Pergamon

Energy 27 (2002) 739–755

ENERGY

www.elsevier.com/locate/energy

Multi-criteria assessment of new and renewable energy power plants

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Received 24 February 2001

Abstract

The multi-criteria evaluation of new and renewable technologies demonstrates the potential analysis of complex systems. Every energy system under consideration is an entity by itself, defined by the respective number of parameters which are deterministically interrelated according to the physical laws. Sustainability indicators take into account the economic and environmental resources parameters. This paper presents selection of criteria and options for the new and renewable energy technologies assessment based on the analysis and synthesis of parameters under the information deficiency method. In order to present an evaluation of the new energy technologies, a number of options featuring some of the characteristics measured by the selected sustainability indicators are taken into consideration. For each option under consideration, the sustainability indicators are defined in order to verify their rating under the specific constraints and to obtain the generalised index of sustainability rating of all options. The aim of this paper is to define energy indicators used in the assessment of energy systems which meet the sustainability criterion. In this respect, the following indicators are taken into consideration: energy resources, environment capacity, social indicators and economic indicators.

1. Multicriteria evaluation

System analysis is both a philosophical approach and a collection of techniques, including simulations developed explicitly to address problems dealing with complex systems. System analysis emphasizes a holistic approach to the problem, by the solving and use of mathematical models to identify and solve important characteristics of the complex systems. A mathematical model is the set of equations that describes interrelations among those objects. By solving equa-

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PII: S0360-5442(02)00019-1

tions describing a model of the system, we can mimic or simulate the dynamic behavior of the system

Like many words for which we apply a tentative understanding, “system” is difficult to define precisely. In relation to physical and biological sciences, a system is an organized collection of interrelated components determined by a boundary and functionality. It communicates material, energy and information through its boundaries. The system is defined by internal and external variables. The internal structure of the system and its processes defines its functionality, which is determined by the internal variables of the system. The external variables are defined by the boundaries of the system.

In a simple thermodynamic system, the internal variables of the system are defined by the interaction of a large number of elements leading to the statistical interpretation of the collective behavior of the element. The external variables of the thermodynamic system with additive properties reflects the boundary of the system. Interaction between the system and its surroundings is the principle attribute of a system. The internal structure of the system is another important attribute of a particular system. The conceptual definition of the system defines its purpose and function and demonstrates communication of different fluxes with the surroundings.

An energy system is a complex system with the respective structure and can be defined by different boundaries depending on the problem. In simple analysis with the only function of the energy system designed to convert energy resources into the final energy form, the interaction of the energy system is defined by its thermodynamic efficiency. Adding respective complexity to the energy system, we can follow the interaction of the energy system and the environment. In this respect, a good example is a pollution problem, which is defined as the emission of energy and material species resulting from the conversion process. With a further increase in complexity of the energy system and establishing respective communication through the boundary, there are other entity fluxes between the system and surroundings. Since every energy system has a social function in our life, a link may also be established between the energy system and surroundings taking into consideration the social interaction between the system and the environment. Obviously, additional complexity in the energy system may lead to the exchange of different fluxes. In this respect, the Onsager relation gives a good example of the possible relation among the fluxes of interaction between the system and its environment. In the information theory there is an attempt to define the non-linear relation between fluxes and its relation to the change in the structure of the system [1].

In our analysis, we have assumed that the energy system is a complex system which may interact with its surrounding by utilizing resources, exchanging conversion system products, utilizing economic benefits from the conversion process and absorbing the social consequences of the conversion process. Each of the interaction fluxes is a result of the very complex interaction between the elements of the energy system within the system and the surroundings. In this analysis we will use synthesized parameters for the system in a form defined in classical analyses of energy systems and we will use for the indicator for resource utilization, the resource indicators, for the conversion process effect on the environment, the CO_2 concentration in exhaust gas. The electric energy cost will be used to measure the economic benefits of the energy system and NO_x release of the energy system will be used as its social indicator.

In this analysis, indictors represent the measure of different interactions between the energy system and its surroundings. All indicators are in deterministic or stochastic relation with the respective parameters of the system. Their interpretation and collection require organization and systematization of the parameters of the system and the environment. The process of collection and interpretation of different parameters, which are synthesized in the indicators, can be represented graphically, as shown in Fig. 1 [1].

It can be noted that the data collection for the earth's resources, environmental pollution parameters, economic system parameters, social structure and quality is the first step in generating the indicators. The second step is the definition of the energy system concept, including the definition of the structure and interaction between the elements and processes. This implies the selection of the energy conversion process and its interaction with inlet parameters.

According to the life cycle analysis of the selected energy system, the interpretation of the interaction of the system with its surroundings can be defined by economic, environmental and social indicators. Since each of the selected indicators represents collective interpretations of different interactions of the system and its surroundings, their mutual relation could be interpreted as the independent parameter of the system.

Multi-criteria assessment of the energy system is the method used to establish a measuring parameter, which is comprised of different interactions of the system and its surroundings [2–4]. This may lead to the development of the method, which will help us to understand in deep specific role of energy system selection and quality of our life.

