Multicriteria Decision Analysis for Optimizing Site Selection of Electronic and Electricity Equipment Waste Dismantling and Sorting Facility

(Case Study: in Indonesia, using AHP)

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***Abstract*— E-waste management involves the selection of e-waste location of dismantling and sorting facility (DSF). Unfortunately, Indonesia, at present, has no disposal sites. Site selection decision complexity involves a lot of criteria to filter the various alternative locations. As the initial step, the aims of this study is to select the optimal location of DSF in Indonesia using multi-criteria decision analysis. In this case, Analytic Hierarchy Process (AHP) model was applied. Eight criteria were selected to choose the optimal location, e.g. local population (C_1), population served (C_2), percentage of monthly non-food expenditure (C_3), distance from existing e-waste dismantling and sorting facility (C_4), average house per unit (C_5), unemployed population (C_6), financial status of local population (C_7), and distance from the nearest port (C_8). Data of eight criteria then were ranked based on the objective function of each criterion, which were maximizing function (C_1, C_2, C_3, C_4, C_6) and minimize function (C_5, C_7, C_8). The results of those ranking then summed based on the weight resulted from AHP, and finally generated five main alternatives in selecting e-waste DSF. Based on this model, West Java was selected as the optimal location of e-waste DSF. West Java is one of the most populated provinces in Indonesia and located near the capital city of Indonesia.**

Keywords—e-waste; dismantling and sorting facility; optimization; multicriteria decision analysis; AHP

I. Introduction

Electronic and electrical products (e-products) have to be managed and treated carefully once they reach their end-of-life products. The end-of-life e-products (e-waste) often included in hazardous waste due to its toxic materials content [1]. Toxic chemical derived from uncontrolled recycling processes could contaminate the environment [2],[3]. In the other hand, end-of-life e-products have recently received attention as secondary metal sources [4]. Moreover, Song et al. [5] mentioned that e-waste treatment enterprise can generate large economic benefits and its environmental impact can be relatively moderate.

Managing e-products efficiently requires an adequate infrastructure [6]. The e-waste collection center could be established in the level of regional, even in local area where e-waste might be generated in a large amount. The collected e-waste could be transported to the e-waste treatment center. Taking into account the investment costs for the development of a reverse supply chain network, one of the most crucial aspects for any e-waste collective take-back and recycling scheme relates to the required Dismantling and Sorting Facility (DSF). Given that Indonesia has a vast area, it is important to be able to choose the optimal location to build these facilities.

Indonesia, currently has no facility for e-waste handling, particularly in e-waste which came from households. The total estimated accumulation of generated e-waste from households in 2015 and 2025 is about 285,000 and 622,000 tonnes respectively [7]. This estimated amount of e-waste did not include the e-waste generated both from government and business sector. Therefore, the total amount could be actually higher than this estimation. Formal recycling of e-waste using efficient technologies and facilities are rare, therefore electronic wastes are managed through various low-end management alternatives. However, there are industries in Indonesia that recycles electronic equipment that comes from business activities or import. Based MoE and BCRC-SEA [8] survey, e-waste is written as metal scrap to their documents. Waste recycling business potential can be said to be feasible if supported by additional funding mechanism [9].

Selecting an optimal location is a complex task, since it involves various connected problems and conflicting objectives. It involves various connected problems and must achieve objectives that are often in conflict. The decision makers have to be able to justify the choice of criteria involved with due consideration for environment and economic impact which have to be identified. In this case, decision support system could be developed to create a tractable interface between mathematical modeling and policymaking. The decision support system enables the evaluation of sites for the location of e-waste DSF in terms of their combined impact on environmental and economic aspects of alternative locations [6]. The strength of the integrated system approach to waste

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management has underlined and shown the usefulness of DSS in this area [10]. This approach has been applied to municipal solid waste management [11],[12],[13]. A study of DSS application to e-waste management has been done by Achillas et al. [6] using ELECTRE III for optimizing the optimal location of electrical and electronic equipment in Greece.

Some studies of decision making model using AHP were undertaken to solve environmental issues, particularly in solid waste management, such as to choose on waste reduction alternatives [14], to calculate social impacts of sustainable recovery network of end-of-life products design [15], to assess the sustainability of a waste management scenario with energy recovery [16], to assign weightage of each performance indicator for solid waste management [17], and to solve the route optimization problem [18].

