



## CO<sub>2</sub> Emission Multiplier Effects of Taiwan's Electricity Sector by Input-output Analysis

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### ABSTRACT

From 1990–2009, electricity has played a critical role in supporting industrial development and economic growth in Taiwan. In this study, a 42-sector input-output table provided the basis for examination of linkage effects among various sectors and electric industry concerning their CO<sub>2</sub> emissions. These forward and backward linkage effects were inferred from analysis of the sensibility index of dispersion and the power index of dispersion. From results we suggest that, according to the CO<sub>2</sub> multipliers and linkage effects, artificial fiber, coal products, cement, and land transportation are the top four CO<sub>2</sub>-intensive sectors related to electricity sector in Taiwan. It is worth noting that many sectors in Taiwan have larger indirect CO<sub>2</sub> emissions than direct CO<sub>2</sub> emissions. This finding provides a focal point for researchers and related governmental agencies to explore mitigations for CO<sub>2</sub> reduction and to enhance effective environmental practices. Decision-makers from other countries with similar power plants may apply the similar approach and methodology to prioritize their strategies for abatement of CO<sub>2</sub> emissions from the electricity sector.

**Keywords:** Input-output analysis; Multiplier effect; CO<sub>2</sub> emission; Electricity sector; Inter-industry linkage.

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### INTRODUCTION

Simultaneous with the economic growth in Taiwan, electricity demand is rapidly increased to satisfy these needs. Taiwan now imports about 98% of large quantity raw fuels for power generation. The annual energy statistics from the Bureau of Energy (2010) showed that the gross power generation in Taiwan grew from 90,204 GWh in 1990 to 247,046 GWh in 2010, an average annual increase of 5.17% (Table 1). The state-run industry, Taiwan Power Company (TPC), generated 165,010 GWh, accounting for 66.8% of total output, followed by 40,787 GWh (16.5%) from independent power producers (IPPs) and 40,599 GWh (16.4%) from co-generation systems in 2010.

The electricity produced from thermal power plants increased rapidly from 49,147 GWh (54.5%) in 1990 to 197,113 GWh (79.8%) in 2010 (Table 1) (Bureau of Energy, 2011). On the other hand, due to the national goal of the “nuclear-free homeland” policy in Taiwan and the Fukushima nuclear accident in Japan, the government

proposes that there is no extension for any existing nuclear power plants and wish to phase out most nuclear plants for a “nuclear-free homeland” in the future. The percentage of electricity produced from nuclear power plants decreased gradually from 36.4% in 1990 to 16.9% in 2010. In addition, the gross electricity generation of hydro-power systems reduced from 8,188 GWh (9.1%) in 1990 to 7,255 GWh (2.9%) in 2010. Wind power and other green energy supply systems only operated on a limited scale and comprised less than 0.5% in 2010. All of this indicates that thermal power generation is the dominant source of electricity in Taiwan.

Fuel consumption of TPC and independent thermal power plants in Taiwan for 1991–2010 is shown in Table 2. Considering TPC thermal power plants, the total fuel consumption increased from 13,172 thousand kilo liter of oil equivalent (KLOE) in 1991 to 28,860 thousand KLOE in 2010. Bituminous coal is the most important fuel supply, accounting for 54%, and the share of LNG, sub-bituminous coal, and fuel oil were about 29%, 9% and 7% in 2010.

According to the National Energy Conservation and Carbon Reduction Master Program (2010) suggested that the quantity of GHG emissions in 2020 should be reduced to the level of that in 2005, and the quantity of GHG emissions in 2025 should be reduced to the level of that in 2000. Based on these goals, Taiwan Power Company has set up GHG control strategies to reduce GHG emissions

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(Taiwan Power Company, 2010). One of the strategies is to increase the ratio of natural gas power to 25% in 2025. Therefore, the fuel consumption of LNG has increased from 693 thousand KLOE in 1991 to 8,490 thousand KLOE

in 2010, with an annual growth rate of 14.9%. The fuel consumption of diesel oil and fuel oil has decreased to 59 and 2,113 thousand KLOE in 2010 with an attempt to reduce carbon emission and lower electricity generation costs.

**Table 1.** Electricity generation in Taiwan (1990–2010) (Unit: GWh).

| Year | Thermal power |       | Hydro power |      | Nuclear power |       | Geothermal electricity, Solar photovoltaic & wind energy |       | Total   |
|------|---------------|-------|-------------|------|---------------|-------|--|-------|---------|
| 1990 | 49,147        | 54.5% | 8,188       | 9.1% | 32,866        | 36.4% | 3  | 0.00% | 90,204  |
| 1991 | 58,378        | 58.9% | 5,508       | 5.6% | 35,290        | 35.6% | 2  | 0.00% | 99,178  |
| 1992 | 63,332        | 60.0% | 8,351       | 7.9% | 33,845        | 32.1% | 2  | 0.00% | 105,530 |
| 1993 | 74,132        | 64.3% | 6,719       | 5.8% | 34,354        | 29.8% | 1  | 0.00% | 115,206 |
| 1994 | 80,878        | 64.9% | 8,887       | 7.1% | 34,871        | 28.0% | 0  | 0.00% | 124,635 |
| 1995 | 88,922        | 66.8% | 8,879       | 6.7% | 35,316        | 26.5% | 0  | 0.00% | 133,117 |
| 1996 | 95,131        | 67.0% | 9,044       | 6.4% | 37,788        | 26.6% | 0  | 0.00% | 141,962 |
| 1997 | 104,650       | 69.5% | 9,567       | 6.4% | 36,269        | 24.1% | 0  | 0.00% | 150,486 |
| 1998 | 115,754       | 70.9% | 10,608      | 6.5% | 36,824        | 22.6% | 0  | 0.00% | 163,186 |
| 1999 | 122,115       | 72.1% | 8,942       | 5.3% | 38,416        | 22.7% | 0  | 0.00% | 169,473 |
| 2000 | 137,480       | 74.4% | 8,870       | 4.8% | 38,503        | 20.8% | 2  | 0.00% | 184,854 |
| 2001 | 143,863       | 76.3% | 9,169       | 4.9% | 35,486        | 18.8% | 12   | 0.01% | 188,532 |
| 2002 | 152,900       | 76.9% | 6,360       | 3.2% | 39,553        | 19.9% | 16   | 0.01% | 198,829 |
| 2003 | 163,262       | 78.1% | 6,895       | 3.3% | 38,890        | 18.6% | 24   | 0.01% | 209,070 |
| 2004 | 172,325       | 78.9% | 6,556       | 3.0% | 39,490        | 18.1% | 26   | 0.01% | 218,397 |
| 2005 | 179,475       | 78.9% | 7,910       | 3.5% | 39,972        | 17.6% | 92   | 0.04% | 227,449 |
| 2006 | 187,316       | 79.6% | 7,999       | 3.4% | 39,870        | 16.9% | 279  | 0.12% | 235,465 |
| 2007 | 193,780       | 79.7% | 8,350       | 3.4% | 40,539        | 16.7% | 446  | 0.18% | 243,115 |
| 2008 | 189,133       | 79.4% | 7,772       | 3.3% | 40,827        | 17.1% | 593  | 0.25% | 238,326 |
| 2009 | 180,275       | 78.5% | 7,053       | 3.1% | 41,571        | 18.1% | 795  | 0.35% | 229,694 |
| 2010 | 197,113       | 79.8% | 7,255       | 2.9% | 41,629        | 16.9% | 1,048  | 0.42% | 247,046 |

Data source: Energy statistical annual reports, 2011.

