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Eco-efficiency evaluation of the petroleum and petrochemical group in the map Ta Phut Industrial Estate, Thailand

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A B S T R A C T

Map Ta Phut Industrial Estate (MTPIE), located in Rayong province, eastern of Thailand, was developed by the state enterprise, Industrial Estate Authority of Thailand, Ministry of Industry, to serve industries that use natural gas as the main raw material development. This research presents the eco-efficiency evaluation of the petroleum and petrochemical group (PP) in the MTPIE. There are 31 factories in the PP group, which can be divided into three categories: upstream, intermediate, and downstream. The eco-efficiency values of the PP group were evaluated according to the World Business Council for Sustainable Development recommendations. The comparison of eco-efficiency values between three industrial categories in the PP group demonstrates that factories in the downstream category obtained particularly good eco-efficiency results concerning material consumption, water use, and hazardous waste generation. The eco-efficiency trends of the PP group were simply analyzed by snapshot graph. With the availability of the data on environmental indicator, the water use indicator was selected to be an example indicator for analyzing the eco-efficiency trends of the PP group. The eco-efficiency snapshot concerning the net sale and water use during the year of 2003–2005 showed that the eco-efficiency trends of the PP group in the MTPIE shifted from half eco-efficient in 2004 to fully eco-efficient in 2005. This research can provide a basic framework on eco-efficiency evaluation for the industrial sector in Thailand, which will feed into strategic development, and would enable public participation in the discussion on branch developments and contributions to national trends.

1. Introduction

Eco-efficiency concept has emerged as a valuable tool toward the target of sustainable development. In this concept, the World Business Council for Sustainable Development (WBCSD) states that "eco-efficiency is reached by the delivery of competitively priced goods and services that satisfy human needs and bring quality of life, while progressively reducing environmental impacts and resource intensity throughout the life cycle, to a level at least in line with the earth's estimated carrying capacity" (World Business Council for Sustainable Development, 2000). However, different global, regional, and national organizations have categorized their own definitions of eco-efficiency. The theme of definition is common as producing more with less impact or doing more with less. Eco-efficiency can be quantified through indicators based on the ratio of economy and environment (National Round Table on the Environment and the Economy, 2001). Each part of an indicator can be expressed positively or negatively, such as value or cost from the economic aspect, and improvement or damage from the environmental aspect. Generally, the eco-efficiency indicators are defined by combining the cost with the environmental improvement and the economic value creation with the environmental damage. The current development of eco-efficiency indicators focuses on enterprise, sectoral, or national levels of the user needs, which greatly vary from each other (Anite Systems, 1999; Verfaillie and Bidwell, 2000).

Industries have been contributing factors for both enhancing economic activities and sources of environmental pollutions. Industry is indispensable motor for economic growth of modern society and inevitable to developing countries. Most of human needs are fulfilled through goods and services produced by industry (World Commission on Environment and Development, WCED, 1987). Rapid economic growth has resulted in changing as well as unsustainable patterns of consumption of consumer goods and natural resources especially in Asia Pacific region (Chiu

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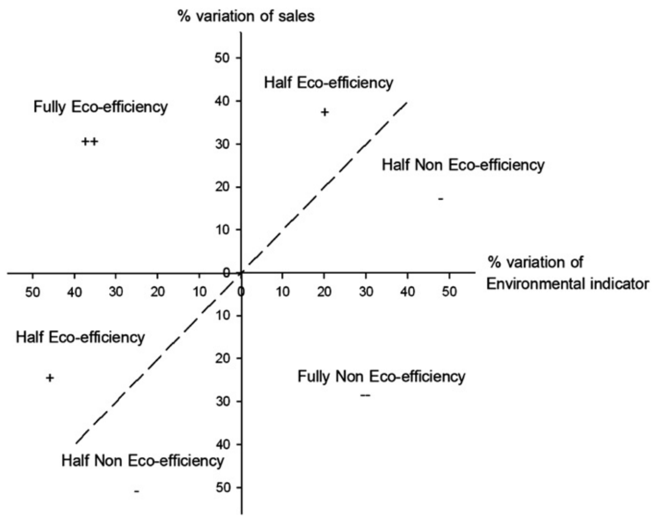


Fig. 1. The classification of eco-efficiency trend.

and Yong, 2004). Chui et al. (2009) suggested that eco-efficiency is one of the key issues and challenges for the development of eco-industrial park and sustainable consumption and production.

With the rapid expansion of industry in Thailand, Thailand's government has been paying attention to environmental protection, and supporting the development of environmental management strategies for industrial sector. From the data in 2005, there are 34 industrial estates in Thailand were 11 of them are operated by Industrial Estate Authority of Thailand (IEAT), and 22 of them are jointly operated with developers. Map Ta Phut Industrial Estate (MTPIE) is the biggest industrial estate, which is located in Rayong province, East of Thailand. It was developed in 1989 by the state enterprise, 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. Presently there are 53 factories located within the MTPIE. These factories can be divided into five industrial groups: petroleum and petrochemical group (PP) group, industrial gas group, utility group, iron and steel industry group, and chemical industry group. Petroleum and petrochemical group was found to be the most important group in MTPIE containing 31 factories, accounting for 58.49 percent of the total number of factories in this group (Charmondusit et al., 2007).

This paper presents the use of eco-efficiency indicators focusing on the sectoral level. The eco-efficiency of the PP group in the MTPIE was evaluated as the ratio of economic value to specific environmental influences. Net sale and gross margin in unit of baht (B) were selected as the economic performance indicator (rates of exchange for 1 US dollar were 41.5 baht, 40.2 baht and 39 baht in 2003–2005, respectively). The environmental performance indicator consists of four specific indicators which are materials consumption in tons (T), energy intensity in giga joules (GJ), water use in cubic meters (m^3), and hazardous waste generation in tons (T). The compilation data for the indicators during the period 2003–2005 were used. Data were mainly obtained from existing monitoring reports, databases and interviews. The eco-efficiency values were calculated according to the WBCSD recommendations. The eco-efficiency trends of the PP group were also analyzed by using