2. NRES power plants selection

2.1. Pulverised coal fired power plant (PCPP)

Under the pulverised-coal fired power plant we will take 300 MW a plant with the lignite fuel combustion at the maximum gas temperature 1200 °C and steam pressure p=165 bar, steam

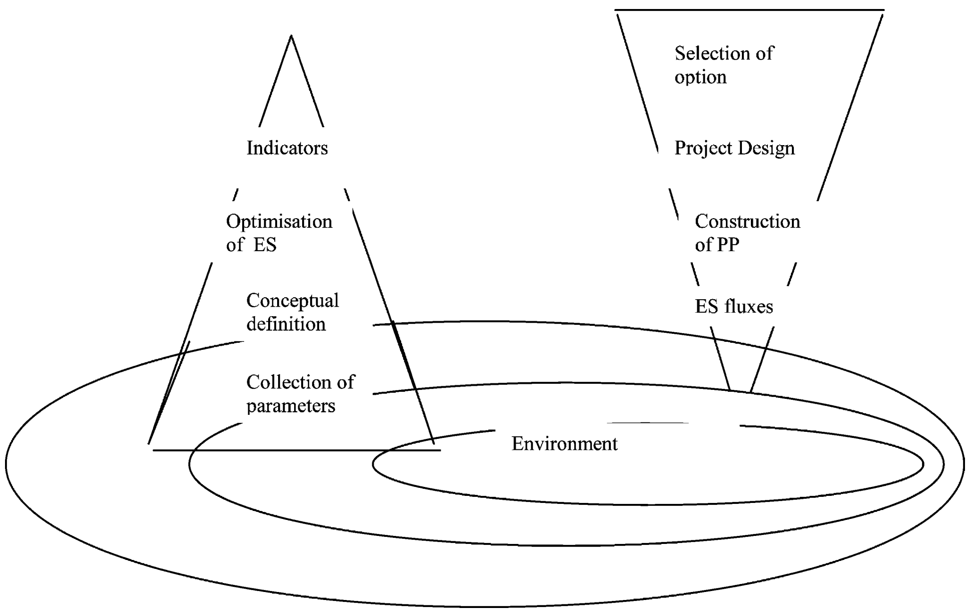

Fig. 1. Interpretation, collection, organization and systematization of the system and environment parameters.

temperature T_{steam}=570 °C. The thermal efficiency of the plant is η_{el}=0.43. The emission of CO_2 of the plant is assumed to be 0.82 g CO_2/kWh. The installation cost is estimated to be 1200–1500 USD/kW [5]. The modern pulverised coal fired power plants incorporate several clean air technologies. Among those technologies are: pulverised coal combustion, new design of burners, new scheme of organisation of combustion in the boiler furnace, new design of steam superheaters and gas cleaning system.

2.2. Solar–thermal power plant

Solar–thermal technologies work by converting the sun's energy into heat, which is then used to produce steam for driving a turbine and generator. The thermal efficiency of the plant is about 15% of the sun's energy. All solar–thermal systems consists of four basic components: a collector, receiver, transport–storage system and power conversion system. There are limited data on installation and electricity cost, so for this experiment the cost data are evaluated from the central receiver power plant. This system requires a large land area but has no other environmental impact [5,6].

2.3. Geothermal power plant

The binary geothermal system utilizes a secondary working fluid , which has a low boiling point and high vapor pressure at low temperature. This secondary fluid operates through a conventional Rankine cycle. By selecting an appropriate working fluid, binary systems can be designed to operate with the inlet temperature in the range 85–170 °C. The inlet temperature influences the size of the turbine, heat exchanger and cooling tower. The installation costs do not include well development [5,7].

2.4. Biomass power plant

The source of biomass energy is a form of plant-derived material such as wood, herbaceous crops and forest residues. Biomass is produced by photosynthesis. The rate at which solar energy is converted into biomass through photosynthesis ranged from 3.3% for so called C_3 plants (wheat, rice, trees) to 6.7% for C_4 plants (maize, sugar cane). The main biomass technologies presently used are: direct firing of biomass and co-firing of biomass [5,8].

2.5. Nuclear power plant

The nuclear industry is a mature business. Since 1980, the industry has made significant changes in the way it operates nuclear power plants. These changes, which required increased staffing and safety improvement at work, boosted plant performance, reliability and output.

At the same time, they pushed up operating and maintenance (O&M) costs. As these changes became institutionalized in utility programs, however, O&M cost has stabilized. The average O&M cost for nuclear plants—measured in 1996 dollars—were 1.48 cents in 1994, 1.39 cents in 1995 and 1.36 cents in 1996, based on figures from the Utility Data Institute, an independent research organization. Moreover, nuclear energy is competitive with other sources of electricity production, with the average electric energy production costs being, including fuel, 1.91 cents per kWh in 1996. For plants performing well (with capacity factors greater than 90%), the fuel costs are nominally 0.45–0.56 cents per kWh; O&M costs are 1.2–1.8 cents per kWh and capital costs are 1.4–2.0 cents per kWh [5,9]

2.6. PV solar power plant

The solar cell costs are important elements of the PV economic viability . The modules account for about 50% of cost of a PV power plant. The solar cells themselves for account for about half of the module cost, or 20% of the total system cost. Thin film polycrystalline technology may make it possible to have the module cost at about 50 USD/m and an electricity price of 6 cents/kWh. This is only a planning target for 10% efficiency. With the increase of efficiency to 20% the target will be 4 cents/kWh.

The production of the solar cells themselves leads to the emission of greenhouse gases. Taking a life cycle perspective of a PV plant, it will produce more electric energy during its life than it takes to build it [5,10].

