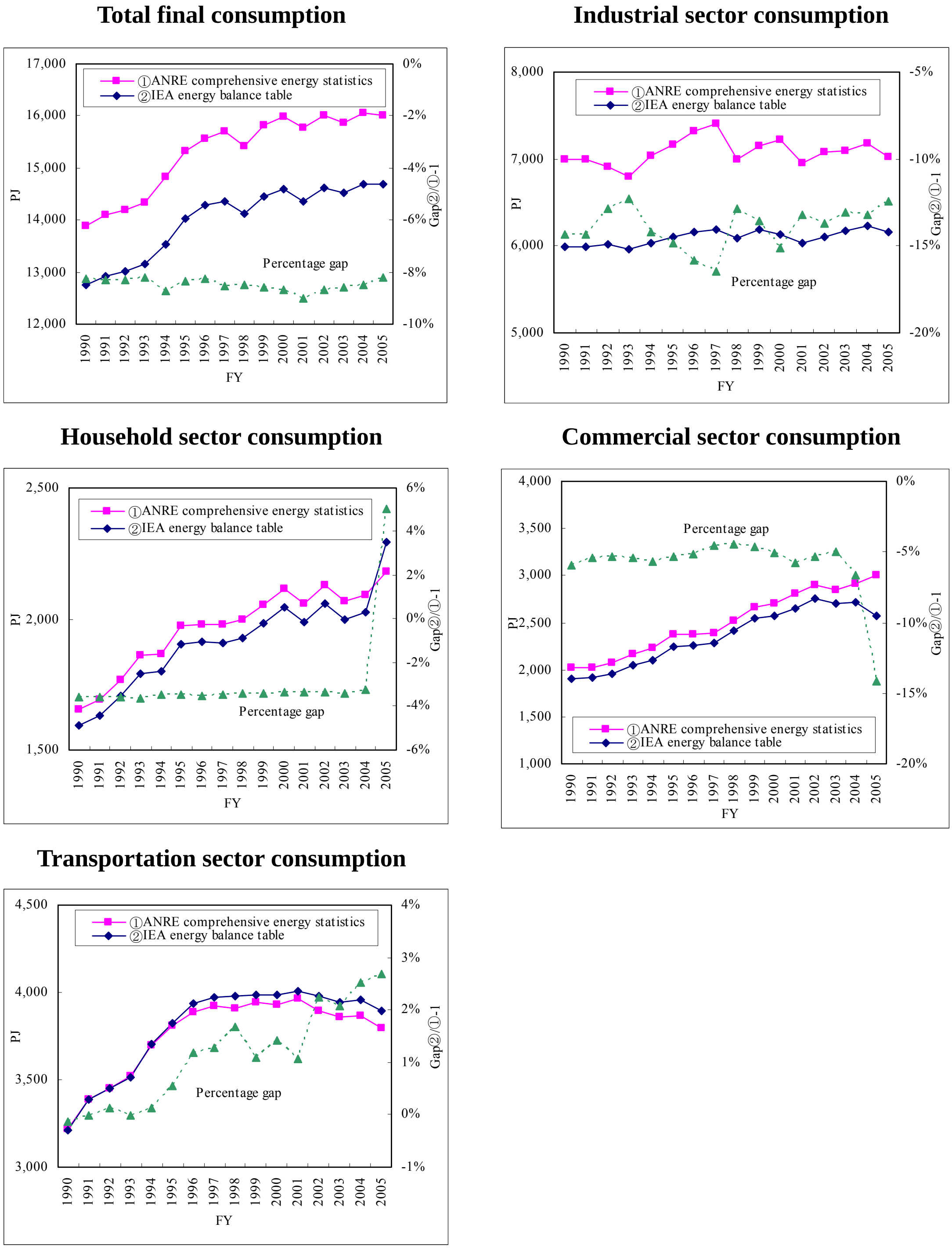


Note: Gross calorific values are adopted for the ANRE comprehensive energy statistics and net calorific values for the IEA energy balance table.
Sources: ANRE Comprehensive Energy Statistics, IEA Energy Balance Table

Figure 3 Comparison of Primary Fossil Fuel Supply Data

Similarly, total final energy consumption in the IEA table is 8-9% less than in the ANRE statistics. Final energy consumption in the IEA table is some 15% less than in the ANRE statistics for the industrial sector, some 4% less for the household sector and some 5% (some 15% in fiscal 2005) less for the commercial sector. For the transportation sector, however, final energy consumption in the IEA table is up to 3% more than in the ANRE statistics.

