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Chapter Two : National Greenhouse Gas Inventories of Taiwan

2.1 Method and Its Uncertainty on Estimating the Emission of Greenhouse Gases by IPCC

The statistics and estimation of the emission of greenhouse gases practiced internationally are based on the 'IPCC Draft Guidelines for National Greenhouse Gas Inventories' (hereinafter referred to IPCC method) set by the Intergovernmental Panel on Climate Change, IPCC. In recent years, the statistics of greenhouse gas emission in Taiwan are also mainly based on the estimation by IPCC method, but some of the information also includes local measurements on emission. The reliability and accuracy on the estimation of carbon dioxide emission are high, but those of methane and nitrous oxide are relatively low. In addition, the statistics on emission of other greenhouse gases are not complete, yet. Furthermore, the government is also monitoring the emission of greenhouse gases and estimating the carbon dioxide removal capability of forests and offshore seawater.

In 1994, the IPCC method was passed after several consultations by the experts of IPCC and IEA in 1993, and further revised at a meeting of experts in 1995. The revised version announced in 1996 not only increases and amends the original estimation method but also specifies the quantified description of the accuracy on estimated data that the uncertainty of the data can be determined.

The IPCC method suggests that the governments calculate the emission and removal of important greenhouse gases according to the following 6 sectors:

1. Energy: the total emission of greenhouse gases by energy utilization includes the production of greenhouse gases on the use of fuels, the production, transportation, storage and transmission processes of energy, but not counting the part used in international bunkers.
2. Industrial Processes: not counting the emission from the use of energy, the total emission of greenhouse gases produced in industrial processes should be reported individually according to International Standard Industrial Classification of all Economic Activities.
3. Agriculture: the estimation of the emission of greenhouse gases according to agricultural activities does not include the estimation from the combustion of biomass fuels.
4. Land Use Change and Forestry: the emission and removal of greenhouse gases from the land use change and forestry.
5. Waste: the emission of greenhouse gases from landfills and treatment of wastewater.
6. Solvent and Other Product Use: the IPCC has yet to suggest the estimation method on the emission of non-methane volatile organic carbon (NMVOC) from the use of solvent and other materials containing volatile carbons.

The Information needed for estimating the emission of greenhouse gases by IPCC method includes two categories of activity data and the emission factor. In calculating the carbon dioxide emission from the combustion of fossil fuels, the activity data are the measurements of the quantity of all kinds of fossil fuels used, and the emission factor is the amount of greenhouse gases emitted from the technique used by individual fuels. The activity data may be taken from the official yearly statistical information from the government, or investigation should be carried out if this is unavailable. If the emission factor is not established, value suggested by IPCC may be used. But the value suggested by IPCC is a common value that would not reflect the special characteristics of individual country or area. Hence, IPCC encourages each participating government to carry out her own investigation that the local emission factor may be used to improve the accuracy of the information. In addition, IPCC requests all the reference materials of activity data and emission factor of each member government to be submitted for appraisal by its experts.

The main elements that were revised in the 1996 IPCC method of estimating greenhouse gases are as follows:

1. Energy : It provides method for simple calculation of Tier 1 gases excluding carbon dioxide and sulfur dioxide and Tier 1 calculation of sectoral emission of carbon dioxide, integrates calculating

method for Tier 2 air vessels, incorporates the automobile manufacturers in the calculations on the sources, as well as suggests new emission factors for combustion of biomass fuels and mobile sources.

2. Industrial Processes: It adds new greenhouse gases to include hydrofluorocarbons (HFCs), hexafluoride sulfur (SF6), perfluorocarbons (PFCs), ozone and aerosol precursors etc.
3. Agricultural Sector: It revises calculating units of nitrous oxide to incorporate nitrous oxide emission sources from soil and livestock, and modifies the emission factors and quantities of methane emission from rice cultivation.
4. Land Use Change and Forestry: It improves information contents in activity data including quality and quantity of biological materials on earth, forestry conversion rates, as well as adding calculation of carbon in soil.
5. Waste: It revises the definition of treatment (landfill, abandon, etc.), provides more data on ratios of degradable organic carbon in garbage, and modifies categorization of wastewater treatment such as industrial, commercial and residential waste water, etc.

Taiwan's Environmental Protection Administration (EPA) used the IPCC GHG Software (version 1.1) to estimate the 1990~2000 National GHG inventories and established an electronic database using the UNFCCC Common Reporting Format (UNFCCC CRF, v1.01). Tables 2.1 through 2.5 are Taiwan's national greenhouse gas inventories in 1990, 1994, 1996, 1999 and 2000, respectively, showing anthropogenic emissions and removal by sink of carbon dioxide, methane, and nitrous oxide. Under the auspices of the EPA, the Energy Commission, and the Council of Agriculture, the emissions of carbon dioxide, methane and nitrous oxides in Taiwan area have been estimated using IPCC method as well as measurements. The estimation of carbon dioxide emission basically falls within the range of uncertainty mentioned in the IPCC method. On the other hand, the differences between the measurements and the IPCC estimation of

Table 2.1 Carbon Dioxide, Methane and Nitrous Oxide Emission Inventory of Taiwan in 1990

Units : thousand metric tons

GHG Emission Source and Sink Categories	Carbon Dioxide	Methane	Nitrous Oxide
National Total (Net) Emission	114,620.19	663.27	45.16
1. Energy	120,969.06	80.75	1.43
A. Combustion from Fuels (reference)	113,539.83		
(sectoral)	120185.55	9.59	1.43
1. Energy Industry	46,185.55	1.21	0.64
2. Manufacturing Industries and Construction	43,740.31	3.22	0.54
3. Transport	22,329.07	4.12	0.19
4. Other Sectors	4,654.65	0.17	0.01
5. Other	4,059.48	0.87	0.05
B. Fugitive Emissions from Fuels	0.00	71.16	0.00
1. Solid Fuels	NE	37.32	0.00
2. Oil and Natural Gas	NE	33.84	0.00
2. Industrial Processes	11,547.17	0.23	0.59
A. Mineral Products	10,445.42	0.00	0.00
B. Chemical Industry	461.82	0.23	0.59
C. Metal Production	639.95	0.00	0.00
D. Other Production	0.00	NA	NA
E. Production of Halocarbons and SF6	NE	NA	NA
F. Consumption of Halocarbons and SF6	NE	NA	NA
G. Other	0.00	0.00	0.00
3. Solvent and Other Product Use	0.00	NA	0.00
4. Agriculture	0.00	119.45	41.58
A. Enteric Fermentation	NA	21.72	NA
B. Manure Management	NA	38.28	2.67
C. Rice Cultivation	NA	57.64	NA
D. Agricultural Soil	NO	0.00	38.87
E. Prescribed Burning of Savannas	NA	0.00	0.00
F. Field Burning of Agricultural Residues	NA	1.81	0.04
G. Other	NA	0.00	0.00
5. Land-Use Change and Forestry	-17,896.06	0.01	0.00
6. Waste	0.00	462.83	1.56
A. Solid Waste Disposal on Land	NE	445.33	NA

B. Wastewater Handling	NA	17.50	1.56
C. Waste Incineration	NE	0.00	0.00
D. Other	NE	0.00	0.00
7. Others	0.00	0.00	0.00
Memo Items:			
International Bunkers	6,612.36	0.00	0.00
Aviation	1,723.61	0.00	0.00
Marine	4,889.25	0.00	0.00
Multiple Operations	NE	NE	NE
CO2 Emissions from Biomass	NE	NE	NA

GHG Emission Source and Removal	CO2 Emission	CO2 Removal	Net CO2 Removal	CH4	N2O
Total Land-Use Change and Forestry	2,753	-20649	-17,896	0.0	0.0
A. Change in Forest and Other Woody Biomass Stocks	501	-20,570	-20,070		
B. Forest and Grassland Conversion	2,252			0.0	0.0
C. Abandonment of Managed Lands	NE	-78	-78		
D. CO2 Emissions and Removals from Soil	NE	NE	NE		
E. Other (Please Specify)					