**Table 2.** Fuel mix of TPC and independent thermal power plants in Taiwan (1991–2010) (Unit: 10<sup>3</sup> K.L.O.E.).

| Year | Bituminous coal– Steam coal |          | Sub-bituminous coal |        | Diesel oil |        | Fuel oil |        | LNG   |        | Total  |        |
|------|-----------------------------|----------|---------------------|--------|------------|--------|----------|--------|-------|--------|--------|--------|
|      | TPC*                        | Indep.** | TPC                 | Indep. | TPC        | Indep. | TPC      | Indep. | TPC   | Indep. | TPC    | Indep. |
| 1991 | 6,343                       | 0        | 0                   | 0      | 489        | 0      | 5,647    | 0      | 693   | 0      | 13,172 | 0      |
| 1992 | 8,040                       | 0        | 0                   | 0      | 268        | 0      | 4,697    | 0      | 716   | 0      | 13,721 | 0      |
| 1993 | 8,932                       | 0        | 0                   | 0      | 394        | 0      | 5,456    | 0      | 595   | 0      | 15,377 | 0      |
| 1994 | 9,657                       | 0        | 0                   | 0      | 664        | 0      | 5,276    | 0      | 1,268 | 0      | 16,866 | 0      |
| 1995 | 9,788                       | 0        | 35                  | 0      | 762        | 0      | 6,429    | 0      | 1,358 | 0      | 18,372 | 0      |
| 1996 | 11,616                      | 0        | 152                 | 0      | 505        | 0      | 5,526    | 0      | 1,459 | 0      | 19,257 | 0      |
| 1997 | 13,000                      | 0        | 263                 | 0      | 158        | 0      | 6,032    | 0      | 2,071 | 0      | 21,525 | 0      |
| 1998 | 13,470                      | 0        | 1,364               | 0      | 371        | 0      | 5,884    | 0      | 3,144 | 0      | 24,234 | 0      |
| 1999 | 13,554                      | 855      | 1,512               | 0      | 583        | 3      | 6,042    | 6      | 3,104 | 20     | 24,795 | 885    |
| 2000 | 12,429                      | 2,237    | 2,959               | 0      | 509        | 3      | 5,854    | 7      | 3,469 | 94     | 25,220 | 2,341  |
| 2001 | 11,999                      | 3,262    | 3,662               | 0      | 143        | 3      | 4,990    | 6      | 4,066 | 233    | 24,860 | 3,503  |
| 2002 | 12,793                      | 4,403    | 3,294               | 0      | 133        | 18     | 3,839    | 7      | 4,271 | 924    | 24,330 | 5,352  |
| 2003 | 13,503                      | 5,547    | 3,188               | 0      | 111        | 13     | 3,418    | 5      | 4,401 | 1,023  | 24,621 | 6,588  |
| 2004 | 13,848                      | 5,309    | 3,262               | 0      | 81         | 8      | 2,860    | 5      | 4,186 | 2,580  | 24,237 | 7,902  |
| 2005 | 15,612                      | 5,559    | 2,879               | 0      | 140        | 9      | 2,647    | 6      | 4,627 | 2,787  | 25,905 | 8,362  |
| 2006 | 16,221                      | 5,700    | 3,186               | 0      | 255        | 6      | 3,389    | 4      | 5,033 | 2,617  | 28,084 | 8,327  |
| 2007 | 16,096                      | 5,775    | 3,677               | 0      | 120        | 9      | 2,982    | 3      | 5,798 | 2,702  | 28,673 | 8,489  |
| 2008 | 15,981                      | 5,638    | 3,524               | 0      | 128        | 7      | 2,799    | 4      | 6,505 | 2,882  | 28,937 | 8,531  |
| 2009 | 14,266                      | 6,145    | 3,765               | 0      | 59         | 4      | 1,552    | 1      | 6,092 | 2,780  | 25,734 | 8,931  |
| 2010 | 15,555                      | 6,186    | 2,643               | 0      | 59         | 4      | 2,113    | 3      | 8,490 | 3,023  | 28,860 | 9,215  |

Data source: Bureau of Energy, 2011.

\* TPC = Taiwan Power Company thermal power plants, \*\* Indep. = Independent thermal power plants.

Also, independent thermal power plants (Table 2) have played an important role in the energy structure. The total fuel consumption increased from 885 thousand KLOE in 1999 to 9,215 thousand KLOE in 2010 from these plants. The first independent power plant, located in Yunlin County, started operation in 1999, and then the proportion of IPPs power generation in Taiwan increased gradually. The bituminous coal and LNG were the major fuel sources, accounting for 67% and 33%, respectively in 2010. Consider the quantity of GDP, electricity consumption and energy consumption in Taiwan during 1995 to 2010 (Table 3), whereas GDP increased from  $7,536 \times 10^9$  NT\$ in 1995 to  $14,210 \times 10^9$  NT\$ in 2010, with an annual growth rate of 4.32%.

It is worth noting that the electricity consumption in Taiwan increased from  $30,432 \times 10^3$  KLOE in 1995 to  $58,466 \times 10^3$  KLOE in 2010, with an annual growth rate of 4.45%. Moreover, the annual growth rate of energy consumption for this 15-year period was 3.83%. The electricity consumption growth rate was higher than the energy consumption growth rate; this shows that the electricity consumption was more significant than the consumption of other energy sources such as coal and oil in Taiwan. In other words, electricity played a very critical role in support of industrial development and economic growth.

Numerous important studies related to characteristics of air pollutants and air quality improvement had been extensively discussed in recent years. Hung *et al.* (2005) and Hsieh and Chen (2010) evaluated the characteristics of volatile organic compounds (VOC) and ammonia around industrial parks. Lee *et al.* (2003; 2004) and Hu *et al.* (2009) evaluated the characteristics of polychlorinated dibenzo-*p*-dioxins/dibenzofuran in Taiwan. Wang *et al.* (2010) evaluated

the characteristics of heavy metals emitted from power plants. Fang *et al.* (2011) measured the concentration of As and dry deposition fluxes. Also, issues related to climate change and greenhouse gas (GHG) effects have gained significant notice during the two decades. In this study, our purpose focused on the modeling of economic-based linkage effects of CO<sub>2</sub> emissions from electricity sector in Taiwan. The linkage effect analysis is used to evaluate the inter-industry relationships of the electricity sector for a 42-sector input-output table. The sensibility index of dispersion and the power index of dispersion are calculated to measure the forward and backward linkage effects. In addition, the CO<sub>2</sub> multipliers of all 42 sectors from fossil fuel combustion in Taiwan in 2004 and 2006 are calculated to identify the sum of direct and indirect CO<sub>2</sub> emissions intensity. For the electricity sector, we further discuss the differences between the quantity of CO<sub>2</sub> emissions factor and that of CO<sub>2</sub> multipliers.

