The Assessment of Eco-Industrial Parks in Thailand using VIKOR Method

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Abstract

This paper aims to present a performance assessment of Eco-Industrial Parks (EIP) in Thailand using VIKOR method. A performance measurement model consists of five dimension and 23 criteria (KPIs) was used to assess five industrial parks: A1, A2, A3, A4 and A5. Five dimensions involving with EIP performance were physical aspect, economical aspect, environmental aspect, societal aspect and managerial aspect. Performance indicators used as assessment criteria were divided into benefit and cost criteria. All criteria's numerical data were obtained from EIA reports and from industrial parks themselves. By using Opricovic's VIKOR method, it was found that the best eco-industrial park and the runner-ups were industrial park A4, industrial park A3, industrial.park A5, industrial park A2, and industrial park A1, respectively. Then, guidance for improving EIP performance for each industrial park was proposed.

Keywords: Eco-industrial Park, Assessment, MCDM, VIKOR Method

1. Background/ Objectives and Goals

Nowadays, the environment problems such as global warming, pollution, climate change, deforestation, and many more, require global attention and urgent action. Some of them have small impacts but some can cause harmful effects that make everyday life vulnerable to disaster and tragedy. For example, global warming causes the increasing in the average temperature of the Earth's atmosphere which predictively will increase from 3° to 5° c by the year 2100. This change in temperature has global effects on extreme weather consequences such as the increase of the frequency, duration, and intensity of floods, heat waves, droughts, and tornadoes.

For a decade, in industrial sector, several measures have been proposed to provide better solution for those problems. The important one and related to our research is eco-industry development concept (EID) which is a framework for industry to develop while reducing its impacts on the environment. It uses a closed loop production cycle to tackle a broad set of environmental challenges such as soil and water pollution, desertification, species preservation, energy management, by-product synergy, resource efficiency, air quality, etc. (Cohen-Rosenthal, 2003). Many countries have been implementing EID such as America, Canada, Sweden, Denmark, Germany, England, Japan, China, Hong Kong, and Vietnam. However, implementation of this concept in Thailand is still in an early stage. Launched in 2000, the Industrial Estate Authority of Thailand (IEAT) introduced and implemented the eco-concept, which was called the Eco-Industrial Estates Development (EIED). In 2004, some good results of the implementation which were increasing public's awareness, promoting collaboration, and gaining financial benefit were reported in the 2nd International Conference & workshop. However, there still are several issues that need solutions such as lacking of eco-concept knowledge among participating companies in the industrial estate as well as lacking of awareness among staff and public. Then, during 2010-2014 the sustainability development and EIED concept were re-launched and planned which aimed to transform the rest of industrial estates in Thailand to completely achieve eco-indicators by 2019, which the eco-indicators are defined by IEAT to consist of 5 aspects and 22 areas as shown in the following table 1 (Panyathanakul *et al.*, 2012).

Table 1. The IEAT's Eco-indicators with 5 Aspects and 22 Areas (IEAT, 2010)

Aspects	Objectives	Areas
Physical	To achieve a proper landscaping plan and good infrastructure development	• Eco-design • Eco-center
Economical	To achieve growth and sustained economy	• Economy of industries • Growth of local • Economy of community • Marketing • Transportation and logistics
Environmental	To encourage the efficient use of resources	• Water management • Air pollution management • Industrial wastes • Energy • Noise • Health and safety • Environmental monitoring • Industrial process

		• Eco-efficiency
Societal	To encourage the better quality of life of people	• Quality of life of worker • Quality of life of community
Managerial	To establish the systematic management process and continuous improvement	• Collaboration • Improvement of quality of people • Improvement and maintenance of management system

IEAT is not the only one that implementing the EIED; Thailand Ministry of Industry also released the policy of Development Eco-Industrial towns in five provinces including Samut Prakan, Samut Sakorn, Chachoengsao, Rayong, and Prachin Buri. In these five provinces, there are nine involved industrial parks, namely IRPC Rayong, Bagkadi, 304, Sahapat Chonburi, Sahapat Kabin Buri, Sahapat Pachin Buri, Rojana, IPP, Hemaraj Rayong, and Hemaraj Saraburi. The study of this implementation is partially reported in Teeravaraprug and Podcharathitikull (2016). In their work, the Analytical Hierarchy Process (AHP), developed by Saaty (1980), is used to determine the factors for success in Eco-Industrial Town development. The result shows that the most important factor is related to government sector including law, regulations, and supporting on necessary resources. In this paper, we extend their work to present a framework for the performance assessment of EIP. This can help the industry parks to realize their ranks and what need to be done for transforming to EIP. However, stemmed from the lack of efficient central database system, all required numerical data is not available in some industrial parks; hence we selected only five industrial parks which have the most complete necessary data sets to include in our study.