Source: Environmental Protection Administration of the Executive Yuan (2001)

Table 2.2 Carbon Dioxide, Methane and Nitrous Oxide Emission Inventory of Taiwan in 1994

Units : thousand metric tons

GHG Emission Source and Sink	Categories Carbon	Dioxide Methane	Nitrous Oxide
National Total (Net) Emission	152,988.84	954.47	50.14
1. Energy	158,842.81	103.94	1.78
A. Combustion from Fuels (reference)	151,242.69		
(sectoral)	158,842.81	12.42	1.78
1. Energy Industry	69,865.42	1.45	0.81
2. Manufacturing Industries and Construction	50,268.07	3.77	0.63
3. Transport	29,959.72	5.74	0.27
4. Other Sectors	5,286.58	0.58	0.02
5. Other	3,463.02	0.88	0.05
B. Fugitive Emissions from Fuels	0.00	91.52	0.00
1. Solid Fuels	NE	48.63	0.00
2. Oil and Natural Gas	NE	42.89	0.00
2. Industrial Processes	14,493.70	0.22	0.54
A. Mineral Products	13,485.94	0.00	0.00
B. Chemical Industry	485.14	0.22	0.54
C. Metal Production	549.62	0.00	0.00
D. Other Production	0.00	NA	NA
E. Production of Halocarbons and SF6	NA	NA	NA
F. Consumption of Halocarbons and SF6	NA	NA	NA
G. Other	0.00	0.00	0.00
3. Solvent and Other Product Use	0.00	NA	0.00

4. Agriculture	0.00	118.53	46.11
A. Enteric Fermentation	NA	25.35	NA
B. Manure Management	NA	45.60	3.32
C. Rice Cultivation	NA	45.94	NA
D. Agricultural Soil	NO	0.00	42.75
E. Prescribed Burning of Savannas	NA	0.00	0.00
F. Field Burning of Agricultural Residues	NA	1.64	0.04
G. Other	NA	0.00	0.00
5. Land-Use Change and Forestry	-20,347.67	0.01	0.00
6. Waste	0.00	731.77	1.71
A. Solid Waste Disposal on Land	NE	713.18	NA
B. Wastewater Handling	NA	18.59	1.71
C. Waste Incineration	NE	0.00	0.00
D. Other	NE	0.00	0.00
7. Others	0.00	0.00	0.00
Memo Items:			
International Bunkers	10,006.55	0.00	0.00
Aviation	3,340.87	0.00	0.00
Marine	6,665.68	0.00	0.00
Multiple Operations	NE	NE	NE
CO2 Emissions from Biomass	NE	NE	NA

GHG Emission Source and Removal	CO2 Emission	CO2 Remova	Net CO2 Removal	CH4	N2O
Total Land-Use Change and Forestry	2,488	-22,836	-20,348	0.0	0.0
A. Change in Forest and Other Woody Biomass Stocks	155	-22,742	-22587		
B. Forest and Grassland Conversion	2,333			0.0	0.0
C. Abandonment of Managed Lands	NE	-93	-93		
D. CO2 Emissions and Removals from Soil	NE	NE	NE		
E. Other (Please Specify)					

Source: Environmental Protection Administration of the Executive Yuan (2001)

Table 2.3 Carbon Dioxide, Methane and Nitrous Oxide Emission Inventory of Taiwan in 1996

Units : thousand metric tons

GHG Emission Source and Sink Categories	Carbon Dioxide	Methane	Nitrous Oxide
National Total (Net) Emission	206,385.60	960.01	43.64
1. Energy	206,385.60	151.7	2.41
A. Combustion from Fuels (reference)	204,456.15		
(sectoral)	206,385.60	15.30	2.41
1. Energy Industry	106,583.37	1.99	1.27
2. Manufacturing Industries and Construction	57,739.13	4.24	0.67
3. Transport	34,993.28	6.97	0.32
4. Other Sectors	6,729.83	0.91	0.05
5. Other	339.99	1.19+	0.10
B. Fugitive Emissions from Fuels	0.00	136.40	0.00
1. Solid Fuels	NE	70.07	0.00
2. Oil and Natural Gas	NE	66.33	0.00
2. Industrial Processes	11,746.10	0.30	0.53
A. Mineral Products	10,911.46	0.00	0.00
B. Chemical Industry	312.47	0.90	0.53
C. Metal Production	522.17	0.00	0.00
D. Other Production	0.00	NA	NA
E. Production of Halocarbons and SF6	NA	NA	NA
F. Consumption of Halocarbons and SF6	NA	NA	NA

F. Consumption of Halocarbons and SF6	NA	NA	NA
G. Other	0.00	0.00	0.00
3. Solvent and Other Product Use	0.00	NA	0.00
4. Agriculture	0.00	97.40	38.91
A. Enteric Fermentation	NA	18.28	NA
B. Manure Management	NA	34.80	3.41
C. Rice Cultivation	NA	42.83	NA
D. Agricultural Soil	NO	0.00	35.46
E. Prescribed Burning of Savannas	NA	0.00	0.00
F. Field Burning of Agricultural Residues	NA	1.49	0.04
G. Other	NA	0.00	0.00
5. Land-Use Change and Forestry	-20,437.23	0.01	0.00
6. Waste	0.00	710.60	1.79
A. Solid Waste Disposal on Land	NE	684.18	NA
B. Wastewater Handling	NA	26.42	1.79
C. Waste Incineration	NE	0.00	0.00
D. Other	NE	0.00	0.00
7. Others	0.00	0.00	0.00
Memo Items:			
International Bunkers	17,176.29	0.00	0.00
Aviation	4,984.73	0.00	0.00
Marine	12,191.56	0.00	0.00
Multiple Operations	NE	NE	NE
CO2 Emissions from Biomass	NE	NA	NA

GHG Emission Source and Removal	CO2 Emission	CO2 Remova	Net CO2 Removal	CH4	N2O
Total Land-Use Change and Forestry	2,471	-22,908	-20437	0.0	0.0
A. Change in Forest and Other Woody Biomass Stocks	141	-22,741	-22,599		
B. Forest and Grassland Conversion	2,329			0.0	0.0
C. Abandonment of Managed Lands	NE	-167	-167		
D. CO2 Emissions and Removals from Soil	NE	NE	NE		
E. Other (Please Specify)					

Source: Environmental Protection Administration of the Executive Yuan (2001)

Table Table 2.5 Carbon Dioxide, Methane and Nitrous Oxide Emission Inventory of Taiwan in 2000

Units : thousand metric tons

GHG Emission Source and Sink Categories	Carbon Dioxide	Methane	Nitrous Oxide
National Total (Net) Emission	218,488.86	595.20	37.87
1. Energy	229,764.14	11.72	2.27
A. Combustion from Fuels (reference)	218,551.46		
(sectoral)	229,764.14	16.80	2.70
1. Energy Industry	120,172.94	2.14	1.47
2. Manufacturing Industries and Construction	63,544.92	4.79	0.78
3. Transport	35,601.04	7.08	0.32
4. Other Sectors	6,662.06	0.90	0.05
5. Other	3,783.18	1.89	0.08
B. Fugitive Emissions from Fuels	0.00	94.92	0.00
1. Solid Fuels	NE	77.15	0.00
2. Oil and Natural Gas	NE	17.77	0.00
2. Industrial Processes	9,171.83	0.38	0.37
A. Mineral Products	8,589.14	0.00	0.00
B. Chemical Industry	51.59	0.38	0.37
C. Metal Production	531.10	0.00	0.00
D. Other Production	0.00	NA	NA
E. Production of Halocarbons and SF6	NA	NA	NA
F. Consumption of Halocarbons and SF6	NA	NA	NA
G. Other	0.00	0.00	0.00

