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ENERGY

Energy 31 (2006) 2276–2284

www.elsevier.com/locate/energy

Sustainability assessment of cogeneration sector development in Croatia

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Abstract

The effective and rational energy generation and supply is one of the main presumptions of sustainable development. Combined heat and power production, or co-generation, has clear environmental advantages by increasing energy efficiency and decreasing carbon emissions. However, higher investment cost and more complicated design and maintenance sometimes-present disadvantages from the economical viability point of view. As in the case of most of economies in transition in Central and Eastern Europe, Croatia has a strong but not very efficient co-generation sector, delivering 12% of the final energy consumption. District heating systems in the country's capital Zagreb and in city of Osijek represent the large share of the overall co-generation capacity. Besides district heating, co-generation in industry sector is also relatively well developed. The paper presents an attempt to assess the sustainability of Croatian co-generation sector future development. The sustainability assessment requires multi-criteria assessment of specific scenarios to be taken into consideration. In this respect three scenarios of Croatian co-generation sector future development are taken into consideration and for each of them environmental, social and economic sustainability indicators are defined and calculated. The assessment of complex relationships between environmental, social and economic aspects of the system is based on the multi-criteria decision-making procedure. The sustainability assessment is based on the General Sustainability Index rating for different cases reflecting different criteria and their priority. The method of sustainability assessment is applied to the Croatian co-generation sector contributing to the evaluation of different strategies and definition of a foundation for policy related to the sustainable future cogeneration sector development.

Keywords: Cogeneration; Sustainability assessment; Multi-criteria analysis

1. Introduction

Development of the cogeneration sector in Croatia started in the mid-20th century and followed the growing requirements for heat and process steam in industry as well as the increasing heat demand in the district heating utilities. At present cogeneration plants represent a significant part of the country's energy sector. However, the cogeneration plants were sometimes built and commissioned under the conditions that

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doi:10.1016/j.energy.2006.01.024

were not consistent with the accepted principles of economic efficiency and rational use of energy. Also, for different reasons, there was a long period without any or very small investments in maintenance, especially in industry. As a consequence, like in most of Central and Eastern Europe economies in transition, the cogeneration sector in Croatia is relatively big but inefficient and not fully prepared for the forthcoming market competition.

In 1987, the World Commission on Environment and Development (Brundtland Commission) called for the development of new ways to measure and assess progress toward sustainable development [1]. The commission defined sustainable development as "satisfying present needs of the population without compromising the ability of future generations to meet their own needs". This paper tries to assess the possible paths of the Croatian cogeneration sector development from the sustainability point of view. Also, the aim is to present the multicriteria method of sustainability assessment. Three different scenarios for future development of the Croatian cogeneration sector were defined and sustainability indicators were determined for each of the scenarios reflecting environment, social and economic aspects. The multicriteria decision-making procedure was used as a tool in assessing the sustainability of the scenarios.

2. The cogeneration sector in Croatia

Electricity production data for Croatia in the year 2001 are shown in Fig. 1. The data show that the relative share of electricity production in public and industrial cogeneration plants is approximately 11.5% with respect to total energy supply. With respect to steam and hot water production, the share of public and industrial cogeneration plants was as much as 69.2% in 2001 [2].

These data show that the public cogeneration plants dominate within the cogeneration sector. The industrial sector is also relatively strong especially with respect to steam and hot water production. However, the relative share of the electricity production from industrial cogeneration plants has a decreasing trend in the last couple of years and this part of the sector faces certain challenges. Namely, after a long period of low or even zero investments in maintenance in many companies the decision has to be made weather to replace, refurbish or decommission ageing power plants.

3. Scenarios taken into consideration

Three different scenarios have been defined and taken into consideration with respect to the future development of the Croatian cogeneration sector. When defining each scenario, different factors have been taken into consideration. These factors can be divided into three main groups:

- *Market factors*: Electricity and fuel prices, equipment prices and cost of capital.
- *Technology factors*: Progress of the microcogeneration and RES technology development as well as progress of centralised power generation development.
- *Policy factors*: Impact of the EU accession process, liberalization of the gas, oil and electricity market, national carbon emission reduction strategy and the tariff system.