Decision-making on the optimal location for DSF development in Indonesia is a very important issue, both for the survival of the investment itself and the efficiency of electronic waste collection schemes. Therefore, as an initial step, this study aims to identify the most optimal location of facilities for the e-waste dismantling and sorting facility in Indonesia using AHP.

II. Methodology

A. Modelling of AHP

To select an optimal alternative location to build e-waste DSF, a method that support decision analysis to evaluate alternatives is needed. Each of these alternatives will have benefit or deficiency, thus making it difficult for deciding the optimal one. Therefore, based on this reason, one of the analyses in accordance with the decision of this problem is the Multi-Criteria Decision Making (MCDM). MCDM is a tool in decision making among several alternatives. Decision-making is done by selecting / formulating attributes, objects, or different purposes. Attributes, object and purpose often referred to as criteria. Criteria is a measure or rules that guides decision-making and built from the basic needs and preferences.

The multi criteria evaluation of the alternative sites (A1, A2, A3,…) for the location of DSF on the attributes was performed as objectively as possible. This study attempted to select the best location of e-waste DSF based on provinces in Indonesia. Indeed, the provinces of Indonesia comprise of different size of area, from the small area to large area. In the case of e-waste dismantling facility, the main concern was to collect e-waste as many as possible, hence, the size of area was assumed not to be influenced by the results since a large area did not mean a large population. Province has been chosen to distinguish the area of Indonesia because most of statistical data were available based on the province.

The process of aggregating attributes into criteria involves a first level of subjectivity. At this level, it is important that criteria and the way they are elaborated are accepted by the various decision makers; such as government, manufacturers, distributors, retailers, and even consumers/communities. However, in this study, the set of criteria (C_1, C_2, C_3,…) was selected according to Achillas et al [6] study and modified based on the available data in Indonesia. A second level of subjectivity, taken into account in a later stage of the approach, deals with preference information that reflects, for example, the relative importance of each criterion. Here, each decision maker has the opportunity to express his/her own view so as to confront the different value systems at stake.

One of the techniques in MCDM is Analytic Hierarchy Process (AHP). AHP is one of the comprehensive decision making models by considering qualitative and quantitative matters. AHP also could consider a system structurally. Saaty [19] mentioned that AHP provided a framework that enabled to make decision effectively of a complex issue.

The principle of AHP is simplification of a complex problem by arranging it in a hierarchy. Then, level of importance of each variable is given by numerical value subjectively about the meaning of the variable relatively to other variable. Marimin [20] stated that based on the various considerations, synthesis to assign a variable which has high priority and has a role to affect the results in the system.

AHP was carried out by these following steps:

1. To establish a hierarchy of the problem. The problems were divided into several levels, e.g. objectives, criteria or sub-criteria, and alternatives;
2. To assess criteria or alternatives. Criteria and alternatives assessed through technique of pairwise comparison using scale from 1 to 9. According to Saaty [21], a scale of 1 to 9 is the best scale in giving opinion.
   Comparison was undertaken based on the policy of decision makers by assessing level of importance one element towards other elements. Pairwise comparison started from the highest-level hierarchy which aimed to choose alternative, for example, A. Then, compared element (i.e. C_1, C_2, and C_3) was taken. To determine the level of importance relative among the element using scale from 1 until 9 according to Table I.

TABLE I. Intensity of Importance

Intensity of importance	Description
1	Both element is equal
3	One element is a little bit more important than other
5	One element is more important than other
7	One element is obviously more important than other
9	One element is absolutely more important than other
2,4,6,8	Values betweeen two values of adjacent comparison

   This assessment was done by decision makers, which have expertise in this field. If an element compared to itself then value of 1 was given. If element i compared with element j, it will get a value. If element j compared to element i it will get the reverse value. In this AHP, alternative assessment could be done by direct method, namely method that used to entry quantitative data. This value usually came from a previous analysis. In this study, quantitative data was used to determine the comparison.
3. Priority determination. For each criterion and alternative, pairwise comparisons were necessary. Relative value

comparisons then were treated to determine the alternative rank of the entire alternatives.

