PERGAMON

Omega 30 (2002) 89–95

omega
The International Journal of Management Science

www.elsevier.com/locate/dsw

Aggregation of preferences in an environmental economics context: a goal-programming approach

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Received 25 October 2001; accepted 16 November 2001

Abstract

This paper has been devised with two different and at the same time complementary aims. First, to propose a methodology based upon goal programming that allows the aggregation of individual preferences provided by several social groups towards different criteria in a cardinal manner. The main feature of the procedure lies in the easy utility interpretation of the social consensus obtained. Second, to apply the proposed methodology to a case study on electricity planning in Spain within an environmental context, where several criteria of different nature and some social groups with different interests are involved. The social weights that have to be attached to the different criteria in a multi-objective programming model are obtained this way.

Keywords: Group decisions; Goal programming; Environmental economics

1. The problem

Electricity planning is a very complex decision problem for at least two different reasons like the multiplicity of criteria of a very different nature (economic, environmental, social, etc.) involved in the process, and/or the manner in which different segments of society or social groups perceive these criteria. Nowadays, electricity planning is considered a decision-making problem with several criteria and different decision makers (social groups) involved (see [1,2]).

There are basically two approaches to solve this problem. The "neoclassical" approach tries to reduce all criteria to one expressed in monetary terms, by the economic valuation of environmental or social criteria. Several methodologies have been developed lately for this purpose, among which we may cite the ExternE methodology [3] as most widespread and successful. However, still few decision makers dare to rely on the values produced, because of the large uncertainties underlying the monetary valuation of health and environmental impacts. The alternative approach is based on multiple criteria decision-making (MCDM) methods, which attempt to aggregate the different criteria by means of the preferences towards them for all actors involved in the decision-making process. Although this approach may be considered more subjective, it is greatly valued because it allows a greater participation of these actors, and also because it is more transparent and flexible than the monetary valuation approach [4,5].

In the MCDM context outlined above, a crucial matter lies in addressing the problem of how to aggregate the preferences that the members of each social group have revealed for each relevant criterion. Normally, preferences attached by each social group to each criterion are elicited through an interactive process with a sample from members of different groups. Once the group preferences are obtained, the next step will consist in the aggregation of these preferences in order to obtain the preferences attached by the society as a whole to every criterion. These aggregate or social

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0305-0483/02/$ - see front matter
PII: S0305-0483(01)00059-7

preferences are a crucial element in the construction of any decision-making model for electricity planning.

Several procedures have been used to address this task. Georgopoulou et al. [1] or Hobbs and Horn [6] obtain the group preferences for different energy alternatives by means of direct interaction with the members of the group, once the concordance and discordance between them have been identified. When this interaction is not feasible, other methods, such as the GDSS PROMETHEE procedure [7] have been used. The geometric mean and the arithmetic mean methods have also been applied when the analytic hierarchy process (AHP) [8] was used to elicit individual preferences [9].

The problem outlined above is addressed in this paper by adapting a methodology recently proposed by González–Pachón and Romero [10] to determine consensus-ordinal-rankings for a cardinal case. The proposed methodology uses goal programming (GP) in an unusually explored manner that was suggested by Ignizio [11]. It consists in using GP as a device to induce distance-based consensus models [12]. In this case, GP is used to induce models for the aggregation of individual preferences in a cardinal fashion. An additional advantage of the proposed methodology is that it allows for the calculation of a consensus index, which is not available in popular methods, such as the geometric mean [13].

The starting point of the analysis consists in obtaining the preferences attached by the members of the different social groups to each of the criteria considered relevant. These preferences, when used in the context of compromise programming models as in this case, are expressed as weights affecting the different criteria in the objective function. These weights are usually normalised (by dividing them by their total sum) so that they represent the fraction of the objective function covered by each criterion. Their determination can be accomplished by resorting to any procedure designed for this purpose, for instance, the AHP approach. Once the individual weights are obtained, the proposed approach evolves in two different phases. The first consists in deriving from these initial weights the "group weights"; that is, the social group's preferences for each relevant criterion. The second phase derives from the "group weights" the final social weights; that is, the weights attached to each criterion by the society as a whole. These final weights represent the social or aggregate preferences for different criteria.

