AN INTEGRATED FUZZY METHODOLOGY FOR WASTE OF ELECTRICAL AND ELECTRONIC EQUIPMENT (WEEE) MANAGEMENT SYSTEM

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ABSTRACT

Because the resources of the world are already limited for the next periods, we have to produce, consume then produce and use again the one consumed. Thus the waste management which could be defined as recovery of used products is becoming very critical. The tools selected to evaluate alternative scenarios are an important part of the waste management models. Most waste management models consider economic and environmental aspects, but very few consider social aspects. For a waste management system to be sustainable, it needs to be environmentally effective, technologically reliable, economically affordable and socially acceptable. This study provides a multi-criteria decision making tool integrating Fuzzy AHP and Fuzzy ANP to select the best scenarios for WEEE management. An illustrative application is also provided. The presented methodological framework provides to DMs an easy-to-use tool that could be employed either by producers of EEE or governments. The methodology has been successfully implemented for EEE case. However, the procedure could be easily adopted (with slight modifications) in order to solve similar problems in other environmental management fields, since waste management of certain waste streams is considered as significant environmental issue throughout the world.

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1 INTRODUCTION

The production of electrical and electronic equipment (EEE) is one of the fastest growing global manufacturing activities. This development has resulted in an increase of waste of electrical and electronic equipment (WEEE). Rapid economic growth, coupled with urbanization and growing demand for consumer goods, has increased both the consumption of EEE and the production of WEEE, which can be a source of hazardous wastes that pose a risk to the environment and to sustainable economic growth.

To face potential environmental problems that could stem from improper management of WEEE, many countries and organizations have drafted national legislation to improve the reuse, recycling and other forms of material recovery from WEEE to reduce the amount and types of materials disposed in landfills.

WEEE constitutes one of the most complicated solid waste streams in terms of its composition, and, as a result, it is difficult to be effectively managed. The selection of a technologically reliable, environmentally friendly, economically affordable and socially acceptable management scenario for WEEE is a significant question. The use of multiple attribute decision making (MADM) methods in WEEE management has the advantage of rendering subjective and implicit decision making more objective and transparent. The aim of this study is to provide an analytical tool to select the best WEEE management scenario.

Analytic Hierarchical Process (AHP) is an analytical tool which can be used to handle a MADM problem. However, a shortfall of AHP is that it lacks in considering interdependencies, if any, among the selection criteria. Analytic Network Process (ANP) is a similar technique, but can capture the interdependencies between the criteria under consideration, hence allowing for a more systematic analysis. It can allow inclusion of criteria, both tangible and intangible (difficult to quantify), which has some bearing on making the best decision. Further, many of these criteria have some level of interdependency among them, thus making ANP modeling better fit for the problem under study.

However, the ANP based decision model seems to be ineffective in dealing with the inherent fuzziness or uncertainty in judgment during the pairwise comparison process. Although the use of the discrete scale of 1-9 to represent the verbal judgment in pairwise comparisons has the advantage of simplicity, it does not take into account the uncertainty associated with the mapping of one’s perception or judgment to a number. In real-life decision-making situation, the decision makers or stakeholders could be uncertain about their own level of preference, due to incomplete information or knowledge, complexity and uncertainty within the decision environment. They also tend to specify preferences in the form of natural language expressions which are most often vague and uncertain. Such conditions may occur when evaluating WEEE management scenarios. For this reason, in this study, the usage of the fuzzy version of ANP is proposed to make a multiple attribute selection among WEEE management scenarios. In the proposed methodology, the decision makers’ opinions on the relative importance of the selection criteria are determined by a fuzzy AHP procedure. To do this, Zeng et al.’s [1] method was modified to follow a similar way to classical AHP. The aim of this paper is to provide a multi-criteria decision making tool to select the best scenario. Firstly, fuzzy AHP is used to determine the relative importance of the selection criteria. And then, with a fuzzy version of ANP, different WEEE management systems are evaluated. An illustrative application is also presented. The rest of the study is organized as follows: Section 2 represents the definition and the recovery process of WEEE. Section 3 presents the management of WEEE. Section 4 describes fuzzy set theory. Section 5 analyzes the fuzzy decision making methodologies employed in this study for the evaluation of alternative WEEE management scenarios. Section 6 presents the application of the proposed method to Turkey’s WEEE management problem. Finally, conclusions are provided in Section 7.
2 WASTE OF ELECTRICAL AND ELECTRONIC EQUIPMENT (WEEE)