2.7. Wind power plant

The present technology, including new material for wind turbine blades, has reached the size of 1.5 MW for off-shore use. Its three blade rotor diameter is 63 m, while the swept area is 3117 m^2. It rotates at a constant speed, 21 rpm, and has a noise level of 104 dBA. The tower height is 57.8 m. It starts delivering energy at a wind speed above 4 m/s, reaches full power at a wind of 15 m/s and stops at a speed above 25 m/s. For annual average wind speed between 6 and 10 m/s its production varies between 2.4 and 6.5 GWh. Since 1981 the installation cost of typical wind turbines has been decreasing and has reached 1000 USD/kW. The electricity price is 7–9 cent/kWh, with a further cost reduction expected through the economics of scale, low-cost manufacturing and improved design. Wind farms require a lot of space. Most wind farms fall into a range of 0.1–1 km^2 per installed MW [5,11]

2.8. Ocean power plant

In this analysis we will take into a consideration the ocean thermal energy conversion. The idea is to make use of the temperature difference between the surface water of a tropical ocean (at around 25 °C) and deep ocean (5 °C at 1000 m). The technology that work according to the principle of ocean thermal energy conversion are intrinsically limited to a low efficiency of about 6–7%, but in practice the efficiency is even lower, with a maximum of 3–4%. The estimates based on the present ocean thermal design lead to capital costs for such a system close to 10 000 USD/kW. Because of the high capital cost, the generation cost would likely be 12–25 cent/kWh [5].

2.9. Hydro power plant

The economic viability of a hydro power plant depends on a number of factors, such as the installation cost of a dam, the size of the reservoir, the operation and maintenance costs, the distance from the dam to consumers, the availability of high efficiency long distance power transmission technology, and the projects exposed to environmental positive and negative.

The installation cost for a capacity above 10 MW, ranges from 600 to about 2000 USD/kW. The price of the electric package and hydro mechanical equipment varies depending on the location. The price difference can be a factor of four in extreme cases. The ratio of a hydropower plant installed capacity to the area inundated is a rough measure of its environmental impact [5,12].

2.10. Natural gas combined cycle (NGCC)

Due to favourable conditions with gas resources, recently it has become interesting to investigate the natural gas cycle power plant as a potential option in power generation. With the present design of gas turbines the efficiency of the NGC cycle has become very attractive in many respects. With other advantages, such as easy control, NO_x control and limited air pollution, NGCC has become one of the most promising options in the future strategy of energy system development [5,13].

3. Multicriteria sustainability assessment

The multi-criteria assessment is based on the decision making procedure [14–18] reflecting the combined effect of all the criteria under consideration and is expressed in the form of a General Index of Sustainability. A selected number of indicators are taken as the measure of the criteria comprising specific information of the options under consideration. The procedure is aimed to express option properties by the respective set of indicators [19].

3.1. Indicator definition

The decision making procedure comprises several steps in order to obtain a mathematical tool for the assessment of rating among the options under consideration [20] In order to prepare respective data for the energy technology assessment the Table 1 presents the date to be used in the analysis.

The next step in the preparation of data for the multi-criteria sustainability assessment is the aritimetization of date.

This step consists in the formation of particular membership functions $q_1(x_1),...,q_m(x_m)$. For every Indicator x_i we have: (1) to fix two values $MIN(i),MAX(i)$; (2) to indicate is the function $q_i(x_i)$ decreasing or increasing with argument x_i increasing; (3) to choice the exponent's value λ in the formula

Table 1
Sustainability indicators

	Efficiency (%)	Installation (USD/kW)	Elect. Cost (c/kWh)	CO_2 ($kgCO_2$/kWh)	Area (km^2/kW)
Coal	43	1000	5.4	0.82	0.4
Solar Thermal	15	3500	17	0.1	0.08
Geothermal	8	2500	8	0.06	0.03
Biomass	1	2500	14	1.18	5.2
Nuclear	33	2300	4	0.025	0.01
PV solar	10	4500	75	0.1	0.12
Wind	28	1100	7	0.02	0.79
Ocean	3	10000	25	0.02	0.28
Hydro	80	2000	8	0.04	0.13
Gas	38	650	4	0.38	0.04

$$q_i(x_i) = \begin{cases} 0, \text{ if } x_i \leq \mathrm{MIN}(i), \\ \left(\dfrac{x_i - \mathrm{MIN}(i)}{\mathrm{MAX}(i) - \mathrm{MIN}(i)}\right)^{\lambda}, \text{ if } \mathrm{MIN}(i) < x_i \leq \mathrm{MAX}(i), \\ 1, \text{ if } x_i > \mathrm{MAX}(i) \end{cases} \tag{1}$$

for the increasing function $q_i(x_i)$.

The functions $q_1(x_1),\ldots,q_m(x_m)$ formation process is being finished with a matrix $(q_i^{(j)}), i = 1,\ldots,m, j = 1,\ldots,k$, where an element $q_i^{(j)}$ is a value of i-th particular criterion for j-th option. In this analysis it assumed that the linear functions $q_1(x_1),\ldots,q_m(x_m)$ are used. For the membership functions q_2, q_3 q_4 and q_5 the decreasing functions are adapted. For the membership function q_1 the increasing function is used. In the Table 2 are shown values of the functions $q_1(x_1),\ldots,q_m(x_m)$.

