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Research on eco-efficiency of industrial parks in Taiwan

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Abstract

In the current global industrial development trend, creating economic benefits is no longer the sole objective of industrial development. Increasing emphasis is being placed to the concept of compatible and perpetual development of economy, environment, and society, and it has begun to advocate using "eco-efficiency" to measure the relation between economic value and environmental impact. Furthermore, the eco-industrial park has also become the best channel for realizing industrial perpetual development. Looking back on the development path of the industrial park in Taiwan, over the decade of building eco-industrial parks, we have attached more importance to building Recycling Eco-Town-and-Country as our industrial development vision on a macroscopic level, besides our efforts in the industrial ecology on microscopic and intermediate levels. Local and international policy recommendations have also called for the eco-efficiency of industrial parks. Through reviewing literature, that past indicative system and evaluation method for the eco-efficiency, without considering the three aspects of sustainability, is not applicable for the comparison between industrial parks. Therefore, the research aims to demonstrate the sustainability of the industrial park through a set of objective and comprehensive evaluation model.

This research aims to build an economy and environment eco-efficiency measurement model. The research evaluates the industrial eco-efficiency based on Data Envelopment Analysis (DEA) model by using panel date of 60 industrial parks in Taiwan, assessing the Technical Efficiency(TE), Pure Technical Efficiency(PTE) and Scale Efficiency(SE), and taking regional exploration and comparison.

According to the research result, there remains a big improvement space for many industrial parks about eco-efficiency. Overall, in the event of excessive power consumption, only 15 industrial parks have reached the most appropriate scale and developed relative eco-efficiency; other industrial parks are all in an inefficient status and require identifying possible improvement directions and degrees through slack variable analysis, making improvement strategy to enhance their eco-efficiency.

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Keywords: Eco-Industrial Park, Eco-efficiency, Data Envelopment Analysis ;

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1. Introduction

In the current global industrial development trend, creating economic benefits is no longer the sole objective of industrial development. Increasing emphasis is being placed to the concept of compatible and perpetual development of economy, environment and society, and it has begun to advocate using “eco-efficiency” to measure the relation between economic value and environmental impact. An Eco-Industrial Park is based on the concept of Industrial Ecology (IE), which refers to the capability to plan the exchange of material and energy resources of the industrial system, to seek to minimize resource consumption and reduce waste emissions, and establish the sustainable relationship of economic, environmental and social aspects [1]. The eco-industrial park has also become the best channel for realizing industrial perpetual development. Looking back on the development path of the industrial park in Taiwan, over the decade of building eco-industrial parks, we have attached more importance to building Recycling Eco-Town-and-Country as our industrial development vision on a macroscopic level, besides our efforts in the industrial ecology on microscopic and intermediate levels. Local and international policy recommendations have also called for the eco-efficiency of industrial parks. Through reviewing literature, that past indicative system and evaluation method for the eco-efficiency, without considering the three aspects of sustainability, is not applicable for the comparison between industrial parks. Therefore, the research aims to demonstrate the sustainability of the industrial park through a set of objective and comprehensive evaluation model.

Looking at the literature about eco-industrial parks, currently, there is no quantitative empirical study on ecological efficiency applied to the whole industrial parks of Taiwan. Only the establishment of a qualitative index system cannot truly reflect the effectiveness of the development of the ecological industrial park in Taiwan. Therefore, the purpose of this study is to establish an objective and comprehensive method to measure the sustainability of the industrial park. This study uses the DEA model to quantify the ecological efficiency of the industrial park. It will help to identify for each industrial park strategies to improve its eco-efficiency and operationalize sustainable development.

2. Literature Review

2.1. Eco-Industrial Park: some concept

The international definition of Eco-Industrial Park is based on the 1996 President of the United States President's Council of Sustainable Development seminar conclusions, summed up the two definitions:(1)The Eco-Industrial Park is a community composed of enterprises, it combines the local community residents and the efficient sharing of resources to achieve economic and environmental quality improvement. (2)To seek the exchange of material and energy resources through the planning system in order to minimize resource consumption and reduce waste emissions, and establish the sustainable relationship of economic, environmental and social aspects [2].

