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Multi-criteria decision aid approach for the selection of the best compromise management scheme for ELVs: The case of Cyprus

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Abstract

Each alternative scheme for treating a vehicle at its end of life has its own consequences from a social, environmental, economic and technical point of view. Furthermore, the criteria used to determine these consequences are often contradictory and not equally important. In the presence of multiple conflicting criteria, an optimal alternative scheme never exists. A multiple-criteria decision aid (MCDA) method to aid the Decision Maker (DM) in selecting the best compromise scheme for the management of End-of-Life Vehicles (ELVs) is presented in this paper. The constitution of a set of alternatives schemes, the selection of a list of relevant criteria to evaluate these alternative schemes and the choice of an appropriate management system are also analyzed in this framework. The proposed procedure relies on the PROMETHEE method which belongs to the well-known family of multiple criteria outranking methods. For this purpose, level, linear and Gaussian functions are used as preference functions.

Keywords: ELVs; Multi-criteria decision aid; PROMETHEE; Scheme selection

1. Introduction

There is an increased interest from producers, consumers and authorities for the management at the end of life phase (EOL) of a product. The amount of products that reach their end of life is growing due to changes in consumer attitude. Landfills are saturated and their expansion is not always possible, either because of the propagation of harm that can be caused by such expansion to the environment and neighbouring populations or because of practical reasons, since the space to be used for landfilling is in general very limited. In addition to the problem of finding landfills for disposing the huge volume of discarded products, one has to address the hazardous nature of some of their components [1]. The abandoned waste products present a potential threat to the environment, since substances of this waste stream, for instance fluids and heavy metals, can be leached and released to the soil and water.

End-of-Life Vehicles (ELVs) constitute a significant problem in most countries. In accordance with the provisions of the principles of the European environmental policy on waste, priority must be given to the application of the three R management practices (Recovery, Reuse, Recycling) and the establishment of the principle of producer's responsibility. In order for the European Community to handle this issue, the Directive 2000/53/EC has been adopted. Priority in this Directive is drawn to the prevention of waste from vehicles and secondly to the reuse (any procedure by which components of ELVs are used for the same purpose for which they were conceived), the recycling (the reprocessing in a production process of the waste materials for the original purpose or for other purposes excluding the processing for use as fuel) and other forms of recovery of vehicles and their components [2,3]. The ELV Directive and its amendment Directives [4] require the limitation, to the furthest obtainable extent, of all hazardous substances that may cause severe damage to the environment and forbid the use of certain materials, such as lead, cadmium, mercury and hexavalent chromium.

Cyprus, as a new member state of the European Union, has been harmonized with the provisions of the relative aforementioned European Directives via the Law 157(I) of 2003 on ELVs. The law sets the same quantitative targets as the EU Directives, that is:

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(i) Reuse and recovery of at least 85% (75% for old cars), reuse and recycling at least 80% (70% for old cars) until 1st January 2006.
(ii) Reuse and recovery at least 95%, reuse and recycling at least 85% until 1st January 2015.

To achieve policy objectives and targets, interrelated sequences of single innovations in both upstream (car making) and downstream (car recycling/recovery) of the ELV system, which give rise to different 'innovation paths', should take place [5].

The selection of an appropriate alternative management scheme for treating ELVs concerns different sectors, such as manufacturers, importers, recyclers and competent authorities. These sectors and authorities have their own objectives and priorities and it is possible that a good EOL alternative for one user is not necessarily good for another user. Additionally, different users do not necessarily consider the same set of EOL alternatives and the same set of criteria. In fact, even if two different users consider the same EOL alternatives and the same criteria, it is possible that they allocate different weights for the same criterion that is for each criterion the same score of an EOL alternative has not necessarily the same importance according to the two users. To achieve this goal, the most important EOL alternatives should be considered and compared on the basis of their performances with respect to the relevant criteria and the preferences of the user in order to select the best compromise EOL alternative. Usually, the criteria are conflicting and not equally important. To deal with such decision-making situations, a MCDA approach is suitable [1].

According to Costa et al. [6], the structuring and framing of a decision-making situation is a constructive learning process which seeks to build a more-or-less formal representation, integrating the objective environmental components of the decision context, with the subjective and context dependent points of view, concerns or objectives, in such a way that the value systems of actors or stakeholders are made explicit.

Finding an optimal alternative management scheme for the treatment of ELVs with respect to all criteria is the ideal goal. However, since the criteria are often conflicting, such management scheme cannot exist. In this paper, an alternative scheme that constitutes a compromise between all the criteria is searched. For this reason, the management scheme derived from the utilization of a multi-criteria method aid is called the best compromise ELVs alternative and not the best ELVs alternative scheme. In any case, monitoring of innovation by the authorities, focusing on coordination mechanisms, is a crucial issue on the success of the implementation of the management schemes [7].

2. Choice of an appropriate MCDA method

2.1. General description

Several methodologies exist for multi-criteria decision aiding [8–10]. There are no better or worse techniques, but techniques better suited to particular decision problems than others [11].

It is essential to develop in detail all elements related to the situation of MCDA before carrying out the selection of an appropriate MCDA method in order to solve the problem under investigation [1]. The choice of a certain MCDA method cannot be made at the beginning of the process. This decision should wait until the analyst and the DMs understand the problem, the feasible alternatives, different outcomes, conflicts between the criteria and the level of the data uncertainty [12].

It is generally believed that outranking methods are well suited for energy and environmental planning issues [13–18]. They provide deep insight into the structuring of the problem, they model realistically the DMs preference structure and they could treat the uncertainty of the required information through probability distributions, fuzzy sets and threshold values inclusion. On the other hand, some of them, namely the ELECTRE III are considered to be complicated and, not easily understood by DMs [11].

In this study, the PROMETHEE method was selected due to its simplicity and its capacity to approximate the way that human mind expresses and synthesizes preferences when facing multiple contradictory decision perspectives. PROMETHEE method belongs to the wider family of the outranking methods. In present work, the most important underlying concepts are presented, while more details are provided by Brans et al. [19].

2.2. The PROMETHEE method

2.2.1. Principles

Like all outranking methods, PROMETHEE proceeds to a pair of wise comparison of alternatives in each single criterion in order to determine partial binary relations denoting the strength of preference of an alternative a over alternative b. The evaluation table is the starting point of the PROMETHEE method. In this table, the alternatives are evaluated on the different criteria. These evaluations involve mainly quantitative data.