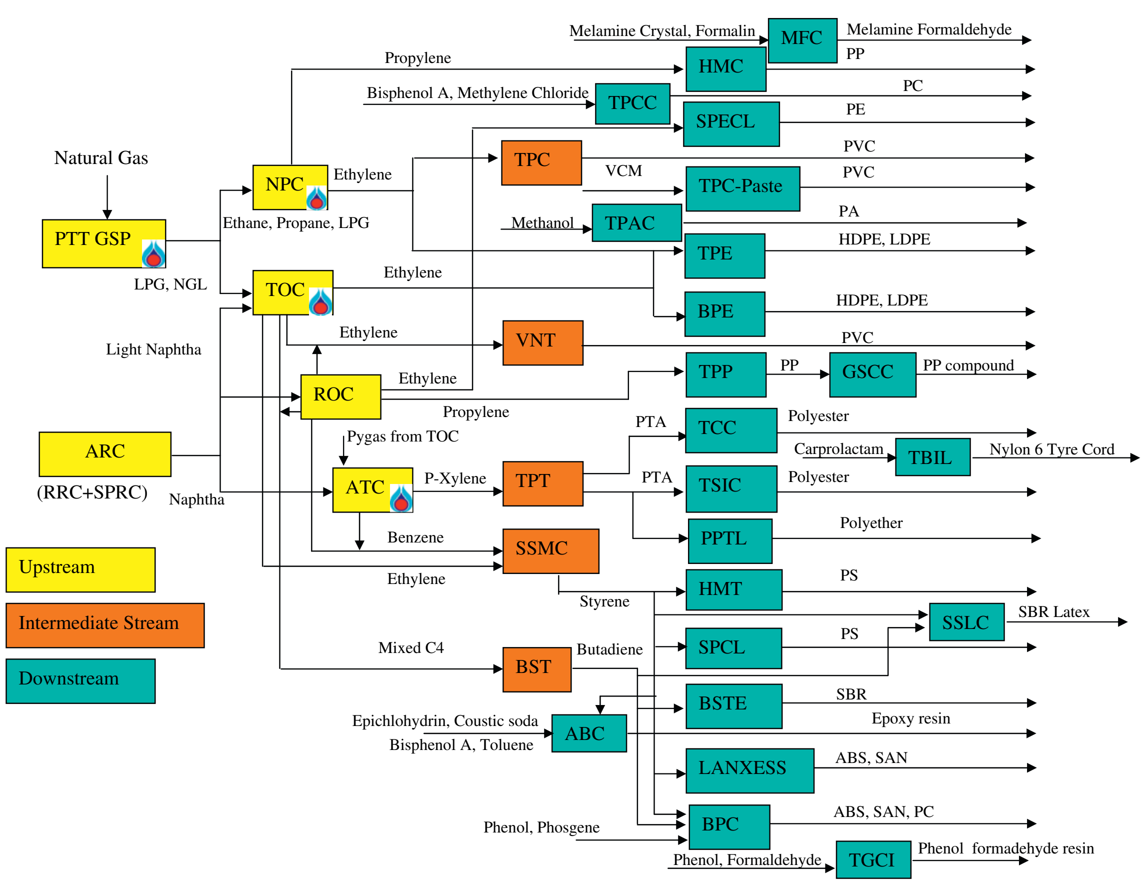


Fig. 2. Material flow diagram of industries in the PP group.

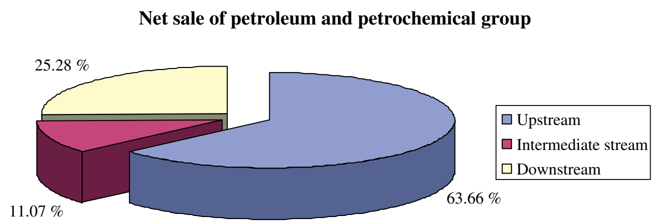


Fig. 3. Distribution of net sale of the PP group.

snapshot graph. The ultimate aim of eco-efficiency is to scrutinize activities with evaluation to improve the performance of industry.

2. Method

2.1. Data collection

Data collection was mainly done via field site investigations. Economic and environmental data from 2003 to 2005 were used from the existing monitoring reports and databases at the MTPIE office and Ministry of Commerce.

2.2. Eco-efficiency evaluation

The evaluation of eco-efficiency values used for this research was gathered from the WBCSD approach and previous literature (World Business Council for Sustainable Development, 2000; UNCTAD, United Nations Conference on Trade and Development, 2004; Kharel and Charmondusit, 2008). The mathematic notations of eco-efficiency as a combination of economic and ecological performance are expressed by the ratio in the following equation:

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

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 environmental burdens from activities carried out in PP group and '*n*' is industry in the PP group, located within MTPIE.

$\sum EN_{nm}$ implies that '*m*' type of environmental influences of the PP 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 has a separate unit. The calculations of energy, material, water, and hazardous waste were conducted separately. In the equation below, '*t*' denotes total sum of each environmental influence and '*r*' denotes different sources.

$$\sum Enm = f\left[\sum_{t=1}^{r} E_t, \sum_{t=1}^{r} M_t, \sum_{t=1}^{r} W_t, \sum_{t=1}^{r} W_{st}\right]\rangle 0 \quad (2)$$

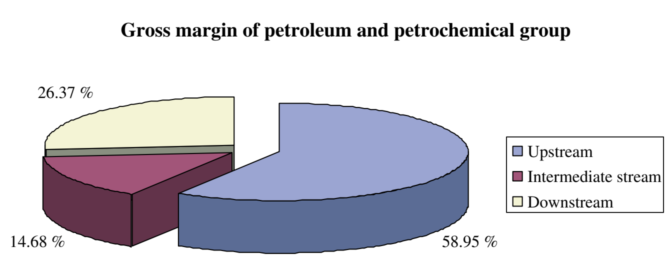
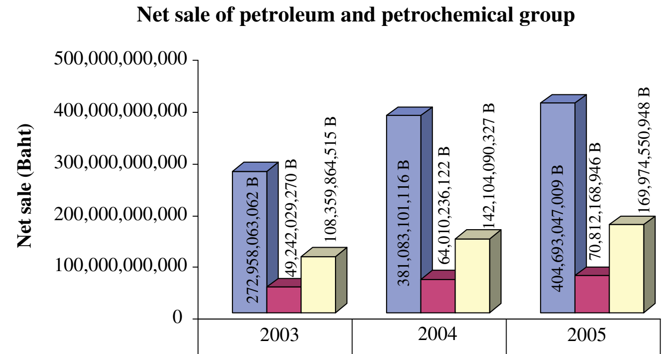


Fig. 4. 1 Distribution of gross margin of the PP group.



	2003	2004	2005
Upstream	272,958,063,062	381,083,101,116	404,693,047,009
Intermediate stream	49,242,029,270	64,010,236,122	70,812,168,946
Downstream	108,359,864,515	142,104,090,327	169,974,550,948

Fig. 5. Net sale of the PP group in year 2003–2005.

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 water use from '*r*' different sources

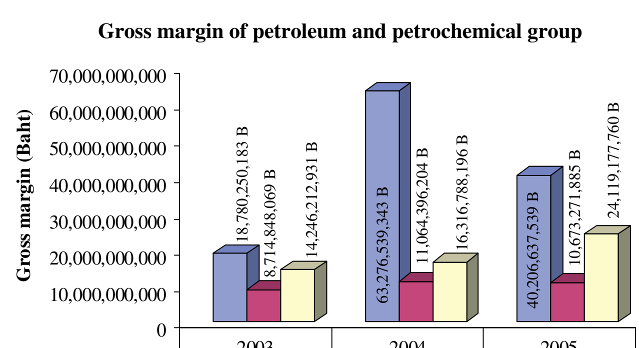
2.3. Analysis of eco-efficiency trend

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 the Anite System in Netherland (Anite Systems, 1999), was applied as a tool to analyze the eco-efficiency trend of the PP group in MTPIE. The percent variations of the selected economic indicator and environmental indicator were calculated based on the following formula:

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

where $\%VE$ = Percent variation of economic or environmental indicators

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



	2003	2004	2005
Upstream	18,780,250,183	63,276,539,343	40,206,637,539
Intermediate stream	8,714,848,069	11,064,396,204	10,673,271,885
Downstream	14,246,212,931	16,316,788,196	24,119,177,760

Fig. 6. Gross margin of the PP group in year 2003–2005.

