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A STUDY ON ECO-EFFICIENCY OF THE MANUFACTURING SECTOR IN MALAYSIA

This study evaluates the technical and eco-efficiency of manufacturing industry in Malaysia over the period of 2001–2010 by applying data envelopment analysis (DEA) and directional distance function (DDF) approaches. The evaluation is carried out through the joint production framework involving desirable and undesirable outputs. For overall result, Pulau Pinang, Sarawak and Labuan appeared to be the most efficient states for both technical and eco-efficiency with Terengganu being the least. It is also observed that the omission of the undesirable output in the analysis may lead to misleading results on the technical efficiency level indicating erroneous modelling of the production process. The findings of this study offer insights to policy makers and manufacturers of the ways to improve the level of efficiency in the context of achieving sustainable development.

Keywords: eco-efficiency, technical efficiency, undesirable outputs, data envelopment analysis, directional distance function.

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ДОСЛІДЖЕННЯ ЕКОЛОГІЧНОЇ ЕФЕКТИВНОСТІ ВИРОБНИЧОГО СЕКТОРУ В МАЛАЙЗІЇ

У статті оцінено технічну та екологічну ефективність обробної промисловості в Малайзії за період 2001–2010 рр. із застосуванням аналізу середовища функціонування і функції відстані. Оцінювання проведено за моделлю спільного виробництва з урахуванням бажаних і небажаних наслідків. Найбільш технічно та екологічно ефективними штатами виявилися Пулау-Пінанг, Саравак і Лабуан, найменш ефективним – Теренггану. Якщо знехтувати небажаними результатами виробництва в аналізі, можна отримати помилкові висновки про рівень технічної ефективності, що вказує на помилкове моделювання виробничих процесів. За результатами дослідження запропоновано рекомендації для керівників щодо способів підвищення рівня ефективності в контексті концепції сталого розвитку.

Ключові слова: екологічна ефективність, технічна ефективність, небажані наслідки, аналіз середовища функціонування, функція відстані.

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ИССЛЕДОВАНИЕ ЭКОЛОГИЧЕСКОЙ ЭФФЕКТИВНОСТИ ПРОИЗВОДСТВЕННОГО СЕКТОРА В МАЛАЙЗИИ

В статье оценена техническая и экологическая эффективность обрабатывающей промышленности в Малайзии за период 2001–2010 гг. с применением анализа среды функционирования и функции расстояния. Оценка проведена по модели совместного производства с учетом желательных и нежелательных последствий. Наиболее технически и экологически эффективными штатами оказались Пулау-Пинанг, Саравак и Лабуан, наименее эффективным – Теренггану. Если пренебречь нежелательными результатами производства в анализе, можно получить ошибочные выводы об уровне технической эффективности, что указывает на ошибочное моделирование производственных процессов. По результатам исследования предложены рекомендации для руководителей относительно способов повышения уровня эффективности в контексте концепции устойчивого развития.

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Ключевые слова: экологическая эффективность, техническая эффективность, нежелательные последствия, анализ среды функционирования, функция расстояния.

1. Introduction

In recent years, there has been a growing concern about the global environmental sustainability. Increased economic activities, especially in industrial countries, has been recognised as yielding environmental pollution, and manufacturing activities is no exception to this. Malaysia, which has transformed from a predominant agricultural economy to an industrialized one over the last three decades, is one of the largest emitter of CO₂ with a total of 164.2 mln tons from fuel combustion and has one of the largest carbon footprint at 5.98 tons per person amongst the South East Asian countries in 2009 (International Energy Agency, 2011). Total CO₂ emission in Malaysia has increased by 235.6% from 1990 to 2009 and the manufacturing sector contributes 20% of total CO₂ emission in 2009 (International Energy Agency, 2011). Malaysia needs to move to a greener economy which implies meeting development and environmental sustainability which will take into consideration not only economic but also environment criteria. The assessment of environmental performance is important to monitor and evaluate firm performance in terms of both economic and ecological efficiency (or eco-efficiency) in order to achieve environmental sustainability.

