A comparative analysis of the potential South African renewable energy sources using Analytical Hierarchy Process

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Abstract

South Africa one of the most developed country in the continent of Africa had been dealing with serious challenges such as substantial growth in residents and increasing per capita electrical energy use that requires maximum utilization of existing electricity generating sources. Presently, more than 88% of electricity is being generated by means of fossil fuels with coal leading the raking by feeding the national power grid with approximately 72% of electrical energy produced. However, this power supply system puts a colossal strain on the economy and triggers significant damage to the ecosystem in general. To mitigate, this high reliance over non-renewable electricity producing resources, the South African government along with its department of energy as well as the electricity utility decided to implement measures with the aim of promoting the production of electricity through the renewable energy resources. However, these decisions have been primarily made with the goal of reducing the power crisis, without giving a significant consideration to the environmental, economic, social, and technical aspects concerning all the proposed renewable energy resource alternatives. To bridge this gap, this paper used the Analytical Hierarchy Process (AHP) in order to define the absolute priorities of the renewable energy sources in the South African energy sector. The parameters such as environmental, economic, social, and technical were taken into account in this study with the aim of identifying and ranking the electricity technologies such as biomass, wind, hydro, and solar energy. Various analyses including sensitivity ones were conducted in order to determine the most promising energy source between these technologies. The outcomes of these analyses indicate that biomass is the most promising option with 52.6%, followed by wind with 27.2%, hydro 12.9%, and solar energy 6,9%.

Keywords.
Renewable energy sources, the South African energy sector, sustainable development, Analytical Hierarchy Process.

I. Introduction

Electricity is the key element in evaluating the welfare of humans and community as a whole. considering this, in order to develop an unbiassed and adequate community, it is important to make sure that the everybody within the current and future generations has an easy and fair access to electricity to achieve their needs. Nevertheless, with a momentous size of the present electricity demand that is being met by means of a restricted means, generally fossil fuels, the current generation are facing several challenges to ensure an easy access to electricity to underprivileged communities as impartially as it might attain in well-off communities [5]. Current's power infrastructure comprising of integrated power infrastructure necessitates a huge amount of capital cost to put into service and, thus, makes it out of the reach of deprived societies. The ability of fossil fuel reserve as well resources that future generations cannot be ensured the extent of welfare that being enjoyed from nowadays' electricity interplay [5, 6, 7, 9]. Furthermore, in relation to energy efficiency, present's approach of producing electrical energy is a significant depletion of a finite reserve, as best-instance conversion efficiency from fossil fuel to electrical energy is under half of the original main power accessible. Thus, we are rapidly consuming the same reserve, which would have lasted twice as long, to the disadvantage of future generations [2, 8, 10]

The [2]; [9] emphasized also by saying that electricity is an important key for day-to-day survival, and in industrialized countries, electrical power is the utmost prevalent energy supplier, distributed to nearly every household and business organization. Producing a steadfast and cheap supply of electricity is vital for the development of any country's economy and the wellbeing of its inhabitants. Since the introduction of electrical energy in day-to-day human activities, it has improved both economic and social well-being, through jobs creation and social services, between urban and rural areas, and improving the overall standard of living [5, 6; 11]. Presently, fossil fuels are the most sources of electricity that are widely used around the world. During the combustion phase of fossil fuels various harmful substances are released within the environment; consequently, the atmosphere is seriously affected, and significantly increase the temperature of the globe and damage the climate [8]. To this end, there has been a growing awareness regarding the effects of substances as well as the exhaustion of natural resources when producing electricity. This awareness, hitched with a growing initiative regarding the sustainability of the power supply system, has led many countries, including the South African government to explore the possibilities for lowering the harmful effects of power generation plants that have over the environment, such initiatives were the implementation of renewable energy sources, as well as nuclear power. However, these two options have not met the expected outcomes as 94% of electricity still generated coal one of the most fossil fuels internationally.

II. The South African Case

The main challenges that the South African electricity sector has been facing over the past decades is to meet the ever-growing electricity demand, and at the same time to make power supply sustainable for the current and future generation [2]. With no doubt electricity is an essential component for the economic and social development. Though power supply system in general has got the reputation of having negative impact over the environment, especially fossils fuels that are the most sources of electricity used globally due to their abundance availability. The management of environmental concerns related to electricity supply system has been one of the important objective of energy policy in accordance with [10]. Followed by rendering electricity development more sustainable at regional and national levels. While, diminishing climate change is a serious energy concern in many countries including South Africa. The issue associated with climate change in South Africa is basically due to its reliance on fossil fuels to generate electricity. To this end, this study proposes renewable energy sources as a roadmap for future electricity generation in South Africa. And also, the study used Analytic Hierarchy Process to select the most promising renewable energy source. This will assist decision makers with a more accurate picture of the trade-offs involved in decisions affecting the electricity utility.