## INPUT-OUTPUT ANALYSIS

### Literature Review

A number of studies have applied input-output analysis to environmental issues related to the energy sector. The pioneer in this area was Leontief (1970), who initiated input-output analysis for computing pollutant emission and evaluating control strategies for major industries in the U.S.A. Chen and Wu (1994) applied input-output analysis to analyze the sources of change in the electricity demands of the industrial sectors in Taiwan. Their results showed that economic growth had the dominant impact on electricity use. Furthermore, Lin and Chang (1997) used input-output analysis to assess the impacts of oil consumption industries on environmental quality and inter-industry relationships

**Table 3.** GDP, electricity consumption and energy consumption in Taiwan (1990–2010).

|           | GDP                  | Economic growth rate | Electricity consumption | Electricity consumption growth rate | Energy consumption   | Energy consumption growth rate |
|-----------|----------------------|----------------------|-------------------------|-------------------------------------|----------------------|--------------------------------|
|           | 10 <sup>9</sup> NT\$ |                      | 10 <sup>3</sup> KLOE    |                                     | 10 <sup>3</sup> KLOE |                                |
| 1995      | 7,536                |                      | 30,432                  |                                     | 68,473               |                                |
| 1996      | 7,954                | 5.54%                | 32,288                  | 6.10%                               | 71,755               | 4.79%                          |
| 1997      | 8,389                | 5.48%                | 35,100                  | 8.71%                               | 75,357               | 5.02%                          |
| 1998      | 8,680                | 3.47%                | 38,566                  | 9.88%                               | 80,291               | 6.55%                          |
| 1999      | 9,198                | 5.97%                | 41,405                  | 7.36%                               | 84,652               | 5.43%                          |
| 2000      | 9,731                | 5.80%                | 46,210                  | 11.60%                              | 91,737               | 8.37%                          |
| 2001      | 9,571                | -1.65%               | 47,290                  | 2.34%                               | 97,055               | 5.80%                          |
| 2002      | 10,074               | 5.26%                | 48,897                  | 3.40%                               | 100,498              | 3.55%                          |
| 2003      | 10,444               | 3.67%                | 50,996                  | 4.29%                               | 104,370              | 3.85%                          |
| 2004      | 11,090               | 6.19%                | 53,088                  | 4.10%                               | 108,760              | 4.21%                          |
| 2005      | 11,612               | 4.70%                | 55,455                  | 4.46%                               | 111,168              | 2.21%                          |
| 2006      | 12,243               | 5.44%                | 57,662                  | 3.98%                               | 113,739              | 2.31%                          |
| 2007      | 12,976               | 5.98%                | 59,157                  | 2.59%                               | 119,188              | 4.79%                          |
| 2008      | 13,071               | 0.73%                | 58,620                  | -0.91%                              | 115,699              | -2.93%                         |
| 2009      | 12,834               | -1.81%               | 55,729                  | -4.93%                              | 113,073              | -3.22%                         |
| 2010      | 14,210               | 10.72%               | 58,466                  | 4.91%                               | 120,308              | 3.98%                          |
| 1995–2010 |                      | 4.32%                |                         | 4.45%                               |                      | 3.83%                          |

Data source: Directorate-General of Budget, Accounting and Statistics, 2011; Bureau of Energy, 2011.

in Taiwan. Results of inter-industry linkages confirm that investment of the power generation, other industrial chemicals, paper products, non-metallic mineral products, petrochemical materials, rubber products, cement and textiles should be adjusted to better energy efficiency, environmental quality and economic bases.

Han *et al.* (2004) used input-output analysis to investigate the role of the four electric power sectors (hydroelectric, fossil-fuels, nuclear and non-utility) in the Korean national economy for the period 1985–1998. The results revealed that the non-utility electric sector was superior in terms of national economy-wide effects to the other three sectors through out the period. Yabe (2004) examined the factors that have an effect on CO<sub>2</sub> emissions from Japanese industries between 1985 and 1995 by using input–output tables. The backward and forward linkage effects of each sector were calculated to show the extent of each sector spreads or receives CO<sub>2</sub> emissions across all of sectors. The results showed that the backward and forward linkage effects decreased during the late in 1980s but not the recession of the early 1990s, while the chemical products and electrical machinery sectors continued to reduce both effects. This indicates that both sectors were relatively successful in decreasing their CO<sub>2</sub> emissions between 1985 and 1995. Kwak *et al.* (2005) employed input-output analysis to examine the role of the maritime industry in the Korean economy for the period 1975–1998. They addressed inter-industry linkage effects in 32 sectors, production-inducing effects, employment-inducing effects and supply-shortage effects of the maritime sector.

Yoo and Yoo (2009) applied input-output analysis to investigate the role of the nuclear power generation in the Korean economy. They paid particular attention to the nuclear power generation sector by taking the sector as exogenous and then investigating its economic impacts. Alcántara *et al.* (2010) identify those sectors that contribute most to electricity consumption in Spain, using a methodology based on input–output tables, and to derive some recommendations aimed at increasing energy efficiency in those sectors. The results suggested that policy instruments should be applied in order to increase both energy efficiency in the electricity generation sector as well as electricity efficiency in end-use electricity sectors.

All of the above studies indicate that the IO method is a very powerful tool to analyze the interrelationships and linkages of energy uses and effects on CO<sub>2</sub> emissions. In order to better understand this method, it is important to mention the basic theory related to it.

**General Framework of Input-output Analysis**

Input–output analysis is a top-down method to analyze mutual inter-relationships between various sectors of a complex economic system. Each sector’s production process can be represented by a vector of structural coefficients that describes quantitatively the relationship between the input into and the output of production. Wassily W. Leontief (Leontief, 1970) who received the Nobel Prize in 1973 constructed the basic framework of input-output study, he also indicated that the interdependence between the sectors

of a given economy system can be defined by a set of linear equations to express the balances between the total input and the aggregated output of each product and service.

The basic equations of the input–output model can be presented as: (Lin and Chang, 1997)

$$\sum_{j=1}^n x_{ij} + F_i = X_i \tag{1}$$

$$\sum_{i=1}^n x_{ij} + V_j = X_j \tag{2}$$

$$\sum_{j=1}^n a_{ij} X_j + F_i = X_i \tag{3}$$

where

X<sub>i</sub> = total gross output produced in sector *i*,

X<sub>j</sub> = total gross input required in sector *j*,

F<sub>i</sub> = product of sector *i* delivered to the final demand,

V<sub>j</sub> = final payment (value added) by sector *j*,

x<sub>ij</sub> = the amount of the product sector *i* used by per unit of output of sector *j*,

a<sub>ij</sub> = x<sub>ij</sub>/X<sub>j</sub>, the direct input or technical coefficient of product of sector *i* into sector *j*.