The differences in energy consumption data are attributable primarily to the gap between gross and net calorific values. As for the industrial sector, however, the energy consumption gap is attributable partly to a difference in energy consumption for steelmakers that account for more than 20% of industrial sector energy consumption. The steel industry energy consumption data gap emerges from a difference in the definition of the process for conversion of coke into blast furnace gas.



Note: Gross calorific values are adopted for the ANRE comprehensive energy statistics and net calorific values for the IEA energy balance table.
Sources: ANRE Comprehensive Energy Statistics, IEA Energy Balance Table

Figure 4 Comparison of Total Final Energy Consumption Data

(4) Difference in emission factors

Emission factors (CO_2 emissions per calorific value) used for the Japanese GHG inventory report are exclusively estimated by the Ministry of the Environment (on a gross calorific value basis). Those for some energy sources are updated annually. The IEA uses emission factors (average values on a net calorific value basis) recommended by the 1996 revised version of the IPCC guidelines.

Table 2 Comparison of Emission Factors

Gg-C/10^{10}kcal

	Japanese GHG inventory report	IEA statistics	Emission coefficient ratio
	(A)	(B)	(B/A)
Coking coal	1.0260	1.0802	1.053
Steaming coal	1.0344	1.0802	1.044
Crude oil	0.7811	0.8374	1.072
Gasoline	0.7656	0.7913	1.034
Naphtha	0.7606	0.8374	1.101
Diesel oil	0.7840	0.8457	1.079
Fuel oil C	0.8180	0.8834	1.080
Natural gas	0.5819	0.6406	1.101

Note: Gross calorific values are adopted for the Japanese GHG inventory report and net calorific values for the IEA statistics.
Sources: "National GHG Inventory Report (NIR) of Japan," Greenhouse Gas Inventory Office; "CO_2 Emission from Fuel Combustion 2007," IEA

(5) Differences Fraction of Carbon Oxidised

In addition to emission factors, Fraction of Carbon Oxidised indicating combustion (oxidation) conditions for energy sources are taken into account for computation of CO_2 emissions. The Japanese GHG inventory report puts the oxidation factor at 1.0 (complete combustion) for all of coal, oil and gas. But the IEA uses the (universal) factors recommended by the 1996 version of the IPCC guidelines.

Table 3 Comparison of Fraction of Carbon Oxidised

	Japanese GHG inventory report	IEA statistics
Coal	1.0	0.980
Oil	1.0	0.990
Gas	1.0	0.995
Heat for power generation	1.0	0.990

Sources: "National GHG Inventory Report (NIR) of Japan," Greenhouse Gas Inventory Office; "CO_2 Emission from Fuel Combustion 2007," IEA

(6) Impact of differences in calorific values, emission factors and Fraction of Carbon Oxidised

Gross calorific values are adopted for the Japanese GHG inventory report against net calorific values for the IEA statistics. Irrespective of such difference, the same unit emissions are expected to result from the calculating formula of "Calorific value × Emission factor × Oxidation factor." But there are gaps between unit emissions (emissions per energy consumption) in the Japanese GHG inventory report and the IEA statistics. The gap is slightly more than 3% for steaming coal, slightly less than 8% for fuel oil C, slightly less than 4% for diesel oil and some 4% for natural gas. Even if energy consumption is the same for the Japanese GHG inventory report and the IEA statistics, emissions in the Japanese report deviate by 3-8% from those in the IEA statistics depending on differences in calorific values, emission factors and Fraction of Carbon Oxidised.

Table 4 Impacts of Differences in Calorific Values, Emission Factors and Fraction of Carbon Oxidised

	①Japanese GHG inventory report				②IEA statistics				Emission ratio ②/①
	Calorific value	Emission coefficient	Oxidation coefficient	Unit emissions	Calorific value	Emission coefficient	Oxidation coefficient	Unit emissions	
	kcal／kg, L, m^3	Gg-C/10^{10}kcal		g-C/kg, L, m^3	kcal／kg, L, m^3	Gg-C/10^{10}kcal		g-C/kg, L, m^3	
Coking coal (kg)	6,928	1.0260	1.00	711	6,777	1.0802	0.98	717	1.009
Steaming coal (kg)	6,139	1.0344	1.00	635	6,194	1.0802	0.98	656	1.033
Crude oil (L)	9,126	0.7811	1.00	713	8,671	0.8374	0.99	719	1.008
Gasoline (L)	8,266	0.7656	1.00	633	7,886	0.7913	0.99	618	0.976
Naphtha (L)	8,027	0.7606	1.00	611	7,923	0.8374	0.99	657	1.076
Diesel oil (L)	9,006	0.7840	1.00	706	8,725	0.8457	0.99	731	1.035
Fuel oil C (L)	10,009	0.8180	1.00	819	8,640	0.8834	0.99	756	0.923
Natural gas (m^3)	10,392	0.5819	1.00	605	9,111	0.6406	1.00	581	0.960