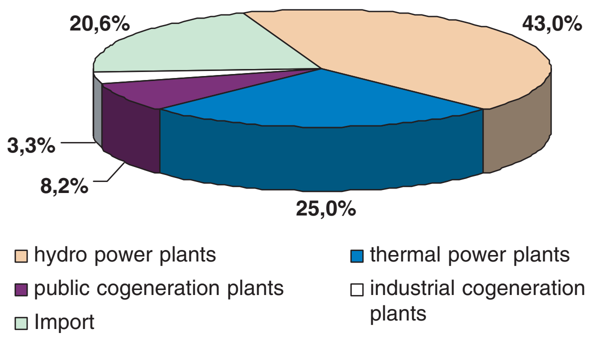

Fig. 1. Relative share of electricity production and import in 2001.

3.1. ProCHP scenario

The first scenario, named ProCHP scenario, is the most beneficial to the development of cogeneration. This scenario is based on a scenario developed by the Croatian Energy Institute ''Hrvoje Požar'', published in KOGEN and presented as a part of the national energy strategy [3]. This scenario includes internalisation of the external benefits of cogeneration trough the introduction of number of policy mechanisms. Microcogeneration technology develops successfully and becomes technically and economically feasible. Old cogeneration plants in urban areas of Zagreb and Osijek as well as many industrial plants are being optimised or replaced with new and more efficient cogeneration technology. This is the best-case scenario for the development of the Croatian cogeneration sector.

3.2. Business as usual scenario

The Business as Usual scenario for the Croatian cogeneration sector is considered as a most probable case if no changes of the present situation happen in the future. This scenario is based upon the similar scenario for the cogeneration sector in Central and Eastern Europe, developed within the FutureCOGEN project supported by the European Commission [4]. Business as Usual scenario is based on the assumption of a continuation of the present energy policy, particularly one that is related to cogeneration. Liberalization of the energy market in Croatia continues in that case and it is expected to be complete by 2015. There would be no revolutionary new technology and applications development related to cogeneration.

3.3. ContraCHP scenario

The ContraCHP scenario is the case when cogeneration does not develop any more in Croatia and existing district heating network and industrial plants are gradually replaced with other energy providing solutions. Like the ContraCHP scenario it is also based on the similar ''Deregulated liberalization'' scenario developed within the FutureCOGEN project. It predicts continuation of liberalization of European energy markets but with no incentives for decentralized power generation capacity, especially of a smaller type. The electricity market is expected to be dominated by big centralized generators. The result of such conditions is that cogeneration and especially small cogeneration plants could become non-competitive, without any significant development of the sector on the whole and even some existing plants being closed. Large public district heating cogeneration plants are slowly being replaced by other technologies under this scenario.

Three scenarios taken into consideration with respect to the overall installed capacity of cogeneration plants in Croatia are presented in Fig. 2. It is evident from the diagram that while the ContraCHP scenario assumes

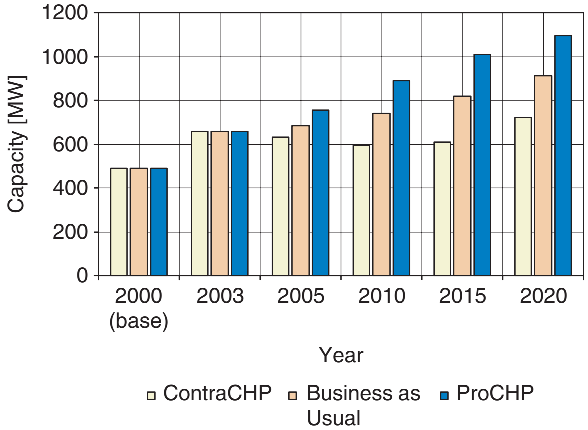

Fig. 2. Scenarios taken into consideration.