The underpinnings of the efficiency measurement began with the work of Debreu (1951) and Koopmans (1957). Debreu provided the first measure of efficiency, which is the 'coefficient of resource utilization' while Koopmans was the first who defined the concept of technical efficiency. Technical efficiency focuses on the ability to increase the output while keeping the input constant or the ability to reduce the input while keeping the output constant. Technical efficiency involves either a single or multiple input and output in the analysis. When incorporating undesirable outputs such as pollutants, the measurement of environmental or ecological efficiency in paramount. The concept of eco-efficiency can be classified as a measurement of efficiency with the integration of environmental pollutions that are regarded as undesirable outputs together with desirable outputs (Arocena and Waddams Price, 2002).

Recent scientific research indicates that not enough attention is paid to the integration of environmental concerns into the standard economic efficiency measures. A non-parametric technique for efficiency analysis, data envelopment analysis (DEA) introduced by Charnes et al. (1978) has been employed for environmental performance evaluation (see Coli et al., 2011; Choia et al., 2012; Jaraitea, Maria, 2012; Wu et al., 2012). Pollution is measured as undesirable or bad outputs of a production model and is treated as freely disposable inputs. Another approach that has gained popularity called the directional distance function (DDF) approach proposed by Chung et al. (1997) uses the hyperbolic DEA method based on the notion of weakly disposable undesirable outputs as pollution reduction is considered to be costly.

Despite the existence of many DEA-related approaches for modelling environmental performance, there is a lack of studies in Malaysia employing it to analyse the eco-efficiency of manufacturing firms in Malaysia. Therefore, this study applies the DEA and DDF approaches to evaluate the technical and ecological efficiency of manufacturing industries in Malaysia at the state level over the period of 2004 until

2009 by using a joint production framework involving desirable and undesirable outputs simultaneously.

2. Methodology

In this study the authors apply two models to measure efficiency. First, the technical efficiency is measured employing DEA subject to desirable output only, ignoring the undesirable one. Next, the DDF approach has been used to measure eco-efficiency using a joint production framework incorporating both the desirable and the undesirable outputs.

DEA is a linear programming technique for measuring the relative efficiency of a set of decision making units (DMUs) or units of assessment in the use of multiple inputs to produce multiple outputs. DEA identifies a subset of efficient 'best practice' DMUs and for the remaining DMUs, their efficiency level is derived by comparing them to a frontier constructed from the 'best practice' DMUs. Each DMU is analysed separately to examine whether the DMU under consideration could improve its performance by increasing its output or decreasing its input. DEA can be viewed as a benchmarking technique, as it allows decision makers to locate and understand the nature of the inefficiencies of a DMU by comparing it with a selected set of efficient DMUs with a similar profile. To begin with this analysis, some notations have been made. Let $x \in R_+^I$ represents an input vector and $y \in R_+^J$ represents an output vector. Thus, x_i represents the i^{th} input, and y_j represents the j^{th} output of a DMU.

$$S = \{(x, y) : x \text{ can produce } y\} \quad (1)$$

The above formula defines production possibilities as the set of input-output vectors that are attainable given the production technology (S). Following Fare et al. (1994) the connection between DEA efficiency measurement and the representation of the technology is given by

$$S = \{(x, y) : \sum_{n=1}^N z_n x_{in} \leq x_{im}; i = 1, 2, \dots, I; \\ \sum_{n=1}^N z_n y_{jn} \geq \theta_m y_{jm}; j = 1, 2, \dots, J; \\ z_n \geq 0; n = 1, 2, \dots, N\} \quad (2)$$

The mathematical formulation in case of strong disposability and output oriented DEA – CRS model for DMU m based on the given technology above is as follows:

Max θ_m

Subject to

$$\sum_{n=1}^N z_n x_{in} \leq x_{im}; i = 1, 2, \dots, I \\ \sum_{n=1}^N z_n y_{jn} \geq \theta_m y_{jm}; j = 1, 2, \dots, J \\ z_n \geq 0; n = 1, 2, \dots, N, \quad (3)$$

where z_n – intensity variables, x_{in} – i^{th} input of the n^{th} DMU, y_{jn} – j^{th} output of the n^{th} DMU, x_{im} – i^{th} input of the m^{th} DMU, y_{jm} – j^{th} output of the m^{th} DMU and $n = 1, 2, \dots, N$ DMUs.

