Turkish J. Eng. Env. Sci.
34 (2010) , 145 – 154.

doi:10.3906/muh-0906-47

Choosing a recycling system using ANP and ELECTRE III techniques

Müfide BANAR[1], Aysun ÖZKAN[1], Alev KULAÇ[2]
[1] *Anadolu University, Faculty of Engineering & Architecture,*
Department of Environmental Engineering, 26555 Eskişehir, TURKEY
e-mail: mbanar@anadolu.edu.tr, aysunozkan@anadolu.edu.tr
[2] *Eskişehir Tepebaşı Municipality, Köprübaşı, Eskişehir-TURKEY*
e-mail: alevkulac@yahoo.com

Received 24.06.2009

Abstract

The process of coordinating with the European Union forced the Turkish government to set up new obligations and an environmental policy for Turkey. The new regulations are more obligatory and have more district lines than the preceding policies. According to the new regulations, municipalities have to prepare packaging waste management plans. In this manner, choosing a packaging waste management system appears to be an important decision making problem. Hence, economic, social, cultural, and technical factors in choosing packaging waste management systems should be considered together. A system may have several criteria to be evaluated and different alternatives to be chosen. Due to the structure of this type of problem, it is considered as a multicriteria decision making problem. Taking this fact into consideration, within the scope of the present study, which it is hoped will provide alternatives for decision makers, 5 recycling scenarios were presented concerning the composition of municipal solid waste in Eskişehir. Consequently, these scenarios were evaluated according to their benefits, costs, and risk factors, using analytic network process (ANP) and ELECTRE III techniques. The results of both techniques were compared. Scenario 3a [10% curbside collection (commingled recyclables) + 5% recycling containers + 5% material recovery facility] was determined to be the most appropriate recycling system with both techniques.

Key Words: ANP, ELECTRE III, Multicriteria decision making, Recycling, Solid waste

Introduction

Waste management can be a complex and interdisciplinary problem that considers the technical, social, and economic factors for recycling and sustainable development. The policies and legislations of the member states of the European Union (EU) related to waste management are required to be feasible, in terms of being transparent, sustainable, technical, and economical (EU, 2005, 2008). The EU national waste management plans include promoting the prevention, safe recovery, and final disposal of waste (Tanskanen and Melanen, 1999). In accordance with EU directives, the competent authorities of member states and candidate countries should outline a national waste management plan, which must take into account the data on waste, the current state of waste management, the development targets, and the procedures required to achieve those targets.

The need for credible and scientific information for more knowledgeable waste management judgments has accelerated the development of a decision support tool for municipal solid waste (MSW). Often, decision makers (DMs) are faced with complex and deficient information that might have major economic and environmental implications (Thorneloe et al., 2007). In Turkey, more than 24.2 million metric tons of MSW was generated in 2004 and a large budget was spent on its management (Ministry of Environment and Forestry of Turkey, 2006). Finding more efficient alternatives might help to reduce the cost and environmental burdens.

Taking the waste management policy of the EU into consideration and aiming to establish a sustainable recycling system for Eskişehir, Turkey, some alternatives were offered in the present study, and the most appropriate of those alternatives were examined with ANP and ELECTRE III, 2 of the common multicriteria decision making (MCDM) methods.

Choosing the best alternative among a finite number of alternatives according to the given criteria is the focus of MCDM, which is a developing research area (Vincke, 1992). There are several methods used to solve MCDM problems, such as goal programming, ANP, PROMETHEE, TOPSIS, and ELECTRE (I, II, III, IV, TRI) (Figueira et al., 2005). Although these methods have been used in several disciplines, as well as in environmental engineering, ELECTRE and ANP were chosen to be used in this study. ELECTRE III is one of the multiobjective ranking methods based on outranking relations. Indifference, weak preference, strong preference, and incomparability are used for the extended model of the DM's local preferences in ELECTRE III (Zak, 2005). ANP, another MCDM method, is based on the utility function that aggregates different criteria (points of view) into one global criterion. The difference between ANP and ELECTRE is incomparability among the alternatives; specifically, ANP eliminates incomparability between alternatives, while ELECTRE III takes it into account. Hence, ELECTRE III and ANP were considered in this study because of their different viewpoints.