Table 1
Cogeneration sustainability indicators

Indicator	Unit	ProCHP scenario	Business as Usual scenario	ContraCHP scenario
Carbon dioxide emissions indicator	kg/kWhe	0.7068	0.7634	0.8109
Sulphur dioxide emissions indicator	kg/kWhe	0.003326	0.003221	0.003131
Particles emissions indicator	kg/kWhe	0.0002334	0.0002354	0.0002369
Health social indicator	\$/kWhe	0.00881	0.00855	0.00835
Public acceptance social indicator	—	356	482	181
Specific investment cost	€/kW	761.39	783.35	1163.86
Specific fuel cost	€/kWhel	0.0444	0.0515	0.0556

stagnation in the cogeneration sector, the Business as Usual scenario predicts moderate increase and the ProCHP scenarios predicts a significant increase in the overall installed capacity.

4. Cogeneration sustainability indicators

In order to facilitate the tool for sustainability assessment indicators are used as parameters for the measurement of sustainability [5]. Measuring sustainability is a major issue as well as a driving force in the discussion on sustainable development. The multiplicity of indicators and measuring tools being developed in this fast growing field shows the importance of the conceptual and methodological work in this area [5–7]. In that respect, the indicators have to meet certain specific requirements, in other words they have to be relevant, understandable, and reliable. Also, they must take a long-term view, in this case 20 years (year 2000–2020).

Three groups of indicators were defined and calculated as measurable elements for the sustainability assessment. Each of the indicators represents a certain characteristic of the Croatian cogeneration sector for the three above described scenarios (Table 1).

4.1. Environmental indicators (EI)

Emissions of exhaust gases and particles represent the biggest impact on environment on behalf of cogeneration plants. Carbon dioxide, sulphur dioxide and particulate emissions are chosen as measurable element in calculating EI. These indicators are defined as the total amount of respective gas emissions in the period between year 2000 and 2020 divided by the total electricity production in the same period.

4.2. Social indicators (SI)

SI reflect the social aspect of options under consideration [8]. They are a measurable element in assessing how each of the scenarios under consideration affects the local community. Two indicators for the developed scenarios were defined: The health indicator and the social acceptance indicator. The health SI was defined as the cost of the health care due to the specific impact of the cogeneration plants. In this case, the specific impact was the emission of nitrogen oxides. Nitrogen oxides (NO_x) comprise a group of molecules that can contribute to local air pollution, acid deposition and global climate change. They are among the most frequently reported atmospheric emissions, and the most commonly regulated ones [9]. Therefore, they have a direct impact on the health of the community and an indirect impact on the social state of the community.

The reason for the definition and determination of the public acceptance indicator was to obtain an overview of opinions related to the heating system from the consumer point of view. The assumption was that the quality of heating differs for each kind of heating system. The methodology for obtaining the SI for each scenario was based on the results of the survey carried out in the city of Zagreb. A specific method has been developed in order to numerically quantify the public acceptance of the district heating system having in mind that the district heating system supplies heat to consumers from cogeneration plants.

4.3. Economic indicators (EcI)

Two sets of EcI were defined and calculated for each scenario. The capital investment cost indicator indicates the increase in value of the capital investment into different cogeneration systems during the observed period of time. It is the ratio between the amount of money invested in the construction of the cogeneration systems and the total generated electricity during the observed 20-year period. The fuel cost indicator reflects the relative cost of fuel used for the energy production in each of the scenarios. The fuel cost indicators is obtained taking into consideration the assumed fuel price level for each of the scenarios during the observed period and dividing the overall fuel cost with the total electricity production.

5. Sustainability assessment procedure

The sustainability assessment procedure is based on the Decision Support System's Shell (DSSS) programme ASPID-3W [10,11], which is a computer realisation of the Analysis and Synthesis of Parameters under Information Deficiency method (ASPID) [12].

The multicriteria sustainability assessment procedure using the ASPID method can be mathematically described as a series of steps:

5.1. (1) Initial attributes $x_1,\ldots, x_m$ for the complex quality (preference) estimation of the object are fixed

Let us assume that a set $X = \{x^{(j)}, j = 1,\ldots,k\}$ of k options is fixed. In our case there are three scenarios for the Croatian cogeneration sector development ($k = 3$); $x^{(1)}$–ProCHP scenario, $x^{(2)}$–Business as Usual scenario, $x^{(3)}$–ContraCHP scenario.