2. Methods

The methods start with defining the assessment matrix parameters which are number of alternatives time number of criteria. There are 5 alternatives and 23 criteria (KPIs) divided into benefit and cost criteria, see Table 2 and Table 3 in appendix. These criteria are obtained from two sources; IEAT's Eco Indicators as well as experts' opinion. However, this data pattern (5 alternatives and 23 criteria) is not suitable for some Multi-criteria decision method (MCDM) method such as Data Envelopment Analysis (DEA) which recommended number of decision criteria should be three times the number of DMUs (alternatives) (Bowlin, 1998). Stemmed from this fact, we select the more suitable VIKOR method which was developed by Opricovic (1998). This method ranks alternatives and determines the compromise solution that is the closet to the "Ideal". Regarding the rapid growth of use of VIKOR among practitioners, more than 200 scholarly papers and conference proceeding have subjected VIKOR as one of the brilliant technique and or combined with other MCDM methods (Yazdani and Graeml, 2014). VIKOR method includes a multi-criteria optimization of complex systems that focuses on ranking and selecting from a set of alternatives among conflicting area. It helps to solve MCDM problems regarding its two advantages; it provides a maximum of the individual regret of the opponent and a minimum of the individual regret of the opponent (Opricovic and Tzeng, 2004). VIKOR method has four steps explained in following section 2.1.

2.1 VIKOR method

Denoted that, m = number of alternatives and n = number of criteria

Step 1. Determine the best f_i^* and the worst f_i^- values for all criterion function

For ith function represents a benefit

$f_i^* = max(f_{ij}),$ i= 1,2,.....,n (1)

$f_i^- = min(f_{ij}),$ i= 1,2,.....,n (2)

For ith function represents a cost

$f_i^* = min(f_{ij}),$ i= 1,2,.....,n (3)

$f_i^- = max(f_{ij}),$ i= 1,2,.....,n (4)

where f_{ij} is the value of the ith function for alternative j.

Step 2. Calculate the value of S_j and R_j

$$S_j = \sum_{i=1}^{n} w_i \left(\frac{f_i^* - f_{ij}}{f_i^* - f_i^-}\right), \qquad (5)$$

$$R_j = max\left[w_i \left(\frac{f_i^* - f_{ij}}{f_i^* - f_i^-}\right)\right], \qquad (6)$$

where S_j and R_j denote the utility measure and regret measure for alternative j, and w_i is the weight of each criteria.

In this research, the weights of relative importance of the criteria are assigned using AHP (Saaty, 1998). The detail of this method is explained step by step as follow.

i. Design weight of relative importance questionnaire.
 In this step, we design the questionnaire using AHP scale (1-9). Then, we conduct an in depth interview with all the experts one by one. The weights of relative importance of the criteria are obtained by conducting pairwise comparison explained in the following step ii.

ii. Construct a pairwise comparison

The relative importance of all criteria is determined by comparing each pair of criteria. The pairwise comparison matrix is obtained. The next step is to check consistency in the comparison, explained as the following step iii.

iii. Check for consistency of comparison

In this step, the consistency of comparison is calculated. If the consistency value is less than 0.1 the degree of consistency is satisfactory, but if the consistency value greater than 0.1; serious inconsistencies may exist. In that case, the comparison has to be readjusted until the condition is met.

Step 3. Calculate the value of S^*, R^*, S^-, and R^-

$$S^* = min(S_j),\ S^- = max(S_j), \quad j= 1,2,...,m \tag{7}$$

$$R^* = min(S_j),\ R^- = max(S_j), \quad j= 1,2,...,m \tag{8}$$

Step 4. Determine the value of Q_j for j= 1,2,...,m

$$Q_j = v\left(\frac{S_j-S^*}{S^--S^*}\right) + (1-v)\left(\frac{R_j-R^*}{R^--R^*}\right), \tag{9}$$

where v is the weight for the strategy of maximum group utility and $(1-v)$ is the weight of the individual regret. Usually $v = 0.5$ and when $v > 0.5$, the index of Q_j will tend to majority agreement and clearly when $v < 0.5$, the index of Q_j will indicate majority negative attitude

Step 5. Rank the alternatives, sorting by the value of *S*, *R*, and *Q* in decreasing order. The results are three ranking lists. Proposed as a compromise solution the alternative $A^{(1)}$, which is the best ranked by the measure *Q* (minimum), if the following two conditions are satisfied.

a. 1st condition: Acceptable advantage. $Q(A^{(2)}) - Q(A^{(1)}) \geq DQ$, where $DQ = 1/(j-1)$ and $A^{(2)}$ is the alternative with second position on the ranking by *Q*;

b. 2nd condition: Acceptable stability in decision-making. The alternative $A^{(1)}$ must also be the best ranked by *S* or/and *R*. This compromise solution is stable within a decision-making process, which could be the strategy of maximum group utility (when $v > 0.5$ is needed), or "by consensus" ($v \approx 0.5$), or with veto ($v < 0.5$).