ANP and ELECTRE III were used to choose the most suitable recycling program for Eskişehir in this study. In this context, this study is the first and only such research conducted in the city, and in all of Turkey. Considering the waste characteristics of Eskişehir, 5 scenarios and 17 criteria for those scenarios were developed and then evaluated with ANP and ELECTRE III. Super Decisions Software was used for ANP, and Microsoft Excel and VBA were used for ELECTRE III. Finally, the obtained results are compared and interpreted.

The ELECTRE III and ANP Methods

ELECTRE III, developed by Bernard Roy in 1968, was built based on outranking relations for modeling the DM's preferences. The method is based on a pairwise comparison that establishes the degree of dominance or the outranking of alternatives (Rogers and Bruen, 2000). The outranking relation in ELECTRE III is a fuzzy (imprecise and uncertain) binary relation (Roy, 1991). ELECTRE III allows 3 phenomena to be taken into account, which are imprecision, uncertainty, and indetermination (Takeda, 2001).

For more details on the calculation of the discordance matrix and the distillation procedure, the studies of Tam et al. (2003), Hokkanen and Salminen (1997), and Rogers and Bruen (2000) can be examined.

ANP is the general form of the analytic hierarchy process (AHP) and expresses the relationships between components like networks, by describing the directions of the components. AHP is a method that obtains the relative significance of decision alternatives by pairwise comparisons in multicriteria decision problems. In this structure, the indirect interactions between the components and the feedbacks are considered. In ANP processes, the alternatives are ranked from the most important to the least important, by the DM's judgments.

In addition, ANP results involve a numerical ratio for each alternative. The basic ANP structure is only one network. The most complex consists of benefit, opportunity, cost, and risk, which may have different significance degrees according to the problem (Saaty, 2001).

ELECTRE III and ANP are also used for environmental decision making problems such as, for example, choosing a solid waste management system (Hokkanen and Salminen, 1997; Karagiannidis and Moussiopoulos, 1997; Khan and Faisal, 2008; Tseng, 2009) or locating waste treatment plants (Norese, 2006; Banar et al., 2007).

Municipal Solid Waste Management in Eskişehir

Eskişehir is located in the northwest of the Central Anatolia region of Turkey. The city has an area of 13,652 km^2 and a population of 669,440, according to the census of 2009 (TÜİK, 2010). The MSW quantity in Eskişehir was 750 ton/day in 2008, with percentages of the components given in Table 1 (Banar and Özkan, 2008).

Table 1. MSW characterization for Eskişehir city (Banar and Özkan, 2008).

Components	% (weight)
Paper/cardboard	10.07
Metal	1.26
Glass	2.49
Plastic	5.62
Food waste	67.06
Ash	3.86
Miscellaneous	9.64

As of recently, Eskişehir municipal solid wastes are deposited in an unregulated dumping site, which is the property of the Metropolitan Municipality of Eskişehir. The vehicles of the 2 private companies that are employed by the 2 submunicipalities have been employed for collecting municipal wastes. The wastes are transported to the site and dumped there at all hours of the day in an unregulated way. This unregulated dumping site is an open area, where the wastes are partially classified and recycled under unhygienic conditions. The dumping site receives household wastes, some industrial wastes, and healthcare wastes. Waste has been dumped in an unregulated fashion on the surface of the natural valley since 1986, and about 2.5 million m^3 of MSW have been held in reserve there (Documents of Metropolitan Municipality of Eskişehir, 2003).

Recyclable household waste (i.e. mostly packaging waste) was a major focus of this study. Recovery of plastics, papers, glasses, and metals from MSW is mostly conducted, as indicated above, by the scrap dealers and individual collectors, such as scavengers. These individual collectors and scrap dealers purchase the packaging waste (mostly paper and cardboard) from commercial units, markets, and business centers, and reprocess (sort and bale) these materials to sell directly to the industrial recycling facilities. In addition, scavenging and collection from the waste bins is a widespread activity. Since this type of collection and recovery process is a part of the "unregistered" economic activity, it is difficult to specify figures reflecting actual collection and recovery.