3. Solvent and Other Product Use	0.00	NA	0.00
4. Agriculture	0.00	93.62	33.00
A. Enteric Fermentation	NA	20.16	NA
B. Manure Management	NA	31.91	0.91
C. Rice Cultivation	NA	40.01	NA
D. Agricultural Soil	NO	0.00	32.06
E. Prescribed Burning of Savannas	NA	0.00	0.00
F. Field Burning of Agricultural Residues	NA	0.148	0.03
G. Other	NA	0.00	0.00
5. Land-Use Change and Forestry	-20,447.11	0.00	0.00
6. Waste	0.00	389.48	1.80
A. Solid Waste Disposal on Land	NE	353.11	NA
B. Wastewater Handling	NA	36.37	1.80
C. Waste Incineration	NE	0.00	0.00
D. Other	NE	0.00	0.00
7. Others	0.00	0.00	0.00
Memo Items:			
International Bunkers	16,445.22	0.00	0.00
Aviation	5,360.05	0.00	0.00
Marine	11,085.17	0.00	0.00
Multiple Operations	NE	NE	NE
CO2 Emissions from Biomass	NE	NA	NA

GHG Emission Source and Removal	CO2 Emission	CO2 Remova	Net CO2 Removal	CH4	N2O
Total Land-Use Change and Forestry	2,461	-22,908	-20,447	0.0	0.0
A. Change in Forest and Other Woody Biomass Stocks	133	-22,740	-22,607		
B. Forest and Grassland Conversion	2,327			0.0	0.0
C. Abandonment of Managed Lands	NE	-167	-167		
D. CO2 Emissions and Removals from Soil	NE	NE	NE		
E. Other (Please Specify)					

Source: Environmental Protection Administration of the Executive Yuan (2001)

Methane and nitrous oxide are relatively large and need further investigation. In the tables, NA refers to "Not Applicable", indicating no such gas emission from that category; NE refers to "Not Estimated", indicating insufficient information or the statistical work is not completed; NO refers to "Not Occurring", indicating no emission activity from that category; and IE refers to "Included Elsewhere", indicating the calculation is listed under different category. The blocks in gray indicate that the estimation of that gas is not necessary for that category.

2.2 Carbon Dioxide Emission Statistics

Carbon dioxide from the combustion of fossil energy is the main source of anthropogenic emission of greenhouse gases from all industrialized countries in the world, and Taiwan is no exception. In burning fossil fuels, carbon atoms are oxidized into carbon dioxide and emitted to the atmosphere. The carbon content of different fossil fuels differs from each other, so as the resulting carbon dioxide emission from the combustion of different fuels. Among different fossil fuels, coal has the highest carbon content whereas the carbon content of petroleum and natural gas accounts for 78 % and 59 % that of coal respectively.

Table 2.6 displays the total carbon dioxide emission of Taiwan in 1990 - 2000. Figure 2.1 shows the trend in Taiwan's carbon dioxide emission by main sectors in 1990 - 2000. According to Table 2.6 and Figure 2.1, the total carbon dioxide emission without LUCF was 132.5 million metric tons in 1990 and increased up to 238.9 million metric tons in 2000. From 1990 to 2000, it shows an increase of 80.3%. During the same period, carbon dioxide emission from the energy sector increased by 89.9% and that from the industrial processes sector decreased by 20.6%.

The emission from the energy sector is calculated from the Sectoral Approach of the IPCC method and the Energy Balance Sheet published by the Energy Commission. On the other hand, the calculations from the Reference Approach of the IPCC method show that the carbon dioxide emission from the combustion of fuels increased from 27.5 million metric tons to 73.1 million metric tons from 1970 to 1980, averaging an annual increase of 9.2 %. The carbon dioxide emission from combustion of fuels increased from 67.8 million metric tons to 111.5 million metric tons from 1980 to 1990, averaging an

annual increase of 5.3 %. From 1991 to 2000, the carbon dioxide emission from the combustion of fuels increased from 113.5 million metric tons to 204.8 million metric tons, an average of 6.8 % increase each year. (Figure 2.2) Upon analysis, the per capita carbon dioxide emission of Taiwan is 5.58 metric tons in 1990, 7.60 metric tons in 1995, 8.99 metric tons in 1998, and 9.8 metric tons in 2000. From 1990 to 2000, the average annual rate of increase is 5.5 %.

Figure 2.3 shows the carbon dioxide from the combustion of fuels in Taiwan area in 1954 - 1999 according to different forms of fuels as in gaseous, liquid and solid states. The carbon dioxide emission from the combustion of gaseous, liquid and solid fuels in 1990 are 4.4, 66.4 and 42.8 million metric tons respectively whereas in 1999, the corresponding values are 13.4, 95.1 and 96.2 million metric tons.

In reference to the rules set by sectoral approach of IPCC, the carbon dioxide emission from thermal power generation is listed under energy industry. Accordingly, carbon dioxide emission from energy generation is the highest among energy industry (mainly comprised of refining petroleum as well

Table 2.6 Total Carbon Dioxide Emission of Taiwan in 1990 - 2000

Units : thousand metric tons

	Sector	Energy	Industrial Processes	Land-Use Change and Forestry	Total Emissions/Removals with LUCF	Total Emissions without LUCF
Year	-	-	-	-	-	-
1990	-	120,969.06	11,547.19	-17,896.06	114,620.19	132,516.25
1991	-	130,500.97	10,467.354	-18,037.73	122,930.59	140,968.32
1992	-	138,232.78	13,039.26	-18,130.67	133,141.37	151,272.04
1993	-	149,136.03	15,099.41	-18,430.58	145,804.86	164,272.04
1994	-	158,842.81	14,493.70	-20,347.67	152,988.84	173,336.51
1995	-	165,277.69	14,132.34	-20,302.25	159,107.78	179,410.03
1996	-	175,426.10	14,130.42	-20,207.15	169,349.37	189,556.52
1997	-	188,508.48	14,927.19	-20,295.55	183,140.12	203,435.67
1998	-	203,149.14	12,937.30	-20,333.93	195,752.51	216,086.44
1999	-	206,385.60	11,746.10	-20,437.23	197,694.47	218,131.70
2000	-	229,764.14	9,171.83	-20,447.11	218,488.86	238,935.97

Source: Environmental Protection Administration of the Executive Yuan (2001)

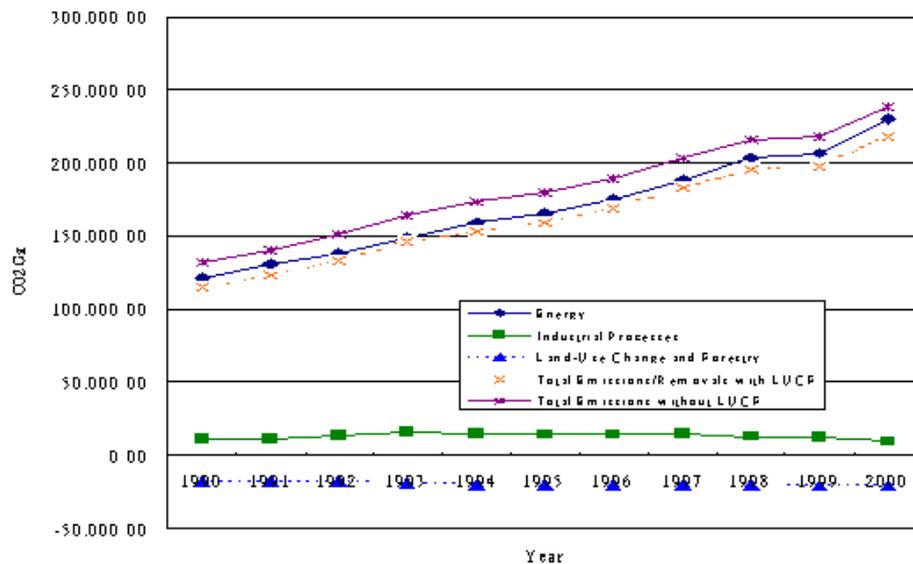


Figure 2.1 Trend in Taiwan's Carbon Dioxide Emission by Main Sectors in 1990 - 2000
Source: Environmental Protection Administration of the Executive Yuan (2001)



