FEMISE RESEARCH PROGRAMME

Managing and Resolving Water-Related Conflicts in Agricultural Euro-Mediterranean Trade Agreements

Jacques Ganoulis
Aristotle University of Thessaloniki, Greece

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Summary of the project:

The project aims to define different water price options that should be implemented in order to achieve a more competitive and at the same time sustainable use of water in the agricultural sector around the Mediterranean basin. Water pricing is considered as one important component of the integrated approach for sustainable agriculture. The main idea, which takes a quantitative form in this project, is the integration of economic, environmental, social and technical factors through the application of Multicriterion Decision Making (MCDM) methodology in order to define "the best" water pricing policy.

By developing two characteristic case studies from Greece and Spain we show how the proposed methodology may be applied in every part of the Mediterranean. Although the methodology is general, water pricing is very much depending on local factors which are reflected by some characteristic data.

In order to apply the MCDM methodology we need to specify:

- **The objectives**, which indicate the directions of state change of the system under examination and need to be maximized, minimized or maintained in the same position.
- **The attributes**, which refer to the characteristics, factors, indices of the alternative management scenarios. An attribute should provide the means for evaluating the levels of an objective.
- **The constraints,** which are restrictions on attributes and decision variables that can or cannot be expressed mathematically.

Three different MCDA techniques, namely, ELECTRE-3 (outranking), ELECTRE-4 (outranking), and Compromise Programming (distance-based) have been applied for the sustainable water resources planning in the case study of Spanish and Greek irrigated agriculture. Water pricing is determined as one component of the most “suitable” alternative strategy to be implemented in the agricultural sector.

Objectives of the project:

- Provide useful methodologies that can be used as economic tools to allow the policy decision makers to evaluate the different alternative strategies in order to reorient the water management of the agricultural sector towards sustainability.
- Construct a MCDM set of water pricing policies, which can be adapted to every Mediterranean basin country, taking into account of course the specialties of each country.
- Propose ways (modifications in policy) to control water demand in the agriculture.
- Evaluate existing situation, by gathering the appropriate data for the use of water, taking into account different variables that interact and influence this use.
- Demonstrate the MCDM methodology for some characteristic case studies.

We are presenting two case studies: one from Greece (1) with a quantitative approach (numerical data) and one from Spain (2) using a qualitative approach.

(1) THE GREEK CASE STUDY

The regions under study for the Greek case are Larissa, Thessalia and Imathia located in central and northern Greece. For these areas consideration of economic, agronomic and environmental aspects have been taken into account. The gathered data examine and evaluate the following:

- Irrigation systems, types of crops, period of cultivation, price of water and water allocation/crop, kind of fertilizers used, policy of subsidies
- The evolution of agricultural occupation and agricultural income which reflect the economic status of farmers in Greece. From the collected data (see tables in the Appendix for the Greek case), through the application of MCDM methodologies some "good" alternative policies have been identified, taking into consideration all economic, environmental and social factors.

The case of Greece is an interesting one, since Greece is considered to be an agricultural country with a consumption of 85% of water to be consumed for agricultural purposes. Agriculture in Greece is a vital source of economy. 22% of working Greeks are occupied as agriculturists. As far as crops are concerned the main ones are summarized in table1in the Appendix. In 1997-98 there is a remarkable change in the production of different crops. More specifically, there is a decline in the production of sugar beets, maize, fruits and an increase in the production of olives. The irrigation system that is most popular in the areas under study is surface irrigation which reaches up to 75% in use and there is a trend towards drip irrigation the last years. Drip irrigation is a sustainable irrigation method but needs to be subsidized to be widely used.

The cost of a product consists of the variable cost of seeds, fertilizers, pesticides, selection of mechanical means and some indicators that varied according to the crop. In the calculation of the cost of the product labor cost should be taken into account and the cost of the irrigation system applied and also subsidies per crop.

Poor performance in Greece has been caused by the failure of the public sector to collect funds from the farmers to support operation and maintenance.

Inappropriate water pricing and allocation policies fail to encourage efficient water use. The reorientation of the existing agricultural policy towards the direction of the protection of water resources, especially through the application of available water pricing methods is a possible solution to the problem.

The Greece region has long seen extensive irrigation networks to allow agriculture in this dry and arid area. However, the growth of human populations has resulted in more intensive agricultural practices and the use of irrigation systems. Considering the growing importance of irrigation systems in Greece, there is fear that intensive use of water resources may lead to water sustainability problems. 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 report 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.

Multicriterion 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 (Goicoechea et al., 1982; Szidarovszky et al., 1986; Pomerol and Romero, 2000). The study is divided into problem description, formulation of payoff matrix, description and application of three MCDM techniques, namely, Compromise Programming (CP), ELECTRE-3 and ELECTRE-4 to rank alternative strategies followed by sensitivity analysis and conclusions.

PROBLEM DESCRIPTION AND FORMULATION

The study area consists of Hmathia and Larisa irrigated area in Greece. Water for irrigation is taken mostly from rivers (Pinios in Larisa and Aliakmon in Imathia) and water also comes from artificial lakes and drillings. The department of Larisa consists of 1.168.334 stremmas (42,1%) of the Thessalian valley.

Temperature is mild with wet winters and hot, dry summers with insufficient rain during the whole year. Irrigation is thus essential to enable agricultural production. Water deficits are common. The terrain is mostly mountainous with ranges extending into sea as peninsulas or chains of islands. According to 1993 estimates, generally for Greece, arable land occupies 19%, permanent crops 8%, permanent pastures 41%, forests and woodland 20% and other 12% which clearly indicated that land area available for irrigation is limited. Crops in the command area are : cotton, fruit, maize, sugar beet, grass, rice. Irrigation efficiency is estimated to be around 40%. Water pollution is a major problem due to the salinity and water logging effects. Some of the points with respect to Greek irrigation systems emanated after discussion with researchers are:

1. High rate of seepage, absence of regular water courses and the lack of field channels are contributing to the poor utilisation of the surface water resources.
2. Growing water intensive crops (cotton, fruit), use of unlined distributories and uncontrolled outlets are contributing to the inefficient use of the irrigation system.
3. Traditional cropping pattern is not able to harness the full potentiality of the irrigation facility.
4. Lack of irrigation planning involving all disciplines and inadequate participation of concerned agencies for monitoring and evaluating the distributories are contributing to the sub-optimal performance of the system.
5. Poor economic conditions of the farmers are also responsible for the non adoption of modern farm practices.
6. Nominal rate of water charges are also causing wastage of water.