The implementation of PROMETHEE requires two additional types of information, namely:

- the information on the relative importance that is the weights of the criteria considered and
- the information on the DM preference function, which he/she uses when comparing the contribution of the alternatives in terms of each separate criterion.

2.2.2. The weights

The weights coefficients can be determined according to various methods [20]. In the present paper, weight factors reflecting the DMs previous experience and their insights are adopted.

2.2.3. The preference function

The preference function (P_j) translates the difference between the evaluations obtained by two alternatives (a and b) in terms of a particular criterion, into a preference degree ranging from 0 to 1. Let

$$P_{j(a,b)} = G_j[f_j(a) - f_j(b)] \tag{1}$$

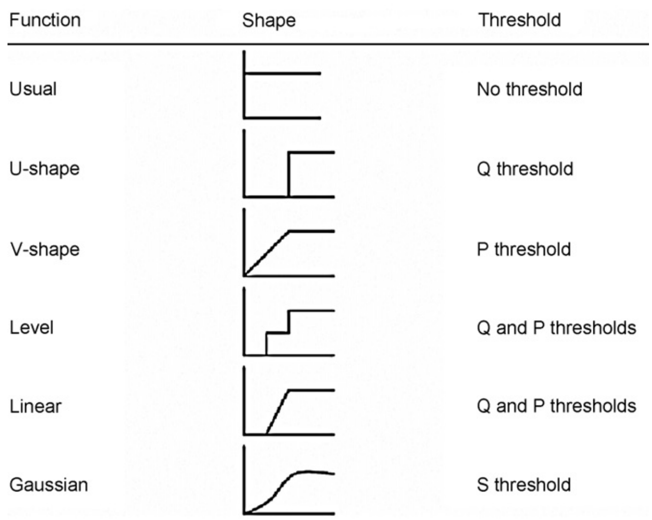

Fig. 1. Preference functions of PROMETHEE.

$$0 \leq P_{j(a,b)} \leq 1 \tag{2}$$

be the preference function associated to the criterion, $f_j(i)$ where G_j is a nondecreasing function of the observed deviation (d) between $f_j(a)$ and $f_j(b)$.

In order to facilitate the selection of a specific preference function, six basic types have been proposed: usual function, U-shape function, V-shape function, level function, linear function and Gaussian function (as presented in Fig. 1) [19–21].

2.2.4. Individual group analysis

PROMETHEE permits the computation of the following quantities for each alternative a and b:

$$\pi_{\mathrm{r}}(a, b) = \sum_{j=1}^{k} P_j(a, b) w_{r,j}, \qquad \varphi^{+}(\alpha) = \sum\nolimits_{x \in \mathrm{A}} \pi_{\mathrm{r}}(x, a),$$

$$\varphi^{-}(\alpha) = \sum\nolimits_{x \in \mathrm{A}} \pi_{\mathrm{r}}(a, x), \qquad \varphi(\alpha) = \varphi^{+}(\alpha) - \varphi^{-}(\alpha) \tag{3}$$

For each alternative a, belonging to the set A of alternatives, $\pi(a,b)$ is an overall preference index of a over b, taking into account all the criteria, $\varphi^{+}(\alpha)$ and $\varphi^{-}(\alpha)$. $\varphi(\alpha)$ represent a value function, whereby a higher value reflects a higher attractiveness of alternative a and is called net flow.

The two main PROMETHEE tools can be used to analyse the evaluation problem:

- the PROMETHEE I partial ranking,
- the PROMETHEE II complete ranking.

The PROMETHEE I partial ranking provides a ranking of alternatives. In some cases, this ranking may be incomplete. This means that some alternatives cannot be compared and, therefore, cannot be included in a complete ranking. This occurs when the first alternative obtains high scores on particular criteria for which the second alternative obtains low scores and the opposite occurs for other criteria. The use of PROMETHEE I, then, suggests that the DM should engage in additional evaluation efforts. PROMETHEE II provides a complete ranking of the alternatives from the best to the worst one. Here, the net flow is used to rank the alternatives.

Additional tools, such as the ‘walking weights’, can be used to further analyse the sensitivity of the results in function of weight changes.

2.3. Alternative schemes for the management of ELVs in Cyprus

In this section, the six alternative schemes concerning the management of ELVs in Cyprus are presented. The management schemes are based on:

- the dismantling of the ELVs
- the shredding of the hulk
- the management of the automobile shredder residue (ASR)

The main characteristics of the partial and complete dismantling as well as information regarding the shredding process and the management of ASR are described below.

2.3.1. Complete dismantling

The complete dismantling of the ELVs can be done in four stages. In the first stage, hazardous substances such as gasoline, oil, batteries and toxic fluids (brake fluids, engine oils, antifreezing solutions, lubricants, windscreen cleanser and fluids in airbag capsule) are removed. Some of these hazardous materials are sent for chemical recycling. In the second stage, doors, windows, bumpers, tires, dashboards, lights and seats are removed. Generally, some of these parts, which are in good condition, are sent for reuse and the others for parts’ recycling. The removal of the suspensions, the engine, the gear box, the differential gear, the springs and the exhaust system is executed in the third stage while in the last stage all the removed materials are separated to follow the process of recycling.

2.3.2. Partial dismantling

Partial dismantling can also be concluded in four stages. The first stage in partial dismantling is similar with the equivalent in complete dismantling. In second stage, parts such as doors, windows, tires and lights are removed while parts consisting of plastics such as bumper and seats can remain behind and be compressed with the body. The third stage regards the removal of the suspensions, the engine, the gear box, the differential gear, the springs and the exhaust system. The diversification of this stage of the equivalent stage in complete dismantling process is that parts such as the heating system, the wiring and the plastic parts of the motor remain with the body. Finally, the last stage is the same with the last stage in the complete dismantling process.

2.3.3. Shredding process

‘Hulk’, what remains after the dismantling activities, includes metal components of vehicle body, some electronics parts (which are difficult to be removed) and parts consisting of plastics, glass and rubber. This can be transported to a shredder site.

Recovery of ferrous (with magnetic separation) and nonferrous metals (mostly with handpicking) is feasible during shredding process.

2.3.4. Management of automobile shredder residue (ASR)

Approximately 50% of the ASR consists of combustible materials, while the remaining is incombustible [22]. Several technologies, such as pyrolysis and incineration are under examination for the recovery as a heat resource of ASR combustible material [23–27]. Until recently, the incombustible fraction of ASR was led for landfilling. A recent study shows that this fraction can be used in production processes, e.g. cement industries [22].