Both qualitative criteria and quantitative criteria could be compared according to the determined value for resulting in weight and priority. Weight or priority was calculated by manipulating matrix or by solving mathematical equation. Considerations for pairwise comparisons to obtain the overall priority were synthesized through the following stages:

a. To square the pairwise results comparison matrices
b. To calculate the total value of each row and then do the normalization matrix.

4. Logical consistency. All the elements were grouped logically and consistently according to a logical criterion. Weighting matrix obtained from the pairwise comparison should relate to the cardinal and ordinal. The relationship can be expressed as follows [22].

Cardinal relation: $a_{ij} \cdot a_{jk} = a_{ik}$

Ordinal relation: If $A_i > A_j$, $A_j > A_k$ then $A_i > A_k$

Logical consistency calculations were carried out according to the following steps:

a. To multiply matrices with corresponding priority;
b. To sum up the results of multiplications per row;
c. The sum of each row was divided by related priority and the results summed;
d. The results of c step were divided by the number of element, λ max was obtained;
e. Consistency Index (CI) = $(\lambda_{max}\text{-n}) / (\text{n-1})$
f. Consistency ratio = CI / RI, where RI is a random index consistency. If the consistency ratio ≤ 0.1, the result of calculation data could be justified.

B. Selected Criteria

In this study, the set of criteria (C_1, C_2, C_3,…) was adapted from Achillas et al (2010) [6] study and modified based on the available data in Indonesia. As mentioned previously, in Indonesia, no official e-waste DSF has been established. Indonesia has 1,904,569 km^2 of land area, with population of 248,514,200 people. In this study, all of 34 provinces will be considered as the potential location of DSF. Since 2013, Indonesia has expanded its province from 27 provinces to 34 provinces, hence, some data are not available yet (such as the price of house, etc.), particularly in North Kalimantan data. The map of provinces in Indonesia can be seen in Fig. 1.

In any study concerning site locations, the most important question is defining criteria to be considered [6]. The criteria used in Achillas et al [6] were selected based on personal interview to all experts on the thematic area under their study and thus very well informed on the current status of e-waste alternative management in Greece. Compared to the Achillas et al. study [6] in Greece, indeed, there are some different conditions in Indonesia, so that a criterion has been omitted and an assumption has been made, but a new criterion has been added. The criterion of 'land connection' was excluded from the criteria because all provinces already have the transportation infrastructure (road). The location of DSF was assumed to be in 10 km from capital of the province, hence, the criterion 'distance from the capital region' also was omitted, because all of the provinces have the same value. In addition, the criterion of 'land value' was reflected on the average house price per unit. In Indonesia, the wealth often represents in the nonfood commodities expenditure so it is assumed that the nonfood expenditure increases, the probability of having e-product(s) also increase and it is more favorable. Therefore, a new criterion has been added, e.g. Percentage of monthly expenditure.

Finally, eight attributes has been chosen to be criteria for selecting the optimal location of DSF. The table of performances of alternatives location on each criterion can be seen in Table II. The criteria chosen are as follows:

a. Local population (C_1) as an estimation for generated e-waste amount (because the quantities of e-waste data were not available for each province. This criterion could also indicate chances for the promotion of DSF's end products to the secondary market (recyclers, exporters, manufacturers, etc.).
b. Population served (C_2) could be regarded as e-waste quantities that can be handled by the DSF.
c. Percentage of monthly expenditure (nonfood commodities) per capita in urban areas (C_3) as an indicator that drives e-waste generation. As this percentage increases, the probability of having e-products also increases.

Fig. 1. Provinces of Indonesia [24]

d. Average house price per unit (C_4) could be considered as the land value that represents the investment cost. Since land value of each province was not officially available, this criterion should fit a figure of investment cost at each province in Indonesia. If the land value is high, the house price will be high as well.

e. Unemployed population (C_5) as an indicator for available workforce. The new DSF should be able to create employment. Moreover, this criterion could indicate social acceptance for the development of an industrial facility.

f. Financial status of local population (C_6) as another indicator for social acceptance of the facility, expressed in term of Gross Domestic Product per capita.

g. Distance from existing DSF (C_7) can represents the competitiveness of existing e-waste collection sites. In Indonesia, there is an unofficial end-of-life electronic equipment treatment site, namely Batam island (Kepulauan Riau Province) which has special authority to import e-products without tax (special bonded zone) and an industry area in East Java Province where some industries have