In light of the above points and considering the socio-economic conditions of the farmers, it is felt that a suitable irrigation strategy is to be formulated to minimise the above drawbacks, as discussed in the next section.

IDENTIFICATION OF CRITERIA

In order to find the best possible applied strategies, three groups of criteria are identified and are given below with notations.

1. Economic factors including Initial cost often paid by the State (CR1), Maintenance cost (CR2), Profitability of crops (CR3).

2. **Environmental (sustainability related) factors** including Irrigation water volume used (CR4), Water pollution during and after irrigation (CR5), Efficiency of water use (CR6).

3. Social factors including Employment of the population (CR7).

Furthermore, there are three groups of decision makers, namely, 1) those who prioritise economic effects 2) those who prioritise environmental (sustainability) effects 3) those who prioritise social effects. These opinions are reflected by three sets of criterion weights. Set 1 is represented by weights (0.10, 0.10, 0.30), (0.10, 0.06, 0.09), 0.25 for C1 to C7. These are (0.09, 0.06, 0.10), (0.15, 0.15, 0.20), 0.25 for set 2 and (0.09, 0.06, 0.10), (0.10, 0.06, 0.09), 0.50 for set 3. However, studies are also made by giving economic, environmental (sustainability) and social effects equal or at least a balanced importance.

FORMULATION OF ALTERNATIVE STRATEGIES

The following four 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 schemes (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: Moderate, B2: high water prices, B3: very high water prices).

3. Distribution of crops over the area under study (factor C with two levels representing C1 : Existing cropping pattern; C2 : Existing cropping pattern by reducing growth of cotton and increase of fruits/vegetables acreage).

4. The kind of fertiliser used, with different consequences for the environment (factor D with two levels representing D1 : Chemical fertiliser, D2 : Green fertilisers).

All the criteria are considered/assumed subjective due to the lack of precise numerical data. However, these subjectivity data is produced based on the available published reports. Subjectivity has been considered systematically in ELECTRE-3,4 methods using pseudo criterion concept. Table 1 presents notations for the subjective data. Table 2 presents a linearly consensus quantified (LCQ) matrix (actions versus direct consequences on different system criteria). Starting from the set of four elements (irrigation scheme, water pricing, crop distribution and fertilisers) and their subdivisions all these elements are mixed to create alternative policies. From the ten factors in the Table 2, divided into four major sectors, the total number of combinations leads to 3x3x2x2 = 36 different alternative policies. Table 3 presents a payoff matrix obtained by the above procedure.

DESCRIPTION AND APPLICATION OF MULTICRITERION DECISION MAKING TECHNIQUES (MCDM)

In the present study three MCDM techniques, namely, ELECTRE-3 (outranking), ELECTRE-4 (outranking) and Compromise Programming (CP; distance) are applied to the planning problem. Brief descriptions of the MCDM techniques are presented below.

Table 1 Notations for the Subjective Data

Notation	Numerical value
Very high performance/very high profitability/very cheap cost	1
High performance/High profitability/Cheap cost	0.8
Average	0.6
Low performance/Low profitability/high cost	0.4
Very low performance/very low profitability/very high cost	0.2
No significant effect on the planning problem	----

Table 2. Consensus Quantified Matrix (CQM)

Details	A1	A2	A3	B1	B2	B3	C1	C2	D1	D2
Initial Cost	1.0	0.6	0.6	0.0	---	---	0.4	0.6	0.4	0.8
Maintenance Cost	0.4	0.4	0.6	0.8	0.8	0.4	0.8	0.6	---	---
Profitability	0.6	0.8	1.0	0.8	0.6	0.4	0.8	0.6	0.6	0.8
Water VolumeUsed	0.4	0.6	0.8	0.6	0.6	0.8	0.6	0.4	---	---
Effect of Pollution	0.4	0.6	0.8	---	---	---	0.6	0.6	0.4	0.8
Water useEfficiency	0.4	0.6	0.8	0.6	0.6	0.8	0.8	0.6	---	---
Social Impact	0.6	0.4	0.4	1.0	0.4	0.2	0.8	1.0	0.4	0.8

Table 3. Payoff Matrix

Alternative	CR1	CR2	CR3	CR4	CR5	CR6	CR7
1	1.80	2.00	2.80	1.60	1.40	1.80	2.80
2	2.20	2.00	3.00	1.60	1.80	1.80	3.20
3	2.00	1.80	2.60	1.40	1.40	1.60	3.00
4	2.40	1.80	2.80	1.40	1.80	1.60	3.40
5	1.80	2.00	2.60	1.60	1.40	1.80	2.20
6	2.20	2.00	2.80	1.60	1.80	1.80	2.60
7	2.00	1.80	2.40	1.40	1.40	1.60	2.40
8	2.40	1.80	2.60	1.40	1.80	1.60	2.80
9	1.80	1.60	2.40	1.80	1.40	2.00	2.00
10	2.20	1.60	2.60	1.80	1.80	2.00	2.40
11	2.00	1.40	2.20	1.60	1.40	1.80	2.20
12	2.40	1.40	2.40	1.60	1.80	1.80	2.60
13	1.40	2.00	3.00	1.80	1.60	2.00	2.60
14	1.80	2.00	3.20	1.80	2.00	2.00	3.00
15	1.60	1.80	2.80	1.60	1.60	1.80	2.80
16	2.00	1.80	3.00	1.60	2.00	1.80	3.20
17	1.40	2.00	2.80	1.80	1.60	2.00	2.00
18	1.80	2.00	3.00	1.80	2.00	2.00	2.40
19	1.60	1.80	2.60	1.60	1.60	1.80	2.20
20	2.00	1.80	2.80	1.60	2.00	1.80	2.60
21	1.40	1.60	2.60	2.00	1.60	2.20	1.80
22	1.80	1.60	2.80	2.00	2.00	2.20	2.20
23	1.60	1.40	2.40	1.80	1.60	2.00	2.00
24	2.00	1.40	2.60	1.80	2.00	2.00	2.40
25	1.40	2.20	3.20	2.00	1.80	2.20	2.60
26	1.80	2.20	3.40	2.00	2.20	2.20	3.00
27	1.60	2.00	3.00	1.80	1.80	2.00	2.80
28	2.00	2.00	3.20	1.80	2.20	2.00	3.20
29	1.40	2.20	3.00	2.00	1.80	2.20	2.00
30	1.80	2.20	3.20	2.00	2.20	2.20	2.40
31	1.60	2.00	2.80	1.80	1.80	2.00	2.20
32	2.00	2.00	3.00	1.80	2.20	2.00	2.60
33	1.40	1.80	2.80	2.20	1.80	2.40	1.80
34	1.80	1.80	3.00	2.20	2.20	2.40	2.20
35	1.60	1.60	2.60	2.00	1.80	2.20	2.00
36	2.00	1.60	2.80	2.00	2.20	2.20	2.40