III. Analytic Hierarchical Process (AHP)

AHP is an approach that saw its development in 1970s by Saaty. It is one of Multi Criteria Decision Analysis (MDCA) approach. The acceptance and popularity of AHP has been increasing over the past decades in many studies due to its utility outweighs other rating methods [12]. In 1993, the AHP was accepted by the international scientific community as a reliable and robust MDCA means designed at addressing intricate decision issues [1, 3]. The robustness of this tool lies on breaching the intricate decision problem within a rational way into different trivial, however, associated sub- issues within the form of stages of a hierarchy [4]. The hierarchical structure of the AHP method allows stakeholders to assess and compare the various prioritization criteria and alternatives more efficiently. This approach makes use of a consistency analysis, which check inconsistent decisions. The AHP is based on different steps as presented in the figure below:

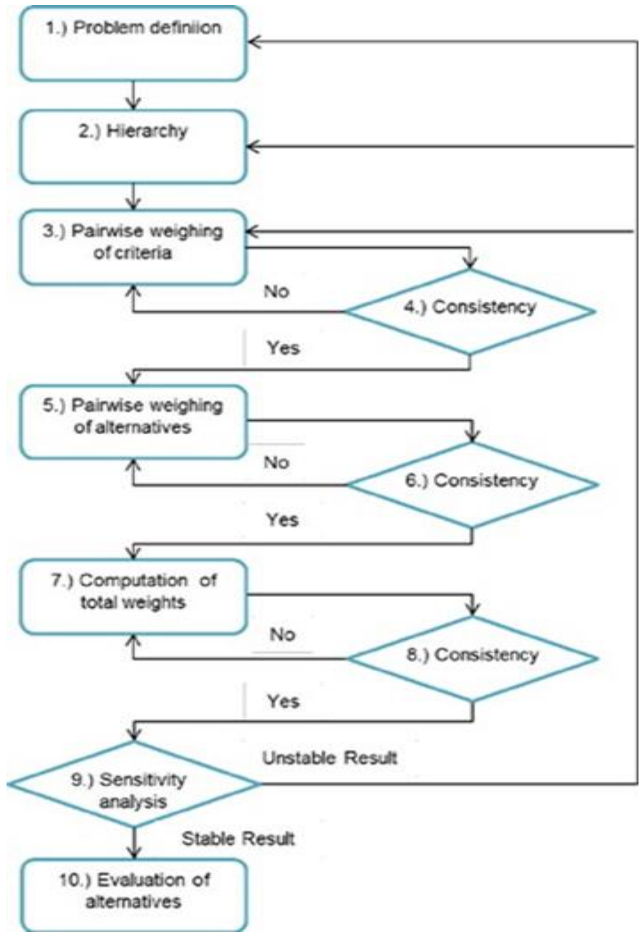

Figure 1. Analytic Hierarchical Process flow chart [12]

The figure above demonstrates different types of steps when conducting the AHP process. In the first stage, the issue and the criteria influencing the main goal must be determined. The problem is organized regarding hierarchy of aim, criteria, sub-criteria, and different alternatives. Whilst, In the second phase of the hierarchy. Pair-wise comparison of altogether factors is performed and the judgments are introduced within a matrix. The Saaty's scale as per demonstrated in the table 1 is employed in this regard. Local priority vector is achieved through normalization of the factors in an apiece column of the matrix of decisions by means of averaging the outcomes in different columns independently and dividing each element of the column by the column averaged value and computing the average over the rows related to the resultant matrix. Afterward, the consistency ratio of the matrix concerning the judgments is calculated to ensure that the decisions made are consistent. Furthermore, step 3 should be echoed regarding all factors within an ensuing stage, however, relating to apiece criteria within the preceding stage. Additionally, the local priorities over the hierarchy to have an absolute priority regarding each alternative are integrated.

Table I. Computation of priorities for each attribute [12]

Verbal judgment	***Numeric value***
Extremely important	9
	8
Very Strongly more important	7
	6

	5
Strongly more important	4
	3
Moderately more important	2
Equally important	1

It should be noted that the benefits of this hierarchical decomposition are well-defined. Through the organization of the problem within this manner, it is therefore feasible to have a deep understanding concerning the judgements to be made, the criteria to be employed and the different alternatives to be appraised. This phase is very critical, and this is where, in more intricate matters, it is feasible to appeal the involvement of various stakeholders and decisions makers to guarantee that all criteria and potential options are taken into account.