Methodology

In the present study, concerning the MSW characteristics of Eskişehir, 5 scenarios and 17 criteria were developed, and those scenarios were evaluated along with the criteria by using ANP and ELECTRE III.

Table 2. The criteria and their explanations.

Criteria no.	Name of criteria	Unit ascending order (for ELECTRE)	Explanations
Benefit Cluster (for ANP)			
g1	Employment	Score (1-9) Increasing	New employment areas from all systems.
g2	Aesthetics	Score (1-9) Increasing	Aesthetic pollution due to wastes, birds, and trucks.
g3	Waste quality	Score (1-9) Increasing	Quality of recyclable wastes.
g4	Time	Score (1-9) Decreasing	Minimum completion time of processes for DMs.
g5	Revenues	$/year Increasing	Revenue of recyclable material.
Cost Cluster (for ANP)			
g6	Equipment and vehicle costs	$ Decreasing	Costs of recycling containers and vehicles.
g7	Personnel costs	$/year Decreasing	Costs of personnel in transportation and separation.
g8	Maintenance costs	$/year Decreasing	Maintenance costs of containers, equipment in separation plant, and transportation vehicles.
g9	Public reactions (PR) costs	Score (1-9) Decreasing	PR studies required for recycling program efficiency.
Risk Cluster (for ANP)			
g10	Public access issues	Score (1-9) Decreasing	Public participation required for sustainability of project.
g11	Hygiene	Score (1-9) Increasing	Hygienic conditions for human and environmental health.
g12	Scavengers	Score (1-9) Decreasing	Risks for waste quality, human and environment health, and aesthetics.
g13	Vector impacts	Score (1-9) Decreasing	Wandering animals and insects.
g14	Traffic density	Score (1-9) Decreasing	Traffic density of vehicles used for transportation.
g15	Accident	Score (1-9) Decreasing	Risks of work and traffic accident.
g16	Pollution potential	Score (1-9) Decreasing	Air pollution from collection operations and processing facilities, particularly curbside recycling programs and exhaust emissions to the atmosphere from vehicles.
g17	Fire	Score (1-9) Decreasing	Fire risk of waste reserved in containers and separation building.

The scenarios were created according to the MSW composition shown in Table 1. In this case, 5 different recycling programs were defined by DMs as scenarios including 20% packaging wastes. Municipal authorities (waste collectors, officials from the office in charge, etc.) and academic staff were considered as DMs in this study.

The scenarios were as follows:

Scenario 1a: [15% curbside collection (commingled recyclables) + 5% material recovery facility]

Scenario 1b: [15% curbside collection (the source is separated into 4 subgroups, paper, metal, plastic, and glass) + 5% material recovery facility]

Scenario 2: [15% recycling containers + 5% material recovery facility]

Table 3. Calculation of costs and revenues.

Revenues/Costs*	Explanation
Revenues	It was assumed that loss of recyclable waste was 30% for Scenarios 1a and 3a, 10% for Scenarios 1b and 3b, 20% for Scenario 2, and 50% for the material recovery facility (MRF) in all scenarios. The amount of recyclable materials was calculated as yearly totals and, based on data, was obtained through personal exchange of information with a private recycling company in Eskişehir. The estimated revenues of recyclable materials were $65/ton for paper/cardboard and metal, $150/ton for plastic, and $3/ton for glass
Equipment and vehicle costs	In order to estimate the equipment cost, the costs of recycling containers were assumed first. However, since recycling containers would not be used in Scenarios 1a or 1b, this cost was estimated only for Scenarios 2, 3a, and 3b. It was assumed that the price of a container with a 0.7 m^3 capacity (an $11 \times 10.6 \times 6$ dm^3 wheeled container) was around $870. In terms of vehicle costs, the number of vehicles essential for recyclable waste collection was projected. It is worth mentioning that this number might change regarding the collection types and recyclable waste quantities. In terms of the characteristics of vehicles, they are specially designed hydraulic compaction trucks (known as BMC Fatih 180 (4×2)) with 6 wheels, and they have 13+1.5 m^3 loading capacity. Their current price is around $90,000.
Personnel costs	In order to define the personnel costs, the required numbers of personnel were established first. Furthermore, the labor efficiency in collection was measured by the productivity of each person on collection routes and at the MRF. As a result, it was assumed that 1 supervisor and 7 workers could work together in the MRF. It was assumed that the salary of a driver or supervisor was $480/month per person, and that the salary of a worker was $380/month.
Maintenance cost	In terms of estimating the maintenance costs, recycling containers, equipment in the MRF, and vehicles were considered. Regarding the related data, the annual maintenance cost was estimated as 10% of all investment costs for vehicles and the MRF, and as 5% of all investment costs for containers.