TABLE II. PERFORMANCES OF THE ALTERNATIVE LOCATION FOR SELECTED CRITERIA

Alternative location	Local population (residents)	Population served (residents)	Percentage of monthly non-food expenditure	Distance from existing DSF (km)	Average house price per unit (IDR)	Unemployed population	Financial status of local population (GDP/capita)	Distance (direct line) from the nearest port (km)
	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
Aceh	4,811,100	18,401,400	40.73%	1138	-	10.30	20,486,200	5.476
North Sumatera	13,590,300	29,501,200	44.62%	688	76,200,000	6.53	26,568,900	21.818
West Sumatera	5,066,500	29,790,600	44.60%	488	75,490,000	6.99	22,208,600	5.381
Riau	6,033,300	27,976,200	46.75%	303	75,760,000	5.50	79,112,700	124.615
Jambi	3,286,100	27,205,500	44.73%	313	75,320,000	4.84	22,404,700	93.846
South Sumatera	7,828,700	24,037,800	45.10%	469	181,500,000	5.00	26,790,900	2.619
Bengkulu	1,814,400	27,242,900	46.80%	606	72,960,000	4.74	13,682,000	13.619
Lampung	7,932,100	84,850,900	45.19%	769	141,830,000	5.85	18,611,500	6.190
Kep. Bangka Belitung	1,315,100	50,671,900	47.74%	453	-	3.70	26,441,400	14.182
Kep. Riau	1,861,400	28,209,700	53.78%	52	73,850,000	6.25	49,644,300	1.476
DKI Jakarta	9,969,900	162,129,700	60.53%	656	333,110,000	9.02	112,141,700	13.810
West Java	45,340,800	151,232,800	48.83%	550	19,770,000	9.22	21,254,600	120.000
Central Java	33,264,300	162,129,700	49.63%	228	154,140,000	6.02	17,140,200	1.647
D.I. Yogyakarta	3,594,900	141,985,600	54.49%	218	72,710,000	3.34	16,227,100	-
East Java	38,363,200	160,489,400	49.81%	73	128,160,000	4.33	26,444,800	10.286
Banten	11,452,500	157,735,600	47.44%	863	134,720,000	9.90	19,003,500	47.667
Bali	4,056,300	66,512,700	55.49%	363	70,740,000	1.79	20,742,900	6.818
West Nusa Tenggara	4,710,800	30,718,800	42.19%	463	91,780,000	5.38	10,796,400	17.273
East Nusa Tenggara	4,954,000	21,191,900	44.40%	1350	78,330,000	3.16	7,249,000	2.409
West Kalimantan	4,641,400	118,021,300	45.40%	631	89,260,000	4.03	16,831,700	1.381
Central Kalimantan	2,384,700	97,285,600	46.71%	669	84,950,000	3.09	24,467,600	2.738
South Kalimantan	3,870,800	112,532,400	45.84%	575	77,080,000	3.79	20,196,900	3.452
East Kalimantan	3,550,600	87,445,700	55.22%	519	77,450,000	8.04	109,664,400	1.429
North Kalimantan					72,660,000	-		
North Sulawesi	2,360,400	22,882,400	49.74%	1838	98,910,000	6.68	20,344,800	40.385
Central Sulawesi	2,785,500	19,424,000	50.53%	1225	61,160,000	4.27	18,709,400	20.545
South Sulawesi	8,342,000	29,564,900	49.47%	888	100,120,000	5.10	19,465,500	3.238
South-East Sulawesi	2,396,700	21,221,500	49.75%	1288	74,340,000	4.46	15,785,700	1.429
Gorontalo	1,098,000	9,811,400	52.38%	1588	69,690,000	4.12	9,563,000	4.048
West Sulawesi	1,234,300	28,550,300	41.58%	963	-	2.33	11,828,900	3.000
Maluku	1,628,400	22,049,800	48.15%	1810	15,480,000	9.75	7,096,800	0.778
North Maluku	1,114,900	12,212,200	44.47%	1905	-	3.86	6,366,700	1.476
West Papua	828,300	6,604,100	48.33%	2524	-	4.62	52,383,900	0.667
Papua	3,032,500	3,032,500	43.80%	3214	148,640,000	3.23	24,729,900	1.262

Source: BPS, 2014 [23]

bonded facilities import tax exemption only for product which will be exported.

h. Distance from the nearest port (C_8) indicates available infrastructure and also determines the transportation cost.