2.3.5. Management schemes description

Taking into consideration the points mentioned above, the following six alternative management schemes/systems are examined.

- *Scheme 1*: Partial disassembling – shredding – separation – recovery of ferrous and nonferrous metals – landfilling of shredded residues.
- *Scheme 2*: Partial disassembling – shredding – separation – recovery of ferrous and nonferrous metals – thermal recovery of combustible shredded residues – landfilling of noncombustible shredded residues.
- *Scheme 3*: Partial disassembling – shredding – separation – recovery of ferrous and nonferrous metals – thermal recovery of combustible shredded residues – utilization of noncombustible shredded residues in cement industries.
- *Scheme 4*: Complete disassembling – shredding – separation – recovery of ferrous and nonferrous metals – landfilling of shredded residues.
- *Scheme 5*: Complete disassembling – shredding – separation – recovery of ferrous and nonferrous metals – thermal recovery of combustible shredded residues – landfilling of noncombustible shredded residues.
- *Scheme 6*: Complete disassembling – shredding – separation – recovery of ferrous and nonferrous metals – thermal recovery of combustible shredded residues – utilization of noncombustible shredded residues in cement industries.

Figs. 2 and 3 present the resemblances and the differences of the alternative management schemes.

All scenarios include the stage of complete or partial dismantling of ELVs (instead of the direct shredding of ELVs as a whole). This management stage focuses on the removal of hazardous substances, a portion of which could be sent for recycling (e.g. batteries, lubricants, etc.), as well as the removal of parts of the vehicles that could be reused or/and recycling (e.g. doors, windows, tires, engine).

Also, all the candidate scenarios include the stage of shredding of the remaining hulk after dismantling in order to facilitate the separation and recovery of ferrous and nonferrous metals.

Finally, the scenarios 2 and 5 examine the possibility of thermal recovery of the combustible shredded residues, while the

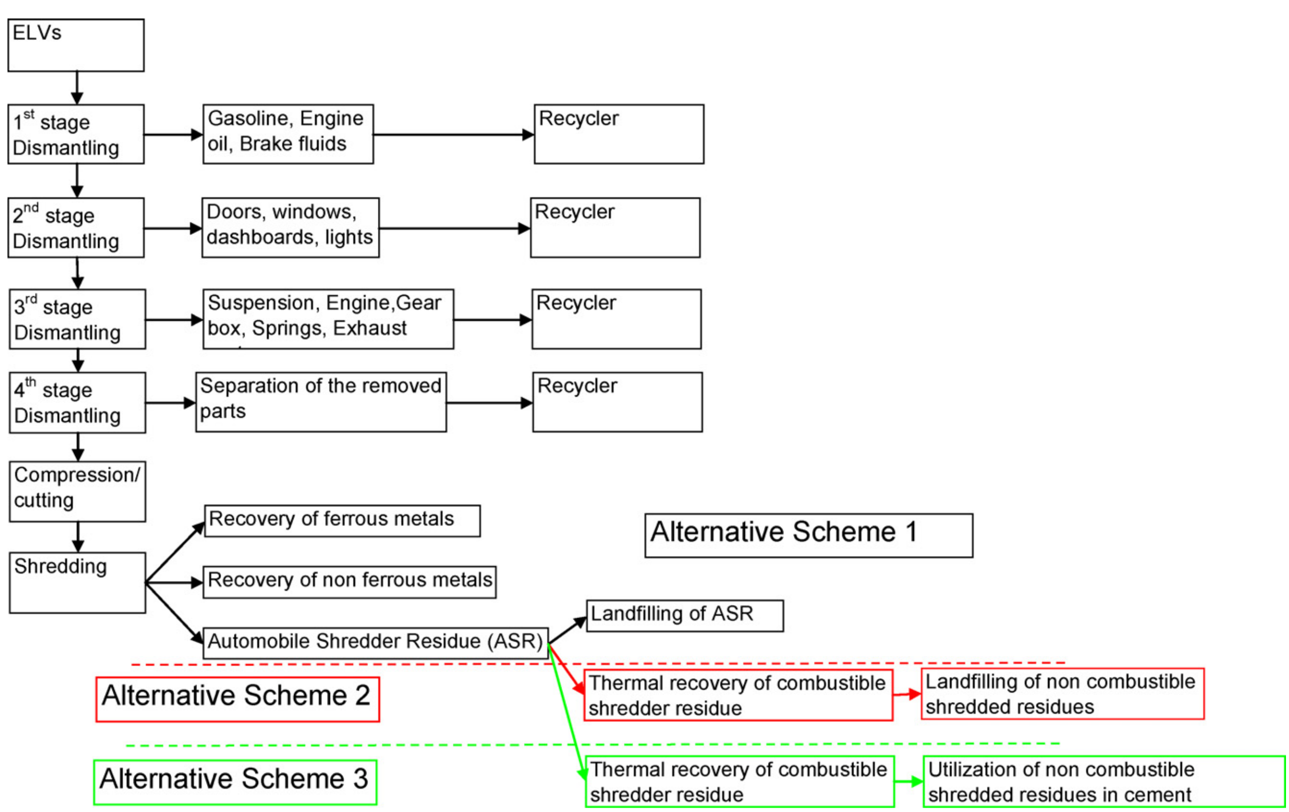

Fig. 2. Flow sheet of alternative schemes 1, 2 and 3.