If one of the conditions is not satisfied, then a set of compromise solutions is proposed, which consists of:

c. Alternative $A^{(1)}$ and $A^{(2)}$ if 2nd condition is not satisfied, or

d. Alternative $A^{(1)}$, $A^{(2)}$,..., $A^{(M)}$ if 1st condition is not satisfied. $A^{(M)}$ is determined by the relation $Q(A^{(M)})$ - $Q(A^{(1)}) < DQ$ for maximum n (the positions of these alternatives are "in closeness") (Cristobal, 2011).

2.2 Numerical Data

As previously mentioned in this research, we select five industry parks denoted A1 to A5. Their numerical data are collected and some criteria which have the same magnitude are deleted from further consideration. Then, the criteria are divided into benefit and cost criteria as shown in Table 2 and Table 3 in appendix respectively. As previously mentioned, these criteria are obtained from experts' opinions who participated in Thailand Ministry of Industry's Eco- Industrial town deployment project and IEAT's eco indictors. All numerical data are obtained from EIA reports and from industrial parks themselves.

3. Result

Implementing VIKOR method, the result of each step is represented as follow:

Step 1. The best f_i^* and the worst f_i^- values for all criterion function are determined using equation (1) to (4), shown in the following table 4.

Table 4: Values of f_i^* and f_i^-

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
f*	50	64.6	4.906	78635	22	96.72	59.02	10.53	27.27	18.42	4	40
f⁻	0	4.9	0.7956	17623	1	60.61	2.63	0	3.64	2.42	3	8.29

Table 4 (cont.): Values of f_i^* and f_i^-

	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22	C23
f*	39.47	53.91	2.63	4	12.92	0.16	0	0	1.04	0	0.3
f⁻	3.28	13.92	0	1	275.97	3.08	5	2.93	1.81	1	1.42

Step 2. The values of S_j and R_j are calculated using equation (5) and (6) and illustrated in the following table 5.

Table 5: Values of S_j and R_j

	S_j	R_j
A1	0.757	0.116
A2	0.571	0.131
A3	0.582	0.102
A4	0.383	0.102
A5	0.443	0.139

The relative importance weights of all the criteria are then calculated using AHP method via "The Expert Choice software", their values are obtained and illustrated in the Table 6 in the appendix. The consistency degree value is 0.07 which smaller than 0.1, therefore the consistency degree is satisfied.

Step 3. The values of S^*, R^*, S^-, and $R^-$are calculated using equation (7) and (8) and illustrated in the following table 7.

Table 7: Values of S^*, R^*, S^-, and R^-

S*	0.382762
S⁻	0.75729
R*	0.101756
R⁻	0.13866

Step 4. The values of Q_j are calculated using equation (9) and the alternatives are ranking as follow:

Table 8: Values of *Q* for different values of v

v	A1	A2	A3	A4	A5
0	0.374	0.797	0.000	0.000	1.000
0.2	0.500	0.738	0.106	0.000	0.832
0.4	0.625	0.679	0.212	0.000	0.664
0.5	0.687	0.650	0.265	0.000	0.580
0.6	0.750	0.620	0.318	0.000	0.496
0.8	0.875	0.561	0.425	0.000	0.328
1	1.000	0.502	0.531	0.000	0.160

From Table 8, for values of v =0.5 (normally used) the 1st condition (step IV, a.); $Q(A^{(3)}) - Q(A^{(4)}) \geq DQ$, and the 2nd condition (step IV, b.) are satisfied. Therefore, the alternative A4 is the best ranked by *Q* as also best ranked by *S* and *R*. To be specific, the best EIP is the industrial park#4 (A4), then industrial park#3(A3), industrial park#5 (A5), industrial park#2 (A2), and the worst is industrial park#1 (A1), respectively.