Due to various units applied to the value of each criterion, it is necessary to normalize that value into comparable value between individual criteria. The quantified values of all criteria j for all alternative locations A are normalized in a scale 0 – 100, as follows:

$$N_j(A) = \frac{g_j(A) - g_j^{min}}{g_j^{max} - g_j^{min}} \cdot 100 \qquad (1)$$

where $g_j(A)$ is the value of criterion j for alternative A, g_j^{min} is the minimum value of criterion j, g_j^{max} is the maximum value of criterion j.

III. Results and Discussion

A. *Results of The AHP model*

Decision making on the optimal location for the development of an e-waste DSF in Indonesia constitutes an issue of critical importance, both for the viability of the investment itself and the efficiency of the e-waste collection scheme. Using AHP model, the pairwise comparison can be seen in Table III. The criteria preferences in Table III adapted from Achillas et al (2010) [6] show that criterion C_1 3 times more important than criterion C_3, twice more important than C_4, 4 times more important than C_5, 4 times more important than C_6, twice more important than C_7, and 7 times more important than C_8. Then, this interpretation also could be applied to the other criteria.

TABLE III. Pairwise Comparisons

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
C_1	1	1/2	3	2	4	4	2	7
C_2	2	1	4	2	5	5	3	9
C_3	1/3	1/4	1	1/2	2	2	1/2	3
C_4	1/2	1/2	2	1	3	3	2	5
C_5	1/4	1/5	1/2	1/3	1	1	1/2	2
C_6	1/4	1/5	1/2	1/3	1	1	1/2	2
C_7	1/2	1/3	2	1/2	2	2	1	4
C_8	1/7	1/9	1/3	1/5	1/2	1/2	1/4	1

Elements in each column were divided by the sum of corresponding column then weight of each criterion could be obtained. Based on the pairwise comparison, the weight of each criterion could be obtained (at fourth iteration), e.g. C_1 (20.60%), C_2 (32,40%), C_3 (7.70%), C_4 (15.00%), C_5 (5.50%), C_6 (5.50%), C_7 (10.40%), and C_8 (3.00%). Then, the sum of each column was multiplied by each criterion and resulted in maximum eigen (lambda, at fourth iteration), namely 8.112213. Because the pairwise comparison matrix had 8 order (consisted of 8 criteria), consistency index was obtained as follows:

$$CI = \frac{\lambda - n}{n - 1} = \frac{8.112213 - 8}{8 - 1} = 0.016031 \text{ (fourth iteration)}$$

As for n=8, RI=1.41 (Saaty Table [19]), then:

$$CR = \frac{CI}{RI} = \frac{0.016031}{1.41} = 0.011369 \text{ (fourth iteration)}$$

Meanwhile, Table IV shows the results of iteration. The results of iteration show consistency ratio • 0.1 so it can be inferred that the data calculation was correct. Data of 8 criteria then were ranked based on the objective function of each criterion, which were maximizing function (criterion 1, 2, 3, 4, 6) and minimize function (criterion 5, 7, 8). The results of those ranking then summed based on the weight resulted from AHP, and finally generated five main alternatives in selecting e-waste DSF (see Table IV).

According to the AHP model, the most powerful criteria are criteria Population Served (C_2). It can be seen from the priority vector (see Table IV, 4th iteration). The strongest alternative on each criterion, are: West Java (C_1), Central Java (C_2), Jakarta (C_3), Papua (C_4), Maluku (C_5, C_7, C_8), and Banten (C_6). The most optimal site location for e-waste DSF was West Java Province. West Java Province can be interpreted as results from performance of the alternative West Java, e.g. Served Population (C_2), the position of West Java that is strategic and its surrounding provinces also have significant population that can be served. West Java is also close to DKI Jakarta where capital city is located. It could be inferred that West Java is well developed. Other optimal site locations of e-waste DSF were Central Java, Banten, DKI Jakarta, or East Java. DKI Jakarta performance as alternative site is obviously preferable due to high local population (C_1) and served population (C_2). However, other alternatives such as Central Java and East Java were restricted because of existing e-waste recycling center (for e-waste from business sector and imported *metal scrap*) in East Java.

