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MULTICRITERIA ANALYSIS FOR SUSTAINABLE WATER RESOURCES PLANNING: A CASE STUDY IN SPAIN

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Analyse multicritère de la planificattion soutenable des ressources en eau:un cas d'espèce espagnol.

Résumé

On applique une analyse multicritèreà la gestion d'une surface irriguée, Flumen Monegros située dans la province espagnole deHuesca. Les critères d'évaluation Comprennent:1)des grandeurs économiques,tels les cûts d'investissement et de maintenance, les bénéfices provenant de la vente des récoltes, subventions de la communauté européenne; 2)facteurs environnementaux, tels le volume d'eau utilisé,la qualité des eaux usées après irrigation, efficacité de l'utilisation de l'eau,et la résistance aux inondations et sécheresses 3) facteurs sociauxtels main-d'œuvre rurale employée aire non cultivée.. les politiques alternatives sont forméespar la combinaison deséléments: type d'irrigation, tarification et allocation de l'eau. palette de cultures, engrais utilisés.subventions reçues. La matrice d'évaluation obtenue étant trop vomumineuse, on rédui tle nombre d'alternatives à l'aide d' ELECTRE TRI. Cinq techniques multicritères, PROMETHEE-2, EXPROM-2,ELECTRE3 et 4, et compromise programmingsont appliquées à la classification des alternatives. Le coedfficient de correlation de rang de Spearmanest calculé pour évaluerles corrélations entre les classifications issues des differentes méthodes. On trouve que La stratégie préférée par les cinq techniques est la même.

Mots-Clés

Décision multicritère,planification de l'irrigation, ELECTRE TRI, coefficient de Spearman, Espagne.

1. Introduction

The Mediterranean region has long seen extensive irrigation networks to allow agriculture in this dry and arid area. However, the growth of human population has resulted in more intensive agricultural practices and the use of irrigation systems. Considering the growing importance of irrigation systems all around the Mediterranean, there is fear that intensive use of water resources may lead to water sustainability problems in these countries. Furthermore, policies are being devised by governments to regulate this water use. These policies may be oriented towards the economic criterion which is used to consider the profitability of a strategy and its economic consequences. However, the present study suggests a suitable alternative strategy by also considering environmental and social consequences to account for the sustainability concept in a more realistic and practical way.

On the other hand, Multicriteria Decision Making (MCDM) techniques are gaining importance as potential tools for complex real world problems because of their inherent ability to judge different alternative scenarios for possible selection of the best which may be further analysed in depth for its final implementation. This decision making shares common characteristics such as the presence of multiple non commensurable and conflicting criteria, different units of measurement among the criteria, and the presence of quite different alternative policies [LOUCKS *et al.* (1981), GOICOECHEA *et al.* (1982), SZIDAROVSZKY *et al.* (1986), BOGARDI (1994), POMEROL and CAMERO (2000)]. Multicriterion Decision Making suggested as [CONNEL *et al.* (2000)] one of the approaches for developing sustainable water resources management. Although application oriented papers [DUCKSTEIN *et al.* (1994), BENDER and SIMONOVIC (2000)] have tried to bridge the gap between theory and practice, much is still left to be done to apply the MCDM approach to real engineering planning and design problems involving conflicting objectives. The study is divided into following sections. Section 2 deals with problem description and formulation of payoff matrix. Section 3 deals with application of Multicriteria Sorting Technique (MCST) ELECTRE-TRI to reduce the payoff matrix to a manageable set. Section 4 deals with brief description and application of five MCDM techniques, namely, PROMETHEE-2, EXPROM-2, ELECTRE-3, ELECTRE-4, and Compromise Programming (CP) to rank alternatives along with correlation analysis followed by discussions and conclusions.

2. Problem description and formulation

The study area comprises two administrative districts: Hoya de Huesca and Monegros. The total area of both districts is 85,500 hectares, of which around 61,200 (71.6%) are cultivated and 44,900 (52.5%) are under irrigation [BREUIL *et al.* (2000)]. The climate is semiarid with insufficient rain during the whole year. Irrigation is thus essential to enable agricultural production. Water deficits in both areas are common. The source of irrigation water is the Sotonera dam, which has a capacity of 187 million cubic meters (Mm^3), and supplemental water from the Cinca river system. There are around 13,200 hectares of soils with problems of salinity and sodality. Two important aspects in the soils of the area are salinity and water holding capacity. The latter criterion determines irrigation efficiency. Because of soil characteristics and the fact that the study area is surface irrigated, irrigation efficiency is estimated at 40 to 80% depending on soil quality (These efficiencies have been used to calculate the irrigation water needed by crops).

2.1 Identification of criteria

Three groups of criteria are identified and are given below with notations.

1. Economic factors including Initial cost often paid by the State (C1), Maintenance cost (C2), Profitability of crops (C3), Extent of European subsidies (C4).

2. Environmental (sustainability based) factors including Irrigation water volume (C5), Water quality after irrigation (C6), Efficiency of water use (C7), Resistance to floods or droughts (C8).

3. Social factors including Employment of the population (C9), Land area which is not cultivated (C10).

A scale of 0-100 is chosen to rank the criteria (100 for very high important, 80 for very important, 60 for important, 40 for average, 20 for satisfactory and 0 for unsatisfactory). However option is also given to decision maker to choose the intermediate values to minimize subjectivity while estimating the weights. These weights are [40, 40, 80, 40] for economic factors, [40,25,25,10] for environmental factors and [50,50] for social factors. Normalised weights are [0.1, 0.1, 0.2, 0.1] for economic factors, [0.1, 0.06, 0.06, 0.03] for environmental factors and [0.125, 0.125] for social factors.

2.2 Formulation of alternative strategies

The following six factors are found to be useful to define a set of alternative strategies (policies) that could change the planning scenario of the irrigation system and are presented in Table 1.

1. Various irrigation systems (factor A with three levels representing A1: Surface, A2: Sprinkler , A3: Drip)

2. Price of water in the district chosen (factor B with three levels representing B1: Do nothing , B2: Raise Prices to 10 ptas/m^3 , B3: Raise Prices to 20 ptas/m^3).

