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DEVELOPMENT OF ECO-EFFICIENCY INDICATORS FOR ASSESSMENT OF INDUSTRIAL ESTATE

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Abstract

Eco-efficiency is an instrument for sustainability analysis of industry, indicating an empirical relation in economic activities between environmental cost or value and environmental impact. The development of eco-efficiency indicators for assessment of Map Ta Phut Industrial Estate (MTPIE) in Thailand is presented. MTPIE locates in Rayong province, eastern of Thailand. It was developed by the state enterprise, Industrial Estate Authority of Thailand (IEAT), Ministry of Industry, to serve industries that use natural gas as the main raw material development. Regarding to the expansion of industry in MTPIE area, the development of eco-industrial estate and networks project in MTPIE began in 2000 in order to develop the industries in harmony with environment and society. A recent study of the eco-efficiency indicators in MTPIE area has been initiated by the Thailand Research Fund (TRF) with the corporation of Mahidol University and IEAT. The industries in MPTIE area were divided in 5 groups, which are Petroleum and Petrochemical group, Chemical group, Iron and Steel group, Industrial Gas group, and Utility group. The material and product flow diagrams were established in order to study the relationship of each industrial group in MPTIE. The Eco-Forum meeting has been started to develop the corporation among industries in MPTIE area. The eco-efficiency evaluation results show that the eco-efficiency values of the PP group were mostly higher than those of other groups. The gross margin eco-efficiency values were lower than that of net sale eco-efficiency values. Cost and the fluctuations of raw material price were observed as the main influence factors for the decrease of gross margin eco-efficiency value. The eco-efficiency trends of industrial sectors in MTPIE were simply analyzed by using the snapshot monograph. The eco-efficiency snapshot concerning gross margin and water use during the period of 2003 to 2005 showed that the eco-efficiency trends of industrial sectors in the MTP area shifted from half eco-efficiency level in the year 2004 to fully eco-efficiency level in the year 2005.

The research can provide a basic framework on eco-efficiency evaluation for the industrial sectors in Thailand, which will feed into strategic development and would enable further development to be as a useful tool for industrial assessment. It also could be used to examine alternative governmental policies in the same way that companies rate product alternatives, which tells little about the direction of progress toward the goal of sustainable development.

Keywords: Eco-Efficiency, Eco-Industrial Estate, Economic Indicator, Environmental Indicator, Map Ta Phut Industrial Estate

1. Introduction

Since the release of Our Common Future in 1987 and Agenda 21 in 1992, government and industry have emphasized on the sustainability, which has embraced the integration of economic, ecology and social dimensions. In order to reach the sustainability goals, the concept of industrial ecosystems, one aspect of the industrial ecology field, was introduced to industrial park through the promotion and development of eco-industrial parks [1, 2]. There are many eco-industrial parks, which have been developed in Europe, United State, Canada, and Asia, for example, Kalundborg eco-industrial park in Denmark, Trenton eco-industrial complex in United State, Burnside industrial park in Canada, Guigang eco-industrial park in China, and Map Ta Phut industrial estate in Thailand [3-5].

Eco-efficiency emerged in the 1990 as an applicable concept, which has emphasized the linkage between economy and environment with less being paid to the social dimension of sustainability. Furthermore, it can be as an indicator tool used for measuring performance and assisting with decision making [6]. The eco-efficiency indicators are generally expressed by the ratio of economic value and environmental influence. It has been widely promoted for manufacturing throughout the world such as Toshiba company in Japan using eco-efficiency indicator as a measuring tool for reporting of product and service performances [7]. Agriculture and Agri-Food Canada is developing eco-efficiency indicators in an effort to build a framework for a sustainable production system for the Canadian food and beverage industry [8]. Iron rod industry in Nepal was developed specific eco-efficiency indicators of energy intensity, material consumption, water use, waste generation, and carbon dioxide emission for evaluation of their process performance [9].