WEEE is one of the priority streams in waste management because of its major challenges. It has in fact become an issue of concern to solid waste management professionals. Challenges faced by WEEE management are not only consequences of growing quantities of waste but also the complexity of WEEE. As a result of the variety of product models, size changes, compatibility issues, etc., the recovery of WEEE is very challenging [2]. Recycling of WEEE is important not only to reduce the amount of waste requiring treatment, but also to promote the recovery of valuable materials [3].

A broad range of goods are classified as EEE, including large and small household appliances; information and technology (IT) equipments including computers, computer games and peripherals; mobile phones and other telecommunication equipments; portable electronic devices such as portable digital assistants (PDAs), video and audio equipment, including MP3 players and peripherals; and electrical tools [3]. Once these products reach the end of their useful life, they become e-waste or WEEE. EEE has been defined as any equipment that is dependent on electric currents or electromagnetic fields in order to work properly, including equipment for the generation, transfer, and measurement of current. In response to the increasing volumes of WEEE and their potential environmental impacts through various disposal routes, the EC has published a proposal in 2002 for Directives on Waste from Electrical and Electronic Equipment.

2.1 Characteristics of WEEE

Waste of electrical and electronic equipment is non-homogeneous and complex in terms of materials and components. In order to develop a cost-effective, socially acceptable and environmentally friendly recycling system, it is important to identify and quantify valuable materials and hazardous substances of this waste stream [4]. Waste of electrical and electronic equipment is a complex material containing various fractions. The various elements present in WEEE are shown in Figure 1. It is estimated that about 66% of WEEE by weight consists of metals such as iron, copper, aluminum and gold and nonmetals, with other pollutants making up about 34% of the waste. Ferrous metal is the most common material found in electric and electronic components [3].

![Figure 1: Materials Found In Electronic Equipment](image)

The main economic driving force for the recycling of electronic scrap is the recovery of precious metals. However, the content of precious metals in WEEE is steadily decreasing. According to the U.S. General Accounting Office (GAO) (November 2005), “computers
contain precious metals, such as gold, silver, and platinum, which require substantial amounts of energy and land to extract [6]. These metals can often be extracted with less environmental impact from used electronics than from the environment. Wireless phones also contain a number of toxic materials, such as lead and brominated flame retardants, which are released into the environment when they are disposed of in a landfill or incinerator [6].

WEEE consists of a large number of components of various sizes and shapes, some of which contain hazardous components that need be removed for separate treatment. With these hazardous elements, WEEE can cause serious environmental problems during disposal if not properly pretreated. For example, the cadmium from one mobile phone battery is sufficient to pollute 600,000 lt. of water [7]. Televisions (TVs) and video and computer monitors use cathode ray-tubes (CRTs), which have significant amounts of lead. CRTs were used in all television sets until the late twentieth century. Because of the x-ray hazard in TVs, the glass envelopes of most modern CRTs are made from heavily leaded glass. The lead in this glass may represent an environmental hazard, especially in the presence of acid rain leaching through landfills. Finally, most indirectly-heated vacuum tubes (including CRTs) use various highly reactive materials to enhance their cathode emissions and performance of their getter assemblies. Printed circuit boards contain primarily plastic and copper, and most have small amounts of chromium, lead solder, nickel, and zinc. Relays and switches in electronics, especially older ones, may contain mercury [6].

2.2 Treatment Options of WEEE

WEEE recycling is in its infancy, and consumer recognition of the need for recycling is a critical factor in the further expansion of this industry. More than 90% of WEEE is landfilled, and a large fraction of WEEE from households ends up in waste incinerators. Many consumers do not immediately discard or recycle unused electronics, since they think that they retain value. More than 70% of retired EEEs are kept in storage for 3-5 years [7]. However, with the rapid development of electronic technologies, the residual value of outdated electronic devices decreases rapidly; both the recovery value of parts and the machine resale value drop rapidly as machines and devices age. Recycling of WEEE is an important step of the end-of life strategies for WEEE treatment. The maximization of valuable material recovery and the consequent minimization of disposal rely on the technologies used in the process. With the steadily decrease of the precious metal contents in EEE, the precious metal oriented recovery techniques, such as hydrometallurgy and pyrometallurgy, are facing great challenges.

