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Multi-criteria decision analysis for simplified evaluation of clean energy technologies

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Abstract

Technology assessment (TA) is not a new concept. High value energy technology identification needs to be followed by a decision process in which all shareholders contribute. A case study on Combined and Heat Power (CHP) technologies considered is presented to illustrate the applicability of fuzzy analytical hierarchy assessment approach (FAHP). The goal of this paper is to identify and evaluate the best variant of CHP technologies using multi-criteria that are technical feasibly and cost effective reflecting performance parameters. The results depict that technology A2 with an overall ranking of 0.438 is the best alternative compared to others. Taking into consideration decision parameters for the section, A1 is found to be relatively most important with a rating of 0.434 with its reliability and cost effectiveness. The presented fuzzy-based methodology is general expected to be used by a diverse target groups in energy sectors.

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1. Introduction

Clean technologies have been widely reviewed in terms of technological changes and their performance have been clearly established (Schot, 1992). Technology selection, mainly driven by process economics are usually based on the net present value (NPV) should be used as a selection criterion rather than investment costs. Economies of scale are more important in technologies, at increased airflow volumes, their reduction in overall costs is more extreme when compared to the alternative technologies. Simple and qualitative methods are selected for the assessment focusing on the interaction of technology elements.

High value energy technology identification needs to be followed by a decision process in which all shareholders contribute. Decision makers would decide to formalize and to implement technology assessment to accomplish the right selection among proposed technologies, or to work randomly without any specific methodology (Bakouros, 2000). This highlights the need to develop a method that can help plant managers to take decisions to select appropriate technology based on assessment criteria. Furthermore, some information may be somewhat imprecise and fuzzy. A case study on CHP technologies considered is presented to illustrate the applicability of the method.

Additionally, in most of the literature on energy technologies, they dealt with three dimensions of the sustainability, namely environmental economic and social considerations that they should be met simultaneously. Sachs reinforced the argument to restrict the discussion to an extra dimension focusing on political systems (Sachs, 1999; Assefa and Frostell, 2007). Harris and Goodwin (2001) clarified the three dimensions of sustainability from the perspective of important features of a sustainable system. However, as with many studies (Singh et al., 2012; Singh et al., 2014), its results are not always fully utilized providing a well-founded conceptual framework (Grundwald and Roetsch, 2011) or the issue of developing a combined method as multi-criteria at the technology level is not properly addressed (e.g. too general in sustainability assessments). In identifying research goals, additional study on energy technology assessment, not considering the "integrating approach" related to sustainability and their evaluation criteria, is required.

The goal of this paper is to evaluate Combined and Heat Power (CHP) technologies assessment using multi-criteria that reflect performance parameters gathered in economic viability, technical feasibility, and environmental protection aspects. By providing a coherent methodology the technology assessment will support operative decision-making of users and non-experts "making possible to eliminate characteristic with least significance when it comes to the linear ordering concept". It prioritizes available alternatives in order to bridge the energy technology gap.

The case study used can provide potential users, and decision makers with a coherent methodological framework for technology assessment, including application of a fuzzy analytical hierarchy approach (FAHP). In this case, fuzzy AHP is applied to select energy technologies. However, these criteria are shifting with economic viability, technical feasibility and reliability becoming as important as process economics.

2. Literature review

Technology assessment (TA) is not a new concept. TA focuses on "maintaining and enhancing the diversity of economic and technological approaches to addressing specified challenges" (Ely et al., 2011). There are differences between traditional and new approach to technology assessment, which can be overcome by introducing technology assessment program. The basic technology assessment definition given by Coates (1976) reflects the dimension of studying the systematizing, social aspects and forecasting future issues. A new approach of technology assessment is broadened into technological choices among technologies and their associated criteria by which they to be evaluated. From other side, the basic approach in decision analysis and multiple criteria decision making theory concentrates on subjective ranking. Most of the multiple criteria decision making methods looks relative distance from the ideally positive or negative solution or compares utility function's scores of available solutions with the ideally positive alternative or with the best or worst alternative of investigated alternatives.