Note: Unit emissions = Calorific value × Emission factor × Oxidation factor

Sources: "National GHG Inventory Report (NIR) of Japan," Greenhouse Gas Inventory Office; "CO_2 Emission from Fuel Combustion 2007," IEA

(7) Difference in treatment of non-energy use of energy sources

CO_2 emissions for the Japanese GHG inventory report are computed in the following way[2]:

$$E_{ij}=\Sigma(A_{ij}-N_{ij})*GCV_i*10^{-3}*GEF_i*OF_i*44/12$$

E: CO_2 emissions(t-CO_2)

A: Energy consumption(t, kL, m^3)

N: Non-energy use of energy sources(t, kL, m^3)

GCV: Gross calorific value (MJ/kg, MJ/L, MJ/ m^3)

GEF: GCV-based carbon emission factor (t-C/TJ)

OF: Oxidation factor

i: Energy source

j: Sector

[2]The molecular weight of CO_2 is 44 covering 12 for carbon (C) and 16 for oxygen (O). A carbon equivalent tonnage is multiplied by 44/12 for its conversion into a CO_2 equivalent tonnage.

For the Japanese GHG inventory report, non-energy use of energy sources is considered as emitting no CO_2.

CO_2 emissions for the IEA statistics are computed in the following way:

$$E_{ij}=\Sigma(A_{ij}-N_{ij}*CS_i)*NCV_i*10^{-3}*NEF_i*OF_i*44/12$$

E: CO_2 emissions(t-CO_2)

A: Energy consumption(t, kL, m^3)

N: Non-energy consumption(t, kL, m^3)

NCV: Net calorific value (MJ/kg, MJ/L, MJ/ m^3)

NEF: NCV-based carbon emission factor (t-C/TJ)

OF: Oxidation factor

CS: Subtraction factor for non-energy use of energy sources

i: Energy source

j: Sector

For the IEA statistics, some part of non-energy use (consumption of energy sources as raw materials) is considered as emitting CO_2. Relevant energy sources are listed in the following table. Relevant non-energy use is multiplied by the following IPCC-defined subtraction factors into emissions for subtraction. The remaining emissions after the subtraction are booked as final emissions.

Table 5 Subtraction Factors for Non-energy Use of Energy Sources under 1996 IPCC Guidelines

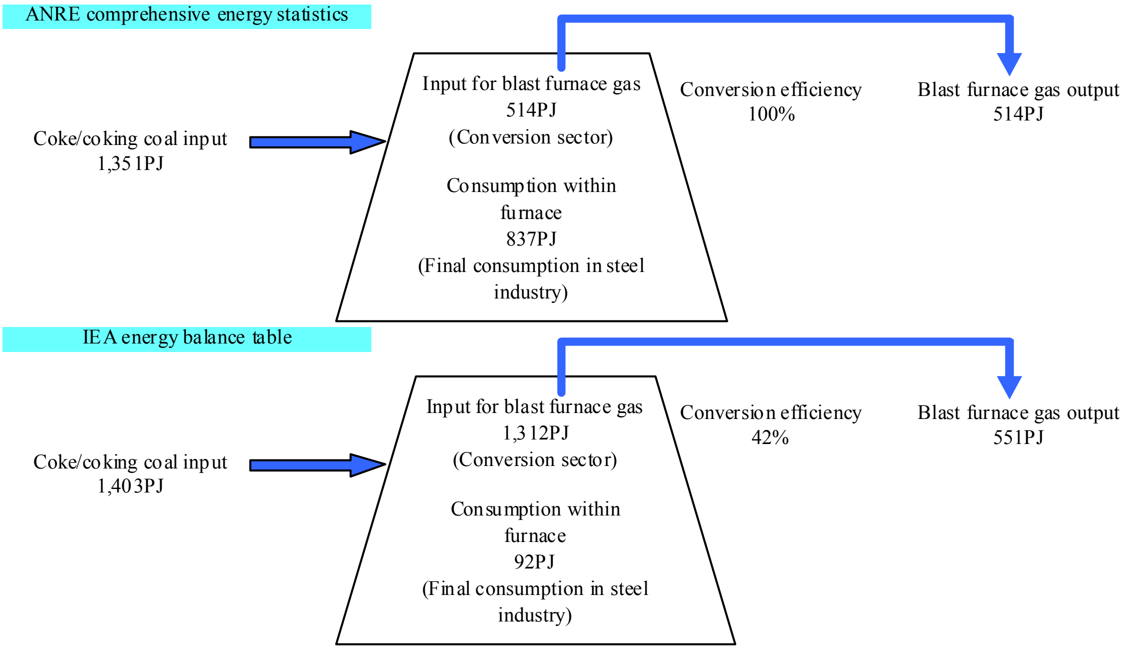
	Subtraction factor
Naphtha	0.80
Lubricant oil	0.50
Asphalt	1.00
Coking coal, coal tar	0.75
Natural gas	0.33
Diesel oil	0.50
LPG	0.80
Ethane	0.80