Each scenario $x^{(j)}$ is defined with a vector $x^{(j)} = (x_i^{(j)},\ldots,x_m^{(j)})$. A component $x_i^{(j)}$ of a vector $x^{(j)}$ is treated as a value of an initial *attribute* (parameter, variable, characteristic, property, etc.) x_i of the option $x^{(j)}$. In our case initial attributes are three sets of indicators each of them aggregated in one indicator representing the respective set: x_1—EI, x_2—SI, x_3—EcI.

So, the vector $x^{(j)} = (x_1^{(j)},\ldots,x_m^{(j)})$ may be treated as a value of the attribute-vector $x = (x_1,\ldots,x_m)$. It is assumed that each indicator x_i is necessary and the whole attribute-vector is sufficient for a fixed *quality* (sustainability—in this case) of the scenario estimation. In the context of decision-making, the quality under consideration may be identified with the *preference* of the scenario for a decision maker.

5.2. (2) Specific criteria (indices) $q_i,\ldots, q_m$ for the fixed quality evaluation are chosen and represented in the form $q_i(x_i)$, $0\leqslant q_i\leqslant 1$, $i = 1, \ldots, m$, where $q_i(x_i)$ is a normalised function

A fixed quality of a scenario $x^{(j)}, j = 1,\ldots,k$ is defined by criteria $q_i,\ldots,q_m$ each of them being a function of a corresponding indicator $q_i = q_i(x_i), i = 1,\ldots,m$. A value $q_i^{(j)} = q_i(x_i^{(j)})$ is an estimation of a quality level (degree of preference) of jth option from the point of view of ith specific (individual) criterion (indicator). Without loss in generality it may be surmised that all specific criteria are normalized, i.e., any criterion q_i that meets the inequality $0\leqslant q_i\leqslant 1$. As this normalization takes place, the nominal value $q_i^{(j)} = 0$of the ith criterion is correlated with a scenario $x^{(j)}$, which has a minimal degree of preference (from the point of view of the ith criterion), and maximal value $q_i^{(j)} = 1$ with a scenario $x^{(j)}$ which has a maximal degree of preference (from the same point of view). So, every option (scenario) $x^{(j)} \in X$ gets a multicriteria indicator $q^{(j)} = (q_1^{(j)},\ldots,q_m^{(j)})$, where $0\leqslant q_i^{(j)}\leqslant 1$, which must be treated as a value of criteria vector $q = (q_1,\ldots,q_m)$.

In this analysis it is assumed that the linear normalization function $q_i = q_i(x_i)$ is used which falls into two types. If preferability for any scenario increases (from the point of view of any ith criterion) with increase of the argument x_i than we shall use an increasing normalisation function determined by the formula:

$$q_i(x_i) = \begin{cases} 0 & \text{if} \quad x_i\leqslant \mathrm{MIN}_i \\ \left(\frac{x_i-\mathrm{MIN}(i)}{\mathrm{MAX}(i)-\mathrm{MIN}(i)}\right)^{\lambda} & \text{if} \quad \mathrm{MIN}_i< x_i\leqslant \mathrm{MAX}_i\,. \\ 1 & \text{if} \quad x_i>\mathrm{MAX}_i \end{cases} \tag{1}$$

Table 2
Values of normalized sustainability indicators for each of the scenarios

Scenario	Environmental indicator (EI)	Social indicator (SI)	Economic indicator (EcI)
ProCHP	0.727	0.279	0.941
Business as usual	0.557	0.776	0.607
ContraCHP	0.162	0.500	0.000

If preferability of any scenario is decreasing (from the point of view of any ith criterion) with increasing of the argument x_i than we shall use a decreasing normalisation function determined by the formula:

$$q_i(x_i) = \begin{cases} 0 & \text{if} \quad x_i \leqslant \mathrm{MIN}_i \\ \left(\frac{\mathrm{MAX}(i)-x_i}{\mathrm{MAX}(i)-\mathrm{MIN}(i)}\right)^{\lambda} & \text{if} \quad \mathrm{MIN}_i < x_i \leqslant \mathrm{MAX}_i\,. \\ 1 & \text{if} \quad x_i > \mathrm{MAX}_i \end{cases} \tag{2}$$

The values MIN_i and MAX_i in (2) may be chosen by the simplest way as the minimal (maximal) value from the set $\{x_i^{(j)}, j = 1, \ldots, k\}$ (Table 2).