Additionally, reasons for the shortcoming are problems with using inadequacies in analytic tools or theoretical understanding, precise evaluation or institutional problems due to constrains upon the interests that each individual decision-maker is encouraged to treat as his/her own. The specific literature on multi-criteria decisions (MCDA) methods does not discuss this aspect in particular, nevertheless, their structure does not limit the number and type of criteria to be used as input parameters. In essence there are no alternatives to technology assessment techniques (Oteng-Seifah and Adjei-Kumi, 2007; Bertoni et al., 2015). Decision makers would decide to formalize and to implement technology assessment to accomplish the right selection among proposed technologies, or to work randomly without any specific methodology (Bakouros, 2010). Therefore, combined MCDA methodologies should determine overall preferences among alternative technology options according to the different criteria being difficult while comparing with one another (Kluczek, 2016).

More "integrating concept" of technology assessment is taken into consideration of connections between environmental and socio-economic issues as well as concerns for the future of humanity (Azapagic and Perdan, 2005a, 2005b). This approach represents the "three pillars" of sustainability: environmental, economic, and social values (TBL). These MCDA methods used to sustainability assessment rely on key interactions between infrastructure and surrounding environmental, economic, and social issues and uses sustainability criteria and indicators as a way of understanding and quantifying such interacting effects. While traditional forms of sustainability technology assessment focused on individual technologies considered separately, additional technical realities in terms of technical reliability necessitate a more holistic assessment, becoming as important as process economics. A review of technology assessments approaches are presented in (Gładysz and Kluczek, 2017). Many MCDA approaches are designed to deal multi-criteria problems such ELECTRE, Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) (Liu, 2009) applied in various fields, e.g. for industrial practices (Kluczek and Gładysz, 2015) or manufacturing in detail or suppliers selection (Ayhan, 2013). Other approach, ANFIS (Adaptive Neuro-Fuzzy Inference System) uses adaptive neuro-fuzzy inference system based on fuzzy modeling with linguistic numbers (Jang, 1993).

FAHP was found to be widely used in the application of building research teams (Dąbrowski and Skrzypek, 2016). The main concern of other is dealing with inconsistences related with arising with the expert opinions, what is the main reason for the implementation of the AHP.

This intricacy has been dealt with giving weights for characteristics, which are determined on the basis of fuzzy expert opinions and then to "establish priorities". Due to expert's statements are uncertain in their nature, human thoughts are fuzzy and the problem being analyzed is complex, then it is proposed to apply successfully fuzzy logic to help handle imprecision in multi-criteria decision making processes (Varela and Ribeiro, 2003; Kluczek, 2016). Hence, this study presented seeks to evaluate and select the best clean energy technology. The FAHP will be used as a guide by planners improving the quality multi-criteria decision making.

3. Experimental

Multi-criteria evaluation procedure for simplified evaluation of clean energy technologies is employed involving description of technologies, establishing criteria as well as establishing an evaluation model based on the characteristics of stone processing production. Based on data collection fourth stage involves employing the evaluation system to select the best clean energy technology. The proposed procedure for simplified evaluation of energy technologies alternatives is outlined in Fig. 1.