Thus, the technical structure of the entire system can be represented by the matrix of technical input–output coefficients of all its sectors. Eq. (3) can be rewritten in the following matrix form:

$$\begin{aligned} AX + F &= X \\ (I - A) X &= F \\ \text{or} & \\ X &= (I - A)^{-1} F \\ &= [b_{ij}] F \\ &= B F \end{aligned} \tag{4}$$

where

A = the direct input coefficient matrix of a<sub>ij</sub>,

I = the identity matrix,

B = the Leontief inverse matrix,

b<sub>ij</sub> = the element of the Leontief inverse matrix, representing the total direct and indirect requirement of sector *i* by per unit of output sector *j* to final demand.

**Linkage Effect Analysis**

Besides input-output analysis, linkages between inputs and outputs are equally important. The concept of linkage effect was developed by Hirschman (1985). It is based on the assumption that the economy could be promoted by adopting an imbalanced investment policy to generate an equilibrium growth among the related industries. In other words, economy in related industries can be boosted through linking input/output activities.

In general, linkage effect is classified into “forward linkage effect” and “backward linkage effect”. The former indicates that the increase of a certain industry’s outputs which can used as materials to other industries may promote

the outputs of other industries, with the latter indicating that production of a certain industry may induce the consumption of more products from other industries as the inputs to the certain industry (Lin and Chang, 1997). The calculation of the inter-industry linkage effect can be presented as the following (Directorate-General of Budget, Accounting and Statistics, 2004):

$$U_i^f = \frac{\sum_{j=1}^n b_{ij}}{\frac{1}{n} \sum_{i=1}^n b_{ij} \sum_{j=1}^n b_{ij}} \quad (5)$$

$$U_j^b = \frac{\sum_{i=1}^n b_{ij}}{\frac{1}{n} \sum_{i=1}^n b_{ij} \sum_{j=1}^n b_{ij}} \quad (6)$$

where,  $U_i^f$  is the sensibility index of dispersion, denoting the forward linkage effect,

$U_j^b$  is the power index of dispersion, denoting the backward linkage effect,

$b_{ij}$  is the element of the Leontief inverse matrix,

$\sum_{j=1}^n b_{ij}$  is the sum of elements in row  $i$  of the Leontief inverse matrix,

$\sum_{i=1}^n b_{ij}$  is the sum of elements in column  $j$  of the Leontief inverse matrix.

### CO<sub>2</sub> Multipliers

By regarding pollution as the “externality” of regular economic activities, many forms of pollutants can be related in a measurable way to energy consumption or production processes (Lin and Chang, 1997). In this study, the category “externalities” is incorporated into the conventional input-output analysis. The concept of multiplier was first applied by Wright (1974) for defining the energy commodity in input-output analysis. Also, Miller and Blair (1985) elaborated the energy and environmental input-output analysis to quantify the total impact of energy commodity input coefficients and pollutant output coefficients. In this study, the CO<sub>2</sub> multipliers were calculated by the following Eq. (7):

$$Q = q(I - A)^{-1} \quad (7)$$

where

$Q = [q_j]_{1 \times n}$ , total impact of CO<sub>2</sub> emission coefficient, which specifies the amount of CO<sub>2</sub> emitted directly and indirectly caused by per \$10<sup>6</sup> worth of output of industry  $j$ ,

$(I - A)^{-1}$  = the Leontief inverse matrix,

$q = [q_j]_{1 \times n}$ , CO<sub>2</sub> emission coefficient from industry  $j$  (ton pollutant/\$10<sup>6</sup>).

### DATA CONSOLIDATION

The basic input-output table was originally developed by the Directorate-General of Budget, Accounting and Statistics of Executive Yuan in Taiwan. The input-output table used in this study includes a 160-sector table for 2001 (Directorate-General of Budget, Accounting and Statistics, 2004), a 161-sector table for 2004 (Directorate-General of Budget, Accounting and Statistics, 2007), and a 166-sector table for 2006 (Directorate-General of Budget, Accounting and Statistics, 2009) which is the most update information in Taiwan regarding IO table.

The energy consumption of the electricity sector is based on the data from the “Taiwan Energy Balance Sheets” (Bureau of Energy, 2010). Because the sector classifications of the basic input-output table and the “Taiwan Energy Balance Sheets” are not identical, we combined them into a 42-sector table (Table 4). In addition, the CO<sub>2</sub> emissions from fuel combustion of 42 sectors are estimated according to the IPCC guidelines (IPCC, 2006), while emissions caused by the electricity and power generation sectors are allocated to various industries according to the rate of electricity consumption.

### RESULTS AND DISCUSSION

#### Inter-industry Relationships

The results of inter-industry relationships (Table 5) show that the electricity sector has increased forward linkage effects (sensibility index of dispersion > 1) in 2004 and 2006. Thus, the electricity sector is indispensable in supporting other industries as intermediate inputs or services to their production development. Moreover, the ranking of the electricity sector’s forward linkage effect did not change much from 2004 to 2006. This reveals that the electricity sector has always been one of the most important sectors to support the economic development and industrial growth in Taiwan.

On the contrary, the electricity sector has relatively small backward linkage effects (power index of dispersion < 1) for 2004 and 2006; therefore, the development of the electricity sector would not greatly promote the progress of its upstream sectors listed in the input-output table. However, the electricity sector’s backward linkage effects increased from 0.806 in 2004 to 0.934 in 2006, and its ranking improved by three places. It shows that the electricity sector has gradually increased in importance for advancing the development of other raw-material-related upstream industries. The overall linkage effects and rankings of the electricity sector are 2.107 (14) and 2.138 (12) in 2004 and 2006. This means that the electricity sector plays one of the most critical roles among the entire industries in Taiwan, and it can significantly influence other industry’s development.