DESCRIPTION OF MCDM TECHNIQUES

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

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

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 $2 \le p \le \infty$ 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).

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 pair-wise 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 into 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 by Rogers et al. (2000).

APPLICATION OF MCDM TECHNIQUES

Multicriterion Decision Support System (DSS) MULTICRIT developed by Raju and Duckstein (2000) is employed to solve Compromise Programming. 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. Results are discussed with reference to weight set 1 (economy inclined decision maker). In two outranking techniques, namely, ELECTRE-3, ELECTRE-4 preference thresholds are fixed as 0.5 to consider the subjectivity in the data. However, extensive sensitivity analysis is performed for all the techniques to assess the ranking pattern for various thresholds, type of criterion functions, distillation coefficients, weights.

Distillation coefficients employed in ELECTRE-3 method are –0.15 and 0.3. The final ranking of alternatives resulting from intersection of 2 preorders are given in Table 4. It can be seen **that alternative 26 is best followed by alternative 28**. Equal weight analysis is also performed for all the criteria (0.1428 for each). In this case also **alternatives 26 and 28** occupy first and second positions respectively. Table 4 also presents ranking patterns of ELECTRE-4. Distillation coefficient employed in this method is 0.1. In this method, alternatives 26,28 are tied at rank 1. Alternatives 2,30,32 occupy second position. It is also observed that ranking pattern obtained by **ELECTRE-3** for equal weightage scenario is same as of **ELECTRE-4** particularly for **alternatives 26 and 28.**

Ideal and anti-ideal values in Compromise Programming (CP) are obtained from Table 3. Alternative with the minimum L_p metric distance is selected as the compromise solution. Table 4 presents ranking pattern for CP. Table 5 presents L_p metric values and corresponding ranking pattern for top five alternative policies for three values of p=1,2,∞ for weight set 1. For p=1,2 alternative 26 is ranked as best (due to low L_p metric values of 0.19278 and 0.10566 p=1 and for p=2) where as for p=∞ these are 28,26. Based on the results in Table 5 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 26 is found to be ranked best.

Table 4. Ranking pattern obtained by different MCDM techniques (Economic scenario)

Rank/Method	ELECTRE-3	ELECTRE-4	CP(p=1)	CP(p=2)	CP(p=∞)
1	26	26,28	26	26	28
2	28	2,30,32	28	28	26
3	2,4,14	14,34	14	14	14
4	16,25,30,32	4,36	30	2	2
5	27,34	10,16,18	2	16	16
6	36	12,25,27	25	25	17
7	3,8,18,33	6	16	27	25
8	1,13	8,20,22,29	32	30	32
9	6,29	24,31,33	34	32	13
10	15,20,22	1,35	4	13	1
11	10	3,13	27	18	15
12	24,31	15	18	4	4
13	12	5,17	36	1	30

14	35	19,21	13	6	18
15	17	7	6	34	6
16	5,7,21	9	29	15	20
17	19	11,23	20	20	36
18	9		1	36	34
19	11,23		22	22	22
20			15	3	31
21			8	29	3
22			31	31	8
23			10	8	10
24			33	10	24
25			3	24	29
26			24	17	5
27			17	5	19
28			12	19	17
29			35	33	35
30			5	12	12
31			19	35	33
32			21	7	7
33			7	21	21
34			9	9	9
35			23	23	23
36			11	11	11

Table 5 L_p- distance from ideal solution for top five alternatives resulting from Compromise Programming (Economic scenario)

Rank	L_p metric value p=1	Alter	L_p metric value p=2	Alter	L_p metric value p=∞	Alter
1	.17000	26	.09294	26	.06247	28
2	.24125	28	.10113	28	.07054	26
3	.30750	14	.12402	14	.07609	14
4	.31375	30	.15193	2	.10672	2
5	.34875	2	.15963	16	.10729	16

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Considering all the scenarios along with extensive sensitivity analysis for all the techniques for different parameters it is concluded that alternative 26 (combination of Drip irrigation system with moderate change in the existing water pricing with existing cropping pattern and growing crop with green fertilisers) is selected as the best.

CONCLUSIONS

Three MCDM techniques, namely, ELECTRE-3 (outranking), ELECTRE-4 (outranking), Compromise Programming (distance) have been applied for the sustainable water resources planning of the case study of Greek Irrigation System. All data used are presented in the Appendix section.The following conclusions may be drawn:

1. Alternative 26 which consists of a strategy that takes into account the combination of the selection of drip irrigation system with moderate change in the existing water pricing, not emphasizing much the factor of "water price", cultivating the existing cropping (remaining also the water intensive ones) pattern and growing crop with green fertilisers as the major change with regard to the environment is selected as the best. This policy is characterized as rather conservative, since it only promotes the use of more environmentally friendly fertilisers, giving priority to water quality and do not generally permit many differences in the present situation. As far as crop selection is concerned, the wide differences in crop values and their water standards provides significant flexibility for irrigated agriculture to adjust to changes in water availability. Farmers can adjust to physical water shortages in the area, by adjusting cropping choices to maintain production of the higher-valued crops. Sustainability concept is introduced into the planning problem by incorporating criteria such as water volume used, water pollution during and after irrigation, efficiency of the use of water, employment of rural labour, especially unskilled labour.

2. 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 more inputs.