Eco-Industrial Park is composed of enterprises that pursue their private interests, but also it takes into account the realization of the public interest, so its outcome is desirable for the wider society. On the application level, it can be divided into three levels: (1) micro-level is an industry within the industrial ecology, (2) the meso-level is in the industrial system within the industry mutual cooperation,(3) the macro-level is the eco-industrial network or ecological urban and rural areas[2] [3]. Whether from the perspective of individual manufacturers or from the perspective of overall urban and rural development, eco-industrial parks emphasize the need to become an ecosystem with natural and economic resources coexisting. In the past, the research on Eco-Industrial Park has been discussed on the basis of the theoretical basis, the development type or related cases of the Eco-Industrial Park [1] [2] [4] [5] [6]. The research on the comparison of the multiple ecological industrial parks in Taiwan is lacking.

2.2. Eco-efficiency

Eco-efficiency for each organization means "with less input to create more intended output, and as far as possible, to reduce the impact on the environment and the consumption of natural resources in the production process" [7]. Eco-efficiency become a concept not limited to a single plant or enterprise micro level, but gradually extended to the macro level, such as regional development, cross-industry cooperation, residential development, transportation,

departments and national governments and other levels[8] [9] [10]. For the integration of regional development and industrial eco-industrial park, ecological efficiency is the key and challenge of developing the eco-industrial park and green consumption [11]. When the concept of eco-efficiency is applied to industrial environmental management systems, the micro and macro levels must be parallel. This will not only enable enterprises to assess their own internal Eco-efficiency but also encourage them to continue to improve the performance in both economic and environmental terms. Eco-efficiency value can be used as a reference for the policies of the government management agencies [11].

The evaluation model of industrial parks' eco-efficiency can be divided into two steps. The first is to perform the qualitative analysis of the evaluation index items. The second is to quantify the indicators by means of assessment methods. First of all, in establishing the qualitative analysis of evaluation indicators, in order to evaluate the sustainability of industrial parks, the evaluation index includes three aspects: economy, environment, and society[13] [14]. By establishing the qualitative analysis of index evaluation, weight is not only susceptible to subjective influence [10], but also cannot consider the interaction effects of multiple inputs and outputs simultaneously. In quantitative analysis (Table 1), multiple criteria decision-making (MCDM) was often used to measure a variety of factors. Compared with the evaluation method of a single evaluation project, it is objective to use the multi-oriented ecological efficiency, because it ignores the interaction effects between the evaluation projects. However, the substance flow analysis (SFA) is more objective, which accounts for the majority of the quantitative analysis. Because industrial park classification is much, and data collection is difficult, so the object of study is mostly for one industrial park or an industrial category, and lacks quantitative analysis of multiple industrial parks.

Table 1. Comparison of Eco-Efficiency Evaluation Methods

Method	Advantage	Disadvantages
Life cycle assessment (LCA)	With a holistic thinking, the steps are easy to understand.	There is a lack of a common model for the evaluation of Multiple assessment objects.
Multi-criteria decision-making (MCDM)	Consider the multi-evaluation project, with objectivity.	Assuming that the evaluation projects are independent, the AHP may have problems such as the insufficient representation of the experts.
Substance Flow Analysis, (SFA)	With the actual data assessment, good stability, to avoid the subjectivity.	Can not reflect the relationship between the environment and the economy, the assessment unit can measure the Substance Flow project inconsistent.
Data Envelopment Analysis (DEA)	Nonparametric methods can reduce the subjective influence.	The efficiency values obtained are relative values, non-absolute values, high sensitivity, and are also affected by outliers.

Data Envelopment Analysis (DEA) has the advantage of multi-criteria decision-making method, it can deal with the problem of multi-input and output items evaluation, and does not need to preset the form and weight of functions. It can also give clear improvement suggestions for all or single assessment units. The efficiency value obtained by DEA is relative efficiency, but it can be used to compare and analyze the ecological efficiency of various industrial parks. Therefore, this study chooses the DEA to measure the ecological efficiency of multiple industrial parks.