If the values $q_i^{(j)}, i = 1, \ldots, m, j = 1, \ldots, k,$ of specific indices $q_1, \ldots, q_m$ for all options from set X are fixed, then we can try to compare *general preferences* of each of the scenarios with help of a component-wise preference relation $\succ$ determined on the $X = \{x^{(j)}, j = 1, \ldots, k\}$ by the condition:

$$\forall x^{(j)}, x^{(l)} \in X (x^{(j)} \succ x^{(l)}) \Leftrightarrow ((\forall_i q_i^{(j)} \geqslant q_i^{(l)}) \text{ and } (\exists s : q_s^{(j)} > q_s^{(l)})). \tag{3}$$

In plain words, scenario $x^{(j)}$ is more preferable "in general" than then scenario $x^{(l)}$ ($x^{(j)} \succ x^{(l)}$) if and only if scenario $x^{(l)}$ is not more preferable than $x^{(j)}$ from the point of view of each specific criterion $q_i(q_i^{(j)} \geqslant q_i^{(l)}, i = 1, \ldots, m)$ and there exists a specific criterion q_s such that $x^{(j)}$ is more preferable than $x^{(l)}$ from the point of view of the criterion $(q_s^{(j)} > q_s^{(l)})$.

Two scenarios $x^{(j)}, x^{(l)} \in X$ are incomparable if they meet the condition:

$$(\exists r : q_r^{(j)} > q_r^{(l)}) \text{ and } (\exists s : q_s^{(j)} < q_s^{(l)}). \tag{4}$$

For example, multicriteria indicators $q^{(l)} = (q_1^{(l)}, \ldots, q_3^{(l)}) = (0.727, 0.279, 0.941)$, $q^{(l)} = (q_1(l), \ldots, q_3^{(l)}) = (0.162, 0.500, 0,000)$ of scenarios ProCHP and ContraCHP sustainability are incomparable since ProCHP scenario is "better" (more preferable) than ContraCHP scenario by criteria q_1, q_3, but the ContraCHP scenario is "better" than ProCHP scenario by criteria q_2.

5.3. (3) An aggregative function $Q(q,w)$ of multicriteria estimation $q(q_1, \ldots, q_m)$ with a vectorial parameter $w = (w_1, \ldots, w_m)$, $w_i \geqslant 0$, $w_1 + \ldots + w_m = 1$, is selected for specific criteria $q_1, \ldots, q_m$ convolution into one general index (general criterion) $Q = Q(q,w)$

The problem of scenarios multicriteria incomparability may be resolved by synthesis of specific criteria $q_1, \ldots, q_m$ into one *general criterion* (index) Q determined by a scalar function $Q = Q(q) = Q(q_1, \ldots, q_m)$, which meets the condition of monotonicity $((x^{(j)} \succ x^{(l)}) \Rightarrow (q(q^{(j)}) \geqslant q(q^{(l)})))$ and fulfils the requirements: (1) $Q(0, \ldots, 0) = 0$; (2) $Q(1, \ldots, 1) = 1$.

Inequality $Q(q^{(j)} > Q(q^{(j)})$ means that jth scenario is more preferable than lth scenario. Now all scenarios are comparable as there are only three alternatives for any pair of scenarios $x^{(j)}, x^{(l)}$: $Q(q^{(j)} > Q(q^{(l)})$; $Q(q^{(l)} < Q(q^{(l)})$; $Q(q^{(j)} = Q(q^{(l)})$.

The synthesizing functions Q are a generalized weighted mean, namely *additive aggregative* function (weighted arithmetical mean).

$$Q_+(q, w) = \sum_{i=1}^{m} w_i q_i. \tag{5}$$

In this formula $w = (w_1, \ldots, w_m)$, $w \geqslant 0, w_1 + \ldots + w_m = 1$, is a vector of *weight coefficients* $w_1, \ldots, w_m$ (weight vector). A weight coefficient w_i is a measure of relative significance of the corresponding specific criterion q_i for aggregate estimation $q(q^{(j)})$ of general preference of an scenario $x^{(j)} \in$. It is a qualitative and not quantitative measure, in other words, non-numeric information.

