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Applying IO Approaches for Estimating Environmental Impacts of Industry and Policy in a Life Cycle Perspective

A case study: GHGs emission of semiconductor industry and "Two Trillion & Twin Star" Policy in Taiwan

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Abstract

The indirect environmental impacts of industries or policies caused by the activities of a supply chain were sometimes to be neglected although the prevention of direct impacts from industries was addressed and several measures were taken. IO approach is a powerful tool to analyze the activities in a supply chain. Industrial interdependence analysis and EIO LCA, which are IO approaches, are applied in this study to evaluate semiconductor industry and estimate the overall GHGs emission of “Two Trillion and Twin Star” policy in Taiwan. By undertaking the calculation of IO table and sectoral GHGs emission data, the level of industrial interdependence could be determined, and the increment of overall GHGs emission under the policy could be also estimated.

Results show that semiconductor industry exhibits above-average influence and sensitivity among 161 sectors. Its overall GHGs emission, 46 million ton CO_2e in which chemical material manufacturing sector contributes the most, is much more than its direct emission, 8.9million ton CO_2e. The increment of GHGs emission would be around 10 million tons CO_2e if “Two Trillion and Twin Star” policy were adopted. We also found that IO approach can not exactly reflect the reality while it has a defective assumption of fixed input structure. EIO LCA might be an appropriate tool to analyze a macro system. However, too general categorization of sectors and geographic boundary might limit the application of EIO LCA. The outcome of this research is mainly targeted for policymakers of industrial policy. The knowledge gained from the research could hopefully be assisted to draw up the policy in the future.

Executive Summary

Simultaneously enhancing economy and environmental quality of a country is always the target of a government which emphasizes sustainability. Recently, the environmental performance of industries or policies was gradually regarded as important as economic performance due to several critical issues of environment. Although the prevention of direct environmental impacts from industries was addressed and several measures were taken, the indirect influences on environment caused by the activities of a supply chain were sometimes to be neglected. Industrial interdependence analysis and EIO LCA which are IO approaches are powerful tools to analyze the economic activities and environmental impacts in a supply chain. In this study, those approaches are applied to evaluate semiconductor industry and estimate the overall GHGs emission of "Two Trillion and Twin Star" policy in Taiwan. The outcome of this research is mainly targeted for policymakers of industrial policy. The knowledge gained from the research could hopefully be assisted to draw up the policy in the future.

The level of industrial interdependence of semiconductor industry could be determined in an industrial interdependence analysis by calculating a 161*161 sector matrix of Taiwanese IO table. EIO LCA combining IO analysis and LCA also could estimate its direct and indirect GHGs emission by using the GHGs emission data of 28 sectors and a 28*28 sector matrix, which is re-categorized in the study. The following are the main findings of the study.

1. Among 161 sectors in Taiwanese economic system, semiconductor industry exhibits above-average influence and sensitivity, which ranks 70th and 13th individually, to other industries.

2. In a life cycle perspective, the overall GHGs emission, 46 million ton CO_2e, of Taiwanese semiconductor industry is estimated. It is much more than its direct emission, 8.9million ton CO_2e. Among its suppliers, chemical material manufacturing sector contributes the most GHGs emission.

3. The overall GHGs emission would increase additional 10 million tons CO_2e if "Two Trillion and Twin Star" policy were adopted. It's difficult to simultaneously improve both the economic and, especially, environmental performance by the policy which only enhances the turnover of the semiconductor industry. In order to achieve the overall environmental performance of high-level, the further improvement of environmental performance in the critical sectors is essential. We should be carefully aware the indirect influence while drawing an industrial policy or developing certain industries.

Some findings about the application of the methods are concluded as the followings.

1. EIO LCA and industrial interdependence analysis both based on IO analysis which assumes that supply (input) always follows under the fixed purchasing (input) structure while additional demand occurring. However, the reality is that both the supply side and the demand side are responsible for the consequences of industrial activities. This might be an issue for the methodology to be improved the in the future.

2. EIO LCA seems to be inappropriate to be applied to obtain specific information of a micro system such as a product, especially a product with rapid changing manufacturing processes. However, EIO LCA might be an appropriate tool to analyze a macro system, e.g. an industry or a certain policy, because of its further advantage, less time- and resource-consuming and circumvention of boundary problem.

3. To prevent a bias of EIO LCA, dividing a general category of an IO table into more specific sectors, even into specific companies or products, is suggested. However, the premise is the detail inventory of these sectors has been further developed.

4. EIO LCA is hardly to determine the environmental impacts caused in the use and end-of-use phases, and could only comprise the sector's activities from gate to gate and all industry tiers in the supply chain. Moreover, impacts outside the geographical boundary might be also critical. Expanding the geographical scope of the study which could eliminate some uncertainties is suggested in the future.

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1 Introduction

Simultaneously enhancing economy and environmental quality of a country is always the target of a government which emphasizes sustainability. The trend of industrial development in a country somehow dominates the country's economic and environmental performance in the future. In the past, it was usually concerned in industrial policies about the profitability and the driving force of industries in the entire economic system. However, as the requirements of environmental quality rising and ardent discussion on some environmental topics such as Global Climate Change, the environmental performance of industries or policies was gradually regarded as important as economic performance and economic issues were no longer the only concern of industries.

To maintain a fine environmental performance, both industries and governments considered all kinds of environmental aspects in their business. Although the prevention of direct environmental impacts from industries was addressed and several measures were taken, the indirect influences on environment caused by the activities of a supply chain were sometimes to be neglected. Indirect impacts from other sectors, however, are usually much more than the direct impacts. For instance, dairy industry produces small amount of environmental burdens, e.g. electricity consumption, wastewater, and waste, during their manufacturing processes. However, the production activities of husbandry, agriculture, and packaging industry which support the production of dairy industry produce much larger environmental burdens than the single industry. The critical environmental aspects include land use, water usage, the emission of nitrate and phosphate, and energy. Therefore, evaluating the environmental performance of an industry only by its direct environmental impacts is unfair, but including indirect ones in a life-cycle perspective.

LCA (Life Cycle Assessment) is a tool to estimate both indirect and indirect environmental impacts of a product or service in all stages of its life-cycle. Through scoping, LCI (Life Cycle Inventory), LCIA (Life Cycle Impact Assessment), and interpretation steps, the environmental performance of a product or service could be then generated. (Lindfors, 1995) However, it is more difficult to apply traditional LCA approach on an industry than a product or service because it is extremely time- and resource-consuming to investigate all tiers of an industry in a supply chain. Moreover, due to the variation of manufacturing processes or product properties among companies in the same industry, it is also impropriate to utilize the LCA result of a certain product instead of its whole industry. Therefore, a method that could provide a rapid and fairly accurate estimation which could cover a whole industry is needed if we want to figure out the environmental performance of an industry.

Input–output (IO) approach is a powerful tool to analyze the economic flow between industries by applying economic transaction table, so called IO table. Through the approach, the activities in a supply chain could be then demonstrated. Based on this idea, several applications including industrial interdependence analysis and EIO LCA (Economic Input-output Life Cycle Assessment) which are used in this study were developed. By calculating the data of economic transaction among sectors, industrial interdependence analysis assists to exhibit the influential level of an industry in economic activities. EIO LCA which combines IO and LCA approaches could allocates and estimate environmental impacts according to economic activities in a supply chain (by IO table). More details of these methods are introduced in Chapter 2.

In order to demonstrate the IO approaches and to see the feasibility of the approaches for estimating environmental impacts of an industry and a policy, a Taiwanese case—

semiconductor industry and "Two Trillion and Twin Star" is applied. The background and the introduction of case are also addressed in the following sections.

1.1 Case Background

In 60s' and 70s', a successful industrial policy in Taiwan which focused on the development of light and processing industries for exporting helped enhance the entire industrial activities effectively and create the average 7% of annual GDP growth. Figure 1-1 shows the trend of the economic growth in Taiwan. (Ministry of Economic Affairs, DS 2007) The huge demand of raw materials, e.g. steel, plastic, cotton, etc., caused by the manufacturing activities of high intensity also stimulated the development of heavy industries. Although the nationwide economy had flourished significantly due to the successful industrial policy, serious environmental impacts were also brought behind the thriving industrial activities. In the 80s', Taiwanese Environmental Protection Administration (TEPA) was established by Taiwanese government in order to mitigate the environmental deterioration. TEPA invested a huge budget for the research on the pollution control, and tightened the grip on industrial pollution by stringent regulations. However, the improvement of environmental quality was limited because of focusing on end-of-pipe remediation. Therefore, a preventative concept of pollution control was formed gradually among the public and the government. In the aspect of industrial policy, policymakers emphasize the environmental performance of an industry, and the new policy started to encourage the development of an industry with low environmental burdens and high added value, e.g. subsidiary measures which provides favourable tax rate for so called "green" industries such as semiconductor industry. "Two Trillion & Twin Star" industrial policy, the study case in this paper, was formed under the circumstance.

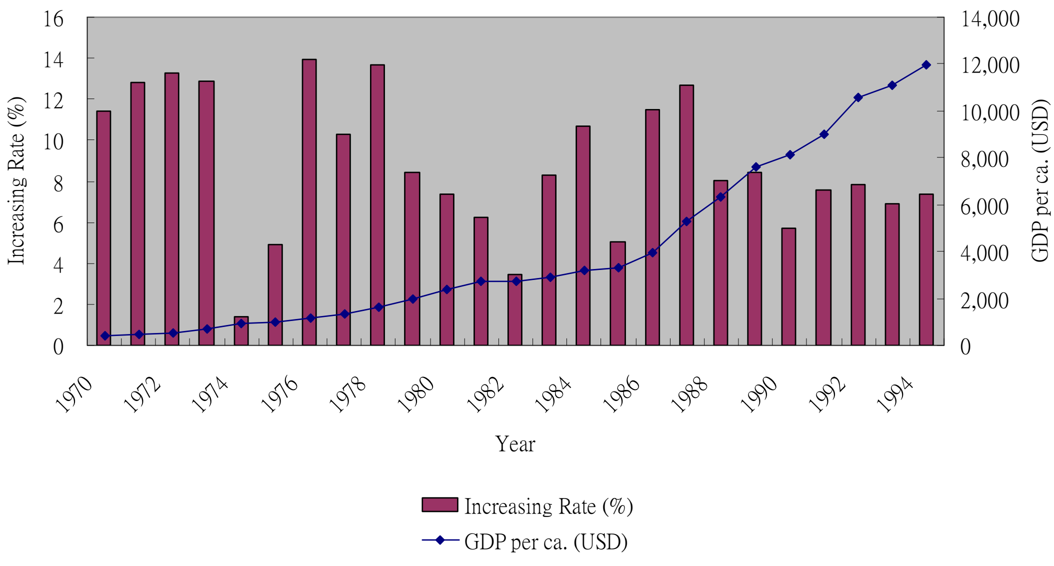

Figure 1-1 the trend of GDP growth in Taiwan

1.2 Industrial Policy: "Two Trillion & Twin Star"

"Two Trillion & Twin Star" policy which was drawn up by Ministry of Economic Affairs (MOEA), Taiwan tries to encourage selected industries, i.e. semiconductor, digital display (e.g. LED or TFT LCD), digital content, and biotech industries, to achieve the certain target of business turnover. (MOEA, 2004; MOEA IDB, 2006) Under the policy, government assists semiconductor and digital display industry, so called "Two Trillion" industries, to enhance their business and achieve the turnover target of one trillion NTD (New Taiwan Dollars) (equals to around 30 billion USD) by providing them favourable tax rate and other subsidiary measures. "Twin Star" means digital content and biotech industries, the potential industries of high growth in the future, which government assists to nurture their business in the world. Government focuses on assisting the development of these industries because they produce less environmental burdens than those so called traditional industries. Moreover, IC (Integrated Circuit) and TFT LCD (Thin Film Transistor Liquid Crystal Display) manufacturing industries, which belong to semiconductor, digital display industries, have obtained the leading position in the world. By suitable industrial policies and measures, they will get great opportunities to extend their market because of economies of scale. In the economic aspect, Taiwanese government indeed utilizes the advantage of the industries properly to enhance the development of industry and economy in Taiwan. However, some aspects of the policy, especially environmental aspect, are not well considered thoroughly by policymakers. Although these industries themselves might produce less environmental burdens, as the government claimed, in comparison with other traditional industries, the indirect burdens which are generated from the industrial interaction or activities of a supply chain, e.g. the transportation of raw materials and products, are still unknown and might be a significant issue. Therefore, before drawing up an industrial policy of sustainable development, it's necessary to consider and estimate both the direct and indirect consequence of a policy. A sound approach for evaluating environmental performance of an industry and a policy is, undoubtedly, needed to be further developed.

1.3 Research Question and Limitation

In this research, the overall (including direct and indirect) environmental impacts of an industry, i.e. semiconductor industry, and a policy, i.e. "Two Trillion & Twin Star" policy, is tried to be estimated. However, due to the limitation of time and resources, the study only could focus on one of the four industries, the semiconductor industry which includes IC design, IC manufacturing, IC packaging and testing industries, and eliminate the other three industries. Two critical reasons are addressed as the following.

1. No specific classification for the target industries except the semiconductor industry in the Taiwanese IO table. According to the IO table made by MOEA, Taiwan, there are 161 sectors included in the table. Semiconductor industry has its own independent (separated) category of industries in the IO table unlike the other three target industries. They are shared with other industries in the different categories, and difficult and questionable to scope and separate each industry from its belonged category. For example, biotech industry might belong to pharmacy industry or agriculture industry, but it is hard to identify its proper proportion of inputs or outputs in these industries.