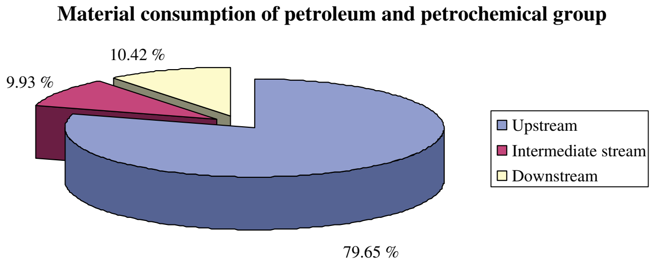


Fig. 7. Average distribution of material consumption in year 2003–2005.

$\sum E_b$ = 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 subsequently 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 (Fig. 1).

The interpretation of the snapshot graph was made easier because the *X*–*Y* plan was 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 was 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 coordinates of every indicator varied in the preferable direction.

Half eco-efficiency: in the (+) area, every indicator had one coordinate varying in the preferable direction and the other one in the unfavorable direction. Moreover, the variation of the coordinate, which was in the preferable direction, compensated for the other indicator's direction.

Fully non-eco-efficiency: In the (−−) area, both economic and environmental indicators varied in the unfavorable direction (i.e., economic performance decreased and environmental performance also increased).

Half non-eco-efficient: In the (−) area, every indicator had one coordinate varying in the preferable direction and the other one in the unfavorable direction. However, the variation of the coordinate, which was in the preferable direction, did not compensate for the other.

3. Results and discussion

3.1. Characterization of the PP group in the MTPIE

The PP group represented approximately 58.49 percent of the total number of factories in MTPIE which was equivalent to 31 factories. Within this group, the factories could be divided into three categories: (i) petroleum and upstream petrochemical industry consisting of six factories or 19.35 percent of the total number of factories in the PP group; (ii) intermediate stream industry consisting of five factories or 16.13 percent of the total number of factories in the PP group; and (iii) downstream industry consisting of 20 factories or 64.52 percent of the total number of factories in the PP group. The characterization of industries in the PP group was studied by using material flow diagram (Charmondusit and Keartpakpraek, 2008), which is shown in Fig. 2. From Fig. 2, it can be concluded that:

i Factories in the PP group were related as a supply chain.
ii Along supply chain, factories within the upstream category were a primary source of material for the intermediate and downstream categories.

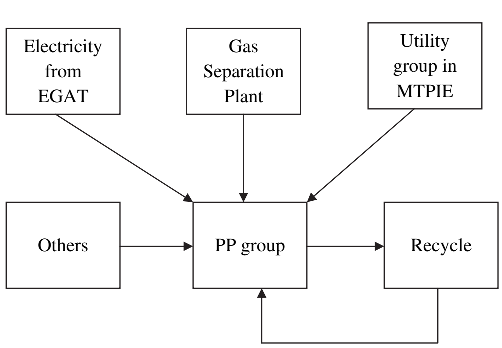


Fig. 8. Diagram of energy sources of the PP group.

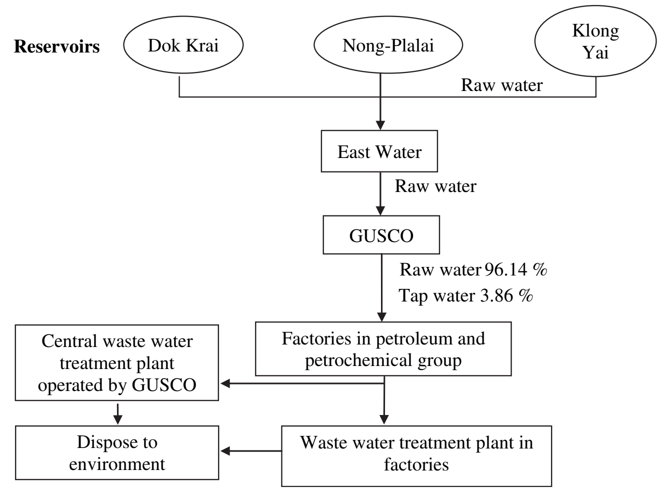


Fig. 9. The overview of water flow diagram of the PP group.

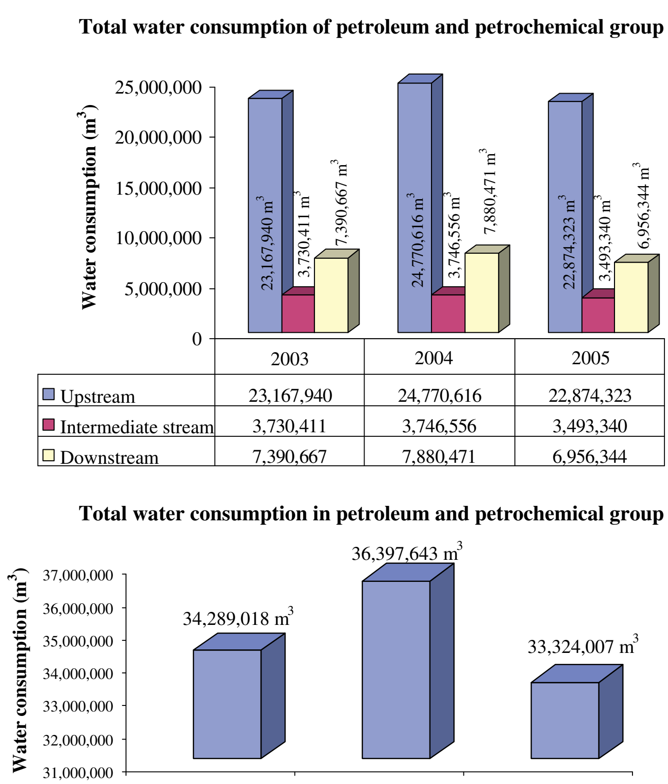


Fig. 10. Water consumption of the PP group from year 2003 to year 2005.

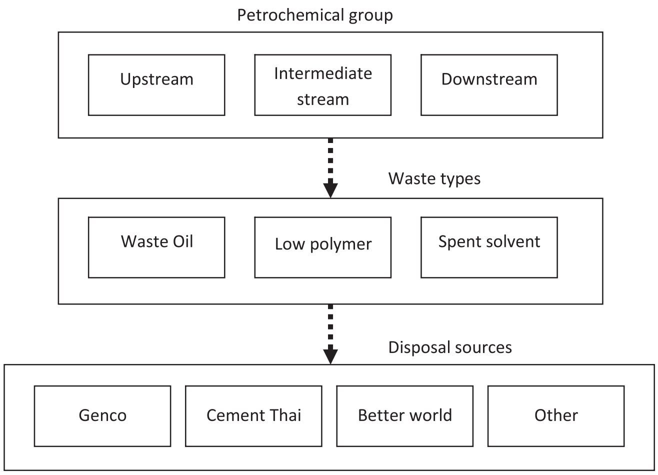


Fig. 11. Diagram of hazardous waste types and disposal source of the PP group.

iii Factories in the intermediate category received products from the upstream and transformed them into products, which were used as a major raw material for the downstream category.

