MULTI-CRITERIA SUSTAINABILITY ASSESSMENT – A TOOL FOR EVALUATION OF NEW ENERGY SYSTEM

by

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One of perspective methods for the evaluation of quality of energy system is the multi-criteria sustainability assessment, based on the analysis and synthesis of indicators expressing different aspects of the system. Application of this methodology in the cases of information deficiency (ASPID methodology) enables evaluation of various energy systems.

In the paper, the multi-criteria sustainability assessment of energy systems of various energy sources is used to evaluate the energy power system of Bosnia and Herzegovina. Eight different energy system options are taken into a consideration as the potential options for the capacity building within the energy power system of Bosnia and Herzegovina. It has included various renewable sources and fossil fuel clean technologies.

Within the multi-criteria sustainability assessment method, sustainability indicators and weighting coefficients are defined and calculated, including: resource indicator, environment indicator, social indicator and economic indicator with respective weighting factors. The methodology includes the system of stochastic models of uncertainty in order to realize the assessment from various supporting systems, and to obtain respective normalization indexes by using non-numeric (ordinal), non-exact (interval), and non-complete information (NNN- information), for sources of various reliability and probability.

By the analysis of multi-criteria sustainability assessment of selected options, the decision makers could be enabled to form opinion on quality of considered energy systems, and from the aspect of sustainability, make selection an optimum option of energy system.

Key words: *energy power system, sustainability, sustainability indicators, single criteria analysis, multi-criteria sustainability assessment*

Introduction

Traditionally, decision-making method based on a single criteria analysis. It becomes unacceptable, because it is often necessary to take into account more aspects of sustainability at the same time. In the sustainability assessment of energy system, the set of priorities that include functional requirements, costs, possibilities, and risks. Thus, the evaluation of complex system depends on a number of parameters; economic, technological, environmental, social, geographical, ethics, and so on.

An innovative and perspective method for evaluation of energy system quality is *multi-criteria sustainability assessment.* It is based on the analysis and synthesis of indicators expressing different aspects of the system.

In this work, multi-criteria sustainability assessment is used for the objective evaluation of energy system. The energy power system of Bosnia and Herzegovina (B&H), is evaluated. It proves that it can be used for the evaluation of complex system [1].

Energy systems under consideration

The energy system under consideration is the energy power system of B&H, in the domain covered by the Public Enterprise JP Elektroprivreda B&H (PE JPE). This is a power system with various energy sources. The company temporary comprise into the system: thermal power plants, large hydro power plants, small hydro power plants, and a biomass power plant.

The assessments of electricity consumption in the domain of PE JPE, is made by known consulting companies, and have shown that the growth of electricity consumption in the next period (till year 2020) will continue, fig. 1. Thus, as the first step in the development of the electric power system a new policy was adapted. It was decided to enlarge the electric power capacity by additional 7,875 GWh during the next 15 years. This re-