3. Water allocation in the district chosen (factor C with three levels representing C1 : Do nothing , C2 : Market of quotas , C3: Assigned quotas).

4. Distribution of crops over the area studied (factor D with four levels representing D1 : Do nothing , D2 : Wheat/barley, D3 : Fruit and vegetables, D4 :Sugar beet).

5. The kind of fertiliser used, with different consequences for the environment (factor E with three levels representing E1 : Do nothing, E2 : Use of city sludge , E3 : Green fertilisers).

6. Policy of subsidies from the European community (factor F with two levels representing F1 : Yes, F2 : No).

It may be noted that the element subsidies belongs to both the criterion set under C4 and the alternative set (element 6, Factor F). Actually, C4 is controllable by the region, as an "endogenous " factor, while F is not controllable, it depends on EC policy and is thus an "exogenous" factor. Subsidies have an effect on practically on all elements of the payoff matrix (alternatives versus criteria).

Every factor and its subdivisions are evaluated by a team of experts who are familiar with the planning area by considering economic, environmental and social criteria. Non-numerical indicators are used for evaluation. Table 1 presents a linearly quantified matrix (actions versus direct consequences on different system criteria). Notations are as follows: A represents very high / very cheap; B, good/cheap ; C, average ; D, poor/low ; E, very poor/very low ; X, No effect for the planning problem. These are converted into numerical values 50, 40, 30, 20, 10, 0 for further usage. Details of the factors are explained below with reference to the case study and Table 1.

Table 1
Quantitative matrix : actions versus direct consequences on different system criteria

	A1	A2	A3	B1	B2	B3	C1	C2	C3	D1	D2	D3	D4	E1	E2	E3	F1	F2
C1	A	C	E	X	X	X	X	X	X	A	C	E	C	C	A	D	X	X
C2	B	C	E	B	E	E	X	X	X	D	C	E	D	X	X	X	X	X
C3	C	C	B	A	C	E	X	X	X	B	B	A	A	B	B	B	X	X
C4	X	X	X	X	X	X	X	X	X	B	A	E	E	E	B	C	B	E
C5	E	C	A	D	D	B	D	B	B	D	B	C	A	X	X	X	X	X
C6	E	C	B	X	X	X	X	X	X	D	D	E	A	D	E	B	X	X
C7	D	C	A	X	X	X	X	X	X	D	C	A	X	X	X	X	X	X
C8	E	A	A	X	X	X	X	X	X	D	B	D	C	D	E	A	X	X
C9	A	C	D	C	D	E	C	E	D	D	D	B	D	C	B	C	B	E
C10	X	X	X	C	D	E	C	E	D	C	D	E	D	C	D	B	B	E

2.2.1 Evaluating irrigation systems

The first irrigation system evaluated is surface irrigation. This system is given high marks for initial cost because it is already in place in most parts of the study region.

It should thus not need any further development. A good mark is given in terms of maintenance costs. Indeed, such a system only needs constant unspecialised labour to take care of the water channels. Profitability is given an average mark considering better performances from other irrigation systems. Because of its high use of water and low efficiency, surface irrigation is given bad to very bad marks on its environmental component. Finally, this system is given a high mark for employment considering it needs a lot of unskilled labour force to maintain the system in working order. The sprinkler irrigation system is given average marks in terms of economic income because both initial costs and maintenance costs can be quite high. Likewise, this irrigation system is given average marks for its environmental and social components considering the range of possible ratings on these two groups of criteria. The drip irrigation system is given very bad marks for its initial cost because of the special equipment required. It is also given bad marks for maintenance costs because of the expensive skilled labour required to keep it working. However, a good mark is given for the profitability of crops, drip irrigation being used to the crop's best advantage. A very high mark is given to the drip irrigation system in terms of environmental criteria because of its low use of water and high efficiency. A restraint is given in terms of water quality after irrigation to take account of the risk of increasing local soil salinity. Finally, drip irrigation is given a bad mark for its social criterion because it does not need a lot of unskilled labour and thus does not encourage employment in the region.

2.2.2 Evaluating water allocation and water pricing

Possible water pricing actions are divided into three different sets of actions. The "Do nothing" scenario includes no specific change in the actual water pricing and water allocation policy. This means water is priced at 2 ptas/m^3 (15.6 dollars/ acre foot) and allocated using the system described above. Two "Raise prices" scenarios are used. The thresholds 10 ptas/m^3 and 20 ptas/m^3 are chosen because these limits are those of inelasticity and elasticity of the water demand. A good mark is given to the "Do nothing" scenario because it did not burden farmers with a supplementary cost. Both "Raise prices" scenarios are given very bad marks for different reasons. When one raises the water price to 10 ptas/m^3 the demand stays inelastic and there is no influence on the water volume used by farmers. They use as much water as before and pay more. As for the 20 ptas/m^3 scenario, the demand starts becoming elastic. However, though farmers use less water, water price is higher and the overall price is still high. Only the 20 ptas/m^3 scenario is given a good environmental influence mark because it directly influences the total water volume used. Both "Raise prices" scenarios are given bad marks on the social criteria. Indeed, it is considered that increasing water prices would deter some farmers from taking care of their land which would decrease employment in the region as well as increase the area of non cultivated land. Both scenarios of water quotas are judged to be more environmentally friendly because they reduce the total volume of water used. On the other hand, the "Market of quotas" scenario is considered very bad on the social criteria because it enables water marketing. This system would enable farmers not to farm their land and still receive an income from their water marketing. Both unemployment and area of non cultivated land would thus rise.