3.2. Identification of eco-efficiency indicators

Two dimensions of eco-efficiency, where "eco" stands for economically efficient and ecologically efficient (Lehni, 1998) that relates to products value with environmental influences, were calculated. The data availability for each environmental indicator was a major problem for this study. For instance, the compiled secondary data on material consumption for each factory in the PP group was restricted to the year 2003. Few data for the energy intensity indicator were gathered, and only secondary data for 28 factories in the PP group could be compiled on the hazardous waste generation indicator. Nonetheless, complete water consumption data for the year 2003–2005 in the PP group was available and collected. In order to solve the lack of data issue, we decided to use the average secondary data in the year 2003 as a representative material consumption data for evaluating material eco-efficiency, and compiled secondary data of hazardous waste generation from 28 factories for evaluating hazardous waste eco-efficiency.

3.2.1. Economic indicator

Net sale and gross margin, which were defined as the total recorded sales and net sales minus costs of goods and services sold, respectively, were used as economic indicators to evaluate eco-efficiency for the PP group in MTPIE. Net sale and gross margin were important and common measures of the economic output. They were selected for several reasons: (i) they were widely used in economic assessments of profitability and productivity; (ii) they were significant and relevant indicators at industrial sector level as they enable comparability across branches and within branches; and (iii) their data were available.

The economic indicator data for the factories in the PP group from 2003 to 2005 were collected. The main data source for the economic eco-efficiency indicator was the database at the Ministry of Commerce. The distributions of economic eco-efficiency indicator among categories in the PP group are shown in Figs. 3 and 4.

Figs. 3 and 4 illustrates that factories in the upstream categories were the major distribution of economic in the PP group, which were comprised of 63.6% and 58.95% of the net sale and gross margin, respectively. Following the next segments were the factories in the downstream and intermediate segments, which were comprised of 25.28% and 11.07% of net sale and 26.37% and 14.68% of gross margin, respectively.

The trends of the economic indicator for each category in the PP group are shown in Figs. 5 and 6. The trends for net sales for each category in the PP group increased from 2003 to 2005, which appeared to be due to the internal and external demands. On the other hand, the gross margin of upstream segment trends decreased after 2004. This was due to the fluctuation of the world's crude oil price, which rose by 37 percent between 2004 and 2005 (average the West Texas Intermediate (WTI) crude oil was 41.4 US$/bbl in 2004 and 56.3 US$/bbl in 2005).

3.2.2. Environmental indicator

3.2.2.1. Material indicator. The material flow diagram and the average distribution of material consumption from year 2003 to year 2005 are shown in Figs. 2 and 7. The figures show that the factories in the upstream segment were the major materials consumers in the PP group, which comprised 79.65% of the total

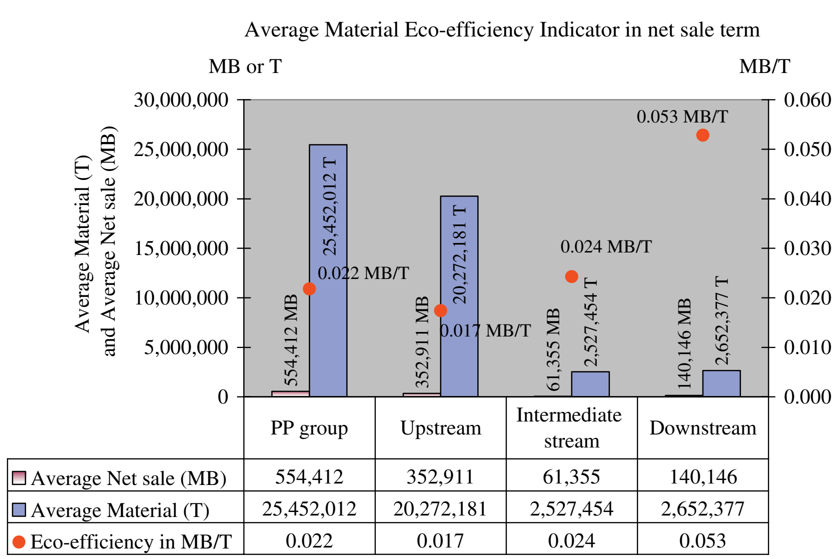
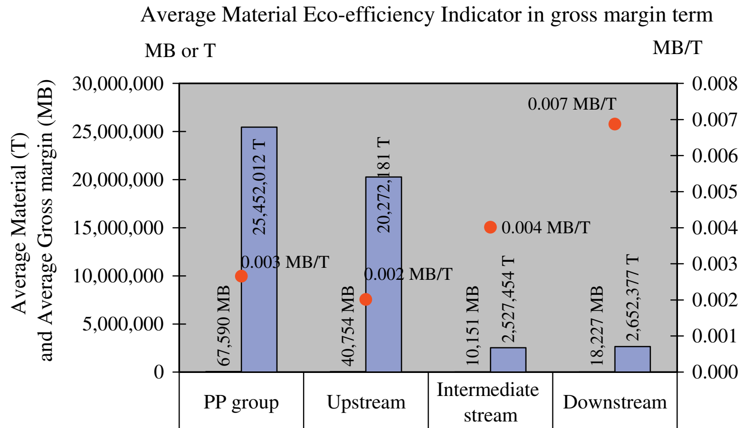


Fig. 12. Material eco-efficiency indicator of the PP group in term of net sale value.



	PP group	Upstream	Intermediate stream	Downstream
Average Gross margin (MB)	67,590	40,754	10,151	18,227
Average Material (T)	25,452,012	20,272,181	2,527,454	2,652,377
Eco-efficiency in MB/T	0.003	0.002	0.004	0.007

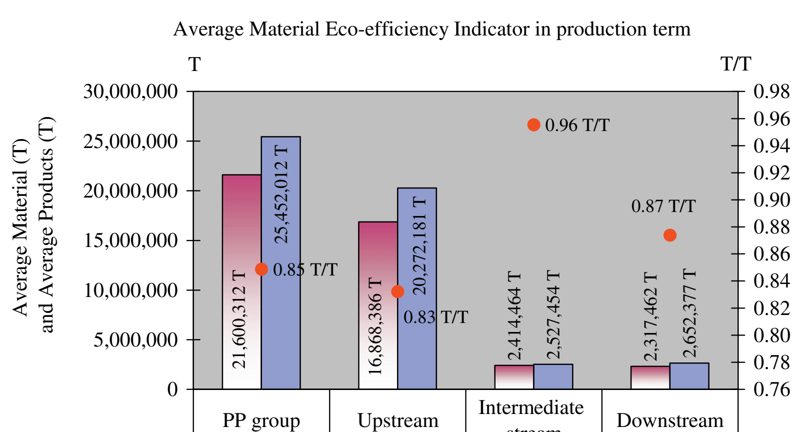
Fig. 13. Material eco-efficiency indicator of the PP group in term of gross margin value.

material consumption in the PP group. The major raw materials for factories in the upstream category were crude oil and natural gas.

3.2.2.2. Energy indicator. Due to the data availability, various types of energy consumption and restricted data compilation, we were unable to construct the complete flow diagram for energy consumption in the PP group. Fig. 8 shows the preliminary diagram of energy source in the PP group. Electricity in MTPIE was supplied from internal generation, utilities group in MTPIE area, and external supplier (Electricity Generating Authority of Thailand: EGAT). Natural gas was supplied from the upstream factories in the PP group. Most of factories in MTPIE had their own steam generation system or purchased from the utilities group in MTPIE. Coal and other energy types were imported from outside MTPIE area.