The DEA output oriented envelopment model seeks a set of z values which maximize the θ_m and identifies a point within the production possibilities set, whereby

output levels of DMU m can be increased as high as possible proportion while input remain at current level (Ramanathan, 2003). The efficiency scores of DMUs in this model are bounded between zero and one. The best performing DMUs are assigned an efficiency score of one while the performances of other DMUs that score less than one are inefficient. In this analysis, a constant return to scale (CRS) technology assumption has been assumed to measure technical efficiency.

To describe the efficient frontier by using the output oriented Data Envelopment Analysis (DEA) approach, Figure 1 exhibits 5 DMUs, which are A, B, C, D and E. Assume that all DMUs use a similar quantity of a single input (x) level and 2 different quantity of output (y_1, y_2) levels. The output oriented DEA identifies A, B, C and D as the best practice units whereby this line is also known as the efficient frontier. DMU E lies below the efficient frontier, thus DMU E is regarded inefficient. Point E' is the benchmarking standard for DMU E. The efficiency score for DMU E can be computed by OE/OE' which is the ratio of radial distances. This implies that DMU E can improve its efficiency by as much as EE'/OE' to hit the target E'.

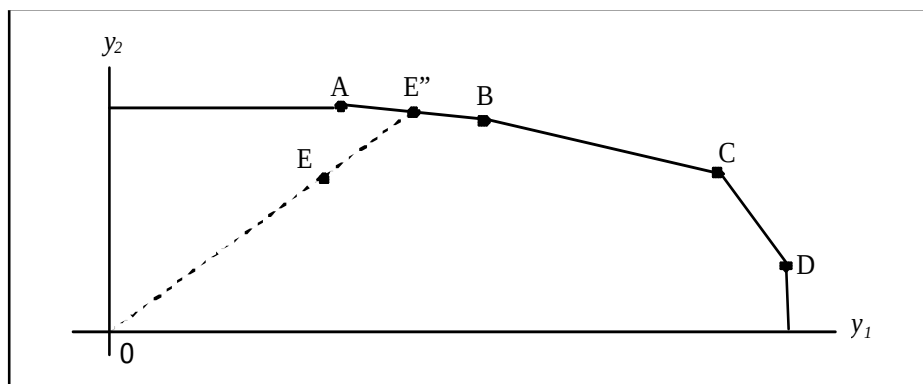


Figure 1. Efficient frontier for output oriented DEA model

Nevertheless this conventional DEA model accounts for only 2 categories of variable which are the input and the desirable output variables. When undesirable outputs are present, the model of DEA is no longer applicable. For instance, in Figure 1, DMU E is inefficient and its efficiency can be evaluated by referring to the frontier lines on DMU E'. This evaluation implies that DMU E needs to increase both y_1 and y_2 in order to improve the efficiency. If y_1 axis is substituted by undesirable output (u), then the concept of undesirable outputs is erroneous within the model of DEA. This is because the concept of desirable output contradicts with undesirable output. The desirable output needs to be increased while undesirable output needs to be decreased.

In 1997, Chung et al. introduced an approach that incorporated the production of desirable and undesirable outputs in measuring the efficiency score. The DDF idea is to expand desirable outputs and reduce inputs and/or undesirable outputs simultaneously based on a given direction vector (Chung et al., 1997). The purpose of this approach is to provide measures of performance that directly account for the reductions in undesirable outputs.

To begin with this analysis, additional notations have been added to the formula (1). To avoid confusion in the model development, the notations used in the directional distance function are similar to the ones used in previous DEA models. Let $x \in R_+^I$ represents an input vector, $y \in R_+^J$ represents a desirable output vector while $u \in R_+^K$ represents an undesirable output vector. So now, the above definition simply describes the "environmental output set" for production technology T .

$$T = \{(x, y, u) : x \text{ can produce } (y, u)\} \quad (4)$$

According to Fare and Grosskopf (2004), if the set is formulated in the DEA framework, the weak disposability reference technology can be called an environmental DEA technology. The term weak disposability is appropriate if both desirable and undesirable outputs are released, and the undesirable outputs may not be released without costs. The environmental DEA technology exhibiting constant returns to scale (CRS) can be depicted as below:

$$\begin{aligned} T = \{(x, y, u) : & \sum_{n=1}^N z_n x_{in} \leq x_{im}; i = 1, 2, \dots, I; \\ & \sum_{n=1}^N z_n y_{jn} \geq y_{jm}; j = 1, 2, \dots, J; \\ & \sum_{n=1}^N z_n u_{kn} = u_{km}; k = 1, 2, \dots, K; \\ & z_n \geq 0; n = 1, 2, \dots, N\} \end{aligned} \quad (5)$$

The directional distance function (DDF) on the technology T , can be defined as below:

$$\bar{D}_T(x, y, u; g_y, g_u) = \text{Max}\{\beta : (y + \beta g_y, u - \beta g_u) \in T\} \quad (6)$$

The distance function above attempts to search for the extension of desirable outputs in the g_y direction and reduction of undesirable outputs in the g_u direction. In other words, proportion β seeks to increase the desirable outputs and reduce the undesirable outputs simultaneously.