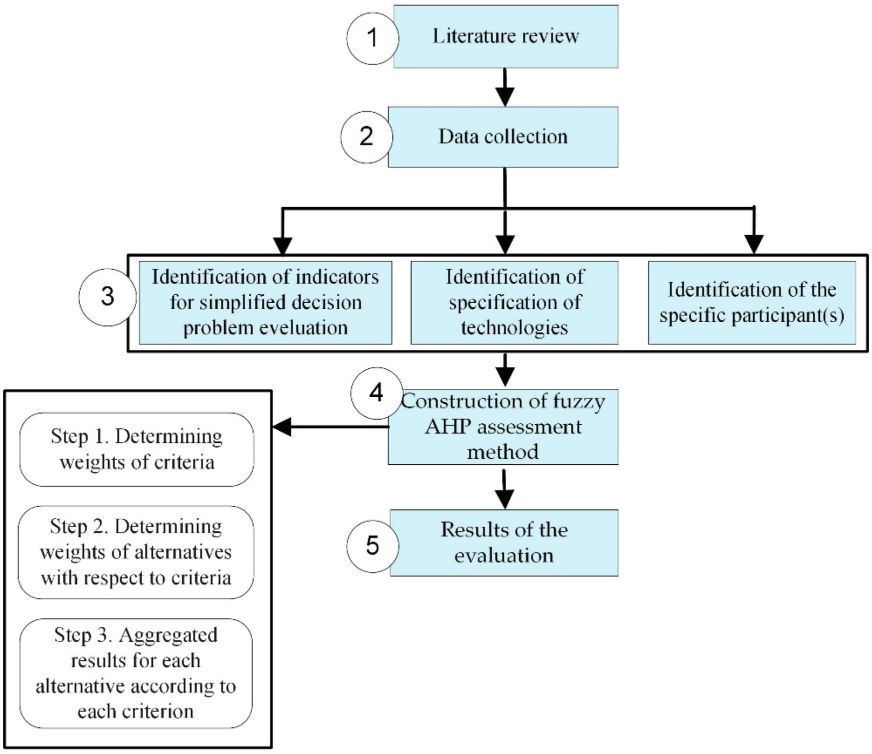

Fig. 1. Multi-criteria evaluation procedure for simplified evaluation of clean energy technologies

3.1. Selection and specification of technologies

This step of the decision-support framework is aimed at identifying the best CHP technology taking into account the specific conditions of the technologies. Technologies to be applied as recommendations of energy audits are described in Table 1.

3.2. Data collection

Appropriate research material has to be collected before applying of the presented FAHP based procedure. Once the technologies have been selected to be evaluated, they need to be characterized with respect to their capacities, efficiencies, capacity factors, lifetimes, emissions to the environment. Selection and assessment is carried out by using fuzzy AHP. This data (although imprecise) will be sufficient to show the principal feasibility of the ranking procedure.

However, it should be borne in mind that the format for data collection has to reflect the requirements imposed by the application of fuzzy sets in data analysis.

3.3. Identification of the specific representatives

This phase entailed identifying the individuals who would be participant were identified from the group of energy lead auditors available at the university. Due to the confidentially of the representatives, their names are not disclosed in this research. The decision-makers were asked to assess technologies by giving the best outcome in terms of the criteria mentioned (Klevas et al., 2009).

Table 1. Collected data on considered CHP technology alternatives

Description of technologies	
Natural Gas Engine CHP	Industrial natural gas-fired turbines operate to generate electricity. These turbines are located in close proximity to where the electricity being generated will be used. Industrial turbines – producing electricity through the use of high temperature, high pressure gas to turn a turbine that generates a current – are compact, lightweight, easily started, and simple to operate. Due to the advantages of these types of generation units, a great deal of research is being put into developing more efficient, advanced gas turbines for distributed generation.
Steam Turbine CHP	A steam turbine is captive to a separate heat source and does not directly convert a fuel source to electric energy. Steam turbines require a source of high pressure steam that is produced in a boiler or heat recovery steam generator (HRSG).The capacity of steam turbines can range from a fractional horsepower to more than 1,300 MW for large utility power plants. They are widely used for CHP applications in the U.S. and Europe where special designs have been developed to maximize efficient steam utilization.
Gas turbines	Gas turbines are a cost effective CHP alternative for commercial and industrial end-users with a base load electric demand greater than about 5 MW. (Gas turbines with HRSG for power demand usually between a few MWe and 25 MWe). They perform best at full power although they can also be operated at partial load. Waste heat is recovered in the HRSG to generate high- or low pressure steam or hot water. The thermal output can be used directly or converted into chilled water by single or double-effect absorption chillers.