2. The environmental information of semiconductor industry is easier to access relative to the other three industries. The development of semiconductor industry in Taiwan has a long history. TSIA (Taiwan Semiconductor Industry Association) organized by the semiconductor manufacturers and research institute in Taiwan also publishes annually the information about the environmental impacts of the whole industry in Taiwan.

There are also three basic assumptions in the study as the following.

1. The level of direct environmental impacts in an industry has positive correlation to its economic activities. For example, if an industry with 1 million EURs turnovers produces 100 tons of pollutants, it would produce 200 tons while its turnover increases to 2 million EURs. That is also the basic assumption of EIO LCA.

2. The system boundary covers 161 sectors (or products) which are included in Taiwanese IO table in 2004. The geographic and temporal boundary is limited in Taiwan in 2004. It means that the industrial structure is based on the status in 2004, and the impact or turnovers generated outside Taiwan (outside the geographic boundary) are neglected.

3. GHGs (Greenhouse Gases) emission is assumed to be as the only indicator of environmental impacts due to the inaccessibility of information in other environmental aspects. We merely choose GHGs emission which could be obtained in public information although GHGs emission only could represent one environmental aspect.

The following research question is addressed:

How to apply IO approaches to evaluate and what is the environmental performance of semiconductor industry and "Two trillion and Twin Star" policy in a life cycle perspective in Taiwan?

The paper will try to answer the following sub- questions:

- How to apply industrial interdependence analysis (an IO approach) for evaluating semiconductor industry in Taiwan?

    i. How is the level of economic influence of semiconductor industry in Taiwan?

    ii. What are the limitations or critical issues while applying industrial interdependence analysis in this study?

- How to apply EIO LCA to estimate and what is the GHGs emission of semiconductor industry and "Two trillion and Twin Star" policy in a life cycle perspective?

    i. What is the direct and indirect GHGs emission of semiconductor industry in Taiwan?

    ii. What is the overall GHGs emission after implementing "Two trillion and Twin Star" policy?

    iii. What and where are the critical issues (or industries) for reducing the GHGs emission?

    iv. What are the limitations or critical issues while applying EIO LCA in this study?

The outcome of this research is targeted for any group interested in evaluating the environmental performance of an industry and a policy. Yet, the main target group is the policymaker of industrial policy. The knowledge gained from the research not only could improve the environmental performance of existing policy, but also could hopefully be assisted to draw up the policy in the future.

2 Methodology

It's necessary to notice the variation of activities in a supply chain while considering the performance of all aspects in a large economic system. Just like evaluating the overall environmental performance of an industry or a policy, the variation of supply chain activities which might be caused by a certain policy affects the outcome of the evaluation significantly. Finding a proper approach which could consider the factor of the variation would be an important issue for dealing with large systems. IO analysis (Input-output analysis), a historical methodology, is usually applied for identifying the critical factor of economic input and output. Through the calculation of an IO table, the level of industrial interdependence could be estimated by the results. In other words, economic or environmental output from the economic variation could also be figured out through the concept. In this chapter, two methods combined with IO analysis, i.e. industrial interdependence analysis and EIO LCA are introduced. Through the connection with the IO table, these methods show the great ability to deal with questions related to complicated interaction in the entire economic system. They also assist to extend the boundary of the focused system in a research. Therefore, the results of the methods, as supporting tools, could provide policymakers with more useful and deeper information of decision making. More detail of the methods is addressed as the following. Figure 2-1 shows the structure of this research.

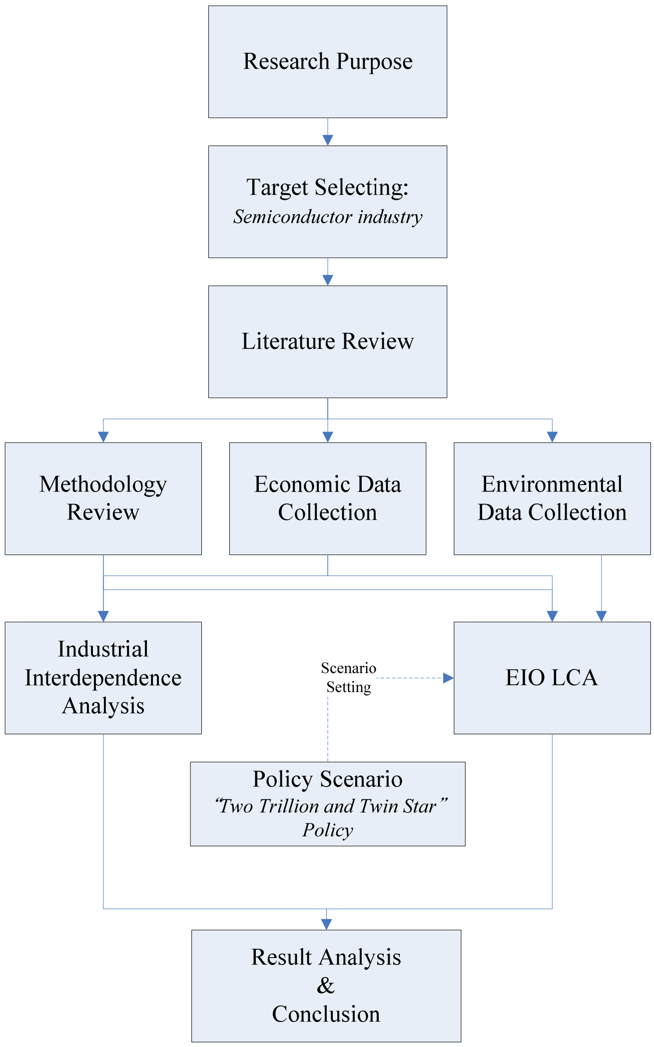

Figure 2-1 research structure of this study

2.1 Industrial Interdependence Analysis

2.1.1 Input-Output Analysis

Input–output (IO) was introduced by Leontief (1936) and since then has become a powerful tool in economic planning. An IO table shown as Table 2-1 presents the simplified economic IO model showing the inputs from industry sectors represented by rows, and outputs and final demand sectors represented by columns. A simple Leontief input-output model, which is applied in this case, would be established under three basic assumptions (Wang, 1986):

1. One product in each industry: It assumes that one industry (or one category of industries) only produces one kind of product. If one industry produces two or more than two kinds of products, they will be regarded as the same product, i.e. the major product, of the industry.

2. Fixed IO coefficient: It assumes that the ratio of IO in an industry is fixed. In other words, it assumes that the added value of an industry (or a product) is unchangeable (fixed added value).

Fixed input ratio in each industry: It assumes that the ratio of the input from other industry (or other products) to produce a unit product is fixed. It also implies that the production pattern and technology is assumed to be the same while calculating.

Table 2-1 a simplified IO table

Input	Output	Intermediate Demand				Final Demand (Y=D+E)		Total Output (X)
		Sectors (j= 1,…., n)				Domestic	Export	
Intermediate Input	Sectors (i=1,…, n)	Z_{11}	Z_{12}	…	Z_{1n}	D_1	E_1	X_1
		Z_{21}	Z_{22}	…	Z_{2n}	D_2	E_2	X_2
		.	.		.	.	.	.
		.	.		.	.	.	.
		.	.		.	.	.	.
		Z_{n1}	Z_{n2}	…	Z_{nn}	D_n	E_n	X_n
Primary Input (V)		V_1	V_1	…	V_n			
Total Input (X)		X_1	X_1	…	X_n			

According to the table shown above, the transactions table sectors may be written as follows (Leontief, 1936, 1970; Yu, 2003; San Cristobal and Biezma, 2006):

$$\sum_{j=1}^{n} Z_{ij} + Y_i = X_i \qquad \forall i = 1,2,...,n \qquad (1)$$

where, Z_{ij} are the sales from sector i (rows) to sector j (columns), Y_i the sales from sector i to final demand and X_i the total output of sector i. We could define the direct input coefficient, so called technical coefficients, for each sector (a_{ij}) which divides each column of Z by the gross output of the sector associated with that column:

$$a_{ij} = \frac{Z_{ij}}{X_j} \qquad (2)$$

Then,

$$Z_{ij} = a_{ij} \times X_j \qquad (3)$$

Substituting Eq. (3) into Eq. (1), we rewrite the equation for the transactions table as follows:

$$\sum_{j=1}^{n} a_{ij} X_j + Y_i = X_i \qquad \forall i = 1,2,\ldots,n \qquad (4)$$

Thus, Eq. (4) describes a demand-driven model by viewing the IO table vertically. If we treat the final demand (Y) as exogenous:

$$X_i - \sum_{j=1}^{n} a_{ij} X_j = Y_i \qquad \forall i = 1,2,\ldots,n \qquad (5)$$

In matrix notation,

$$\begin{bmatrix} (1-a_{11}) & -a_{12} & \cdots & -a_{1n} \\ -a_{21} & -a_{22} & \cdots & -a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ -a_{n1} & -a_{n2} & \cdots & -a_{nn} \end{bmatrix} \begin{bmatrix} X_1 \\ X_2 \\ \vdots \\ X_n \end{bmatrix} = \begin{bmatrix} Y_1 \\ Y_2 \\ \vdots \\ Y_n \end{bmatrix} \qquad (6)$$

Or,

$$[1-A]X = Y \Rightarrow X = Y[1-A]^{-1} \qquad (7)$$

Where $[1-A]^{-1}$ is the Leontief inverse matrix (or inter-industry interdependence coefficients matrix) from the vertical column view, of which elements **(b_{ij})** represent the total direct and indirect outputs in sector i per unit of final demand in sector j. We could observe the level of the industrial interdependence through the matrix.

2.1.2 Inter-industry Linkage Analysis

The idea of inter-industry linkage, so called forward and backward inter-industry linkages, as measures of structural interdependence was introduced by Rasmussen (1956). Subsequently, Hirschman (1958) also applied this idea to identify the key sectors. He postulated that economic development and structural change proceed predominantly along above-average linkages, so that a relatively small number of industries accelerate and amplify initially small changes, which eventually affect the whole economy.

The idea is that the increase of final input in j industry drives the increase of the total intermediate input of j industry which affects the input from other industries simultaneously. The level of the linkage relation, so called Backward Linkage (BL), could be expressed by the summation of the column (j industry) as Equation (8), where $\mathbf{b_{ij}}$ is as $[1-A]^{-1}$ (Yu, 2003):

$$BL_j = \sum_{i=1}^{n} b_{ij} \qquad (8)$$

On the other hand, the increase of final output in i industry drives the increase of the total intermediate output of i industry which affects the output from other industries simultaneously. The value of the linkage relation, so called Forward Linkage (FL), could be expressed by the summation of the row (i industry) as Equation (9):

$$FL_i = \sum_{j=1}^{n} b_{ij} \qquad (9)$$

Then, the value of backward and forward linage could be transformed to the "index of power of dispersion" (IPD) and the "index of sensitivity of dispersion" (ISD) by normalization as Equation (10) and (11) in order to compare in the same baseline.

$$RB_j = \frac{\sum_{i=1}^{n} b_{ij}}{\frac{1}{n}\sum_{i=1}^{n}\sum_{j=1}^{n} b_{ij}} \qquad (10)$$

$$RF_i = \frac{\sum_{j=1}^{n} b_{ij}}{\frac{1}{n}\sum_{i=1}^{n}\sum_{j=1}^{n} b_{ij}} \qquad (11)$$

where, RB_j is the "index of power of dispersion" and RF_i is the "index of sensitivity of dispersion". While $RB_j > 1$, it shows that the sector (or industry) exhibits both above-average dependence and influence on other sectors. In the other hand, while $RF_i > 1$, it shows that the sector (or industry) exhibits above-average sensitivity to other sectors.

2.2 Economic Input-output Life-Cycle Assessment (EIO LCA)

The challenge in assessing the environmental impact and burden of a policy is the complicated variation of industrial interaction due to a policy. Once the output of a certain industry is changed caused by the policy, the intermediate input and output from other industries are then changed. Consequently, the environmental impacts generated by industrial activities are varied. Besides, it is also difficult and resource-consuming to gather huge physical data of each industry (or product), e.g. raw materials, water, or electricity input. Therefore, a method without physical inventory data input is needed to be developed. EIO LCA combines economy-wide data on cross-sector economic flows (through economic IO table) with environmental data on total emissions from each sector. It could be applied to estimate the overall environmental performance of an industrial policy under the "ultimate" system boundary. (Koellner, Suh, Weber, Moser, Scholz, 2007) Unlike traditional LCA which is a bottom-up approach, EIO LCA is a top-down approach based on the economic transaction data, i.e. economic IO table. Advantages of applying EIO LCA are speed of analysis, significant reduced costs, circumvention of boundary problem, and availability of a wide range of environmental endpoints. (Krishnan, Boyd, Rosales, Dornfeld, 2004) Several research on EIO LCA have been discussed or ongoing in the world. For instance, Green Design Institute (GDI) in Carnegie Mellon University and Centre of Environmental Science (CML) in Leiden University have applied EIO LCA to all kinds of policy analysis, and established a large-scale matrix of environmental impacts, which contains U.S. 485 sectors in GDI project and 200 sectors in CML project. (EIO-LCA 2008; CML 2000) Moreover, not only regional case, but EIO LCA also could be applied for evaluating embodied CO_2 emission from international trades. (Weber and Matthew, 2007) Figure 2-1 shows the basic concept of applying EIO LCA in the research. The basic structure of EIO LCA is addressed below.