2.2.3 Evaluating crop systems

Four different scenarios are considered. The "Do nothing" scenario considers the present distribution of crops in the region. The essential characteristic of this scenario is the maintenance of a diverse crop rotation and the use of rice. Such crops need a lot of irrigation water. Such a scenario is thus given very good marks in the initial costs because it does not require any change from the old system of production. Recent studies of the area show that the actual system still gives a good profitability margin [BREUIL *et al.* (2000)]. However due to the high use of water for rice growing, this scenario receives bad marks on its environmental criteria. The "Wheat/barley" scenario is an alternative to the former scenario because both these crops can give a good yield while being produced under dry conditions. It is also a staple of the existing crop distribution. It thus received average marks for initial and maintenance costs. However these cereals are highly subsidised by the Common Agricultural Policy (CAP) which gives the farmers growing these crops some incentive. Wheat and barley production have good marks as regards the environmental criteria. Indeed, these crops are sown in the autumn, the soil is thus covered by grass nearly all year long. This highly reduces risks of soil loss caused by erosion. However, the changing of cropping system may encourage some farmers not to bother and to change their activity thus increasing unemployment and the area of non cultivated land. The "Fruit and vegetables" scenario is chosen because of its high profitability and the possibility of growing such crops in a sunny area. However, the implementation of such an action would be very costly to farmers who would have to change completely their production system. Furthermore, fruit and vegetables do not receive any subsidy from the CAP. All revenues must come from the crops themselves. Fruit and vegetables also use a considerable amount of fertiliser and fungicides. This deteriorates the water quality after irrigation. On the other hand, efficiency of irrigation is generally good considering the big intake of water by these crops. Fruit and vegetables are also particularly vulnerable crop to natural hazards which results in getting a bad mark for resistance to floods and droughts. Finally, these crops are a good way of creating seasonal labour for harvesting but surplus land area not occupied by fruit is generally left abandoned. Finally, a "Sugar beet" scenario is studied because of its very good profitability and its not needing water for irrigation. However, there is no CAP subsidy system for sugar beet, the crop being regulated by a quota for each country of land area that may be planted with beets. The advantages of this crop come mainly from its not needing any irrigation water. The other factors are seen as identical to those of other crops.

2.2.4 Evaluating fertiliser use

Because there are no important animal farms in the region, animal manure is not considered as fertiliser. The "Do nothing" scenario involves use of chemical fertiliser. This scenario mainly has disadvantages, the only advantage being its good fertilising power and thus a good profitability of crops. It has been decided to add the scenario "Use of city sludge". This scenario, though being very polluting has economic advantages: the cities may be ready to pay the farmers to get rid of their sludge. It can also help start up a delivery network and thus develop labour around this network. Finally, the scenario "green fertiliser" has mainly environmental advantages. But this scenario implies that farmers must plough and sow their field twice a year which can be costly in hourly labour and fuel for the tractors. Furthermore, the seeds for the green fertiliser must be bought. All these factors gave a bad mark for the initial cost of the practice.

2.2.5 Subsidies from the european community

In European Community (EC) countries, agriculture is subsidised by the Common Agriculture Policy (CAP). These subsidies depend on the type of crop, and on the surface of plots.Though most direct subsidies as a percentage of production have been eliminated due to concern of unfair trade distortion, actual subsidies are based on the production area of a farm. The trade issues today in the EC are based in principle on the reorientation of all agricultural subsidies to the preservation of the public good, environment and landscape. Farmers will in effect receive money not according to their production level but according to their level of environmental action. Some subsidies are to be placed into an "eco-conditionality" clause: farmers will be subsidised only if they show sufficient environmental friendliness.

Starting from the set of six elements (irrigation system, water pricing, water allocation, crop distribution, fertilisers and subsidies) and their subdivisions all these elements are mixed to create alternative policies. From the eighteen factors in the Table 1, divided into six major sectors, the total number of combinations leads to 3x3x3x4x3x2 = 648 different alternative policies. Out of 648 policies 487 policies are discarded (161 remained) with the approval of experts and the decision maker (here the second author) as they are found to be incompatible and irrational due to the reasons such as the following ones:

- All scenarios combining surface irrigation and use of city sludge are not considered because such an action is too damageable to the environment.

- Drip irrigation for sugar beet crop is not taken into account considering sugar beet does not need any irrigation and thus has no need of a sophisticated irrigation system.

- The fruit and vegetables and use of city sludge combinations are not considered because direct contact of city sludge with the produce would not be accepted by the consumer, and public or health authorities.

- Raising water prices and cutting off CAP subsidies automatically changes the crop distribution. Accordingly, all scenarios where water prices are raised and/or CAP subsidies cut off while the crop distribution stays unchanged are discarded [BREUIL *et al.* (2000)].

- The policy that combines drip irrigation and low water prices is also discarded because of the important costs needed to transform the existing irrigation system into drip irrigation. This initial cost would be too high considering the low price of water used by the current surface irrigation. On the other hand, the opposite scenario of surface irrigation and very high water prices is deleted. Since surface irrigation uses a lot of water, raising water prices would deter farmers from using this irrigation system.

- The combination of low water prices and water quotas is not taken into account.

- Finally, the scenario combining unchanged CAP subsidies and a market of quotas policy is discarded because the liberal policy of marketing water quotas would be contradictory to the subsidies given to agriculture.

Decision maker felt that size of the payoff matrix (161 alternatives and 10 criteria) is still large for further evaluation with MCDM techniques [ROGERS *et al.* (2000)]. They suggested that if too many options are identified at the start of the process and some of the chosen options are so closely linked that they are variants of each other, these can be represented by one option for the purpose of decision making. In this study effort is made to utilise ELECTRE-TRI as a screening procedure in advance of the application of a ranking procedure as explained below.