The DDF uses linear programming to compute environmental efficiency of the m^{th} DMU under constant returns to scale and weak disposability of outputs assumptions. It is formulated as below (see Chung et al, 1997):

$$\begin{aligned} & \text{Max } \beta_m \\ & \text{Subject to} \end{aligned}$$

$$\begin{aligned} & \sum_{n=1}^N z_n x_{ni} \leq x_{mi}; i = 1, 2, \dots, I \\ & \sum_{n=1}^N z_n y_{nj} \geq y_{mj} + \beta_m g_{y_j}; j = 1, 2, \dots, J \\ & \sum_{n=1}^N z_n u_{nk} = u_{mk} - \beta_m g_{u_k}; k = 1, 2, \dots, K \\ & z_n \geq 0; n = 1, 2, \dots, N, \end{aligned} \quad (7)$$

where z_n – intensity variables, x_{ni} – i^{th} input of the n^{th} DMU, x_{mi} – i^{th} input of the m^{th} DMU, y_{nj} – j^{th} desirable output of the n^{th} DMU, y_{mj} – j^{th} desirable output of the m^{th} DMU, u_{nk} – k^{th} undesirable output of the n^{th} DMU, u_{mk} – k^{th} undesirable output of the m^{th} DMU, g_y – direction vector of desirable output and g_u – direction vector of undesirable output.

Figure 2 illustrates the environmental output set (T) for the directional distance function approach which is bounded by $0ABCD0$. Assume that all DMUs use a similar quantity of a single input (x) to produce a dissimilar quantity of a single desirable (y) and a single undesirable (u) output. The efficient frontier is represented by the line $0, A, B, C$ and D . From the illustration, DMU E below is the efficient frontier, thus it can be categorized as inefficient DMU. Through DDF model, a direction is from E to E' whereby it has an effect on the levels of both directions – desirable and undesirable outputs and is determined by the direction vector of $g = (g_y, -g_u)$. If $g = (1, -1)$ which means that the desirable output is increased and undesirable output is decreased by 1 and -1, respectively, with an equal emphasise on the expansion of desirable output and reduction of undesirable output. Therefore, in Figure 2 the directional output distance function will expand the output bundle (y, u) at E , along the g direction until it hits the production boundary of $y + \beta g_y, u - \beta g_u$ at E' .

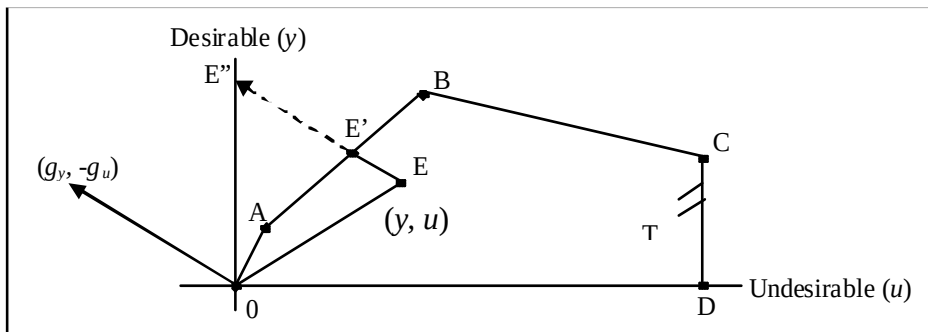


Figure 2. Efficient frontier for directional distance function

Additionally, in this study the authors have attempted the efficiency analysis of the manufacturing sector using the DDF method proposed by Chung et al. (1997) because it is simple, intuitive and can be easily put into practice. In fact, many published papers have used this approach (see Boyd et al., 2002; Watanabe and Tanaka, 2007; Zha and Zhou, 2009; Mandal and Madheswaran, 2010; Piot-Lepetit, 2010; Wanga et al., 2012). Furthermore, the DDF is flexible as it allows for the evaluation of efficiency using a single direction vector from the observed points.