Map Ta Phut Industrial Estate (MTPIE) locates in Rayong province, east of Thailand. It was developed in 1989 by the state enterprise, Industrial Estate Authority of Thailand (IEAT), Ministry of Industry. MTPIE is considered to be industrial area No. 3 as factories located within this area are entitled to receive the most benefits, encouraging investments from both Thai and foreign investors. Regarding to the expansion of industry in Thailand, IEAT incorporation with the Deutshe Gesellschaft fur Technische Zusammenarbeit (GTZ) developed the Development of Eco-Industrial Estate and Networks (DEE+Net) Project, which was started in year 2000 until year 2004. MTPIE was selected as a pilot site that implemented the concept of by product exchange and co-operation principle for 9 parts of industrial development.

This paper presents the development of eco-efficiency indicators for assessment of eco-efficiency of the MTPIE. The eco-efficiency of industrial sectors in MTPIE was measured by using the key indicators of economic and environment according to the WBCSD recommendations such as net sale, gross margin, material consumption, energy intensity, water use, and waste generation. Finally, the eco-efficiency trends of each industrial group were simply analyzed by using snapshot graph.

2. Methodology

2.1 Data Collection

Data collection was mainly done by field site investigation. Economic and environmental data over the period of year 2003 to 2005 were received from the existing monitoring report and data availability at the MTPIE office and Ministry of commerce. The potential sources and status of data are shown in Table 1.

2.2 Eco-Efficiency Evaluation

The evaluation of eco-efficiency values used for this research was gathered from the WBCSD approach and previous literature [9, 10]. The mathematic notations of eco-efficiency as a combination of economic and ecological performance are expressed by the ratio as follows:

$$EE_n = \frac{EI_n}{\sum EN_{nm}} \qquad (1)$$

Table 1. The potential sources and status of data

Indicator	Status	Potential Sources
Net sale Gross margin	Completed Completed	Ministry of commerce
Material	Not Completed (50% of data availability)	Monitoring report and MTPIE office
Energy	Not Completed (20% of data availability)	
Water	Completed	
Waste	Not Completed (70% of data availability)	

Where EI_n is an economic performance indicator in unit of baht (B) and the environmental performance indicator is referred by EN_{nm}. 'm' is regarded as many environmental burdens from activities carried out in industrial group and 'n' is industry in the group in MTPIE selected.

$\sum EN_{nm}$ implies 'm' type of environmental influences of industrial group is the function (f) of various independent categories of total energy intensity, material consumption, and water use along with hazardous waste generation. Each environmental influence have separate unit and have been calculated energy separately, material separately, water separately and waste separately. Where, 't' denotes total sum of each environmental influence and 'r' denotes different sources.

$$\sum E_{nm} = f\left[\ \sum_{t=1}^{r} E_t, \sum_{t=1}^{r} M_t, \sum_{t=1}^{r} W_t, \sum_{t=1}^{r} W_{st}\ \right] > 0 \qquad (2)$$

Where, $\sum_{t=1}^{r} E_t$ = Total energy consumption from 'r' different sources

$\sum_{t=1}^{r} M_t$ = Total materials utilization from 'r' different sources

$\sum_{t=1}^{r} W_t$ = Total water use from 'r' different sources

$\sum_{t=1}^{r} W_{st}$ = Total hazardous waste generation from 'r' different processes

The calculation of the proposed eco-efficiency indicators is summarized in Table 2.