5.4. (4) After the carrying out the analysis in terms of inputting the necessary information, the program gives the output information

The output information is: (1) The average general estimation of a general criterion index; (2) standard deviations $S(q^{(1)}; I), \ldots, S(q^{(k)}; I)$; (3) Measures of reliability of revealed preference relations between scenarios $x^{(j)}$, $x^{(l)} \in X$. These output results are graphically presented in the form of ASPID-diagram. The above-mentioned quantitative image of qualitative information for weight coefficients is represented in the form of ASPID-diagram too.

6. General index of sustainability (GIS)

The GIS was obtained for each scenario as a result of the DSSS procedure. While carrying out the analysis, different alternatives regarding individual criteria and weighting factors were taken into consideration. Among the relatively large number of different options it was assumed that when obtaining the aggregated EI preference will be given to the carbon dioxide emissions indicator and in the case of obtaining the aggregated SI as well as the EcI there will be no preference given to the specific indicator.

Three cases were taken into account when obtaining the GIS each of them reflecting the difference in mutual relation of weighting factors on the decision-making process. The cases were designed to give the higher priority to a single indicator with other indicators having equal priority.

6.1. Case 1: EI > SI = EcI

Case 1 reflects those situations when priority is given to the environment criteria in comparison to social and economic criteria. Since the primary assumption when defining the aggregated Environment Indicator was that the CO_2 emission indicator is has dominancy, this implies that the scenario with a lower CO_2 emission gains higher priority. Under such a mutual relation of weighting factors the highest value of the General Index of Sustainability is obtained in case of the ProCHP scenario (Figs. 3 and 4).

6.2. Case 2: SI > EI = EcI

This case represents the situation when the priority is given to the social criteria. The change in the priority list has led to a significant change in GIS rating. The Business as Usual scenario achieves the highest GIS now. At the same time GIS for the ProCHP and ContraCHP scenarios exhibit marginal different between themselves. It is of interest to note the strong influence of a single priority criterion on the final sustainability rating. Also, it should be noted that this case is not acceptable since the value of the probability of dominancy between options under consideration is less than 50%, as defined in Eq. (4) (Figs. 5 and 6).

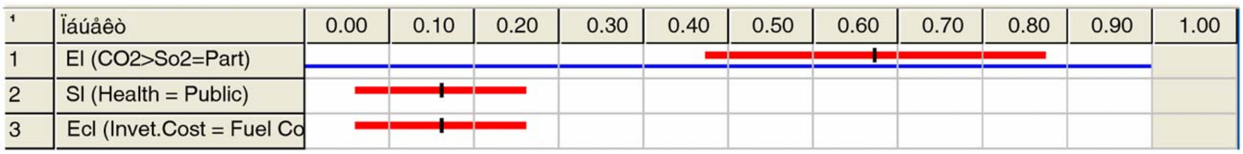

Fig. 3. Weighting coefficients rating in case 1.

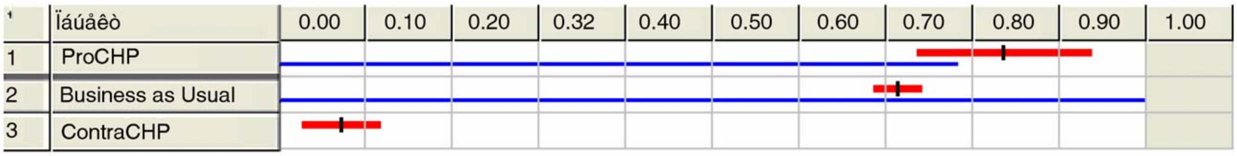

Fig. 4. General Index of Sustainability rating for case 1.

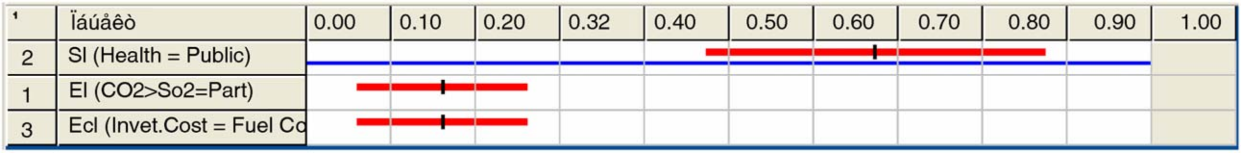

Fig. 5. Weighting coefficients rating in case 2.

