Strategy for minimizing risk of electronic waste management using the Analytical Hierarchy Process (AHP)

D Rimantho¹, E Noor², Eriyatno³ and H Effendi²

¹Management of Natural Resources and the Environment-Bogor Agricultural University, Bogor, (16144) Indonesia
²Department of Agricultural Technology Industry, Bogor Agricultural University, Bogor, (16144), Indonesia
³Research Center for Agriculture and Village, Bogor Agricultural University, Bogor, (16144), Indonesia

erlizanoo@yahoo.com

Abstract. Electronic waste management is one problem that has the potential to pose a risk to the environment and human health. The strategy to minimize the impact level on e-waste management has been extensively carried out in almost all countries. This paper aims to analyse strategies for minimizing the risk of e-waste management. The AHP method was used in this study. The assessment used a paired comparison questionnaire by five experts such as academics, governments and NGO. Studies show the first priority strategy is improving regulation and monitoring with a weight around 0.493. In addition, the sub-criteria chosen by experts are legal compliance with a weight of approximately 0.629 and the criteria that are the top priority are regulations with a weight of around 0.525. The assessment by experts also shows the value of the consistency ratio of around 0.07. This research can be a strategy by policy makers to manage sustainable e-waste. It is considered necessary to conduct further research related to other criteria and sub-criteria that may be different in the management of e-waste in other regions.

1. Introduction
E-waste management is one of the problems of pollution throughout the world. The emergence of new technology has encouraged electronic equipment to be discontinued and ended up in landfill. This has the potential to pose a risk to the environment. The problem of e-waste management in developing countries is triggered by the import of electronic waste and used electronic products from developed countries. The study conducted by Hicks et al. shows that about 80% of e-waste from developed countries is sent to developing countries [1].

Potential risks not only arise from the volume of waste but also the content of toxic chemicals in e-waste. Some researchers point to the presence of organic metals including polychlorinated of biphenyls (PCBs) released by e-waste [2]. There are two ways to impact exposure to e-waste from electronic waste disposal. First, through the food chain caused by the contamination of toxic compounds in the recycling process that produces by-products and enters the food chain. Second, direct exposure to workers who carry out e-waste recycling activities. Research related to direct exposure to recycling activities has attracted the attention of researchers because of the toxicity of e-waste on human health. This also encourages other problems [3], [4].
The strategy to minimize the impact level on e-waste management has been extensively carried out in almost all countries. Several methods have been developed and began to be applied to waste management such as Life Cycle Analysis (LCA), Material Flow Analysis (MFA), Multi Criteria Analysis (MCA) and Extended Producer Responsibility (EPR). Studies show that e-waste management in industrialized countries has taken better steps by making directives for waste electronics and electricity products. The expected target of this direction is to reduce waste disposal and improve environmental quality [5].

E-waste management policy must be based on the risk in order to produce decisions that have priority, qualified and can be applied by the stakeholders. Risk management has an important role in protecting environmental safety and human health. Risk management provides the authority of the government to share its management with stakeholders, communities and institutions that are partners. The main purpose of risk management is to create, protect, and increase shareholder value by managing uncertainties that affect the achievement of company goals. The factor that determines the success of these directives is decision making.

One method that is widely used in decision making is Multi Criteria Decision Making (MCDM). The complexity of the problems and the importance of decisions forces researchers and practitioners in the environmental field to use analytical decision-making tools. Kiker et al. applied the AHP method to environmental management decision making [6]. In addition, the application of the AHP method can also be a solution to solving solid waste management problems [7]. Application of the AHP method to find options for processing food waste in Japan [8]. The AHP method also used to analyse environmental risks in Iran [9]. The application of multi-criteria decision making methods in the management of solid waste [10].

The wide application of the AHP method proves that AHP is a credible decision-making tool. AHP can handle complicated decision making in almost all fields. AHP as a tool for decision making in risk management is only widely used in inventory risk management and project management. The lack of studies in risk management motivates this research to explore whether AHP can be used as a decision-making tool in electronic waste management risk management.

