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A multiple criteria decision making approach for electricity planning in Spain: economic versus environmental objectives

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Growing social concern about the environmental impact of economic development has drawn attention to the need to integrate environmental criteria into energy decision-making problems. This has made electricity planning issues more complex given the multiplicity of objectives and decision-makers involved in the decision making process. This paper proposes a methodology that combines several multi-criteria methods to address electricity planning problems within a realistic context. The method is applied to an electricity planning exercise in Spain with a planning horizon set for the year 2030. The model includes the following objectives: (1) total cost; (2) $C0_2$; (3) SO_2; and (4) NO_x emissions as well as the amount of radioactive waste produced. An efficient social compromise between these conflicting objectives is obtained, which shows the advantages of using this model for policy-making purposes.

Keywords: multiple criteria decision making; energy; environmental studies; compromise programming

Introduction

In the last few decades, modern societies have realised the need for a sustainable development that requires that both economic and environmental resources be allocated efficiently from a social point of view. Unfortunately, this socially-efficient allocation cannot be carried out solely by market mechanisms, because of the existence of environmental externalities, namely the effects on the environment caused by human activities, which are not included in the market price. In fact, it is well known that the presence of externalities generates a 'market failure', implying that the allocation of resources provided by the market mechanisms is inefficient. This is especially relevant in the electricity sector due to its significant environmental impact. For this reason, institutions such as the European Commission[1] have recently proposed that the implementation of policies to internalise these environmental externalities in order to integrate them into the energy decision-making processes is the only way to achieve a socially-efficient allocation of resources.

This task requires the introduction of environmental criteria into the already complex electricity operation and planning models.[2] Initial attempts to achieve this purpose have consisted of the introduction of environmental constraints into traditional models.[3] Unfortunately, this approach does not guarantee socially-efficient solutions. In fact, to achieve this, it is necessary to consider the relevant environmental objectives at the same decision level as traditional economic or reliability objectives. To undertake this task, two general approaches or frameworks have been used: (1) economic assessment of the environmental externalities[4] and (2) the application of multiple criteria decision making (MCDM) methods.[5–7] However, these approaches have rarely been applied to a large-scale, realistic electricity planning problem with multiple objectives and several decision-makers.

This paper presents a methodology that combines several multi-criteria methods to determine optimal electricity planning strategies from a social point of view. It considers multiple and conflicting economic and environmental objectives and integrates, in a consistent way, the decision-makers' preferences into the planning process. This proposed method has been applied to an electricity planning exercise in Spain with the planning horizon set in the year 2030.

Main features of the basic model

The following notation is introduced:

R = number of resources considered $(1, \ldots, i, \ldots, R)$
T = number of technologies considered $(1, \ldots, j, \ldots, T)$
H = number of time periods considered $(1, \ldots, k, \ldots, H)$
l_k = length of each time period considered (hours)
d = discount rate (%)

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v_{ij} = investment life for the ith resource and for the jth technology (years).
nf = sub-set of technology and resource combinations using national fuel.
D_k = energy demand for the kth time period (TWh).
IP_{ij} = installed power for the ith resource and for the jth technology (TW).
CP_{ijk} = committed power for the ith resource, for jth technology and for the kth time period (TW).
CO_{ij} = CO_2 emission rate for the ith resource and for the jth technology (kg/TWh).
SO_{ij} = SO_2 emission rate for the ith resource and for the jth technology (kg/TWh).
NO_{ij} = NO_x emission rate for the ith resource and for the jth technology (kg/TWh).
RW_{ij} = generation of radioactive wastes for the ith resource and for the jth technology (Tbq/TWh).
FP_{ij} = available power coefficient (considering unavailability and forced-outage rates) for the ith resource and for the jth technology (%).
CE_{ij} = fuel consumption for the ith resource and for the jth technology (TWh/TWh).
IC_{ij} = investment cost for the ith resource and for the jth technology (M$/TW).
DC_{ij} = dismantling cost for the ith resource and for the jth technology (discounted at the discount rate d for the investment life v_{ij}) (M$/TW).
FMC_{ij} = fixed annual maintenance and operation cost for the ith resource and for the jth technology (M$/TW·year).
VMC_{ij} = variable maintenance and operation cost for the ith resource and for the jth technology (M$/TWh).
FC_{ij} = fuel cost for the ith resource and for the jth technology (M$/TWh).
AR_i = available quantity for the ith resource (in terms of energy) (Twh).
AT_j = maxim capacity for the jth technology (in terms of installed power) (TW).
PRM = power reserve margin (%).
CC = domestic fuel quota (%).
SC = energy security coefficient (% of the total energy allowed to be supplied by a single resource) (%).