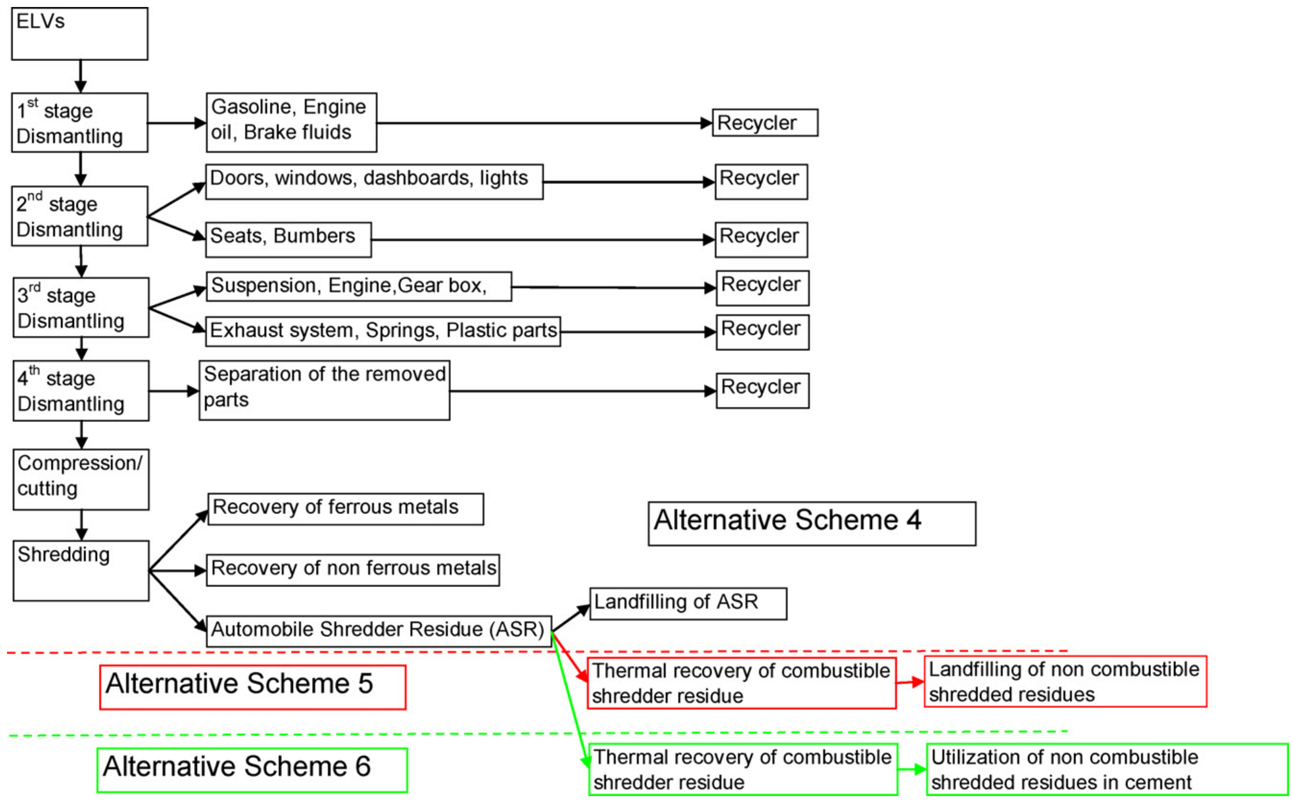

Fig. 3. Flow sheet of alternative schemes 4, 5 and 6.

scenarios 3 and 6, additionally to the thermal recovery of the combustible shredded residues, examine the possibility of the utilization of the noncombustible shredded residues in industrial processes (cement industries).

2.4. Evaluation criteria

An important step in a decision analysis is one in which the DM structure the hierarchy of the criteria. In this step, a complex group criteria problem is decomposed into sub-criteria (Fig. 4). The criteria that are used in this research fall into the following four categories that is social, environmental, financial and technical. Under these four categories a total of 17 different evaluation criteria are defined. These include both quantitative and qualitative measures. The criteria used are described analytically while their calibration, in a scale of 1–10, is given according to their characteristics in Table 1.

- (S_1) *Harmonization with the existing legislative framework*: informing on the degree each type of scheme is harmonized with the existing legislative framework of Cyprus.
- (S_2) *Application of priorities of legislation*: the adopting of priorities of Cyprus environmental policy is examined and more specifically in the first phase the recovery of materials for recycling or/and reuse and in second phase the utilization of waste for energy production.
- (S_3) *Social acceptance*: the degree of the social acceptance of the proposed management practice is examined.
- (S_4) *Possibilities of new job positions*: the possibility for labor's absorption is tested according to the demands which will arise from the application of the proposed management scheme.
- (E_1) *Level of possible environmental repercussions-demands in antilitter systems*: assessing the degree of possible environmental repercussions from the alternative management system in combination with the demands and use of antilitter

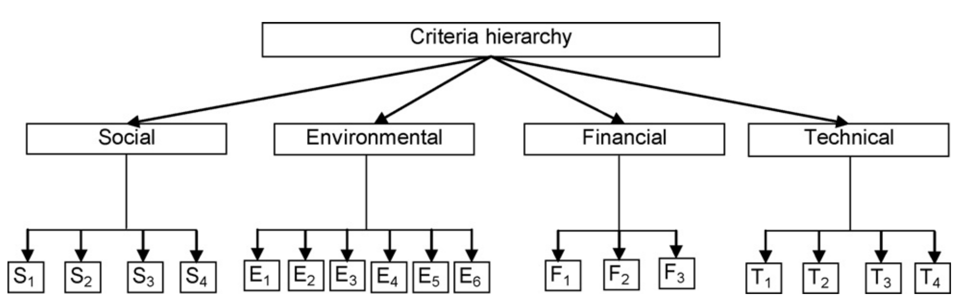

Fig. 4. Criteria hierarchy for management schemes of ELVs in Cyprus.

Table 1
Calibration of the 17 criteria in the (1–10) scale

Criterion	Description	Score
S_1	Complete harmonization	10
	Partial harmonization	5
	No harmonization	1
S_2	Complete application	10
	Partial application	5
	Application in low level	3
	Opposition with the guidelines	1
S_3	Complete social acceptance after informing	10
	Partial social acceptance	5
	Social acceptance because of a lack of informing	3
	No social acceptance because of a lack of informing	3
	No social acceptance after informing	1
S_4	Creation of new job positions to a great extent	9
	Creation of new job positions to a limited extent	4
	No creation of new job positions	1
E_1	Environmental repercussions to an insignificant extent	7
	Environmental repercussions to a limited extent	4
	Environmental repercussions to a great extent	1
E_2	Significant air emissions and odors (controlled)	6
	Limited air emissions and odors (controlled)	8
	Insignificant (minimum) air emissions and odors (controlled)	9
E_3	Significant production of humid waste (controlled)	6
	Limited production of humid waste (controlled)	8
	Insignificant (minimum) production of humid waste (controlled)	9
E_4	Significant production of solid outcast-residue (controlled)	6
	Limited production of solid outcast-residue (controlled)	8
	Insignificant (minimum) production of solid outcast-residue (controlled)	9
E_5	Minimum noise pollution	9
	Limited noise pollution	7
	Relatively high noise pollution	4
	Extreme noise pollution	1
E_6	Pleasant aesthetic condition	9
	Relatively pleasant aesthetic condition	7
	Moderate aesthetic condition	4
	Nasty aesthetic condition	1
F_1	Low total investment cost (covered by others)	10
	Moderate total investment cost (covered by others)	8
	High total investment cost (covered by others)	5
F_2	Low operation-maintenance cost	9
	Moderate operation-maintenance cost	7
	Relatively high operation-maintenance cost	4
	High operation-maintenance cost	1
F_3	High land cost	1
	Relatively high land cost	3
	Lack of land	1
	Moderate land cost	7
	Low land cost	9
T_1	High functionality	9
	Relatively high functionality	7
	Moderate functionality	5
	Low functionality	3
	Very low functionality	1
T_2	High existing experience	10
	Relatively high existing experience	7
	Moderate existing experience	5
	Low existing experience	3
	Very low existing experience	1
T_3	High adaptability	10
	Relatively high adaptability	7
	Moderate adaptability	5
	Low adaptability	3
	Very low adaptability	1
T_4	High flexibility	10
	Relatively high flexibility	7
	Moderate flexibility	5
	Low flexibility	3
	Very low flexibility	1