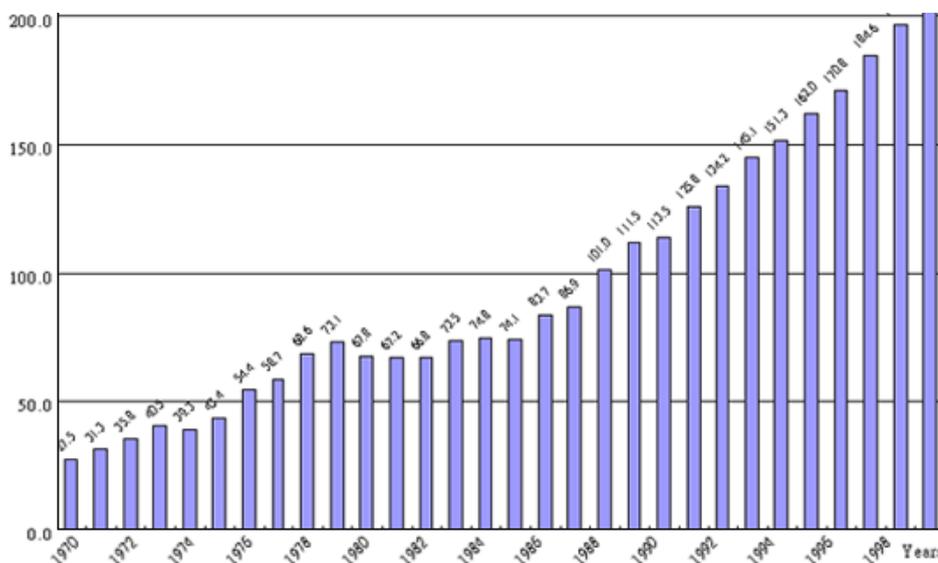


Figure 2.2 Total Carbon Dioxide Emission from Fuel Consumption in the Taiwan Area in 1970 - 2000 (million metric tons)
 Source: Energy Commission of the Ministry of Economic affairs (2000)
 Data from Emission Calculated from Reference Approach

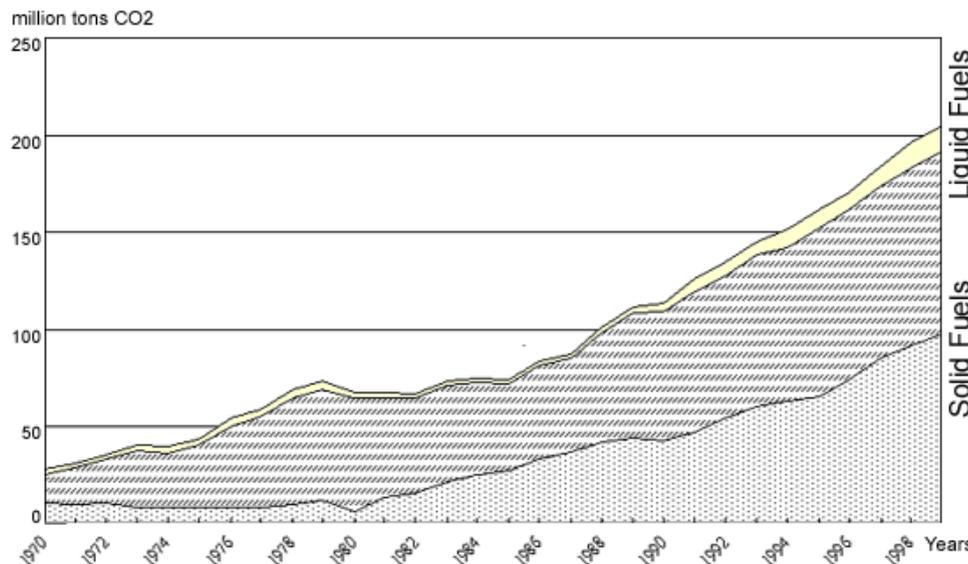


Figure 2.3 Trend in Carbon Dioxide Emission from Fuel Combustion in the Taiwan Area Gaseous Fuels
 Source: Energy Commission of the Ministry of Economic affairs (2000)

as power generation). However, although thermal power plants are the main source of carbon dioxide emission, the power generated is mostly used in other sectors. If the carbon dioxide emission from thermal power generation is allocated to different sectors according to the capacity of electricity used (this method is not in accord with IPCC method but can reflect the real carbon dioxide emission contributed by each sector), the new structure of carbon dioxide emission from different sectors is shown in Figures 2.4 and 2.5.

Figure 2.4 shows the carbon dioxide emission from fuel used by major sectors in the Taiwan area from 1970 to 1990. Figure 2.5 is the structure of carbon dioxide emission from energy utilization in Taiwan area in 1990 and 2000 according to different sectors.

In 1990, the carbon dioxide emission from the combustion of fuels from the industrial sector is 66.0 million metric tons accounting for 55 % of the total national emission. Among the carbon dioxide emission, 74 % is from direct combustion (steam generation and process heat) and 26 % is from power generation (driving motors, electric furnace and lighting). Besides, the transportation sector contributes 16 % of the total carbon dioxide emission, among which 60 % is from gasoline utilization and the rest is from emission from the combustion of diesel and aviation fuels. The emission from the commercial sector accounts for 13 % of the total emission with major emission from electricity utilization (67 %) and the rest is from the emission from combustion of natural gas, liquefied petroleum gas and fuel oil. The carbon dioxide emission from the agriculture, forestry, and fishing

industry is about 3.7 million metric tons, accounting for 3 % of the total emission.