The following objectives were considered in the model.

Minimisation of the total cost

This objective implies the minimisation of the annual cost of energy for the planning horizon considered, which is a certain year in which all the power generation options are assumed to be already installed. Therefore, these costs include the annualised investment and dismantling costs plus the fixed operation and maintenance costs for that year incurred by the existence of certain power plants (represented by the installed power). These costs also include the variable operation and maintenance plus the fuel costs incurred by generating energy with these power plants. Investment and dismantling costs are annualised by using the discount rate d over all the investment lifetime v_{ij}

$$f_1 = \sum_{i=1}^{R}\sum_{j=1}^{T}\left[(IC_{ij}+DC_{ij})\frac{(1+d)^{v_{ij}}d}{(1+d)^{v_{ij}}-1}+FMC_{ij}\right]IP_{ij} + \sum_{i=1}^{R}\sum_{j=1}^{T}(VMC_{ij}+FC_{ij}CE_{ij})FP_{ij}\sum_{k=1}^{H}l_k CP_{ijk} \quad (1)$$

Minimisation of CO_2 emissions

This objective is determined according to the fuel carbon content and the technology conversion efficiency. In this way, a constant emission rate for each combination resource-technology is determined as a function of the total electricity supplied

$$f_2 = \sum_{i=1}^{R}\sum_{j=1}^{T}CO_{ij}FP_{ij}\sum_{k=1}^{H}l_k CP_{ijk} \quad (2)$$

Minimisation of SO_2 emissions

This objective is determined according to the fuel sulphur content, technological conversion efficiency and the desulphurisation measures. A constant emission rate for each combination resource-technology is again determined as a function of the total electricity supplied

$$f_3 = \sum_{i=1}^{R}\sum_{j=1}^{T}SO_{ij}FP_{ij}\sum_{k=1}^{H}l_k CP_{ijk} \quad (3)$$

Minimisation of NO_x emissions

NO_x emissions are determined similarly to CO_2 and SO_2 emissions. However, in this case the emissions also depend on the values of additional parameters such as combustion air or temperature

$$f_4 = \sum_{i=1}^{R}\sum_{j=1}^{T}NO_{ij}FP_{ij}\sum_{k=1}^{H}l_k CP_{ijk} \quad (4)$$

Minimisation of the radioactive wastes produced

The production of radioactive wastes is considered constant and depends on the amount of electricity produced, the kind of technology and the amount of fuel used

$$f_5 = \sum_{i=1}^{R}\sum_{j=1}^{T}RW_{ij}FP_{ij}\sum_{k=1}^{H}l_k CP_{ijk} \quad (5)$$

The constraints of the problem are the following.

Demand requirements

The sum of committed power in each period has to be larger than or equal to the demand in that period, corrected by the corresponding power reserve margin

$$\sum_{i=1}^{R}\sum_{j=1}^{T} l_k CP_{ijk} FP_{ij} \geqslant l_k D_k (1 + PRM), \forall k \tag{6}$$

Resource availability

The consumption of each energy resource has to be less than or equal to the available potential for that resource for the year considered (this is relevant for domestic resources such as renewable energies, for which no global market or storage exist)

$$\sum_{j=1}^{T} CE_{ij} FP_{ij} \sum_{k=1}^{H} l_k CP_{ijk} \leqslant AR_i, \forall i \tag{7}$$

Limits to technologies

The maximum installed power for some technologies may be limited due to political, environmental or technological reasons (hydro, or nuclear).

$$\sum_{i=1}^{R} IP_{ij} \leqslant AT_j, \forall j \tag{8}$$

Domestic fuel quotas

According to current legislation each country of the European Union can require that a certain percentage (currently a minimum bound of 15%) of the primary energy used comes from native sources.

$$\left(\sum_{i=1}^{R}\sum_{j=1}^{T} CE_{ij} FP_{ij} \sum_{k=1}^{H} l_k CP_{ijk}\right)_{nf} \geqslant CC \sum_{i=1}^{R}\sum_{j=1}^{T} CE_{ij} FP_{ij} \sum_{k=1}^{H} l_k CP_{ijk} \tag{9}$$