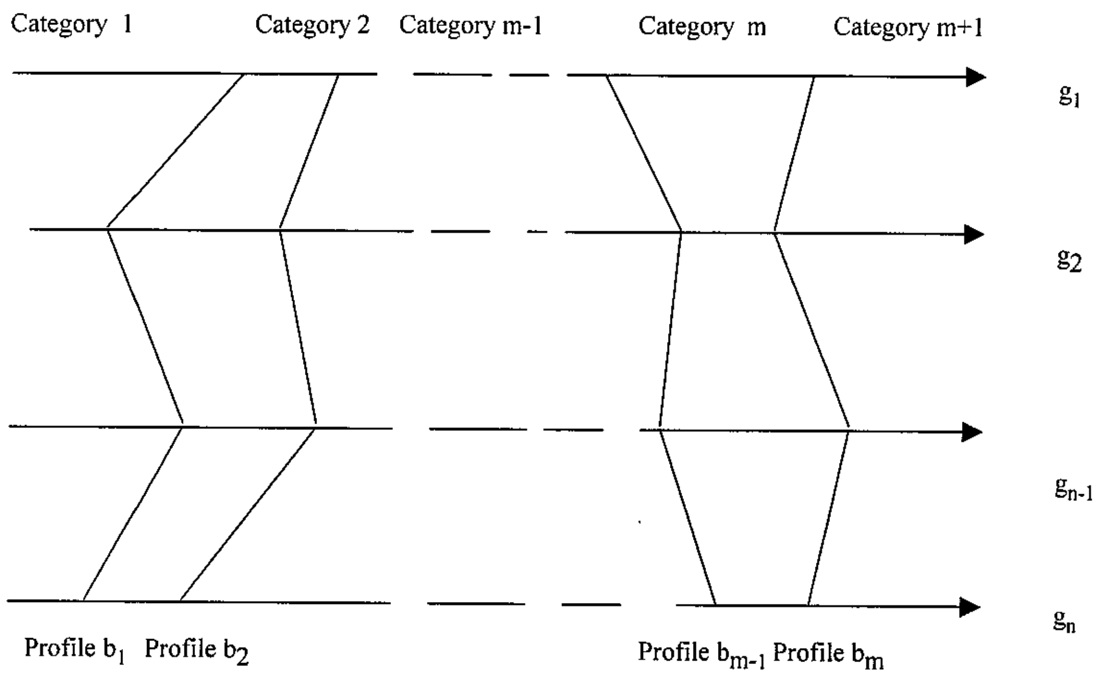
3. Description and application of ELECTRE-TRI

ELECTRE-TRI is a multiple criteria assignment method. It allows the assignment of actions (or alternatives) to some predefined ordered categories [YU (1992), ROY and BOUYSSOU (1993), ARONDEL and GIRADIN (2000), ROGERS *et al.* (2000)]. Figure 1 presents different criteria, categories and profiles (g is the notation for criterion, n the number of criteria). One assumes that preference increases with the value of each criterion. The limit between two consecutive categories is formalised by a profile (or 'reference action'). Each category is defined by two profiles : a lower profile and an upper profile (for example, category C_m is defined by the lower profile b_{m-1} and the upper profile b_m). Categories are mutually exclusive: One action cannot be assigned to two different categories. In order to assign each action to one category, the action is compared with the profiles. The ELECTRE-TRI method proceeds in two consecutive steps:

Step 1 : Construction of an outranking relation S : Let a be the action and b_h be the upper profile of category C_h (and also the lower profile of category C_{h+1}). ELECTRE-TRI uses an outranking relation S, i.e., validates or invalidates the assertion aSb_h (and b_hSa), whose meaning is ' a is at least as good as b_h' . In order to validate the assertion aSb_h (or b_hSa), two conditions concordance and non discordance should be verified. An index $\sigma(a,b_h)$; $\sigma \in [0,1]$ is built and represents the degree of credibility of the fuzzy outranking relation assertion aSb_h (or b_hSa). In order to obtain a crisp (non-fuzzy) relation S, a cutting level λ is introduced ($\lambda \in [0.5,1]$). The assertion aSb_h (or b_hSa) is considered to be valid if $\sigma(a,b_h) \geq \lambda$ ($\sigma(b_h,a) \geq \lambda$).

Step 2: Exploitation of 'S' in order to assign actions to categories : Two assignment procedures namely, pessimistic (conjunctive) and optimistic (or disjunctive) are available. The role of these exploitation procedures is to analyse the way in which an action a is compared to the profiles so as to determine the category to which action a should be assigned.

Figure 1
Description of categories and profiles for ELECTRE-TRI method



ELECTRE-TRI method is applied using the software ELECTRE-TRI [MOUSSEAU *et al.* (1999)]. The software uses two sorting processes : an optimistic assignment (disjunctive logic: the best ranked criterion determines the assignment) and a pessimistic assignment (conjunctive logic : the worst ranked criterion determines the assignment). In the present analysis cutting level λ=0.5 is considered (with out considering veto thresholds) in which case both optimistic and pessimistic assignments are the same. Boundaries of the profiles for each criterion are determined by the decision maker through category profiles. In the present study seven profiles Pr01 to Pr07 are proposed (i.e., 8 categories CA01 to CA08). Pr01 represents profile between best (CA01) and second best (CA02) categories. Other profiles are similarly defined. Figure 2 presents the boundaries of profiles defined for each criterion. Indifference, preference thresholds are fixed at zero and ten for each criterion and for each profile. These are fixed after detailed discussion with the decision maker. Among eight categories, remaining 161 alternatives have fallen into 7 categories (CA01 to CA07). There is no alternative in category 8. Same alternatives are assigned in both optimistic and pessimistic assignments due to value of λ=0.5 (as no veto thresholds are considered). Out of 161 alternatives, 9 alternatives fall into category 1, and 20, 17, 32, 41, 41, 1 into categories 2,3,4,5,6,7. It is assumed that alternatives in a particular category are equivalent. However, a sum of squared error methodology is employed to select one alternative from each category. The alternatives having minimum total squared error value from ideal values of each category are computed. Table 2 presents the payoff matrix representing 7 alternative strategies (representing 7 categories) for 10 criteria.

Table 2
Payoff matrix

Alternative	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
1	80	100	210	120	110	90	60	140	180	160
2	100	90	210	110	90	90	50	120	180	170
3	80	70	190	120	110	90	60	140	170	150
4	80	70	170	120	130	90	60	140	160	140
5	90	50	160	100	130	70	80	100	140	100
6	60	50	160	90	150	100	80	140	120	110
7	90	60	140	30	160	100	30	100	110	80

In Table 2 alternative 1 indicates combination of sprinkler irrigation system, with no change in the existing water pricing and allocation policy. Wheat/ Barley is the growing crop with green fertilisers and without change in the present subsidy policy. Alternative 2 is a modification of alternative 1 with out change in the existing cropping pattern i.e., rice. Alternative 3 is a modification of alternative 1 with an increase of water pricing to 10ptas/m^3. Alternative 4 is modification of alternative 1 with increase of water pricing to 20ptas/m^3 by keeping other factors the same. Alternative 5 is quite different from alternative 1. Alternative 5 indicates a combination of drip irrigation system with increase of water pricing to 10ptas/m^3 with existing water allocation policy. Wheat/barely as the growing crop with city sludge as fertiliser and with subsidies cut off. Alternative 6 indicates a combination of drip irrigation system with increase of water pricing to 10ptas/m^3 with introduction water quotas. Wheat/barely as the growing crop with green fertilisers and with subsidies cut off. Alternative 7 indicates combination of sprinkler irrigation system, with increase of water pricing to 20ptas/m^3 with introduction market quotas. Sugar beet is the chosen crop with existing fertiliser policy and subsidies cut off. It is observed that surface irrigation system and fruit and vegetables scenarios drop out of the analysis: these alternatives may not be feasible for the planning problem as modelled herein.