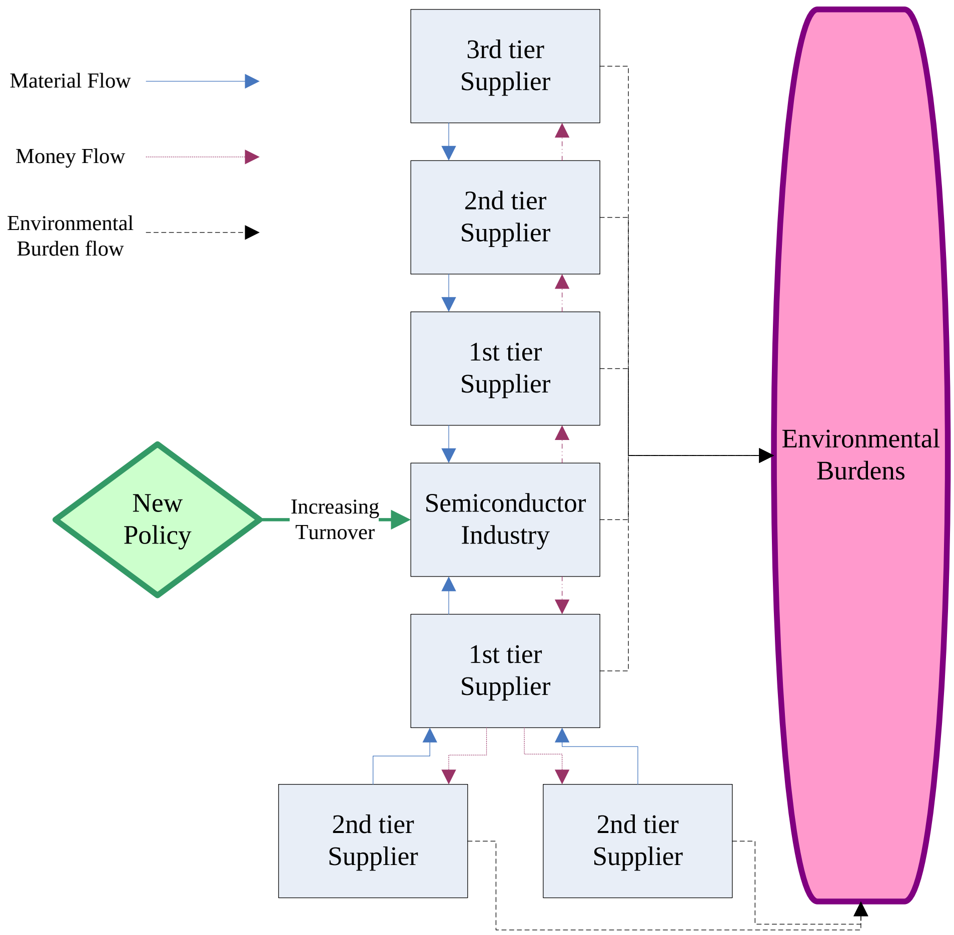

Figure 2-2 the concept of applying EIO LCA in the research

The calculation of EIO LCA is almost based on the structure of IO analysis. (Hendrickson, Horvath, Joshi, Lave, 1998) The direct supplier process inputs vector for a certain industry, $X_{\text{direct suppliers}}$, can be obtained by multiplying the matrix (I + Z) by the vector of required outputs (intermediate demand) of the industry:

$$X_{\text{direct suppliers}} = [I + Z]Y \qquad (12)$$

The elements of $X_{\text{direct suppliers}}$ are the direct supplier inputs to produce a product in the industry. I matrix is an identity matrix (to account for the output of the production stage itself), Z is the direct requirements matrix shown in Table 2-1 (Z_{ij}), and Y is a vector of output of final demand. The calculation of direct supplier output is shown as Equation (6).

Generally speaking, an LCA should take into account the entire supply chain for a product, including indirect suppliers (suppliers to a supplier). In a basic structure of supply chain, only direct supplier inputs to the production processes are indicated, so the supply chain is only one level deep. The second-level supplier demands could be calculated as the multiplication ZZY, but in some cases, a third or fourth level of supply also exists. Allowing for added levels of supplier interactions, the total output for the various process stages can be calculated as

$$X = [I + Z + ZZ + ZZZ + \ldots]Y \qquad (13)$$

where X now takes into account all supplier input levels, I matrix is the identity matrix, Z is the requirements matrix, and Y is the vector representing the final demand of a certain product in an industry. The supplier requirements series $[I + Z + ZZ + ZZZ + \ldots]$ is equal to $(I - Z)^{-1}$, so the total input, including the influences of all direct and indirect suppliers, is then converted to:

$$X = [I - Z]^{-1} Y \qquad (14)$$

Once the economic output for each process stage is calculated, a vector of environmental outputs, then, can be obtained by multiplying the economic output at each stage by the environmental impact per dollar of output:

$$B_i = R_i X = R_i (I - Z)^{-1} Y \qquad (15)$$

B is the vector of environmental outputs, the subscript i denotes the type of burden, e.g. CO_2, NO_X, SO_X, PM_{10}, hazardous waste, BOD, etc., and R_i is a matrix that has diagonal elements representing the environmental impact per dollar of output for each industry. A variety of environmental burdens might be included in this calculation. Analyses have been performed that include resource inputs such as electricity, fuels, ores, and fertilizers, and environmental outputs such as toxic emissions, hazardous waste generation and management, conventional air pollutant emissions, global warming potential, and ozone-depleting substances.

3 Data Processing

Several data sets, including nationwide economic IO table and sectoral environmental impacts, are required in our analysis, i.e. industrial interdependence analysis and EIO LCA. However, the classification and format of these data from different organizations in Taiwan government are different. Therefore, some of them are required to be transformed, allocated or aggregated in order to correspond well with each other before our analysis proceeding. Table 3-1 summarizes the various data sets, availability and use both in industrial interdependence analysis and EIO LCA. In the following sections, the various manipulations are described in detail.

Table 3-1 Summary of data types used, availability and model use

Data Type	Availability	Model Use
Economic Data: National economic transaction data	Taiwanese economic IO table (161*161 sectors version)	**Industrial interdependence analysis:** Directly apply the data of 161*161 matrix in the analysis **EIO LCA:** Aggregate the original data of 161 sectors into 28 sectors
Environmental Impacts Data: GHGs emission of 28 sectors	1. Energy Balance Sheet of Taiwan 2004 2. UNFCCC National Communication of the Republic of China (Taiwan) 3. 2006 IPCC Guidelines	**EIO LCA:** Sum up the GHGs emission of each sector (28 sectors) in 2004
Environmental Impacts Data: GHGs emission of semiconductor industry	Interior report of GHGs emission inventory in semiconductor industry (commissioned by TSIA)	**EIO LCA:** Sum up CO_2 emission form energy demand side and PFCs usage in 2004

3.1 Economic Input-output Data

Official Taiwanese economic data over the years (every three years from 1995 to 2004) are available in the website of Directorate-General of Budget, Accounting and Statistics, Executive Yuan, Taiwan (Executive Yuan Directorate-General of Budget, Accounting and Statistics, 2007). Two versions of the IO tables which are 49*49 sector matrix and 161*161 matrix could be obtained from the website. The 161*161 matrix table in 2004 is chosen for the industrial interdependence analysis since the version of IO table contains semiconductor industry. The definition of the semiconductor industry in the IO table, which includes wafer manufacturing, IC manufacturing, IC packaging, and IC testing industries, also matches our research target. (EY DBAS, 2007)

The 161*161 IO table in 2004 is also applicable to the calculation of EIO LCA. However, it may suffer some difficulties while directly applying 161-sector data in EIO LCA calculation because the environmental impacts data corresponding to these sectors are not available. In Taiwan, we hardly could access the detail environmental information of specific industries, but some common aspects, e.g. CO2 emission, of major sectors. In this case, in order to match the industry categories of environmental information (see Section 3.2), the economic IO data of 161 sectors are concentrated into 28 major sectors. Therefore, appropriate allocation and aggregation of economic IO are needed to be done before EIO LCA proceeding. Figure 3-1 shows the original categories of economic data which cover 161 sectors, and Figure 3-2 is the new industrial structure after appropriate allocation and aggregation. The economic IO table could be then renewed into a 28*28-sector one shown as Table 3-2 to Table 3-5.