Energy security

Electricity produced with each resource cannot surpass a determined percentage of the total production. This requirement guarantees a certain diversification of the electricity supply

$$\sum_{j=1}^{T} FP_{ij} \sum_{k=1}^{H} l_k CP_{ijk} \leqslant SC \sum_{k=1}^{H} l_k D_k, \forall i \tag{1}$$

Bound for committed power

For logical reasons, committed power cannot be larger than the installed power along the planning horizon.

$$CP_{ijk} \leqslant IP_{ij}, \forall k \tag{11}$$

A compromise model

The objectives and constraints defined in the basic model lead to the following optimisation model:

$$\text{Eff}\mathbf{f} = [f_1, f_2, f_3, f_4, f_5] \tag{12}$$

subject to

$$\text{constraints (6)–(11)}$$

Where Eff means the search for efficient or Paretian solutions in a minimising sense. The multiobjective programming model (12), although a useful first step in our analysis, presents two problems. Firstly, the precise generation of the efficient set for a problem of this size is a very difficult task even for the most powerful software available[8] (see next section for details on the size of the model). Secondly, even if only the set of extreme efficient points is approximated with the help of generating techniques, its final size will be huge. In fact, a model the size of (12) can generate thousands of extreme efficient points,[9] which is obviously useless to any decision-maker.

Due to these reasons only some best-compromise solutions for the above model will be sought. To this end the following compromise programming model is formulated.[10–12]

$$L_p = \left[\sum_{i=1}^{5}\left[w_i \frac{f_i - f_i^*}{f_{j^*} - f_i^*}\right]^p\right]^{1/p} \tag{13}$$

subject to

$$\text{constraints (6)–(11)}$$

where:

p = metric defining the family of distance functions
w_i = preferential weight attached to the ith objective
f_i^* = ideal or anchor value for the ith objective
f_{i^*} = anti-ideal or nadir value for the ith objective.

The ideal values f_i^* are obtained by minimising each objective over the constraint set. The nadir values f_{i^*} are obtained in the following way, the decision variables corresponding to each ideal value are substituted in the other objectives, obtaining the worst (maximum) or anti-ideal value in this way. The denominators $f_{i^*} - f_i^*$ seek to normalise the five objectives considered. In fact, without normalisation comparing and/or aggregating the objectives is meaningless.

Yu[10] demonstrated that for bi-objective problems the $p = 1$ and $p = \infty$ metrics define a subset of the efficient set called the compromise set. Recently Blasco *et al*[13] demonstrated that the boundedness of the compromise set by metrics $p = 1$ and $p = \infty$ for more than two objectives is guaranteed under very general conditions. These conditions are the usual in economics such as the differentiability and concavity towards the origin of the transformation hypersurface defined in the positive orthant. It has also been demonstrated that, again under weak conditions, the optimum of the unknown utility function will belong to the compromise set.[14,15] All these results justify the compromise set as a sound surrogate for the true but unknown utility optimum.

The L_1 bound of the compromise set will be obtained by making $p = 1$ in (13), therefore, leading to the following linear programme (LP):

$$L_1 = \sum_{i=1}^{5} W_i \frac{f_i - f_i^*}{f_{i*} - f_i^*} \tag{14}$$

subject to

constraints (6)–(11)

From a preferential point of view, the bound L_1 corresponds to the maximisation of a separable and additive utility function $u(f_1 + \cdots + f_5)$ such as $u = k_1 f_1 + \cdots + k_5 f_5$. This optimum means a solution of maximum efficiency, since the weighted sum of the achievements for the all the objectives considered is maximised.[16]

The L_∞ bound of the compromise set will be obtained by making $p = \infty$ in (13). This leads to the following linear program:

$$\min L_\infty = D$$

subject to

$$W_i \frac{f_i - f_i^*}{f_{i*} - f_i^*} \leqslant D \qquad i = 1, \ldots, 5 \tag{15}$$

constraints (6)–(11)

where D is the maximum deviation. From a preferential point of view, the bound L_∞ corresponds to the maximisation of a Rawlsian utility function $u = -\{\max[w_1(f_1 - f_1^*)/(f_{1*} - f_1^*), \ldots, w_5(f_5 - f_5^*)/(f_{5*} - f_5^*)]\}$, that seeks a perfectly balanced situation between the achievements of all the objectives considered. When a perfectly balanced solution exists it implies that the following chain of equalities hold:[16]

$$W_1 \frac{f_1 - f_1^*}{f_{1*} - f_1^*} = \ldots \qquad \ldots W_5 \frac{f_5 - f_5^*}{f_{5*} - f_5^*} \tag{16}$$