B. *Comparison to The Previous Study*

AHP is one of the decision-making methods. AHP was used to find ratio scale both discrete pairwise comparison and continuous. To solve the problem in this study, there are some aspects that should be understood, e.g. decomposition, comparative judgment, synthesis of priority, and logical consistency. Using the data adopted from Achillas et al [6], AHP in this research was not based only on intuition but also from secondary data which has reliable information. Compared to their study, this research used AHP instead of ELECTRE III. AHP and ELECTRE III have been widely used to solve multicriteria decision problem mainly in waste management. The main difference between them is that the AHP started from the goal of the decision which then criteria are arisen out related to alternatives being chosen by experts, while ELECTRE III concerns with outranking methods. However, ELECTRE III does have a veto threshold where the outranking could be canceled while AHP does not have this feature. In addition, if the selected criteria has a large number, AHP is not preferable due to time consuming, i.e. to deal with the decision makers. Nevertheless, AHP is the most common approach in multiple stakeholders in multicriteria decision-making in the context of municipal solid waste (MSW) management [25], where e-waste generated from households is a part of MSW. The model in this study could be easily re-simulated if the stakeholders consider different relative importance compared to this study.

TABLE IV. RESULTS OF ITERATION

1st Iteration	CA	Lambda	CI	CI/RI	2nd Iteration	CA	Lambda	CI	CI/RI
0.216	1.075156	8.122896	0.017557	0.012451	0.207	1.031499	8.090632	0.001295	0.009183
0.305	0.942760				0.325	1.004617			
0.082	1.089997				0.076	1.014008			
0.155	1.063181				0.149	1.026410			
0.053	0.973357				0.054	1.001434			
0.053	0.973357				0.054	1.001434			
0.109	1.061539				0.104	1.014709			
0.029	0.943549				0.030	0.996521			
3rd Iteration	**CA**	**Lambda**	**CI**	**CI/RI**	**4th Iteration**	**CA**	**Lambda**	**CI**	**CI/RI**
0.206	1.025154	8.112401	0.016057	0.011388	0.206	1.025220	8.112213	0.016031	0.011369
0.324	1.002331				0.324	1.002352			
0.077	1.020299				0.077	1.020256			
0.150	1.030090				0.150	1.030042			
0.055	1.008522				0.055	1.008462			
0.055	1.008522				0.055	1.008462			
0.104	1.015407				0.104	1.015389			
0.030	1.002076				0.030	1.002031			

IV. CONCLUSIONS

According to the AHP model, the optimal location of e-waste DSF in Indonesia was West Java Province. Existing e-waste treatment facility has made the alternative location East Java Province has been avoided. The AHP method is very useful to create decision that often conflicting each other such as the attributes that each alternative location has. However, in the further research it is recommended to specify the available area where the e-waste DSF could be located (considering the legal approach) so that the distance could be measured accurately.

REFERENCES

[1] E. Dimitrakakis, A. Janz, B. Bilitewski, and E. Gidarakos, “Small WEEE: determining recyclables and hazardous substances in plastics,” J. Hazard. Mater., vol. 161, pp. 913–919, 2009.

[2] A. Leung, Z. W. Cai, and M. H. Wong, “Environmental contamination from electronic waste recycling at Guiyu, southeast China,” J. Mater. Cycles Waste Manag., vol. 8, pp. 21–33, 2006.

[3] M.H. Wong, S.C. Wu, W.J. Deng, X.Z. Yu, Q. Luo, A.O.W. Leung, C.S.C. Wong, W.J. Luksemburg, and A.S. Wong, “Export of toxic chemicals e A review of the case of uncontrolled electronic-waste recycling,” Environ. Pollut., vol. 149, pp. 131-140, 2007.

[4] M. Oguchi, S. Murakami, H. Sakanakura, A. Kida, and T. Kameya, “A preliminary categorization of end-of-life electrical and electronic equipment as secondary metal resources,” Waste Manage., vol. 31, pp. 2150–2160, 2011.

[5] Q. Song, Z. Wang, J. Li, and H. Duan, “Sustainability evaluation of an e-waste treatment enterprise based on emergy analysis in China,” Ecol. Eng., vol. 42, pp. 223-231, 2012.