This study involves the manufacturing sector in 15 states throughout Malaysia. In this analysis, two inputs are employed i.e. operating expenditure (opex) and capital and two outputs: one desirable and the other – undesirable. A single desirable output is sales in the manufacturing industry while undesirable output is carbon dioxide (CO_2) emissions. It has been determined that among the industrial sources of air pollution, CO_2 is the main by-product of industrial activities as the combustion of fossil fuels in the manufacturing process produces CO_2 . Therefore, CO_2 emission has been included as an undesirable output in this analysis.

The input and desirable output data for the observed period between 2004 and 2009 were obtained from the Department of Statistics, Malaysia. The data are aggregated values for all manufacturing activities in each state. As no state level data is

available for the amount of CO₂ released, the authors calculate the CO₂ emissions based on fuel combustion in the manufacturing sector using the 2006 Inter-government Panel on Climate Change (IPCC) guidelines for National Greenhouse Gas Inventories (Eggleston et al., 2006).

3. Research findings

Table 1 and 2 present the results of the technical and eco-efficiency analysis of the manufacturing sector in 15 states (including the Federal Territories of Kuala Lumpur and Labuan) throughout Malaysia between 2004 and 2009. The scores for technical and eco-efficiency were obtained from the equations (3) and (7) respectively. The results are presented by industrial categories of the state i.e. the free industrial zone (FIZ) states and the non-free industrial zone (N-FIZ) states for technical and eco-efficiency in Table 1 and Table 2, respectively. The FIZ covers a free zone for manufacturing companies that produce or assemble products mainly for export purposes. The FIZ consists of 5 states, namely, Johor, Melaka, Pulau Pinang, Perak and Selangor while the N-FIZ are made up of ten states, that is, Kedah, Kelantan, Negeri Sembilan, Pahang, Perlis, Terengganu, Sabah, Sarawak and the Federal Territories of Kuala Lumpur and Labuan.

The conventional DEA approach in the equation (3) that measures technical efficiency in Table 1 indicates the presence and extent of inefficient use of outputs and the possibility for each state to increase outputs while maintaining existing inputs. For example, in 2004, Perak was 63.8% efficient. This result suggests that Perak could increase their sales in manufacturing roughly by 36.2% while maintaining the current inputs of opex and capital. It should be noted that any state that has an efficiency score equal to 100% is defined as efficient, and a score of less than 100% is regarded as inefficient.

The outcomes as reported in Table 1 show that there are consistent efficiency scores for each state over the 6 years analysis. For instance, Pulau Pinang performs almost 100% efficient over the six years except for 2008 in which there is a slightly drop to 90.3% efficiency score. With a 98% efficiency score in average, the manufacturing sector of Pulau Pinang is almost on the production possibility frontier and can be considered technically efficient.

The impact of the economic crisis that occurred in 2008 has been felt most strongly in a manufacturing sector of the Malaysian economy. Referring to 2008 annual report published by the bank Negara Malaysia, the crisis started to impact the Malaysian economy in the fourth quarter of 2008 whereby gross exports declined by 20% during the quarter while manufacturing production declined by 11.1%. This turn down in manufacturing sector results a subsequent reduction in technical efficiency score in 2008 particularly for the FIZ states. It can be seen that the FIZ states contributed significantly (92.6%, 92.9% and 92.2%) to the Malaysian economy between 2005 and 2007, and then dropped in their average score to 86.1% in 2008. Out of five states under FIZ category, Pulau Pinang appears the only state experiencing an impressive increase which is about 10% in their efficiency score after the economic crisis, from 90.3% in 2008 to 99.7% efficient in 2009. Other states including Johor, Melaka, Perak and Selangor in FIZ states exhibit decreasing efficiency score.