3. Research Methods and Hypotheses

In this study, DEA was used to construct the Eco-efficiency evaluation model of the industrial park. However, the Eco-efficiency of DEA assessment can only represent the two aspects of economy and environment, but to achieve sustainable Eco-Industrial Park, we must take into account the economic, environmental and social aspects. As a result, this study reviews the relevant theories and understands that the eco-industrial park is not only the industrial symbiosis system within the park, but also more towards the macro-level cycle of eco-urban and rural development. This indicates that the industrial park is closely related to the surrounding urban and rural environment, and is also the meaning of the index of the social orientation of the industrial park. Therefore, we should further understand the relationship between the urban and rural environment and the ecological efficiency in the social orientation.

3.1. Data Envelopment Analysis

The Data Envelopment Analysis is a method of analyzing the leading edge of maternal efficiency without giving the function type and weight in advance. It evaluates the relative efficiency of the Decision-Making Unit (DMU) by

assessing the efficiency of the DMU by determining the efficiency of the front edge and the efficiency of the origin to zero, and to estimate the relative efficiency of the DMU's reason.

In 1978, Charnes, Cooper and Rhodes explored the use of mathematical programming model to establish the efficiency evaluation model under the assumption of fixed scale pay, that is, the CCR model, where the efficiency value obtained is the total Technical Efficiency (TE). In 1984, Banker, Charnes, and Cooper modified the model that was built under the premise of returns to scale invariable (CCR model) to the model under the premise of returns to scale variable (BCC mode) .The efficiency was further divided into Pure Technical Efficiency (PTE) and Scale Efficiency (SE). Returns to scale invariable means the proportion of the increase in production is equal to the increase in the factors of production.

The industrial park belongs to the variable returns to scale, so the BCC mode should be used. However, in its hypothesis, although it can make up for the lack of CCR, still can't assess the total technical efficiency, pure technical efficiency and scale efficiency of the industrial park. Therefore, combining both CCR and BCC is the most appropriate DEA assessment model for this study. In addition, the industrial park discussed in this study is mainly affected by the input factors, so the author uses the input-oriented model to explore the parts of the investment that can be reduced or adjusted, under the condition of the fixed output of the Industrial Park.

3.2. Data Envelopment Analysis

When selecting a DEA input-output project, it is necessary to consider the project related to efficiency, whether the project is related to the goal to be achieved, and the project information as easy as possible and credible. Therefore, in order to assess the sustainability of the industrial park, the input-output project (Table 2) covers the economic, environmental and social aspects. Through the review of the literature and related theories, preliminary select the projects for input and output and then using correlation analysis to examine the integrity of data obtained.

Table 2 DEA Input Output Variance List

project	oriented	category	Variable name	Unit	Variable definition meaning
Input	Resource consumption	Land resources	Site area	m^2	Land use by manufacturers in industrial parks
		Capital	Capital	100 million yuan	Total capital of all manufacturers in industrial parks
		Labor force	Employment No.	person	The total number of employees in the industrial park to understand the degree of enthusiasm of the manufacturers stationed
		Other energy resources	Water consumption	10^6m^3	The balance of water supply in the region to understand the consumption of water resources in the park
			Electricity consumption	KW·h/Day	The park's total electricity consumption, in order to understand the park power consumption situation
	Environmental impact	Waste material	Waste discharge	T/Year	Through the total amount of waste in the industrial park (not including temporary storage), to understand the situation of waste dumps in various industrial parks
		Air pollution	Airborne Particles	$\mu g/m^3$	The average amount of airborne particulate PM10 (fine particles below 10 microns) is used to understand the air pollution
Output	Economic benefits	Output	Output	100 million yuan	Industrial park manufacturers within the overall operating income, To understand the degree of activity in the industrial park

3.3. Sources and Restriction

The sources of this study, includes: Electricity from the Taiwan Electric Power Company with the Ministry of Economic Affairs issued by the "economic geography information plans to build the project", Waste Disposal from the Ministry of Economic Affairs of the Ministry of Economic Affairs, "2012 Industrial Zone Energy Integration to Promote the Report Final Report" [15]. Other information comes from the "Industrial Zone Development Dynamic Inventory" [16] report of the "Industrial Land Planning and Activation Strategy" report of the Ministry of Economic

Affairs. In all the parks, the data of Nangang Software Park is incomplete, so it is not assessed, the remaining 60 parks are used as evaluation objects.