Table 2. Calculation of the proposed eco-efficiency indicators

Indicator	Equation	Terms

Material	$EE_{n\ (M)} = \dfrac{EI_n}{\sum_{t=1}^{r} M_t} = \dfrac{EI_n}{(M_{n1}\ x\ CF_1 + M_{n2}\ x\ CF_2 .... + M_{nr}\ x\ CF_r)}$	(M_{n1}, M_{n2} .... M_{nr}) represents various materials involved in the group and (CF_1, CF_2 ... CF_r) means relevant conversion factors used to convert all the materials in to common unit of Ton (T).
Energy	$EE_{n\ (E)} = \dfrac{EIn}{\sum_{t=1}^{r} E_t} = \dfrac{EI_n}{(E_{n1}\ x\ CF_1 + E_{n2}\ x\ CF_2 .... + E_{nr}\ x\ CF_r)}$	(E_{n1}, E_{n2} .... E_{nr}) represents energy used in the group, and (CF_1, CF_2 ... CF_r) imply relevant conversion factors utilized to convert all the energy sources in to common unit of giga-joules (GJ).
Water	$EE_{n\ (W)} = \dfrac{EI_n}{\sum_{t=1}^{r} W_t} = \dfrac{EI_n}{(W_{n1} + W_{n2} .... + W_{nr})}$	(W_{n1}, W_{n2} ...., W_{nr}) indicated water used from separated sources evaluated in cubic meter (m^3).
Waste	$EE_{n\ (Ws)} = \dfrac{EI_n}{\sum_{t=1}^{r} Wst} = \dfrac{SR_n}{(Ws_{n1} + Ws_{n2} .... + Ws_{nr})}$	(Ws_{n1}, Ws_{n2} .... Ws_{nr}) indicates separated hazardous waste sources of the group evaluated in Ton (T).

2.3 Analysis of Eco-Efficiency Trend

In order to look at an overview of the trends of environmental indicators in relation to the trends in economic indicators, the snapshot graph analysis, which was adopted by Anite System in Netherland [11] was applied to use as a tool for analyzes the eco-efficiency trend of each industrial groups in MTPIE. The percent variations of the selected economic indicator and environmental indicator were calculated following the formula [12]:

$$\%VE = \left[\frac{\sum E_i - \sum E_b}{\sum E_b}\right] \times 100 \qquad (3)$$

Where % VE = Percent variation of economic or environmental indicators

$\sum E_i$ = Summation of economic or environmental indicators in the selected time period

$\sum E_b$ = Summation of economic or environmental indicators in the selected base year (the year 2003 was selected as a base year for this study)

The calculated percent variation of economic and environmental indicators were then plotted in one graph, where the Y axis represents the variation of the percent variation of the selected economic indicator and the X axis represents the variation of the percent variation of the selected environmental indicator. The interpretation of the eco-efficiency level is made by the X-Y plan, which shows in Figure 1.

The interpretation of the snapshot graph is made easier because the X-Y plan is divided into two sub-plans, the one under the bi-sector (the positive or, eco-efficient plan), the other below the bi-sector (the negative or, non-eco-efficient plan). Each sub-plan is divided into two types of area: for the eco-efficient plan, (++) and (+), and/or the non-eco-efficient one, (--) and (-).

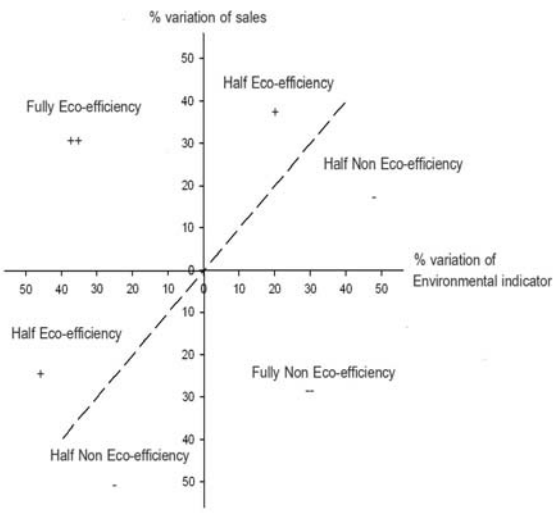
Fully eco-efficiency: In the (++) area both co-ordinates of every indicator varies in the preferable direction.

Half eco-efficiency: In the (+) area every indicator has one co-ordinate varying in the preferable direction and the other one in the unfavorable direction. Moreover, the variation of the co-ordinate which goes in the preferable direction compensates the other.

Fully non eco-efficiency: In the (--) area, both economic and environmental indicators vary in the unfavorable direction: economic performance decreases and environmental performance increases.

Figure 1. The classification of eco-efficiency trend.

Half non eco-efficient: In the (-) area



every indicator has one co-ordinate varying in the preferable direction and the other one in the unfavorable direction. However, the variation of the co-ordinate which goes in the preferable direction does not compensate the other.