The general indices method comprises the formation of an aggregative function with the weighted arithmetic mean as the synthesizing function defined as

$$Q(q;w) = \sum_{i=1}^{m} p_i q_i \tag{2}$$

where p_i, weight-coefficients elements of vector **w**; and q_i, indicators of the specific criteria.

In order to define the weight-coefficient vector the randomization of uncertainty is introduced. The randomization produces stochastic values of indicators and realization of corresponding sets of functions and a random weight-vector. It is assumed that the measurement of the weight coef-

Table 2
Normalized values of sustainability indicators

	EfI	InI	ElI	EnI	ArI
Coal	0.873	0.888	0.815	0.000	0.602
Solar thermal	0.262	0.404	0.601	0.727	0.707
Geothermal	0.110	0.598	0.798	0.779	0.724
Biomass	0.000	0.198	0.667	0.000	0.000
Nuclear	0.655	0.637	0.886	0.824	0.730
PV solar	0.183	0.210	0.000	0.727	0.694
Wind	0.546	0.869	0.820	0.831	0.473
Ocean	0.001	0.000	0.425	0.831	0.641
Hydro	1.000	0.695	0.798	0.805	0.691
Gas	0.764	0.958	0.886	0.363	0.721

ficients is accurate to within steps $h=1/n$, with n a positive integer. In this case the infinite set of all possible vectors may be approximated by the finite set $W(m,n)$ of all possible weight vectors with discrete components. In our case, we will use $m=5$, and $n=35$ so that the total number of elements of the set $W(m,n)$ is $N(m,n)=92\ 251$.

For non-numeric, inexact and incomplete information $I = OI \cup II$ (the set of non-numerical information is the set of ordinal information which belongs to the set of interval information) is used for the reduction of the set $W(m,n)$ of all possible vectors $\mathbf{w}$ to obtain the discrete components set $W(I;n,m)$ is defined by a number of constraints reflecting non-numeric information about the mutual relation among the criteria under consideration. (OI is ordinal information and II is interval information) [20].

The probability of dominancy is defined as

$$P\{Q(q^r) > Q(q^s)\} = \frac{N\{t{:}Q(q^r;p^{(t)}) > Q(q^s;p^{(t)}\}}{N(m,n,I)}. \quad (3)$$

By the definition of the probability of dominancy between the options under consideration we are introducing an additional factor to measure rating among the options. Namely, the probability of dominancy is defined as the measure reflecting the comparison between two successive options, so that a higher value of the probability of dominancy means that the respective pair of options in the rating list of options is highly estimated. With the lower value of probability of dominancy between the successive pair of options, the successive pair is not very certain.

4. Selection of cases

As the non-numerical information, we will impose conditions which will define the mutual relations of the individual criteria. This will give us the possibility of introducing a qualitative measure between the criteria. The most important step in the application of the method using the random parameters is the determination of weighting coefficients p_1, p_2, p_3, p_4 and p_5 which define the effect of q_1 q_2, q_3, q_4 and q_5 to the General Index of Sustainability.

To begin a consideration of different variants of this realisation we will assume that the selection of weight coefficients vector $p=(p_1, p_2, p_3 \ldots p_n)$ from the discrete simplex $S(m,n)=\{p^{(t)}=(p_1^{(t)}, p_2^{(t)}, p_3^{(t)} \ldots p_m^{(t)}):p_i^{(t)} \in \{0,n,2n \ldots ..(n-1)n,1\}, \ p_1^{(t)}+p_2^{(t)} \ldots p_m^{(t)}=1, t \in T(m,n)=\{1,2 \ldots N(m,n)=N(m,n)\}\}$ is modelled by the multidimensional random variable $p*=(p_1*, p_2* \ldots p_m*)$ which has an uniform distribution in the set $S(m,n)$. Taking additional information, which imposes some limitation on weight coefficients, it will be possible to form a more narrow set of permissible vectors of weight coefficients $W(m,n,I) \subset S(m,n)$ which will contain a smaller number of elements $N(m,n,I) < N(m,n)$.

If we generate all permissible weight coefficients $p_1^{(t)}$, $p_2^{(t)}$, $p_3^{(t)} \ldots p_m^{(t)}$, $t \in T(m,n,I) \subset T(m,n)$, we will have the possibility of calculating the stochastic characteristics of vectors with the random weight coefficients $p(I)*=(p_1*(I), p_2*(I) \ldots p_m*(I))$ and corresponding General Index of Sustainability $Q(q)=Q(q,I)$.

Among the cases to be analysed there are two groups: one including those which are designed by introducing the priority of one criteria with the other being the same; the second, comprising cases with priority given to one criteria and others are rated by respective number of the criteria. The low values of the probability of dominance reflects the uncertainty of the priority list obtained by this condition.

4.1. Priority given to one indicator with others being the same

This group of cases are designed to give the priority to the single indicator with other indicators having the same values. Each case will represent a different option in the priority of criteria as they are used in the definition General Index of Sustainability. Among the cases which are designed with the preference of single options are cases 1.1–1.5.