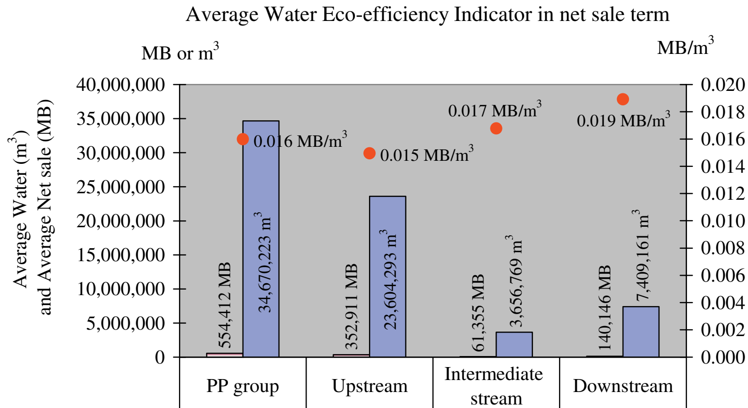
3.2.2.3. Water indicator. The overview of water flow diagram is shown in Fig. 9. The distribution of water consumption in the PP group is presented in Fig. 10. Raw water supplied in the MTPIE was taken from the three reservoirs located in Rayong province: Dok krai, Nong-plalai, and Klong yai reservoirs; which together had total water volume of approximately 180 million cubic meters (m^3). East Water Resources Development and Management Public Company Limited was a major company, which supplied raw water from three reservoirs to the Global Utilities Service Company Limited (GUSCO). Fresh water and tap water distributed to the factories in the MTPIE area were supplied by GUSCO. Wastewater from industrial activities had to be treated before being released to environment. Most of factories in MTPIE had their own wastewater treatment system, which were checked by monthly report of electricity and chemical usage. MITPE also provides three reserve central wastewater treatment systems, located in general industrial and business industrial areas.

From Fig. 10, the water consumption of the PP group increased around six percent from the year 2003 to 2004 and decreased around 8 percent from the year 2004 to 2005. The decline of water consumption from the year 2004 to 2005 was observed in all categories in the PP group, which could be explained by the introduction of 3R (Reduce, Reuse, and Recycle) strategies to the factories in MTPIE area after the water crisis incident in 2004. Factories in the upstream category were still the major water



	PP group	Upstream	Intermediate stream	Downstream
Average Products (T)	21,600,312	16,868,386	2,414,464	2,317,462
Average Material (T)	25,452,012	20,272,181	2,527,454	2,652,377
Eco-efficiency in T/T	0.85	0.83	0.96	0.87

Fig. 14. Material eco-efficiency indicator of the PP group in term of production value.



	PP group	Upstream	Intermediate stream	Downstream
Average Net sale (MB)	554,412	352,911	61,355	140,146
Average Water (cubic meter)	34,670,223	23,604,293	3,656,769	7,409,161
Eco-efficiency in MB/cubic meter	0.016	0.015	0.017	0.019

Fig. 15. Water eco-efficiency indicator of the PP group in term of net sale value.

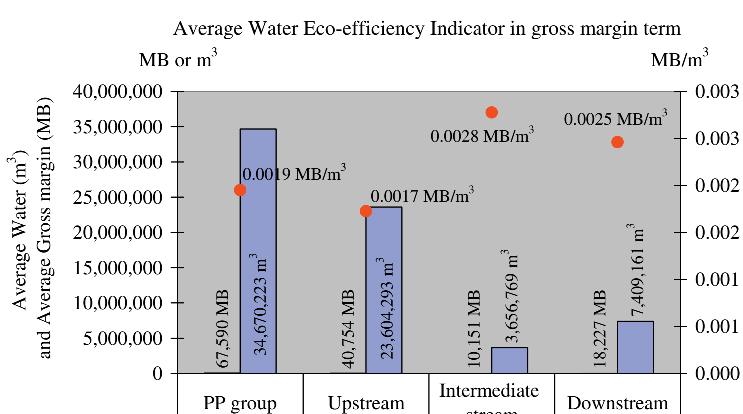
consumer compared to other categories within the PP group. The proportional water consumption in the PP group was 68.08% for the upstream category, 21.37% for the intermediate stream category, and 10.55% for the downstream category.

3.2.2.4. Hazardous waste indicator. Following the laws and regulations, all factories located in MTPIE had to apply for permission to take the wastes outside the MTPIE area. General waste or non-hazardous waste is taken to Map Ta Phut Municipality according to the Municipality Parliament. Non-hazardous industrial waste can be embedded under the sanitary landfill at the excavation that was permitted for transaction by Department of Industrial Works, Ministry of Industry. Hazardous industrial waste could be managed under the secured landfill or high temperature incineration that was permitted for transaction by Department of Industrial Works. Hazardous industrial wastes generated from factories in the PP group could be classified into three categories, which were waste oil, low polymer, and spent solvent. The upstream category generated the highest amount of hazardous industrial wastes (Fig. 11) compared to other categories within the PP group. Hazardous industrial wastes generated from the PP group were mostly disposed by secured land filling (98.45%) at the General Environmental Conservation Company Limited and the Better World Green Public Company Limited, which are located inside and outside the MTPIE area, respectively.

3.3. Evaluation of eco-efficiency indicators

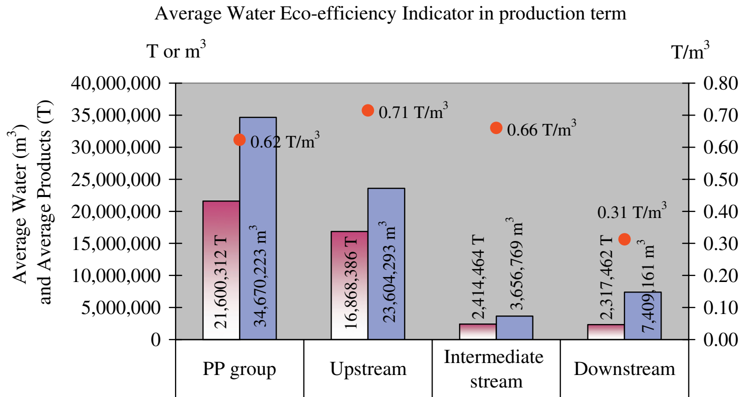
3.3.1. Material eco-efficiency

The evaluation results of material eco-efficiency of the PP group in MTPIE are presented in Figs. 12–14. Evaluation of material eco-efficiency in the ratio of average economic value (net sale) in million baht (MB) and average material utilized in tons (T) from Fig. 12 shows that material eco-efficiency for the PP group was 0.22 MB/T, the upstream category was 0.017 MB/T, the intermediate stream category was 0.024 MB/T, and the downstream category was 0.053 MB/T. These results showed that the downstream category gave higher material eco-efficiency when compared to the upstream and intermediate stream categories by 211.76% and 120.83%, respectively.



	PP group	Upstream	Intermediate stream	Downstream
Average Gross margin (MB)	67,590	40,754	10,151	18,227
Average Water (cubic meter)	34,670,223	23,604,293	3,656,769	7,409,161
Eco-efficiency in MB/cubic meter	0.0019	0.0017	0.0028	0.0025

Fig. 16. Water eco-efficiency indicator of the PP group in term of gross margin value.