*For the cost estimations, the recyclable waste collection period for all of the scenarios was determined as 2 or 3 trips per week. Additionally, the density of uncompacted waste was assumed to be 0.6 ton/m^3, and the volume of recyclable wastes that would be separated at the source per day was calculated. Regarding this information, it could be said that the amount of recyclable waste that would be separated at the source is around 187.5 m^3/day in Eskişehir. In terms of workdays, it was assumed that there were about 300 workdays per year. Also, different vehicles, trips, and shifts for each scenario were taken into consideration because of the time difference between curbside and recycling container collection systems, as follows:

- 6 vehicles (each vehicle has 2 workers and 1 driver), which make 1 trip in 2 shifts for Scenarios 1a and 1b.
- 2 vehicles (each vehicle has 1 worker and 1 driver), which make 2 trips in 3 shifts for Scenario 2.
- 6 vehicles (6 drivers, 10 workers), which make 2 trips in 1 shift for Scenarios 3a and 3b; 2 of those 6 vehicles employ only 1 worker for recyclable containers, while the others employ 2 workers.

Scenario 3a: [10% curbside collection (commingled recyclables) + 5% recycling containers + 5% material recovery facility]

Scenario 3b: [10% curbside collection (the source is separated into 4 subgroups, paper, metal, plastic, and glass) + 5% recycling containers + 5% material recovery facility]

The criteria used in this study are shown in Table 2, and a comparison of the scenarios according to the costs and revenues, considering the data, is shown in Table 3.

ANP studies

The packaging waste management problem involves social, economic, and technical aspects. Thus, technical, economic, and social criteria were determined to solve this problem, and a model of benefit-cost-risk was established in the ANP study by municipal authorities according to municipal practices. The opportunity group was ignored because it did not separate well from the benefit cluster (Banar et al., 2007). Super Decisions Software was used, and the significance of the weights of the chosen criteria was formulated in the program as follows:

Benefit : 1/6

Cost: 1/3

Risk: 1/2

Formula $= \text{benefit} + \frac{1}{\text{cost}} + \frac{1}{\text{risk}}$

In this context, each cluster is first rated separately. These ratings are then combined using cluster weighting and the formulas, including that to multiply the benefit ratios, reciprocals of cost, and risk ratios. Finally, these raw results are normalized and these values can be used as a percentage for evaluation of the alternatives (Saaty, 2001).

ELECTRE III studies

Performance values of the criteria are illustrated in Table 4. First, the ascending orders were considered for the evaluation of the criteria with nonnumerical values, and the DMs were asked to assign first place to the least important criterion. The other importance values were then assigned based on how many times more important they appeared as compared to the least important criterion. Thus, if a criterion was considered, for example, 3 times more important than the least important criterion, 3 was the value to be assigned to that criterion.

In a case like the packaging waste management system problem, the number of DMs is often large, and they do not give equal values to the individual weights. Thus, to give useful information on the importance of the various criteria, an inquiry needs to be carried out. The data then need to be formulated in some sensible manner to obtain the overall weights of the group. First, the DMs were asked to assign the criteria weights, where the sum of these values was 100.