4.1.1. Case 1.1

Even though this case is not very realistic from the assessment point of view it provides the possibility of evaluating the importance of this case as a neutral logic occasion. The high rating of hydro, nuclear, gas and wind options is expected due to the relation of indicators for the individual criteria. (Fig. 2)

4.1.2. Case 1.2

This case reflects the priority given to the energy system efficiency criteria. As has been shown, the efficiency of systems with the different basic principles is not a very realistic indicator to be used for the comparison of the system. This suggests that in evaluation of the efficiency criteria it would be better to use the relative value of the efficiency for each system. For example, for the heat conversion system the Carnot efficiency should be used as the absolute efficiency. (Fig. 3)

As a result of this constraint we have again obtained a highly exaggerated priority of the hydro power plant while other options are divided into two group with similar values of the General Index of Sustainability. With the high value of the probability of dominance in this case it can be concluded that this priority list gives high confidence in obtained results

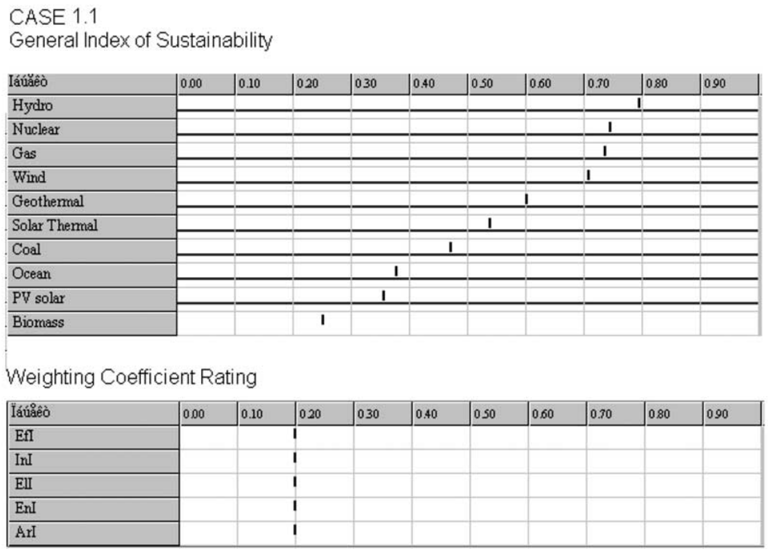

Fig. 2. General index of sustainability and weighting coefficients for case 1.6.

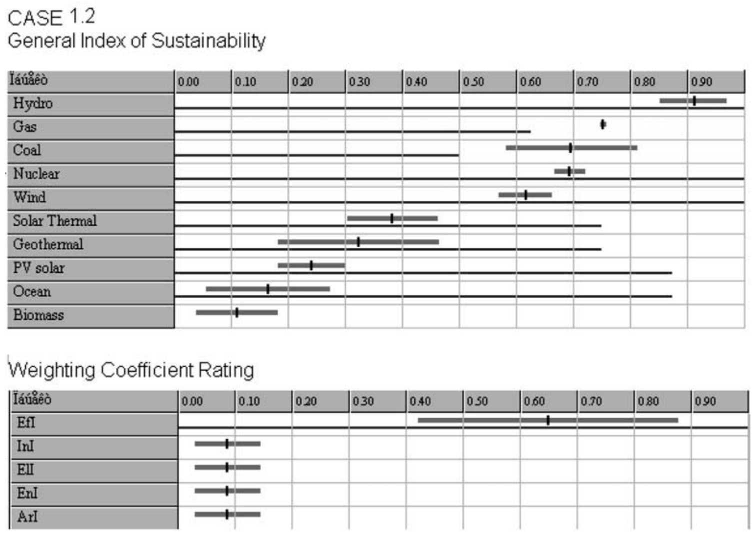

Fig. 3. General index of sustainability and weighting coefficients for case 1.2.

4.1.3. Case 1.3

The change in priority from the efficiency criteria to installation cost criteria has lead to a drastic change in the priority list. Hydro, nuclear, wind and geothermal energy systems form a single group with the General Index of Sustainability being marginally different among themselves. It is interesting to notice that a single criteria can be so strong to bring into the picture different priority list. From the values for probability of dominance in this case it is visible that this case is not a very certain option. (Fig. 4)

4.1.4. Case 1.4

This case represents the situation when priority is given to the environmental criteria. This implies that the CO_2 production indicator is having dominancy over the other indicators, while they are considered to be of equal value. It can be noticed that under these conditions all options with a low production of CO_2 have gained higher priority in comparison with those with the high CO_2 production. In this case, we can see that the single indicator might substantially affect the rating of options. (Fig. 5)

4.1.5. Case 1.5

The case with priority given to the area needed for the power plant, can be envisaged as part of the social assessment of options. In this respect this case reflects the impact of the respective power plant on the environment, social structure and land use. With the high values of probability of dominance between the pair of options in this case, the priority list is with high certainty. (Fig. 6)

4.2. Priority of the criteria selected by number orders

The following cases are designed with intention to give priority to one option and the others to be ordered by the number of indicator. The first case within this group reflects the intention to give priority to the efficiency criteria. There are several features which are exercised through these examples. It is shown that due to the selection of priority in the criteria, the priority list