4. Description and application of multicriteria decision making techniques

In the present study five MCDM techniques, namely, PROMETHEE-2 (outranking), EXPROM-2 (combination of outranking and distance), ELECTRE-3 (outranking), ELECTRE-4 (outranking) and Compromise Programming (CP; distance) are applied to the planning problem. Brief description of the MCDM techniques are presented below.

4.1 Description of MCDM techniques

PROMETHEE-2 (Preference Ranking Organisation METHod of Enrichment Evaluation) is of outranking nature. The method uses preference function $P_j(a,b)$ which is a function of the difference d_j between the ratings of two alternatives for every criterion j i.e., $d_j = f(a,j)-f(b,j)$ where $f(a,j)$ and $f(b,j)$ are values of criterion j of two alternatives a and b. Six types of criterion functions, namely, Usual criterion, Quasi criterion, Criterion with linear preference, Level criterion, Criterion with linear preference and indifference area and Gaussian criterion are proposed [BRANS *et al.*(1986)]. Indifference and preference thresholds q' and p' may also have to be defined depending on the type of criterion function. Multicriteria preference index, $\Pi(a,b)$, a weighted average of the preference functions $P_j(a,b)$ for all the criteria is defined as

$$\pi(a,b) = \frac{\sum_{j=1}^{J} w_j P_j(a,b)}{\sum_{j=1}^{J} w_j} \quad (1)$$

$$\phi^+(a) = \sum_A \pi(a,b) \quad (2)$$

$$\phi^-(a) = \sum_A \pi(b,a) \quad (3)$$

$$\phi(a) = \phi^+(a) - \phi^-(a) \quad (4)$$

where w_j = Weight assigned to the criterion j; $\phi^+(a)$ =Outranking index of a in the alternative set A; $\phi^-(a)$ = Outranked index of a in the alternative set A; $\phi(a)$= Net ranking of a in the alternative set A. The value having maximum $\phi(a)$ is considered as the best.

a outranks b iff $\phi(a) > \phi(b)$

a is indifferent to b iff $\phi(a) = \phi(b)$

EXPROM-2 is a extended version of PROMETHEE-2 method [DIAKOULAKI and KOUMOUTSOS (1991)] which is based on the notion of ideal and anti-ideal (maximum and minimum) solutions. The relative performance of one alternative over the other is defined by two preference indices, one by weak preference index (based on outranking i.e., Multicriteria preference index in PROMETHEE-2), and the other by a strict preference index (based on the notion of ideal and anti ideal). The total preference index $TP(a,b)$ i.e., summation of strict and weak preference indices in the fuzzy environment is taken as a measure of the intensity of preference of one alternative over the other for all criteria.

$$TP(a,b) = Min[1; SP(a,b) + WP(a,b)] \qquad (5)$$

where *WP (a,b)*=Weak preference index (Multicriteria preference index of PROMETHEE-2). The remaining procedure is the same as in the PROMETHEE-2 method.

ELECTRE-3 represents the characteristics of the decision maker's preferences by pairwise concordance and discordance tables calculated for each criterion [ROGERS *et al.* (2000)]. The concordance index $c_j(a,b)$ expresses the fuzzy membership value of the statement alternative a is at least as good as alternative b as far as criterion j is concerned, while the discordance index evaluates the 'compatibility of actions a and b, i.e., tests whether or not their range is beyond a veto threshold for the j th criterion scale. Using a set of criterion weights, it is then possible to aggregate these concordance and discordance indices into an overall credibility matrix which contains in row **A** and column **B** the general valuation for the assertion action a outranks action b, i.e., the relative positive global weight in favour of a (whenever a can be compared to b). As this fuzzy outranking relation is usually too refined for any practical use, a distillation procedure is implemented to approximate this complex pairwise comparison by two complete preorders obtained by 'cutting' the fuzzy outranking relations with slicing thresholds (distillation coefficients), first in a decreasing and then in an increasing order.

ELECTRE-4 is different from ELECTRE-3 as no criterion weights are incorporated in the method. The model avoids weights by assuming that no preference structure should be based on the greater or lesser importance of the criteria. No single criterion may dominate the decision making process. The method utilises five parameters Quasi-dominance S_q, Canonic dominance S_c, Pseudo dominance S_p, Sub dominance S_s, Veto - Dominance S_v to construct fuzzy outranking relationships. Degree of credibility *S(a,b)* is computed based on above five parameters. The outranking relationship is exploited using ascending and descending distillations. The partial preorder is constructed similar to ELECTRE-3. Excellent description of ELECTRE-3 and ELECTRE-4 are reported [ROGERS *et al.* (2000)].

Compromise Programming (CP) defines the 'best' solution as the one in the set of efficient solutions whose point is at the least distance from an ideal point [ZELENY (1982)]. The aim is to obtain a solution that is as 'close' as possible to some ideal. The distance measure used in Compromise Programming is the family of L_p - metrics and given as

$$L_p(a) = \left[\sum_{j=1}^{J} w_j^p \left| \frac{f_j^* - f(a)}{M_j - m_j} \right|^p \right]^{\frac{1}{p}} \qquad (6)$$

$L_p(a)$ = L_p - metric for alternative a, $f(a)$ = Value of criterion j for alternative a, M_j = Maximum (ideal) value of criterion j in set A, m_j = Minimum (anti ideal) value of criterion j in set A, f_j^* = Ideal value of criterion j , w_j = Weight of the criterion j, p = Parameter reflecting the attitude of the decision maker with respect to compensation between deviations. For p=1, all deviations from f_j^* are taken into account in direct proportion to their magnitudes meaning that there is full (weighted) compensation between deviations. For $2 \leq p \leq \infty$ the largest deviation has the greatest influence so that compensation is only partial (large deviations are penalised) . For $p=\infty$, the largest deviation is the only one taken into account (min-max criterion) corresponding to zero compensation between deviations (perfect equity).