IV. Application of AHP to the South African Renewable Energy Sources

In this paper, the AHP approach was carried out by considering the factors such Economic (EC), Environmental (EV), Social (SC), and Technical (TC). The alternatives considered were Biomass (B), Wind (W), Hydro (H), and Solar energy (S). The arithmetical score set up to compare each factor is allocated from the comparisons as presented from table 2 to 12 below:

Table II. Pairwise comparison and normalized matrix

	EC	**EV**	**SC**	**TC**
EC	1.000	3.000	2.000	2.000
EV	0.333	1.000	1.000	1.000
SC	0.500	1.000	1.000	2.000
TC	0.500	1.000	0.500	1.000
Sum	2.333	6.000	4.500	6.000

Table III. Computation of priorities for each attribute

	EC	**EV**	**SC**	**TC**	**Priority**
EC	0.429	0.500	0.444	0.333	0.426
EV	0.143	0.167	0.222	0.167	0.175
SC	0.214	0.167	0.222	0.333	0.234
TC	0.214	0.167	0.111	0.167	0.164

Table IV. Priorities as factors

	EC	EV	SC	TC	Priorities
EC	1.000	3.000	2.000	2.000	0.426
EV	0.333	1.000	1.000	1.000	0.175
SC	0.500	1.000	1.000	2.000	0.234
TC	0.500	1.000	0.500	1.000	0.164

Table V. Computation of weighted sum (WS)

	EC	EV	SC	TC	WS
EC	0.426	0.525	0.468	0.328	1.747
EV	0.142	0.175	0.234	0.164	0.715
SC	0.213	0.175	0.234	0.328	0.950
TC	0.213	0.175	0.117	0.164	0.669

Table VI. Computation of Lambda (XMAX)

WS	Priority	
1.747/	0.426	4.101
0.715/	0.175	4.086
0.950/	0.234	4.059
0.669/	0.164	4.079
	Xmax	4.081

After computing the Xmax, we have calculated the consistency index (CI) and consistency ratio (CR) as follows:

C.I = (4.081-4)/ (4-1) = 0.027 CR = 0.027/0.9 = 0.03
The result indicate that CI and CR are less than 0.1, which means that we have a good level of consistency in comparison evaluations.

Table VI. Comparison and preference of alternatives: Environmental

	B	W	H	S
B	1.000	3.000	7.000	5.000
W	0.333	1.000	2.000	3.000
H	0.143	0.500	1.000	4.000
S	0.200	0.333	0.250	1.000
Sum	1.676	4.833	10.25	13

Table VII. Results in connection with environmental

	B	W	H	S	Priority
B	0.597	0.621	0.683	0.385	0.572
W	0.199	0.207	0.195	0.231	0.208
H	0.085	0.103	0.097	0.308	0.148
S	0.119	0.067	0.024	0.077	0.072

Table VIII. Comparison and preference of alternatives: Economic

	B	W	H	S
B	1.000	2.000	3.000	4.000
W	0.500	1.000	4.000	5.000
H	0.333	0.250	1.000	2.000
S	0.250	0.200	0.500	1.000
Sum	2.083	3.450	8.500	12.000

Table IX. Results in connection with economic

	B	W	H	S	Priority
B	0.480	0.579	0.353	0.333	0.436
W	0.240	0.289	0.470	0.416	0.354
H	0.159	0.072	0.117	0.167	0.129
S	0.120	0.057	0.058	0.083	0.079

Table X. Comparison and preference of alternatives: social

	B	W	H	S
H	0.200	0.167	1.000	4.000
S	0.143	0.333	0.250	1.000
Sum	1.593	5.500	12.250	15.000

Table XI. Results in connection with social

	B	W	H	S	Priority
B	0.627	0.727	0.408	0.467	0.557
W	0.156	0.181	0.489	0.200	0.256
H	0.125	0.030	0.081	0.267	0.126
S	0.089	0.060	0.020	0.067	0.059

Table XII. Comparison and preference of alternatives: technical

	B	W	H	S
B	1.000	6.000	8.000	9.000
W	0.167	1.000	3.000	2.000
H	0.125	0.333	1.000	4.000
S	0.111	0.500	0.250	1.000
Sum	1.403	7.833	12.250	16.000

Table XIII. Results in connection with technical

	B	W	H	S	Priority
B	0.713	0.765	0.653	0.562	0.673
W	0.119	0.127	0.245	0.125	0.154
H	0.089	0.042	0.082	0.250	0.116
S	0.079	0.064	0.020	0.062	0.056

V. Discussion of the Results

In this section, we are going to discuss the results related to the AHP approach applied to the potential South African renewable energy sources. To this end, the second figure will present the results associated with the overall priority as calculated in this study. Whilst, the third figure will present the results from the sensitivity analysis.