Note: For example, CO_2 is considered as being emitted by 20% of naphtha consumption for non-energy purposes.
Source: "CO_2 Emission from Fuel Combustion 2007," IEA

(8) Difference in energy conversion efficiency in energy conversion, coal product manufacturing and steelmaking gas sectors

In the pig iron production process, some carbon portion of coke and coking coal for injection in a steelmaking blast furnace is oxidized to emit coal gas (blast furnace gas). The definition of the coke-to-blast furnace gas conversion efficiency for the ANRE comprehensive energy statistics is different from that for the IEA energy balance table. The conversion efficiency is defined as 100% with no energy loss taken into account for the ANRE comprehensive energy statistics. For the IEA energy balance table, however, it is defined as about 40%[3].

By defining a lower conversion efficiency than adopted for the ANRE comprehensive energy statistics, the IEA energy balance table makes a lower estimate for coke consumption in the steel industry while giving a higher estimate for coke put into for blast furnace gas production in the conversion sector. While no difference exists between quantities of coke and coking coal for injection in the ANRE comprehensive energy statistics and the IEA energy balance table, the steel industry's coke consumption in the IEA table is some one-ninth of that in the ANRE statistics.



Note: Calorific values of coke and coking coal input in the ANRE comprehensive energy statistics and the IEA energy balance table do not match due to their calorific value gap. But coke and coking coal input quantities in the two statistics are almost the same.
Sources: ANRE Comprehensive Energy Statistics, IEA Energy Balance Table

Figure 5 Difference in Energy Conversion Efficiency in Energy Conversion, Coal Product Manufacturing and Steelmaking Gas Sectors (FY 2005)

[3] The coke-to-blast furnace gas conversion efficiency for the IEA energy balance table changes every year according to the IEA's own estimates, ranging from 40% to 43%.

4. Comparative Analysis of CO_2 Emissions and Factor Decomposition

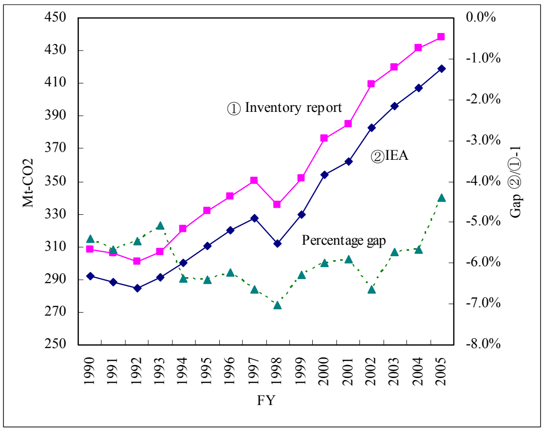
(1) Comparison of emissions by energy source

This section deals with a comparative analysis of emissions in the Japanese GHG inventory report and the IEA statistics. In a bid to make emission definitions in the two compatible to the minimum extent, the reporter has used indirect emissions (after electricity and heat allocation) in the Japanese GHG inventory report and the sectoral approach (fossil fuel plus proportional electricity allocation)[4] in the IEA statistics.