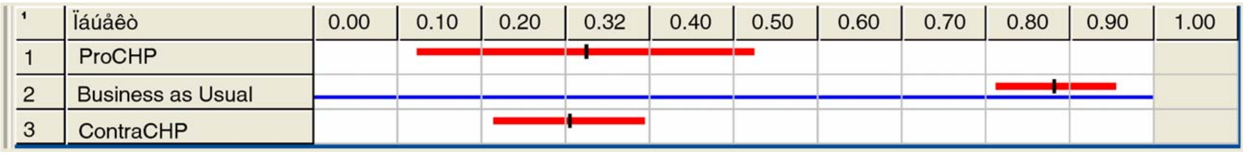

Fig. 6. General Index of Sustainability rating for case 2.

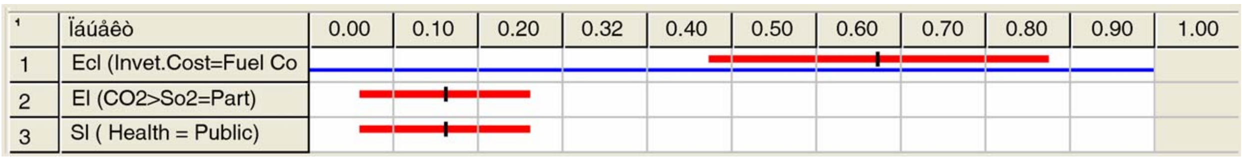

Fig. 7. Weighting coefficients rating in case 3.

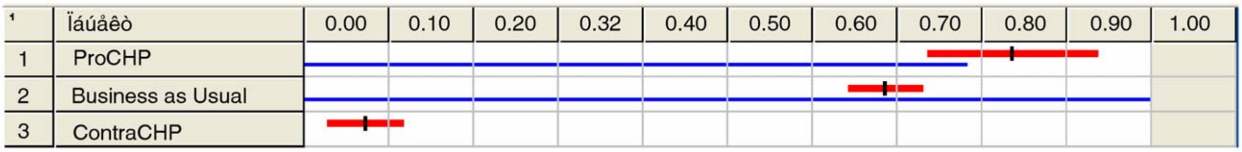

Fig. 8. General Index of Sustainability rating for case 3.

6.3. *Case 3: EcI > EI = SI*

In the 3rd case the, priority was given to the economic criteria. Namely, weighting factor for the EI had a higher priority. As in the first case, the ProCHP scenario obtains the highest value of the GIS. However, in this case the difference between values of GIS for respective scenarios is greater than in the first case of analysis (Figs. 7 and 8).

7. Conclusions and recommendations

The multicriteria analysis carried out and presented in this paper shows the potential direction that has to be followed in the Croatian cogeneration sector in order to meet the conditions for sustainable development.

Namely, the analysis has shown that the ProCHP scenario obtains the highest General Index of Sustainability value for two of three cases considered. It should however be emphasised that the reliability and availability of data used in the analysis was limited. That resulted in a relatively low number of different options and criteria taken into consideration. Also, the accuracy of the method presented strongly depends on the accuracy of data used in the analysis. The primary goal of the analysis was therefore to introduce the sustainability assessment procedure and to point out the potential direction in further work. The demonstrated analysis and its results proved that the decision-making procedure very much depends on the priority given to the specific criteria. That means that it is of interest for the decision-making process to use a higher number of criteria if possible. Since sustainable development is all about the different aspects of development, the multicriteria method used proved to be a very suitable method for sustainability assessment. Therefore, more thorough and wider analysis of the Croatian cogeneration sector using the multicriteria assessment method is clearly justified and highly recommended.

Acknowledgements

This paper is a result of cooperation of Faculty of Mechanical Engineering and Naval Architecture at the University of Zagreb, Centre for Technology Transfer and Instituto Superior Técnico in Lisbon, as a part of the ''Sustainable Development of Croatian Capacity in CHP Sector'' project within LIFE 3rd Countries programme, financed by the European Commission.

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