To determine the thresholds, all of the DMs might assume different thresholds according to the criteria values. In this case, the average of these thresholds was used. The veto thresholds for all criteria were omitted. Using veto thresholds affects the final ranking. However, in this study, the DMs stated that there was not any alternative that could be vetoed. Hence, the veto threshold was not used in this study, and the discordance matrix was not considered. However, if needed, the spreadsheet tool developed for this study did have the capability to incorporate the veto threshold. For indifference and preference thresholds, while α_q and α_p were given as 0, β_q and β_p are given in Table 5. Also, for ELECTRE III, accordingly, weights that were determined by the DMs for each criterion are given in Table 5.

Table 4. Performance values of criteria.

Criteria no.	**S1a**	**S1b**	**S2**	**S3a**	**S3b**
g1	8	8	1	4	3
g2	4	2	9	8	6
g3	7	9	3	5	9
g4	7	9	5	6	8
g5	2,949,847	3,630,582	2,722,936	3,063,303	3,517,126
g6	540,000	540,000	413,160	618,300	618,300
g7	216,240	216,240	99,600	117,840	117,840
g8	66,500	66,500	42,158	70,415	70,415
g9	6	9	3	4	8
g10	6	9	3	4	9
g11	5	5	7	6	6
g12	4	4	1	2	2
g13	4	4	1	2	2
g14	4	4	1	2	2
g15	3	3	1	2	2
g16	4	4	1	2	2
g17	2	2	8	5	5

Nonnumerical values were scaled from 1 to 9, where Excellent = 9, Very good = 8, Good = 7, More or less good = 6, Indifferent = 5, Somewhat bad = 4, Bad = 3, Very bad = 2, and Awful = 1 for increasing ascending order, and Excellent = 1, Very good = 2, Good = 3, More or less good = 4, Indifferent = 5, Somewhat bad = 6, Bad = 7, Very bad = 8, and Awful = 9 for decreasing ascending order.

Table 5. Threshold and weights of criteria for ELECTRE III.

Criteria no.	β_q	β_p	w
g1	1	2	3
g2	2	3	2
g3	2	4	14
g4	3	2	5
g5	300,000	500,000	12
g6	100,000	50,000	5
g7	100,000	30,000	12
g8	20,000	10,000	3
g9	2	1	3
g10	2	4	2
g11	2	3	3
g12	3	2	6
g13	3	2	3
g14	3	2	2
g15	3	2	5
g16	3	1	3
g17	3	1	17

Results and Discussion

The alternatives for choosing the most suitable recycling program in Eskişehir were evaluated with ANP and ELECTRE III techniques. For ELECTRE III, the concordance index and outranking degree means credibility matrix were obtained using an Excel worksheet that was developed by the researchers for similar MCDM problems. The distillation procedure that gives outranking orders for the present study is illustrated in Table 6. Since the veto threshold was not used in this study, a discordance matrix was not calculated. The credibility matrix that gave the outranking degree was equal to the concordance matrix because the discordance matrix was not used. The value that approaches 1 gives the most preferable alternative. For ANP, according to the criteria and the formula above, the appropriate order of recycling scenarios was evaluated and is presented in the Figure.

Table 6. Concordance matrix.

	S1a	**S1b**	**S2**	**S3a**	**S3b**
S1a	-	1	0.7	1	1
S1b	0.9	-	0.6	0.7	1
S2	0.8	0.8	-	0.9	0.9
S3a	1	1	1	-	1
S3b	0.9	1	0.7	0.8	-