As for N-FIZ states, Terengganu remained the least technically efficient throughout the study period with an average efficiency score of 68%. Terengganu

consistently has the biggest potential to increase sales on average of up to 32% since this state is significantly below the efficient frontier. On a year-by-year basis, the trends seemed to fluctuate for all the states except for the state of Sarawak. The trend for Sarawak seemed to be upward. For instance, the efficiency score was 83.1% in 2004, and then increased drastically to 98.1% in 2005 and consistently 100% between 2006 and 2009. As for Labuan, it can be observed that this state obtained the greatest gain in efficiency, growing at an annual rate of 29.3% from 2008 (77.3%) to 2009 (100%) throughout the period of the study.

Table 1. Results of DEA technical efficiency score and rank between 2004 and 2009

Year	2004		2005		2006		2007		2008		2009		Average	
State	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank
FIZ	%		%		%		%		%		%		%	
1. Johor	84.8	7	91.6	7	93.7	7	94.1	6	86.9	7	85.6	7	89.5	8
2. Melaka	90.1	5	100	1	100	1	100	1	95.7	4	90.4	6	96.0	5
3. Pulau Pinang	100	1	100	1	98.3	4	99.9	4	90.3	6	99.7	4	98.0	1
4. Perak	63.8	15	79.8	14	82.5	12	78.2	12	76.1	12	74.0	13	75.7	13
5. Selangor	85.4	6	91.4	8	90.0	9	89.0	8	81.7	9	80.8	10	86.4	9
Geometric mean	84.8		92.6		92.9		92.2		86.1		86.1		89.1	
N-FIZ														
6. Kedah	69.3	11	83.0	12	81.8	13	76.1	13	71.4	13	74.2	12	76.0	12
7. Kelantan	90.6	4	91.3	9	96.5	5	86.4	9	100	1	81.4	9	91.0	7
8. Negeri Sembilan	81.4	10	93.1	6	93.5	8	93.5	7	90.7	5	97.9	5	91.7	6
9. Pahang	65.3	14	81.0	13	85.4	11	84.8	10	82.1	8	76.2	11	79.1	11
10. Perlis	67.7	12	84.2	11	78.8	14	73.4	14	70.9	14	72.4	14	74.6	14
11. Terengganu	66.6	13	65.8	15	70.9	15	66.5	15	68.4	15	69.5	15	68.0	15
12. Sabah	92.6	3	94.2	5	96.3	6	95.8	5	100	1	100	1	96.5	3
13. Sarawak	83.1	9	98.1	4	100	1	100	1	100	1	100	1	96.9	2
14. Kuala Lumpur	83.9	8	88.0	10	88.5	10	78.9	11	77.6	10	83.6	8	83.4	10
15. Labuan	100	1	100	1	100	1	100	1	77.3	11	100	1	96.2	4
Geometric mean	80.1		87.9		89.2		85.5		83.8		85.5		85.3	
Total geometric mean	81.6		89.4		90.4		87.8		84.6		85.7		86.6	

The technical efficiency of states across 2004–2009 ranges from as low as 65.8% to up 100%. Looking at the last column of Table 1, the average technical efficiency score for FIZ category (89.1%) was a slightly higher than N-FIZ category (85.3%). The results also indicate that majority of the Malaysian states in the manufacturing sector experience high technical efficiency with more than a score of 60% during the 6 years period of study. This high technical efficiency by the manufacturing sector made the Malaysian economy as one of the most remarkable growth records. This result shows the ample potential that improvements in technical efficiency could imply for economic growth. In addition, the original data for all the states shows an increase in operating expenditure and sales from 2004 to 2006 and this has affected efficiency which can be seen in the total geometric mean in that period whereby it increased progressively from 81.6% to 89.4% and then to 90.4% in 2006. However, the subsequent years saw a decline in efficiency, stabilizing at around 85%.

Turning to eco-efficiency score, it indicates the extent of desirable output expansion and undesirable output reduction. For instance, in 2004, Johor was 96.5% efficient. This result suggests that Johor could expand its desirable output by as much as

3.5% while concurrently contracting its undesirable outputs by 3.5% to achieve full efficiency.

Under the FIZ category, Melaka and Pulau Pinang achieved full eco-efficient throughout the study period. The results may appear to be counter intuitive as these states have a lot of manufacturing activities likely to release air pollution. However, note that eco-efficiency does not only take into account undesirable outputs but also desirable outputs. The high levels of CO₂ are concurrent with a high level of inputs and desirable output. Hence, Melaka and Pulau Pinang are categorized as eco-efficient. On the other hand, Perak is one of the most eco-inefficient states. This is in keeping with the report that was published by the Department of Environment in 2008 identifying Perak as one of the states with numerous sources of industrial air pollution (Department of Statistics Malaysia 2008).