	PP group	Upstream	Intermediate stream	Downstream
Average Products (T)	21,600,312	16,868,386	2,414,464	2,317,462
Average Water (cubic meter)	34,670,223	23,604,293	3,656,769	7,409,161
Eco-efficiency in T/cubic meter	0.62	0.71	0.66	0.31

Fig. 17. Water eco-efficiency indicator of the PP group in term of production value.

Evaluation of material eco-efficiency in the ratio of average gross margin in million baht and average material utilized in tons in Fig. 13 illustrates that the overall material eco-efficiency for the PP group was 0.003 MB/T. The material eco-efficiencies were 0.002 MB/T, 0.004 MB/T, and 0.007 MB/T for the upstream, intermediate, and downstream categories, respectively. Materials eco-efficiency in term of gross margin of the downstream category showed the highest eco-efficiency when compared to the upstream and intermediate stream categories by 250% and 75%, respectively.

Evaluation of material eco-efficiency was made based on the ratio of the average production value in tons and the average material utilized in tons as presented in Fig. 14, which shows that materials eco-efficiency values for the PP group was 0.85 T/T, the upstream category was 0.83 T/T, the intermediate stream category was 0.96 T/T, and the downstream category was 0.87 T/T. Taking into consideration of overall material eco-efficiency, the upstream category was found to be the highest material consumer. Material consumption of the intermediate stream category was the same as the consumption of the downstream category, but the higher material utilization in term of economic performance of the downstream category was observed.

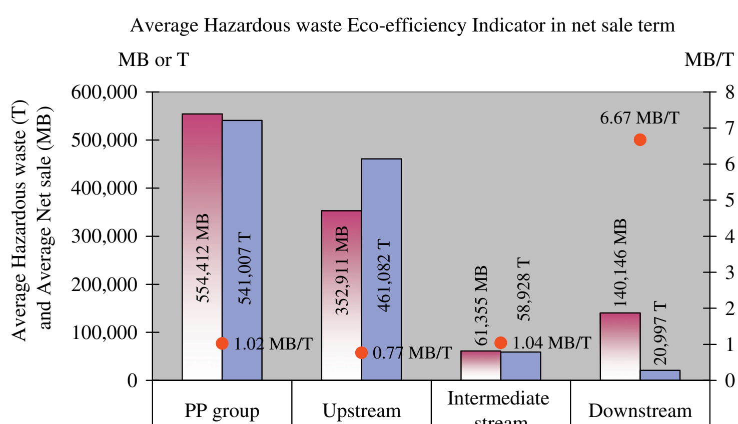
3.3.2. Energy eco-efficiency

Due to the lack of certain data on various types of energy consumption and restricted data compilation, we could not evaluate for energy eco-efficiency of the PP group in the MTPIE.

3.3.3. Water eco-efficiency

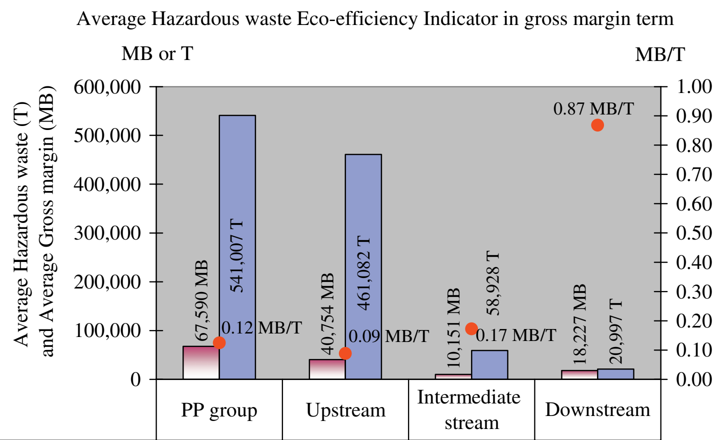
Evaluations of water eco-efficiency in the ratio of average economic value (net sale) in million baht and average water use in cubic meter were assessed. As illustrated in Fig. 15, the water eco-efficiency for the PP group was 0.016 MB/m^3, the upstream category was 0.015 MB/m^3, the intermediate stream category was 0.017 MB/m^3, and the downstream category was 0.019 MB/m^3. These results showed that the downstream category gave higher water eco-efficiency when compared to the upstream and intermediate stream categories by 26.67% and 11.76%, respectively.

Evaluation of water eco-efficiency in the ratio of average gross margin value in million baht and average water used in cubic meter in Fig. 16 illustrates that the water eco-efficiency for the PP group was 0.0019 MB/m^3, the upstream category was 0.0017 MB/m^3, the intermediate stream category was 0.0028 MB/m^3, and the downstream category was 0.0025 MB/m^3. These results indicated that



	PP group	Upstream	Intermediate stream	Downstream
Average Net sale (MB)	554,412	352,911	61,355	140,146
Average Waste (T)	541,007	461,082	58,928	20,997
Eco-efficiency in MB/T	1.02	0.77	1.04	6.67

Fig. 18. Hazardous waste eco-efficiency indicator of the PP group in term of net sale value.



	PP group	Upstream	Intermediate stream	Downstream
Average Gross margin (MB)	67,590	40,754	10,151	18,227
Average Waste (T)	541,007	461,082	58,928	20,997
Eco-efficiency in MB/T	0.12	0.09	0.17	0.87

Fig. 19. Hazardous waste eco-efficiency indicator of the PP group in term of gross margin value.

the water eco-efficiency for intermediate category was higher than the water eco-efficiency for the upstream and downstream categories by 64.71% and 12%, respectively.

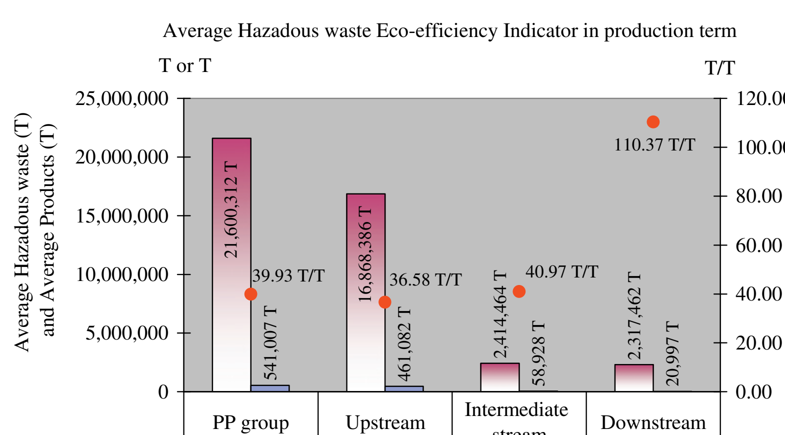
Evaluations of water eco-efficiency in the ratio of average production value in tons and average water use in cubic meter were assessed. In Fig. 17, the water eco-efficiency for the PP group was 0.62 T/m^3, the upstream category was 0.71 T/m^3, the intermediate stream category was 0.66 T/m^3, and the downstream category was 0.31 T/m^3. Looking at the overall water eco-efficiency, the upstream category was found to be the highest water consumer. Water consumption of the intermediate stream category was twofold lower than that of the downstream category.