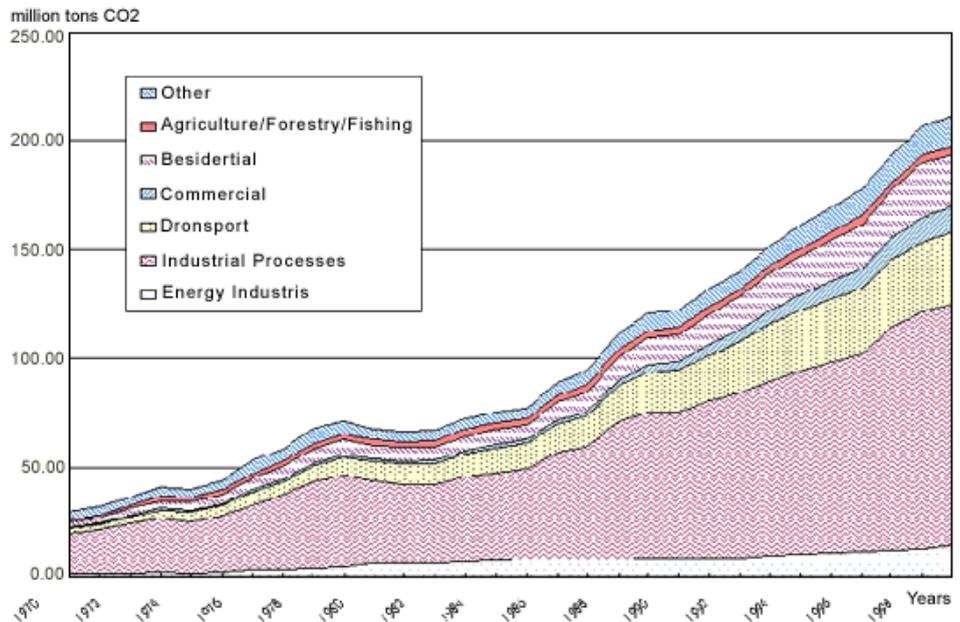
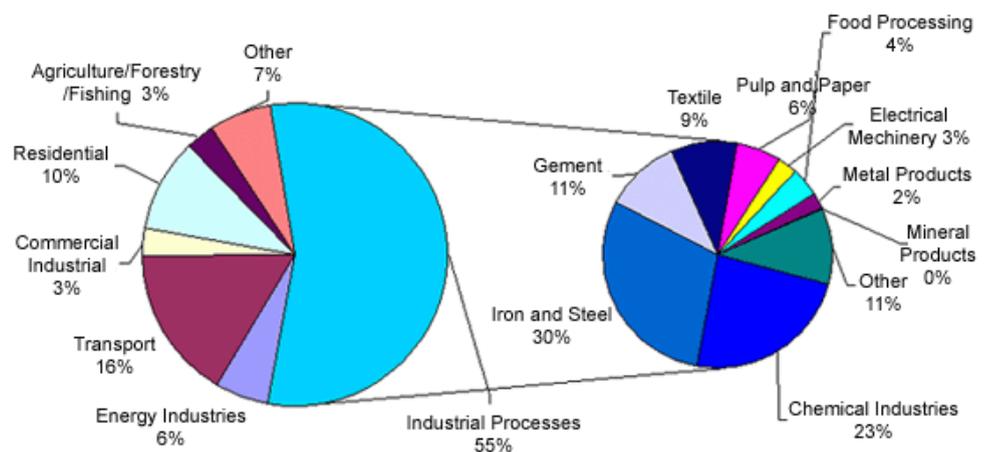


Figure 2.4 Trend in Carbon Dioxide Emission from Fuel Consumption by Main Sectors in the Taiwan Area

Source: Energy Commission of the Ministry of Economic affairs (2000)



For the carbon dioxide emission from the industries in 1990, the iron and steel industry accounts for about 30 %, the chemical industry for about 23 %, the cement industry for about 9 %, the textile industry for about 9 %, the pulp and paper industry about 6 %, and the food industry for about 4 %. The carbon dioxide emission from different industries in 2000 still shows that iron / steel and chemical industries are the highest with about 30 % and 28 %, respectively, and textile and cement industries account for 9 % and 6.5 %, respectively.

2.3 Methane Emission Statistics

The main source of methane emission is from solid waste disposal on land and agricultural activities.

The main source of methane emission is from solid waste disposal on land and agricultural activities. Methane is produced from anaerobic fermentation of biological substances. This biological reaction is

greatly affected by characteristics of local environments. Hence, in addition to using IPCC method, this statistics need inputs from local parameters. For the methane emission from the agriculture, forestry, and fishing industry in Taiwan, since the comprehensive information based on actual measurement of the area is not available except for some limited data from individual investigations used for reference only, this value is mainly estimated.

Table 2.7 lists the methane gas emission of Taiwan in 1990 - 2000. Figure 2.6 shows the trend in the methane gas emission of Taiwan. The total methane emission in the Taiwan area in 1990 was about 663.27 thousand metric tons. The largest emission was from solid waste disposal on land (67%), followed by emission from rice cultivation (9%) and emission from manure management (6%). It is seen in Table 2.7 that the total methane emission in the Taiwan area has increased year after year. In 1994, it reached 954.47 thousand metric tons, of which 75% was from solid waste disposal on land, 5.0 % from solid fuels, 4.8% from rice cultivation, and 4.77% from manure management. The percentage from the rice cultivation slipped because the cultivation area has decreased annually, thus resulting in the reduction of methane emission. The methane emission from the mining industry is mainly produced by imported coal. The total methane emission in 2000 fell to 595.2 thousand metric tons, of which 59.0% was from solid waste disposal on land, 13.0 % from solid fuels, 6.7% from rice cultivation, and 6.1% from wastewater treatment.

Since 1994, the methane emission from solid waste disposal on land has basically shown a falling trend. This should be related to the gradual shift of the main method of waste treatment to incineration in Taiwan. The main reason of the sharp fall of methane emission from manure management from 45.6 thousand metric tons in 1994, 48.8 thousand metric tons in 1996 to 34.8 thousand metric tons in 1999, and 32.0 thousand metric tons in 2000, is the outbreak of foot and mouth disease in the swine industry.

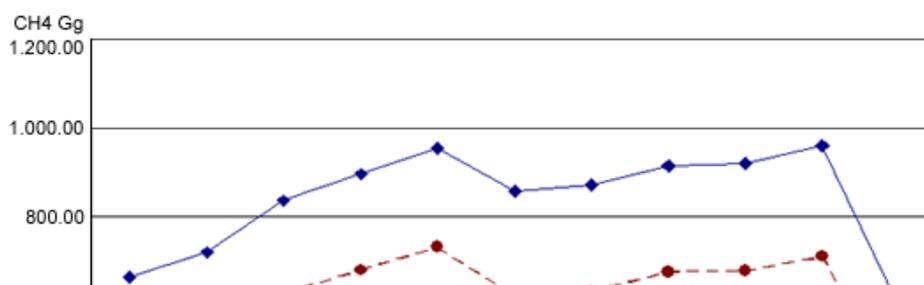
The methane emission from agricultural activities in the Taiwan area from 1990 - 2000 shows that except for the flourishing pig and chicken farming in earlier periods making both the number of animals farmed and methane emission reaching their respective highest points, the population of the rest of agriculture, forestry, and fishing industries diminishes. Hence, the production from this industry gradually slipped, making methane emission from the agriculture, forestry, and fishing industries decreased respectively. As of 1997, the government ardently pursued to enter the World Trade Organization (WTO)

Table 2.7 Methane Emission of Taiwan by Main Sectors in 1990 - 2000

Units : thousand metric tons

	Sector	Energy	Industrial Processes	Agriculture	Land-Use Change and Forestry	Waste	Total Emissions
Year	-	-	-	-	-	-	-
1990	-	80.75	0.23	119.45	0.01	462.83	663.27
1991	-	84.94	0.16	125.07	0.05	509.61	719.83
1992	-	91.30	0.15	119.77	0.01	625.69	836.92
1993	-	96.34	0.18	119.68	0.06	680.02	896.28
1994	-	103.94	0.22	118.53	0.01	731.77	854.47
1995	-	114.55	0.28	120.08	0.01	622.03	856.95
1996	-	117.90	0.27	121.21	0.15	631.56	871.08
1997	-	132.21	0.29	106.20	0.00	675.28	913.98
1998	-	145.36	0.22	96.51	0.01	677.54	919.64
1999	-	151.70	0.30	97.4	0.01	710.60	960.01
2000	-	111.72	0.38	93.62	0.00	389.48	595.2

Source: Environmental Protection Administration of the Executive Yuan (2001)



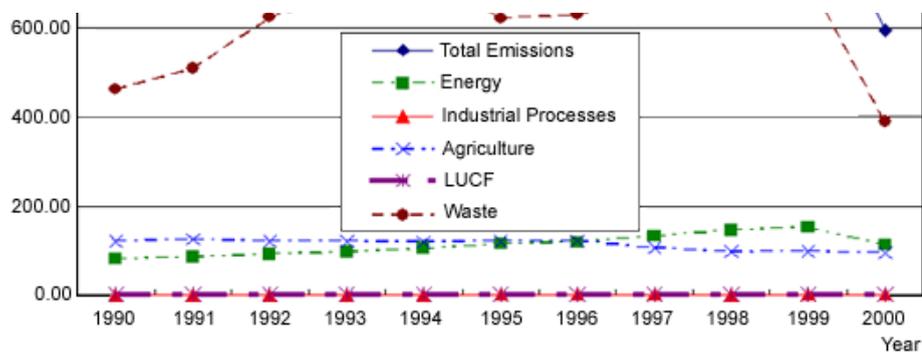


Figure 2.6 Trend in Taiwan's Methane Emission by Main Sectors in 1990 - 2000
Source: Environmental Protection Administration of the Executive Yuan (2001)

and relative complementary policies such as encouraging farmers to leave the industry, practicing sabbatical farmlands, adjusting the use of farmlands, restructuring of the industry as well as changing the management modes are implemented. Further impacts such as the inability of exporting pork due to the outbreak of foot and mouth disease cut back the production of the agricultural, forestry, and fishing industries, and the methane emission. It is expected that after entering the WTO, Taiwan will experience continuing decrease in production of the agricultural, fishery and livestock industries for a few years and then level out to a stable situation. Hence, the methane emission from agricultural activities in the Taiwan area will predictably follow the same trend, first decreases and then stabilizes.