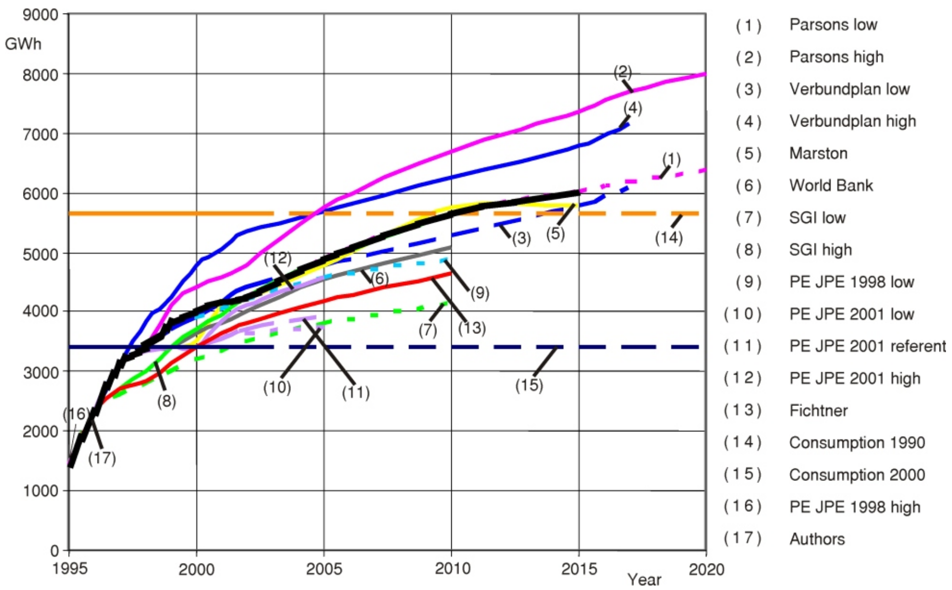

Figure 1. Estimation of electricity consumption in domain of PE JPE

quires an average annually electricity production of 525 GWh, that should be provided either by upgrading the existing or by installation a new power station.

Eight options for providing the additional power capacity for the system are considered. Renewable resources and fossil fuel clean technologies are also included into consideration. The following options are considered:

Option 1: Reconstruction of pulverized coal fired unit in condensing regime;
Option 2: Reconstruction of coal fired unit in co-generation regime;
Option 3: Fluidized bed combustion unit – New power station;
Option 4: Combined cycle gas turbine power plant – New power station;
Option 5: Reconstruction of big hydro power plant;
Option 6: Power plants on solar energy (PV systems) – New power station;
Option 7: Wind turbines power – New power units;
Option 8: Biomass power plants – New power station.

Some of energy power plant under consideration will produce simultaneously electricity and heat energy (co-generation), taking into account that this co-generation plants will also produce 7,875 GWh of electricity in projected lifetime.

Option 1 – Reconstruction of pulverized coal fired unit in condensing regime. The 110 MW pulverized coal fired power plant with the slag tap boiler furnace is considered, operating in condensing regime. The investment for this option is aimed to improve boiler efficiency and upgrade the power capacity. By the reconstruction of boiler, the boiler efficiency is increased from 85% up to 90%; the slag tap furnace is extended by 2 m, and new low-NO_x burners are installed. Furthermore, upgrading of the plant is performed through reconstruction of the steam turbine. The output power is increased from 110 MW up to 118.55 MW. These reconstruction changes are affecting environment issues, and they have contributed to the considerable reducing of CO_2, NO_x, and SO_2 emission.

Option 2 – Reconstruction of coal-fired unit in co-generation regime. The 110 MW pulverized coal fired power plant with slag tap boiler furnace operating in co-generation rime is considered. Additional investment, comparing to the option 1, relates to the control of steam extraction system on the steam turbine. Additional 80 MW of heat power is provided by steam extraction.

Option 3 – New power station – a 110 MW fluidized bed combustion unit. The power plant should operate in co-generation regime, producing additional 80 MWh of heat. A modern design of the fluidized bed furnace with internal circulation enables a combustion of low caloric coals. Efficiency of the unit is 45%.

Option 4 – Combined cycle gas turbine power plant. Installed capacity of this plant is 102 MW, under the assumption that all output is electricity generation. The fuel is natural gas with heating value of 45,500 kJ/kg. Estimated heat consumption of the plant is 6,545 kJ/kWh.

Option 5 – Reconstruction of hydro power plant of 6 × 25 MW power installed. The upgrading of plant by additional 30 MW of the installed power is obtained, and the increase of efficiency by 4% is obtained.. This is provided through the increasing of design head by 6 m, increasing of installed flow by 10%, and introducing new state-of-the-art of Francis turbines.

Option 6 – Solar power plant (PV systems) with total installed capacity of 210 MW. Covered surface of this solar field is 266,000 m^2, or 1.26 m^2/kW.