The methodology proposed in the paper differs with respect to other recent approaches based on GP dealing with similar problems. For example, Bryson and Joseph [14] proposed a logarithmic GP approach for using AHP in group decision-making situations. However, this approach and the one presented in this paper differ not only in their analytical structure but also in their utility interpretation as well as in the situational context or general purpose pursued by both approaches.

It should be noted that preference weights in the sense defined here have precise meaning only within the context of the decision-making model being used. In this sense, the final social preference weights obtained will be attached to a multi-objective programming model that looks for obtaining the best-compromise electricity plan. Although this matter will be clarified in Section 3 it is important to have in mind from the beginning the purpose as well as the context where the preference weights elicited will be used.

The paper is organised as follows. Section 2 presents a formalisation of the approach. In this sense, two different GP formulations are proposed. In the same section, a utility interpretation of the social consensus obtained is undertaken. In Section 3, the analytical framework is applied to a case study of electricity planning in Spain. Thus, four social groups that represent the different perceptions of the society, evaluate one economic criterion and four environmental criteria. The main conclusions derived from this research are presented in Section 4.

2. Analytical framework

Let us consider $i = 1, 2, \dots, q$ criteria to be assessed by $j = 1, 2, \dots, m$ social groups. The following notations will be used throughout the paper:

$N_j =$ number of members of the jth group.
$a_i^{kj} =$ preference weight attached to the ith criterion by the kth member of the jth group.
$W_i^j =$ preference weight attached to the ith criterion by the jth social group.
$W_i^S =$ preference weight attached to the ith criterion by the society (aggregate weight).

The analysis starts with an interactive phase with the members of different social groups in order to obtain the a_i^{kj} preference weights (normalised between 0 and 1). The interaction can be implemented with the help of the AHP procedure or any other alternative procedure. The final social preference weights W_i^S are determined from the a_i^{kj} weights. The first stage in the procedure consists in deriving from the a_i^{kj} weights the W_i^j weights. This operation is an intermediate and necessary step to obtain the final W_i^S weights.

To determine the W_i^j preference weights associated with the ith criterion by the jth social group the following weighted goal programming (WGP) model is proposed [15]:

Achievement function:

$$\text{Min} \quad \sum_{i=1}^{q} \sum_{k=1}^{N_j} (n_{ik} + p_{ik})^{\pi}$$

s.t.

Goals:

$$W_i^j + n_{ik} - p_{ik} = a_i^{kj} \quad i \in \{1, \dots, q\}, \quad k \in \{1, \dots, N_j\}, \tag{1}$$

where π is a parameter representing a general metric.

There is no need in this model, to normalise the deviation variables n_{ik} and p_{ik}, as required usually in the WGP models. In fact, aspiration levels a_i^{kj} have already been normalised as weights, and therefore the sum of the deviation variables is already a sum of percentage deviations, which needs to be minimised in a WGP model [16]. Finally, the weights W_i^j obtained by solving model (1) will be normalised in the usual way.

By formulating and solving m similar WGP models, the $m \times q$ W_i^j weights attached to each criterion by every social group are obtained. Metric π acts as a weight attached to the sum of deviation variables. Thus, as π increases, more importance is given to the largest deviation or more importance is attached to the minority or outlier group (that is one group's opinion that significantly differs from the other groups). The utility meaning of the solution obtained by solving (1) implies the maximisation of a separable and additive utility function [17]. For $\pi = 1$ metric, the structure of preferences, in our context, represents a solution where the sum of individual disagreements is minimised [10]. The consensus attached to this solution is statistically defined by the median weight [12]. This consensus seems suitable for the first phase of the procedure, since in this case, the possible minorities or outliers are members of the same social group. Consequently, their relative influence may not be important. In fact, the possible biased character of the different points of view or perceptions are not between groups but among members of the same group with coherently similar social perceptions.

The second phase of the procedure starts once the W_i^j preference weights are determined. In other words, the W_i^{S} social weights are elicited from the W_i^j "group weights". To achieve this, the following WGP is formulated:

Achievement function:

$$\text{Min} \quad \sum_{i=1}^{q} \sum_{j=1}^{m} (\bar{n}_{ij} + \bar{p}_{ij})^{\pi}$$

s.t.