The top ten sectors with high forward/backward linkage effects to the electricity sector in 2004 and 2006 are presented in Table 6 and Table 7. The results show that all sectors such as “crude petroleum, coal & natural gas extraction” in Table 6 are major suppliers that support the

power generation process in the electricity sector (by definition of forward linkage). When more electricity is produced, it increases the demand of intermediate inputs such as coal and natural gas. The upstream sectors like the

**Table 4.** Sector classification.

| Sector   | Energy balance sheets | 161-sector IO table (2004) | 161-sector IO table (2006)                     |
|--|-----------------------|----------------------------|--|
| 1 Agricultural & forestry                        | 80                    | 1–9, 11                    | 1–8, 10  |
| 2 Fishery products                               | 81                    | 12                         | 11   |
| 3 Crude petroleum, coal & natural gas extraction | 20, 23                | 13                         | 12, 1520                                       |
| 4 Minerals                                       | 33                    | 14, 15, 16                 | 13, 14, 15 <sup>a</sup>                        |
| 5 Food, tobacco & alcoholic beverages            | 34                    | 17–32                      | 16–30  |
| 6 Fabrics & wearing apparel                      | 35                    | 33–41                      | 31–39  |
| 7 Leather and products                           | 36                    | 42–44                      | 40–42  |
| 8 Wood, bamboo & rattan products                 | 37                    | 45–48                      | 43–45, 103                                     |
| 9 Paper and products                             | 38                    | 49–50                      | 46, 47   |
| 10 Printing                                      | 39                    | 51–52                      | 48, 131  |
| 11 Petrochemical raw materials                   | 43, 44                | 54                         | 52   |
| 12 Basic chemical materials                      | 42                    | 53, 59                     | 51, 55   |
| 13 Chemical products                             | 45, 48, 49            | 55, 60–64                  | 53, 58–62                                      |
| 14 Artificial fibers                             | 46                    | 56, 57                     | 56, 57   |
| 15 Plastics (synthetic resins)                   | 47                    | 58                         | 54   |
| 16 Petroleum refining products                   | 24                    | 65                         | 49   |
| 17 Coal products                                 | 21                    | 66                         | 50   |
| 18 Rubber products                               | 50                    | 67                         | 63   |
| 19 Plastics products                             | 51                    | 68–69                      | 64   |
| 20 Other non-metallic mineral products           | 54, 55, 56            | 70–71, 74                  | 65, 66, 69                                     |
| 21 Cement  | 53                    | 72–73                      | 67, 68   |
| 22 Iron & steel                                  | 22, 58                | 75–76                      | 70, 71   |
| 23 Non-ferrous metal                             | 59, 60                | 77–81                      | 72, 73, 74, 104                                |
| 24 Metal products                                | 61                    | 82–85                      | 75–78  |
| 25 Machinery                                     | 62                    | 86–90                      | 94–97, 107                                     |
| 26 3C products manufacturing                     | 63, 64                | 91–104                     | 79–87, 89–93                                   |
| 27 Transport equipments                          | 65                    | 105–109                    | 98–102   |
| 28 Other manufactures                            | 66, 67, 70            | 110–112                    | 88, 105, 106                                   |
| 29 Electricity generation                        | 25, 26, 27            | 113                        | 108  |
| 30 Gas supply                                    | 28                    | 114                        | 109  |
| 31 Water supply                                  | 68                    | 115                        | 110  |
| 32 Construction                                  | 69                    | 116–119                    | 115–118  |
| 33 Wholesale & retail trade                      | 83                    | 120–123                    | 119–121  |
| 34 Land Transportation                           | 74                    | 127                        | 123  |
| 35 Other Transportation                          | 72–73, 75–78          | 126, 128–129               | 122, 124, 125                                  |
| 36 Supporting services to transportation         | 85                    | 130                        | 126  |
| 37 Warehousing & storage                         | 86                    | 132                        | 127  |
| 38 Postal & telecommunication services           | 87                    | 133–134                    | 128, 134                                       |
| 39 Finance & Insurance                           | 88                    | 135–137                    | 137–139  |
| 40 Accommodation & food services                 | 84                    | 124–125                    | 129–130  |
| 41 Public administration services                | 91                    | 160                        | 155  |
| 42 Other services                                | 89, 90, 92            | 10, 131, 138–159, 161      | 9, 111–114, 132–133, 135–136, 140–154, 155–156 |

Note: <sup>a</sup> In 2006, 15 represents the "other non-metal mineral" sector without 1520 (coal).

**Table 5.** Inter-industry relationships of the electricity sector in Taiwan.

| Year | Sensibility index of dispersion | Ranking* | Power index of dispersion | Ranking* | Overall linkage | Ranking* |
|------|---------------------------------|----------|---------------------------|----------|-----------------|----------|
| 2004 | 1.301                           | 9        | 0.806                     | 30       | 2.107           | 14       |
| 2006 | 1.204                           | 8        | 0.934                     | 27       | 2.138           | 12       |

\* Ranking is the order of "electricity sector" among the total 42 sectors.

**Table 6.** Top 10 large forward linkage effects sectors to the electricity sector.

| Ranking | 2004   | 2006   |
|---------|--|--|
| 1       | Crude petroleum, coal & natural gas extraction | Crude petroleum, coal & natural gas extraction |
| 2       | Petroleum refining products                    | Petroleum refining products                    |
| 3       | Other services                                 | Other services                                 |
| 4       | 3C products manufacturing                      | Machinery                                      |
| 5       | Finance & Insurance                            | Wholesale & retail trade                       |
| 6       | Iron & steel                                   | Iron & steel                                   |
| 7       | Machinery                                      | Finance & Insurance                            |
| 8       | Wholesale & retail trade                       | 3C products manufacturing                      |
| 9       | Basic chemical materials                       | Chemical products                              |
| 10      | Construction                                   | Non-ferrous metal                              |

**Table 7.** Top ten large backward linkage effects sectors to the electricity sector.

| Ranking | 2004                                | 2006                                |
|---------|-------------------------------------|-------------------------------------|
| 1       | Basic chemical materials            | Artificial fibers                   |
| 2       | Artificial fibers                   | Basic chemical materials            |
| 3       | Plastics (synthetic resins)         | Plastics (synthetic resins)         |
| 4       | Petrochemical raw materials         | Petrochemical raw materials         |
| 5       | Fabrics & wearing apparel           | Fabrics & wearing apparel           |
| 6       | Paper and products                  | Paper and products                  |
| 7       | Plastic products                    | Plastic products                    |
| 8       | Non-ferrous metal                   | Other non-metallic mineral products |
| 9       | Other non-metallic mineral products | Cement                              |
| 10      | Cement                              | Iron & steel                        |

“petroleum refining products” sector must increase their outputs to meet the raising demand from electricity generation, and then the development of these upstream sectors would be promoted (by definition of backward linkage). In addition, all sectors such as “artificial fibers” in Table 7 are high energy intensive sectors. In other words, these sectors are main electricity consumers in Taiwan. The production processes of these sectors always depend on a large, reliable, and steady electricity supply. The electricity sector supports the development of these sectors.

#### **CO<sub>2</sub> Emissions Factors and Multipliers**

The CO<sub>2</sub> emissions, monetary CO<sub>2</sub> emissions factors and CO<sub>2</sub> multipliers from fossil fuel combustion in Taiwan in 2004 and 2006 are given in Tables 8 and 9. As mentioned above, CO<sub>2</sub> emissions that resulted from electricity generation are allocated to various sectors according to the percentage of each sector’s electricity consumption. Therefore, the quantity of CO<sub>2</sub> emissions of each sector in Tables 8 and 9 results from fossil fuel consumption and purchased electricity. Results reveal that the “land transportation”, “iron and steel” and “petrochemical raw materials” sectors are the most significant CO<sub>2</sub> emissions sources for the two years. These sectors are highly energy-intensive, and the sum of their CO<sub>2</sub> emissions represents more than 30% of the total CO<sub>2</sub> emissions.