systems for prevention or/and confrontation of these repercussions.

- (E_2) *Air emissions*: air emissions vary in proportion the management method and the specific technique which is followed. Particular attention is given in those which generate negative repercussions to the environment and the public health.
- (E_3) *Production of humid waste*: Management practices are diversified according to this criterion. Furthermore, particular attention is given to the negative repercussions to the environment and also the public health.
- (E_4) *Production of solid outcast*: possible generation of solid waste from the management techniques is tested.
- (E_5) *Noise pollution*: is a factor which should be taken into account at the design of management practices. Furthermore, noise pollution which is caused during the transport of the waste to the management area should also be taken into consideration.
- (E_6) *Aesthetic harmful effect*: depends on the necessary mechanical equipment which is needed as well as from the requirements for additional infrastructure.
- (F_1) *Total investment cost*: is among the top factors as regards the viability of the management practise. This criterion acquires additional value if part of the total investment cost is defrayed by the citizens.
- (F_2) *Operation and maintenance cost*: includes expenses for the maintenance of schemes, personnel cost, auxiliary supplies, antilitter technology, control and surveillance of the scheme, waste transport etc.
- (F_3) *Land requirement*: management practices are diversified notably as regards this criterion in proportion the required area is needed for the installation of the mechanical equipment as well as the auxiliary infrastructures.
- (T_1) *Functionality*: parameters, such as the possibility of constant operation, requirements in expert personnel, facility in maintenance, simplicity in operation, endurance (durability) of mechanical equipment both at time and at use, among others, are examined in this criterion.
- (T_2) *Existing experience–reliability*: is important especially when the adoption of a new technology is required.

- (T_3) *Adaptability in the local conditions*: the effectiveness and the viability of each scheme is depended swiftly from the geographical and other characteristics in issue area such as the available waste quantities for management and the minimum required capacity.
- (T_4) *Flexibility*: the possibility of the alternative schemes to the potential variations in quantity and in composition of the waste is examined.

It should be noted that the innovations in the management of ELVs are incorporated in the criteria that were used and, in particular, through the criteria S_1: Harmonization with the existing legislative framework and S_2: Application of the priorities of the legislation.

Cost and benefit issues are always crucial for the final choice of the most suitable management schemes. At the present work, financial issues are taken into consideration through the examination of the financial group of criteria—total investment cost, operational and maintenance cost, land requirement. Additionally, the results that were obtained from the application of the multi-criteria decision method were used as a basis for the development of a detailed techno-economic study for the implementation of the optimum management systems that were selected. This study (the results of which will be presented in a new article) determines, in detail, all the issues of technical and economic nature, such as:

- Technology that is used.
- Demands, type and cost of equipment.
- Size and capacity of installations.
- Cost for the construction of the plants, including auxiliary works.
- Operational costs (utilities, energy demands, personnel and other costs).
- Costs for the collection and transfer of wastes to the installations.
- Costs of the transfer of recovered materials and residues from the processing.
- Costs for final disposal of the residues obtained from the processing.
- Plants and equipment depreciation.
- Total expenses for the construction, operation and maintenance of the installations.
- Income from the selling of recovered materials per category.
- Total incoming from the operation of the installations (selling of recovered materials).
- Balance between expenses and income in order to determine the viability of each installation.

2.5. Criteria weight coefficients

The most important step in multi-criteria evaluation methods is the assignment of weight coefficients of each criterion, since these coefficients reflect the relative importance of the various impacts considered. PROMETHEE does not provide specific guidelines for determining these weights, but assumes that the DM is able to weigh the criteria appropriately, at least when the number of criteria is not too large.

At the present work, all the criteria were weighed according to their significance, through setting weight coefficient per groups of criteria and then per individual criterion. Differences in the importance of goals are attributed to the particular interests of the affected parties and the DMs. The determination of the criteria weight coefficients was based on:

i. the experience gained from relative applications,
ii. the specific characteristics of the country, such as the capability to establish installations of high capacity, since the waste quantities are quite low, fact that affects the economic and technical groups of criteria, the existing infrastructures in the country, etc.,
iii. the opinion/suggestions of all the Cypriot actors involved in the field, such as ministries, companies, Association of Recyclers, local authorities, etc. (for this purpose, appropriate informative printed material, accompanied with a form to be filled in, were distributed to more than 100 representatives of the Cypriot actors and authorities involved).

The weights of the environmental and financial groups were set at 30%, while social and technical ones at 15% and 25%, respectively. These scores show that the criteria are not equally important. Highest attention has been given to the environmental and financial fields. The same procedure has been followed for the evaluation of individual criteria inside the groups. For instance, the scores of F_1 and F_2 were set at 40%, while the score of F_3 at 20%, reflecting in this way the preference of the DMs. The final coefficients were derived after the multiplication of each criterion weight with the group weight that it belongs. Table 2 presents the weight coefficients of the criteria group and of every single criterion in the group as well as the final weight coefficient as described above.