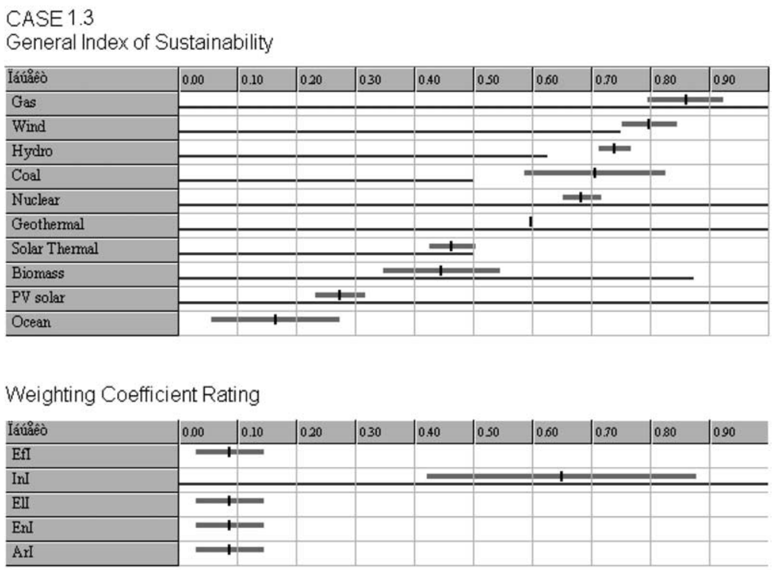

Fig. 4. General index of sustainability and weighting coefficients for case 1.3.

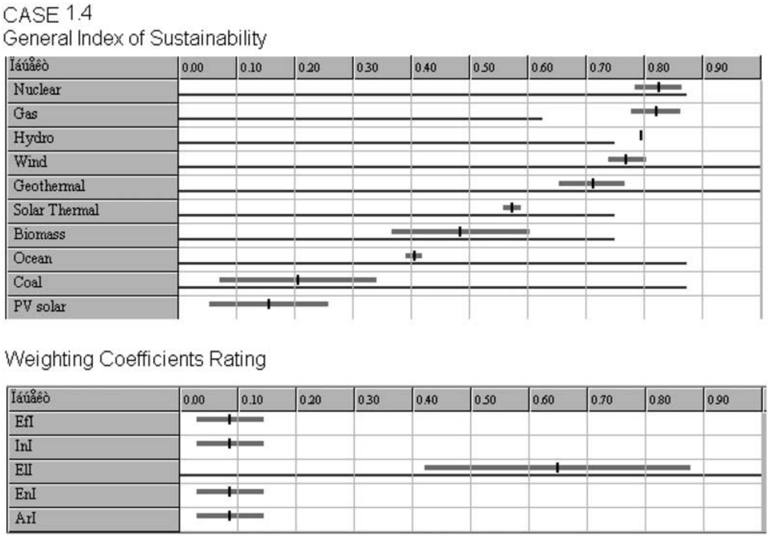

Fig. 5. General index of sustainability and weighting coefficients for case 1.4.

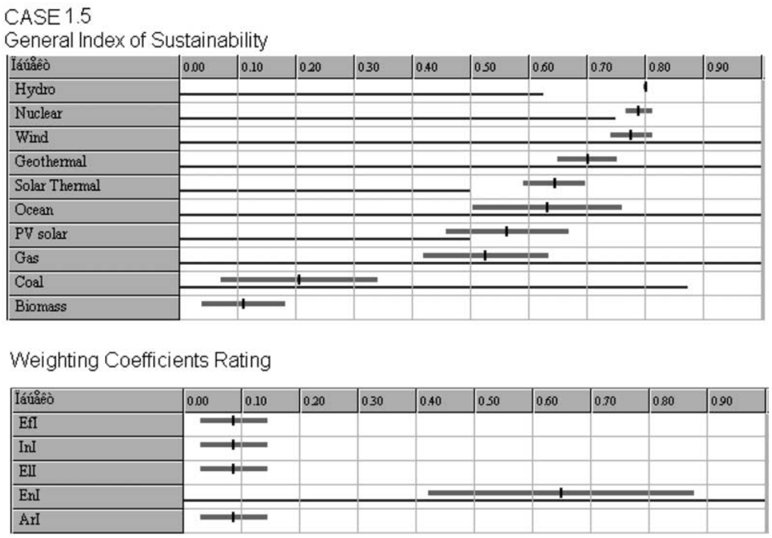

Fig. 6. General index of sustainability and weighting coefficients for case 1.5.

can be changed. Also, it could be noticed that the probability of dominance among the pair of options is subject to change in accordance with the priority given to the individual criteria.

4.2.1. Case 2.1

If the priority is given to the efficiency criteria then the rating list of options under consideration is presented in the following figure (Fig. 7). It can be noticed that some pairs are having a very low probability of dominancy in the priority list what is resulting in the low certainty of the

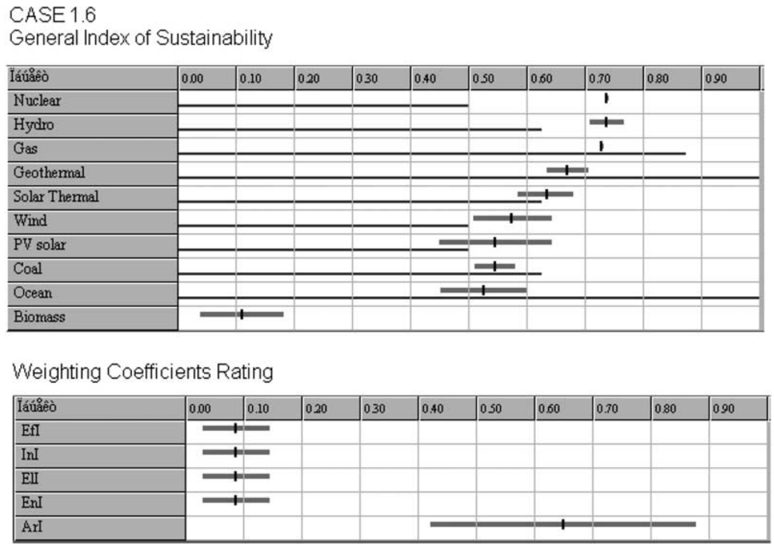

Fig. 7. General index of sustainability and weighting coefficients for case 2.1.

priority list for this Case. It is of interest to note that under this constrain of criteria the nuclear option is getting first priority on the rating list.