2.4 Nitrous Oxide Emission Statistics

The uncertainty is relatively large when using the IPCC method in estimating the nitrous oxide emission. Therefore, more reliable results can be obtained when both IPCC method and actual emission data obtained locally are used simultaneously. Table 2.8 is the nitrous oxide emission of Taiwan in 1990 - 2000. Figure 2.7 shows the trend in the nitrous oxide emission of Taiwan. The total

nitrous oxide emission decreased from 45.16 thousand metric tons to 37.87 thousand metric tons from 1990 to 2000, showing a decrease of 16.1%. During the same period, the nitrous oxide emission from agriculture sector decreased 25.7% and that from waste sector increased 15.4%.

The total nitrous oxide emission of Taiwan in 1990 was about 45.16 thousand metric tons (see Table 2.8), of which the highest came from agricultural activities (92.0%), next was from waste sector (3.5%), and then from combustion of fuels (3.2%). The total nitrous oxide emission in 1994 was about 50.14 thousand metric tons, of which 92.0% came from agricultural activities, about 3.6% was from the combustion of fuels, and about 3.4% from waste sector. The total nitrous oxide emission in 1999 was about 43.64 thousand metric tons, of which 89% was from agricultural activities, about 5.6 % from the combustion of fuels, and about 4.1% was from the waste sector. The total nitrous oxide emission in 2000 was about 37.87 thousand metric tons, of which 87.0% came from agricultural activities, 7.1% from the combustion of fuels, and 4.8% from the waste sector. Because the agricultural activities continue to withdraw, the nitrous oxide emission from the agricultural sector also diminished by the year. In addition, the average families in Taiwan use anaerobic digestion to treat human wastes and thus produced nitrous oxide. This should be further studied in the future.

Table 2.8 Nitrous Oxide Emission of Taiwan by Main Sectors in 1990 - 2000

Units : thousand metric tons

Sector	Energy	Industrial Processes	Agriculture	Waste	Total Emissions
--------	--------	----------------------	-------------	-------	-----------------

Year	-	-	-	-	-	-
1990	-	1.43	0.59	41.52	1.56	45.16
1991	-	4.42	0.63	44.39	1.58	48.02
1992	-	1.55	0.57	44.11	1.60	47.83
1993	-	1.69	0.59	45.11	1.61	49.00
1994	-	1.78	0.54	46.11	1.71	50.14
1995	-	1.81	0.63	45.83	1.73	50.00
1996	-	1.95	0.66	47.03	1.74	51.38
1997	-	2.11	0.74	40.76	1.76	45.37
1998	-	2.29	0.71	39.25	1.78	44.03
1999	-	2.41	0.53	38.91	1.79	43.64
2000	-	2.70	0.37	33.00	1.80	37.87

Source: Environmental Protection Administration of the Executive Yuan (2001)

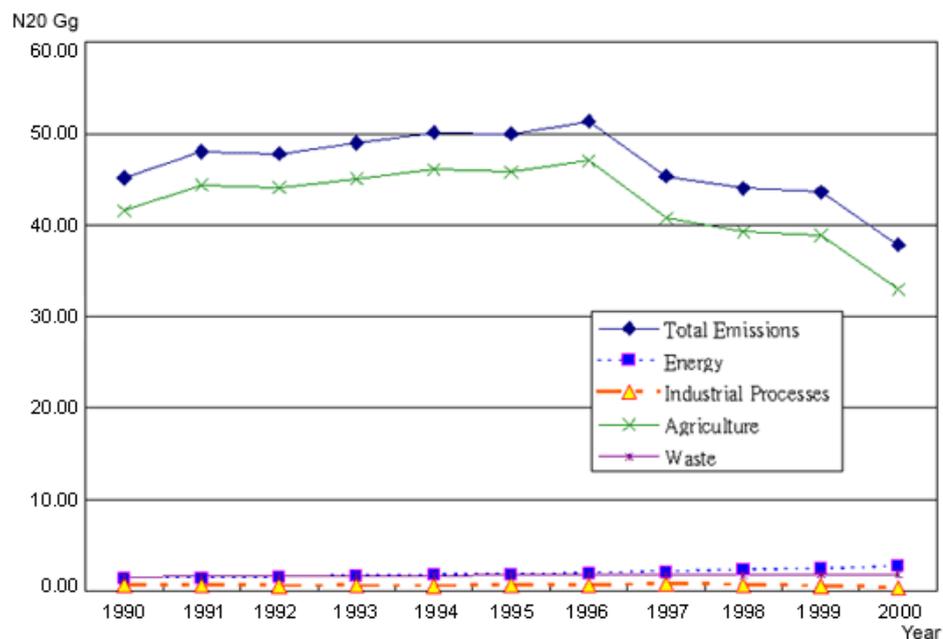


Figure 2.7 Trend in Taiwan's Nitrous Oxide Emission by Main Sectors in 1990 - 2000

Source: Environmental Protection Administration of the Executive Yuan (2001)

2.5 Sink and Monitoring

Using the IPCC method to formulate the amount of carbon dioxide absorbed by the forests in the Taiwan area, the net carbon removal can be calculated from the difference between the number of trees planted and the number of trees cut or the amount of wood consumed each year. Table 2.9 lists the information on the three investigations of forest resources in 1954, 1977 and 1994 in Taiwan. The total forest area in Taiwan in 1994 was 2,102,400 hectares, in which there were 1,120,400 hectares of broad leaf trees, 391,200 hectares of mixed coniferous/broad leaf trees, 438,500 hectares of coniferous leaf trees and 152,300 hectares of bamboo. The total storage volume was 358,744 thousand cubic meters, which 132,973 thousand cubic meters were from broad leaf forests, 99,401

hectares were from mixed coniferous/broad leaf forests, 125,835 thousand cubic meters from coniferous leaf forests, and 535 thousand cubic meters from bamboo forests with 1,127,831 thousand bamboos. According to the IPCC method, the carbon dioxide absorbed by the forests in Taiwan was 26.4 million metric tons in 1954, 19.8 million metric tons in 1977 and 22.6 million metric tons in 1994, not much change through these years (Environmental Protection Administration of the Executive Yuan, 2000). Please notice that the forestry area, and the area of different types of trees were obtained by using different investigation methods. Hence, the change in area of different types of trees did not necessarily represent the change in actual forest area. Using IPCC method, a recent study estimates the carbon dioxide absorbed by the forestry in Taiwan area in 1996 to be about 21.9 million metric tons, which was less than the previous estimation (Environmental Protection Administration of the Executive Yuan, 1998b). In addition, in estimating the carbon dioxide removal in sea waters and the dedicated economic area, the continental shelf can absorb 22.4 million metric tons, East Sea and the deep sea area of the Philippine Sea can absorb 41.4 million metric tons, and the deep sea area of the South Sea can absorb 42.9 million metric tons. The total carbon dioxide removal was about 106.7 million metric tons, with the uncertainty about 20 %.