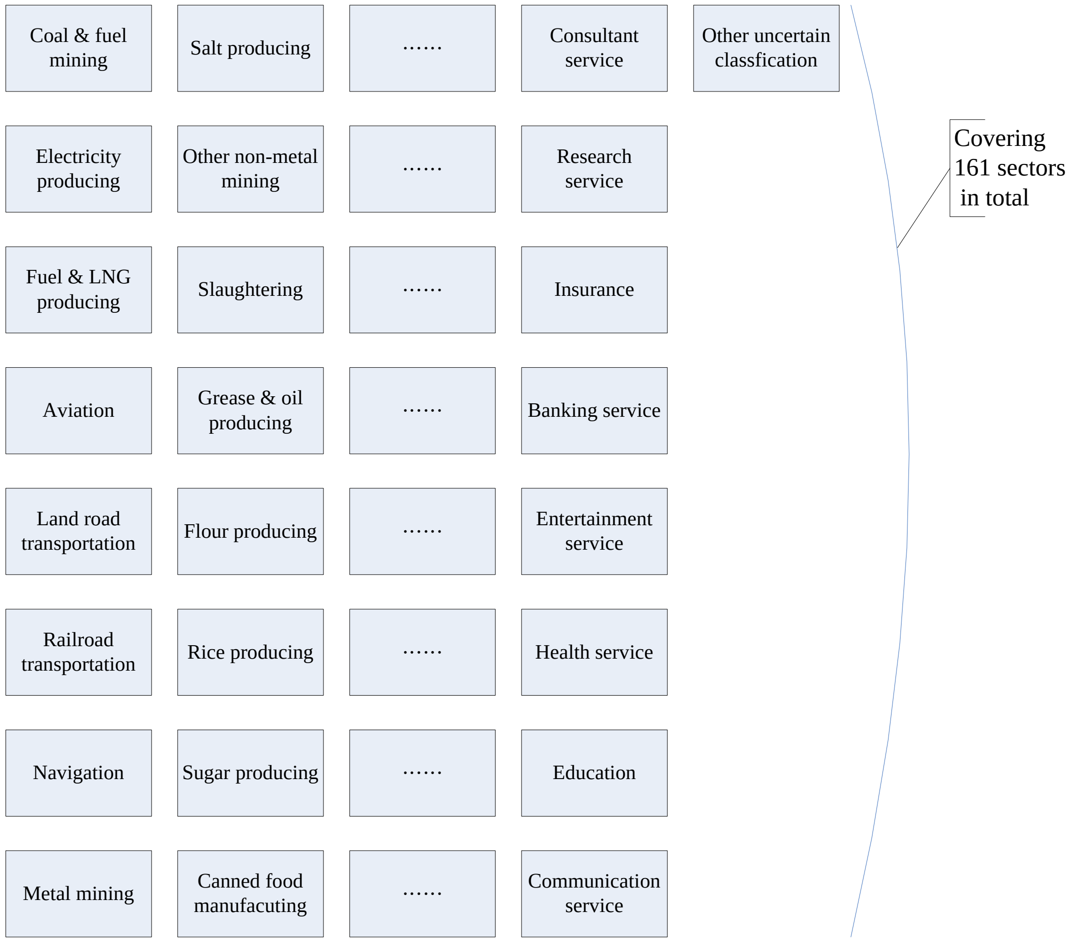

Figure 3-1 original industrial classification (161 sectors) in economic IO table

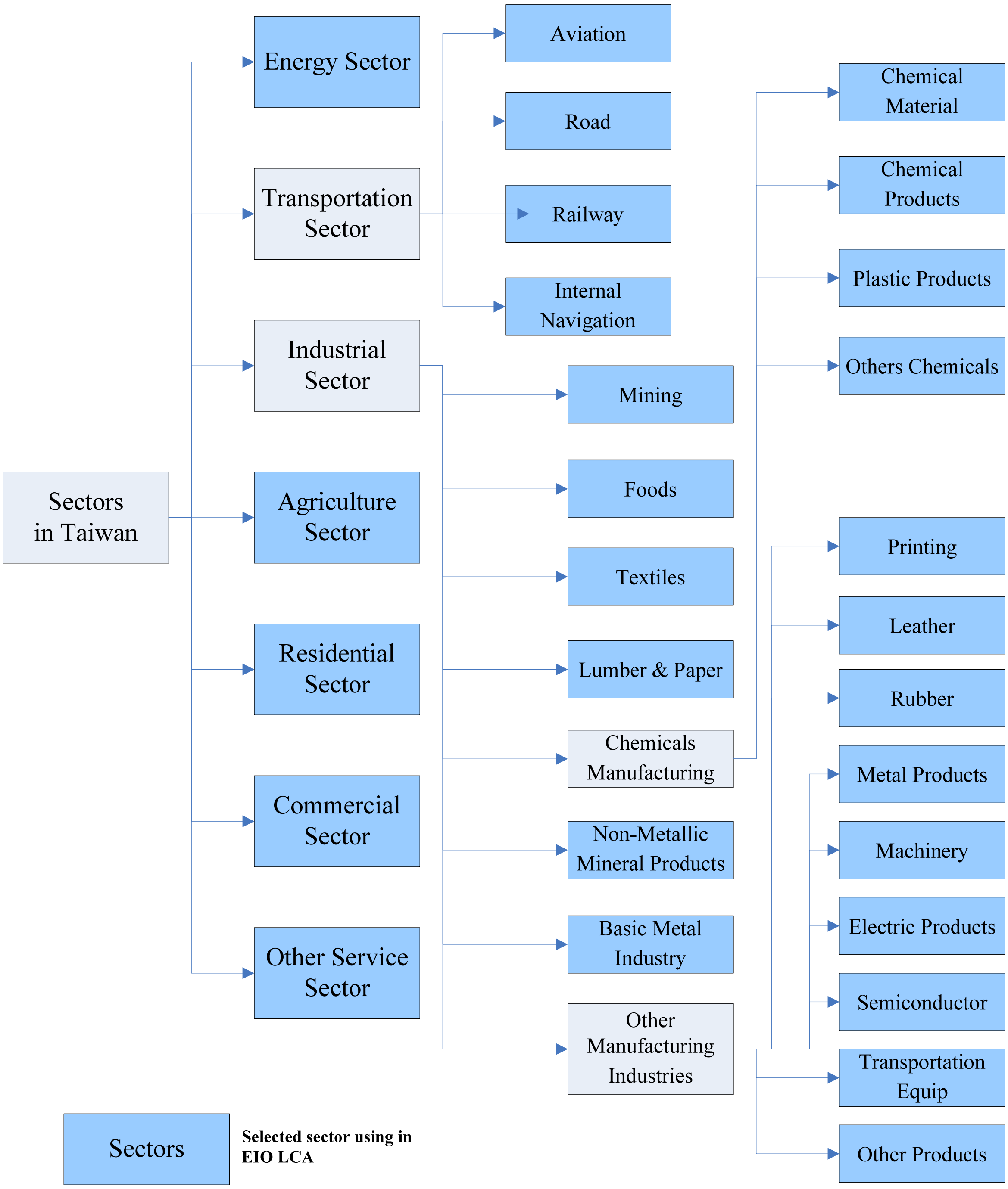

Figure 3-2 new industrial classification (28 sectors) after allocation and aggregation

*Table 3-2 renewed economic IO table (28*28 Sectors)*

Sectors (Unit: million NTD) [1]				Intermediate Demand (Output)								
				Energy sector	Transportation sector				Industrial sector			
					Aviation	Road	Railway	Internal Navigation	Mining	Foods	Textiles	Lumber & Paper
INTERMEDIATE INPUT	Energy sector			189,384	910	1,078	1,610	333	3,211	8,574	15,973	8,717
	Transportation sector	Aviation		127	19,960	379	5	364	19	209	354	88
		Road		2,042	1,027	1,862	906	728	556	5,148	3,283	2,979
		Railway		113	252	196	5	203	29	352	174	143
		Internal Navigation		717	4	131	2	51,756	156	244	260	134
	Industrial sector	Mining		14	0	0	0	0	14,959	588	23	643
		Foods		40	0	0	0	0	36	89,056	198	1,014
		Textiles		97	0	28	21	126	64	378	197,564	2,155
		Lumber & Paper		15	45	4	2	116	653	10,632	3,366	93,518
		Chemicals Manufacturing	Chemical Material	4,146	0	0	0	0	150	3,081	97,873	5,319
			Chemical Products	247	3	0	0	219	1,137	3,003	14,846	4,453
			Plastic Products	46	0	0	0	0	231	11,331	4,794	4,583
			Others Chemicals	50,198	46,148	70,053	513	26,012	9,566	6,916	7,074	3,868
		Non-Metallic Mineral Products		216	0	0	0	8	228	1,693	71	415
		Basic Metal Industry		169	0	0	45	270	279	1,649	105	702
		Other Manufacturing Industries	Printing	592	478	157	27	483	48	1,073	592	557
			Leather	0	0	0	0	0	0	0	373	398
			Rubber	71	27	4,829	0	42	352	117	2,203	294
			Metal Products	217	12	412	22	55	752	10,291	792	1,058
			Machinery	4,243	1,096	165	259	2,212	5,351	1,957	4,276	2,088
			Electric Products	12,238	423	263	55	115	426	345	895	971
			Semiconductor	0	0	0	30	0	0	0	0	0
			Transportation Equip	61	19,834	6,422	6,082	5,885	20	120	206	139
			Other Products	1,212	68	333	18	86	57	1,061	2,987	151
	Agricultural Sector			0	0	0	0	0	0	201,771	14,841	5,570
	Residential Sector			5,934	206	767	3,790	136	423	537	1,002	516
	Commercial Sector			2,934	9,995	10,046	56	5,799	1,827	36,533	21,579	21,121
	Other Service Sector			23,059	53,126	38,981	2,131	47,357	2,394	42,412	33,254	28,835

[1]: 30 NTD≒1 USD

*Table 3-3 renewed economic IO table (28*28 Sectors) (Continue 1)*

Sectors (Unit: million NTD)				Intermediate Demand (Output)							
				Industrial sector							
				Chemicals Manufacturing				Non-Metallic Mineral Products	Basic Metal Industry	Other Manufacturing Industries	
				Chemical Material	Chemical Products	Plastic Products	Others Chemicals			Printing	Leather
INTERMEDIATE INPUT	Energy sector			47,820	2,041	11,624	475,209	18,317	29,282	2,393	423
	Transportation sector	Aviation		155	123	170	132	83	234	190	13
		Road		7,696	1,103	2,184	4,268	6,790	7,162	1,204	358
		Railway		93	191	87	109	504	190	172	23
		Internal Navigation		1,567	89	216	1,298	824	960	40	36
	Industrial sector	Mining		5,605	244	13	1,670	47,320	29,870	0	32
		Foods		995	404	4	343	10	0	0	10,400
		Textiles		390	51	4,704	1,062	431	306	221	656
		Lumber & Paper		7,706	2,652	3,412	1,604	4,033	1,520	38,533	359
		Chemicals Manufacturing	Chemical Material	827,052	55,365	148,838	17,676	10,117	15,475	570	1,783
			Chemical Products	13,262	34,645	13,985	3,510	3,385	4,938	7,610	1,677
			Plastic Products	3,094	6,240	53,040	2,114	1,010	1,386	2,513	661
			Others Chemicals	198,094	2,479	4,176	42,093	11,153	28,479	1,018	368
		Non-Metallic Mineral Products		1,850	692	1,151	2,000	40,419	6,711	15	2
		Basic Metal Industry		8,789	1,918	1,046	843	3,753	749,772	2,182	17
		Other Manufacturing Industries	Printing	500	637	660	243	311	984	4,455	76
			Leather	41	0	258	15	0	13	69	10,530
			Rubber	1,367	51	2,534	264	288	384	15	103
			Metal Products	2,363	1,716	4,734	789	1,248	12,614	499	137
			Machinery	10,301	588	3,702	2,245	5,742	13,922	937	87
			Electric Products	1,968	517	1,231	617	911	2,182	173	24
			Semiconductor	0	0	0	0	0	0	0	0
			Transportation Equip	148	11	548	564	272	81	351	5
			Other Products	679	209	380	428	160	144	4,165	89
	Agricultural Sector			353	722	130	331	0	0	0	1
	Residential Sector			1,265	299	745	651	1,104	831	398	60
	Commercial Sector			33,859	14,868	22,371	8,383	15,293	65,926	14,310	1,906
	Other Service Sector			50,017	17,330	31,095	27,484	21,112	111,317	16,577	3,038

*Table 3-4 renewed economic IO table (28*28 Sectors) (Continue 2)*

Sectors (Unit: million NTD)				Intermediate Demand (Output) – Industrial sector – Other Manufacturing Industries: Rubber	Metal Products	Machinery	Electric Products	Semiconductor	Transportation Equip	Other Products
INTERMEDIATE INPUT	Energy sector			1,657	9,183	5,468	24,348	18,022	5,155	2,637
	Transportation sector	Aviation		32	149	1,072	1,321	354	572	179
		Road		440	3,920	5,480	12,595	3,902	106	1,745
		Railway		43	105	684	1,129	188	339	207
		Internal Navigation		47	199	446	314	75	72	48
	Industrial sector	Mining		10	258	217	169	1	0	275
		Foods		0	0	8	0	0	2,520	2,001
		Textiles		2,721	1,368	386	1,037	664	5,125	5,771
		Lumber & Paper		369	4,705	2,316	13,062	1,552	8,269	5,417
		Chemicals Manufacturing	Chemical Material	16,276	7,963	3,897	89,134	83,002	4,893	12,110
			Chemical Products	2,685	11,112	863	31,329	19,291	18,377	1,510
			Plastic Products	541	8,224	7,103	91,315	9,890	2,601	14,951
			Others Chemicals	1,365	4,400	4,070	5,047	781	5,892	1,221
		Non-Metallic Mineral Products		8	2,335	1,435	67,131	3,959	74,631	5,817
		Basic Metal Industry		2,324	203,966	153,616	144,072	19,292	106	20,169
		Other Manufacturing Industries	Printing	6	698	566	2,320	578	2,421	872
			Leather	0	301	429	52	0	11,656	942
			Rubber	5,044	598	7,849	4,963	1,062	22,254	1,258
			Metal Products	629	56,155	37,267	38,470	1,149	13,213	11,333
			Machinery	837	5,995	109,336	35,570	33,416	18,720	3,735
			Electric Products	417	2,356	57,827	717,325	54,719	983	27,775
			Semiconductor	0	0	3,799	409,681	372,554	192,942	15,332
			Transportation Equip	42	193	417	390	10	18,720	287
			Other Products	84	591	2,925	9,011	6,596	3,888	26,504
	Agricultural Sector			4,122	0	8	21	0	156	356
	Residential Sector			78	665	1,771	2,650	1,733	775	316
	Commercial Sector			3,364	38,351	47,555	111,700	23,603	42,749	14,326
	Other Service Sector			6,199	35,351	43,519	240,358	145,742	43,704	20,445

*Table 3-5 renewed economic IO table (28*28 Sectors) (Continue 3)*

Sectors (Unit: million NTD)				Intermediate Demand (Output) Agricultural Sector	Residential Sector	Commercial Sector	Other Service Sector	Total Intermediate Demand	Final Demand
INTERMEDIATE INPUT	Energy sector			3,959	1,909	51,275	58,212	998,724	108,612
	Transportation sector	Aviation		0	507	3,714	10,728	41,233	245,146
		Road		3,588	30,389	8,981	25,683	149,644	167,198
		Railway		29	431	829	6,650	13,237	16,534
		Internal Navigation		271	1,525	2,070	3,383	67,151	173,041
	Industrial sector	Mining		16	49,824	78	147	152,048	227
		Foods		72,186	0	1,876	5,732	184,303	561,045
		Textiles		2,011	417	4,996	6,795	236,940	395,706
		Lumber & Paper		1,307	25,915	22,788	19,593	270,319	90,193
		Chemicals Manufacturing	Chemical Material	8,123	1,314	6	15,392	1,432,931	490,408
			Chemical Products	4,106	10,054	3,595	28,264	224,622	104,468
			Plastic Products	2,383	32,443	34,575	12,409	323,254	195,276
			Others Chemicals	20,535	23,288	36,602	65,681	673,799	349,517
		Non-Metallic Mineral Products		65	130,196	1,600	5,659	279,568	53,056
		Basic Metal Industry		154	151,587	427	13,966	1,55,743	310,371
		Other Manufacturing Industries	Printing	684	744	21,577	115,034	155,058	43,069
			Leather	0	0	2	221	16,065	47,902
			Rubber	410	859	79	5,015	51,734	38,990
			Metal Products	1,221	66,864	1,646	9,870	284,569	300,498
			Machinery	1,990	16,510	3,119	23,432	306,324	969,220
			Electric Products	348	84,942	1,889	86,427	1,076,099	2,252,150
			Semiconductor	0	0	0	26,052	828,431	998,777
			Transportation Equip	3,341	78	4,304	34,416	277,169	584,111
			Other Products	1,063	1,024	3,808	50,367	118,088	494,415
	Agricultural Sector			76,426	1,419	31	1,315	307,573	261,662
	Residential Sector			808	678	7,344	114,609	150,092	934,017
	Commercial Sector			18,270	72,951	54,832	124,741	839,248	2,033,290
	Other Service Sector			20,783	90,630	588,102	1,540,916	3,325,268	4,473,613

3.2 Environmental Impact Data

Unlike explicit databases in USA, e.g. National Emission Inventory (NEI) which is covering 491 sectors and maintained by USEPA (United States Environmental Protection Agency), (USEPA, 2008) the environmental databases in Taiwan merely cover only several critical pollutants, e.g. NO_x emission, emitted by some major sectors. It would take lots of efforts to investigate the all kinds of environmental aspects from 28 sectors if we consider all the impacts in EIO LCA study. Therefore, in order to facilitate the application of our study, we'd only focus on the GHGs emission, which we could obtain from national database of energy consumption and other reports, since GHGs emission has been regarded as a significant issue of global warming in this century. Although we could not estimate the overall impacts of different environmental aspects due to the inaccessible information, we could still prove the feasibility of applying EIO LCA in the study through the calculation of a single aspect, global warming in this case. Further estimation of other impacts could be done while sufficient environmental impact data are updated in the future.