3 WASTE MANAGEMENT MODELS

The tools selected to evaluate alternative scenarios are an important part of the waste management models. The type of tool selected also depends on the decision being made and on the decision-makers [8]. In some cases, the goal of the model is simple, (to optimize waste collection routes for vehicles), while in others, it is more complex (to evaluate alternative waste management scenarios). Most waste management models consider economic and environmental aspects, but very few consider social aspects. For a waste management system to be sustainable, it needs to be environmentally effective, economically affordable and socially acceptable. Rogers [9] groups models into two categories: those that use optimizing methods and those that use compromising methods. While Rogers’s categorization is centred around engineering project appraisal, it can be applied to waste management models as well. Optimizing models assume that the different objectives of the proposal can be expressed in a common denominator or scale of measurement, whereby the loss in one objective can be directly evaluated against a gain in another. Optimization models include cost benefit analysis and present worth evaluation with the common scale of measurement usually expressed in monetary
terms. In contrast, compromising methods assume that the decision maker may have limited knowledge regarding the decision situation.

Numerous applications in the literature have shown that the use of MCDM is a suitable method for making decisions in the area of waste management. Multiple criteria methods can be applied to any complex decision and can consider criteria such as risk, economics, safety, etc. Some recent MCDM studies in the field of WEEE are given in Table 1.

### Table 1: WEEE Management Studies Using MCDM Methods

<table>
<thead>
<tr>
<th>Year</th>
<th>Authors</th>
<th>Article Title</th>
<th>Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>Ravi et al. [10]</td>
<td>Analysing alternatives in reverse logistics for EOL computers: ANP and balanced scorecard approach</td>
<td>ANP and BSC</td>
</tr>
<tr>
<td>2008</td>
<td>Queiruga et al. [12]</td>
<td>Evaluation of sites for location of WEEE recycling plants in Spain</td>
<td>PROMETHEE</td>
</tr>
<tr>
<td>2009</td>
<td>Achillas et al. [13]</td>
<td>Decision support system for the optimal location of electrical and electronic waste treatment plants. A case study in Greece</td>
<td>ELECTRE III</td>
</tr>
</tbody>
</table>

## 4 FUZZY SETS AND FUZZY NUMBERS

To deal with vagueness of human thought, Zadeh [15] first introduced the fuzzy set theory, which was based on the rationality of uncertainty due to imprecision or vagueness. A major contribution of fuzzy set theory is its capability of representing vague knowledge. The theory also allows mathematical operators and programming to apply to the fuzzy domain.

A fuzzy number is a normal and convex fuzzy set with membership function $\mu_A(x)$which both satisfies normality: $\mu_A(x) = 1$, for at least one $x \in R$ and convexity: $\mu_A(x') \geq \mu_A(x_1) \land \mu_A(x_2)$, where $\mu_A(x) \in [0,1]$ and $\forall x' \in [x_1, x_2]$ ‘$\land$’ stands for the minimization operator. A fuzzy number is a special fuzzy subset of the real numbers. A trapezoidal fuzzy number (TFN) is shown in Fig. 2. The membership function of an TFN, $\tilde{V}$, is defined by

$$\mu(x|\tilde{V}) = \left( m_1, f_1(y|\tilde{V}) / m_2, m_3 / f_2(y|\tilde{V}), m_4 \right),$$

where $m_1 < m_2 < m_3 < m_4$, $f_1(y|\tilde{V})$ is a continuous monotone increasing function of $y$ for $0 \leq y \leq 1$ with $f_1(0|\tilde{V}) = m_1$ and $f_1(1|\tilde{V}) = m_2$ and $f_2(y|\tilde{V})$ is continuous monotone decreasing function of $y$ for $0 \leq y \leq 1$ with $f_2(1|\tilde{V}) = m_3$ and $f_2(0|\tilde{V}) = m_4$. $\mu(x|\tilde{V})$ is denoted simply as $(m_1 / m_2, m_3 / m_4)$. 