3. Results and Discussion

3.1 Characterization of Industrial Group in the MTPIE

MTPIE is a petrochemical based industrial estate. There are 53 factories located within the MTPIE, which can divided into 5 industrial groups such as petroleum and petrochemical group (PP), industrial gas group (IG), utility group (U), iron and steel industry group (IS) and chemical industry group (CH). PP group is the biggest group, which are 31 factories or 58.49 percent of the total factories located in this group, followed with chemical industry group (8 factories), iron and steel industry group (7 companies), utility group (5 companies) and industrial gas group (3 companies) [12]. The characterization of industrial group in the MTPIE can be studied by using material and product flow diagrams, which are shown in Figure 2-6.

Factories in the PP group (Figure 1) can be divided into 3 categories i) Petroleum and upstream petrochemical industry consists of 6 factories or 19.35 percent of the total factories in PP group ii) Intermediate stream industry consists of 5 factories or 16.13 percent of the total factories in PP group iii) Downstream industry consists of 20 factories or 64.52 percent of the total factories in the PP group. There are related as a supply chain that factories within the upstream category are a primary source of material for intermediate and downstream

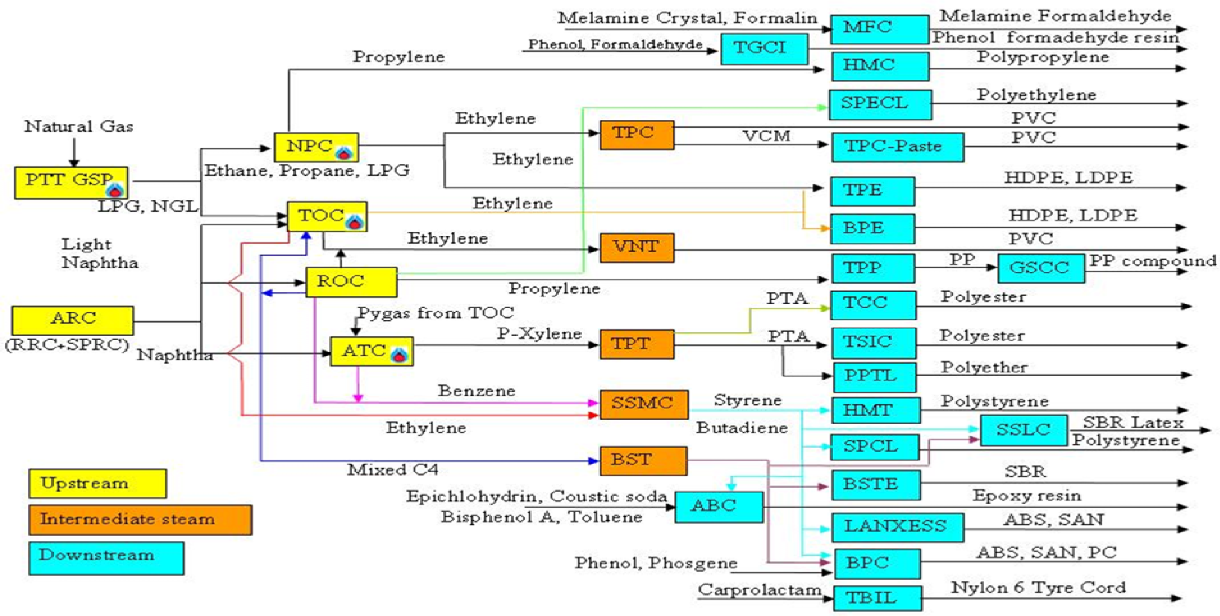


Figure 2. Material and product flow diagram of the petroleum and petrochemical group