3. All the three MCDM techniques find the same alternative strategy as the best.

4. New MCDM approaches like ELECTRE-3,4 have been employed which consider the subjectivity of the data using the pseudo criterion concept.

SUGGESTIONS

Agriculture in Greece has not been practiced in the past years in regard to proper use of inputs (green fertilizers, water efficiency, selection of seeds) and certainly without the appropriate care for environmental protection in the sense of water quality, water resources preservation and sustainability.

However the reorientation of the existing situation in the agricultural economy in Greece, towards more sustainable use of water resources, better sited on the available resources, high land productivity, social welfare of a big working part of the population and irrigation efficiency that consist some of the elements of the problem can not be obtained solely through a water pricing reform.

As the results of the MCDM techniques have shown the best solution sustains a moderate change in the pricing policy and reinforce the option of an integrated approach.

1. The first step for the integrated approach is the establishment of policies connected with water and agricultural preservation, giving high priority to *economic efficiency, social equity and environmental protection,* to be consolidated at government levels in order to meet the expectations of the different components. For the better application of these

policies both better performance by those responsible for water supply and more efficient use by the different users (agriculturists) need to be considered.

2. Unless effective cooperation arises among the different parties (users, government) there is likely to be over-exploitation and abuse of water resources.

3. Water is lost in leakage and evaporation before it gets in the point due to the applied irrigation systems. The transformation of the surface irrigation system though, towards drip needs the interference of the government because the economic status of the Greek farmers does not permit such an expensive investment.

4. By raising the water tariffs in a way that reflect its true price the confining of its use to where it is really valuable can be achieved.

Measures that must be taken into account are:

1. Change the legal and economic framework within water is supplied and used.

2. Give incentives to influence the behavior of users to use water more carefully

3. Proceed to direct interventions through investments, programmes to encourage saving techniques.

4. Increase productivity as a consequence of the use of environmentally friendly fertilizers, better selection of crops probably not so water intensive ones, and of course adoption of biotechnology.

5. As regards irrigation, the world tendency has been the reduction of products that need much water and are not so profitable and the cultivation of crops with high commercial value.

6. With appropriate public education and participation, better water and soil conservation, improved water irrigation systems (drip) that reduce water wastage and proper selection of crops with accordance to a water pricing policy that assures water resources sustainability concept it is possible that economic efficiency, environmental protection, social equity and irrigation system effectiveness will be achieved.

APPENDIX I (GREECE)

In the appendix there are all data used for the evaluation of the Greek case study.

TABLE 1: PRODUCTION OF MAIN CROPS IN GREECE

PRODUCTS (TONS)	1997	1998	% CHANGE
Tomato total	2.013.279	2.085.110	+3.6
Olives	1.674.018	2.068.167	+23,5
Sugar beets	2.797.807	1.995.937	-28,7
Corn	2.025.281	1.816.441	-10.3
Cotton	1.126.674	1.186.682	+5.3
Oranges	1.010.914	813.553	-19.5
Water melons	670.794	661.769	-1.3
Peaches	588.574	527.583	-10.4
Apples	373.323	358.090	-4.1
Rice	213.893	208.975	-2.3

TABLE 2: MAIN PRODUCTS OF THE AREA UNDER STUDY (YEAR 1998)

SOURCE: GREEK NATIONAL STATISTICS

CROPS(TONS)	AREA STUDIED	TOTAL GREECE	% OF TOTAL
Cotton	290.545	1.186.682	24
Fruits	459.803	1.003.651	46
Corn	118.639	1.816.441	7
Sugar beets	425.308	1.995.937	21
Grass	61.325	1.266.932	5
Rice	21.245	208.975	10

Table 3: Irrigated land of the area under study (Year 1998)Source: National Statistics

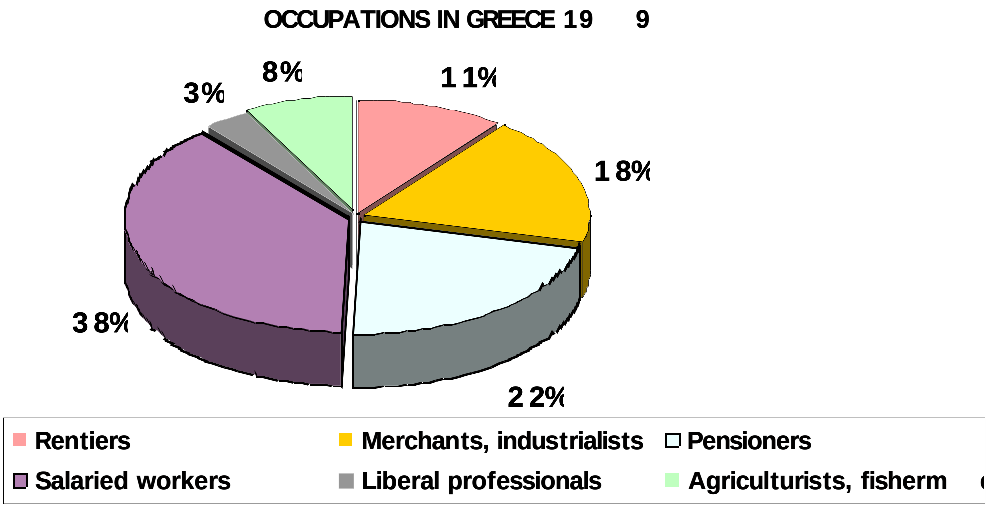
IRRIGATED LAND (STREMMAS)	AREA STUDIED	TOTAL GREECE	% OF TOTAL
Cotton	871.036	4.234.393	5
Fruits	379.713	3.213.404	8
Corn	118.639	1.816.441	15
Sugar beets	44.430	410.190	9
Grass	14.954	775.316	5.2
Rice	24.853	259.481	10

Total agricultural land under study: 3.089.978 stremmas. (8%)

Total Greek agricultural land: 38.817.994 stremmas.

Total Greek irrigated land:14.219.128 stremmas.