As for the N-FIZ states, it can be observed that, in 2009, Terengganu had the biggest potential to expand its desirable output by up to 40.8% while concurrently contracting the undesirable outputs by about 40.8%, since this state was significantly below the efficient frontier. Terengganu, which was fully eco-efficient in 2004, performed worse for the subsequent years.

Table 2. Results of DDF eco-efficiency score analysis and rank

Year	2004		2005		2006		2007		2008		2009		Average	
State	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank
FIZ	%		%		%		%		%		%		%	
1. Johor	96.5	8	94.2	11	93.3	10	98.7	8	93.9	8	89.8	8	94.4	8
2. Melaka	100	1	100	1	100	1	100	1	100	1	100	1	100	1
3. Pulau Pinang	100	1	100	1	100	1	100	1	100	1	100	1	100	1
4. Perak	80.8	14	84.2	14	78.8	13	78.6	13	74.2	13	79.2	13	79.3	13
5. Selangor	99.6	6	95.2	10	91.3	11	92.3	9	92.7	9	89.7	9	93.5	9
Geometric mean	95.1		94.5		92.3		93.5		91.6		91.4		93.1	
N-FIZ														
6. Kedah	92.9	11	96.8	7	95.4	8	86.4	11	87.0	10	87.6	10	91.0	11
7. Kelantan	96.4	9	90.6	12	100	1	86.5	10	100	1	86.8	11	93.4	10
8. Negeri Sembilan	92.9	11	96.5	8	94.5	9	100	1	99.7	7	100	1	97.3	6
9. Pahang	75.8	15	86.5	13	83.7	12	84.5	12	85.2	11	81.5	12	82.9	12
10. Perlis	81.9	13	83.2	15	73.1	15	71.1	14	73.4	14	73.3	14	76.0	14
11. Terengganu	100	1	97.0	6	73.0	14	59.5	15	61.2	15	59.2	15	75.0	15
12. Sabah	96.4	9	100	1	100	1	100	1	100	1	100	1	99.4	5
13. Sarawak	100	1	100	1	100	1	100	1	100	1	100	1	100	1
14. Kuala Lumpur	99.4	7	96.0	9	100	1	100	1	81.3	12	99.5	7	96.0	7
15. Labuan	100	1	100	1	100	1	100	1	100	1	100	1	100	1
Geometric mean	93.2		94.5		91.3		87.6		87.7		87.6		90.6	
Total geometric mean	93.8		94.5		91.6		89.6		89.0		88.9		91.4	

The outcome also revealed that Sarawak and Labuan are consistently ranked first throughout the study period. This could be attributed to the fact that these states have no heavy industries and manufacturing activities are at their minimum. Thus, the impact on air pollution is marginal. For instance, the Federal Territory of Labuan, an autonomous state located within the state of Sabah, is more focused in shipping routes and offshore oil and gas fields and has limited manufacturing activities such as

paper industry which contributes only 9% of the manufacturing sector's carbon emissions. Sarawak, on the other hand, is the largest state in Malaysia, and also fully eco-efficient. 80% of Sarawak's total land area is covered by forest rather than residential or industrial areas. Therefore, Sarawak is largely free from air pollution.

Comparing technical and eco-efficiency score, the results presented in Table 1 and Table 2 show some perturbations between both the efficiency models. When the element of CO₂ is ignored in technical efficiency, only 2 or 3 states are 100% efficient. However, when the element of CO₂ is incorporated in eco-efficiency, there are 5–7 states that are measured as 100% efficient. It is worth noting that as the number of variables increases (for example, with the inclusion of undesirable output in this case) the efficiency scores and the number of fully efficient states will increase. Apart from that, most of the total geometric means also exhibit lower technical efficiency scores than eco-efficiency scores. This indicates that when undesirable output is omitted in the efficiency analysis, the results can be misleading. The trends in technical efficiency and eco-efficiency are displayed in Figure 3.