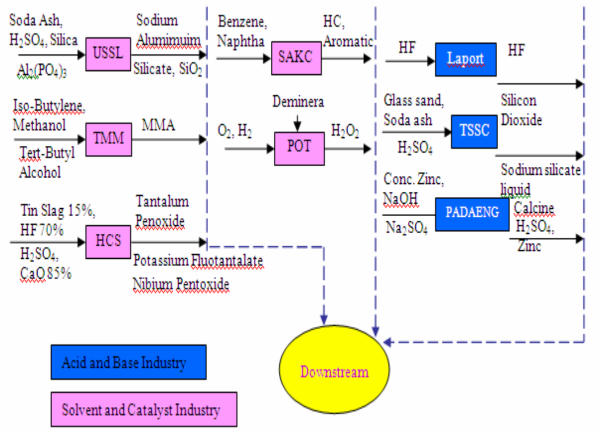


Figure 3. Material and product flow diagram of the chemical industry group.

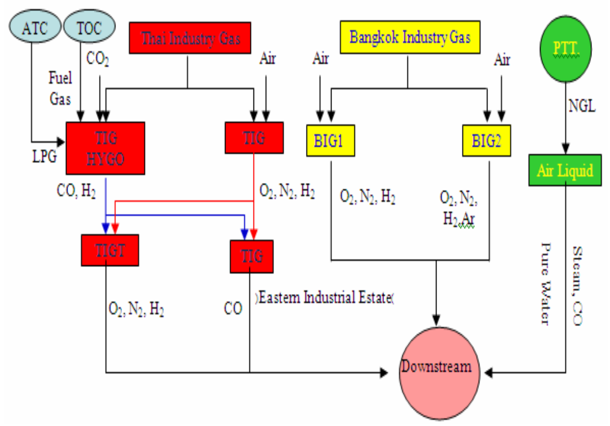


Figure 5. Material and product flow diagram of the industrial gas group.

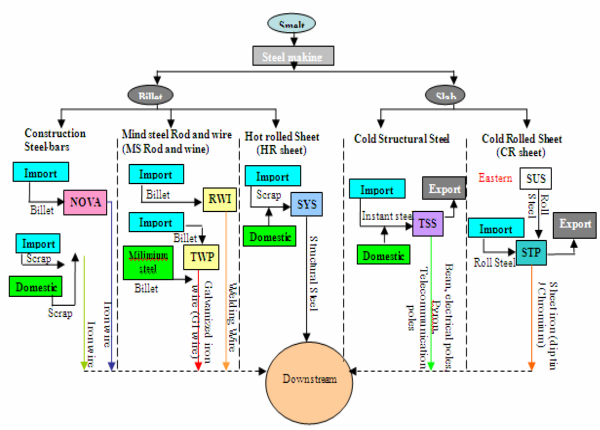


Figure 4. Material and product flow diagram of the iron and steel industry group.

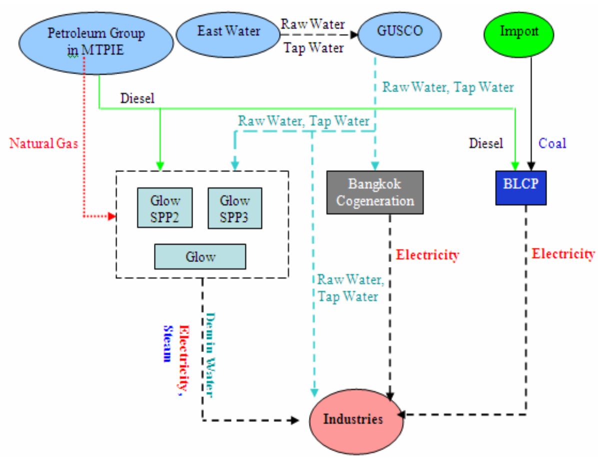


Figure 6. Material and product flow diagram of the utility group.

categories. Factories in intermediate category receive products from up-stream and transform it into products, which are used as a major raw material for downstream.

3.2 Eco-Efficiency Evaluation

Due to the quantity of data availability, we have decided to use the average eco-efficiency indicators (from year 2003 - year 2005) in order to assess the performance of each industrial group in the MTPIE. Evaluation of eco-efficiency indicators in the ratio of average economic values (net sate and gross margin) and average environmental influences are shown in Table 3.

Table 3. The results of eco-efficiency indicators evaluation.