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The membership function of a TFN is given by Eq. (2)

\[
\mu(x) = \begin{cases} 
0, & x < m_1, \\
\frac{x - m_1}{m_2 - m_1}, & m_1 \leq x \leq m_2, \\
1, & m_2 \leq x \leq m_3, \\
\frac{m_4 - x}{m_4 - m_3}, & m_3 \leq x \leq m_4, \\
0, & x > m_4.
\end{cases}
\]

One of the most basic concepts of fuzzy set theory which can be used to generalize crisp mathematical concepts to fuzzy sets is the extension principle. Let \( X \) be a Cartesian product of universes \( X = X_1, \ldots, X_r \), and \( \tilde{A}_1, \ldots, \tilde{A}_r \) be \( r \) fuzzy sets in \( X_1, \ldots, X_r \), respectively. \( f \) is a mapping from \( X \) to universe \( Y \), \( y = f(x_1, \ldots, x_r) \). Then the extension principle allows us to define a fuzzy set \( \tilde{B} \) in \( Y \) by.

\[
\tilde{B} = \left\{ (y, \mu_{\tilde{B}}(y)) \mid y = f(x_1, \ldots, x_r), (x_1, \ldots, x_r) \in X \right\}
\]

where

\[
\mu_{\tilde{B}}(y) = \begin{cases} 
\sup_{(x_1, \ldots, x_r) \in f^{-1}(y)} \min \left\{ \mu_{\tilde{A}_1}(x_1), \ldots, \mu_{\tilde{A}_r}(x_r) \in X \right\}, & \text{if } f^{-1}(y) \neq \emptyset, \\
0, & \text{otherwise},
\end{cases}
\]

where \( f^{-1} \) is the inverse of \( f \).
5 Fuzzy Analytic Hierarchy Process and Fuzzy Analytic Network Process

There are many fuzzy AHP methods proposed by various authors. These methods are systematic approaches to the alternative selection and justification problem by using the concepts of the fuzzy set theory and hierarchical structure analysis. Decision makers usually find that it is more confident to give interval judgments than fixed value judgments. This is because usually he/she is unable to explicit about his/her preferences due to the fuzzy nature of the comparison process. We partially use Zeng et al.’s [1] approach to obtain the weights from pairwise comparison matrices. But, a shortfall of AHP is that it lacks in considering interdependencies, if any, among the selection criteria. Analytic Network Process (ANP) is a similar technique, but can capture the interdependencies between the criteria under consideration, hence allowing for a more systemic analysis. It can allow inclusion of criteria, both tangible and intangible, which has some bearing on making the best decision [16]. Further, many of these factors have some level of interdependency among them, thus making ANP modeling better fit for the problem under study. Fuzzy ANP method adapts the subjectivity of human judgement as being expressed in natural language. The proposed method includes simplified fuzzy operations and similar steps to classical AHP. In this method, fuzzy aggregation is used to create group decisions, and then defuzzification is employed to transform the fuzzy scales into crisp scales for the computation of priority weights. The group preference of each factor is then calculated by applying fuzzy aggregation operators, i.e. fuzzy multiplication and addition operators. So a final step is integrated to fuzzy AHP method.

Here are the steps of the methodology.

Step 1: Compare factors using pairwise comparisons. The experts are required to provide their judgments on the basis of their knowledge and expertise for each factor at the hierarchy. The experts can provide a precise numerical value, a range of numerical values, a linguistic term or a fuzzy number.

Step 2: Convert preferences into standardized trapezoidal fuzzy numbers (STFNs). Because the values of factors provided by experts are crisp numbers, range of numerical values, linguistic terms or fuzzy numbers, STFNs are employed to convert these experts’ judgments into a universal format for the composition of group preferences.