Total irrigated land under study:1.737.315 stremmas.(12%)



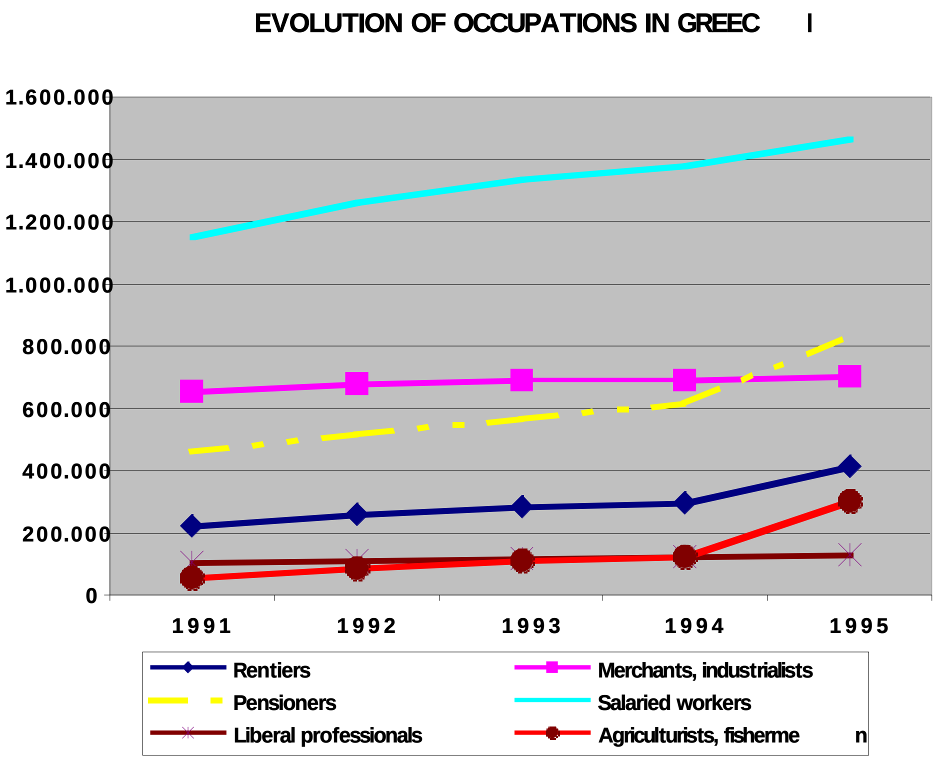


TABLE 4: PRICE OF ELECTRICITY (1998) FOR AGRICULTURAL USES

IRRIGATION (BASIC PRICE RATE)	MONTHLY OR IN 4 MONTHS
Flat fee	0 ecu
Energy:First 300 (MaD) KWh	20.03 drx./kwh= 0.06 ecu/kwh
All other Kwh	15.98 drx./kwh=0.05 ecu/kwh
Min rate:	2674*(MaD) drx.=7.98*(MaD)ecu
MaD: Max Annual Demand	

TABLE 5: ELECTRICITY RATE FOR AGRICULTURISTS

RATE FOR AGRICULTURISTS	MONTHLY OR IN 4 MONTHS
Flat fee:	0 ecu
Energy:All Kwh	10.84 drx./kwh=0.03 ecu/kwh
Min rate:	60% of the min basic price rate

The cost of water in Greece concerns only the cost from the electricity needed for the functioning of the drillings. Opportunity cost or environmental cost is not included. There is also an annual flat fee according to the cultivation of crop and mostly according to the irrigation system applied.

As far as the distribution of the income throughout Greece is concerned the table below explains the different occupations.

TABLE 6: INCOME AND TAXABLE INCOME IN GREECE (IN MILLION DRX.)

GROUPS OF OCCUPATIONS	1991	1992	1993	1994	1995
Rentiers	222.780	257.285	281.443	293.820	409.998
Merchants, industrialists	655.255	677.262	687.110	689.189	704.513
Pensioners	463.141	516.202	569.159	614.317	831.597
Salaried workers	1.151.256	1.258.733	1.333.617	1.378.998	1.466.207
Liberal professionals	106.344	110.493	116.340	120.570	127.026
Agriculturers	56.700	84.185	108.721	121.829	300.730
Number of tax payers	2.655.446	2.904.160	3.096.390	3.218.723	3.840.071
Agriculturists					
Total of tax	1.315	2.102	2.283	3.196	4.641
Exemptions and untaxed amounts	58.721	103.139	4.843	5.890	9.077
Agriculturists	44.925	75.303	126.468	157.566	271.517

Rentiers	197999	250711	340438	391846	490536
Merchants, industrialists	893382	1075958	1224095	1417052	2156288
Salaried workers	2397223	2913476	3393525	3838796	4485083
Liberal professionals	283546	343318	413347	486446	642854
Pensioners	838876	1042856	1247672	1446446	1909842

1 ECU=335 DRX.

TABLE 7: IRRIGATION SYSTEM APPLIED IN LARISA

IR. SYSTEM	**1994**	**1995**	**1996**	**1997**	**1998**
Surface irrigation	1,233 (3,05%)	781 (0,29%)	604 (0,22%)	554 (0,22%)	540 (0,2%)
Artificial rain	21,332 (52,76%)	184,259 (69,02%)	161,809 (59,48%)	139,479 (55,30%)	128,577 (50,26%)
Drip irrigation	17,865 (44,18%)	81,926 (30,69%)	109,604 (40,29%)	112,184 (44,48%)	126,694 (49,54%)
Total	100%	100%	100%	100%	100%

TABLE 8: IRRIGATION SYSTEMS APPLIED IN IMATHIA

IR. SYSTEM	**1995**	**1996**	**1997**	**1998**
Surface irrigation	303878 (75,84%)	310890 (74,86%)	309096 (75,42%)	312519 (74,99%)
Artificial rain	85519 (21,34%)	82069 (19,76)	83219 (20,25%)	82069 (19,69%)
Drip irrigation	11272 (2,82%)	22341 (5,38%)	18586 (4,33%)	22144 (5,32%)
Total	100%	100%	100%	100%

TABLE 9: WATER NEEDS PER CROP

LARISA	CROPS	WATER NEEDED/CROP (M3/STREMMA)	IRRGATION PERIOD	AV.IRRIGATION LAND (1993-98) IN STREMMA
	cotton	650	15/4- 30/8	704,559
	Corn	700	1 /5 –30 /8	60,000
	Sugar beets	750	1 /4 – 15 /8	41,721
	Grass	930	1 /5 – 30 /9	34,512
	Fruits	700	1 /5 – 30 /9	119,482
	Others	600	1 /4 –30 /9	7,102