Table 2.9 Forest Change in the Taiwan Area in 1954, 1977, 1994 and the Estimated Change in Carbon Dioxide According to IPCC Method

Year	Broad Leaf Forests (thousand hectares)	Broad/Coniferous Mixed Forests (thousand hectares)	Coniferous Forests (thousand hectares)	Bamboo Forests (thousand hectares)	Carbon Dioxide Absorbed by Forests (thousand hectares)	
1954	1,668	55.3	449.1	152.1	26.4	
1977		1,158	157.5	416.7	133.5	19.8
1994	1,120	391.2	438.5	152.3	22.6	

Source: Environmental Protection Administration of the Executive Yuan (2000)

The study sponsored by the National Science Council of the Executive Yuan is the main investigation on monitoring the greenhouse gas in Taiwan. Presently, the focus is on methane and nitrous oxide emission from wetlands, rivers, lakes, fishery ponds, dry farmlands, rice paddies and landfills (National Science Council of the Executive Yuan, 1999). On the other hand, the emission and monitoring of air pollutants such as NO_x, CO, NMVOC and SO₂, etc. are mainly performed by the Environmental Protection Administration of the Executive Yuan. In studying the reliability and the accuracy of the statistical information of the greenhouse gas emission in Taiwan, the relative statistical data of the information (not estimated, part or all) and the relative accuracy (low, medium, high) are investigated, and the results are listed in Table 2.10. It can be seen that the information on the carbon dioxide emission from the energy sector is most complete and detailed. Because the information is not sufficient, the errors on the emission of methane and nitrous oxide may be relative large and further investigations are needed to confirm the results.

2.6 Other Greenhouse Gases

Chlorofluorocarbons (CFCs) are substances that destroy ozone layer, and are also the greenhouse gases that raise the temperature of the surface of the earth. Taiwan observes the international regulations of 'Vienna Accord' and the 'Montreal Protocol' by strengthening the regulation on chlorofluorocarbons on schedule as well as promoting the recovery of these gases to be re-used. A hundred percent cutting rate was reached in 1996 and the import and production of such substances were totally banned. At present, hydrofluorocarbons (HCFCs) are also being under regulated on schedule.

The greenhouse gases added in the 1996 IPCC method and the 1997 Kyoto Protocol on 'International Accord on Climate Change' primarily are those used in the industrial processes such as HCFCs, SF₆ and PFCs, etc.. The emission inventory of alkyl halides and SF₆ of Taiwan in 1990 - 2000 is listed in Table 2.11. In Taiwan, the HCFCs and PFCs, are mainly used as the substitutes of chlorofluorocarbons in the refrigeration and air conditioning systems, semi-conductors manufacturing processes, high voltage circuit breakers and insulating gases of other breaking devices, foaming agents and fire extinguishers, etc. As shown in Table 2.11, the HCFCs emissions in 1998, 1999 and 2000 in Taiwan calculated by IPCC method are 17442, 16726 and 5612 thousand metric tons of carbon dioxide equivalents, respectively. The PFCs emissions in 1998, 1999 and 2000 are 536, 1310 and 2721 thousand metric tons of carbon dioxide equivalents, respectively, whereas those values of SF₆ are 61, 99 and 114 thousand metric tons of carbon dioxide equivalents, respectively.

2.7 Conclusion and Suggestion

It is shown in Table 2.12 that the total greenhouse gases emissions of Taiwan in 1990 - 2000 are transformed in the unit of thousand metric ton of carbon dioxide equivalent. Figure 2.8 is the trend of the total greenhouse gases emissions in Taiwan. Taiwan started the estimation of HFCs emission

from 1992 and the emissions of PFCs and SF6 from 1998. The total greenhouse gases emissions without LUCF in Taiwan showed a rising trend from 1990. In 2000, it increases up to 271622.24 thousand metric tons of CO2 equivalent, of which 88.0% was from CO2, 4.6% from CH4 and 4.3% from N2O. Carbon dioxide accounts for the largest emission among all greenhouse gases.

Table 2.10 Greenhouse Gas Emission Source and Sink Categories, and the Uncertainty of Their Estimated Value

GHG Emission Source and Sink Categories	CO2		CH4		N2O	
	Estimation	Accuracy	Estimation	Accuracy	Estimation	Accuracy
National Total (Net) Emission						
1. Energy						
A. Combustion from Fuels (reference) (sectoral)	ALL	H	ALL	M	ALL	M
1. Energy Industry	ALL	H				
2. Manufacturing Industries and Construction	ALL	H	ALL	M	ALL	M
3. Transport	ALL	H	ALL	M	ALL	M
4. Other Sectors	ALL	H	ALL	M	ALL	M
5. Other						
B. Fugitive Emissions from Fuels	ALL	H	ALL	M	ALL	M
1. Solid Fuels	ALL	H	ALL	M	ALL	M
2. Oil and Natural Gas	ALL	H	ALL	M	ALL	M
2. Industrial Processes	NE	NE	ALL	M	NE	M
A. Mineral Products	NE	NE	ALL	M	NE	NE
B. Chemical Industry	NE	NE	ALL	M	NE	NE
C. Metal Production						
D. Other Production	ALL	H	NA	NA		
E. Production of Halocarbons and SF6						
F. Consumption of Halocarbons and SF6						
G. Other						
3. Solvent and Other Product Use	NA	NA			NA	NA
4. Agriculture	NE	NE				
A. Enteric Fermentation			ALL	H		
B. Manure Management			ALL	H	ALL	H
C. Rice Cultivation			ALL	H		
D. Agricultural Soil	NE	M	NE	NE	ALL	H
E. Prescribed Burning of Savannas			NA	NA	ALL	NA
F. Field Burning of Agricultural Residues			ALL	H	ALL	H
G. Other						
5. Land-Use Change and Forestry	PART	M	PART	L		
6. Waste						
A. Solid Waste Disposal on Land	NE	NE	PART	M		
B. Wastewater Handling			PART	M	PART	M
C. Waste Incineration	NE	NE				
D. Other						
7. Others						
Memo Items:						
International Bunkers	ALL	H	ALL	M	ALL	M
Aviation						
Marine						
Multiple Operations	NE	NE	NE	NE	NE	NE

Production												
E. Production of Halocarbons and SF6	NO											
F. Consumption of Halocarbons and SF6	NE											
G. Other	NE											
3. Solvent and Other Product Use												
4. Agriculture												
5. Land-Use Change and Forestry												
6. Waste												

NA: (Not Applicable), no such gas emission from that category
 NE: (Not Estimated), insufficient information or the statistical work is not completed
 NO: (Not Occurring), no emission activity from that category
 IE: (Included Elsewhere), the calculation is listed under different category
 Column in gray: the estimation of that gas is not necessary for that category
 Source: Environmental Protection Administration of the Executive Yuan (2001)

Table 2.12 Total Greenhouse Gases Emissions of Taiwan in 1990 - 2000 (without LUCF)

Units: thousand metric tons of carbon dioxide equivalent

	CO2	CH4	H2O	HFCS	PFCS	SF6	Tptal*
1990	132516.25	13928.67	13999.60	---	---	---	160444.52
1991	140968.32	15116.43	14886.20	---	---	---	170970.95
1992	151272.04	17575.32	14827.30	702.00	---	---	184376.66
1993	164235.44	18821.88	15190.00	1638.00	---	---	199885.32
1994	173336.51	20043.87	15543.40	1521.00	---	---	210444.78
1995	179410.03	17995.95	15500.00	1755.00	---	---	214660.98
1996	189556.52	18292.68	15927.80	2808.00	---	---	226585.00
1997	203435.67	19193.58	14064.70	3276.00	---	---	239969.95
1998	216086.44	19312.44	13649.30	17442.00	536.00	61.38	267087.56
1999	218131.70	20160.21	13528.40	16726.00	1310.00	98.91	269955.22
2000	238935.97	12499.20	11739.70	5612.00	2721.00	114.37	271622.24