Table 2. Technology data collection

Description	Natural Gas Engine CHP	Steam Turbine CHP	Gas turbines
Estimated installed cost ($/kW) in terms of type of turbine*	800-1500	800-1000 The incremental cost of adding a steam turbine to an existing boiler system or to a combined cycle plant is approximately $400-$800/kW.	700-900
Efficiency [%]	40-60%	Modern large condensing steam turbine plants have efficiencies approaching 40-45%, however, efficiencies of smaller industrial or backpressure turbines can range from 15- 35%.	30-42% (lower heating value)
Technical lifecycle [yrs]	20	50	25
Fuel flexibility/ cells	natural gas, biogas, propane	Steam turbines offer the best fuel flexibility using a variety of fuel sources including nuclear, coal, oil, natural gas, wood and waste products	natural gas, biogas, propane, distillate oil, propane, distillate oil
O&M Cost ($/kWh)	0.007-0.015	0.001-0.006	0.002-0.008
Environmental burden in terms of GHG emissions (sqft/kW)	0.22-0.31	<0.1	0.02-0.61
Uses for Heat Recovery	hot water, LP steam, district heating	LP-HP steam, district heating	direct heat, hot water, LP-HP steam, district heating

3.4. Identification of indicators for a simplified decision problem evaluation

There is a range of significantly important indicators that must be considered when evaluating clean or sustainability of energy technologies (Evans et al., 2009).

Proposed study identifies seven performance parameters treated as decision criteria which affects the decision making process. These parameters are presented and briefly explained in Table 3. Environmental issues have a negligible importance in the hierarchy of technology elements.

The CHP technologies were evaluated based on seven critical indicators in terms of: efficiency, quantifications of operating reliability, sensitivity towards operating parameters like (fuel flexibility, operation and maintenance (O&M), installed cost for technology) and environmental performance impact as well as energy recovery.

Some of the criteria are described based on partially quantitative and mostly qualitative information, difficult to measure and subjective, which are stated in linguistic scale

Table 3. Criteria introduced for selecting appropriate technology

Criteria	Parameters	Description
C1	Efficiency	Efficiencies strongly influence prices as well as sustainability, since the high levels of waste associated with an inefficient process are unsustainable
C2	Operating reliability	Technical lifecycle
C3	Fuel flexibility	Fuel flexibility in terms of ability of energy resources locally for operations and easy to switch
C4	O&M cost	Day-to-day preventative and corrective maintenance and administrative costs relating to technology
C5	Ability to pay for technology	Plant`s ability to pay for estimated installed cost ($/kW) in terms of type of turbine multiplied by including equipment and plant retrofitting costs to the variation in the capacity of a considered industrial plant
C6	Environmental burden in terms of GHG emission	Less damage to natural environment and reducing greenhouse gas emission
C7	Energy recovery	Here, possibility of using for heat recovery

3.5. Development of the decision problem framework

The hierarchical frame of the criteria and the alternatives for the technology selection and assessment can be represented as following Figure 2. Here, both the criteria and the alternative weights should be calculated. The proposed framework is divided into main steps:

1. Determining weights of criteria,
2. Determining weights of alternatives with respect to criteria.

A case study for assessing and selection technologies is revealed in the next section.