Goals:

$$W_i^{\mathrm{S}} + \bar{n}_{ij} - \bar{p}_{ij} = W_i^j \quad i \in \{1,\ldots,q\}, \; j \in \{1,\ldots,m\}. \tag{2}$$

The W_i^{S} preference weights attached by the society to the q criteria considered are obtained by solving model (2). Again, these weights are normalised so that their sum is equal to 1.

The possible biased character underlying a WGP solution for small values of metric π can be of great importance in this second phase of the procedure. In fact, for small values of π, the average agreement provided by (2) can be very biased with respect to the judgements of a particular social group. Hence, model (2), implemented for small values of parameter π can provide a solution where the points of view of a certain group are considerably displaced with respect to the consensus obtained. This fact can make the solution obtained socially unacceptable. This can be avoided by formulating the following MINIMAX or Chebyshev model, where $\pi = \infty$ and consequently, the disagreement of the most displaced social group is minimised [18]. Weight normalisation is also done after the model has been solved:

Achievement function:

$$\text{Min} \quad D$$

s.t.

Goals:

$$\begin{gathered}
\sum_{i=1}^{q} (\bar{n}_{i1} + \bar{p}_{i1}) - D \leqslant 0, \\
\vdots \\
\sum_{i=1}^{q} (\bar{n}_{im} + \bar{p}_{im}) - D \leqslant 0, \\
W_i^{\mathrm{S}} + \bar{n}_{ij} - \bar{p}_{ij} = W_i^j \quad i \in \{1,\ldots,q\}, \; j \in \{1,\ldots,m\}.
\end{gathered} \tag{3}$$

Accounting rows:

$$\begin{gathered}
\sum_{i=1}^{q} (\bar{n}_{i1} + \bar{p}_{i1}) - D_1 = 0, \\
\vdots \\
\sum_{i=1}^{q} (\bar{n}_{im} + \bar{p}_{im}) - D_m = 0,
\end{gathered}$$

where D represents the disagreement of the social group with opinions more significantly different with respect to the consensus obtained. Hence, model (3) provides a consensus that gives the maximum importance to the minority social group. The variables $D_1, \ldots, D_m$ represent the disagreement in each group with respect to the consensus obtained. It is obvious that $D = \max(D_1, \ldots, D_m)$ and that $\sum_{i=1}^{m} D_i$ measures the average agreement (consensus obtained).

From a preferential point of view, solutions provided by model (2) for small values of metric π and by model (3) represent two opposite poles. Thus, the WGP solution provides the consensus where the average agreement is maximised, whereas the MINIMAX or Chebyshev solution provides the consensus for which the disagreement of the most displaced social group is minimised. In practical applications, both solutions can present problems of social acceptability. In fact, for the first case, the interests of one social group (*the minority or outlier*) can be very badly treated, while in the second case only one group (again *the minority or outlier*) can serve to determine the final solution. For these reasons, it can be interesting to look for good compromises between these two opposite solutions. This task can be undertaken by generalising the above analysis with the help of the following formulation, which attempts the aggregation of models (2) and (3) (see Ref. [10] for a similar model but in an ordinal context):

Achievement function:

$$\text{Min} \quad (1-\lambda)D + \lambda \sum_{i=1}^{q} \sum_{j=1}^{m} (\bar{n}_{ij} + \bar{p}_{ij}).$$

Table 1
Weights attached to each criterion by the members of every social group[a]

	Criteria				
	Cost	CO_2 emissions	SO_2 emissions	NO_x emissions	Radioactive waste
Regulator no 1	0.250	0.433	0.087	0.087	0.143
Regulator no 2	0.833	0.022	0.066	0.066	0.013
Regulator no 3	0.667	0.079	0.079	0.159	0.016
Regulator no 4	0.875	0.077	0.011	0.011	0.026
Academic no 2	0.833	0.006	0.018	0.018	0.125
Academic no 3	0.500	0.147	0.029	0.029	0.295
Electricity u. no 2	0.750	0.104	0.021	0.021	0.104
Electricity u. no 4	0.800	0.006	0.018	0.018	0.158
Environmentalist no 1	0.100	0.171	0.024	0.021	0.684
Environmentalist no 2	0.125	0.105	0.021	0.021	0.728
Environmentalist no 4	0.167	0.096	0.032	0.032	0.673

[a]AHP exercise. Consistency index =0.20.

s.t.