3.3.4. *Hazardous waste eco-efficiency*

Hazardous waste eco-efficiency indicator in the ratio of average net sale value in million baht to average hazardous waste generated during manufacturing processes in tons was assessed. In Fig. 18, the hazardous waste eco-efficiency was 1.02 MB/T for the PP group, 0.77 MB/T for the upstream category, 1.04 MB/T for the intermediate stream category, and 6.67 MB/T for the downstream category. The results indicated that the downstream category gave higher eco-efficiency compared to upstream and intermediate stream categories by 766.23% and 541.35%, respectively.

Evaluations of hazardous waste eco-efficiency indicators in ratio of average gross margin value in million baht to average hazardous waste generated during manufacturing processes in tons that shows in Fig. 19, illustrates that hazardous waste eco-efficiency was 0.12 MB/T for the PP group, 0.09 MB/T for the upstream category, 0.17 MB/T for the intermediate stream category, and 0.87 MB/T for the downstream category. Hazardous waste eco-efficiency in term of gross margin of the downstream category showed the highest eco-efficiency, which was similar to the results on hazardous waste eco-efficiency in term of net sale.

Hazardous waste eco-efficiency in ratio of average productions value in tons and average hazardous waste generation in tons (Fig. 20) was 39.93 MB/T for the PP group, 36.58 T/T for the upstream category, 40.97 T/T for the intermediate stream category, and 110.37 T/T for the downstream category. The upstream category was found to be the highest hazardous waste generator. The results indicated that the downstream category gave the highest eco-efficiency when compared to the upstream and intermediate stream categories.



	PP group	Upstream	Intermediate stream	Downstream
Average Products (T)	21,600,312	16,868,386	2,414,464	2,317,462
Average Waste (T)	541,007	461,082	58,928	20,997
Eco-efficiency in T/T	39.93	36.58	40.97	110.37

Fig. 20. Hazardous waste eco-efficiency indicator of the PP group in term of production value.

Table 1
The overview trend of water eco-efficiency across the time comparing with each category in the PP group.

Year		2003	2004	2005	Comparison of Eco-efficiency between (2003 & 2005 only)
Water Eco-Efficiency in term of Net Sales	PP group	0.0160 (MB/m^3)	0.0150 (MB/m^3)	0.0168 (MB/m^3)	5.00% (↑)
	Upstream	0.0118 (MB/m^3)	0.0154 (MB/m^3)	0.0177 (MB/m^3)	50.00% (↑)
	Intermediate	0.0132 (MB/m^3)	0.0171 (MB/m^3)	0.0203 (MB/m^3)	53.78% (↑)
	Downstream	0.0147 (MB/m^3)	0.0180 (MB/m^3)	0.0244 (MB/m^3)	65.98% (↑)
	Comparison of Eco-Efficiency (Upstream-Intermediate)	−11.86% (↓)	−11.03% (↓)	−14.68% (↓)	
	Comparison of Eco-Efficiency (Upstream-Downstream)	−24.57% (↓)	−16.88% (↓)	−37.85% (↓)	
	Comparison of Eco-Efficiency (Intermediate-Downstream)	−11.36% (↓)	−5.26% (↓)	−20.19% (↓)	
Water Eco-Efficiency in term of Gross Margin	PP group	0.0019 (MB/m^3)	0.0017 (MB/m^3)	0.0028 (MB/m^3)	47.36% (↑)
	Upstream	0.0008 (MB/m^3)	0.0026 (MB/m^3)	0.0018 (MB/m^3)	125.00% (↑)
	Intermediate	0.0023 (MB/m^3)	0.0030 (MB/m^3)	0.0203 (MB/m^3)	782.60% (↑)
	Downstream	0.0019 (MB/m^3)	0.0021 (MB/m^3)	0.0035 (MB/m^3)	84.21% (↑)
	Comparison of Eco-Efficiency (Upstream-Intermediate)	−187.50% (↓)	−15.38% (↓)	−1027.78% (↓)	
	Comparison of Eco-Efficiency (Upstream-Downstream)	−137.50% (↓)	19.23% (↑)	−94.44% (↓)	
	Comparison of Eco-Efficiency (Intermediate-Downstream)	17.39% (↓)	30.00% (↑)	82.75% (↑)	

(↑)(↓) Signs Indicate Increasing and Decreasing.

3.4. Analysis of eco-efficiency trend

According to the inventory of available data, the water consumption indicator was selected as an exemplary indicator to demonstrate the overview of the eco-efficiency trend. The overview trend of water eco-efficiency across the time comparing with each group in the PP group is shown in Table 1. The water eco-efficiency with respect to net sale of industries in the upstream, intermediate, and downstream categories, comparison between the year 2003 and 2005 had increased by 0.2000%, 0.2119%, and 0.2480%, respectively; and the water eco-efficiency with respect to gross margin of the upstream, intermediate, and downstream categories also raised by 0.3846%, 0.7964%, and 0.2963%, respectively. The increasing of water eco-efficiency was derived from the raising of net sale value and the reduction of water consumption. The increasing of net sale value depended on the expansion of market and average selling price, which could be increased by the improvement in the product's quality and the rise of the product's quantity. The increases in fossil fuel and plastic demand, both within Thailand and in other countries, were key factors of the market expansion. The 3R (Reduce, Reuse, and Recycle) strategies of water in the MTPIE area were strongly implemented in 2005, which could have led to the reduction of water consumption. Many companies started reusing washed water and treated water from the processes. Reduction of fresh water by using seawater as the cooling water and using reverse osmosis technology in order to produce fresh water from seawater were performed in many major companies.

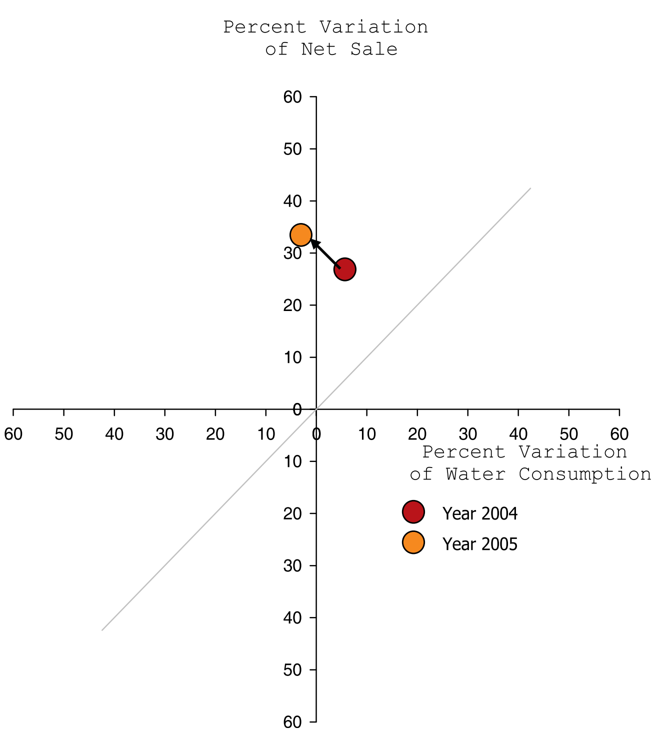


Fig. 21. Snapshot concerning net sale and water use during the year 2003–2005 of the PP group.