4.2 Application of MCDM techniques

Multicriteria Decision Support System (DSS) MULTICRIT is employed to solve the PROMETHEE-2,EXPROM-2, Compromise Programming [RAJU and DUCKSTEIN (2000)]. ELECTRE-3 and ELECTRE-4 are solved using DSS developed by LAMSADE. All the programs are interactive in nature and capable of performing extensive sensitivity analysis. In all the four outranking techniques, namely, PROMETHEE-2, EXPROM-2, ELECTRE-3, ELECTRE-4 indifference and preference thresholds are fixed in compatibility with ELECTRE-TRI inputs. No veto thresholds are considered. However, extensive sensitivity analysis is performed for all the techniques to assess the ranking pattern for various thresholds, type of criterion functions, distillation coefficients.

In PROMETHEE-2 method type 3 criterion function is chosen because of its having no indifference area and a preference threshold approach. Table 3 presents the multicriteria preference index values and ϕ^+, ϕ^-, ϕ. It is observed that diagonal values are zero in the multicriteria preference index since comparison is then for the same alternative. Alternative 1 having highest ϕ value of 0.443 is best followed by alternative 2 having net ϕ value of 0.403. Alternative 7 is least ranked due to its low ϕ value of –0.468. In EXPROM-2 also type 3 criterion function is employed. Ideal and anti-ideal values are obtained from payoff matrix (Table 2). Two types of indices are formulated. Weak preference index is same as multicriteria preference index of PROMETHEE-2 as defined earlier [DIAKOULAKI and KOUMOUTSOS (1991)] . Strict preference index which is based on ideal and anti-ideal values are presented in Table 4. It is observed from Table 4 that some of the elements of strict preference index are significant. But these are always smaller than weak preference index values. Table 5 presents total preference index values which are the summation of weak and strict preference index values. If total preference index values are greater than 1, these are restricted to maximum value of 1 as evident from pair of alternatives (1,5), (1,6), (1,7), (2,5), (2,6), (2,7), (3,5), (3,6), (3,7) , (4,7) due to which ranking pattern may change. It is observed from Table 5 that alternative 1 having highest ϕ value of 0.584 is best followed by alternative 2 having net ϕ value of 0.486. Alternative 7 is least ranked due to its low ϕ value of –0.627. It is observed from Tables 3 and 5 that the ranking pattern is the same in both PROMETHEE-2 and EXPROM-2 irrespective of the contribution of the strict preference index. Table 6 presents credibility index values for ELECTRE-3. Distillation coefficients employed in this method are –0.15 and 0.3. The final ranking of alternatives resulting from intersection of 2 preorders are also given in Table 6. It can be seen that alternative 1 is best followed by alternatives 2,3 being tied at rank 2. Alternatives 4,5,6 are tied at rank 3. Table 7 presents the credibility matrix and ranking patterns of ELECTRE-4. Distillation coefficient employed in this method is 0.1. In this method, alternatives 1 and 4 are occupying first and second positions respectively. Alternatives 2 and 6 occupy third position whereas alternatives 3 and 5 are tied in fourth position. Ideal and anti-ideal values in Compromise Programming (CP) are obtained from Table 2. Alternative with the minimum L_p metric distance is selected as the compromise solution. Table 8 presents L_p metric values and corresponding ranking pattern for each alternative policy for three values of $p=1,2,\infty$. For $p=1,2$ alternatives 1 and 2 are ranked as best (due to low L_p metric values of 0.17932, 0.20211 for $p=1$ and 0.09365, 0.11155 for $p=2$) where as for $p=\infty$ these are 1 and 3. Based on the results in Table 8 it can be seen that when there is either full compensation between alternatives ($p=1$) or when there is a weighted deviation in proportion to the magnitude alternative 1 is found to be ranked best. In all the other cases alternative 7 is ranked last.

Table 9 presents the ranking patterns obtained by all MCDM techniques. Alternative 1 occupies first position in all the MCDM techniques. Alternative 2 occupies second position except in ELECTRE-4 and CP($p=\infty$). It is also observed that PROMETHEE-2, EXPROM-2 and CP($p=1$) provide the same ranking patterns. In all the techniques alternative 7 is last.

Table 3
Multicriteria preference index values and ranking pattern of PROMETHEE-2 (weak preference index values of EXPROM-2)

Alt.	1	2	3	4	5	6	7	$\phi^+(a)$	$\phi^-(a)$	$\phi(a)$	Rank
1	.000	.390	.550	.550	.740	.750	.740	0.620	0.177	0.443	1
2	.225	.000	.650	.650	.840	.750	.840	0.659	0.256	0.403	2
3	.000	.290	.000	.450	.740	.750	.740	0.495	0.340	0.155	3
4	.100	.290	.100	.000	.740	.750	.740	0.453	0.381	0.072	4
5	.260	.160	.260	.160	.000	.325	.610	0.295	0.605	-0.310	6
6	.220	.250	.220	.220	.315	.000	.640	0.310	0.604	-0.294	5
7	.260	.160	.260	.260	.260	.300	.000	0.250	0.718	-0.468	7

Table 4
Strict preference index values of EXPROM-2

Alt.	1	2	3	4	5	6	7
1	.000	.027	.083	.186	.446	.458	.669
2	.033	.000	.107	.210	.405	.503	.612
3	.000	.027	.000	.033	.268	.280	.491
4	.017	.060	.017	.000	.165	.177	.388
5	.032	.080	.032	.015	.000	.088	.226
6	.065	.123	.065	.032	.107	.000	.217
7	.067	.100	.067	.033	.093	.067	.000