2. Methodology
DKI Jakarta province was chosen for a case study for the management of e-waste because DKI Jakarta is considered as one of the big cities that represent other cities in Indonesia. DKI Jakarta Province also has e-waste management problems. In this paper, a framework for integrating various criteria into the management strategy decision-making process is presented. In general, decision making considers criteria such as technology, social, regulatory, recycling and financial. The criteria and sub-criteria involved in making decisions on e-waste management strategies are given in Table 1. The assessment used a paired comparison questionnaire by five experts such as academics, governments and NGO.

Analytic Hierarchy Process (AHP) is one of the MCDM methods developed by Thomas L. Saaty. This is the Eigen value approach for pair-wise comparison. This method is to obtain a ratio scale from paired comparisons to quantitative and qualitative performance measurements. The application of AHP to complex problems usually follows the following stages [11], [12]:

Stage 1: Determine the problem and detail the desired solution.
Stage 2: Develop a hierarchical structure based on setting goals, criteria, sub-criteria, and alternatives.
Step 3: Create a matching matrix after the problem hierarchy structure. The purpose of pairing comparisons is to get the value of relative importance on each criterion and sub-criterion. Assessment is carried out by experts by providing numerical values 1-9 as in Table 1
Stage 4: Synthesize data in paired matrices to get priority for each hierarchy criterion and sub-criteria.
Table 1. Criteria and sub criteria for e-waste management decision-making strategies

| Criteria    | Sub criteria                                | Criteria    | Sub criteria                                |
|-------------|---------------------------------------------|-------------|---------------------------------------------|
| Technology  | Lack of technical infrastructure            | Social      | Lack of community participation             |
|             | Lack of safety tool                         |             | Regional vulnerability                       |
|             | Disposal sites not yet available            |             | Social conflict                             |
|             | Technology manual/traditional               |             |                                             |
|             | Number of technology                        | Regulation  | Lack of compliance                          |
| Recycling   | Recycling locations are not centralized     |             | Policy conflict                             |
|             | Inadequate facilities                       |             | Lack of political support                   |
|             | Skills and competencies of workers are low  |             | Inappropriate management of data            |
|             | The working methods are not appropriate     |             |                                             |
| Financial   | High recycling cost                         |             |                                             |
|             | Price competition                           |             |                                             |
|             | System funding                              |             |                                             |

Stage 5: Perform priority consistency tests that have been obtained
Stage 6: Repeat the steps above for each level of the hierarchy
Stage 7: Use hierarchical composition to weigh priority vectors with weighting criteria and add all priority values that have been weighed with priority values from the next lower level and so on. The result is a comprehensive priority vector for the lowest hierarchy level

3. Result and Discussion

The decision hierarchy is used as a framework for the decision making process. First, hierarchical arrangements are presented to decision makers. This is done to ensure that decisions can be made and know the relationship of each factor or criterion. Second, decision makers are asked to complete three phases of the Hierarchy Analysis Process (AHP), in other words; give weights for objectives, criteria, sub criteria and alternatives.

Figure 1. Structure of the hierarchy of strategies for minimizing the risk of electronic waste management

The process of determining factors or criteria, sub criteria and alternatives is obtained by conducting interviews with 5 experts. This is based on the consideration that the determination of the electronic waste management strategy in DKI Jakarta can be adopted for the implementation of e-waste management in other regions in Indonesia. Based on Table 1, the hierarchical structure can be arranged in Figure 1. Based on the hierarchical structure, a pair of respondents will be evaluated in pairs, where
there are five respondents used in this study. The results of the assessment of paired comparisons for criteria are as follows:

**Table 2. Results of a paired comparison assessment of the criteria**

| Criteria    | Technology | Regulation | Social | Financial | Recycling |
|-------------|------------|------------|--------|-----------|-----------|
| Technology  | 4.5144     | 3.3227     | 3.3658 | 3.1036    |            |
| Regulation  |            | 5.7294     | 4.8286 | 4.8286    | 3.3227    |
| Social      |            |            | 1.2457 |            | 3.0000    |
| Financial   |            |            |        |            |           |
| Recycling   |            |            |        |            |           |

Based on the results of paired comparisons, we can obtain the weight values for each of the criteria shown in Table 3.