4.2.2. *Case 2.2*

Again, it is shown that with specific criteria, the priority of options which reflects the importance of constraints in the decision making process can be obtained. Under this constraint the gas energy system option has the priority on the rating list. Not very high values of the probability of dominance of certain pairs on the priority list leads to the conclusion that this option is not very highly rated in the certainty list of the cases under consideration. (Fig. 8)

4.2.3. *Case 2.3*

Giving priority to the electric energy cost criteria is a very interesting case. It results in the priority of the hydro power plant. The next group, including gas, nuclear, wind and geothermal energy systems only show marginal differences on the rating list. What is even more important, is that the probability of dominance among the successive pairs is very high and gives to this case special importance in the evaluation of the option under consideration. (Fig. 9)

4.2.4. *Case 2.4*

This case represents conditions when the priority is given to the environmental criteria. As it can be noticed the hydro power plant option has the first place on the priority list. The second group with marginal differences are nuclear, wind, gas, solar–thermal and geothermal energy systems.

This implies that if the priority is given to the environmental criteria more different options are at the same level of priority. With the high values of probability of dominancy between the pairs this case is with high certainty in general assessment procedure. (Fig. 10)

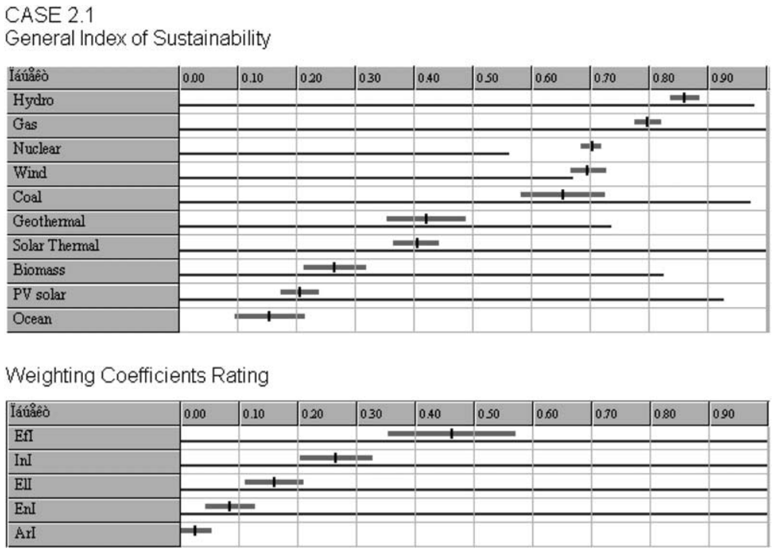

Fig. 8. General index of sustainability and weighting coefficients for case 2.1.

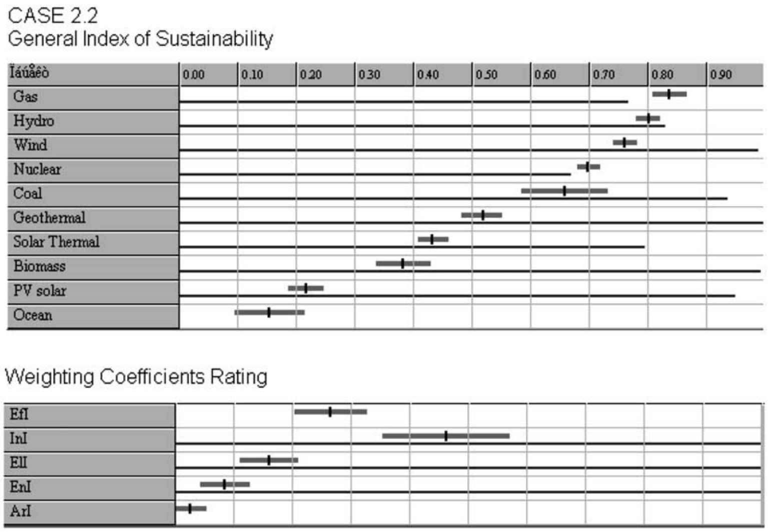

Fig. 9. General index of sustainability and weighting coefficients for case 2.2.