From a preferential point of view L_1 and L_∞ solutions represent two opposite poles. Therefore, the L_1 solution implies the maximum aggregate achievement (*maximum efficiency*), while the L_∞ solution implies the most balanced solution between achievements of different objectives (*maximum equity*). The first solution can be extremely biased towards some of the objectives, whereas the second can provide poor aggregated performance between the different goals. For these reasons, the following generalisation may be useful:[17]

$$\min \varphi = (1 - \lambda)D + \lambda \sum_{i=1}^{5} W_i \frac{f_i - f_i^*}{f_{i*} - f_i^*}$$

subject to

$$W_i \frac{f_i - f_i^*}{f_{i*} - f_i^*} \leqslant D, \quad = i, \ldots, 5 \tag{17}$$

constraints (6)–(11)

For $\lambda = 0$, we have the L_∞ solution, for $\lambda = 1$ the L_1 solution and for other values of parameter λ an intermediate solution between the L_1 and the L_∞ solutions.

Preferential weights elicitation

To implement the analytical framework presented in the previous section, the elicitation of preferential weights $w_1, \ldots, w_5$ has to be addressed. Some authors[18] argue that individual preferences should not be included in energy planning problems to obtain ‘objective’ solutions. However, the incorporation of individual preferences in the decision-making process allows us not only to reflect individual values, but also to provide better information to society, therefore increasing the credibility of the planning process.[19] These latter aspects are especially relevant within a context where the environmental criteria play a key role.

The first step in eliciting preferential weights is to characterise the decision-maker or group of decision-makers. For this energy planning exercise, the group of decision-makers chosen was the one termed as ‘regulators’, that is, energy administrators or regulatory commission members, since they are the ones in charge of planning electricity activities in most countries, and are assumed to represent the interests of society.

The method chosen to derive weights was the Analytic Hierarchy Process (AHP).[20,21] Although the AHP is not devoid of theoretical difficulties,[22] its easy interaction with a group of decision-makers makes it a very suitable vehicle for deriving preferential weights within an energy planning context.

The application procedure of the AHP is as follows. The five objectives considered in our exercise were presented to a group of four regulators for a pairwise comparison. In this way, four Saaty’s matrices were obtained. From these matrices, and by resorting to a goal programming formulation,[23] the corresponding individual weights were found. These four vectors of weights reflect the individual preferences of the ‘regulators’ group. The next step of the procedure consisted in aggregating individual preferences. This task was accomplished by resorting to a weighted arithmetic mean, giving the same weight to each member of the group. This system of aggregation presents some advantages with respect to alternative methods such as the geometric mean.[24] These final weights are used as surrogate of the ‘regulators’ group structure of preferences and are consequently introduced in the compromise model.

An application to the Spanish electricity sector

The model presented above has been applied to the Spanish electricity sector. This application, proposed by energy administration institutions, is justified on the need to reduce the significant environmental impact of this sector, especially with respect to major pollutants such as CO_2, NO_x or SO_2 emissions and radioactive wastes, while at the same time keeping energy costs at reasonable levels.

Indeed, electricity generation in Spain produces around 66% of all SO_2 emissions, 20% of NO_x and CO_2 emissions, and 97% of radioactive wastes. This situation is expected to worsen with the recent restructuring of the electricity market, since environmental impact is usually more widespread in liberalised environments.[25] Therefore, the introduction of environmental criteria into the power system operation and planning processes may be the only way of achieving a socially efficient allocation of resources in a competitive market.

This was acknowledged in the recent Spanish Electricity Act (Law 54/97)[26] in which an indicative planning tool supporting the design and development of energy and environmental policies was proposed so as to achieve this socially efficient allocation of resources. The model presented in this paper may be an answer to this need and has been applied to determine the optimal pollution levels to be attained by the Spanish electricity sector in the long term (year 2030), according to the five objectives described in Section 2. The following steps were taken for this application.