**Table 3. Weight and ranking on criteria**

| No | Criteria       | Weight | Ranking | Consistency Ratio |
|----|----------------|--------|---------|-------------------|
| 1  | Technology     | 0.218  | 2       |                   |
| 2  | Regulation     | 0.525  | 1       | 0.07              |
| 3  | Social         | 0.058  | 5       |                   |
| 4  | Recycling      | 0.067  | 4       |                   |
| 5  | Financial      | 0.132  | 3       |                   |

From the calculation results, information is obtained that the regulatory criteria are the choice of experts with the greatest weight, approximately 0.525 and placing it as the first rank in e-waste management. In addition, the results of the pairwise comparison comparisons of the five criteria have also met the requirements with a consistency ratio around 0.07 and this has met the provisions of the CR value set by Saaty of <0.1.

Based on the assessment of pairwise comparisons conducted by the five respondents, information was obtained that the sub-criteria obtained the highest value on the legal compliance sub-criteria with a weight approximately 0.629 in first place. All sub-criteria show that expert pairwise comparisons show good consistency with values between 0.02 - 0.09 and have met the CR <0.1 value of Saaty.

**Table 4. Pairwise comparison assessment on sub-criteria**

| No | Sub-criteria                                          | Weight | Ranking | Consistency Ratio |
|----|-------------------------------------------------------|--------|---------|-------------------|
| 1  | Technology traditional/manual                        | 0.501  | 5       | 0.09              |
| 2  | Lack of safety tool                                  | 0.090  | 17      |                   |
| 3  | Lack of technical infrastructure                      | 0.149  | 14      |                   |
| 4  | Number of technology                                  | 0.203  | 9       |                   |
| 5  | Disposal sites not yet available                      | 0.056  | 19      |                   |
| 6  | Lack of compliance                                   | 0.629  | 1       | 0.02              |
| 7  | Lack of political support                            | 0.090  | 18      |                   |
| 8  | Policy conflict                                       | 0.173  | 12      |                   |
| 9  | Inappropriate management of data                      | 0.108  | 16      |                   |
| 10 | Lack of community participation                      | 0.572  | 3       | 0.03              |
| 11 | Social conflict                                       | 0.158  | 13      |                   |
| 12 | Regional vulnerability                                | 0.270  | 6       |                   |
| 13 | Skills and competencies of workers are low            | 0.589  | 2       | 0.06              |
| 14 | Inadequate facilities                                | 0.185  | 11      |                   |
| 15 | Inappropriate working methods                         | 0.128  | 15      |                   |
| 16 | Recycling locations are not centralized               | 0.185  | 10      |                   |
| 17 | High recycling cost                                  | 0.546  | 4       | 0.08              |
| 18 | Price competition                                    | 0.211  | 8       |                   |
| 19 | System funding                                       | 0.244  | 7       |                   |
After determining the value of criteria and sub-criteria, the next step is to determine the comparison of alternative pairs that will become an electronic waste management program. There are several alternative solutions that can be carried out such as cooperation between stakeholders, data collection of waste, improvement of community awareness development, development of technological innovation, development of business partnerships and improvement of regulation and monitoring.

The strategy for minimizing the risk of e-waste management is important that controlling electronic waste and recycling promotion in DKI Jakarta is caused by the potential for an increased risk of decreasing environmental quality and human health. At present a large amount of e-waste has not been handled optimally by the DKI Jakarta regional government and in practice the role of the informal sector shows a higher role in terms of e-waste management from households. However, the implementation that took place in the informal sector still leaves problems mainly related to the potential for environmental pollution. Thus, there is an urgent need to determine alternative strategies in efforts to manage e-waste that are more environmentally friendly.

Table 5. The results of pairwise comparison comparisons on alternatives

| No | Alternative                                      | Weight | Ranking |
|----|-------------------------------------------------|--------|---------|
| 1  | Cooperation between stakeholder                 | 0.045  | 6       |
| 2  | Data management of waste                        | 0.050  | 5       |
| 3  | Increasing public awareness                     | 0.196  | 2       |
| 4  | Development of technology innovation            | 0.118  | 3       |
| 5  | Development of business partnership              | 0.098  | 4       |
| 6  | Improved regulation and monitoring              | 0.493  | 1       |

Table 5 provides information related to alternative solutions that can be used in e-waste management in DKI Jakarta. From the results of comparative assessments paired by experts and after analysis, it can be seen that alternative improvements in regulation and monitoring are alternatives with the best weight, which is equal to 0.493 and this is the first ranking alternative that can be done.