4. Conclusions

In this section, we present guidance to improve the alternatives' EIP performance based on the top ten criteria with the highest relative important weight score, shown in Table 9. The important weight scores rank descendingly are C12 (Green area in industrial park), C15 (Percentage of companies with green logistics management), C14 (Percentage of companies with green manufacturing processes), C13 (Percentage of Green Building certified companies), C4 (Employment), C5 (No. of knowledge transfer activities to community per year), C20 (Percentage of occupational illnesses and accidents), C19 (No. of environmental issues complained), C22 (No. of severe accidents affected local community), and C23 (Job Turnover rate) respectively.

Table 9: Top Ten Criteria with the Highest Relative Important Weight Score

	Benefit Criteria						**Cost Criteria**			
	C12	C15	C14	C13	C4	C5	C20	C19	C22	C23
A1	13.57	0	13.92*	10.91	39368	1*	2.93*	0	0	1.3
A2	10	0	23.04	3.28*	78635	1*	0.43	0	0	1.42*
A3	30	0	41.27	9.09	35000	1*	0	4	1	0.9
A4	40	0	53.91	11.43	26959	3	0.44	2	0	0.3
A5	8.29*	2.63	52.63	39.47	17623*	22	0.05	5*	1	0.9

Remark: * represent the criteria needed improvement.

To summarize, each alternative can obtain the better EIP performance score by emphasizing in the following aspects:

1) Alternative#1 (A1) should firstly improve in three issues; C14, C5, and C20.
2) Alternative#2 (A2) should firstly improve in three issues; C13, C5, and C23.
3) Alternative#3 (A3) should firstly improve in one issue, C5.
4) Alternative#4 (A4) is the best candidate, as one can see that there are no weak points.
5) Alternative#5 (A5) should firstly improve in three issues; C12, C4, and C19.

5. Acknowledgement

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7. Appendix

Table 2: Benefit KPIs

	Criteria (Unit)	A1	A2	A3	A4	A5
Benefit	C1: Percentage of waste water recycled (%)	0	0	0	30	50
	C2: Percentage of wastes recycled (%)	4.90	38.20	51.37	50.30	64.60
	C3: Percentage of renewable energy used compared to total energy used (%)	1.75	4.91	2.80	4.80	0.80
	C4: Employment (positions)	39,368	78,635	35,000	26,959	17,623
	C5: No. of knowledge transfer activities to community per year	1	1	1	3	22
	C6: Percentage of ISO 9001-certified companies (%)	87.90	96.72	60.61	80.00	92.11
	C7: Percentage of ISO 50001-certified companies (%)	26.06	59.02	45.45	20.00	2.63
	C8: Percentage of ISO 14001-certified companies (%)	0.00	0.00	0.00	0.00	10.53
	C9: Percentage of TIS 18001-certified companies (%)	3.64	8.20	27.27	4.29	5.26
	C10: Percentage of companies conducting 3Rs (%)	2.42	6.56	12.12	5.71	18.42
	C11: No. of PR media and channels within industrial park	3	3	4	3	3
	C12: Percentage of green area in industrial park (%)	13.57	10.00	30.00	40.00	8.29
	C13: Percentage of Green Building certified companies (%)	10.91	3.28	9.09	11.43	39.47
	C14: Percentage of companies with green manufacturing processes (%)	13.92	23.04	41.27	53.91	52.63
	C15: Percentage of companies with green logistics	0	0	0	0	2.63

	management (%)					
	C16: No. of PR media and channels in community	1	1	4	4	4

Table 3: Cost KPIs

	Criteria (Unit)	A1	A2	A3	A4	A5
Cost	C17: Amount of water consumption per sales (m^3)	275.97	25.90	232.27	107.78	12.92
	C18: Amount of industrial waste and leftovers per sales (tons/THB)	3.08	0.16	1.75	0.17	0.76
	C19: No. of environmental issues complained	0	0	4	2	5
	C20: Percentage of occupational illnesses and accidents (%)	2.93	0.43	0.00	0.44	0.05
	C21: Local occurrence of diseases comparing to average national occurrence from 2002-2011 (fold)	1.48	1.04	1.22	1.81	1.36
	C22: No. of severe accidents affected local community	0	0	1	0	1
	C23: Job Turnover rate (%)	1.3	1.42	0.9	0.3	0.9

Table 6: Relative Importance Weight of Each Criterion

Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
Relative Importance Weight (wi)	0.019	0.022	0.030	0.057	0.044	0.004	0.003	0.008	0.005	0.005	0.005	0.139

Table 6(cont.): Relative Importance Weight of Each Criterion

Criteria	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22	C23
Relative Importance Weight (wi)	0.087	0.100	0.102	0.005	0.012	0.018	0.076	0.090	0.038	0.071	0.061