Option 7 – Wind power plant. According to the available data of wind characteristics on selected micro locations, it is calculated that 438 units of 600 kW wind turbines should be installed to provide average annual production of 525 GWh. This gives an average annual operation of 2000 h.

Option 8 – Biomass power plant. This new plant has 80 MW of installed power, and overall efficiency of 20%. Emission of CO_2 for this option is reduced by the amount of CO_2 absorbed by the plants used as fuel in this power station.

Sustainability assessment of energy system under consideration

Sustainability indicators

The sustainability assessment is based on the definition and calculation of sustainability indicators. In the work, sustainability indicators reflecting 4 criteria of sustainability are defined, and grouped as given in tab. 1. Indicators [2-4] from tab. 1 are calculated for all options under consideration.

Table 1. Sustainability indicators

Type of indicator	Sub-indicator	Unit
Resource indicator (RI)	Fuel indicator	kg/kWh
	Carbon steel indicator	kg/kWh
	Stainless steel indicator	kg/kWh
	Copper indicator	kg/kWh
	Aluminum indicator	kg/kWh
	Insulation indicator	kg/kWh
Environment indicator (EI)	CO_2 indicator	kg/kWh
	SO_2 indicator	kg/kWh
	NO_x indicator	kg/kWh
Economic indicator (EcI)	Energy costs indicator	€/kWh
	Investment indicator	€/kWh
	Efficiency indicator	1/kWh
Social indicator (SI)	Job indicator	h/kWh
	Diversity indicator	–

Single criteria analysis

Single criteria analysis is obtained by the simple comparison of sub-indicators or indicators for all options under consideration. Indicators for the single criteria assessment are presented (figs. 2 and 3).

Case 1

Comparing the considered options according to the environment indicators, *e. g.* indicator of CO_2 emission, see fig. 2, it can be noticed that renewable resources, reconstructed hydro power plant, as well as combined cycle gas turbine station are in advantage in reference to the reconstructed conventional coal-fueled stations and fluidised bed combustion.

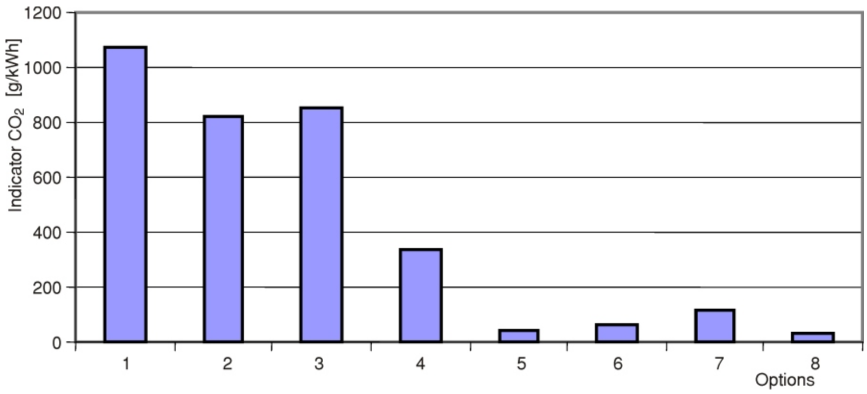

Figure 2. Comparison of CO_2 indicator within single criteria analysis

Case 2

In order to demonstrate the effect of different single indicators as the second example it was used the comparison among options based on the economic indicator. Opposite to the Case 1, the economic indicator, *e. g.* indicator of price of electricity per kWh of power produced, is used shown on fig. 3. It may be concluded that the upgrading of conventional coal-fired power plant is preferable in comparison to the renewable resources. Also, the Case 2 shows that all other options are having the numerical value of electricity price only marginally different.