In the regulatory criteria the results of expert evaluations show a value around 52.5% and the highest alternative regulation and monitoring improvement around 49.3%, increased legal awareness and compliance 19.6%, 11.8% development of technological innovation, 11.4% business partnership development, 9.8% increase in community participation development and data collection 5% waste potential. If the technology criteria increase by around 10%, this will affect other criteria. However, this increase did not have a significant impact on the main alternative strategies, such as improving regulation and monitoring. Likewise, the changes to other criteria will not change the alternative strategy.

Figure 2. Analysis of sensitivity of electronic waste management

Increasing the use of electronic products and their relationship to waste disposal is important in the regulator agenda. Many countries around the world under the pressure of environmental activists have enacted laws to address the problem of waste disposal. Retrieving products based on the Extended
Producer Responsibility (EPR) is one of the most popular types of regulation. The basic idea behind EPR is to ask producers to be physically and financially responsible for the environmental impacts of products that are produced after the life of the product ends [13]. This regulation has been applied to many industries, from automotive to packaging, and batteries for electrical and electronic waste (e-waste). For example, the guidelines for waste electrical and electronic equipment (Directive 2003/108 / EC) are applied in European Union countries [5]. Moreover, in Japan the household appliance recycling law began in 2001. In addition, as many as 22 states in the United States also provide responsibility for managing electronic waste to producers.

The e-waste management policy in DKI Jakarta is formulated by taking into account the current conditions and potential of waste, the results of the analysis of the rate of electronic waste generation, electronic waste material flow, risk analysis and expert opinion. The policy and strategy formulation system can be carried out in a participatory manner. The current condition in DKI Jakarta that has not been optimal in managing e-waste shows the existence of several risk factors that have the potential to produce a high risk of failure in the management of e-waste. This is reasonable because in the electronic waste management process consists of several risk factors of failure such as technology, social, regulatory or legal, recycling and financial which have the potential causes of the risk of failure of electronic waste management. Therefore, in the end it will be able to influence the decline in environmental quality and human health.

In the perspective of legal principles related to the management of electronic waste in DKI Jakarta, among others are:

- a. Presidential Decree 61/1993 concerning the Ratification of the Basel Convention.
- b. Presidential Regulation 47/2005 concerning Ratification of Amendment Tires
- c. Law Number 32 of 2009 concerning Environmental Management
- d. PP Number 18/1999 jo PP Number 85/1999 concerning Hazardous Waste Management
- e. PP Number 101/2014 concerning B3 Waste Management
- f. Law Number 18 of 2008 concerning Waste Management
- g. DKI Jakarta Regional Regulation No. 3 of 2013 concerning Waste Management
- h. DKI Jakarta Governor Regulation No. 284 of 2016 concerning the Organization and Work Procedure of the DKI Jakarta Provincial Environment Agency

In addition, in Government Regulation Number 18/1999 jo PP No. 85/1999 concerning B3 Waste Management is mentioned in detail as follows:

- a. B3 waste from specific sources (Appendix I, Table 2 "List of Specific Hazardous Waste from Source" D219 Waste Code: Electronic Components / Electronic Equipment)
- b. Pollution Sources: Manufacturing and Assembly; Waste Water Management
- c. Origin / Description of Waste: sludge remaining process; coated glass (CRT tube); used solvents; painting waste; solder residues and fluxes (PCB, IC, cable); plastic casing
- d. Other wastes outside the hazardous waste category can be organic or inorganic

The expected objectives of the existing arrangements in the regulations or regulations mentioned above are instruments for managing the environment at each stage of the business or activity. Where in its implementation consists of several activities such as planning and utilization, control, maintenance and supervision. For example, in the context of planning and utilization consists of inventory of natural resources, management planning and environmental control and ecoregion determination. Meanwhile the control activities consist of strategic environmental studies, spatial planning, environmental quality standards, hazardous waste management.