The calculation of GHGs emission in 28 sectors follows the IPCC (Intergovernmental Panel on Climate Change) guideline. (IPCC, 2006) It divides the calculation into four parts, i.e. energy, industrial processes and product use, agriculture and other land use, and waste. The energy consumption data could be found in Energy Balance Sheet of Taiwan 2004 (Taiwanese energy IO table, see as Appendix A). (Bureau of Energy, Ministry of Economic Affairs, 2004) IPCC guideline also provides the GHGs emission factors of different fuel consumption and Global Warming Potential (GWP) factors. (IPCC, 2006) For other part of calculation, UNFCCC National Communication of the Republic of China (Taiwan) also addressed some useful information, including the GHGs emission from industrial processes and product use, agriculture and other land use, and waste.

However, it is also required to obtain GHGs emission data of our target industry, semiconductor industry, while applying EIO LCA approach. Unfortunately, this information is not specified either on the energy IO table and UNFCCC (United Nations Framework Convention on Climate Change) National Communication of Taiwan. Only the information of major categories of industries, e.g. chemical material or electric product manufacturing industry, would be mentioned on them. Therefore, the GHGS emission data of semiconductor industry, which is covered in a major industry, electric product manufacturing industry, needs to be further estimated by other approaches. Industrial Technology Research Institute (ITRI), Taiwan was commissioned by TSIA for a project of GHGs Inventory in semiconductor industry in 2005. (ITRI, 2005) The report mentioned that major GHGs which are generated during manufacturing process are from electricity consumption in clean house and the usage of PFCs (Perfluorocarbons). Table 3-6 shows the usage of PFCs in semiconductor industry from 2001 to 2005. In comparison of the GHGs emission caused by energy use in 2004, 3.41million ton CO_2, PFCs seems to be a critical GHGs in semiconductor industry. After recalculating the data from different references, the emission data of 28 sectors come up as Table 3-7. According to the table, chemical material manufacturing contributes the largest GHGs emission, which is around 68 million ton CO_2 equivalent. The contribution of energy sector is around 15 million ton CO_2 equivalent which merely rank ninth. It's because 35% of energy supply is by nuclear power. Our target industry, semiconductor industry, generates 8.9 million ton CO_2 equivalent GHGs, and the total GHGs emission in 2004 is 304 million ton CO_2 equivalent.

Table 3-6 PFC usage in semiconductor industry from 2001 to 2005

Year	2001	2002	2003	2004	2005
PFCs usage (MMTCE)*	1.15	1.36	1.42	1.50	1.18
PFCs usage (Metric tons CO_2 equivalent)	4,216,667	4,986,667	5,194,217	5,500,000	4,326,667

*: *Metric Tons of Carbon Equivalent*

Table 3-7 PFC usage in semiconductor industry from 2001 to 2005

Sectors			CO_2 (Ton)	CH_4 (Ton)	N_2O (Ton)	PFC* (Ton GWP)	Metric Tons CO_2 Equivalent
Energy sector			14,737,960	213	40	-	14,755,209
Transportation sector	Aviation		6,546,255	275	55	-	6,569,491
	Road		34,547,050	8,970	3,273	-	35,746,639
	Railway		661,984	5	5	-	663,682
	Internal Navigation		1,067,067	46	24	-	1,075,227
Industrial sector	Mining		345,089	5	2	-	345,924
	Foods		3,262,008	47	10	-	3,266,238
	Textiles		8,694,646	145	32	-	8,707,717
	Lumber & Paper		3,507,854	42	22	-	3,515,415
	Chemicals Manufacturing	Chemical Materials	67,305,820	2,165	564	-	67,527,877
		Chemical Products	2,519,554	30	6	-	2,522,247
		Plastic Products	3,003,931	12	2	-	3,004,953
		Others Chemicals	1,066,341	22	3	-	1,067,801
	Non-Metallic Mineral Products		20,336,671	138	119	-	20,375,595
	Basic Metal Industry		25,116,200	235	112	-	25,155,425
	Other Manufacturing Industries	Printing	377,117	1	0	-	377,171
		Leather	315,007	4	1	-	315,377
		Rubber	883,009	10	2	-	883,874
		Metal Products	3,988,653	15	3	-	3,989,998
		Machinery	1,053,107	2	0	-	1,053,270
		Electric Products	11,131,290	15	6	1,264,998	12,398,401
		Semiconductor	3,410,000	0	0	5,500,000	8,910,000
		Transportation Equip	1,703,464	22	6	-	1,705,803
		Other Products	1,299,320	10	1	-	1,300,006
Agricultural Sector			4,697,336	93,783	33,160	-	16,923,534
Residential Sector			30,963,254	109	17	-	30,971,077
Commercial Sector			15,676,282	66	22	-	15,684,478
Other Service Sector			15,516,484	145	75	-	15,542,333
Total			283,732,749	106,530	37,563	6,764,998	304,354,764

4 Results and Discussion

In this chapter, results of our analysis, i.e. industrial interdependence analysis and EIO LCA, are addressed and discussed. The results of industrial interdependence analysis are introduced in Section 4.1, and some uncertainties of the method are also discussed in the sub-section. Section 4.2 describes the outcome of EIO LCA. It shows the real environmental performance, GHGs emission in this case, of semiconductor industry, and the contribution of environmental impacts from other sectors in a perspective of life-cycle concerns. The uncertainties, limitation, and the strategy for dealing those problems in the future are also addressed in the following.

4.1 Industrial Interdependence Analysis

4.1.1 Results

We collected and organized the IO data of 161 sectors as mentioned in Section 3.1. Through the Equation (6) and (7), we could calculate the Leontief inverse matrix of 161 sectors as (b_{ij}). The value of Backward Linkage (BL) and Forward Linkage (FL) could be calculated through Equation (8) and (9) with the matrix. Then, after a normalization process as Equation (10) and (11), the index of power of dispersion (IPD) and sensitivity of dispersion (ISD) could be generated. Table 4-1 and 4-2 summarize the top sectors of results, i.e. BL, FL, ISD and IPD. The detail results of 161 sectors are shown as Appendix B.

Petrochemical industry has the highest values of FL and ISD, which are 18.72 and 6.70 individually. It implies that the variation of its production influences the downstream industries significantly. We also find that some service sectors, i.e. Finance and wholesale service, also rank high (the third and tenth) in ISD among 161 sectors. The reason might be that the manufacturing industries in Taiwan are almost small-medium enterprise (SMEs) or OEM (Original Equipment Manufacturer) companies. Running their business needs some financial service, e.g. enterprise loans, or wholesale activities to buy materials or sell their products. The concerned target, semiconductor industry in this case, which gets 6.51 in FL and 2.33 in ISD also ranks high (the 13^{th}) among the 161 sectors. It may mean that semiconductor industry has higher sensitivity to other industries. In other words, the industry has great influences on its downstream sectors, especially electric product manufacturing industry. The production and export of electric product which produce the turnover of around 1 trillion NTD (33 billion USD) are the major industrial activities in Taiwan.

In comparison of FL and ISD, the BL and IPD values of each sector are much even. The value of IPD varies from 1.7 to around 0.4. The highest value of BL and IPD, 4.77 and 1.71 separately, appears on Metal mining sector because the industry highly relies on the input of electricity and other metals. In another word, the industry highly influences its upstream industry, electricity generation and other metal mining. We also could find that processing industries, e.g. textile, leather, or other metal product manufacturing industries, have higher value of BL and IPD. That indirectly proves that traditional manufacturing industries still highly influence the turnover of material producers although Taiwanese government claimed that these traditional industries have had great transition from processing oriented one to design oriented. Semiconductor industry gets lower rank, the 70^{th}, in BL and IPD value than in FL and ISD. However, the ISD and IPD of semiconductor industry, 1.12 and 2.33 individually, are both above 1.00. It means that semiconductor industry still exhibits above-average influence and sensitivity among 161 sectors. It means the variation of this industry affects the turnover (or activities) of its both upstream, e.g. chemical material industry, and downstream industry, e.g. electric product manufacturing industry. The development of semiconductor industry is not only important to the nationwide economy but also critical to other sectors.

Table 4-1 top 15 sectors of ISD

Rank	Forward Linkage (FL)	Index of Sensitivity of Dispersion (ISD)	Industry
1	18.72	6.70	Petrochemical industry
2	17.77	6.36	Coal and fuel mining
3	17.21	6.15	Finance service
4	14.84	5.31	Petrochemical product manufacturing
5	13.53	4.84	Primary steel product
6	10.10	3.61	Electricity
7	8.14	2.91	Unknown category
8	8.15	2.91	Other metal
9	7.58	2.71	Raw steel and iron
10	7.36	2.63	Wholesale
11	7.02	2.51	Metal mining
12	6.72	2.40	Plastic (resin) material
13	**6.51**	**2.33**	**Semiconductor**
14	6.29	2.25	Retail sale
15	5.95	2.13	Plastic product

Table 4-2 top 10 sectors of IPD and the rank semiconductor industry

Rank	Backward Linkage (BL)	Index of Power of Dispersion (IPD)	Industry
1	4.77	1.71	Metal Mining
2	4.21	1.50	Aluminium
3	4.16	1.49	Synthetic fiber manufacturing
4	4.14	1.48	Plastic (resin) material
5	4.11	1.47	Synthetic fiber textile
6	4.09	1.46	Wool textile
7	4.08	1.46	Wire and cable
8	4.01	1.43	Primary steel product
9	3.96	1.42	Other metals
10	3.92	1.40	Leather
. . .	. . .	. . .	. . .
70	**3.13**	**1.12**	**Semiconductor**

4.1.2 Uncertainties and Limitation

Some uncertainties and limitation of industrial interdependence analysis are addressed in the following.

1. Industrial interdependence analysis which is based on IO approach could analyze the current circumstance of economic transaction in nationwide. However, it hardly describes the economic structure in the future because of its basic assumption, fixed IO structure. It means that in the case that new additional demand occurs in the future, supply have to follow recent input structure. Therefore, it could apply industrial interdependence analysis

for the forecast only if we could accept the assumption that the structure would the same in the future.

In this study, 161 sectors, or we could say 161 products, are considered to cover the whole economic system. However, there are much more sectors or products in reality than the setting of the study. Another assumption that the similar industry or products are assigned in one category is needed. For example, DRAM (Dynamic Random Access Memory) and the CPU chip are both regarded as semiconductor category. Nevertheless, the economic contribution and influence to others are slightly different among specific products. Therefore, we might be still aware the bias while applying the method although the variation might have limited influence on the result.

4.2 EIO LCA

4.2.1 Results

In this study, we only use one environmental aspect, GHGs emission, instead of the overall aspects, e.g. water usage, energy consumption, and other pollutant emission, because of the lack of the environmental information which is mentioned in Section 3.2. The inverse matrix of (I-Z) is calculated by applying organized economic matrix, a 28*28 sector matrix, in the Equation (14). The economic transaction profile of semiconductor industry could be then selected from the $(I-Z)^{-1}$ matrix. By the Equation (15), the outcome of the EIO LCA, the GHGs emission from other sectors in a life-cycle perspective, could be estimated. Table 4-3 and 4-4 show the parameters in the calculation and the results of the analysis in the study.

According to the economic transaction profile (the $(I-Z)^{-1}$ matrix) shown in Table 4-3 and 4-4, other service, chemical materials, basic metal industry, electric products, and energy sectors are the top 5 sectors of economic input ratio except semiconductor industry itself. The value of semiconductor industry itself in the profile is 1. It means, as our assumption, the input from semiconductor industry completely contributes to the output of semiconductor industry. In another word, the production activities (or the GHGs emission) of semiconductor industry 100% contribute the turnover of semiconductor industry. The reason that those sectors, i.e. chemical materials, basic metals, and electric products sectors, have high input ratio is because they are the critical material suppliers of semiconductors. Chemical material industry serves with high quality, also high-price, chemicals, e.g. photoresist, stripper, or etching agent (acid). Basic metal and electric product industries provide with the metal structure, other processing metals, and some parts of IC. IC manufacturing processes which included in semiconductor industry also consumes huge energy, i.e. electricity, to run and maintain the clean room in the process. Therefore, energy sector is one of the sectors with higher economic input ratio to semiconductor industry. Other service sector, which includes financial, research, consultant, IT service … etc., also contributes to the industry very much. As we know, semiconductor industry is a capital-intensive and technology-intensive industry. Therefore, the demand from those service sectors is quite high. The economic input from other sectors, which could be calculated by $(I-Z)^{-1}$ multiplied by Y (sectoral demand), in order to support semiconductor industry is near 1.6 trillion NTD.

Before discussing the GHGs emission caused by other sectors' input, it would be better to address the environmental conversion factor, the GHGs emission intensity in this study. The GHGs emission intensity here means the amount of GHGs emission per unit turnover (million NTD) of a certain industry. Energy sector only generate 14.7 ton CO2e/ million NTD. The reason might be 25% electricity are generated by nuclear power, hydro power, and wind power plants. (MOEA BoE, 2005) Surprisingly, residential sector shows very high value of GHGs emission intensity, 436.50 ton CO2e/ million NTD. It's reasonable that a large amount of GHGs emits from this sector because of huge consumption of electricity and LPG (Liquid Petroleum Gas) in the sector. However, its total demand (output) is not as much as we expect. That might be that household sector which is included in residential sector produces less output to other sectors. Moreover, road transportation sector also exhibits a high vale of the intensity, 238.88 ton CO2e/ million NTD.