Presented examples shows that the single criteria analysis gives biast results, namely it is strongly dependent on selected indicator for comparison and the evaluation expert. It is obvious that selection of optimal option depends exclusively on selected cri-

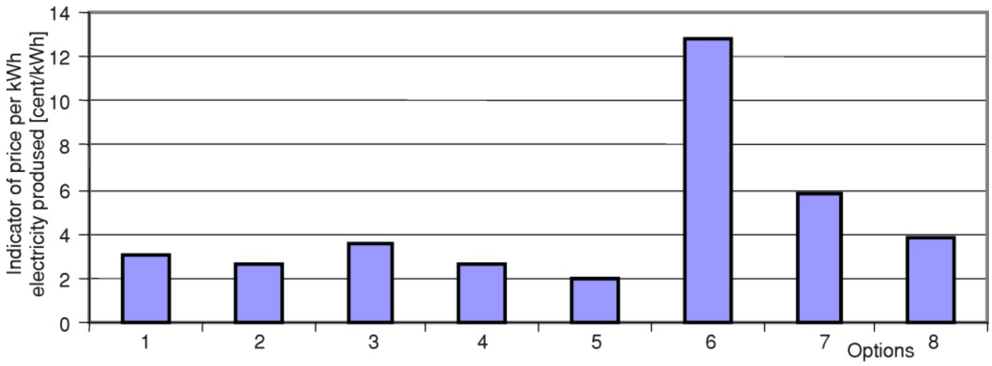

Figure 3. Comparison of power price indicator within single criteria analysis

teria. Consequently, subjectivity of decision-makers in decision-making could be strongly expressed.

The method of multi-criteria sustainability assessment

The multi-criteria sustainability assessment of energy system under consideration is based on ASPID methodology (*Analysis and Synthesis of Index at Information Deficiency)* [5, 6] Used methodology includes the system of stochastic model of uncertainty. The assessment of various supporting systems comprises the normalization of indices by using non-numeric (ordinal), non-exact (interval), and non-complete information (NNN-information). The multi-criteria analysis is based on the selection of sustainability indicators, described in previous chapter, and specific criteria, adopted by weighting factors. With linear function of indicators multiplied by weighting coefficients the agglomerated General sustainability index is obtained. General sustainability index is formed through the following procedure:

(1) Formation of vectors $x = (x_1, ..., x_m)$ of all input attributes that are necessary for the full evaluation of quality of options under considerations. In this work attributes are expressed by 4 group of indicators: Resource indicator, Environment indicators, Social indicators, and Economic indicators.

(2) Formation of vectors of specific criteria $q = (q_1, ..., q_m)$, by which input attributes (indicators) $x_1, ..., x_m$ are to be evaluated.

(3) Introducing of weighting factors, by which the multi-criteria sustainability assessment of options under consideration is expressed by means of additive aggregate function, or synthesized function given by relation (1):

$$Q_+(q,w) = \quad w_i q_i \tag{1}$$

(4) Selection of vectors $w = (w_1, ..., w_m)$, w_i 0, $w_1 + ... w_m = 1$, *i. e.* weighting factors. In praxis, vectors $w = (w_1, ..., w_m)$ often can not be exactly determined due to information deficiency. In such case the method of randomization is used, which enables to obtain values of weighting factors for each considered case.

(5) As the final result of this procedure, the priority list of options under consideration at the defined criteria is obtained.

It is of interest to notice that the mufti-criteria assessment method. The multi-criteria assessment is taking into account all criteria at the same time, where the different criteria are adopted by respective weighting factors, giving a realistic and reliable sustainability rating of the options under consideration for a lifetime.

Results of multi-criteria sustainability assessment of the energy system under consideration

Multi-criteria decision making is a well known method of the decision making procedure. It is a branch of the general class of operations research models which deal with decision problems under the presence of a number of decision criteria. The major class of models is very often called MCDM. This class is further divided into the multi-objective decision making and multi-attribute decision making. Multi-criteria decision making methods deal with the process of making decisions in the presence of multiple objectives. A decision-maker is required to choose quantifiable or non-quantifiable and multiple criteria.