Firstly, expected available technologies and fuels for the year 2030 with regard to electricity generation in Spain were selected. Technologies included traditional steam cycles, fluidised-bed combustion, integrated gasification with combined cycles, fuel cells, nuclear, hydro and renewable technologies (biomass, wind energy, solar thermal, and photovoltaics). The fuels considered were fossil (imported and domestic coal, gas, and oil), nuclear and renewable. The feasible technology-fuel combinations amount to 72. All these combinations were characterised both on economic and technical grounds. Therefore, investment costs, fuel costs, electric conversion efficiencies, and pollutant emissions were determined based on widely accepted databases.[27,28]

A business-as-usual scenario, inspired by a prospective study carried out by the Spanish Ministry of Industry in 1997,[29] and revised by Ministry officials, was assumed for the general macroeconomic framework This base scenario accounts for current economic and energy trends, presenting what is considered the most probable situation by the year 2030. The most relevant assumptions in this scenario are: (a) an expected demand of 234 TWh, resulting from a long-term annual growth of 1%; (b) a high potential for renewable resources, promoted by favourable legislation in the EU and Spain; (c) a real social discount rate around 3% (given that the socially efficient allocation of resources should take into account social, not private, discount rates); (d) an obligation of using at least 15% of domestic primary energy (as stated by Spanish law) and (e) an energy security constraint, requiring that the maximum power provided by any fuel cannot exceed 25% of the total demand for the whole year. More details of this scenario, as well as the description of other possible scenarios, can be found in Linares.[30]

In addition to all these data, the application of the model presented requires the estimation of the decision-makers' preferences involved in the electricity planning processes. In our case, these decision-makers belong to the Ministry of Industry and Energy and to the National Electricity Regulatory Commission. Two members from each institution were selected, and their preferences elicited by the AHP method in the way described in the previous section. The incorporation into the compromise model of the preference weights, the technical and economic data corresponding to the technology-fuel combinations and the general macroeconomic framework produced the results shown in the following section.

Results and discussion

The first result obtained was the pay-off matrix shown in Table 1. The elements of this matrix are obtained by optimising each objective separately over the constraint set and then computing the value of each objective at each of the optimal solutions. The elements of this matrix are easy to understand. For example, the elements in the first row indicate that CO_2 emissions of 73.82 Mt/y, SO_2 emissions of 67.05 kt/y, NO_x emissions of 57.76 kt/y and a total radioactive waste of 3.69 PBq/y corresponding to the least cost solution (9,172 M$/y). The elements of the main diagonal represent the ideal values, whereas the largest value of each column indicates the corresponding anti-ideal.

From the analysis of the information contained in the pay-off matrix, the following conclusions are obtained:

1. There is an important degree of conflict between the five objectives considered. This conflict is especially remarkable between cost and radioactive waste (the minimisation of radioactive waste implies very high costs, and viceversa). In any case, a pairwise comparison between rows of the pay-off matrix shows a significant degree of conflict between the corresponding objectives. Hence, there are no redundant objectives and consequently the five objectives should be considered in the analysis.
2. No solution generated by the single optimisation of any objective seems acceptable. Therefore, it would be useful to look for compromise solutions between the five objectives considered. In this situation, the compromise model devised in Section 3 seems especially relevant.

Table 1 Pay-off matrix for the five objectives considered

Optimisation objective considered	*Values for the different criteria*				
	Cost *(M\$/y)*	*CO_2 emissions (Mt/y)*	*SO_2 emissions (kt/y)*	*NO_x emissions (kt/y)*	*Radioactive waste (PBq/y)*
Cost	**9,172**	73.82	67.05	56.76	3.69
CO_2 emissions	12,069	**15.90**	14.79	20.03	3.69
SO_2 emissions	33,517	28.53	**3.49**	6.43	3.69
NO_x emissions	46,828	42.36	29.59	**4.50**	4.04
Radioactive waste	76,138	148.23	172.83	82.78	**0**

Bold characters denote ideal values and underlined numbers anti-ideals

3. Some indications of the trade-offs (opportunity costs) between objectives can be obtained from the pay-off matrix. Thus, it may be observed that the reduction of radioactive wastes implies a high cost both in terms of money or atmospheric emissions, while the reduction of the other environmental impacts is 'cheaper'. It is also interesting to point out the impossibility of eliminating SO_2 or NO_x emissions, due to the constraints imposed upon the optimisation problem.