Goals and accounting rows of model (3)

Additional accounting row:

$$\sum_{i=1}^{q}\sum_{j=1}^{m}(\bar{n}_{ij}+\bar{p}_{ij})-Z=0. \tag{4}$$

For $\lambda = 0$, we have model (3) for $\pi = \infty$ metric, which defines the consensus by minimising the disagreement of the most displaced social group. For $\lambda = 1$, we have model (2) for $\pi = 1$ metric, which defines the consensus by maximising the average agreement (statistically the median of weights). For intermediate values of parameter λ compromises between these two solutions are obtained. The last row of model (4) is an accounting row measuring average agreement corresponding to each solution. It is obvious that for every solution, the equality $Z = \sum_{i=1}^{m} D_i$ holds.

It is important to note that model (4) implies a search for Paretian efficient solutions in the *Z–D* space of reference. Moreover, it is well known that GP models do not guarantee the efficiency of their solutions (e.g. [19]). Hence, the efficient or non-efficient character of the solutions derived from different values of parameter λ should be tested. This matter will be clarified in the case study presented in the following section.

3. An application

The proposed methodology was applied to a prospective electricity planning exercise in Spain. In this exercise, the objective was to estimate the capacity to be installed for different fuels and technologies for electricity production (72 combinations considered) for year 2020 in Spain, under different energy demands, fuels, technology or macroeconomic constraints. Following a first interaction with the relevant decision makers (regulators, academics, electric utilities and environmentalists, which were assumed to represent the different and conflicting views of society as a whole), five criteria were identified as the most representative:

(a) Minimisation of the total cost of the electricity generation.
(b) Minimisation of CO_2 emissions.
(c) Minimisation of SO_2 emissions.
(d) Minimisation of NO_x emissions.
(e) Minimisation of the radioactive waste produced.

The consideration of each of these criteria individually for the electricity planning model produced very different results: the solution which minimised economic costs also resulted in very large emissions and radioactive wastes. In turn, the "greenest" solution implied a very large cost. Therefore, a compromise solution had to be sought in which each of the conflicting criteria had reasonable values according to the decision makers. This required the construction of a compromise-programming model, and the introduction into this model of the preferences of decision makers towards the criteria proposed. This latter stage is the one described in this paper. More details about the different aspects of the case study can be found in [20,21].

The interactive evaluation process was implemented with the help of the AHP. Table 1 shows the judgement values obtained from a pairwise comparison implemented between the different social groups. Only cases with an inconsistency index lower than 0.20 are shown. These preference weights reflect the individual preferences of each member of each social group for each of the five criteria considered, and are expressed as a fraction of the total sum of weights (that is, as normalised weights). The next step in the procedure consisted in the aggregation of the individual preferences in order to obtain the W_i^j preference weights attached by each social group to each criterion. This task was accomplished by applying model (1) to the data shown in Table 1. In this way, four WGP models were formulated and solved. Table 2 shows, as an example, the formulation of the WGP

Table 2
Determination of the group preferences by a WGP model[a]

Achievement function		
Min $\sum_{i=1}^{5}\sum_{k=1}^{4}(n_{ik}+p_{ik})$		
s.t.		
$W_1^1+n_{11}-p_{11}=0.250$	$W_2^1+n_{21}-p_{21}=0.433$	$W_3^1+n_{31}-p_{31}=0.087$
$W_1^1+n_{12}-p_{12}=0.833$	$W_2^1+n_{22}-p_{22}=0.022$	$W_3^1+n_{32}-p_{32}=0.066$
$W_1^1+n_{13}-p_{13}=0.667$	$W_2^1+n_{23}-p_{23}=0.079$	$W_3^1+n_{33}-p_{33}=0.079$
$W_1^1+n_{14}-p_{14}=0.875$	$W_2^1+n_{24}-p_{24}=0.077$	$W_3^1+n_{34}-p_{34}=0.011$
$W_4^1+n_{41}-p_{41}=0.087$	$W_5^1+n_{51}-p_{51}=0.143$	
$W_4^1+n_{42}-p_{42}=0.066$	$W_5^1+n_{52}-p_{52}=0.013$	
$W_4^1+n_{43}-p_{43}=0.159$	$W_5^1+n_{53}-p_{53}=0.016$	
$W_4^1+n_{44}-p_{44}=0.011$	$W_5^1+n_{54}-p_{54}=0.026$	

[a]"Regulators Group".