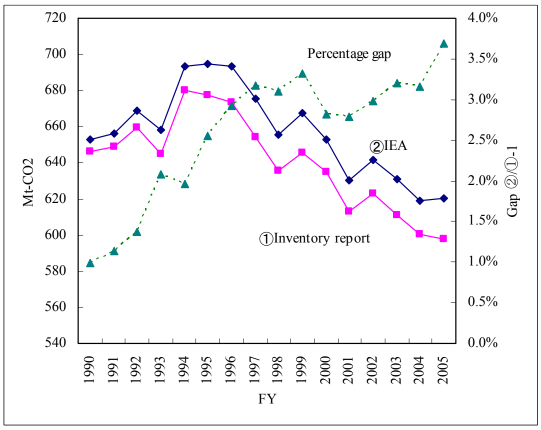
Coal-based emissions in the IEA statistics are 6-8% less than in the Japanese GHG inventory report. Oil-based and gas-based emissions in the IEA statistics are 3-4% more than in the Japanese report.

[4] Used as emissions in the Japanese GHG inventory report are indirect emissions (after electricity and heat allocation) in "Japan's Greenhouse Gas Emission Data" by the Greenhouse Gas Inventory Office. In a bid to adapt IEA statistics data to the indirect emissions, the reporter has distributed (estimated) emissions for power generation (proportional electricity allocation) to sector-by-sector emissions for final fossil fuel demand in accordance with electricity consumption.

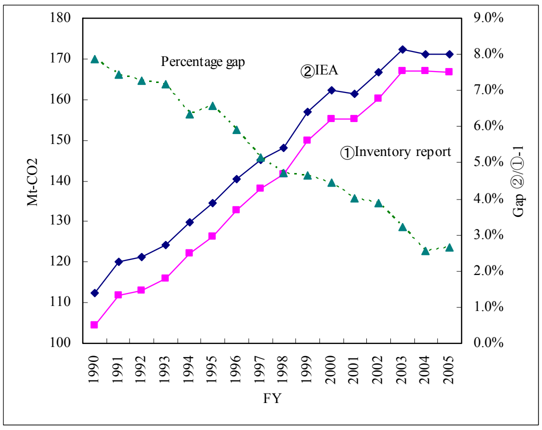
Coal-based emissions



Oil-based emissions



Gas-based emissions



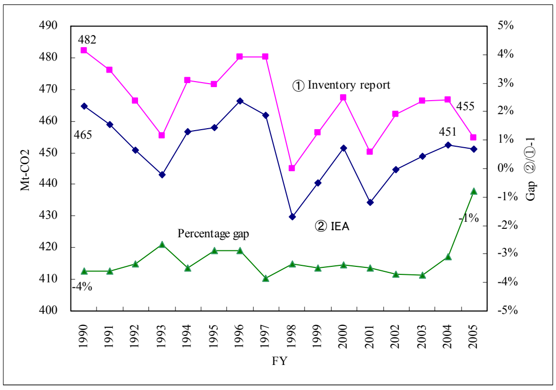
Sources: "Japan's Greenhouse Gas Emission Data," Greenhouse Gas Inventory Office; "CO_2 Emission from Fuel Combustion 2007," IEA

Figure 6 Comparison of Emissions by Energy Source

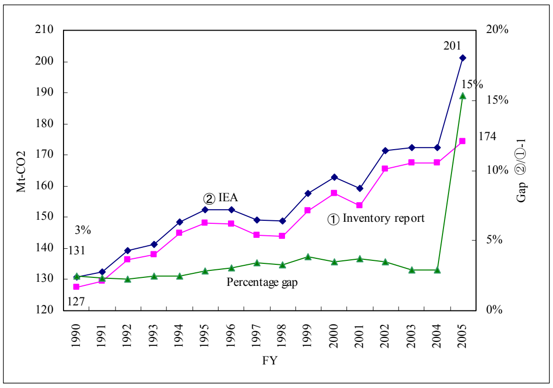
(2) Comparison of sector-by-sector emissions

Among sector-by-sector emissions, the industrial sector's emissions in the IEA statistics are 3-4% less than in the Japanese GHG inventory report. But the percentage gap in fiscal 2005 narrowed to some 1%. The gap in the household sector's emissions in the two reports has been linked to that in energy consumption. The gap remained around 2% before widening to about 15% in fiscal 2005. As for the commercial sector, emissions in the IEA statistics were some 2% more than in the Japanese report until fiscal 2004 before becoming 10% less in fiscal 2005. The commercial sector's emissions are linked to its energy consumption. Little gap exists in the transportation sector's emissions. The energy conversion sector's emissions in the IEA statistics have been about 15% more than in the Japanese report.