TABLE 10: WATER RESOURCES USED TO IRRIGATE LAND

WATER RESOURCE USED TO IRRIGATE LAND	1994 STREMMAS	1995 STREMMAS	1996 STREMMAS	1997 STREMMAS	1998 STREMMAS
Rivers	112,840	132,972	136,227	130,529	132,956
Artificial lakes	14,000	14,000	14,000	14,000	15,000
Pumping	129,058	133,995	135,790	121,688	122,855

TABLE 11: COST PER CROP IN LARISA

VALUE / CROP IN ECU/STREMMA	1994	1995	1996	1997	1998
cotton	16,42	19,40	19,40	19,40	23,88
Corn	24,78	24,96	28,36	28,36	34,78
Sugar beets	24,78	28,36	28,36	28,36	12,69

TABLE 12: WATER RESOURCES IN LARISA

WATER RESOURCE USED TO IRRIGATE LAND	1995 STREMMAS	1996 STREMMAS	1997 STREMMAS	1998 STREMMAS
Rivers	36519	37133	36928	37133
Artificial lakes	367358	355526	359947	356958
Pumping	21900	22641	22394	22641

TABLE 13: WATER NEEDED PER CROP IN IMATHIA

CROPS	WATER NEEDED/CROP (M3/STREMMA)	IRRGATION PERIOD
Cotton	200-240	15/4- 30/8
Rise	2500	
Maize	700	1 /5 –30 /8
Sugar beets	450-500	1 /4 – 15 /8
Grass	500	1 /5 – 30 /9

It is obvious that some kinds of crops are more water demanding than others.

In the case of rice farmers exceed the above mentioned water used which sometimes reach the 4000 m3 / stremma.

TABLE 14: COST OF DIFFERENT CROPS

A. VARIABLE COST (ECU/STR.)	RISE	CORN	SUGAR BEETS	GRASS	COTTON
Seeds	20	12.5	8	-----	7
Fertilisers	12	15	17	18	12
Pesticides	9	14	21	3	18
Selection with mechanical means	0,03	0,04	19	-----	22
Various	22	12,5	11	11	11

A. VARIABLE COST (ECU/STR.)	PEACHES	GRAPES	APPLES
Seeds	-----	-----	-----
Fertilisers	47	20	60
Pesticides	73	75,5	98
Selection with mechanical means	10% of the cost of production	10% of the cost of production	10% of the cost of production
Various	40	53	22

B. LABOUR DEMANDS (HOURS/STR.)	**RISE (1)**	**RISE (2)**	**CORN (1)**	**CORN (2)**	**COTTON(1)**	**COTTON(2)**
Irrigated with gravity	12	4	10	3,5	12	4
Irrigated with pumping	17	9	15	9	17	9
Irrigated with drops	10	13	8	13	10	13
Irrigated with drops and pumping	10	4	8	3,5	10	4

(1) : People

(2) : Machinery

B. LABOUR DEMANDS (HOURS/STR.)	**SUGAR BEETS (1)**	**SUGAR BEETS(2)**	**GRASS (1)**	**GRASS (2)**
Irrigated with gravity	20	5	12	5
Irrigated with pumping	25	11	17	10
Irrigated with drops	18	15	15	14
Irrigated with drops and pumping	18	5	10	5

C .PRODUCTION (KIL./STR.)	**RISE**	**CORN**	**SUGAR BEETS**	**GRASS**	**COTTON**
Non irrigated	---		----	790	140
Irrigated with surface ir. Systems	800	960	5500	1660	300
Drip Irrigation	---	1300	6870	2075	380

	RISE	CORN	SUGAR BEETS	GRASS	COTTON
Product price (ecu/kil.)	0,27	0,15	36,79	0,16	0,84
Subsidies (ecu./str.)	----	14	3	-----	----

	PEACHES	GRAPES	APPLES
Product price (ecu/kil.)	0,30	0,22	0,30
Subsidies (ecu./str.)	----	---	----

For the decrease of pollution from fertilizers and pesticides the agriculturists are obliged to use systems of integrated “ plant-protection ” for each crop.

CROPS	COST OF PLANT PROTECTION (ECU/STR.)
Cotton	71,6
Rise	----
Corn	44,7
Sugar beets	167,1
Fruits	209

(2) THE SPANISH CASE STUDY

The case study from Spain is focalised on the Flumen-Monegros irrigation system of the Huesca area . It studies the irrigation systems built around the Ebro river in that area. However, due to difficulties, only non-numerical data were used in the study. We did not have access to comprehensive and easily accessible numerical data.

In order to define a set of policies, including economic, agronomic and environmental aspects, we have listed the factors that we could control, and which "could" change. These are:

- **Various irrigation systems (our factor A)**, some of them being more efficient than others.
- **Price of water (B)** and **water allocation (C)** in the district chosen.
- **Distribution of crops (D)** over the area studied.
- The kind of **fertiliser (E)** used, with different consequences on the environment.
- Policy of **subsidies (F)** from the European Union.

The aim was to build around **twenty different policies** (on the above criteria) and to choose the one which was **more sustainable and profitable** to farmers. Every factor and its subdivisions were evaluated considering economic, environmental and social criteria.

Our evaluation only used **non numerical** indicators: A means 'very good', B 'good', C 'average', D 'poor' and E means 'very poor'.

The following four *alternative strategies* (policies) were considered

5. *Various irrigation systems* (IS)

IS1: Surface, IS2: Sprinkler, IS3: Drip

6. *Price of water in the district chosen (*WP)

WP1: Raise water price by 5 ptas/m^3, WP2: Raise by 10 ptas/m^3, WP3: Raise by 20 ptas/m^3.

7. *Distribution of crops over the area studied* (CD)

CD1: Do nothing (Existing cropping pattern), CD2 : Fruit and vegetables.