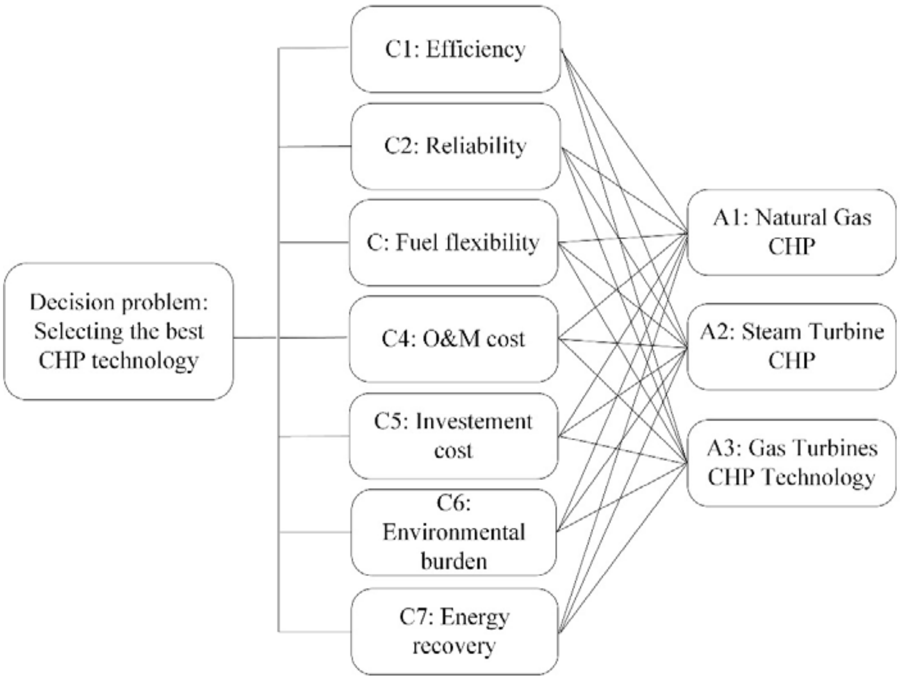

Fig. 2. The hierarchy of the criteria and the alternatives – framework if technology assessment

4. Empirical study

The fuzzy AHP (FAHP) in combined heat and power combined technologies for selection of an efficient and cost effective one. The extended version of AHP is based on fuzzy theory (Zadeh, 1965), where one solution is selected among various possibilities with a number of decision factors. The detailed steps of the procedure within the framework are as follows:

Step 1: Determining weights of criteria

Step 1.1: Construct hierarchical structure of the decision problem (Garg, 2017) in order to select best alternative, here efficient-reliable and cost effective CHP technology. Hence, a pair-wise comparison matrix $\tilde{A}$ with ranked structure using all the decision parameters is developed as below (1):

$$\widetilde{A} = \begin{pmatrix} (l_{11}, m_{11}, u_{11}) & (l_{12}, m_{12}, u_{12}) & (l_{1n}, m_{1n}, u_{1n}) \\ (l_{21}, m_{12}, u_{21}) & (l_{22}, m_{22}, u_{22}) & (l_{2n}, m_{2n}, u_{2n}) \\ (l_{m1}, m_{m1}, u_{m1}) & (l_{m2}, m_{m1}, u_{m1}) & (l_{mn}, m_{mn}, u_{mn}) \end{pmatrix} \tag{1}$$

Step: 1.2: Decision makers (experts) using a pair-wise comparison matrix compare the criteria or alternatives via linguistic scale, shown in Table 4. Let represent a fuzzified reciprocal $\tilde{A} = \left(\widetilde{a_{ij}}\right)_{mxn}$-judgment matrix containing all pairwise comparisons $\widetilde{a_{ij}}$ between elements *i* and *j* for all *i,j* ∈ {1,2,…,*n}*.

Table 4. Fuzzy comparative scale

Saaty`s scale	Linguistic evaluation	Triangularf fuzzy number (l_i; m_i; u_i)
1	Equally important (Eq. Imp.)	(1; 1; 2)
3	Weakly important (W. Imp.)	(2, 3; 4)
5	Fairly important (F. Imp.)	(4, 5, 6)
7	Stronly important (Eq. Imp.)	(6, 7, 8)
9	absolutelyimportant (A .Imp.)	(8, 9, 10)
2	The intermittent values between two adja cent scales	(1, 2, 3)
4		(3, 4, 5)
6		(5, 6, 7)
8		(7, 8, 9)

Source: Based on (Saaty, 1989)

The fuzzy triangular number is than replaced to make it in an increasing order. In this step, the fuzzy weight of criterion is calculated with the equation 3.

$$\widetilde{w_i}\widetilde{r_i} = \otimes\ (\widetilde{r_1} \otimes \widetilde{r_2} \otimes \widetilde{r_1})^{-1} \tag{3}$$

Step 1.4: The fuzzy weights of each criterion can be found with Eq. 3, by incorporating the vector summation of each $\widetilde{r_i}$ and the (-1) power of summation vector (see equation 4).