Step 3: Aggregate individual STFNs into group STFNs. The aggregation of STFN scales is defined as;

\[
\tilde{a}_{ij} = \tilde{a}_{ij1} \otimes \tilde{a}_{ij2} \otimes \ldots \otimes \tilde{a}_{ijm}
\]  (5)

Where \( \otimes \) denotes the fuzzy multiplication operator and \( c_1, c_2, \ldots, c_m \) are contribution factors (CFs) allocated to experts, \( E_1, E_2, \ldots, E_m \) and \( c_1 + c_2 + \ldots + c_m = 1 \). \( \tilde{a}_{ij1} \) is the aggregated fuzzy scale of \( F_i \) comparing to \( F_j \); \( i, j = 1, 2, \ldots, n ; \tilde{a}_{ij1}, \tilde{a}_{ij2}, \ldots, \tilde{a}_{ijm} \) are the corresponding STFN scales of \( F_i \) comparing to \( F_j \) measured by experts \( E_1, E_2, \ldots, E_m \), respectively.

Step 4: Defuzzify the STFN scales. In order to convert the aggregated STFN scales into matching crisp values that can adequately represent the group preferences, a proper defuzzification is needed. Assume an aggregated STFN scale \( \tilde{a}_{ij} = (a_{ij}^l, a_{ij}^m, a_{ij}^u) \), the matching crisp value \( a_{ij} \) can be obtained;

\[
a_{ij} = \frac{a_{ij}^l + 2(a_{ij}^m + a_{ij}^u) + a_{ij}^u}{6}
\]  (6)
where \( a_{ii} = 1, a_{jj} = 1/a_{ij} \).

Consequently, all the aggregated fuzzy scales \( a_{ij} = (i, j = 1, 2, \ldots, n) \) are transferred into crisp scales \( a_{ij} \) within the range of \([0, 9]\).

Let \( F_1, F_2, \ldots, F_n \) be a set of factors in one section, \( a_{ij} \) is the defuzzified scale representing the quantified judgment on \( F_i \) comparing to \( F_j \). Pairwise comparisons between \( F_i \) and \( F_j \) in the same section thus yields a \( n \)-by- \( n \) matrix defined as follows:

\[
A = a_{ij} = \begin{bmatrix}
F_1 & F_2 & \cdots & F_n \\
1 & a_{12} & \cdots & a_{1n} \\
\vdots & \vdots & \ddots & \vdots \\
F_n & 1/a_{1n} & 1/a_{2n} & \cdots & 1
\end{bmatrix}, \quad i, j = 1, 2, \ldots, n
\]

(7)

where \( a_{ii} = 1, a_{jj} = 1/a_{ij} \).

Step 5: The network structure was established by using the Super Decisions software. Normalized weight vector values were entered manually to Super Decisions. This program limits the weighted supermatrix by raising it to a large power \( k \) (where \( k \) is an arbitrarily large number) until it converges into a stable supermatrix. Limit supermatrix shows the importance weights of factors.

6 APPLICATION

6.1 Problem Definition

One of the fastest growing wastes in the world is the waste of electrical and electronic equipment (WEEE). In Europe, for per inhabitant 14 kg WEEE arises annually. This makes 5 million tons of WEEE in Europe. 90 percent of this WEEE is land filled, incinerated or tried to be recovered without pretreatment. With the WEEE directive, instead of disposal and landfill, EC wants to add value to the WEEE by reusing, recycling and recovering with other options on an environmental basis. A case study of WEEE management scenario evaluation is presented to demonstrate the application of the proposed fuzzy ANP methodology. Fuzzy ANP is used to determine the most appropriate WEEE management scenario. Super Decisions software package is used for the ANP computations.

6.2 Solution of the Problem

The decision problem is firstly structured into its important components. The relevant criteria and alternatives are chosen on the basis of the review of literature and discussions with both from industry and academia. The relevant criteria and alternatives are structured in the form of a network. The alternative scenarios for WEEE management are determined as;

(A1) Scenario 1 - Extended producers responsibility: Local authorities collect electrical and electronic equipments at the end of their useful life and private de-manufacturers recycle the collected equipment. In this scenario with the establishment of contemporary recycling plants one can yield full material recovery including plastics. Producers of EEE will finance the recovery of WEEE according to their market share. However, new products purchased will include a user fee for their proper management after the end of their useful life.
(A2) Scenario 2 - Municipal scenario: The municipalities are responsible for the proper management of WEEE. Collected equipment is taken to recycling facilities where partial disassembly and shredding take place. In this scenario most of the WEEE will be disposed or incinerated after pretreatment for the hazardous substances and only metal is recycled. Citizens pay for the proper disposal through an increase in taxation.