A matrix of results of multi-criteria assessment of energy power system of PE JPE is obtained [7, 8]. Generally, obtained results by multi-criteria analysis derogate the results of single criteria analysis.

In order to demonstrate results obtained with multi-criteria evaluation method a following cases are taken into a consideration.

Mcase 1 $(EcI_1 > EI_1 = SI = RI)$

The Mcase 1 is designed with the economic indicator with domination of electricity price indicator is preferable in reference to the other indicators, see fig. 4. A large dispersion of the electricity indicator values effects strongly the value of the General sustainability index for all option under consideration. It can be noticed that option with

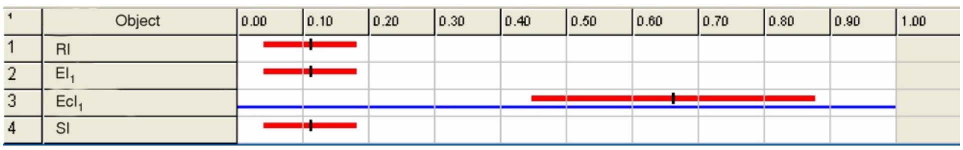

Figure 4. Weighting coefficients for case $EcI_1 > EI_1 = SI = RI$ within multi-criteria assessment

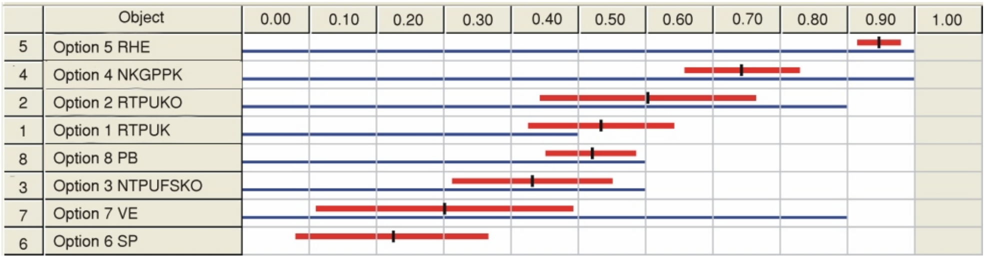

Figure 5. General sustainability index for the case $EcI_1 > EI_1 = SI = RI$ within multi-criteria assessment

the highest value of the General Sustainability index is Option 5 (fig. 5). The reconstruction of coal-fired unit – Option 2 in co-generation regime is ranked on third place of priority list in this case, although this option according to the single criteria assessment is ranked on second place.

Mcase 2 ($EcI_1 > EI_1 = SI = RI$)

The Mcase 2 is designed with weight coefficients rating $EcI_1 = EI_1 = SI = RI$ when economic indicator with the domination of the power price indicator does not have advantage in reference to the other indicators, *i. e.* when weighting factors of all considered indicators are equal, see fig. 6. The Option 2 falls down on the last place in the list of priority, fig. 7, under stronger influence of weighting factors of the other indicators. It can be notice that Option 5 Reconstruction of hydro power plants taking a first place on the priority list. Other option are divided in two group with marginal difference.

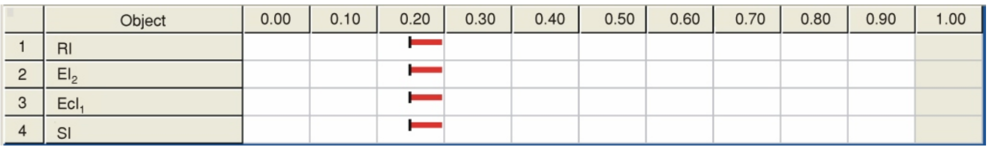

Figure 6. Weighting coefficients for case $EcI_1 = RI = EI_2 = SI$ within multi-criteria assessment