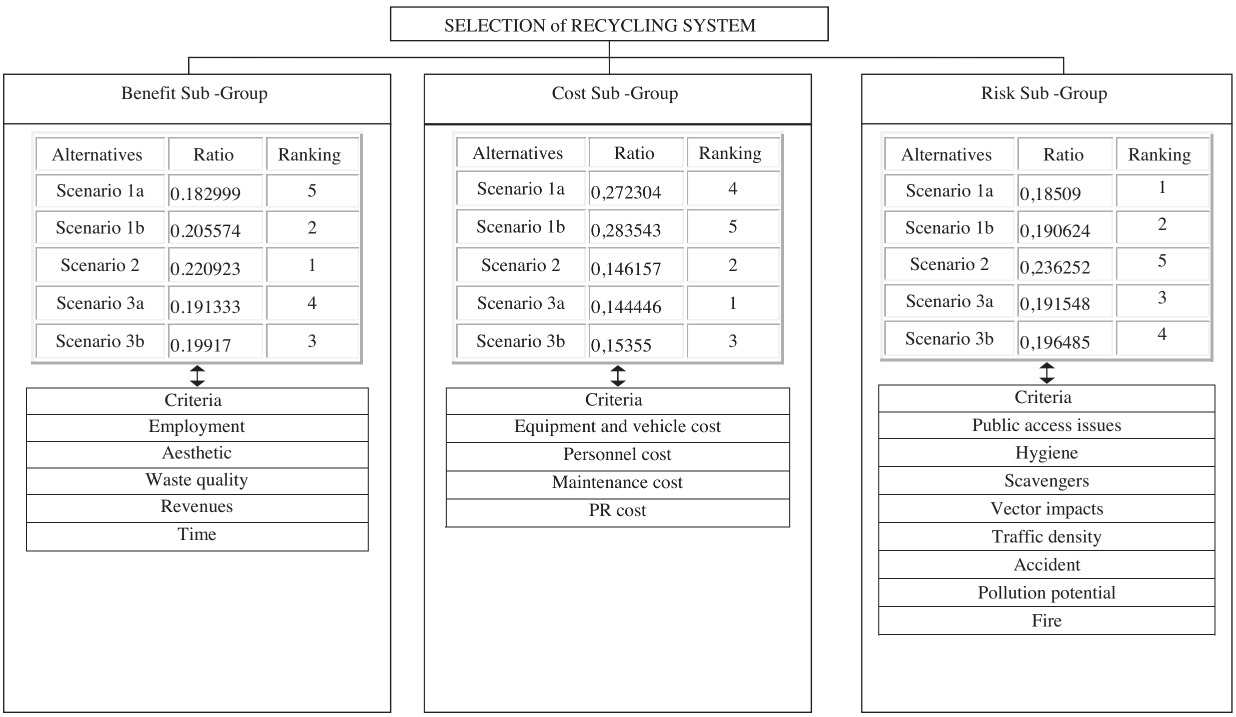

Figure. Flow chart of ANP for the results of evaluation of the recycling scenarios.

With reference to the findings of the present study, which aimed to adopt a suitable recycling system for the MSW of Eskişehir, Scenario 3a [10% curbside collection (commingled recyclables) + 5% recycling containers + 5% material recovery facility] was determined to be the outstandingly most suitable recycling scenario. It was considered most preferable because it was most appropriate for citizens.

Results of both techniques are compared in Table 7. As can be seen, there were changes in the ranking of some scenarios; however, Scenario 3a was found to be the most suitable recycling scenario with both techniques. In the ANP technique, relations and directions between components represent a network. Therefore, it is assumed that indirect interactions and feedbacks between components are not directly associated. On the other hand, although ELECTRE III does not cover the abovementioned network, there are preference and indifference thresholds for all criteria. Therefore, it can be claimed that the most fundamental difference between these techniques is the causing of disparity in ranking. In this manner, while Scenarios 1a and 1b, including only curbside collection and a material recovery facility, were the worst scenarios according to the ANP process, Scenarios 1b and 3b, including curbside collection and containers, were the worst scenarios according to the ELECTRE process.

Table 7. Comparison of the results of ANP and ELECTRE III.

Alternatives	ANP (ranking)	ELECTRE III (ranking)
Scenario 1a	5	2
Scenario 1b	4	3
Scenario 2	3	2
Scenario 3a	1	1
Scenario 3b	2	3

Conclusion

Recycling systems are vital parts of integrated solid waste management. When a recycling system is projected, DMs should consider all of the parameters that might be affected by the system. Taking this fact into consideration, it can be claimed that a useful approach tool for DMs is the MCDM technique. ANP and ELECTRE III, which are 2 well-known MCDM techniques, were used to make a decision about recycling systems. These techniques might have widespread support in decision making on the part of municipal authorities. For future studies, it is recommended that the problem be reconsidered with veto thresholds that the DMs determine and the problem be reexamined to see whether any change occurs in the final ranking when new criteria and a veto threshold for ELECTRE III are added.