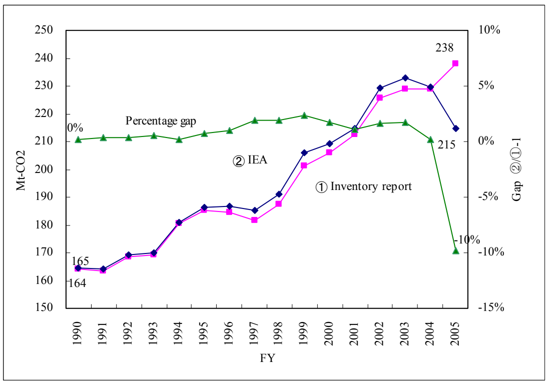
Industrial sector



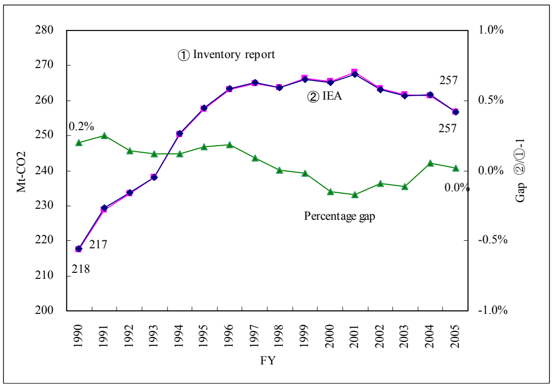
Household sector



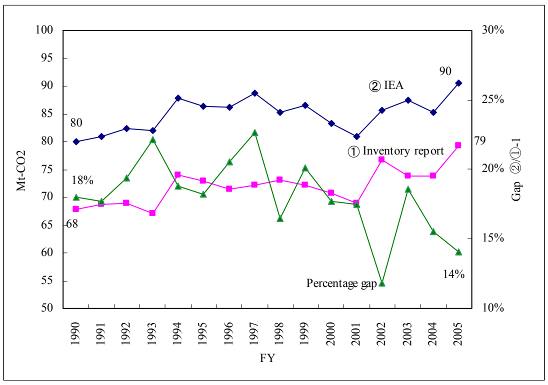
Commercial sector



Transportation sector



Energy conversion sector



Sources: "Japan's Greenhouse Gas Emission Data," Greenhouse Gas Inventory Office; "CO_2 Emission from Fuel Combustion 2007," IEA

Figure 7 Comparison of Sector-by-Sector Emissions

(3) Factor decomposition

Emissions in the IEA statistics matched those in the Japanese GHG inventory report in fiscal 1990 before beginning to exceed them. The gap expanded gradually, reaching about 1% in fiscal 2005. The difference in fiscal 1990 is ignorable. Accumulation of factor decomposition for the 15 years after the year can thus be used for analyzing the difference that emerged in the 15 years or is shown for fiscal 2005.

In order to quantitatively assess factors behind the difference between the Japanese GHG inventory report and the IEA statistics, the reporter has decomposed factors behind the difference (emissions in the IEA statistics minus those in the Japanese GHG inventory report). The analysis period has been set between fiscal 1990 and 2005 in accordance with the IEA statistics.

The factor decomposition has been done in the following way:

$$C_2 - C_1 = C_2/E_2 * E_2 - C_1/E_1 * E_1$$

$$\Delta(C_2 - C_1) = (C_2/E_2) * \Delta E_2 - (C_1/E_1) * \Delta E_1 \quad \text{Energy consumption factor}$$

$$+ \Delta(C_2/E_2) * E_2 - \Delta(C_1/E_1) * E_1 \quad \text{Carbon intensity factor}^{5}$$

$$+ \Delta(C_2/E_2) * \Delta E_2 - \Delta(C_1/E_1) * \Delta E_1 \quad \text{Confounding term}$$

C Emissions (C_1: Japanese GHG inventory report, C_2: IEA statistics)