The overall GHGs emission contributed by the inputs from all sectors (including semiconductor industry itself) to semiconductor industry is around 46 million ton CO_2e according to the calculation through EIO LCA. The figures are much larger than the amount of GHGs emitted by semiconductor industry itself which is nearly 9 million ton CO_2e. It shows that while we consider the emission of a certain industry in a life-cycle perspective, a large amount of emission from the upstream sectors might be produced just behind the industry. The sectoral contribution of GHGs emission to semiconductor industry and its composition of overall emission are shown as Figure 4-1 and 4-2. Among 46 million tons, near 20 million ton CO_2e GHGs, around 43% of overall emission, are contributed by chemical material sector. In other words, chemical material industry produced 20 million ton CO_2e GHGs while producing chemical materials for the supply to the production of semiconductor industry. Other service, basic metal, and energy sectors also contribute a big portion of the overall GHGs emission, which are 7.2, 3.5, 1.9, 1.6 million ton CO_2e GHGs individually. It implies that the GHGs emission should be mitigated significant in these sectors if the environmental performance of semiconductor industry has to be enhanced.

The result of the scenario, "Two Trillion & Twin Star" policy scenario (only consider the turnover of semiconductor industry achieving the target of 1 trillion NTD), is shown in Table 4-5. The added value of the output (production) from semiconductor industry, industrial structure (economic transaction), and the environmental conversion factors are assumed to be constant in the future. The overall GHGs emission would achieve the level of 56 million ton CO_2e while the turnover of semiconductor industry increases to 1 trillion NTD under the policy. The difference of the emission between current status (2004) and the scenario is around 10 million ton CO_2e, which is near the amount of the emission from the whole semiconductor industry.

Some small conclusion may come up with the results discussed above. Firstly, we should realize that except the GHGs emission of semiconductor industry its own, a large amount of emission accompanies with other sectoral activities that supply semiconductor industry. We might further infer that the amount of other pollution or burdens, such as NO_X or SO_X, from those activities, especially in energy sector, might be also huge although semiconductor industry produces less pollution than other sectors. The overall environmental burdens caused by the economic transaction between semiconductor industry and its upstream sectors should be much more than the burden directly caused by the industry. We should pay more attention about this effects while drawing an industrial policy or developing certain industries. Secondly, it hardly improves both the economic and, especially, environmental performance by only enhancing semiconductor industry, so called a green industry. According to scenario analysis, the overall economic performance will gain an increase of 0.7 trillion NTD by enhancing the turnover of semiconductor industry into 1 trillion NTD (increasing 0.17 trillion NTD), but the overall GHGs emission increases almost 10 million ton CO_2e. Although semiconductor industry does drive significant economic improvement of sectors, its indirect environmental burden coming from other sectors also increases. In order to achieve the overall environmental performance of high-level, the further improvement of environmental performance in the critical sectors, e.g. chemical materials, other service, or basic metal sectors, is essential.

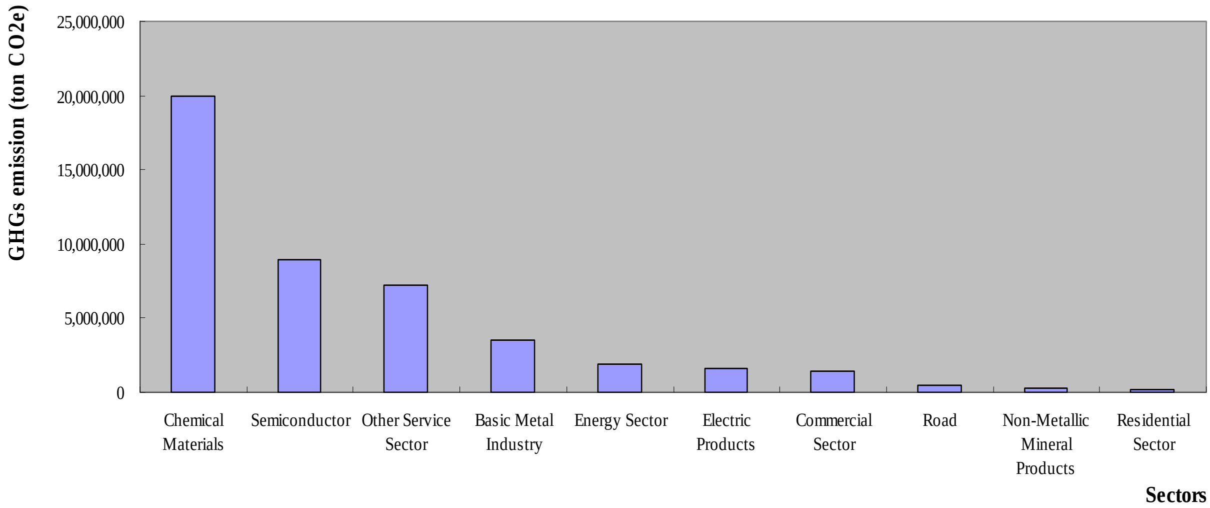

Figure 4-1 the sectoral contribution of GHGs emission to semiconductor industry

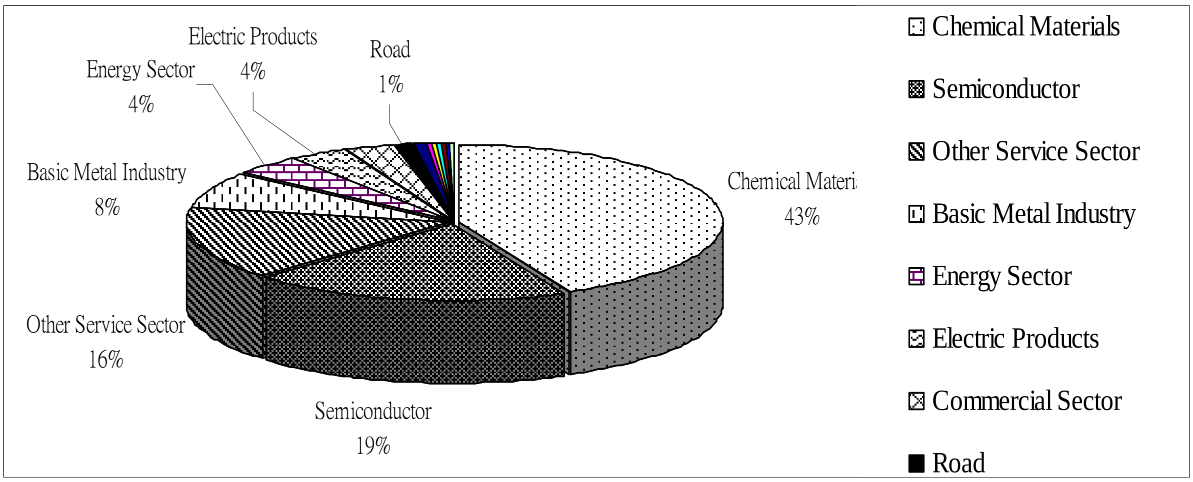

Figure 4-2 the composition of sectoral GHGs contribution to semiconductor industry

Table 4-3 results of EIO LCA for semiconductor industry in 2004

Sectors			Economic Data		
			Economic transaction profile of semiconductor industry $(I-Z)^{-1}$	Sectoral Demand Y (million NTD)	Supply (input) to semiconductor industry from other sectors $(I-Z)^{-1}\times Y$ (million NTD)
Energy Sector			0.1314	998,724	131,191
Transportation Sector	Aviation		0.0025	41,233	105
	Road		0.0138	149,644	2,059
	Railway		0.0012	13,237	16
	Internal Navigation		0.0020	67,151	134
Industrial Sector	Mining		0.0195	152,048	2,965
	Foods		0.0018	184,303	327
	Textiles		0.0039	236,940	935
	Lumber & Paper		0.0215	270,319	5,804
	Chemicals	Chemical Materials	0.2952	1,432,931	423,069
		Chemical Products	0.0472	224,622	10,592
		Plastic Products	0.0271	323,254	8,775
		Others Chemicals	0.0682	673,799	45,968
	Non-Metallic Mineral Products		0.0161	279,568	4,504
	Basic Metal Industry		0.1398	1,555,743	217,472
	Other Manufacturing Industries	Printing	0.0136	155,058	2,103
		Leather	0.0002	16,065	4
		Rubber	0.0045	51,734	231
		Metal Products	0.0146	284,569	4,157
		Machinery	0.0702	306,324	21,514
		Electric Products	0.1324	1,076,099	142,512
		Semiconductor	1.0000	828,431	828,431
		Transportation Equip	0.0046	277,169	1,282
		Other Products	0.0165	118,088	1,949
Agricultural Sector			0.0030	307,573	935
Residential Sector			0.0063	70,953	450
Commercial Sector			0.0915	839,248	76,787
Other Service Sector			0.4628	3,404,407	1,575,515
Total			--	14,339,234	3,509,783

Table 4-4 results of EIO LCA for semiconductor industry in 2004 (Continue 1)

Sectors			Environmental impact data		Result	
*: Indirect emission(excluding semiconductor industry)			Sectrol GHGs emission E (ton CO2 e. (equivalent))	GHGs emission intensity R= Y/ E (ton CO2 e./ million NTD)	GHGs emission contributed from sectors (ton CO2 e) $B= (I-Z)^{-1} \times Y \times R$	Ratio (%)
Energy Sector			14,755,209	14.77	1,938,226	4.19
Transportation Sector	Aviation		6,569,491	159.33	16,692	0.04
	Road		35,746,639	238.88	491,732	1.06
	Railway		663,682	50.14	809	0.00
	Internal Navigation		1,075,227	16.01	2,141	0.00
Industrial Sector	Mining		345,924	2.28	6,745	0.01
	Foods		3,266,238	17.72	5,787	0.01
	Textiles		8,707,717	36.75	34,380	0.07
	Lumber & Paper		3,515,415	13.00	75,480	0.16
	Chemicals	Chemical Materials	67,527,877	47.13	19,937,439	43.13
		Chemical Products	2,522,247	11.23	118,931	0.26
		Plastic Products	3,004,953	9.30	81,568	0.18
		Others Chemicals	1,067,801	1.58	72,847	0.16
	Non-Metallic Mineral Products		20,375,595	72.88	328,238	0.71
	Basic Metal Industry		25,155,425	16.17	3,516,385	7.61
	Other Manufacturing Industries	Printing	377,171	2.43	5,115	0.01
		Leather	315,377	19.63	72	0.00
		Rubber	883,874	17.08	3,946	0.01
		Metal Products	3,989,998	14.02	58,292	0.13
		Machinery	1,053,270	3.44	73,975	0.16
		Electric Products	12,398,401	11.52	1,641,973	3.55
		Semiconductor	8,910,000	10.76	8,910,000	19.27
		Transportation Equip	1,705,803	6.15	7,888	0.02
		Other Products	1,300,006	11.01	21,459	0.05
Agricultural Sector			16,923,534	55.02	51,436	0.11
Residential Sector			30,971,077	436.50	196,511	0.43
Commercial Sector			15,684,478	18.69	1,435,044	3.10
Other Service Sector			15,542,333	4.57	7,192,787	15.56
Total			304,354,762	--	46,225,898(37,315,898)*	100

Table 4-5 the comparison between current status and the scenario of "Two Trillion & Twin Star" policy

Sectors *: Indirect emission(excluding semiconductor industry)			2004 (Current status)		Scenario of "Two Trillion & Twin Star" policy	
			Supply to semiconductor industry from other sectors (million NTD)	GHGs emission contributed from sectors (ton CO2 e)	Supply to semiconductor industry from other sectors (million NTD)	GHGs emission contributed from sectors (ton CO2 e)
Energy Sector			131,191	1,938,226	158,361	2,339,635
Transportation Sector	Aviation		105	16,692	126	20,149
	Road		2,059	491,732	2,485	593,570
	Railway		16	809	19	976
	Internal Navigation		134	2,141	161	2,585
Industrial Sector	Mining		2,965	6,745	3,578	8,141
	Foods		327	5,787	394	6,985
	Textiles		935	34,380	1,129	41,500
	Lumber & Paper		5,804	75,480	7,006	91,112
	Chemicals	Chemical Materials	423,069	19,937,439	510,687	24,066,506
		Chemical Products	10,592	118,931	12,785	143,562
		Plastic Products	8,775	81,568	10,592	98,461
		Others Chemicals	45,968	72,847	55,488	87,934
	Non-Metallic Mineral Products		4,504	328,238	5,436	396,217
	Basic Metal Industry		217,472	3,516,385	262,510	4,244,632
	Other Manufacturing Industries	Printing	2,103	5,115	2,538	6,174
		Leather	4	72	4	87
		Rubber	231	3,946	279	4,764
		Metal Products	4,157	58,292	5,018	70,365
		Machinery	21,514	73,975	25,970	89,295
		Electric Products	142,512	1,641,973	172,027	1,982,028
		Semiconductor	828,431	8,910,000	1,000,000	10,755,271
		Transportation Equip	1,282	7,888	1,547	9,521
		Other Products	1,949	21,459	2,353	25,903
Agricultural Sector			935	51,436	1,128	62,088
Residential Sector			450	196,511	543	237,209
Commercial Sector			76,787	1,435,044	92,689	1,732,243
Other Service Sector			1,575,515	7,192,787	1,901,806	8,682,421
Total			3,509,783	46,225,898(37,315,898)*	4,236,663	55,799,334(45,044,063)*

4.2.2 Uncertainties and Limitation

The EIO LCA applied in the study has some uncertainties and limitation due to the data accessibility in reality and methodology itself. Several aspects including system and geographical boundary, allocation of impacts, data availability, and the classification of industries are described in the followings.