The main factors that were affected in this process were a high investment cost, changes in public participation, pollution from recyclable materials at the source, and changes in the prices of recyclable materials. In this study, it was seen that the most important elements were costs and public participation. For that reason, education and promotion studies are very important for these systems.

References

Banar, M. and Özkan, A., "Characterization of the Municipal Solid Waste in Eskişehir City, Turkey", Environmental Engineering Sciences, 25, 1213-1219, 2008.

Banar, M., Kose, B., Özkan, A. and Acar, I., "Choosing a Municipal Landfill Site by Analytic Network Process", Environmental Geology, 52, 747-751, 2007.

Documents of Metropolitan Municipality of Eskişehir, 2003.

EU, Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on Waste and Repealing Certain Directives, 2008.

EU, Communication from the Commission to the Council, The European Parliament, The European Economic and Social Committee, and The Committee of the Regions, "Taking Sustainable Use of Resources Forward: A Thematic Strategy on the Prevention and Recycling of Waste," COM(2005) 666 Final, Brussels, 2005.

Figueira, J., Greco, S. and Ehrgott, M., Multiple Criteria Decision Analysis: State of the Art Surveys, Springer, Boston, 2005.

Hokkanen, J. and Salminen, P., "Choosing a Solid Waste Management System Using Multicriteria Decision Analysis", European Journal of Operational Research, 98, 19-36, 1997.

Karagiannidis, A. and Moussiopoulos, N., "Application of ELECTRE III for the Integrated Management of Municipal Solid Wastes in the Greater Athens Area", European Journal of Operational Research, 97, 439-449, 1997.

Khan, S. and Faisal, M., "An Analytic Network Process Model for Municipal Solid Waste Disposal Options", Waste Management, 28, 1500-1508, 2008.

Ministry of Environment and Forestry of Turkey, EU Integrated Environmental Approximation Strategy (2007-2023), 2006.

Norese, M.F., "ELECTRE III as a Support for Participatory Decision-Making on the Localisation of Waste-Treatment Plants", Land Use Policy, 23, 76-85, 2006.

Rogers, M. and Bruen, M., "Using ELECTRE III to Choose Route for Dublin Port Motorway", Journal of Transportation Engineering, 126, 313-323, 2000.

Roy, B., "The Outranking Approach and the Foundations of ELECTRE Methods", Theory and Decision, 31, 49-73, 1991.

Saaty, T.L., Fundamentals of Decision Making and Priority Theory with the Analytic Hierarchy Process, RWS Publications, Pittsburgh, 1994.

Saaty, T.L., The Analytic Network Process: Decision Making with Dependence and Feedback, RWS Publications, Pittsburgh, 2001.

Takeda, E., "A Method for Multiple Pseudo-Criteria Decision Problems", Computers & Operations Research, 28, 1427-1439, 2001.

Tam, C.M., Tong, T.K.L. and Lau, C.T., "ELECTRE III in Evaluating Performance of Construction Plants: Case Study on Concrete Vibrators", Construction Innovation, 3, 45-61, 2003.

Tanskanen, J. and Melanen, M., "Modelling Separation Strategies of Municipal Solid Waste in Finland", Waste Management and Research, 17, 80-92, 1999.

Thorneloe, A.S., Weitz, K. and Jambeck, J., "Application of the US Decision Support Tool for Materials and Waste Management", Waste Management, 27, 1006-1020, 2007.

Tseng, M.L., "Application of ANP and DEMATEL to Evaluate the Decision-Making of Municipal Solid Waste Management in Metro Manila", Environmental Monitoring and Assessment, 156, 181-197, 2009.

TUİK, http://tuikapp.tuik.gov.tr/adnksdagitapp/adnks.zul, accessed on 9 July 2010.

Vincke, Ph., Multicriteria Decision-Aid, Wiley, New York, 1992.

Zak, J., "The Comparison of Multiobjective Ranking Methods Applied to Solve the Mass Transit Systems' Decision Problems", Proceedings of the 16th Mini-EURO Conference and 10th Meeting of EWGT, 184-193, 2005.