4. Research Result

In this study, the efficiency values were calculated by using CCR-I and BCC-I models in DEA-SOLVER Pro5.0 software, and the effects of Eco-efficiency analysis, difference variable analysis, scale pay analysis and sensitivity analysis were discussed respectively.

4.1. Analysis of Eco-efficiency values

The CCR and BCC models of DEA were used to detect the Eco-efficiency of industrial parks respectively. According to the total technical efficiency and pure technical performance of each industrial park, the Eco-efficiency can be divided into 15 relatively efficient E-type parks, 12 purely efficient but inefficient T-type parks and 33 overall inefficient N-type parks categories (Figure 1).

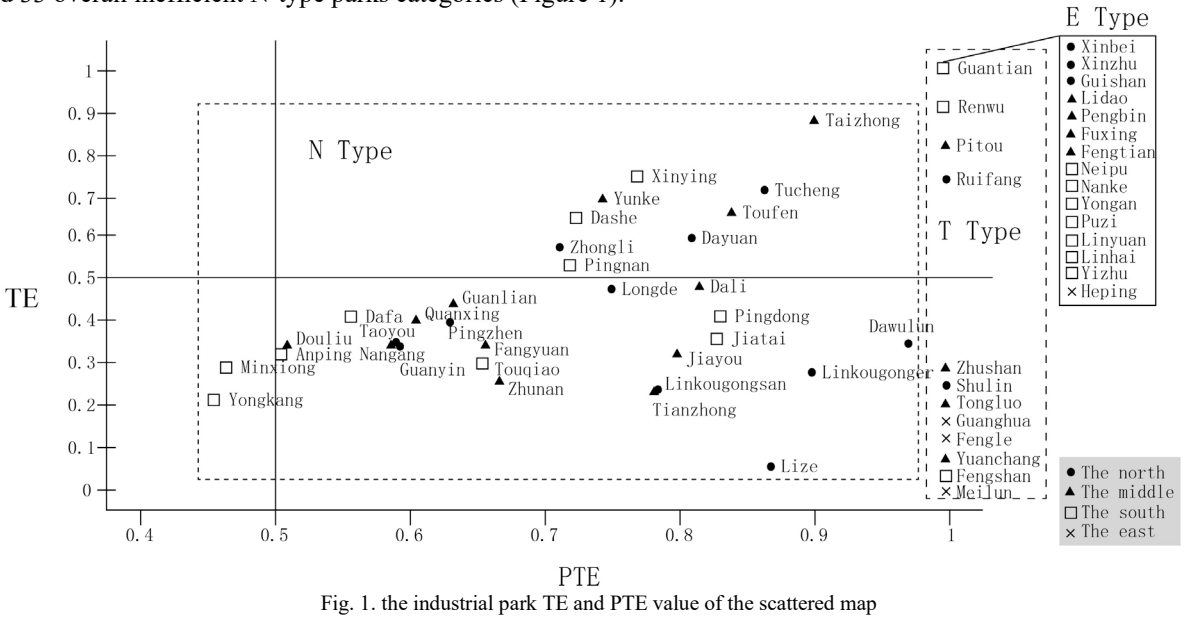

Fig. 1. the industrial park TE and PTE value of the scattered map

The results of the DEA model on the area (Table 3)showed that total technical efficiency is highest in the southern region, and more than half of the parks in the southern region has pure technical efficiency. While the pure technical efficiency value is the highest in the eastern region, the eastern region of the four industrial parks have relatively pure technical efficiency, but only Guanghua industrial park is a strong efficiency unit, the other three industrial parks are the edge of the efficiency of the unit. Pure technical efficiency in the northern region is second only to that of the southern region. On the whole, Taiwan's pure technical efficiency value of 0.8751, but the total technical efficiency value of only 0.5280, and most industrial parks do not reach the Eco-efficiency, said Taiwan's industrial park ecological efficiency is still room for improvement.