Economic Indicator	Environmental Indicator	Average Eco-Efficiency Value				
		PP	CH	IS	U	IG
Net Sale	Material	21.95	20.23	15.82	0.47	5.50
	Energy	25.58	6.01	2.61	0.26	N/A
	Water	16.28	6.14	18.74	1.29	9.73
	Waste	1.02	1.64	0.73	0.11	N/A
Gross Margin	Material	2.78	6.40	1.96	0.08	2.16
	Energy	4.03	2.29	0.93	0.06	N/A
	Water	2.06	1.57	2.32	0.23	3.08
	Waste	0.12	0.48	0.07	0.03	N/A

N/A: No available Data

Eco-efficiency value is normally depending on the proportional of economic and environmental values. From Table 4, it can be seen that the eco-efficiency values of the PP group were mostly higher than those of other groups. This can be explained by the highest net sale and the proportional of economic and environmental dimensions of the PP group.

Net sale and gross margin, which define as the total recorded sales and net sales minus costs of goods and services sold, respectively, were used as an economic indicator to evaluate eco-efficiency of industrial sectors in the MTPIE. Net sale and gross margin are important and common measures of the economic output. It was selected for several reasons: i) Its wide use in economic assessments of e.g. profitability, productivity ii) It is the relevant indicator to be used at industry sector level as it enables comparability across branches and within branches iii) Data availability is good. From Table 4, it can be seen that the gross margin eco-efficiency values were lower than that of net sale eco-efficiency values. This can be explained by the cost and the fluctuations of raw material price, which were observed as the main factors for the decrease of gross margin eco-efficiency value.

It was noted that the data availability is a significance factor for analyzing the eco-efficiency. Water indicator was found to be only indicator (as shown in Table 1), which was not restricted. Therefore, we selected this indicator to be as a representative indicator in order to present the eco-efficiency analysis of MTPIE. Evaluation of water eco-efficiency in MTPIE is shown in Table 4.

Form Table 4, it can be seen that the overall comparison of water eco-efficiency between year 2003 and year 2005 in the ratio of average economic value (net sale) in million baht (MB) and water use in cubic meter (m^3) of the PP, CH, IS, U, and IG groups were increased by 55.18%, 25.81%, 53.81%, 5.82%, and 77.25%, respectively. Lower use of water and higher of overall net sale were the reason of water eco-efficiency increase. Another reason was the water recycle technology, which was considered use in the MTPIE.

Table 4. Evaluation of water eco-efficiency in MTPIE

Industrial Group	Economic Indicator	Eco-Efficiency Value			Comparison of eco-efficiency between (2003 & 2005 only)
		Year 2003	Year 2004	Year 2005	
PP	Net Sale	12.72	16.45	19.74	+55.18
CH		5.48	6.03	6.90	+25.81
IS		15.07	18.13	23.18	+53.81
U		1.29	1.22	1.37	+5.82
IG		7.63	8.80	13.52	+77.25
PP	Gross Margin	1.24	2.55	2.37	+91.64
CH		1.38	1.40	1.92	+39.60
IS		1.76	2.66	2.51	+42.52
U		0.25	0.22	0.23	-6.53
IG		2.72	3.35	4.66	+71.07

Comparison of water eco-efficiencies between year 2003 and year 2005 in the ratio of gross margin and water use of the PP, CH, IS, and IG groups were increased by 91.64%, 39.60%, 42.54%, and 71.07%, respectively. Only water eco-efficiency of U group was decreased by 6.53%. The increase of water eco-efficiency with respect to gross margin came from the decrease of water use and the strategies of 3R water from the MTPIE management board.