However, after we examine CO<sub>2</sub> emissions per million USD gross output (the monetary CO<sub>2</sub> emissions factors), the highly direct CO<sub>2</sub>-intensive sectors are “land transportation”, “coal products”, and “cement”. In spite of the fact that CO<sub>2</sub> emissions of the “coal products”, and “cement” sectors are

not huge (see Tables 8 and 9), it is nevertheless significant because the gross output of two sectors are very small, making them significant CO<sub>2</sub> emissions sources in Taiwan.

After we multiply the monetary CO<sub>2</sub> emissions factors with the Leontief inverse matrix, the CO<sub>2</sub> multipliers show that, considering the linkage effects, the “artificial fibers”, “coal products”, “cement” and “land transportation” are major CO<sub>2</sub>-intensive sectors among all 42 sectors in Taiwan. It is worth noting that for the “artificial fibers” sector the quantity of its CO<sub>2</sub> multiplier is almost double the quantity of its monetary CO<sub>2</sub> emissions factor. This reveals that the level of indirect CO<sub>2</sub> emissions from other sectors is equivalent to that of direct CO<sub>2</sub> emissions from the “artificial fibers” sector itself. In fact, many sectors in Taiwan have larger indirect CO<sub>2</sub> emissions than direct CO<sub>2</sub> emissions (see Table 10). The proportions of indirect emissions from other sectors are increasing gradually to the point where there would be a huge underestimation of global warming effects if the related sectors in the input-output table are omitted from the calculations.

Table 11 shows the CO<sub>2</sub> emissions, monetary CO<sub>2</sub> emissions factor, CO<sub>2</sub> multiplier and ranking of the electricity sector. The results show that although the CO<sub>2</sub> emissions increase continuously from 2004 to 2006, the monetary CO<sub>2</sub> emissions factor decreases from 720.22 ton CO<sub>2</sub>/million USD in 2004 to 705.50 ton CO<sub>2</sub>/million USD in 2006. Since that the gross output of electricity sector increases significantly from 13,163 million USD in 2004 to 15,700 million USD in 2006. Considering the linkage effects, the CO<sub>2</sub> multiplier is clearly unchanged between 2004 and 2006; therefore, the interrelationship of the electricity sector to

related sectors is stable (see Table 5).

Because the electricity sector is one of the fundamental industries in Taiwan, it uses a lot of fossil fuel inputs in support of electricity generation. For this reason, the CO<sub>2</sub> multiplier is slightly larger than the monetary CO<sub>2</sub> emissions factor of the electricity sector. The intensity of direct CO<sub>2</sub> emissions from electricity generation is higher than that of indirect CO<sub>2</sub> emissions from related sectors in the input-output table.

## CONCLUSIONS

In this study, the forward and backward linkage effects of the electricity sector are estimated. Results show that the electricity sector plays a critical role for the entire economy in Taiwan because it can significantly influence other industry's development. The electricity sector is indispensable in support of production development of high energy-intensive sectors such as the "artificial fibers", "paper and products" and "cement" sectors in the input-output table.

In addition, we identify the sum of direct and indirect CO<sub>2</sub> emissions intensity by calculating the CO<sub>2</sub> multipliers of all 42 sectors from fossil fuel combustion in Taiwan in

**Table 8.** CO<sub>2</sub> emissions, monetary emissions factor and multiplier in 2004.

| Sector  | Gross Output<br>(million USD) | CO <sub>2</sub><br>emissions<br>(ton CO <sub>2</sub> ) | Monetary CO <sub>2</sub><br>emission factor<br>(ton CO <sub>2</sub> /million USD) | CO <sub>2</sub> multiplier<br>(ton CO <sub>2</sub> /million USD) |
|---|-------------------------------|--|---|--|
| 1 Agricultural & forestry                       | 12,654                        | 829,496  | 65.55   | 374.99   |
| 2 Fishery products                              | 2,259                         | 3,726,656  | 1,143.62  | 1,564.03   |
| 3 Crudepetroleum, coal & natural gas extraction | 18,849                        | 57,271   | 3.04  | 135.72   |
| 4 Minerals                                      | 4,542                         | 325,582  | 71.68   | 453.17   |
| 5 Food, tobacco & alcoholic beverages           | 22,298                        | 3,295,408  | 147.79  | 594.60   |
| 6 Fabrics & wearing apparel                     | 18,927                        | 8,694,796  | 459.39  | 2,069.82   |
| 7 Leather and products                          | 1,914                         | 297,671  | 155.55  | 813.94   |
| 8 Wood, bamboo & rattan products                | 3,103                         | 287,630  | 92.70   | 640.97   |
| 9 Paper and products                            | 7,683                         | 5,024,999  | 654.00  | 1,528.34   |
| 10 Printing                                     | 5,927                         | 308,360  | 7.00  | 626.87   |
| 11 Petrochemical raw materials                  | 26,573                        | 29,137,337   | 52.02   | 2,597.52   |
| 12 Basic chemical materials                     | 9,094                         | 3,222,031  | 1,096.50  | 1,318.74   |
| 13 Chemical products                            | 13,675                        | 3,659,053  | 354.31  | 1,221.16   |
| 14 Artificial fibers                            | 5,223                         | 10,391,695   | 267.56  | 3,936.03   |
| 15 Plastics (synthetic resins)                  | 16,301                        | 4,909,219  | 1,989.79  | 2,315.42   |
| 16 Petroleum refining products                  | 25,971                        | 10,604,354   | 301.16  | 631.96   |
| 17 Coal products                                | 1,163                         | 3,274,966  | 408.32  | 3,363.83   |
| 18 Rubber products                              | 2,714                         | 828,771  | 2,816.43  | 1,080.53   |
| 19 Plastics products                            | 15,513                        | 4,497,785  | 305.35  | 1051.85  |
| 20 Other non-metallic mineral products          | 6,787                         | 3,653,957  | 289.38  | 1,067.67   |
| 21 Cement                                       | 3,164                         | 7,657,994  | 2,420.23  | 3,460.56   |
| 22 Iron & steel                                 | 43,430                        | 26,063,133   | 600.12  | 1,903.11   |
| 23 Non-ferrous metal                            | 16,061                        | 1,073,661  | 66.85   | 934.34   |
| 24 Metal products                               | 13,841                        | 3,672,428  | 265.34  | 1,209.64   |
| 25 Machinery                                    | 38,160                        | 968,380  | 25.38   | 876.15   |
| 26 3C products manufacturing                    | 154,234                       | 14,570,090   | 94.47   | 705.59   |
| 27 Transport equipments                         | 25,767                        | 1,498,037  | 58.14   | 746.80   |
| 28 Other manufactures                           | 18,324                        | 1,226,561  | 66.94   | 800.69   |
| 29 Electricity generation                       | 13,163                        | 9,480,550  | 720.22  | 1,001.86   |
| 30 Gas supply                                   | 1,115                         | 333,922  | 299.37  | 695.47   |
| 31 Water supply                                 | 1,041                         | 712,655  | 684.85  | 1,055.06   |
| 32 Construction                                 | 32,433                        | 588,902  | 18.16   | 1,052.03   |
| 33 Wholesale & retail trade                     | 72,978                        | 1,259,619  | 17.26   | 173.15   |
| 34 Land Transportation                          | 9,479                         | 34,541,919   | 3,644.08  | 3,904.98   |
| 35 Other Transportation                         | 16,644                        | 8,389,257  | 504.04  | 1,016.73   |
| 36 Supporting services to transportation        | 3,593                         | 6,301,922  | 1,753.73  | 2,027.21   |
| 37 Warehousing & storage                        | 692                           | 404,361  | 584.28  | 974.30   |
| 38 Postal & telecommunication services          | 13,019                        | 807,910  | 62.06   | 187.82   |
| 39 Finance & Insurance                          | 46,409                        | 643,821  | 13.87   | 107.11   |
| 40 Accommodation & food services                | 12,960                        | 2,169,494  | 167.40  | 376.74   |
| 41 Public administration services               | 30,611                        | 5,021,272  | 164.04  | 270.08   |
| 42 Other services                               | 139,070                       | 15,115,375   | 108.69  | 286.93   |