Table 5
Total preference index values and ranking pattern of EXPROM-2

Alt.	1	2	3	4	5	6	7	$\phi^+(a)$	$\phi^-(a)$	$\phi(a)$	Rank
1	.000	.417	.633	.736	1.00	1.00	1.00	0.797	0.213	0.584	1
2	.258	.000	.757	.860	1.00	1.00	1.00	0.812	0.326	0.486	2
3	.000	.317	.000	.483	1.00	1.00	1.00	0.633	0.402	0.231	3
4	.117	.350	.117	.000	.905	.927	1.00	0.569	0.466	0.103	4
5	.292	.240	.292	.175	.000	.412	.836	0.374	0.780	-0.406	6
6	.285	.373	.285	.252	.422	.000	.857	0.412	0.784	-0.372	5
7	.327	.260	.327	.293	.353	.367	.000	0.321	0.948	-0.627	7

Table 6
Credibility matrix of ELECTRE-3
(distillation coefficients -0.15 , 0.3)

Alt.	1	2	3	4	5	6	7	Rank
1	1.00	.770	1.00	.900	.740	.780	.740	1
2	.610	1.00	.710	.710	.840	.750	.840	2
3	.450	.350	1.00	.900	.740	.780	.740	2
4	.450	.350	.550	1.00	.840	.780	.740	3
5	.260	.160	.260	.260	1.00	.690	.740	3
6	.250	.250	.250	.250	.680	1.00	.700	3
7	.260	.160	.260	.260	.390	.360	1.00	4

Table 7 Credibility matrix of ELECTRE-4
distillation coefficients 0, 0.1)

Alt.	1	2	3	4	5	6	7	Rank
1	1.00	.000	1.00	.000	.000	.000	.200	1
2	.000	1.00	.000	.000	.000	.000	.200	3
3	.000	0.00	1.00	.000	.000	.000	.200	4
4	.000	0.00	.000	1.00	.200	.000	.200	2
5	.000	0.00	.000	.000	1.00	.000	.000	4
6	.000	0.00	.000	.000	.000	1.00	.200	3
7	.000	0.00	.000	.000	.000	.000	1.00	5

Table 8
L_p- distance from ideal solution and ranking of alternatives resulting from compromise programming

Alt	L_p metric value p=1	Rank	L_p metric value p=2	Rank	L_p metric value p=∞	Rank
1	.17932	1	.09365	1	.07143	1
2	.20211	2	.11155	2	.10000	3
3	.32821	3	.12858	3	.07158	2
4	.38852	4	.15807	4	.11429	4
5	.59159	6	.22895	5	.14287	5
6	.58095	5	.24525	6	.14289	6
7	.74500	7	.30459	7	.20000	7

Table 9
Ranking pattern obtained by various MCDM techniques

Method	Alternatives 1	2	3	4	5	6	7
PROMETHEE-2	1	2	3	4	6	5	7
EXPROM-2	1	2	3	4	6	5	7
ELECTRE 3	1	2	2	3	3	3	4
ELECTRE 4	1	3	4	2	4	3	5
CP(p=1)	1	2	3	4	6	5	7
CP(p=2)	1	2	3	4	5	6	7
CP(p=∞)	1	3	2	4	5	6	7

4.3 Correlation analysis

Spearman rank correlation coefficient (R) is used to determine the measure of association between ranks obtained by different MCDM techniques [GIBBONS (1971)]. If U_a and V_a denote the ranks achieved by two different MCDM techniques for same alternative a, then coefficient R is defined as

$$R = 1 - \frac{6\sum_{a=1}^{A} D_a^2}{A(A^2-1)} \tag{7}$$

a = Index of alternatives; a = 1,2, ...A; A = Total number of alternatives; D_a = Difference between ranks $(U_a - V_a)$; R = 1 represents perfect association between the ranks; R = 0 represents no association between the ranks; R = -1 represents perfect disagreement between the ranks. The value of R always lies between -1 and +1.

Table 10 presents the Spearman rank coefficient (R) values. It is observed that R values between all the MCDM techniques (except ELECTRE-3, ELECTRE-4) are reasonably high. Good correlation coefficient value of 0.848 is observed between ELECTRE-3 and ELECTRE-4. But low correlation is observed between ELECTRE-3, ELECTRE-4 and other techniques mainly due to the ties in the ranking patterns of ELECTRE-3, ELECTRE-4 which increase the $\sum D_a^2$ value and consequently reduces the R value as observed from Eq. 7.

Table 10
Spearman rank correlation coefficient values between ranking pattern obtained by different MCDM techniques

Method	PROMETHEE –2	EXPROM	ELECT-3	ELECT-4	CP p=1	CP p=2	CP p=∞
PROMETHEE-2	1.000	1.000	0.552	0.673	1.000	0.964	0.929
EXPROM		1.000	0.552	0.673	1.000	0.964	0.929
ELECT-3			1.000	0.848	0.552	0.552	0.552
ELECT-4				1.000	0.673	0.636	0.600
CP(p=1)					1.000	0.964	0.929
CP(p=2)						1.000	0.964
CP(p=∞)							1.000

Considering all the scenarios along with extensive sensitivity analysis for all the techniques, it is concluded that alternative 1 (combination of sprinkler irrigation system, with no change in the existing water pricing and water allocation policy with Wheat/ Barley as the growing crop with green fertilisers and without change in the present subsidy policy) is selected as the best. Alternative 2 which is a modification of alternative 1 without change in the existing cropping pattern (i.e., rice) considered as the next best. These two alternatives can be analysed in depth with precise numerical data for further implementation.

5. Discussion and conclusions

We are of the opinion that modelling a real-life problem should begin by embedding at first all the elements and then reducing the model to a manageable size, yet keeping its realistic features [WYMORE (1997)]. The DM is free to select one of the 161 other than the final seven for further detailed analysis. Five MCDM techniques, namely, PROMETHEE-2 (outranking), EXPROM-2 (distance and outranking), ELECTRE-3 (outranking), ELECTRE-4 (outranking), Compromise Programming (distance) have been applied for the sustainable water resources planning to the case study of Flumen Monegros irrigation area in the Huesca province of Spain and the following conclusions are drawn:

1. Alternative 1 (combination of sprinkler irrigation system, with no change in the existing water pricing and water allocation policy with Wheat/ Barley as the growing crop with green fertilisers and without change in the present subsidy policy) is selected as the best. Alternative 2 which is a modification of alternative 1 without change in the existing cropping pattern (i.e., rice) considered as the next best. These two alternatives can then be analysed in depth with further precise numerical data for final implementation.