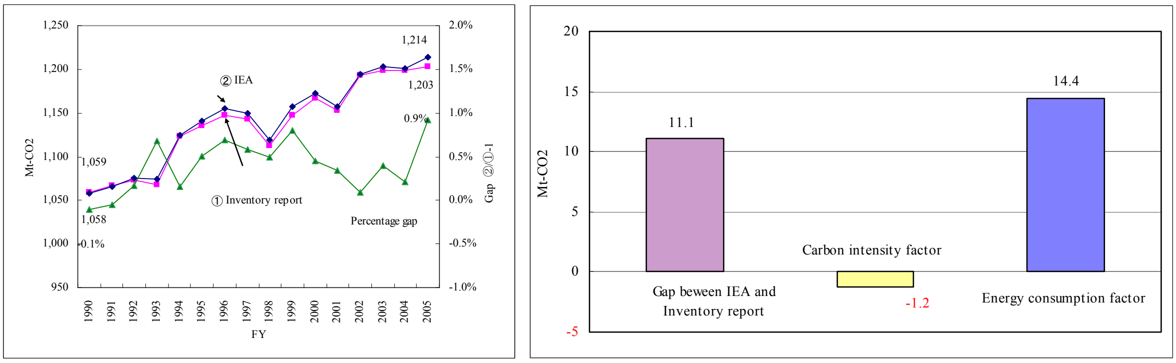
E Energy consumption

(E_1: Japanese GHG inventory report, E_2: IEA statistics)

The decomposition of factors behind the Japanese GHG inventory report's gap with the IEA statistics indicates that the energy consumption factor' contributions came to 14.4 Mt-CO_2 against the nominal gap of 11.1 Mt-CO_2. This means that the IEA statistics emissions’ excess over the Japanese GHG inventory report emissions has emerged primarily from fossil fuel consumption (calorific values).

[5] Contributions by changes in unit emissions accompanying energy consumption mix changes.

Comparison of emissions **Factor decomposition results**

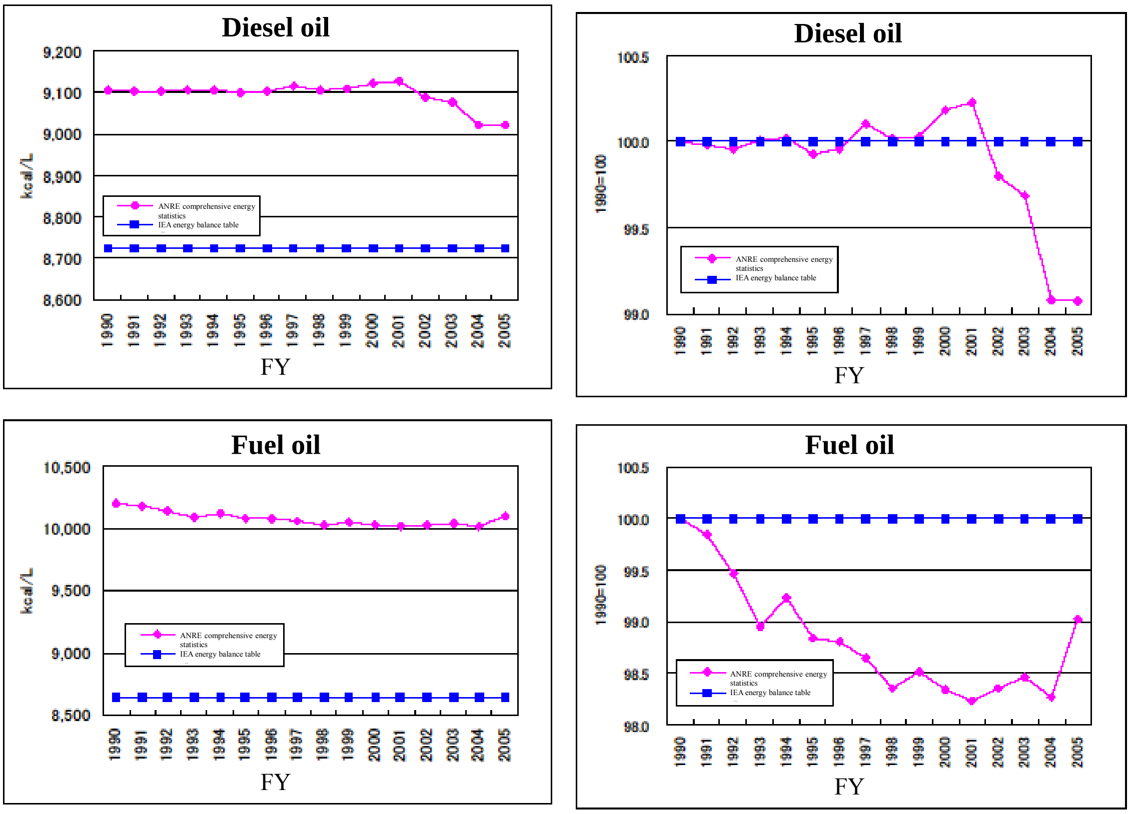


Note: Because of the confounding term, components do not add up to the total

Figure 8 Results of Decomposition of Factors behind Emission Gap between Japanese GHG Inventory Report and IEA Statistics (FY 2005)

The first reason for the emission gap may be the calorific value difference. The calorific values in the ANRE comprehensive energy statistics, on which the inventory report is based, include the Japanese standard calorific value that is updated every five years and the real calorific value that is computed every year in the statistics. Particularly, the real calorific value of petroleum products has changed year by year. Over recent years, it has tended to decline. The decline is remarkable for diesel oil and fuel oil. The IEA enerngy balance table's calorific value for petroleum products is universal, remaining unchanged throughout the assessment period.