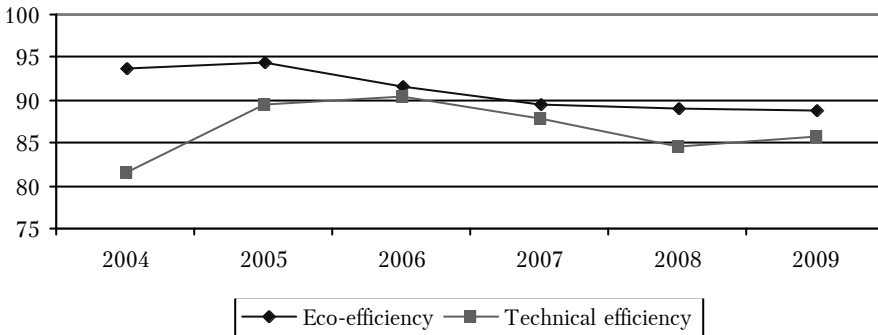


Figure 3. A trend between eco-efficiency and technical efficiency scores

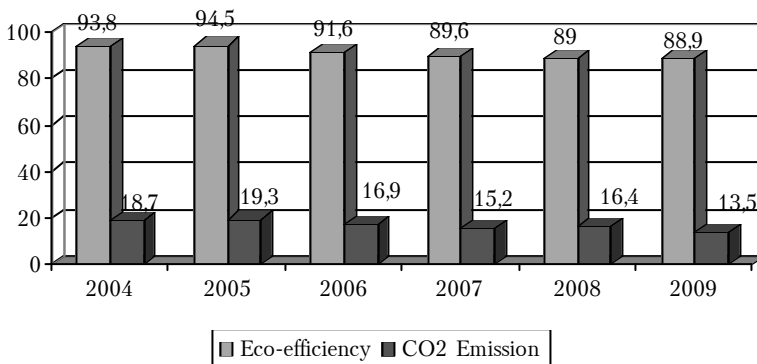


Figure 4. A comparison between eco-efficiency score and CO₂ emissions

The next observation is on the yearly trend in eco-efficiency as compared to the carbon dioxide emission over the period between 2004 and 2009. The yearly result has been presented in Figure 4 where it can be deduced that there is an inconsistent trend

in eco-efficiency score with CO₂ emission released from 2004 up to 2009. The highest CO₂ emission released was in 2005 with 19.3% while the lowest was in 2009 with 13.5%. This demonstration shows that the eco-efficiency score is not being solely influenced by CO₂ emission but needs to incorporate the levels of inputs and desirable outputs as well. All these elements should be combined in order to balance the goals of socio-economic development whilst keeping the environmental conditions.

4. Conclusion

From the analysis that has been carried out, it can be seen that the directional distance function model is an appropriate efficiency measurement approach for the manufacturing sector as industrial activities release pollutant. This model allows to expand the desirable outputs while simultaneously contracting the undesirable outputs. This property is useful in studying the input-output choices of polluting firms facing actions taken by environmental regulatory body.

The results indicate that Pulau Pinang is the most efficient with a score of 100% as the top performer under both formulations of technical and environmental efficiencies. The total geometric mean of technical efficiency score is 86.6%, while environmental efficiency score is 91.4%. As for the overall result, it indicates that the average efficiency scores in terms of technical and environmental are greater for the FIZ compared to N-FIZ states although the differences are not significant. These outcomes also show that if each state desires to achieve full eco-efficiency, they have to reduce the amount of CO₂ emitted and increase the sales. As for the overall result, it can be observed that the average efficiency scores in terms of technical and environmental efficiencies are greater for the FIZ compared to N-FIZ. This result discloses that the Malaysian manufacturing activity in the FIZ states which is categorized under industrial area performs better than the N-FIZ area.

This empirical study also suggests directions in terms of policy, laws and regulations regarding the environmental damages due to manufacturing activities and environmental protection that are relevant to the firms or particular industries. Policies drafted must take into consideration environmental protection besides the sustainability of industrial development. The government may provide a grant for starting a green business with a purpose of promoting environmental concerns among profit-making organizations. A green business concept is an involvement of manufacturing activities that are environmentally friendly. All business operations in such organizations are committed to follow eco-friendly principles so that the environment is not adversely affected. The government may also introduce a carbon tax policy for the organizations. The idea is that polluters will pay per tone of carbon they release into the atmosphere. This initiative would motivate the organizations to increase their eco-efficiency levels besides minimizing their environmental liabilities. Furthermore, this approach could be relatively easy to implement.

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