Table 3 DEA model results summary

	CCR-I				BCC-I				Scale				Remuneration	
	Have TE Efficiency		No TE Efficiency		Have PTE Efficiency		No PTE Efficiency		Have SE Efficiency		No SE Efficiency			
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	Fixed	Increment
Northern Region	3	18.75	13	81.25	5	31.25	11	68.75	3	18.75	13	81.25	3	13
Central Region	4	20.00	16	80.00	8	40.00	12	60.00	4	20.00	16	80.00	4	16
Southern Region	7	35.00	13	65.00	10	50.00	10	50.00	7	35.00	13	65.00	7	13
Eastern Region	1	25.00	3	75.00	4	100.00	0	0.00	1	25.00	3	75.00	1	3
Total	15	25.00	45	75.00	27	45.00	33	55.00	15	25.00	45	75.00	15	45
Average Efficiency	0.528				0.8751				0.6043				-	
Standard deviation	0.3212				0.1733				0.2986				-	
Minimum Value	0.0655				0.4601				0.0655				-	
Maximum Value	1				1				1				-	

4.2. Slack variable analysis

In this study, the CCR model is used to calculate the different variables. Under the assumption of fixed returns to scale, it is suggested that the input and output projects and the improvement degree should be adjusted. As a whole, the most over-invested variable in Taiwan's industrial parks is electricity consumption. While viewed from the region (Table 4), the northern region has over-invested in electricity consumption and the number of employment; the central region in the electricity consumption and site area has over-investment; the southern region in the electricity consumption, capital and Airborne particles have over-investments; the eastern region has over-invested in waste discharge and electricity consumption.

Table 4 Region average reduction range of input

Region	Site area	Capital	Employment No.	Water Consumption	Electricity Consumption	Waste Discharge	Airborne Particles
Northern	6.37%	4.62%	8.49%	2.87%	14.16%	2.45%	7.24%
Central	13.70%	2.69%	9.08%	4.05%	22.05%	1.94%	7.63%
Southern	3.89%	13.30%	3.04%	4.18%	13.57%	4.36%	11.67%
Eastern	3.67%	4.17%	3.70%	2.37%	7.90%	8.71%	5.97%
Average	*7.81%*	*6.84%*	*6.55%*	*3.67%*	*16.18%*	*3.33%*	*8.77%*

4.3. Analysis of the returns to scale

In the case of returns to scale analysis, 15 E-type parks are fixed in scale, indicating that they are in the optimal scale. The remaining 45 parks are in the case of increasing returns to scale, indicating that the majority of industrial parks in Taiwan still need to expand their scale, Increasing returns do not mean to increase investment projects, but to increase the economic benefits of output to enhance ecological efficiency.

4.4. Sensitivity analysis

By taking the method of turning off the variables to detect the change of the DEA efficiency value and the influence degree after each extraction variable in the sensitivity analysis was carried out. The results of the study found that the amount of airborne particulate matter in the eco-efficiency was the most significant, with a change rate of -33.38%, and 46 parks were affected by the removal of airborne particulates. The less sensitive ones are electricity consumption (1.39%), site area (-1.35%) and capital (1.3%)

In addition, it was found that some of the E-type parks did not affect the project after the deletion of the investment projects, namely, the new industrial areas of Xinbei, Nanchu, Yongan, Puzi, Yunlin Islands, Yiwu, and Kameyama, which indicated that the park was eco-efficient High Robustness. And the change is more obvious for

the deduction of airborne particles after the Meilun and Fengshan industrial area said the two have a higher ecological efficiency because of its air quality is better advantage.

5. Conclusions and recommendations

In a word, it is practical and objective to evaluate the ecological efficiency of the industrial park through the DEA model. It is suggested that the government should attach importance to the improvement of the ecological efficiency of industrial parks at the same time of industrial development, regularly review the ecological efficiency of industrial parks, and formulate appropriate improvement strategies for each industrial park. Moreover, the development of circular ecological urban and rural need the joint efforts of industrial parks and local governments. It suggested that the local government in the formulation of policies or planning, should consider the ecological efficiency around the industrial parks. While creating high economic benefits, we should also give consideration to environmental protection and local life quality, give Industrial Park support and create innovative atmosphere, so as to enhance the industry's ecological technology. Besides, in addition to saving energy resources, all industrial parks can actively participate in the energy integration plan, enhance their ecological efficiency and make the Industrial Park develop towards sustainable development.

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