In order to show the simple relative progress and overview of the trend of industrial sector on the economic creation compared to the environmental performance, we decided to use the snapshot graph analysis following the Anite system's method (Anite Systems, 1999). The total net sale value and water consumption of the PP group were selected as economic and environmental indicators to exemplarily analyze the overall eco-efficiency trend. The data compilation in the 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 Fig. 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 period of time. Therefore, each indicator is represented by the coordinates (*X*, *Y*), where *Y* was the

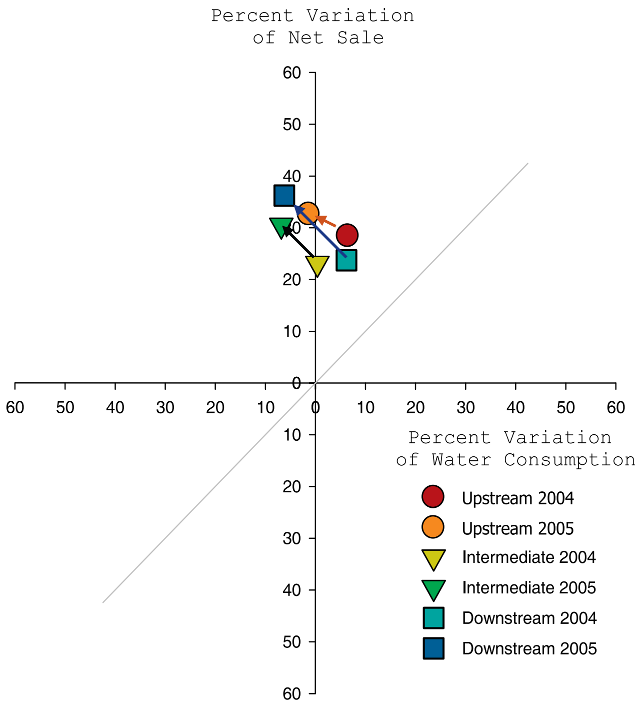


Fig. 22. Snapshot concerning net sale and water use during the year 2003–2005 of each category in the PP group.

percent variation of the net sale and *X* was the percent variation of water consumption.

From Figs. 21 and 22, snapshots concerning the net sale values and water use for the PP group during the year 2003–2005 showed that the eco-efficiency trends of all groups in the PP group were shifted from half eco-efficient in the year 2004 to fully eco-efficient in the year 2005. The raising of percent variation of net sale was due to the market expansion. On the other hand, the percent variation of water consumption decreased from 2004 to 2005 due to the reduction of water usage after 3R strategies were implemented in 2005.

3.5. Feedbacks

The main advantage of using the eco-efficiency concept is that it makes it possible for industries to monitor their performance with regard to eco-efficiency trends. After tracking and quantifying their environmental performance, the industries can also establish new measurement and target goals. Therefore, the industries should apply eco-efficiency to their annual sustainability reports to help them to transform the eco-efficiency ideas into living reality within their organizations.

- This research provides a framework for application of the eco-efficiency concept as a measurement tool for industry. The standardization of definitions and decision-making rules for calculating and reporting eco-efficiency can assist industries in Thailand to set and use measurable eco-efficiency improvement targets and to facilitate comparisons among different industrial and business sectors. Essentially, the process and the results could be widely accepted, quantifiable, and transparent indicators for Thailand and for other countries.
- Many factories in the PP group have started to collect their own data and are calculating their own eco-efficiency performance, which will help them to assess their improvements and will provide the foundation for Thailand's strategy for industrial estate development in the future. For example, industries can re-engineer their processes to reduce the consumption of resources, while at the same time saving costs and cooperating with other industries to re-valorize their by-products (World Business Council for Sustainable Development, 2000).
- People who live near the MTPIE and other stakeholders know the progress about economic risks associated with environmental performance of industries in the PP group.
- The MTPIE office and industries in the PP group have agreed that it would be very useful to develop and to distribute a guidebook pertaining to the basic principles of eco-efficiency to industrial leaders in the MTPIE and within other industrial estates, which could then be used to promote the eco-industrial estate concept in Thailand.
- In order to reach and sustain the fully eco-efficiency, industries in the PP group must try to increase the economic value and decrease the environmental burden by using the renewable energy source and eco-design for process and product modifications.
- As the shortcoming in data may cause some bias in the results, the situation ought to be reassessed when more data are available. Long-term data compilation needs to be considered and initiated.
- Eco-Efficiency is fundamentally a ratio of some measure of economic value to some measure of environmental impact, which is the 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 in future research. For example, the selection of economic and environmental indicators as components for the eco-efficiency indicators could be in line with the core issue (e.g., competitiveness, climate change, toxic dispersion) in the political issue.

4. Conclusions

In applying the eco-efficiency as an evaluation tool for measuring the performance of industrial sector, the study offers very useful insights. The PP group in the MTPIE in Thailand was selected to be an exemplary case study. The 31 factories in the PP group were divided into the upstream, the intermediate, and the downstream categories. It is significant to observe that factories in the upstream category were found to be the highest in material and water consumption and in hazardous waste generation. Factories in the downstream category obtained particularly good eco-efficiency results pertaining to material consumption, water use, and hazardous waste generation. The eco-efficiency trend concerning the net sales and water use showed that the eco-efficiency trend of the PP group in the MTPIE shifted from half eco-efficient 2004 to fully eco-efficient in 2005. This study is a starting point for applying the eco-efficiency concepts to the environmental management system of the industrial sector in both micro and macro levels. In order to meet the goals and benefits of the eco-efficiency, the concepts must be presented to the governmental authority managers. Eco-efficiency workshops for both micro and macro levels need to be held. Lastly, in order to maintain a high level of performance, eco-efficiency must be encouraged to be properly used as a tool in corporate evaluation and reporting.

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List of the factories' abbreviation

ABC: Aditya Birla Chemicals (Thailand) Limited
ATC: Aromatics (Thailand) Public Company Limited
BPC: Bayer Polymers Company Limited
BPE: Bangkok Polyethylene Public Company Limited
BST: Bangkok Synthetics Company Limited
BSTE: BST Elastomers Company Limited
GSCC: Grand Siam Composites Company Limited
HMC: HMC Polymer Company Limited
HMT: HMT Polystyrene Company Limited
LANXESS: LANXESS (Thailand) Company Limited
MFC: Thai MFC Company Limited
NPC: Nation Petrochemical Public Company Limited
PPTL: Pacific Plastics (Thailand) Limited
ROC: Rayong Olefins Company Limited
RRC: Rayong Refinery Public Company Limited
SPCL: Siam Polystyrene Company Limited
SPECL: Siam Polyethylene Company Limited
SPRC: Star Petroleum Refining Company Limited
SSLC: Siam Synthetic Latex Company Limited
SSMC: Siam Styrene Monomer Company Limited
TBIL: Thai Baroda Industries Company Limited
TGCI: Thai GCI Resitop Company Limited
TOC: Thai Olefins Public Company Limited
TPC: Thai Plastic and Chemicals Public Company Limited
TPC-Paste: TPC Paste Resins Company Limited
TPE: Thai Polyethylene Company Limited
TPP: Thai Polypropylene Company Limited
TPT: TPT Petrochemicals Public Company Limited
TSIC: Thai Shinkong Industry Company Limited
TTC: Tuntex (Thailand) Public Company Limited
VNT: Vinythai Public Company Limited

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