2.6. Performance of alternative management schemes

Table 3 presents the performance of the candidate alternative management schemes of the ELVs in each of the above criteria and the conflicts emerging if schemes are ranked with respect to each single criterion. It can namely be seen that alternative schemes presenting a good score in one criterion, appears less effective regarding their performance in one or more other criteria. It can be seen, for instance, that the scenario 1 presents the lowest investment cost and the lowest operation-maintenance cost, since the bigger degree results to low total investment cost and low operation-maintenance cost. However, these cost savings are achieved at the expense of environmental quality. Similarly, the alternative scenario 6 performs best in social criteria, but is associated with much higher financial costs and lower technical performances. As a result, the full satisfaction of all goals is not feasible and that DMs are obliged to find out a compromise solution reflecting the most acceptable balance between their competing aspirations. Details on the measurement of performances in each alternative scheme can be found in Mergias [28]. Schemes performance should

Table 2
Estimation of criteria final weights

Criteria	Group weights (%)	Criteria description	Weight of every criterion (%)	Final weights (%)
Social	15.00	Harmonization with the existing legislative framework (S_1)	30.00	4.50
		Application of priorities of legislation (S_2)	30.00	4.50
		Social acceptance (S_3)	25.00	3.75
		Possibilities of new job positions (S_4)	15.00	2.25
		Subtotal	100.00	15.00
Environmental	30.00	Level of possible environmental repercussions (E_1)	25.00	7.50
		Air emissions (E_2)	20.00	6.00
		Production of humid waste (E_3)	20.00	6.00
		Production of solid outcast (E_4)	20.00	6.00
		Noise pollution (E_5)	10.00	3.00
		Aesthetic harmful effect (E_6)	5.00	1.50
		Subtotal	100.00	45.00
Financial	30.00	Total investment cost (F_1)	40.00	12.00
		Operation and maintenance cost (F_2)	40.00	12.00
		Land requirement (F_3)	20.00	6.00
		Subtotal	100.00	75.00
Technical	25.00	Functionality (T_1)	25.00	6.25
		Existing experience-reliability (T_2)	30.00	7.50
		Adaptability in the local conditions (T_3)	25.00	6.25
		Flexibility (T_4)	20.00	5.00
		Subtotal	100.00	100.00
		Total		100.00

be maximized in all criteria, as ensued from their destination.

2.7. Indifference and preference thresholds

The indifference threshold is set at 10% of the difference between the highest and lowest score while the preference threshold is set at 30% of the same difference. The indifference threshold denotes that if the difference in the performance of two scenarios *a* and *b* in a criterion is lower than this threshold, these are considered as equivalent ($p(a,b) = 0$). The preference threshold denotes that strict preference ($p(a,b) = 1$) of scenario *a* over scenario *b* holds only if the difference in their performance of scenario is higher than this threshold. Table 4 summarizes the criteria indifference and preference thresholds.

3. Results and discussion

Tables 5–7 present the results of the PROMETHEE II method for the candidate management schemes of ELVs in Cyprus with

Table 3
Performances of management schemes in social, environmental, financial and technical criteria

Criteria	Alternative management schemes					
	1	2	3	4	5	6
S_1	9	9	10	8	8	9
S_2	9	9	10	6	6	7
S_3	6	7	8	5	6	7
S_4	6	7	8	7	8	9
E_1	4	5	6	3	4	5
E_2	9	8	7	9	8	7
E_3	8	9	9	8	9	9
E_4	6	7	9	6	7	9
E_5	6	5	4	5	4	3
E_6	6	6	6	5	5	5
F_1	8	7	7	6	5	5
F_2	7	6	6	5	4	4
F_3	9	8	8	7	6	6
T_1	7	7	7	5	5	5
T_2	7	7	7	5	5	5
T_3	8	8	7	6	6	5
T_4	7	7	7	5	5	5

Table 4
Indifference and preference thresholds of criteria

Criteria	Thresholds	
	q	*p*
S_1	0.9	2.7
S_2	0.9	2.7
S_3	0.8	2.4
S_4	0.8	2.4
E_1	0.7	2.1
E_2	0.7	2.1
E_3	0.9	0.9
E_4	0.9	2.7
E_5	0.5	1.5
E_6	0.6	1.8
F_1	0.6	1.8
F_2	0.5	1.5
F_3	0.8	2.4
T_1	0.6	1.8
T_2	0.7	2.1
T_3	0.3	0.9
T_4	0.8	2.4

Table 5
The results of the PROMETHEE II for candidate schemes with the utilization of linear function

Candidate schemes	Positive flow (φ^+)	Negative flow (φ^+)	Net flow (φ)	Rank
Scheme 3	0.6266	0.1555	0.4711	1
Scheme 1	0.6226	0.1924	0.4303	2
Scheme 2	0.5622	0.1639	0.3984	3
Scheme 6	0.1841	0.5661	−0.3820	4
Scheme 4	0.2030	0.6349	−0.4319	5
Scheme 5	0.1246	0.6105	−0.4859	6

Table 6
The results of the PROMETHEE II for candidate schemes with the utilization of level function

Candidate schemes	Positive flow (φ^+)	Negative flow (φ^+)	Net flow (φ)	Rank
Scheme 3	0.6203	0.1555	0.4648	1
Scheme 1	0.6208	0.1882	0.4325	2
Scheme 2	0.5585	0.1598	0.3987	3
Scheme 6	0.1777	0.5642	−0.3865	4
Scheme 4	0.2030	0.6308	−0.4278	5
Scheme 5	0.1228	0.6045	−0.4817	6

Table 7
The results of the PROMETHEE II for candidate schemes with the utilization of Gaussian function

Candidate schemes	Positive flow (φ^+)	Negative flow (φ^+)	Net flow (φ)	Rank
Scheme 3	0.4561	0.0753	0.3808	1
Scheme 1	0.4567	0.1091	0.3476	2
Scheme 2	0.3843	0.0795	0.3048	3
Scheme 6	0.1181	0.4275	−0.3094	4
Scheme 4	0.0940	0.4205	−0.3264	5
Scheme 5	0.0519	0.4492	−0.3974	6

the utilization of linear, level and Gaussian function, respectively.

Fig. 5 presents the partial ranking, while Fig. 6 presents the complete ranking of alternatives schemes from best to worst in terms of their net flow with the utilization of linear function.

The indices shown in Tables 5–7 quantify the degree to which each scenario outranks (positive value) or is outranked (negative value) by the others and add up to zero. The optimal balance among the social, environmental, financial and technical criteria is achieved by the candidate management scheme 3. More specifically, the priorities for the treatment of ELVs are in the following order: *scheme 3*, *scheme 1*, *scheme 2*, *scheme 6*, *scheme 4*, *and scheme 5*.

Fig. 7 is provided by the Profile option of the DECISION LAB software and presents the comparison of the six candidate schemes preference in proportion of different criteria. The scores are between +1 (being the best) and −1 (being the worst). With these evaluations the strong and the weak sides of each management scheme are known in advance.