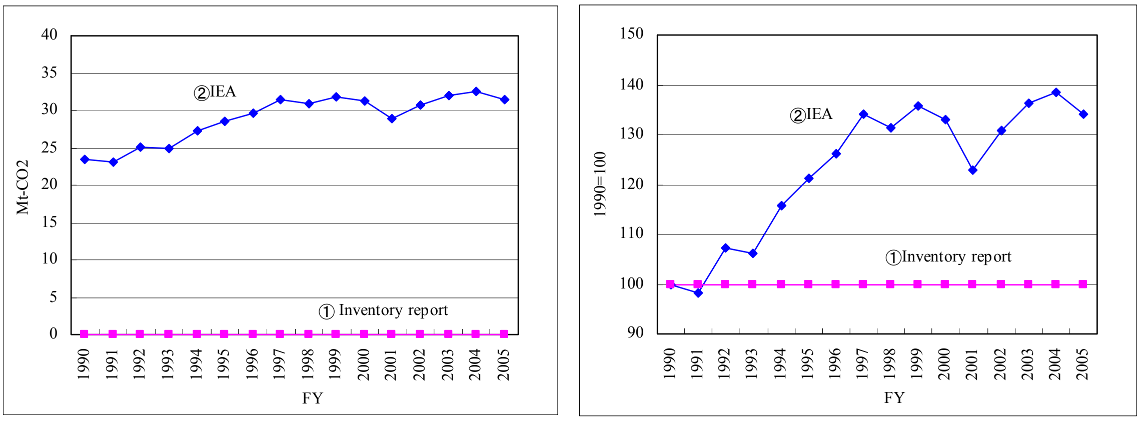
An apparent reason why emissions in the IEA statistics have grown greater than those in the Japanse GHG inventory report is a downward trend of calorific values in the ANRE comprehensive energy statistics. As a calorific value change does not affect the emission factor, or emissions per calorific value, the falling calorific value leads to a decline in emissions.



Note: Gross calorific values are adopted for the ANRE comprehensive energy statistics and net calorific values for the IEA energy balance table.
Sources: ANRE Comprehensive Energy Statistics, IEA Energy Balance Table

Figure 9 Changes in Calorific Values in ANRE Comprehensive Energy Statistics and IEA Energy Balance Table

The second reason for the growing emission gap may be the difference in the treatment of non-energy use of energy sources. The Japanese GHG inventory report considers non-energy use as emitting no CO_2, while the IEA statistics regards some portion of non-energy use as causing CO_2 emissions. The fact that emissions from non-enegy use of energy sources in the IEA statistics have been growing greater than those in the Japanese GHG inventory report is linked to an upward trend of emisions from non-energy use of energy sources in the IEA statistics.



Sources: "Japan's Greenhouse Gas Emission Data," Greenhouse Gas Inventory Office; "CO_2 Emission from Fuel Combustion 2007," IEA

Figure 10 Changes in Emissions from Non-energy Use of Energy Sources in Japanese GHG Inventory Report and IEA Statistics

5. Conclusion

This report has dealt with a comparative analysis of CO_2 emissions in the Japanese GHG inventory report and the IEA statistics. The gap in CO_2 emissions has resulted from a combination of various factors including differences in energy consumption, statistical definitions and concepts of emission computation. The decomposition of energy consumption and carbon intensity factors behind the emission gap indicates that the energy consumption (calorific value) difference has made greater contributions to the emission gap than the carbon intensity difference. This may be primarily attributable to the calorific value gap. While calorific values for petroleum products change every year in the ANRE comprehensive energy statistics, the IEA energy balance table leaves calorific values unchanged. It is also attributable to the difference in the treatment of non-energy use of energy sources.

As the first commitment period of the Kyoto Protocol begins, data for CO_2 emissions from energy sources are expected to be used for more analyses. Analysts using these data should fully understand statistical differences between these data.

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