$$\widetilde{w_i} = \widetilde{r_i} \otimes \left(\textstyle\sum_{i=1}^{n} \widetilde{r_1}\right)^{-1}, i = 1,2, \ldots, n \tag{4}$$

Step 1.3: The averaged pair-wise comparison of the criteria is represented by following Table 3. In addition the geometric mean, fuzzy comparison values of each criterion is calculated by Eq. 1. Here, in this case, $\widetilde{r_i}$ represents triangular fuzzy values of pair-wise comparison matrices $\widetilde{a_{ij}} = \left(l_{ij}, m_{ij}, u_{ij}\right)$, (Buckley, 1985; Davies, 1994) using geometric mean for l_{ij} the lower and u_{ij} the upper limit,

Step 1.5: $\widetilde{w_i}$ as the fuzzy triangular numbers must be defuzzified (Chou and Chang, 2008) by applying the equation 5.

The geometric means of fuzzy comparison values of all criteria are shown in Table 4.

$$M_i = (lw_i + mw_i + uw_i)/3, i = 1,2,\dots,n \qquad (5)$$

Step 1.6: M_i as a non-fuzzy number needs to be normalized by following equation 6. This step provides a normalization of weights of both criteria and the alternatives.

$$N_i = \frac{M_i}{\sum_{i=1}^{n} M_i} \qquad (6)$$

Step 2: Determining weights of alternatives with respect to criteria

The alternatives should be pairwise compared with respect to each criterion particularly. The three technological alternatives A_i, $(i = 1, 2, 3)$ are evaluated by an expert under the seven parameters Cj $(j = 1, 2, 3, 4, 5, 6, 7)$ by using fuzzy decision matrix $D = (\alpha i\ j\ )_{3\times7}$, and their corresponding rating values (Table 7).

The calculation of the consistency ratio CR ensures the consistency of the responses. Ranking is computed using the consistency ratio (CR) by using formula shown in equation 1, so that the random incompatibility (RI) has been created from those matrices for different values of n by generating random matrix. In this work the fuzzy comparison matrix is of the size of 3×7, therefore the value of RI is 1.3

Table 5. Comparison criteria matrix

CRI	C1			C2			C3			C4			C5			C6			C7		
C1	1.0	1.0	1.0	1.0	1.0	2.0	2.0	3.0	4.0	2.0	3.0	4.0	4.0	5.0	6.0	4.0	5.0	6.0	6.0	7.0	8.0
C2	1.0	1.0	0.5	1.0	1.0	1.0	2.0	3.0	4.0	1.0	1.0	2.0	2.0	3.0	4.0	1.0	1.0	2.0	8.0	9.0	10.0
C3	0.5	0.3	0.3	0.5	0.3	0.3	1.0	1.0	1.0	1.0	1.0	2.0	1.0	1.0	2.0	4.0	5.0	6.0	2.0	3.0	4.0
C4	0.5	0.3	0.3	1.0	1.0	0.5	1.0	1.0	0.5	1.0	1.0	1.0	1.0	1.0	2.0	2.0	3.0	4.0	2.0	3.0	4.0
C5	0.3	0.2	0.2	0.5	0.3	0.3	1.0	1.0	0.5	1.0	1.0	0.5	1.0	1.0	1.0	1.0	1.0	2.0	1.0	1.0	2.0
C6	0.3	0.2	0.2	1.0	1.0	0.5	0.3	0.2	0.2	0.5	0.3	0.3	1.0	1.0	0.5	1.0	1.0	1.0	2.0	3.0	4.0
C7	0.2	0.1	0.1	0.1	0.1	0.1	0.5	0.3	0.3	0.5	0.3	0.3	1.0	1.0	0.5	0.5	0.3	0.3	1.0	1.0	1.0

Table 6. Geometric means of fuzzy comparison values r_i , relative fuzzy weights of each criterion w_i , and averaged M_i and normalized N_i relative weights of criteria