**Table 9.** CO<sub>2</sub> emissions, monetary emissions factor and multiplier in 2006.

| Sector   | Gross Output<br>(million USD) | CO <sub>2</sub><br>emissions<br>(ton CO <sub>2</sub> ) | Monetary CO <sub>2</sub><br>emission factor<br>(ton CO <sub>2</sub> /million USD) | CO <sub>2</sub> multiplier<br>(ton CO <sub>2</sub> /million USD) |
|--|-------------------------------|--|---|--|
| 1 Agricultural & forestry                        | 13,221                        | 949,782  | 71.84   | 368.15   |
| 2 Fishery products                               | 2,998                         | 2,345,582  | 782.37  | 1,192.95   |
| 3 Crude petroleum, coal & natural gas extraction | 32,418                        | 53,210   | 1.64  | 250.19   |
| 4 Minerals                                       | 4,313                         | 337,842  | 78.33   | 621.36   |
| 5 Food, tobacco & alcoholic beverages            | 22,941                        | 3,268,198  | 142.46  | 555.92   |
| 6 Fabrics & wearing apparel                      | 17,956                        | 743,064  | 413.82  | 1,931.03   |
| 7 Leather and products                           | 2,535                         | 265,270  | 104.65  | 884.84   |
| 8 Wood, bamboo & rattan products                 | 3,382                         | 301,507  | 89.14   | 602.78   |
| 9 Paper and products                             | 7,872                         | 4,933,414  | 626.73  | 1,511.86   |
| 10 Printing                                      | 6,285                         | 338,600  | 53.88   | 628.16   |
| 11 Petrochemical raw materials                   | 34,734                        | 31,176,925   | 897.58  | 2,343.29   |
| 12 Basic chemical materials                      | 10,448                        | 3,877,313  | 371.11  | 1,266.89   |
| 13 Chemical products                             | 16,772                        | 3,614,123  | 215.48  | 1,201.72   |
| 14 Artificial fibers                             | 5,015                         | 9,753,385  | 1,944.65  | 3,807.89   |
| 15 Plastics (synthetic resins)                   | 19,165                        | 5,618,424  | 293.16  | 2,235.16   |
| 16 Petroleum refining products                   | 40,119                        | 11,138,746   | 277.64  | 569.77   |
| 17 Coal products                                 | 1,268                         | 3,417,692  | 2,695.46  | 3,309.46   |
| 18 Rubber products                               | 3,351                         | 834,949  | 249.16  | 1,007.83   |
| 19 Plastics products                             | 14,449                        | 4,644,542  | 321.43  | 1668.3   |
| 20 Other non-metallic mineral products           | 5,142                         | 3,755,671  | 730.38  | 1,383.27   |
| 21 Cement  | 4,412                         | 10,088,000   | 2,286.33  | 3,334.46   |
| 22 Iron & steel                                  | 15,841                        | 27,266,762   | 594.82  | 1,908.34   |
| 23 Non-ferrous metal                             | 29,133                        | 1,004,039  | 34.46   | 729.28   |
| 24 Metal products                                | 16,677                        | 3,917,363  | 234.90  | 1,124.51   |
| 25 Machinery                                     | 47,561                        | 1,086,715  | 22.85   | 753.47   |
| 26 3C products manufacturing                     | 192,026                       | 18,454,112   | 96.10   | 665.42   |
| 27 Transport equipments                          | 24,473                        | 1,683,483  | 68.79   | 676.23   |
| 28 Other manufactures                            | 18,139                        | 1,527,437  | 84.21   | 775.97   |
| 29 Electricity generation                        | 15,700                        | 11,076,173   | 705.50  | 1,062.89   |
| 30 Gas supply                                    | 1,277                         | 427,152  | 334.53  | 711.65   |
| 31 Water supply                                  | 1,162                         | 770,990  | 663.75  | 1,086.38   |
| 32 Construction                                  | 38,692                        | 580,486  | 15.00   | 959.40   |
| 33 Wholesale & retail trade                      | 110,563                       | 1,435,174  | 12.95   | 155.77   |
| 34 Land Transportation                           | 9,538                         | 35,492,225   | 3,720.99  | 3,951.13   |
| 35 Other Transportation                          | 15,834                        | 8,832,030  | 557.78  | 1,115.73   |
| 36 Supporting services to transportation         | 8,096                         | 6,276,914  | 775.34  | 971.68   |
| 37 Warehousing & storage                         | 772                           | 463,231  | 600.36  | 1,038.99   |
| 38 Postal & telecommunication services           | 13,076                        | 899,857  | 68.82   | 261.08   |
| 39 Finance & Insurance                           | 39,100                        | 717,332  | 18.35   | 97.18  |
| 40 Accommodation & food services                 | 20,872                        | 2,536,005  | 121.51  | 410.40   |
| 41 Public administration services                | 37,122                        | 5,367,016  | 144.58  | 269.80   |
| 42 Other services                                | 156,988                       | 17,125,268   | 109.09  | 285.77   |