1. Restricted system boundary: Because the calculation of EIO LCA is based on economic transaction between sectors and sectors, it's hardly to determine the environmental impacts caused in the use and end-of-use phases which appear on consumers and don't belong to any sectors. Consequently, the system boundary of EIO LCA can only comprise the sector's activities from gate to gate and all industry tiers in the supply chain. (Chen, 2001) We should, therefore, be aware that the result of the environmental impact might be underestimated due to the lack of the use and end-of-use parts.

2. Impacts outside the geographical boundary: It sometimes might happen that the environmental impact data can not be consistent with nationwide economic data because the some companies have industrial activities outside the geographical boundary. For example, in some cases, companies run business in Taiwan but operate their production process in other countries. In other words, it may appear that company might gain economic profits without generating any environmental burdens if we apply economic IO table which accounts in export and import data in our EIO LCA. To avoid the dilution of environmental impacts, the turnover which is produced by local activity (inside the boundary) is only used in our calculation. However, this approach is only useful to local study of EIO LCA, but cannot reflect the real circumstance of a certain industry. For instance, many upstream suppliers of semiconductor industry have gradually moved to China due to the investment condition. The outcomes through the local approach might exhibit that no further environmental burdens appear from the upstream suppliers of semiconductor industry in the future. It's not because of their improvement of environmental performance, but the impacts appear outside the boundary, for instance, China. Therefore, expanding the geographical scope of the study which could eliminate some uncertainties is suggested in the future. However, the accessibility and integration of global information would become another issue.

3. General or specific classification of sectors: Due to the lack of environmental information of specific sectors, we could only aggregate specific sectors that produce similar products or have similar manufacturing processes into a general category in order to be consistence with the classification, the categories of GHGs inventory, in this study. For example, pesticide and pharmacy manufacturing industries are categorized in "other chemical manufacturing sector", or cement and glass product manufacturing industries in "non metal sector". However, different industries in the same category produce different economic outcome and environmental burdens. For instance, photoresist as an important auxiliary material of IC manufacturing is one of the chemical materials, but its price is much higher than common chemical materials, e.g. plastic material. The GHGs emission caused by producing it is less than other materials. (Huang and Shen, 2008) Therefore, the results of the calculation might have some unpreventable bias and could not highlight a specific and critical industry by using these average data. The study could be further strengthened by dividing a general category into more specific

sectors. However, the premise is the detail inventory of these sectors has been further developed.

4. Different performance in individual companies of same sector: In the same industry, different companies might exhibit different environmental performance. Sometimes, even the same products within the different processes might also cause different environmental impacts. In the basic assumption of EIO LCA, all companies in the same sector are regarded as one unit which has the average economic and environmental performance. It implies that the environmental performance of different companies in the same industry shall be regarded as the same. However, it is impossible in reality because the environmental performance varies among companies depending on their quality of environmental management system. (Koellner et al., 2007) Moreover, these companies grow unevenly due to the size of the company while complying with a new policy. Therefore, EIO LCA only could assist us to figure out the general picture of the whole system, but couldn't give us specific details. It is inappropriate to apply EIO LCA if we want to obtain accurate environmental impacts of a certain product, especially a product with rapid changing manufacturing processes. (Krishnan et al., 2004) However, the average environmental performance of a certain industry, semiconductor industry, is targeted in this study. EIO LCA seems to be an appropriate tool to analyze an industry under a certain policy.

5. Fixed transaction structure: EIO LCA is based on the approach of IO analysis which assumes that supplies are perfectly elastic to demands. (Suh, 2005) It means supply (input) always follows under the fixed purchasing (input) structure while additional demand occurring. However, the reality is that both the supply side and the demand side are responsible for the consequences of industrial activities. This might be an issue for the methodology to be improved the in the future.

5 Conclusion

Based on the results, we could conclude that semiconductor industry has above average influence on the whole economic system, and indirect GHGs emission from other sectors is much more than the direct emission in semiconductor industry. Moreover, the overall GHGs emission would increase additional 10 million tons CO_2e if "Two Trillion and Twin Star" policy (the turnover of semiconductor industry increased to 1 trillion NTD) were adopted. Although some flaws or limitation are exhibited in these IO analyses, it could assist us to figure out the whole picture of a macro system, e.g. an industry or a certain policy, efficiently and effectively. Several points including the application of the methods are addressed in the following conclusion.

1. According to the analysis of industrial interdependence, semiconductor industry exhibits above-average influence and sensitivity, which ranks 70^{th} and 13^{th} individually, to other industries among 161 sectors. It means the variation of this industry significantly affects the turnover (or activities) of its both upstream, e.g. chemical material industry, and downstream industry, e.g. computer manufacturing industry. Therefore, it is critical to emphasize the indirect influence and contribution from other sectors while discussing the environmental performance of semiconductor industry.

2. The outcome of EIO LCA shows that a large amount of GHGs emission, 46 million ton CO_2e (including semiconductor industry itself), accompanies with the activities of other sectors that supply semiconductor industry. Among those sectors, chemical material manufacturing sector contributes the most GHGs emission to it. The overall environmental burdens caused by the economic transaction between semiconductor industry and its upstream sectors should be much more than the burden directly caused by semiconductor industry. We should be carefully aware the indirect influence while drawing an industrial policy or developing certain industries.

3. It's difficult to simultaneously improve both the economic and, especially, environmental performance by an industrial policy, "Two Trillion & Twin Star" policy, which only enhances the turnover of the semiconductor industry. Although semiconductor industry does drive significant economic improvement of sectors and produce less environmental burdens itself, its indirect environmental burden coming from other sectors also increases. In order to achieve the overall environmental performance of high-level, the further improvement of environmental performance in the critical sectors, e.g. chemical materials, other service, or basic metal sectors, is essential.

Moreover, some issues about the application of the methods in the study are also concluded as the followings.

1. EIO LCA and industrial interdependence analysis both based on IO analysis which assumes that supply (input) always follows under the fixed purchasing (input) structure while additional demand occurring. However, the reality is that both the supply side and the demand side are responsible for the consequences of industrial activities. This might be an issue for the methodology to be improved the in the future.

2. EIO LCA seems to be inappropriate to be applied to obtain specific information of a micro system such as a product, especially a product with rapid changing manufacturing processes. That's because IO approach could only consider the economic flows (macro variation) between suppliers and manufacturers, but could not reflect the variation of

manufacturing process (micro variation). However, EIO LCA might be an appropriate tool to analyze a macro system, e.g. an industry or a certain policy, because of its further advantage, less time- and resource-consuming and circumvention of boundary problem.

3. The results of EIO LCA might have a slight bias if the sectors of an IO table are categorized generally. Because the industries or products in the same category might produce different economic outcome and environmental burdens, it sometimes might dilute the economic or environmental impacts of a specific product or industry by averaging the performance of industries in a sector. To avoid a bias, dividing a general category into more specific sectors, even into specific companies or products, is suggested. However, the premise is the detail inventory of these sectors has been further developed.

4. System boundary might be an issue while applying EIO LCA although the method could almost include the whole economic system, same as an economic transaction table. EIO LCA is hardly to determine the environmental impacts caused in the use and end-of-use phases, and could only comprise the sector's activities from gate to gate and all industry tiers in the supply chain. We should be aware the result that might lack the use and end-of-use parts. Moreover, impacts outside the geographical boundary might be also critical. It may distort the information of an industry in reality if we eliminate the impact outside the boundary to avoid the bias of results in a local study. Therefore, expanding the geographical scope of the study which could eliminate some uncertainties is suggested in the future. However, the accessibility and integration of global information would become another issue.

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Abbreviations

BL	Backward Linkage
CML	Centre of Environmental Science, Leiden University
DRAM	Dynamic Random Access Memory
EIO LCA	Economic Input-output Life Cycle Assessment
FL	Forward Linkage
GDI	Green Design Institute, Carnegie Mellon University
GHGs	Green House Gases
GWP	Global Warming Potential
IC	Integrated Circuit
IO	Input-output
IPCC	Intergovernmental Panel on Climate Change
IPD	Index of Power of Dispersion
ISD	Index of Sensitivity of Dispersion
ITRI	Industrial Technology Research Institute
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
MOEA	Ministry of Economic Affairs
NEI	National Emission Inventory
NTD	New Taiwan Dollars
PFCs	Perfluorocarbons
SMEs	Small-medium Enterprise
TEPA	Taiwanese Environmental Protection Administration
TFT LCD	Thin Film Transistor Liquid Crystal Display
TSIA	Taiwan Semiconductor Industry Association
UNFCCC	United Nations Framework Convention on Climate Change

Appendix A: Taiwanese Energy IO Table, 2004

Energy Form			Coal and Coal product	Coal	Imported coal	Imported steam coal	Coke	Coke oven gas	Blast furnace gas
Unit			MTCE	MT	MT	MT	MT	1000 M^3	1000 M^3
Energy Sector									
Transportation Sector	Aviation								
	Road								
	Railway								
	Internal Navigation								
Industrial Sector	Mining								
	Foods								
	Textiles		63,284	61,307	61,307	61,307			
	Lumber & Paper		395,414	383,065	383,065	383,065			
	Chemicals	Chemical Materials	3,574,870	3,463,217	3,463,217	3,463,217			
		Chemical Products							
		Plastic Products							
		Others Chemicals							
	Non-Metallic Mineral Products		2,633,754	2,551,492	2,551,492	2,551,492			
	Basic Metal Industry		4,778,958	1,405,569	1,405,569	1,405,569	586,607	1,888,734	9,937,314
	Other Manufacturing Industries	Printing							
		Leather							
		Rubber							
		Metal Products							
		Machinery							
		Electric Products							
		Transportation Equip							
		Other Products							
Agricultural Sector									
Residential Sector									
Commercial Sector									
Other Service Sector									

Energy Form			Refinery gas	LPG	Motor gasoline	Unlead gasoline
Unit			1000 M^3	KL	KL	KL
Energy Sector			1,604,059	298,094	5,940	5,940
Transportation Sector	Aviation			48		
	Road			39,848	10,259,201	10,259,201
	Railway					
	Internal Navigation					
Industrial Sector	Mining			4,803	11	11
	Foods			12,237	1,834	1,834
	Textiles			4,388	28	28
	Lumber & Paper			4,980	375	375
	Chemicals	Chemical Materials		67,072	5	5
		Chemical Products		7,048	64	64
		Plastic Products		9,987	29	29
		Others Chemicals		482,129		
	Non-Metallic Mineral Products			34,595	100	100
	Basic Metal Industry			95,023	258	258
	Other Manufacturing Industries	Printing		7,837	20	20
		Leather		4,773		
		Rubber		10,217	7	7
		Metal Products		18,931	36	36
		Machinery		4,804	137	137
		Electric Products		9,277	513	513
		Transportation Equip		14,024	4,795	4,795
		Other Products		224,126	54	54
Agricultural Sector				29	367	367
Residential Sector				1,945,513		
Commercial Sector				174,461		
Other Service Sector				3,189	70,347	70,347

Energy Form			Jet fuel	Kerosene	Diesel oil	Fuel oil	Naphtha	Petroleum coke	Olefins
Unit			KL	KL	KL	KL	KL	MT	KL
Energy Sector				9	33,338	869,713			
Transportation Sector	Aviation		2,733,437						
	Road				4,124,079				
	Railway				36,600				
	Internal Navigation				124,428	243,972			
Industrial Sector	Mining				11,931	27,881			
	Foods			25	7,025	376,821			
	Textiles				5,811	1,183,874			
	Lumber & Paper			64	843	267,970			
	Chemicals	Chemical Materials	22		88,823	1,269,268	1,789,455		11,548,099
		Chemical Products	575		3,527	255,285			
		Plastic Products			401	89,990			
		Others Chemicals			15	74,190			
	Non-Metallic Mineral Products			13	29,572	429,347		462	
	Basic Metal Industry			7,697	7,648	656,314	22,152		
	Other Manufacturing Industries	Printing			262	2,880			
		Leather			23	37,062			
		Rubber		2	588	81,237			
		Metal Products		42	3,397	100,677			
		Machinery			1,007	9,258			
		Electric Products			26,336	58,559			
		Transportation Equip		989	6,554	28,039			
		Other Products		9	1,804	25,721			
Agricultural Sector					1,106,933	29,383			
Residential Sector									
Commercial Sector				3,433	86,296	309,475			
Other Service Sector			189,125	10,541	368,408	216,954			

Energy Form			Aromatics	Other petro. Products	Natural gas	LNG	Power company	Cogeneration plant	Total electricity
Unit			KL	KL	1000 M^3	1000 M^3	MWH	MWH	MWH
Energy Sector					22,322	266,577	11,519,780	3,328,815	14,848,595
Transportation Sector	Aviation								
	Road								
	Railway						889,337		889,337
	Internal Navigation								
Industrial Sector	Mining				66		349,385		349,385
	Foods				9,048	229	3,281,979	164,702	3,446,681
	Textiles				2,359	41,664	7,706,161	327,634	8,033,795
	Lumber & Paper				4,608	323	2,714,232	1,483,299	4,197,531
	Chemicals	Chemical Materials	1,098,692	2,536,072	11,896	148,799	7,141,830	19,156,154	26,297,984
		Chemical Products			2,601	635	2,733,910		2,733,910
		Plastic Products			432	9,948	4,255,695		4,255,695
		Others Chemicals							
	Non-Metallic Mineral Products				192,016	59,535	4,294,532	229,308	4,523,840
	Basic Metal Industry				10,584	221,059	10,896,303	3,471,542	14,367,845
	Other Manufacturing Industries	Printing					560,179		560,179
		Leather					310,258		310,258
		Rubber				2,609	972,050		972,050
		Metal Products			9,828	14,281	5,676,118		5,676,118
		Machinery			2,466		1,596,314		1,596,314
		Electric Products			78,258	8,859	22,294,646	766,629	23,061,275
		Transportation Equip			12,759	49,471	2,082,894		2,082,894
		Other Products			407	318	1,302,220		1,302,220
Agricultural Sector							2,510,735		2,510,735
Residential Sector					776,227	109,300	39,587,857		39,587,857
Commercial Sector					177,623	48,173	21,683,451		21,683,451
Other Service Sector					27,367	7,604	21,774,858	682,387	22,457,245