Table 3
Group preferences

Social group	Criteria				
	Cost	CO_2 emissions	SO_2 emissions	NO_x emissions	Radioactive waste
Regulators	0.748	0.086	0.074	0.074	0.018
Academics	0.693	0.083	0.025	0.025	0.174
Electric utilities	0.787	0.063	0.022	0.019	0.109
Environmentalists	0.131	0.109	0.025	0.022	0.713

model corresponding to the "regulators" group and Table 3 shows the W_i^j group preference weights attached to the five criteria considered. These weights were also normalised by dividing by their total sum.

It should be noted that, from a statistical point of view, preference weights obtained in this phase are median weights. Consequently, when the number of members of the social group is odd (the case of environmentalists), then the social weight corresponds to the intermediate value that leaves the same even number of observations lower and higher than its value. However, when the number of members of the social group is even (the rest of the cases), then there are alternative optimal solutions. In fact, the closed interval defined by the intermediate values that leave the same odd number of observations lower and higher than the extreme values of the interval represent the set of alternative optimal solutions. It has to be noted that the values to which we refer and the social weights reflected in Table 3 do not coincide because of the normalisation carried out before the social weights are calculated.

Preference weights shown in Table 3 can be considered quite reasonable. Thus, financial cost is the most important criterion for all the groups except for the "environmentalists". For this group, the most important criterion is the minimisation of radioactive wastes, followed by financial cost and CO_2 emissions. The disparity of views between the different social groups in general and especially between "environmentalists" and the rest of the groups can make an average consensus impossible without considerably degrading the points of view of the minority group ("environmentalists" in this application).

The next step of the procedure consisted in the aggregation of the group preferences. In this way, the W_i^S preference weights attached by the society to each of the five criteria considered were obtained. This task was accomplished by applying model (4) to the W_i^j group preferences shown in Table 3. The Extended GP model shown in Table 4 was obtained by operating this way. This model was solved for different values of parameter λ. The results obtained are shown in Table 5. It should be recalled that the preference weights shown in Table 5 have been normalised as it was done with the "group preference weights" shown in Table 3.

The maximum average agreement consensus is obtained for values of parameter λ larger than 0.33. It should be again remarked that these preference values correspond to median weights. The indicator of consensus for this solution is $Z = 1.63$ units. This solution is very biased against the preferences shown by the "environmentalists" group, with a maximum disagreement of 1.13 units. This represents 69.32% of the total disagreement. It is interesting to note that the MINIMAX or Chebyshev solution (i.e. when $\lambda = 0$) is non-efficient. In fact, it is easy to check that the most balanced solution, being efficient at the same time, corresponds to values of parameter λ lower than 0.33 and larger

Table 4
Determination of the social preferences (weights W_i^S) by an Extended GP Model