(A3) Scenario 3 - Take-Back Scenario: OEMs are responsible to manage their own products at the end of their useful life. The customers give back an obsolete appliance while they purchase a new one of the same type. They pay a deposit when buying the product, which is refunded when they dispose the product to an authorized de-manufacturer/recycler.

The next step is to determine the evaluation criteria. In order to proceed with the successful application of multiple attribute analysis, it is essential to determine and examine an adequate number of criteria that will give a representative and complete picture of alternative scenarios that are investigated. The purpose is to find a comprehensive, operational, non-redundant and minimal set of criteria that would represent various objectives. So after determining the objectives preliminary as economic, technical, environmental and socio-political we determined the evaluation criteria from the literature. The performance dimensions and related criteria and sample references about the criteria are listed in Table 2.

Table 2: WEEE Management Scenario Evaluation Criteria

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Criteria</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economic</td>
<td>Availability of Funds (Ec1)</td>
<td>[17]</td>
</tr>
<tr>
<td></td>
<td>Benefits from Recycling (Ec2)</td>
<td>[18]</td>
</tr>
<tr>
<td></td>
<td>Cost of Operations and Maintenance (Ec3)</td>
<td>[11]</td>
</tr>
<tr>
<td></td>
<td>Implementation Cost (Ec4)</td>
<td>[19]</td>
</tr>
<tr>
<td>Technological</td>
<td>Continuity and Predictability (T1)</td>
<td>[20]</td>
</tr>
<tr>
<td></td>
<td>Technical Feasibility (T2)</td>
<td>[21]</td>
</tr>
<tr>
<td></td>
<td>Technical Reliability (T3)</td>
<td>[11]</td>
</tr>
<tr>
<td></td>
<td>Local Technical Know-How (T4)</td>
<td>[17]</td>
</tr>
<tr>
<td></td>
<td>Technical Flexibility (T5)</td>
<td>[11]</td>
</tr>
<tr>
<td>Environmental</td>
<td>Air Emission (En1)</td>
<td>[11]</td>
</tr>
<tr>
<td></td>
<td>Noise Pollution (En2)</td>
<td>[11]</td>
</tr>
<tr>
<td></td>
<td>Generation of Hazardous Waste (En3)</td>
<td>[18]</td>
</tr>
<tr>
<td></td>
<td>Generation of Solid Waste (En3)</td>
<td>[18]</td>
</tr>
<tr>
<td></td>
<td>Waste Recovery (En5)</td>
<td>[22]</td>
</tr>
<tr>
<td>Socio-Political</td>
<td>Compatibility with Legislative and Administrative Situation (Sp1)</td>
<td>[11]</td>
</tr>
<tr>
<td></td>
<td>Political Acceptance (Sp2)</td>
<td>[17]</td>
</tr>
<tr>
<td></td>
<td>Social Acceptance(Sp3)</td>
<td>[17]</td>
</tr>
</tbody>
</table>
After determining the evaluation criteria and the alternatives, the steps of the modified fuzzy ANP algorithm are executed. The first step in any ANP approach is the development of a network decision framework. Super Decisions software package is used for the ANP computations. Figure 3 gives the network structure of the model built using Super Decisions software. And the schematic representation of the relationship among sub-criteria is presented in Figure 4.

Figure 3: Network Structure Of The WEEE Management Scenario Evaluation Problem
Figure 4: Graphical Representation Of Inter-Cluster Influences (Outer Dependencies)

As mentioned before Super Decisions software package is used for the ANP computations. “Super Decisions” program does not have a solution in terms of fuzzy logic. For this reason, the fuzzy data are defuzzified before inputting them into Super Decisions. An interdisciplinary decision group composed of four experts is formed. Each expert provides a decision about his/her judgment as a precise numerical value, a possible range of numerical value, a linguistic term, or a fuzzy number. Then these evaluations are converted into STFNs and aggregated STFNs are defuzzified. A scoring system is shown in Table 3.