Source: Environmental Protection Administration of the Executive Yuan (2001)

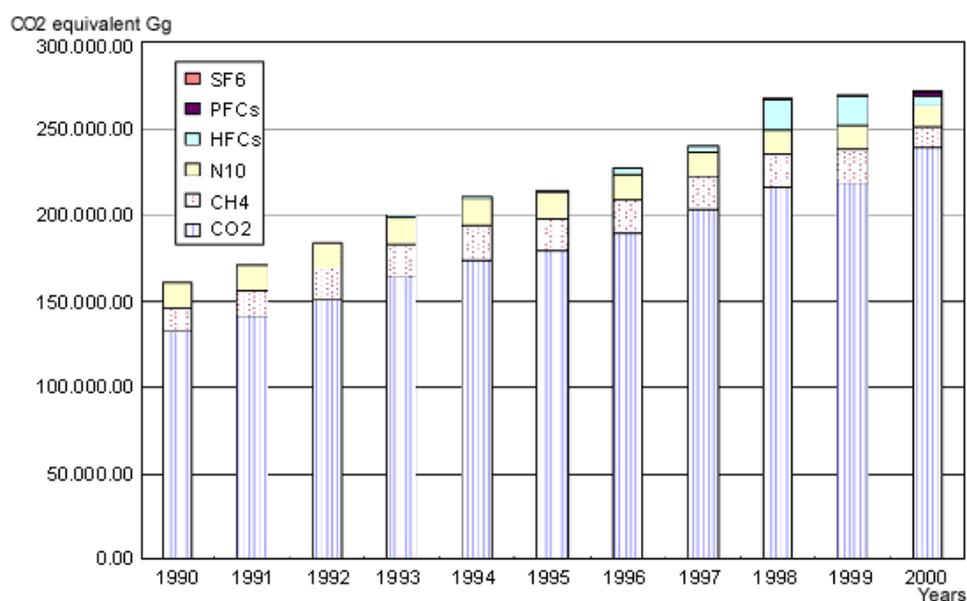


Figure 2.8 Trend in the Total Greenhouse Gases Emissions of Taiwan in 1990 - 2000 (without LUCF)

Source: Environmental Protection Administration of the Executive Yuan (2001)

As shown in Table 2.13, the total greenhouse gases emissions of Taiwan by main sectors in 1990 - 2000 are expressed in the unit of thousand metric ton of carbon dioxide equivalent. Figure 2.9 shows the trend of the total greenhouse gases emissions of Taiwan by main sectors. Energy sector has the

largest emission among all sectors. In 2000, 85.8% of the total greenhouse gases emissions in Taiwan was from the energy sector, 6.5% from industrial process sector, and 4.5% from agriculture sector.

Carbon dioxide emission was the largest greenhouse gas emission in Taiwan, and the main source of carbon dioxide emission was the combustion of fuels. This shows that the main effort for future greenhouse gas reduction should be focussed on energy conservation and the promotion on the use of renewable energy.

Land-Use change and forestry sector was the sector that absorbs carbon dioxide. Because there is no obvious trend of change in forest area in Taiwan, the carbon dioxide absorbed by the forestry sector also shows trend of stability.

Solid waste disposal on land was the largest source of methane emission in Taiwan. As incineration becomes the main method of the treatment of waste in Taiwan, future methane emission should gradually diminish. Nitrous oxide emission mainly came from agricultural sector. As agricultural production in Taiwan continues to shrink, the nitrous oxide emission is expected to decrease gradually.

Because of the rapid growth in semi-conductor industry in Taiwan in recent years, the emission of hydrofluorocarbons (HCFCs), perfluorocarbons (PFCs) and hexafluoride sulfur (SF6) was increasing rapidly accordingly. The potentials of greenhouse effects of these gases are high (several hundred to tens of thousands times that of carbon dioxide), the greenhouse gas emission from the semi-conductor industry should be noted.

Table 2.13 Total Greenhouse Gases Emissions of Taiwan by Main Sectors in 1990 - 2000 (without LUCF)

Units: thousand metric tons of carbon dioxide equivalent

	Energy	Industrial Processes	Agriculture	Waste	Total
1990	123108.11	11734.92	15398.25	10203.03	160444.52
1991	132724.91	10666.01	16387.37	11191.61	170970.95
1992	140630.58	13921.11	16189.27	13635.49	184376.66
1993	151683.07	16924.09	16497.38	14779.52	199885.32
1994	161577.35	16186.72	16789.23	15897.27	210444.78
1995	168244.34	16088.52	16728.98	13598.93	214660.98
1996	178506.50	17148.69	17124.71	13801.95	226585.00
1997	191938.99	18438.68	14865.80	14726.48	239969.95
1998	206911.60	31201.40	14194.21	14780.14	267087.56
1999	210318.40	30051.61	14107.50	15477.50	269955.22
2000	232947.26	17741.88	12196.02	8737.08	271622.24

Source: Environmental Protection Administration of the Executive Yuan (2001)

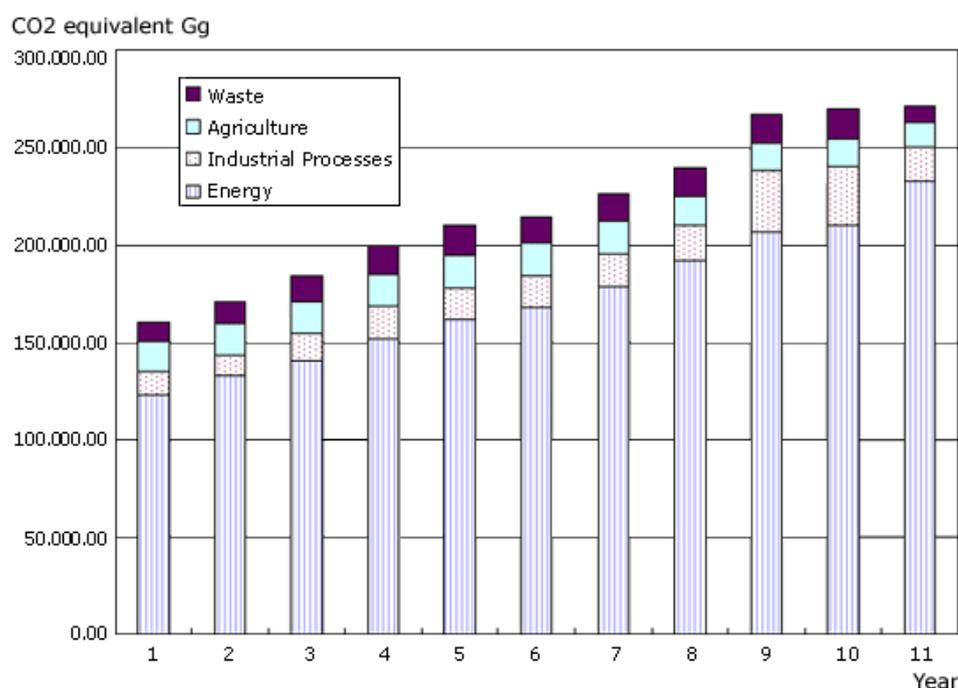


Figure 2.9 Trend in Total Greenhouse Gases Emissions of Taiwan by Main Sectors in 1990 - 2000 (without LUCF)

Source: Environmental Protection Administration of the Executive Yuan (2001)

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