[6] Ch. Achillas, Ch. Vlachokostas, N. Moussiopoulos, and G. Banias, 2010, “Decision support system for the optimal location of electrical and electronic waste treatment plants: A case study in Greece,” Waste Manage.t, vol. 30, pp. 870–879, 2010.

[7] P. Andarani and N. Goto, “Potential e-waste generated from households in Indonesia using material flow analysis,” J. Mater. Cycles Waste Manage., vol. 16, pp. 306-320, 2014.

[8] Ministry of Environment and Basel Convention Regional Centre), Preliminary Inventory of E-waste in Indonesia., 2007.

[9] P. Andarani and N. Goto. “Preliminary Assessment of Economic Feasibility for Establishing Dismantling and Sorting Facility of Household’s E-waste in Serang, Indonesia,” Proceedings of Annual Meeting of Environmental Science Association, pp. 56-60, 2012.

[10] P. Haastrup, V. Maniezzo, M. Mattarelli, F. M. Rinaldi, I. Mendes, and M. Paruccini, “A decision support system for urban waste management,” Eur. J. Oper. Res., vol. 109, pp. 330-341, 1998.

[11] P. Fiorucci, R. Minciardi, M. Robba, and R. Sacile, “Solid waste management in urban areas Development and application of a decision support system,” Resour. Conserv. Recy., vol. 37, pp. 301-328, 2003.

[12] P. Costi, R. Minciardi, M. Robbaa, M. Rovatti, and R. Sacilea, “An environmentally sustainable decision model for urban solid waste management,” Waste Manag., vol. 24, pp. 277–295, 2004.

[13] R. Minciardi, M. Paolucci, M. Robba, and R.Sacile, “Multi-objective optimization of solid waste flows:Environmentally sustainable strategies for municipalities,” Waste Manag., vol. 28, pp. 2202–2212, 2008.

[14] K. Lai, L. Li, S. Mutti, R. Staring, M. J. Umali, and S. Pagsuyoin, “Evaluation of waste reduction and diversion as alternatives to landfill disposal,” Proceeding of 2014 IEEE Systems and Information Engineering Design Symposium, SIEDS 2014, pp. 183-187, April 2014.

[15] F. Dehghanian and S. Mansour, “Designing sustainable recovery network of end-of-life products using genetic algorithm,” Resour. Conserv. Recy., vol. 53, pp. 559-570, 2009.

[16] B. Milutinović, G. Stefanović, M. Dassisti, D. Marković, G. Vučković, “Multi-criteria analysis as a tool for sustainability assessment of a waste management model,” Energy, vol. 74, pp. 190-201, 2014.

[17] H. Parekh, K. Yadav, S. Yadav, N. Shah, “Identification and assigning weight of indicator influencing performance of municipal solid waste management using AHP,” KSCE J. Civ. Eng., in press.

[18] J. A. Ferreira, M. Costa, A. Tereso, J. A. Oliveira, “A multi-criteria decision support system for a routing problem in waste collection,” 8th International Conference on Evolutionary Multi-Criterion Optimization, EMO 2015, vol. 9019, pp. 388-402, March 29th-April 1st 2015.

[19] T.L. Saaty, “Decision Making with Dependence and Feedback, The Analytical Network Process,” University of Pittsburgh, 2001.

[20] Marimin,”Teknik dan Aplikasi Pengambilan Keputusan Kriteria Majemuk”, Grasindo, Jakarta, 2004.

[21] T.L. Saaty, “Multi Criteria Decision Making, The Analytical Hierarchy Process”, British Library Cataloguing in Publication Data, United States of America, 1998.

[22] K. Suryadi and M.A. Ramdhani, “Sistem Pendukung Keputusan,” PT Remaja Rosdakarya, 1998.

[23] BPS, Statistical Pocketbook of Indonesia, 2014.

[24] M.W. Lewis, “North Kalimantan: Indonesia’s Newest Province and Southeast Asian Geopolitical Tensions,” GeoCurrents, 2013.

[25] A. Soltani, K. Hewage, B. Reza, R. Sadiq, “Multiple stakeholders in multi-criteria decision-aking in the context of Municipal Solid Waste Management: A review,” Waste Manage., vol. 35, pp. 318-328, 2015.