4.2.5. Case 2.5

The last case in this group of cases is devoted to the priority given to the criteria reflecting area indicators. The rating among the options is: hydro, gas, nuclear, coal, wind geothermal , solar thermal, PV solar, ocean and biomass energy systems. Due to the high values of the probability of dominancy between the pairs, this case is reflecting a situation with high certainty. (Fig. 11)

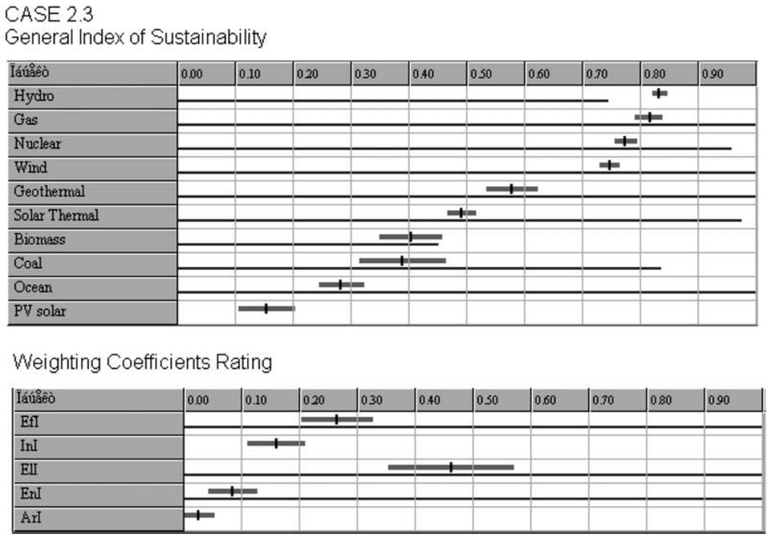

Fig. 10. General index of sustainability and weighting coefficients for case 2.3.

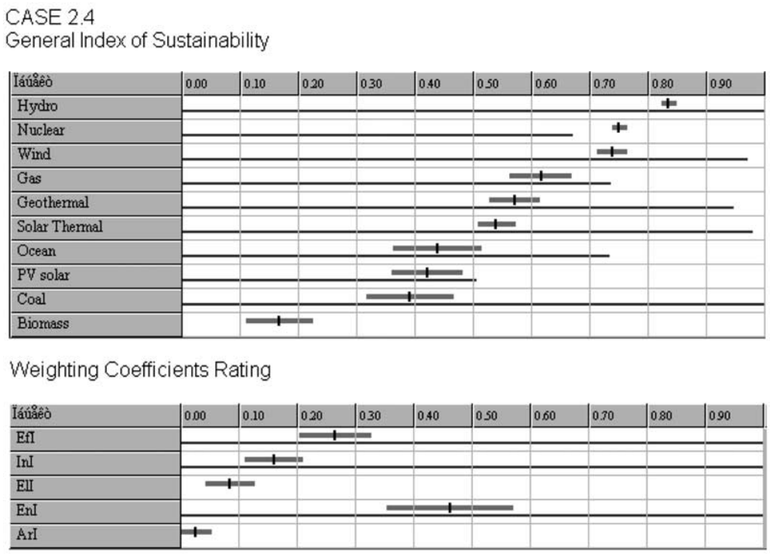

Fig. 11. General index of sustainability and weighting coefficients for case 2.4.

5. Discussion

This study is devoted to the evaluation of the priority rating among the selected options of energy systems. The evaluation is aimed at obtaining the option rating based on the multi-criteria decision making procedure. The primary goal of this analysis is to use the method based on the non-numerical information as the criteria for the design of cases which result in the respective rating among the options.

The selection of two groups of cases enables an evaluation of the options with constraints giving the possibility of having a predetermined relation between indicators.

The first group of cases reflects when single indicators are given priority, under the assumption that the others have the same value of weight coefficients. The second group of cases is designed with priority given to one of the indicators and others rated with succeeding numerical rating on the primary list of indicators.

Even this analysis is based on a limited number of cases taken into consideration. It is shown that priority on the rating list is a result of the respective relation among the criteria under consideration. In the first group, it is shown that the option which is the first on the rating list is closely related to the respective indicator priority and its value. In the first group of cases it is shown that if the priority is given to a single criterion with the other criteria having respective value of indicators for individual option, it may effect the rating list of the options. In this respect the hydro power plant option is first on the rating list if the weighting coefficients of all indicators is the same. If the efficiency criteria has been given priority there are substantial changes in the rating list. The same can be noticed if priority is given to the other indicators. If the installation cost indicator has priority the gas power plant is the first on the rating list of the option under consideration. Also, if the CO_2 production indicator and area indicator, the hydro and nuclear power plants are rated on the first place in the rating list of the options. Beside the changes in the first place on the rating list, it is seen that there are changes in the rating among the other options. Options with renewable energy power plants have gained higher places on the rating list in comparison with cases with equal weighting factors for all indicators.

In the second group of cases, it can be seen that for every case with the different rating among criteria the new rating list is obtained. In case 2.1, with priority given to the efficiency indicator, it is seen that the classical energy power plants form a group with higher priority than the group of renewable energy power plants. Due to the high influence of the efficiency indicator rating in other cases in this group, presented in this analysis, there is no remarkable change in the position of renewable energy power plant options.

It should be mentioned that it would be possible to obtain the required relation among the indicators for the specific rating list among the options if this combination exists within the set of the combination generated in this analysis.

6. Conclusions

The presented cases are only demonstrations of the method to be used in the multi criteria evaluation of energy systems. They have led us to make the following conclusions:

- The presented method is of interest for use in the evaluation of the different option of power plants.
- Non-numerical information expressed in the form of mutual relations between criteria has proved to be a useful tool in the evaluation procedure.
- The decision making method presented in this analysis, is only a tool to be used in the generation of a priority list reflecting individual cases.

- The sensitivity of the priority list on the criteria rating demonstrates the need for a detailed study of the decision-making procedure before the final decision is made.
- With the probability of dominance for each case it is possible to rank the obtained certainty for individual cases.

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