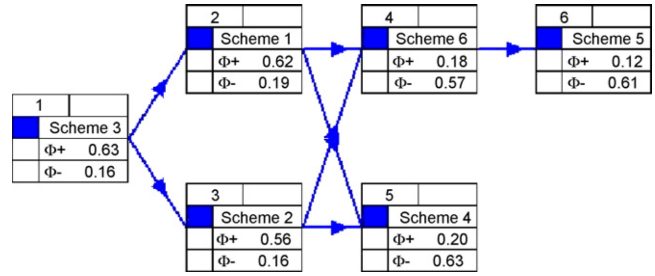

Fig. 5. PROMETHEE I partial ranking of the alternative candidates' management schemes for the treatment of ELVs in Cyprus with the utilization of linear function.

As illustrated in Fig. 7, financial and technical criteria have a positive impact on alternative schemes 1, 2 and 3. On the other hand, these specific criteria influence negatively the alternative schemes 4, 5 and 6. Even though scheme 3 is the strongest scheme according to the overall scores, it is quite weak in air emissions (E_2) and noise pollution (E_5). When the second strongest scheme is considered (scheme 1), it is seen that the ratio of production of solid outcast (E_1), the ratio production of humid waste (E_3) and the ratio level of possible environmental repercussions (E_4) is quite low. The third in the list of performances is scheme 2. It shows moderate performance.

It should also be mentioned that in the criterion S_4 that is possibilities of new job positions, the preference for schemes 1, 2, 4 and 3, 5, 6 have a negative and positive net flow, respectively. Based on this criterion the latter schemes have preference over the former schemes. Those criteria which do not have any bar such as S_3 that is social acceptance for schemes 1 and 6 shows that these two schemes have the same preference over each other.

Resorting to the Walking Weights option of this software the user can see the result of the evaluation through changing the weights of the criteria. Therefore, this option is appropriate for analyzing the sensitivity of the decision problem with respect to the weights of the criteria.

Sensitivity analysis seeks to learn how variations in the input change the output of a model [29]. The output must be interpreted with great care whenever it varies significantly for input fluctuations that are within the real of error or – perhaps more appropriate – within the realm of confidence in their values [30]. Saltelli et al. [31] provided an introduction as well as survey of sensitivity techniques.

Firstly, with sensitivity analysis, the importance of broad uncertainties in data and models is assessed by the DMs. Furthermore, they can judge whether the analysis is necessary or whether they need to gather more data to allow a more sophisti-

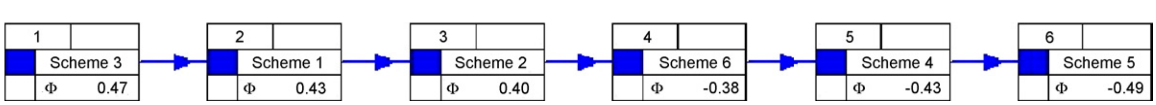

Fig. 6. PROMETHEE II complete ranking of the alternative candidates' management schemes for the treatment of ELVs in Cyprus with the utilization of linear function (schemes are ranked from the most preferred on the extreme left hand side to the least preferred on the extreme right hand).

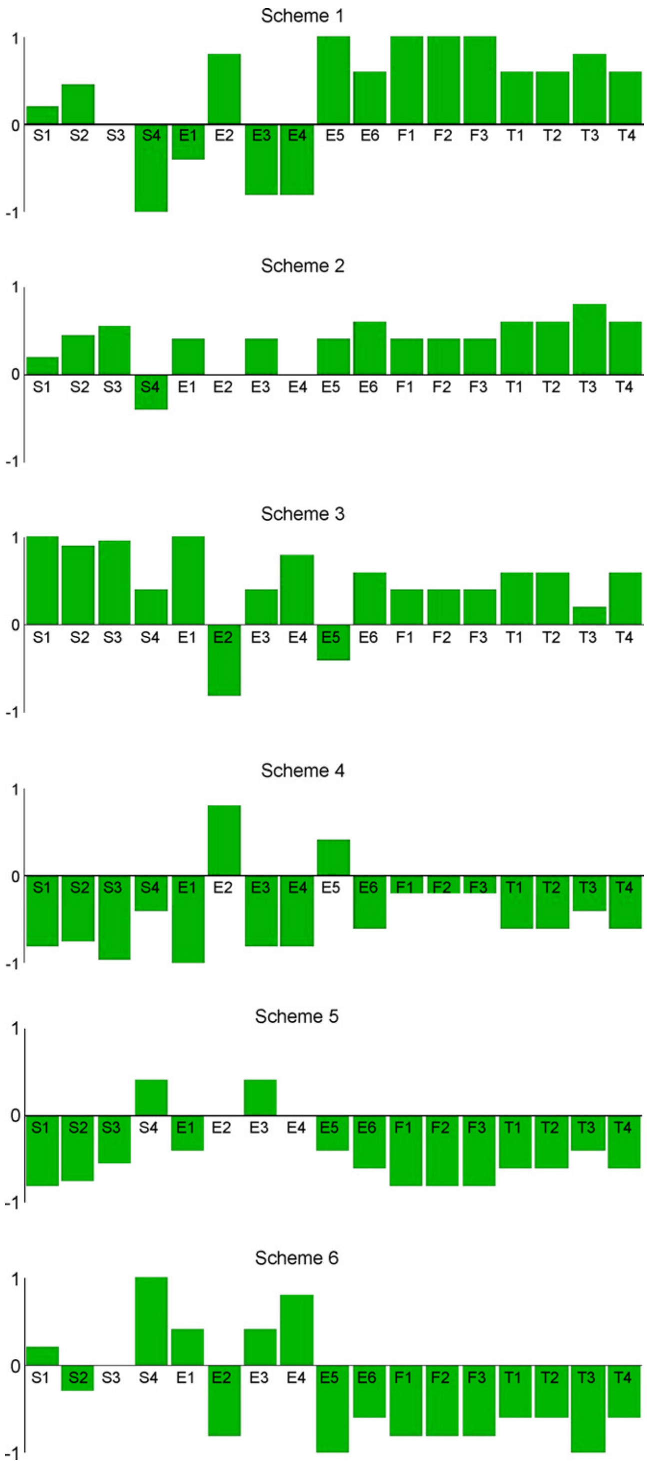

Fig. 7. Comparison of the six candidate schemes preference in proportion of different criteria.

cated analysis [32]. Secondly, it can help build consensus among the DMs [33].