To elicit the preferential weights, the pay-off matrix and a questionnaire based on the AHP method were presented to the four regulators described in the previous section. From the answers to the questionnaire, their preferential weights were elicited with the help of a goal programming formulation.[23] This approach also allowed for the determination of a consistency ratio, which was used to eliminate the preferences of inconsistent decision-makers. Individual preferences were aggregated as a weighted arithmetic mean, giving the same weight to each member of the group. The resulting aggregated weights are the following:

$$
\begin{aligned}
w_1(\text{cost}) &= 0.656\\
w_2(\text{CO}_2 \text{ emissions}) &= 0.153\\
w_3(\text{SO}_2 \text{ emissions}) &= 0.060\\
w_4(z\text{NO}_x \text{ emissions}) &= 0.081\\
w_5(\text{radioactive waste}) &= 0.050
\end{aligned}
$$

These weights may be considered quite reasonable, given the usual views of regulators for the criteria presented. Financial cost is of course the most important attribute, followed by CO_2 emissions (probably because of the recent political interest in this issue). Radioactive wastes, on the other hand, show the smallest weight for regulators, which is also consistent with the current energy policy.

Finally, the regulators' preferences were introduced into the compromise model previously described, in order to obtain the two bounds L_1 and L_∞ of the compromise set and some intermediate solutions. The corresponding best-compromise solutions are presented in Table 2.

Solutions shown in Table 2 represent the range of efficient energy plans that are best-compromise solutions, since their weighted distance with respect to the ideal point is minimal. It is important to remark the closeness of the L_1 and the L_∞ bounds of the compromise set. This means that for this case study, the solutions of maximum efficiency and maximum balance almost coincide. It is obvious that this coincidence makes it easier to choose an energy plan.

The best-compromise solutions generated by our compromise programming model seem attractive. This is especially true when the best-compromise solutions are compared with the single optimisation solutions shown in Table 1. More precisely, when the solutions shown in Table 2 are compared with the traditional least-cost solution (first row of Table 1) the following conclusions are obtained. Best-compromise solutions achieve a 60% reduction in CO_2 emissions, up to a 90% reduction in SO_2 emissions, up to a 70% reduction in NO_x emissions, and a 55% reduction in radioactive wastes, with only a 25% increment in the cost of the electricity produced. This is even more evident for the solution corresponding to the L_∞ metric. In this case, as in many social choice scenarios, this should be

Table 2 Results of the compromise programming model

	L_1	$\lambda = 0.9$	$\lambda = 0.7$	$\lambda = 0.5$	$\lambda = 0.3$	$\lambda = 0.1$	L_∞
Cost (M\$/y)	12,306	12,274	12,258	11,628	11,289	11,256	11,240
CO_2 emissions (Mt/y)	27.58	27.75	27.83	28.82	34.10	33.76	33.65
SO_2 emissions (kt/y)	6.78	6.79	6.79	7.23	10.44	11.03	28.07
NO_x emissions (kt/y)	15.22	15.38	15.51	17.34	22.37	24.46	24.34
Radioactive waste (PBq/y)	1.31	1.30	1.30	1.97	1.70	1.67	1.66

the preferred solution, because of its more equitable character; that is it is the solution that achieves the best equilibrium between the different objectives.

All the solutions (energy plans) have been presented and analysed in the objective space. Because of length constraints, the same cannot be attempted in the decision variable space (technologies and fuels). However, it may be useful for the reader to mention that the best-compromise solutions have a larger contribution of renewable and gas-based technologies, and that coal and nuclear technologies represent less than 10% of the installed power. More details about the solutions in the decision variable space can be found in Linares.[30]

Conclusions

This paper shows how an integration of compromise programming and AHP can be a useful approach to address large-size electricity planning problems. The proposed methodology seems attractive at least for the following reasons. Firstly, it allows the easy accommodation of the significant number of objectives and 'social groups' involved in any electricity planning problem. Secondly, the plans generated by the model can be straightforwardly interpreted in utility terms. These electricity plans range from the solution of maximum efficiency to the solution of maximum equity. Finally, it demonstrates how the model can generate best-compromise plans comprised between the two commented bounds without any difficulties. In short, results obtained confirm the interest of MCDM approaches in electricity planning, since the solutions obtained imply, with respect to classic plans, an important reduction of environmental impacts with a relatively modest cost increment.

The current research may be extended at least in two of the following directions. Firstly, to test the robustness of the electricity plans obtained to different macroeconomic scenarios, and secondly, to define 'social groups' other than regulators and determine their influence in the final electricity plans.

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