2004 and 2006. We find that the “land transportation”, “iron and steel” and “petrochemical raw materials” sectors are the most significant CO<sub>2</sub> emissions sources. Moreover, from the viewpoint of the monetary CO<sub>2</sub> emissions factor, the highly direct CO<sub>2</sub>-intensive sectors are “land transportation”, “coal products”, and “cement” sectors. After considering the linkage effects of sectors, along with the above three highly direct CO<sub>2</sub>-intensive sectors, the “artificial fibers” sector is also a high CO<sub>2</sub>-intensive sector among all 42 sectors in Taiwan because of its huge indirect CO<sub>2</sub> emission intensity. There would be an underestimation of global warming

effects if the indirect CO<sub>2</sub> emissions from the related sectors in the input-output table are omitted from the calculations. However, for the electricity sector, the indirect CO<sub>2</sub> emission intensity is not obvious because the electricity industry uses many primary energy inputs to produce electricity. Suggestions for mitigating indirect CO<sub>2</sub> emissions are as follows. (1) Higher standards and effective incentives need to be enhanced in order to promote more energy-savings in industry. The government must require high energy intensity industries such as IC, petroleum, steel, etc. to meet stricter standards and to upgrade their energy

**Table 10.** Direct/Indirect effects of CO<sub>2</sub> emissions for 42 sectors in Taiwan.

| Sector   | 2004          |                 | 2006          |                 |
|--|---------------|-----------------|---------------|-----------------|
|  | Direct effect | Indirect effect | Direct effect | Indirect effect |
| 1 Agricultural & forestry                        | 17%           | 83%             | 20%           | 80%             |
| 2 Fishery products                               | 73%           | 27%             | 66%           | 34%             |
| 3 Crude petroleum, coal & natural gas extraction | 2%            | 98%             | 1%            | 99%             |
| 4 Minerals                                       | 16%           | 84%             | 13%           | 87%             |
| 5 Food, tobacco & alcoholic beverages            | 25%           | 75%             | 26%           | 74%             |
| 6 Fabrics & wearing apparel                      | 22%           | 75%             | 21%           | 79%             |
| 7 Leather and products                           | 19%           | 81%             | 12%           | 88%             |
| 8 Wood, bamboo & rattan products                 | 14%           | 86%             | 15%           | 85%             |
| 9 Paper and products                             | 43%           | 57%             | 41%           | 59%             |
| 10 Printing                                      | 8%            | 92%             | 9%            | 91%             |
| 11 Petrochemical raw materials                   | 42%           | 58%             | 38%           | 62%             |
| 12 Basic chemical materials                      | 29%           | 73%             | 29%           | 71%             |
| 13 Chemical products                             | 22%           | 78%             | 18%           | 82%             |
| 14 Artificial fibers                             | 51%           | 49%             | 51%           | 49%             |
| 15 Plastics (synthetic resins)                   | 13%           | 87%             | 13%           | 87%             |
| 16 Petroleum refining products                   | 65%           | 35%             | 49%           | 51%             |
| 17 Coal products                                 | 84%           | 16%             | 81%           | 19%             |
| 18 Rubber products                               | 28%           | 72%             | 25%           | 75%             |
| 19 Plastics products                             | 19%           | 81%             | 19%           | 81%             |
| 20 Other non-metallic mineral products           | 50%           | 50%             | 53%           | 47%             |
| 21 Cement  | 70%           | 30%             | 69%           | 31%             |
| 22 Iron & steel                                  | 32%           | 68%             | 31%           | 69%             |
| 23 Non-ferrous metal                             | 7%            | 93%             | 5%            | 95%             |
| 24 Metal products                                | 22%           | 78%             | 21%           | 79%             |
| 25 Machinery                                     | 3%            | 97%             | 3%            | 97%             |
| 26 3C products manufacturing                     | 13%           | 87%             | 14%           | 86%             |
| 27 Transport equipments                          | 8%            | 92%             | 10%           | 90%             |
| 28 Other manufactures                            | 8%            | 92%             | 11%           | 89%             |
| 29 Electricity generation                        | 72%           | 28%             | 66%           | 34%             |
| 30 Gas supply                                    | 43%           | 57%             | 47%           | 53%             |
| 31 Water supply                                  | 65%           | 35%             | 61%           | 39%             |
| 32 Construction                                  | 2%            | 98%             | 2%            | 95%             |
| 33 Wholesale & retail trade                      | 10%           | 90%             | 8%            | 92%             |
| 34 Land Transportation                           | 93%           | 7%              | 94%           | 6%              |
| 35 Other Transportation                          | 50%           | 50%             | 50%           | 50%             |
| 36 Supporting services to transportation         | 87%           | 13%             | 80%           | 20%             |
| 37 Warehousing & storage                         | 60%           | 40%             | 58%           | 42%             |
| 38 Postal & telecommunication services           | 33%           | 67%             | 26%           | 74%             |
| 39 Finance & Insurance                           | 13%           | 87%             | 19%           | 81%             |
| 40 Accommodation & food services                 | 44%           | 56%             | 30%           | 70%             |
| 41 Public administration services                | 61%           | 39%             | 54%           | 46%             |
| 42 Other services                                | 37%           | 63%             | 38%           | 62%             |

**Table 11.** CO<sub>2</sub> emissions, monetary emissions factor, multiplier and ranking of the electricity sector.

| Year | CO <sub>2</sub> emissions<br>(t CO <sub>2</sub> ) | Ranking* | Monetary CO <sub>2</sub> emissions factor<br>(t CO <sub>2</sub> /million USD) | Ranking* | CO <sub>2</sub> multiplier<br>(t CO <sub>2</sub> /million USD) | Ranking* |
|------|---|----------|---|----------|--|----------|
| 2004 | 9,480,550   | 8        | 720.22  | 8        | 1,001.86   | 21       |
| 2006 | 11,076,173  | 7        | 705.50  | 9        | 1,062.89   | 18       |

\* Ranking is the order of "electricity sector" among the total 42 sectors

efficiencies; these industries must also develop voluntary initiatives for energy savings and CO<sub>2</sub> reduction. (2) Major industries in downstream of electricity sector should adjust the fuel consumption structure to low-carbon emissions,

and lower the energy intensity by increasing the proportion of green energy. The industries should accelerate the replacement of antiquated facilities, and moves toward green manufacturing. (3) Demand-side management should

be strengthened by all energy-related sectors so as to cut consumer demand and thereby save more energy. Furthermore, the transportation, residential and commercial sectors must promote the following programs: efficient public transportation, green buildings and energy-saving facilities, upgrade of basic equipment and infrastructure.

In fact, many sectors in Taiwan have larger indirect CO<sub>2</sub> emissions than direct CO<sub>2</sub> emissions. As such, our findings are important to decision-makers to explore effective mitigations on CO<sub>2</sub> reduction from the electric power industry and relevant industries of Taiwan, and also this study is equally important to researchers from other countries and related agencies that have similar power plants to develop a strategic methodology and effective measures for coping with increased CO<sub>2</sub> emissions from their electricity-generating power plants.

## ACKNOWLEDGMENTS

We wish to thank Taiwan's National Science Council (Project NSC 97-2221-E-006-041-MY3) for financial support. Also, we appreciate the valuable comments and suggestions from the reviewers and the editors of our manuscript.

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Received for review, October 5, 2011  
Accepted, January 9, 2012