Achievement function		
Min $(1-\lambda)D + \lambda \sum_{i=1}^{5} \sum_{j=1}^{4} (\bar{n}_{ij} + \bar{p}_{ij})$		
s.t.		
Goals		
$\sum_{i=1}^{5} (\bar{n}_{i1} + \bar{p}_{i1}) - D \leqslant 0$	$W_1^S + \bar{n}_{11} - \bar{p}_{11} = 0.748$	$W_2^S + \bar{n}_{21} - \bar{p}_{21} = 0.086$
$\sum_{i=1}^{5} (\bar{n}_{i2} + \bar{p}_{i2}) - D \leqslant 0$	$W_1^S + \bar{n}_{12} - \bar{p}_{12} = 0.693$	$W_2^S + \bar{n}_{22} - \bar{p}_{22} = 0.083$
$\sum_{i=1}^{5} (\bar{n}_{i3} + \bar{p}_{i3}) - D \leqslant 0$	$W_1^S + \bar{n}_{13} - \bar{p}_{13} = 0.787$	$W_2^S + \bar{n}_{23} - \bar{p}_{23} = 0.063$
$\sum_{i=1}^{5} (\bar{n}_{i4} + \bar{p}_{i4}) - D \leqslant 0$	$W_1^S + \bar{n}_{14} - \bar{p}_{14} = 0.131$	$W_2^S + \bar{n}_{24} - \bar{p}_{24} = 0.109$
$W_3^S + \bar{n}_{31} - \bar{p}_{31} = 0.074$	$W_4^S + \bar{n}_{41} - \bar{p}_{41} = 0.074$	$W_5^S + \bar{n}_{51} - \bar{p}_{51} = 0.018$
$W_3^S + \bar{n}_{32} - \bar{p}_{32} = 0.025$	$W_4^S + \bar{n}_{42} - \bar{p}_{42} = 0.025$	$W_5^S + \bar{n}_{52} - \bar{p}_{52} = 0.174$
$W_3^S + \bar{n}_{33} - \bar{p}_{33} = 0.022$	$W_4^S + \bar{n}_{43} - \bar{p}_{43} = 0.019$	$W_5^S + \bar{n}_{53} - \bar{p}_{53} = 0.109$
$W_3^S + \bar{n}_{34} - \bar{p}_{34} = 0.025$	$W_4^S + \bar{n}_{44} - \bar{p}_{44} = 0.022$	$W_5^S + \bar{n}_{54} - \bar{p}_{54} = 0.713$
Accounting rows		
$\sum_{i=1}^{5} (\bar{n}_{i1} + \bar{p}_{i1}) - D_1 = 0$	$\sum_{i=1}^{5} (\bar{n}_{i3} + \bar{p}_{i3}) - D_3 = 0$	$\sum_{i=1}^{5} \sum_{j=1}^{4} (\bar{n}_{ij} + \bar{p}_{ij}) - Z = 0$
$\sum_{i=1}^{5} (\bar{n}_{i2} + \bar{p}_{i2}) - D_2 = 0$	$\sum_{i=1}^{5} (\bar{n}_{i4} + \bar{p}_{i4}) - D_4 = 0$	

Table 5
Social weights for different values of parameter λ

λ	W_1^S	W_2^S	W_3^S	W_4^S	W_5^S	Z	D	D_1	D_2	D_3	D_4
[1 0.33)	0.694	0.086	0.025	0.022	0.173	1.63	1.13	0.31	0.01	0.19	1.13
[0.33 0)	0.484	0.171	0.039	0.035	0.271	2.45	0.72	0.72	0.41	0.59	0.72
0	0.483	0.145	0.042	0.037	0.293	2.57	0.72	0.72	0.41	0.72	0.72

than 0. The corresponding average agreement is 2.45 units (i.e., 0.82 units worse than the maximum average agreement solution). However, for this solution, disagreement corresponding to the "environmentalists" groups is of 0.72 units (i.e., 0.41 units better than the values provided by the maximum average agreement solution). These figures represent the quantification of the clash between the interest of the majority (average agreement) and the consideration of the interest of the minority or the most displaced social group ("environmentalists" in our application).

4. Concluding remarks

The proposed approach seems attractive, at least for the following reasons. First, from a computational point of view, the method only requires the solution of a limited number of linear programmes of very moderate size. Second, the solutions generated by the different models can be straightforwardly interpreted in utility terms. Third, the analytical procedure can be combined with any method capable of deriving individual weights in multi-criteria problems. Fourth, the procedure can generate solutions with respect to the interests of the majority or the minority, as well as solutions that represent sound compromises between the interests of both groups.

It should be noted that in the proposed procedure there is an underlying assumption that every social group has the same importance or social influence. Nevertheless, the procedure can be easily adapted to a context where weights reflecting different social influences by each group are considered.

The methodology has been applied to a specific case of electricity planning, however, its scope is beyond the particular case analysed. In fact, it is not difficult to imagine many situations where several social groups have perceptions of a very different nature for the criteria considered and the corresponding social weights have to be attached to a multi-objective programming model. Indeed, planning problems in fisheries, forestry, water resources, etc, seem to fit within the analytical framework analysed in this paper, thus reinforcing its pragmatic value.

Acknowledgements

The authors would like to thank the members of the regulators, academics, electric utilities and environmentalist groups that participated in this exercise. Comments raised by Dr. González–Pachón are highly appreciated. Comments raised by the referees are also appreciated. English language was checked by Christine Mendez. A preliminary shorter version of this paper was presented at the 4th Multiobjective Programming and Goal Programming Conference (MOPGP00) (Ustrón, Poland, June 2000). The work by Carlos Romero was supported by Spanish "Comisión Interministerial de Ciencia y Tecnología" and the "Consejería de Educación y Cultura de la Comunidad de Madrid".

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