Table 8 gives for each criterion the limits within 'weight values' can vary without changing the PROMETHEE II complete ranking with utilization of linear, level and Gaussian function.

On the basis of the values of Table 8, it can be concluded that the variation of specific criteria weights, such as T_4, E_6, T_1, T_2, and S_2 cannot change the PROMETHEE II complete ranking, while the criteria F_1, E_1 and T_3 have the greatest impact on the complete ranking. In Table 9, analytical information concerning the alteration of the PROMETHEE II complete ranking by the variation of those criteria weights is presented with the utilization of linear function. Similar results are obtained, as regards the alteration of the PROMETHEE II complete ranking by the utilization of level and Gaussian as preferences functions, and for this reason are not presented here.

As shown in Table 9, the highest impact on the candidate management schemes is because of the variations of the factor concerning the total investment cost. Variations from 12 to 18% and 22% have as a result the candidate scheme 1 to be presented as the preferable solution. Moreover, scheme 1 seems to be the best compromise scheme with the decrease of the factor regarding the level of possible environmental repercussions from 7.5%

Table 8
Stability intervals for linear, level and Gaussian function

Criteria	Weight	Linear (%)		Level (%)		Gaussian (%)	
		Min.	Max.	Min.	Max.	Min.	Max.
S_1	4.50	0.00	100.00	0.49	100.00	1.04	100.00
S_2	4.50	0.00	100.00	0.00	100.00	0.00	100.00
S_3	3.75	0.00	9.02	0.17	9.84	1.71	12.11
S_4	2.25	0.00	7.18	0.00	7.46	0.47	10.75
E_1	7.50	4.72	11.04	5.32	11.24	5.81	14.75
E_2	6.00	2.10	8.34	1.86	7.86	0.00	7.57
E_3	6.00	2.69	8.43	3.40	8.57	2.47	13.81
E_4	6.00	3.54	9.60	4.07	9.81	4.74	15.87
E_5	3.00	0.00	5.75	0.00	5.18	0.00	4.71
E_6	1.50	0.00	100.00	0.00	100.00	0.00	100.00
F_1	12.00	7.06	17.61	6.75	16.49	0.84	15.22
F_2	12.00	7.06	17.61	6.75	16.49	0.84	15.22
F_3	6.00	0.73	12.00	0.40	10.79	0.00	9.44
T_1	6.25	0.00	100.00	0.00	100.00	0.00	100.00
T_2	7.50	0.00	100.00	0.00	100.00	0.00	100.00
T_3	6.25	0.00	12.23	0.00	11.03	0.00	10.28
T_4	5.00	0.00	100.00	0.00	100.00	0.00	100.00

Table 9
PROMETHEE II complete ranking by the variation of specific criteria weight coefficients

Variation of criteria weights	PROMETHEE II complete ranking of candidate management schemes
Total investment cost	
12% → 6%	3 → 2 → 1 → 6 → 4 → 5
12% → 17%	3 → 1 → 2 → 6 → 4 → 5
12% → 18%	1 → 3 → 2 → 6 → 4 → 5
12% → 22%	1 → 3 → 2 → 4 → 6 → 5
Level of possible environmental repercussions	
7.5% → 4%	1 → 3 → 2 → 4 → 6 → 5
7.5% → 9%	3 → 1 → 2 → 6 → 4 → 5
7.5% → 11%	3 → 1 → 2 → 6 → 4 → 5
7.5% → 17%	3 → 2 → 1 → 6 → 5 → 4
Adaptability in the local conditions	
6.25% → 4%	3 → 1 → 2 → 6 → 4 → 5
6.25% → 8%	3 → 1 → 2 → 6 → 4 → 5
6.25% → 11%	3 → 1 → 2 → 6 → 4 → 5
6.25% → 13%	1 → 3 → 2 → 6 → 4 → 5

to 4% and with also the increase of adaptability in the local conditions from 6.25 to 13%. These variations correspond to the most pessimistic conditions as in this way the significance of the rest examining criteria is underrated.

4. Conclusions

The present work proposed a specific MCDA approach to select the best compromise alternative scheme for treating vehicle at its EOL. This selection is based on the comparisons of EOL alternatives according to their performances with respect to relevant social, environmental, financial and technical indicators.

The MCDA approach is based on PROMETHEE method and is implemented from the perspective of Cyprus interests. The analysis proceeds to a step-wise multi-criteria screening by which the six alternative management schemes are hierarchically ordered by way of Cyprus to meet the 2015 recycling quotas. Generally, the first phase regards the depollution and the dismantling (partial or complete) of ELVs, while the second phase concerns the shredding of the hulk where the recovery of ferrous and nonferrous metals is achieved. Three options are considered for the third and last phase of ASR: landfilling, thermal recovery of combustible residue and utilization of noncombustible fraction for the cement production.

The obtained results show that the management scheme 3 (partial disassembling – shredding – separation – recovery of ferrous and nonferrous metals – thermal recovery of combustible shredded residues – utilization of noncombustible shredded residues in cement industries) and scheme 1 (partial disassembling – shredding – separation – recovery of ferrous and nonferrous metals – landfilling of shredded residues) constitute the most preferable solutions in the case of Cyprus. One important thing that can also be concluded is that schemes with partial disassembling are preceded to the ones with complete disassembling. This can be explained logically by two reasons:

- the fleet of ELVs in Cyprus is lower comparing with the other EU Member States. Consequently, plant depreciation for dismantling and shredding companies is not certain, at least in the near future,
- no dismantling and shredder centre exists in Cyprus at present. Therefore, problems which may arise from the operation of such centers cannot be confronted to great extent.

The three R management practices were taken into account for the development of the multi-criteria analysis. The RRR rates could be increased, especially energy recovery (via thermal treatment of ASR) and parts reuse (via dismantling of the ELV). Additionally, this methodology could reduce the ASR landfilling with its utilization in cement industry. Moreover, the approach followed through the method could be used for the development of management schemes and systems in other environmental sectors in Cyprus (management of hazardous waste, used oils, used tyres, sludge, WEEE, etc.). Furthermore, the multi-criteria analysis method that was developed could be used as a guide for handling other waste streams in other EU countries and at international level, since waste management of certain waste streams is considered as significant environmental issue for many countries. European and other countries can follow the same methodology and approach to deal with similar problems.

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