8. *The kind of fertiliser used* (F)

F1 : Do nothing (Chemical fertiliser) , F2 : Green fertilisers

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

4. *Economic factors* including

(C1) Initial cost often paid by the State (C2) Maintenance cost

(C3) Profitability of crops (C4) Extent of European subsidies

5. *Environmental factors* (sustainability based) including

(E1) Irrigation water volume (E2) Water quality after irrigation

(E3) Efficiency of water use (E4) Resistance to floods or droughts

3. *Social factors* including

(S1) Employment of the population (S2) Land area which is not cultivated

All the criteria are given equal importance. Table 1 presents a quantified matrix indicating consequences of alternative actions on different criteria. Notations are as follows: very high / very cheap (1.0); good/cheap (0.8); average (0.6); poor/low (0.4); very poor/very low (0.2); No effect for the planning problem (0). From the set of four alternative strategies shown in Table 1, each with either 3 or 2 different options, the total number of combinations leads to 3x3x2x2 = 36 different alternative actions. Each action may given a set of four digits, i.e. (d1, d2, d3, d4) indicating each option from the four alternative strategies.

Compromise Programming (CP) and the minimum L_p metric were used for ranking alternatives. The ranking pattern for the 5 top alternatives is shown in Table 2.

1. Alternative 26 (-3- drip irrigation system, -1- raise water price by 5ptas/cum, -1- existing cropping pattern and -2- green fertilisers) is selected as the best. Alternative 14, which is a modification of alternative 26 replaced by sprinkler irrigation system is the second best. Alternative 25, which is a modification of alternative 26 replaced by chemical fertiliser, is the next best.
2. Interestingly Alternative 11 is the least preferred. This alternative is a combination of surface irrigation system, raising the water price by 20ptas/cum, and cultivating fruits and vegetables with chemical fertilisers.

Table 1. Consequences of alternatives on different criteria.

Alternatives / Criteria	**IS1**	**IS2**	**IS3**	**WP1**	**WP2**	**WP3**	**CD1**	**CD2**	**F1**	**F2**
C1	1.0	0.6	0.2	0	0	0	1	0.2	0.6	0.4
C2	0.8	0.6	0.2	0.8	0.2	0.2	0.4	0.2	0	0
C3	0.6	0.6	0.8	1.0	0.6	0.2	0.8	1	0.8	0.8
C4	0	0	0	0	0	0	0.8	0.2	0.2	0.6
E1	0.2	0.6	1.0	0.4	0.4	0.8	0.4	0.6	0	0
E2	0.2	0.6	0.8	0	0	0	0.4	0.2	0.4	0.8
E3	0.4	0.6	1	0	0	0	0.4	1.0	0	0
E4	0.2	1	1	0	0	0	0.4	0.4	0.4	1
S1	1.0	0.6	0.4	0.6	0.4	0.2	0.4	0.8	0.6	0.6
S2	0.0	0	0.0	0.6	0.4	0.2	0.6	0.2	0.6	0.8

Table 2. Ranking of alternatives.

Rank	Alternative	Lp metric value
1	26 (3,1,1,2)	0.12
2	14 (2,1,1,2)	0.13
3	25 (3,1,1,1)	0.14
4	16 (2,1,2,2)	0.14
5	28 (3,1,2,2)	0.15

APPENDIX II (SPAIN)

1. Different irrigation systems

Our evaluation of the different irrigation systems can be found in **Table 3**. We would like to focus here on irrigation systems and their **consequences** on:

- The **environment** (soil and water pollution, re-use of water).
- Initial and maintenance **costs**.
- **Efficiency** (on crops).
- **Vulnerability** to climatic changes.

Impact of irrigation on the **environment is complex**:

- Lack of water is a limit to growth and crop yields: irrigation allows production to be sufficient and diverse. It is also important for landscape diversity.
- Irrigation water represents 65% of water use in the world, and 70% in Spain.
- Irrigation can reduce nitrates concentration in soil but increase it in water (lixiviation).

Major risks are linked with excessive amounts of irrigated water:

- Surface runoff (excessive intensity of irrigation): erosion, transfer of fertilisers and nitrates to shallow ground water table.
- Percolation (excessive volume of irrigation water): transfer to deeper water resources.

Heavy investments in irrigation systems are often strongly subsidised by government. Irrigation in the Flumen-Monegros area is **mostly surface irrigation**; this should be considered when suggesting new irrigation systems.

a) Evaluating irrigation

Cf. Table 4.

The first irrigation system evaluated is **surface irrigation**. This system was 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 was given in terms of maintenance costs. Indeed, such a system only needs constant **unspecialised labour** to take care of the water channels. Global profitability was given an average mark considering better performances from other irrigation systems. Because of its **high use of water and low efficiency**, surface irrigation was given bad to very bad marks on its environmental component. Finally, this system was given a high mark for employment considering it needs a lot of unskilled labour force to maintain the system working.

The **sprinkler irrigation system** was given average marks in terms of economic income because both initial costs and maintenance **costs can be quite high** to build such a system. Likewise, this irrigation system was given average marks for its environmental and social components considering the better and worse solutions given by the two other systems.

The **drip irrigation system** was given very bad marks for its initial cost because of the **special equipment required**. It was also given bad marks for maintenance costs because of the expensive **skilled labour** required to keep it working. However, a good mark was given for the profitability of crops, drip irrigation being used to the **crop's best advantage**. A very high mark was given to the drip irrigation system in terms of environmental criteria because of its **low use of water and high efficiency**. A restraint was given in terms of water quality after irrigation to take account of the **risk of increasing local soil salinity**. Finally, drip irrigation was given a bad mark for its social criterion because it does not need a lot of labour and thus does not encourage employment in the region.

2. Water management and water allocation

The type of ownership of water resources has important consequences for the conservation of water resources and the economic efficiency with which resources are used, protected and developed. From an economic point of view, open access to water is not optimal: too many resources are allocated to areas with the highest average productivity, in comparison to those areas with lower productivity. That is why regulation is necessary. A number of policy measures or economic instruments have been suggested, such as:

- Impose a tax on the use of water.
- Impose a quota on the maximum harvest, with the creation of a market of rights or permits.

We chose to implement ELECTRE III. We actually had two sets of criteria:

- Three aggregated criteria: economic, environmental, social.
- Ten primary criteria: initial cost, maintenance cost, water volume used, etc.

These criteria were evaluated with A, B, C, D, E – A being the best mark was given a numerical mark 5; E being the worst was given a 1, so that we had increasing criteria – easier to use with ELECTRE. Thus we chose **a linear model**: the gap between each mark is constant.