Waste minimization activities can be improved through policy considerations by the regional government. For example, the government can use the EPR principle to encourage producers to be responsible for the products produced. Policies related to management processes such as collection, storage, recycling and disposal of electronic waste need to be improved. This can be achieved by integrating together the collection methods by the informal sector and the recycling process by the
formal sector. Various actions can be used as alternative solutions to increase public awareness and actors associated with the e-waste management process. In the business sector both the informal sector and the formal implementation of legal awareness can also be carried out in order to reduce the occurrence of violations. Programs that can be offered include providing regular training for recycling electronic waste actors, making licenses that strictly regulate the process of managing and processing e-waste.

Policies on monitoring and evaluation on procedures for managing that is still very weak both from the informal sector and the formal sector need to get the attention of legal decision makers. Existing policies indicate the need to monitor and evaluate the process regularly. It also need to create or develop a national system or organization that monitors and evaluates the performance of the management process. Through the national information system, it can provide information related to management activities such as the organization or institution responsible, the name and address of the company or business unit, the type of waste managed, the capacity of the waste managed and others. Thus, every process in management can be monitored and evaluated by the procedure.

4. Conclusion

E-waste management is one of the obstacles of pollution throughout the world. The emergence of new technology has encouraged electronic equipment to be discontinued and ended up in landfill. This has the potential to pose a risk to the environment. The results showed that the strategy that could be used as a program to reduce the impact of risk from e-waste management was the improvement of regulation and monitoring with a weight around 0.493 based on the highest sub-criteria for compliance with law weighing approximately 0.629 and regulatory criteria weighing around 0.525. Improvement regulations and monitoring need to be carried out immediately considering the monitoring and evaluation policies regarding management procedures are still very weak both from the informal sector and the formal sector. Existing policies indicate the need to monitor and evaluate processes regularly. It is also necessary to create or develop a national system or organization that monitors and evaluates management process performance. Generally, the results of pairwise comparisons show a good value of consistency ratio because it is still below 10%. The results of this study can be applied by decision makers and replicated in other regions. This research can also be a driving factor in further research related to the evaluation and implications of electronic waste management policies.

References

[1] Hicks C, Dietmar R and Eugster M 2005 Environ. Impact. Asses. 25 459–71.
[2] Robinson B H 2009 Sci. Total. Environ. 408 183–91.
[3] Eguchi A, Nomiyama K, Devanathan G, Subramanian A, Bulbule K A and Parthasarathy P et al 2012 Environ. Int. 47 8–16.
[4] Asante K A, Agusa T, Biney C A, Agyekum W A, Bello M and Otsuka M et al 2012 Sci. Total. Environ. 424 63–73.
[5] EU, 2002 Directive 2002/96/EC of the European parliament and of the council of 27 January 2003 on waste electrical and electronic equipment (WEEE). In: Official Journal of the European Union (Ed.), L037:0024–39.
[6] Kiker G A, Bridges T S, Varghese A, Seager T P and Linkovij I 2005 Integr. Environ. Assess. 1 95–108.
[7] Abd Manaf, Basri H and Basri N E A 2008 Journal of Sustainable Development. 1
[8] Babalola M A 2015 Environment. 2 471–88.
[9] Rezaian S and Jozi S A 2011 2nd Int. Conf. on Environmental Engineering and Applications (Singapore: IACSIT Press).
[10] Coelho L M G, Lange L C and Coelho H M G 2017 Waste. Manage. Res. 35 3–28.
[11] Saaty T L 2000 Fundamentals of decision making and priority theory 2nd Edition (Pittsburg: RWS Publication).
[12] Saaty T L and Vargas L G K 2012 Models, methods, concepts & Applications of the analytic hierarchy process. New York: Springer Science & Business Media. Available at: https://doi.org/10.1007/978-1-4614-3597-6

[13] Lindqvist T 2000 Extended Producer Responsibility in Cleaner Production. The International Institute for Industrial Environmental Economics (IIIEE) (PhD thesis, Lund, Sweden, Lund University).