3.3 Analysis of Eco-Efficiency Trend

In order to show the simple relative progress and overview of the trend of industrial sector on economic creation compared to environmental performance, we decided to use the snapshot graph analysis adopted from the Anite system's method [11]. According to the inventory of available data, gross margin and water consumption were selected as an economic and environmental indicators for exemplarily analyze the overall eco-efficiency trend. The data compilation in year 2003 was selected as a base year for evaluation. The typical snapshot graph for analysis an overall picture on the industrial sector development is shown in Figure 1. The Y axis represents the variation of the economic indicator in the selected time, e.g. 2003-2004. The X axis represents the variation of environmental indicators over the same time period. Therefore, each indicator is represented by the co-ordinates (X, Y), Y being the variation of the gross margin and X being the variation of water consumption. The eco-efficiency trends of the industrial sectors in the MTPIE analyzed by the snapshot graph are presented in Figure 7.

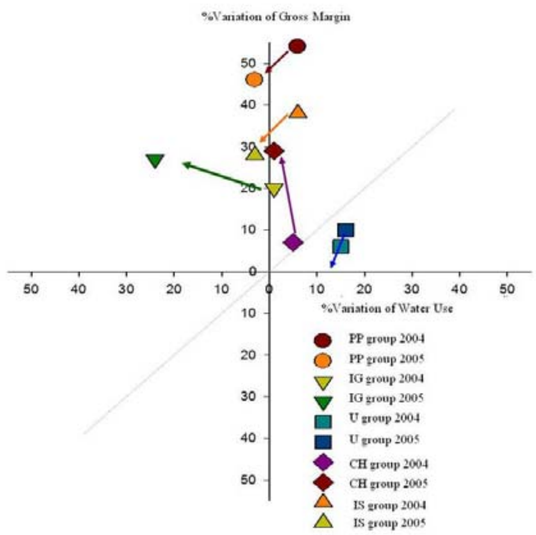


Figure 7. Snapshot concerning the gross margin and water use of each industrial groups in the MTPIE

From Figure 7, it can be seen that the eco-efficiency trends of the PP, CH, IS, and IG groups were shifted from half eco-efficient in year 2004 to fully eco-efficient in year 2005. Only the eco-efficiency trend of the U group remained at the level of half eco-efficient. Snapshots of the PP and IS groups, percent variations of gross margin and water consumption were decreased from 2004 to 2005 due to probably increased of water prices and water crisis in the Rayong province in year 2005. Eco-efficiency shifting of the CH and IG group came from the increase of profit and decrease of water use. From the eco-efficiency trend analysis, it can be seen that the decrease of economic dimension was not affect much to the eco-efficiency level compared to the decrease of water use. This can be suggested that the water use was decreasing in parallel with increased productions. The water eco-efficiency trend was increasing satisfactorily with positive move.

4. Conclusions and Recommendations

The development and use of eco-efficiency indicators is intended as a quantifiable contribution to evaluate the eco-efficient of industrial sector in industrial estate. The evaluation of eco-efficiency ratio can be shown the eco-efficiency values, which can compared between each industrial sectors and used as a benchmark for the micro scale evaluation. The snapshot graph can be simply used to identify the level of eco-efficiency of industrial sectors in the MITPE. Part of the research project output includes a framework of eco-efficiency indicator for industrial sector and to aid in the adoption of eco-efficiency indicators for assessment of industrial estates. The following are some of those recommendations.

1. The compilation of the core set of indicators was restricted. This can affect the eco-efficiency analysis results. In order to improve the data inventory, sharing information among company and industrial groups must be developed. Data update and information center at MTPIE office should be considered.
2. As the shortcoming in data may cause some bias in the results, the situation ought to be reassessed when more data will be available. (long-term data compilation need to be considered)
3. The selection criteria for economic and environmental indicators should be in line with the core issues, such as competitiveness, toxic substance, climate change, and global warming, in the political agenda.
4. In order to reach and sustain the fully eco-efficiency, industries in the MTPIE must increase the economic value and decrease the environmental burden by using the renewable energy source and eco-design for process and product modifications.
5. Industrial estate and companies should adopt this basic research to the guideline of eco-efficiency indicators, which are very useful for distribution to other industries in Thailand.
6. Eco-Efficiency is fundamentally a ratio of some measure of economic value to some measure of environmental impact, which is ability to combine performance along two of the three axes of sustainable development. In order to explain the direction of progress toward the goal of sustainable development, the issues concerning equity and other social properties need to be included for the further study.

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