Table 3: Fuzzy Evaluation Scale

<table>
<thead>
<tr>
<th>Linguistic terms</th>
<th>Fuzzy scale</th>
<th>Fuzzy reciprocal scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equal (E)</td>
<td>(1,1,1)</td>
<td>Equal (E)</td>
</tr>
<tr>
<td>Slightly Strong (SS)</td>
<td>(1,1,3)</td>
<td>Slightly Weak (SW)</td>
</tr>
<tr>
<td>Fairly Strong (FS)</td>
<td>(1,3,5)</td>
<td>Fairly Weak (FW)</td>
</tr>
<tr>
<td>Very Strong (VS)</td>
<td>(3,5,7)</td>
<td>Very Weak (VW)</td>
</tr>
<tr>
<td>Absolutely Strong (AS)</td>
<td>(5,7,9)</td>
<td>Absolutely Weak (AW)</td>
</tr>
</tbody>
</table>

The pairwise comparisons of alternatives with respect to “benefits from recycling” and corresponding STFNs are shown in Table 4.

Table 4: Pairwise Comparison Of Alternatives With Respect To Benefit From Recycling

<table>
<thead>
<tr>
<th></th>
<th>A1 Score</th>
<th>STFNs</th>
<th>A2 Score</th>
<th>STFNs</th>
<th>A3 Score</th>
<th>STFNs</th>
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<tbody>
<tr>
<td>A1</td>
<td></td>
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<td>E1</td>
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<td>E2</td>
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<td>E3</td>
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<td>E4</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Aggregation</td>
<td>1.000</td>
<td></td>
<td>1.86, 2.06, 2.28, 3.22</td>
<td>3.16, 4.79, 5.01, 6.34</td>
<td>4.850</td>
<td></td>
</tr>
<tr>
<td>Defuzzyified V.</td>
<td>2.294</td>
<td></td>
<td></td>
<td></td>
<td>4.850</td>
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<tr>
<td>A2</td>
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<td>E1</td>
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<td>E2</td>
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<td>Aggregation</td>
<td>1.000</td>
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<td>1.32, 2.28, 2.45, 4.16</td>
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<td>2.489</td>
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<td>Defuzzyified V.</td>
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<td>A3</td>
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<td>E1</td>
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<td>E2</td>
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<td>Aggregation</td>
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<td>1.000</td>
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</tbody>
</table>

The aggregation of STFN scales can be calculated by Equation. (5). For example, the STFN scale of comparing Alternative A1 with Alternative A2 can be aggregated by

\[ a_{12^+} = (1,1,3,0.25) \otimes (3,3,3,3) \otimes (2,2,3,3,0.25) \otimes (2,3,3,4,0.25) \]

\[ = (1.86,2.06,2.28,3.22,4.16) \]

By using Equation (6), the STFN scale of comparing alternative A1 with alternative A2 can be defuzzified as
\[ a_{ij} = (1.861 + 2 \times (2.060 + 2.280) + 3.224) / 6 = 2.294 \]

After the above calculations were completed for all the cases, these defuzzified values are entered into the ANP model using the interface provided by Super Decisions package and the ranking of the alternatives are obtained.

7 CONCLUSIONS

In this study we have selected the best WEEE management scenario using a MADM method. In order to get the best result in analysis it is necessary to work with more than one expert and use the right analysis tools. Due to the uncertainty of information and the vagueness of human feeling and recognition, it is difficult to provide exact numerical values for the criteria and to make evaluations which exactly convey the feeling and recognition of objects for decision makers. Therefore, most of the selection parameters cannot be given precisely. For this reason, in this study, the usage of the fuzzy version of ANP has been proposed to make a multiple attribute selection among WEEE management scenarios.

The presented methodological framework provides DMs' with an easy-to-use tool that could be employed either by producers of EEE or governments. The procedure could be easily adopted (with slight modifications) in order to solve similar problems in other countries, since waste management of certain waste streams is considered as significant environmental issue for many countries.

After scoring the scenarios, according to the results from the implementation of the fuzzy ANP methodology, the ranking of the scenarios is derived. Hence, the overall best scenario is the one of “Extended Producer Responsibility”, described earlier.

For further research, we suggest that other multiple criteria methods to be used and compared with those results. The proposed methodological approach is also not limited only to support the specific decision; it can be also used for the evaluation of management scenarios and strategies in other environmental sectors (management of hazardous waste, used oils, used tires, etc.).

ACKNOWLEDGEMENT

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8 REFERENCES