CRI	r_i			**CRI**	w_i			**CRI**	M_i	N_i
C1	2.340	2.863	3.684	C1	0.241	0.332	0.461	C1	0.345	0.339
C2	1.641	1.873	2.280	C2	0.169	0.217	0.285	C2	0.224	0.220
C3	1.104	1.076	1.292	C3	0.114	0.125	0.161	C3	0.133	0.131
C4	1.104	1.170	1.104	C4	0.114	0.136	0.138	C4	0.129	0.127
C5	0.743	0.679	0.635	C5	0.077	0.079	0.079	C5	0.078	0.077
C6	0.673	0.631	0.492	C6	0.069	0.073	0.061	C6	0.068	0.067
C7	0.427	0.346	0.267	C7	0.044	0.040	0.033	C7	0.039	0.039
Total	8.032	8.638	9.754					Total	1.016	
P (-1)	0.125	0.116	0.103							
INCR	0.103	0.116	0.125	Increasing order →						

Table 7. Pairwise comparison matrix of all evaluations

w_i		A1	A2	A3
C1	A1	(1.0;1.0;1.0)	(2.0;3.0,4.0)	(1.0,1.0,2.0)
	A2	(0.5;0.33,0.25)	(1.0;1.0;1.0)	(8.0;9.0;10.0)
	A3	(1.0;1.0;0.5)	(0.13;0.11;0.1)	(1.0;1.0;1.0)
C2	A1	(1.0;1.0;1.0)	(1.0;1.0;2.0)	(2.0;3.0,4.0)
	A2	(1.0;1.0;0.5)	(1.0;1.0;1.0)	(8.0;9.0;10.0)
	A3	(0.5;0.33,0.25)	(0.13;0.11;0.1)	(1.0;1.0;1.0)
C3	A1	(1.0;1.0;1.0)	(1.0;1.0;2.0)	(2.0;3.0;4.0)
	A2	(1.0;1.0;0.5)	(1.0;1.0;1.0)	(8.0;9.0;10.0)
	A3	(0.5;0.33,0.25)	(0.13;0.11;0.1)	(1.0;1.0;1.0)
C4	A1	(1.0;1.0;1.0)	(2.0;3.0;4.0)	(2.0;3.0;4.0)
	A2	(0.5;0.33;0.25)	(1.0;1.0;1.0)	(5.0;6.0;7.0)
	A3	(0.5;0.33;0.25)	(0.2;0.17;0.14)	(1.0;1.0;1.0)
C5	A1	(1.0;1.0;1.0)	(1.0;1.0;2.0)	(1.0;1.0;2.0)
	A2	(1.0;1.0;0.5)	(1.0;1.0;1.0)	(5.0;6.0;7.0)
	A3	(1.0;1.0;0.5)	(2.0; 3.0,4.0)	(1.0;1.0;1.0)
C6	A1	(1.0;1.0;1.0)	(1.0;1.0;2.0)	(1.0;1.0;2.0)
	A2	(1.0;0.5;0.33)	(1.0;1.0;1.0)	(6.0;7.0;8.0)
	A3	(1.0;1.0;0.5)	(0.17;0.14;0.13)	(1.0;1.0;1.0)
C7	A1	(1.0;1.0;1.0)	(2.0; 3.0,4.0)	(1.0;1.0;2.0)
	A2	(0.5;0.33;0.25)	(1.0;1.0;1.0)	(6.0;7.0;8.0)
	A3	(1.0;1.0;0.5)	(0.17;0.14;0.13)	(1.0;1.0;1.0)

$$CR = \frac{CI}{RI} \tag{7}$$

The compatibility of the matrix is accepted, CR = 0.09 is less than 0.1, by using the eigenvalue λmax as follows: CI = (λ_{max}-n)/(n-1), where λ_{max} is the maximum eigenvalue (W) of the matrix of priorities (eq. 8).

$$\begin{pmatrix} a_{11} & a_{12} & a_{1nm} \\ a_{21} & a_{22} & a_{2nm} \\ a_{n1} & a_{n2} & a_{nm} \end{pmatrix} \begin{pmatrix} W_1 \\ W_2 \\ W_n \end{pmatrix} = \begin{pmatrix} \lambda_{max} W_1 \\ \lambda_{max} W_2 \\ \lambda_{max} W_n \end{pmatrix} = AW = \lambda_{max} W \tag{8}$$

Similar to previous described steps, the following parameters are calculated with respect to each criterion, such as: the geometric means of fuzzy comparison values (r_i) and relative fuzzy weights of alternatives for each criterion (w_i), non-fuzzy (Mi) and normalized (Ni) values.