Furthermore, we first of all used **true criteria**: $C_j(a,b)$ is either 0 or 1; over one criterion j, indifference between two actions a and b is just in case $g_j(a)=g_j(b)$. So the thresholds needed for ELECTRE III are 0. We also did not define any discordance set, so that the concordance matrix is not altered by a discordance matrix.

Our aim was to compare the results between on the one hand our ten criteria, and the three aggregated criteria on the other hand. That could also be a way of evaluating the aggregation.

There are different sets of weights, for each decision-maker – whether the decision–maker gives importance to the environmental aspect or the economic one.

1. A decision-maker, called **ECO**, who is concerned above all by economic implications, so that p_{ECO} = 0,6 / p_{ENV}= 0,2 / p_{SURV} = 0,2 .
2. A decision-maker, called **ENV**, who is concerned above all by environmental implications, so that we have: p_{ECO} = 0,2 / p_{ENV}= 0,6 / p_{SURV} = 0,2 .
3. A decision-maker, called **SURV**, who is concerned above all by social implications, so that : p_{ECO} = 0,2 / p_{ENV}= 0,2 / p_{SURV} = 0,6.
4. A decision-maker, called **ID**, who feels equal about the three criteria, so that p_{ECO} = 0,334 / p_{ENV} = 0,333 / p_{SURV} = 0,333.

Table 3: Characteristics of different irrigation systems

	Technique	Advantages	Disadvantages	Environmental consequences	Efficiency	Cost	Maintenance costs	Resistance to natural threats
SURFACE	Gravity irrigation (precise or traditional) Submersion	• Already in place in most parts of the area • No energy needed • Resistant to strong winds • Easier applying of fertiliser and other crop boosters	• Low efficiency • Strong loss of water and soil • Very sensible to floods (run-off)	• Strong nitrates concentration of unused water • Pollution of surface water by runoff • Loss of water by percolation • Soil is compacted	55% for submersion basins 70 to 75% for precision irrigation	A	B	E
SPRINKLING	Sprinkling	• Easier fertilisation and irrigation • Can be used on any kind of soil and slope • Easier crop rotations	• Optimal set-up necessary • Energy hungry • Frailty to wind • Good resistance to floods	• Germs may be dispersed • Clogging of pipes	70 to 75%	E	C	D
LOCALISED	Drip irrigation	• Easier fertilisation and irrigation • Resistant to wind	• All possible disadvantages must be assessed beforehand • Necessary qualified management labour • Water sifting necessary • Salinisation of soil • Excellent resistance to floods	• Possibility of clogging of pipes • Salinisation of soil • Better fertilisation and irrigation possible	85 to 90%	E	E	A

N.B.: Water distribution is not taken into account.

Table 4: **Qualitative matrix: actions versus direct consequences on different system criteria**

	A. IRRIGATION 1			**B. WATER PRICING** **2**			**C. WATER ALLOCATION** **1**		
	Surface	**Sprinkler**	**Drip**	**Do nothing** 2 ptas/m^3	**Raise prices** 10 ptas/m^3	**Raise prices** 20 ptas/m^3	**Do nothing**	**Market of quotas**	**Quotas**
Economic									
Initial cost of irrigation system (high mark means cheap)	A 1	C 1	E 1						
Maintenance cost (high mark means cheap)	B (labour) 2	C 2	E (specialists) 2	B	E	E			
Global profitability of crops	C 1	C 1	B 1						
Importance of subsidies received									
Net income	B 4	C 4	D 4	B	E	E			
Environmental									
Water volume (high mark means less water used)	E 4	C 4	A 4	D	D	B	D	B	B
Water quality	E	C	B						

after irrigation	2	2	2						
Efficiency of the use of water according to the system	D 2	C 2	A 2						
Resistance to floods or droughts	E 1	A 1	A 1						
Global environmental assessment	E 9	C 9	A 9	D	D	B	D	B	B
Survivability									
Employment (high mark means more people employed)	A	C	D	C 2	D 2	E 2	C 2	E (water farming) 2	D 2
Area non cultivated				C 2	D 2	E 2	C 2	E 2	D 2
Global assessment	A	C	D	C 4	D 4	E 4	C 4	E 4	D 4

N.B.: Numbers on the bottom left side of cells represent the weight of each criterion and action.

Table 4 continued

	D. CROP DISTRIBUTION 2				**E. FERTILISERS 1**			**F. SUBSIDIES 2**	
	Do nothing	**Wheat / barley**	**Fruit and vegetables**	**Sugar beet**	**Do nothing**	**Use of city sludg**	**Green fertilisers**	**Do nothing**	**Cut off**
Economic									
Initial cost of crop system (high mark means cheap)	A 1	C 1	E 1	C 1	C 1	A 1	D 1		
Maintenance cost (high mark means cheap)	D 1	C 1	E 1	D 1					
Global profitability of crops	B 2	B 2	A 2	A 2	B 2	B 2	B 2		
Importance of subsidies received	B 2	A 2	E No subsidy	E Quota system	E No subsidy	B Cities pay to get rid of it	C 2	B	E

			2	2	2	2			
Net income	B 6	B 6	D 6	C 6	C 5	B 5	C 5	B	E
Environmental									
Water volume (high mark means less water used)	D 4	B 4	C 4	A 4					
Water quality after irrigation	D 2	D 2	E 2	A 2	D 3	E 3	B 3		
Efficiency of the use of water	D 2	C 2	A 2						
Resistance to floods or droughts	D 1	B 1	D 1	C 1	D 1	E 1	A 1		
Global environmental assessment	D 9	C 9	C 9	B 9	D 4	E 4	C 4		

Survivability									
Employment (high mark means more people employed)	D 2	D 2	B 2	D 2	C 2	B 2	C 2	B 2	E 2
Area non cultivated	C 2	D 2	E 2	D 2	C 2	D 2	B 2	B 2	E 2
Global assessment	C 4	D 4	C 4	D 4	C 4	C 4	C 4	B 4	E 4

Some actions cannot be part of the same policy. For instance, the use of city sludge (E.2) is not compatible with surface irrigation (A.3). The list of these incompatibilities is given in Appendix.