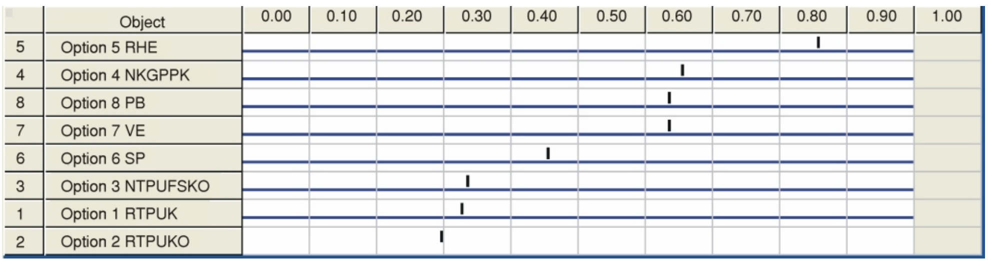

Figure 7. General sustainability index for the case $EcI_1 = RI = EI_2 = SI$ within multi-criteria assessment

These two demonstration examples focus attestation to the diffidence in rating list if priority among options is different.

Multi-criteria evaluation procedure for the selection of the power plant imply the need for large number of cases with different constrains among the weighting coefficients. to be analyzed. In this exercises 25 different cases are analyzed. It should be emphasized that this type of evaluation gives possibility to decision maker to take into a consideration all potential constrains between weight coefficients before making finale decision.

Conclusions

Attention is focused to the assessment of quality of energy system options. Most of the existing models for decision-making for the selection of new capacity of energy system are based on single criteria assessment. Today, the multi-criteria method for energy system options selection is needed. Models are being advanced and sustainability assessment of energy system is adapted. However, lack of information is a main deficiency doesn't enable to obtain a clear assessment of quality of power system option.

One of the innovative and prospective method for evaluation of sustainability of the energy system is the multi-criteria assessment the sustainability based analysis and synthesis of indexes under deficiency of information (ASPID methodology). In the paper the multi-criteria sustainability assessment of energy systems based on definition of following indicators: resource indicators, environment indicators, social indicators, and economic indicators, including also the weight factors is used.

However, lack of information is a limiting factor to obtain the clear assessment of quality of power system option. For this reason a new multi-criteria method based on the sustainability assessment of energy system is developed. The main emphasize in this development is focused on the deficiency of respective quality of indicators. This new development of procedure will decrease the lack of access to the modern energy services presently limited by socio economic development.

In this paper, the multi-criteria assessment of selected options of the new capacity of energy power system of the PE JPE is performed. The obtained results are based on the data determined by the evaluation of the potential need of new electric power production for the increase of the energy power system capacity.

Results of multi-criteria sustainability assessment using ASPID methodology for the evaluation of the energy power system of PE JPE shows the advantage of this method in comparison with the single criteria analysis. For example, considering the case when the sustainability assessment criteria based on the economic indicator with domination of power price indicator is preferable in reference to the other indicators, it can be noticed that option with the highest rating of the sustainability index is option 5 – Reconstruction of hydro power plant. Option 2 and Reconstruction of coal-based unit in co-generation regime are ranked on third place in this case, although this option according to the single criteria assessment is ranked on second place. Further, in the case when economic indicator with the domination of the power price indicator does not have advantage in reference to the other indicators, *i. e.* when weighting factors of all considered indicators are equal, the Option 2 falls down on the last place in the list of priority, under stronger influence of weighting factors of the other indicators.

It is shown on this example that the researched method much less depends on subjectivity of decision-makers than in the case of single criteria analysis. Trough the analysis of multi-criteria assessment of selected options, the decision-makers could be enabled to form opinion related to the selection of an optimum option based on the sustainability assessment.

Nomenclature

EcI – economic indicator
EI – environment indicator
RI – resourse indicator
SI – social indicator
Q_{+} – aggregate function
q – vector of specific criteria
x – vector of input attributes
w – vector of weighting factor

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