Appendix B: Results of industrial interdependence analysis (161 sectors)

Sectors or Products	FL	BL	ISD	IPD	ISD rank	IPD rank
稻穀	1.818140	1.996612	0.650294	0.714129	75	117
雜糧農作物	5.183911	2.053947	1.854131	0.734636	18	115
甘蔗	1.388059	1.924030	0.496468	0.688168	107	121
其他特用作物	1.610041	1.727560	0.575864	0.617897	89	139
水果	1.161532	1.794889	0.415445	0.641978	136	133
蔬菜	1.177418	1.807945	0.421127	0.646648	133	132
其他園藝作物	1.477580	1.633372	0.528486	0.584208	100	146
豬	3.009809	3.099590	1.076519	1.108631	36	73
其他禽畜產	2.708440	3.181803	0.968728	1.138036	48	65
農事服務	4.380097	1.588904	1.566630	0.568304	22	150
林產	2.754029	1.358221	0.985034	0.485795	44	159
漁產	1.369862	2.300589	0.489959	0.822852	110	110
能源礦產	17.771259	1.537217	6.356251	0.549817	2	153
金屬礦產	7.015711	4.771668	2.509311	1.706684	11	1
鹽	1.291262	1.928730	0.461846	0.689849	123	120
其他非金屬礦產	3.313841	1.903338	1.185262	0.680767	32	125
屠宰生肉及副產	2.319393	3.750391	0.829578	1.341403	58	16
食用油脂及副產	2.189832	3.026119	0.783238	1.082353	64	79
製粉	1.547805	2.717232	0.553604	0.971873	93	94
米	1.182871	2.742024	0.423078	0.980741	131	90
糖	2.011165	2.663486	0.719334	0.952650	67	97
飼料	3.674386	3.155730	1.314218	1.128711	30	67
罐頭食品	1.013450	3.070726	0.362481	1.098307	155	77
冷凍食品	1.066835	3.553316	0.381575	1.270915	150	32
味精	1.073356	3.296011	0.383907	1.178885	148	57
其他調味品	1.082714	2.906100	0.387255	1.039425	147	85
乳製品	1.177653	3.407231	0.421212	1.218665	132	47
糖果及烘焙炊蒸食品	1.018082	3.018716	0.364138	1.079705	154	80
其他食品	1.235457	2.935396	0.441886	1.049904	128	83
非酒精飲料	1.059224	3.122663	0.378853	1.116884	152	71
酒	1.008309	1.649701	0.360642	0.590049	156	145
菸	1.083816	1.612495	0.387649	0.576742	146	149
棉及棉紡織品	2.548110	3.217113	0.911383	1.150666	50	63
毛及毛紡織品	1.530971	4.087442	0.547583	1.461956	96	6
人造纖維紡織品	2.733609	4.106394	0.977730	1.468735	47	5
針織布	1.392448	3.712845	0.498037	1.327974	106	18
其他紡織品	1.507160	3.733352	0.539066	1.335309	98	17
印染整理	1.872488	2.857999	0.669733	1.022221	74	86
梭織成衣	1.095310	3.126660	0.391760	1.118313	145	69
針織成衣	1.138584	3.402150	0.407238	1.216848	139	48
紡織製品及服飾品	1.345092	3.399423	0.481099	1.215873	114	49
皮革	2.207420	3.922680	0.789528	1.403026	63	11
皮鞋	1.166960	3.552857	0.417387	1.270751	135	33
其他皮革製品	1.050364	3.420149	0.375684	1.223286	153	46
製材	2.289864	2.478405	0.819016	0.886452	60	106
合板	1.532031	2.811825	0.547962	1.005706	95	88
木竹籐製品	1.321310	2.662642	0.472593	0.952348	118	99
非金屬家具	1.098537	2.792778	0.392914	0.998893	144	89
紙漿及紙	5.512782	3.498842	1.971758	1.251432	16	38
紙製品	3.402051	3.243455	1.216812	1.160087	31	61

Sectors or Products	FL	BL	ISD	IPD	ISD rank	IPD rank
印刷出版品	2.208966	2.546545	0.790081	0.910824	62	103
其他印刷品及裝訂	3.100522	2.720185	1.108964	0.972929	35	93
基本化工原料	5.251110	3.045167	1.878166	1.089166	17	78
石油化工原料	18.720266	3.650756	6.695682	1.305767	1	23
化學肥料	1.988278	3.242246	0.711148	1.159655	69	62
合成纖維	2.935585	4.155894	1.049971	1.486440	39	3
其他人造纖維	1.102716	3.473383	0.394409	1.242326	143	41
塑膠(合成樹脂)	6.715998	4.143547	2.402113	1.482024	12	4
其他化學材料	3.006688	3.441454	1.075403	1.230906	37	43
塗料	2.768844	3.535076	0.990333	1.264392	43	36
醫療藥品	1.741766	2.684355	0.622978	0.960114	80	95
農藥及環境衛生用藥	2.064784	3.006933	0.738512	1.075490	66	81
清潔用品及化粧品	1.326233	3.099491	0.474354	1.108596	117	74
其他化學製品	4.038907	3.422892	1.444597	1.224267	28	45
石油煉製品	14.840803	2.266826	5.308114	0.810776	4	111
煤製品	2.775052	2.481267	0.992553	0.887475	42	105
橡膠製品	2.008590	2.963835	0.718413	1.060076	68	82
橡、塑膠鞋	1.150366	3.593470	0.411452	1.285277	137	29
塑膠製品	5.945765	3.554728	2.126623	1.271420	15	31
陶瓷製品	1.168539	2.469853	0.417952	0.883393	134	107
玻璃及其製品	2.242132	2.566664	0.801944	0.918019	61	101
水泥	1.426560	2.163597	0.510238	0.773854	104	113
水泥製品	1.371178	2.917040	0.490430	1.043338	109	84
其他非金屬礦物製品	1.879335	2.663046	0.672182	0.952492	73	98
生鐵及粗鋼	7.575397	3.692736	2.709494	1.320782	9	20
鋼鐵初級製品	13.526369	4.005567	4.837980	1.432672	5	9
鋁	5.082209	4.206733	1.817755	1.504623	19	2
其他金屬	8.141732	3.963945	2.912055	1.417785	8	10
金屬鍛造及粉末冶金	1.146446	3.393529	0.410050	1.213765	138	50
金屬家用器具	1.071386	3.693991	0.383203	1.321231	149	19
金屬手工具	1.316321	3.769722	0.470809	1.348317	119	14
金屬結構及建築組件	1.500723	3.551668	0.536764	1.270326	99	34
金屬容器	1.632853	3.582407	0.584023	1.281320	88	30
其他金屬製品	3.149597	3.596666	1.126517	1.286420	33	28
金屬表面處理	1.967168	2.825837	0.703597	1.010718	71	87
一般通用機械	2.352764	3.428353	0.841514	1.226220	56	44
金屬加工機械	1.572852	3.754551	0.562562	1.342891	91	15
工業專業機械	2.367209	3.619448	0.846680	1.294569	53	24
其他機械	1.810036	3.679929	0.647396	1.316201	77	21
機械零件及修配	2.883380	3.317732	1.031299	1.186654	40	55
家用電器	1.134700	3.484798	0.405848	1.246409	140	39
照明設備	1.330739	3.265302	0.475966	1.167901	116	59
發電、輸電及配電設備	2.358445	3.780537	0.843546	1.352186	55	13
電線及電纜	2.348421	4.082792	0.839960	1.460293	57	8
其他電機器材	2.743524	3.471704	0.981277	1.241725	46	42
電腦產品	1.299961	3.910337	0.464957	1.398611	120	12
電腦週邊設備	1.275999	3.667567	0.456387	1.311780	125	22
資料儲存媒體	1.249061	3.308829	0.446752	1.183470	127	56
電腦組件	1.456411	3.618110	0.520915	1.294090	102	25
視聽電子產品	1.356229	3.613116	0.485083	1.292304	113	27

Sectors or Products	FL	BL	ISD	IPD	ISD rank	IPD rank
通信器材	1.131002	3.510982	0.404526	1.255774	142	37
Semiconductor	***6.511998***	***3.126655***	***2.329148***	***1.118311***	***13***	***70***
光電元件及材料	2.707948	3.324612	0.968552	1.189115	49	54
電子零組件	3.889128	3.161801	1.391026	1.130882	29	66
船舶	1.451578	3.478339	0.519186	1.244098	103	40
汽車	2.488527	3.333952	0.890072	1.192455	51	53
機車	1.657330	3.541207	0.592778	1.266584	86	35
自行車	1.689742	4.087109	0.604371	1.461837	82	7
其他運輸工具	1.797323	2.737159	0.642849	0.979000	78	91
精密器械	2.302552	3.340331	0.823554	1.194737	59	52
育樂用品	1.332706	3.189858	0.476669	1.140917	115	64
其他製品	1.365172	3.377490	0.488282	1.208028	112	51
電力	10.097380	2.197493	3.611533	0.785978	6	112
燃氣	1.199643	2.608639	0.429077	0.933033	130	100
自來水、暖氣及熱水	1.678608	1.955562	0.600388	0.699447	84	119
住宅工程	1.132489	3.245113	0.405058	1.160680	141	60
其他房屋工程	1.597581	3.286316	0.571407	1.175418	90	58
公共工程	1.252364	3.104635	0.447934	1.110435	126	72
其他營造工程	1.394126	3.098050	0.498637	1.108080	105	75
批發	7.362158	1.716503	2.633225	0.613942	10	141
零售	6.288183	1.555643	2.249096	0.556407	14	151
國際貿易	4.194649	1.902870	1.500301	0.680600	26	126
商品經紀	3.001600	1.827977	1.073583	0.653813	38	128
旅館服務	1.543771	1.904034	0.552161	0.681016	94	124
餐飲服務	1.462632	1.700284	0.523140	0.608141	101	142
軌道車輛運輸	1.291799	2.673847	0.462038	0.956356	122	96
其他陸上運輸	4.198753	2.046731	1.501769	0.732055	25	116
水上運輸	1.940620	2.729565	0.694102	0.976284	72	92
空中運輸	1.565335	2.553369	0.559874	0.913264	92	102
運輸服務	2.126575	1.818512	0.760613	0.650428	65	129
旅行服務	1.065974	1.783375	0.381267	0.637860	151	136
倉儲	1.372923	1.910722	0.491054	0.683409	108	123
郵政服務	1.369383	1.380261	0.489787	0.493678	111	157
電信服務	4.498451	1.780485	1.608962	0.636827	21	137
金融	17.205450	1.883807	6.153878	0.673782	3	127
證券及期貨	1.658072	1.726353	0.593043	0.617465	85	140
保險	2.752415	1.620115	0.984457	0.579467	45	147
住宅服務	1.000159	1.360990	0.357727	0.486785	159	158
不動產服務	4.051548	1.653356	1.449118	0.591356	27	144
租賃服務	2.485892	1.811171	0.889130	0.647802	52	130
法律及會計服務	1.782548	1.398201	0.637564	0.500095	79	156
顧問服務	2.830299	1.730517	1.012314	0.618954	41	138
資訊服務	4.350434	1.912487	1.556021	0.684040	23	122
研究發展服務	4.576434	2.415772	1.636854	0.864050	20	108
廣告服務	4.344649	3.139305	1.553952	1.122836	24	68
其他專業及技術服務	1.977083	2.078304	0.707144	0.743348	70	114
教育訓練服務	1.297447	1.322335	0.464058	0.472960	121	160
醫療保健服務	1.508677	1.613615	0.539609	0.577142	97	148
社會福利服務	1.000000	1.656903	0.357670	0.592625	160	143
廣播、電視及電影服務	3.134472	3.072599	1.121107	1.098977	34	76

Sectors or Products	FL	BL	ISD	IPD	ISD rank	IPD rank
娛樂文化服務	1.282797	1.792135	0.458818	0.640993	124	134
支援服務	2.364564	1.809435	0.845734	0.647181	54	131
環境衛生服務	1.702915	1.982069	0.609082	0.708927	81	118
人民團體服務	1.682488	1.432293	0.601776	0.512289	83	155
其他社會服務	1.000957	1.544220	0.358012	0.552322	158	152
汽車維修服務	1.814480	2.524953	0.648986	0.903100	76	104
其他修理服務	1.232389	2.397598	0.440789	0.857549	129	109
家事服務	1.002594	1.000000	0.358598	0.357670	157	161
其他個人服務	1.641371	1.791749	0.587070	0.640855	87	135
公共行政服務	1.000000	1.503448	0.357670	0.537739	160	154
分類不明	8.145795	3.615154	2.913508	1.293033	7	26