Step 3: Aggregated results for each alternative according to each criterion

The data which was normalized for all alternatives (see Table 8) are multiplied by the relevant normalized weight of each criterion *Ni* (see also Table 6), then ranked the alternative *Ai* (*i* = 1, 2, . . . , m) are ranked according to the descending value of the score values selecting the most desirable alternative.

5. Results and discussion

It is necessary to present achieved results of own research illustrating them by Tables, pictures, diagrams and giving in details relations between stated facts. That section should

The final result of the study is ranked as follows: 1- Gas turbine CHP; 2 – Steam Turbine CHP, 3 – Natural Gas Engine CHP. Gas turbine is the alternative with the greatest "global" weight of 0.438 and would therefore be the most preferable alternative. In this study A2 significantly outperforms A1 and can be thought as the second best clean technology. It shows that the ranking in Table 7 suggests electricity production by application steam turbine CHP is the most sustainable followed by natural gas CHP.

Table 8. Aggregated and ranked score values of technology alternatives

	Criteria (performance parameters)		Results of alternatives with regards to related		
		Weight (Ni)	Weight (Ni)		
			A1	A2	A3
C1.	Efficiency [%]	0.339	0.453	0.418	0.129
C2.	Reliability [years]	0.220	0.411	0.501	0.088
C3.	Fuel flexibility	0.131	0.425	0.476	0.099
C4.	O&M cost [$/kwh]	0.127	0.558	0.339	0.104
C5.	Ability to pay for technology	0.077	0.287	0.399	0.314
C6.	Environmental burden in terms of GHG emission costs	0.067	0.348	0.511	0.141
C7.	Energy recovery (Recovery potential)	0.039	0.464	0.393	0.143
		Score	0.434 [2]	0.438 [1]	0.128 [3]

6. Summary and conclusion

The decision-support method was aimed at identifying the best CHP technology that are technical feasibly and cost effective, taking into account the specific parameters/conditions of considered technologies. Seven significant decision factors related to technology performance parameters were identified and FAHP was used to analyse their proposed alternatives. Result clearly presents, that technology A2 with an overall ranking of 0.438 is the best alternative. Further, among all identified decision parameters for CHP technology towards reliability and cost effectiveness, A1 is found to be relatively most important with a rating of 0.434. The results remain subjective due to technology criteria and their parameters, which can only be based on the information presented to a decision-maker which itself is limited and biased. It can be concluded that that evaluation of energy technologies enables take a decision regarding the efficiency, acceptability, compatibility with the society's opinion of the selected technologies and, to this matter, may lead to selection of more efficient technologies, more attractive ones for the manufacturer or decision makers or society, including of better quality from the reliability and cost-effectiveness point of view. Based on the study the fuzzy evaluation of pair-wise comparisons may be more comfortable and appropriate for decision making. The selection of technologies alternatives could give flexibility to build the technology portfolio and

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用于简化清洁能源技术评估的多标准决策分析

關鍵詞
清洁能源技术
多标准分析

摘要

技术评估（TA）不是一个新概念。高价值的能源技术识别需要遵循所有股东贡献的决策过程。为了说明模糊分析层次评估方法（FAHP）的适用性，提出了一个关于考虑的热电联产（CHP）技术的案例研究。本文的目标是使用多标准来识别和评估CHP技术的最佳变体，这些标准是技术上可行且具有成本效益的反映性能参数。结果表明，与其他技术相比，总体排名为0.438的技术A2是最佳选择。考虑到该部分的决策参数，A1被认为是相对最重要的，其可靠性和成本效益的评级为0.434。所提出的基于模糊的方法通常预期由能源部门中的不同目标群体使用。