2. Sustainability concept is introduced into the planning problem by incorporating criteria such as water volume, water quality after irrigation, efficiency of the use of water, resistance to floods or droughts, employment of rural labour, especially unskilled labour.

3. Traditional approach of surface irrigation has been omitted from the analysis so as to support the sustainability concept of higher efficiency of water which can be further analysed in depth using further inputs.

4. The potential of ELECTRE-TRI as a screening tool is utilised in the present analysis.

5. One hundred and sixty one (161) alternatives are grouped into seven categories using ELECTRE-TRI methodology. Alternative from each category is selected based on minimum square error methodology.

6. Alternative 1 having highest net ϕ value of 0.443 is best followed by alternative 2 having net ϕ value of 0.403 in case of PROMETHEE-2.

7. Alternative 1 having highest net ϕ value of 0.584 is best followed by alternative 2 having net ϕ value of 0.486 in case of EXPROM- 2.

8. It is observed that the ranking pattern is same in both PROMETHEE-2 and EXPROM-2 irrespective of the contribution of the strict preference index.

9. Alternative 1 is best followed by alternatives 2,3 being tied at rank 2 in case of ELECTRE-3.

10. Alternatives 1 and 4 are occupying first and second positions respectively in case of ELECTRE-4.

11. Alternatives 1 and 2 are ranked as best (due to low L_p metric values of 0.17932, 0.20211 for p=1 and 0.09365, 0.11155 for p=2) where as for p=∞ these are 1 and 3 in case of Compromise Programming. But position of alternative 1 remain unaltered

12. It is observed that PROMETHEE-2, EXPROM-2 and CP(p=1) provide the same ranking pattern.

13. All the five MCDM techniques found the same alternative strategy as the best.

14. It is observed that Spearman R values between all the MCDM techniques (except ELECTRE-3, ELECTRE-4) are reasonably high.

15. Good correlation coefficient value of 0.848 is observed between ELECTRE-3 and ELECTRE-4.

16. Low correlation is observed (in the range of 0.552 to 0.673) between ELECTRE-3, ELECTRE-4 and other techniques mainly due to the tie in the ranking patterns of ELECTRE-3, ELECTRE-4.

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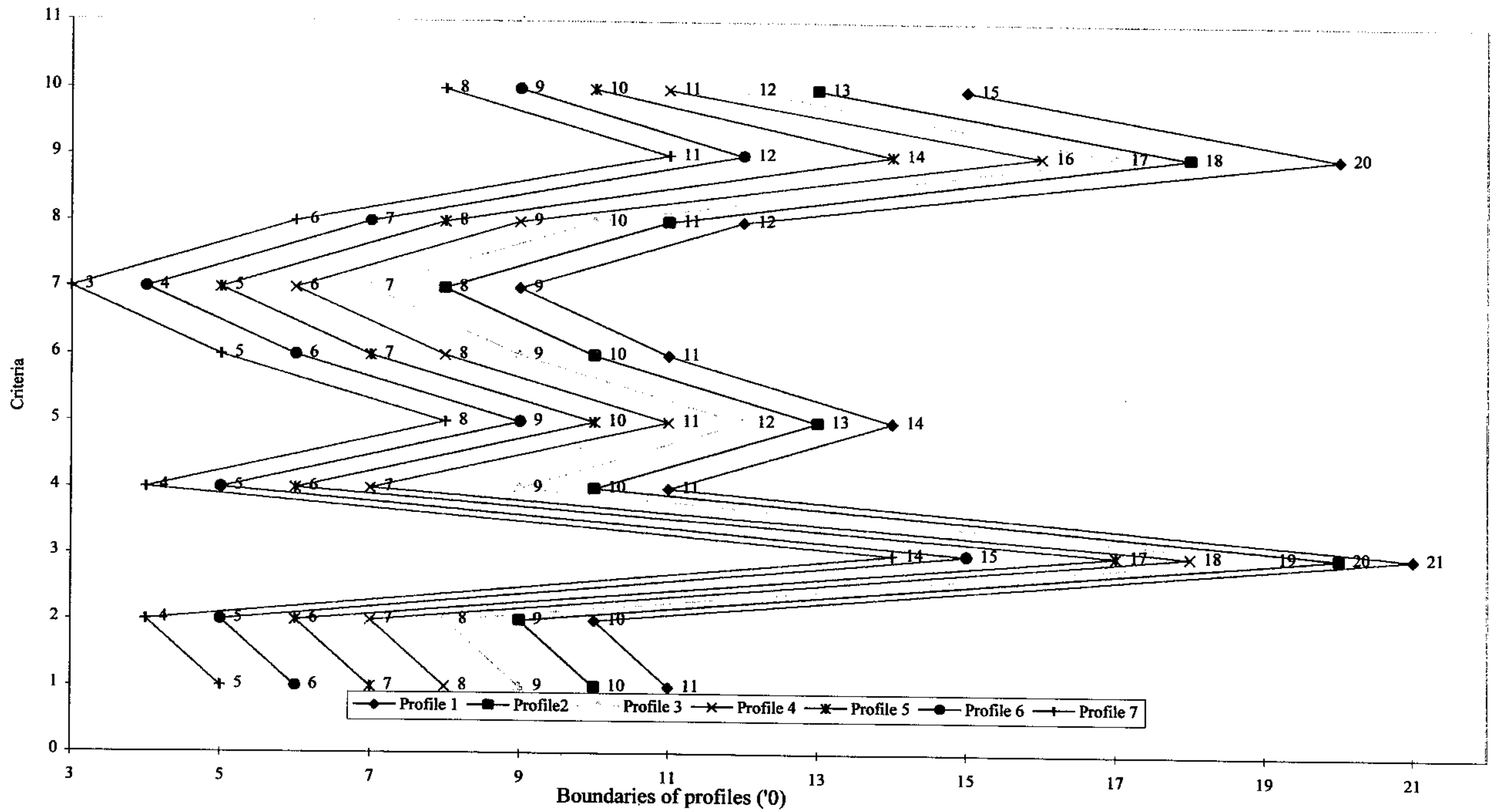

Figure 2. Profile pattern for ELECTRE TRI