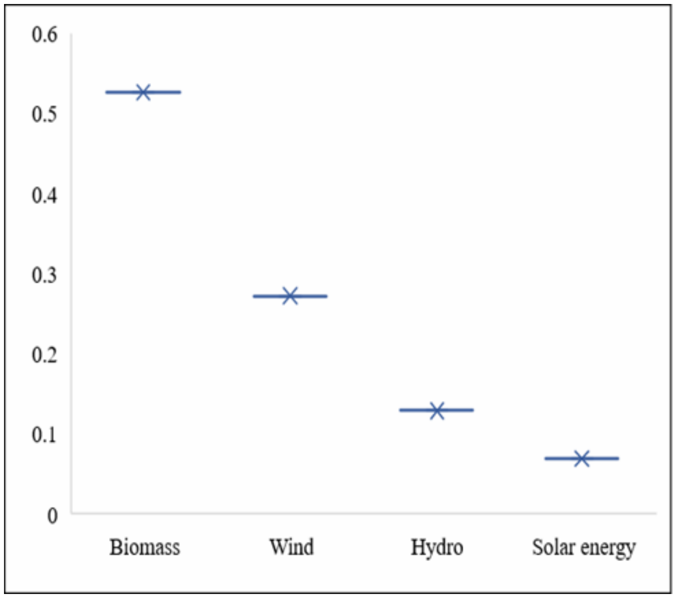

Figure 2. overall priority for each alternative

From the figure 2 above, it can clearly be seen that biomass is the most promising option with 52.6%, followed by wind with 27.2%, hydro 12.9%, and solar energy 6,9%. When computing the priority vector, economic attribute led the raking with 42.6%, followed by social aspect with 23.4%, environmental attribute with 17.5% and in closing technical aspect has had 16.4%.

VI. Sensitivity analysis

It is a known fact that the outcomes of the overall priority as presented in the previous section are mainly affected by the weights allocated to each criterion. Thus, it is important to test the results by means of a sensitivity analysis in order to investigate how the ultimate outcomes would have altered in case the weights of the criteria would have been different. this process assists in understanding how reliable the primary decision and which attribute is influenced the primary outcomes. It should be pointed out that in our study the economic factor has emerged as the most important in terms of priority with 42.6%, followed by social aspect with 23.4%, environmental attribute with 17.5% and in closing technical aspect has had 16.4%. To check the robustness of our results with we have given the same importance of the criteria (0.333) to all the attributes in our case the attributes were; economic, environmental, social and technical.

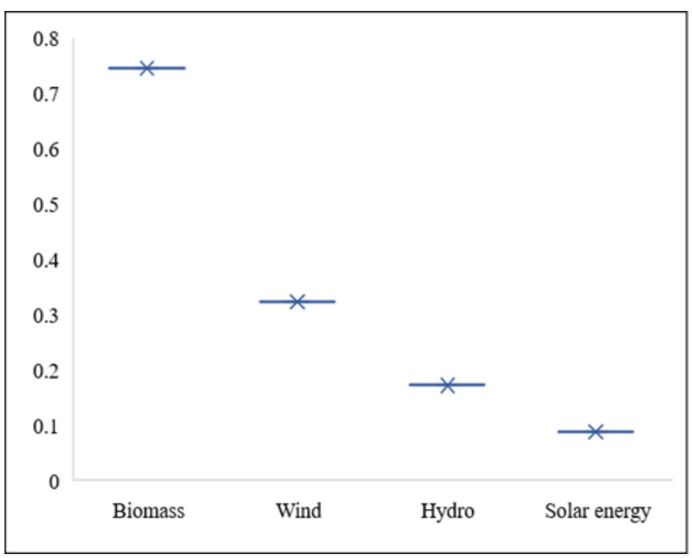

Figure 3. sensitivity analysis results

The figure 3 above displays that though all the attributes were given the same importance of criteria, the raking did not change since biomass technology still leading the raking, followed by wind, hydro, and solar energy. Thus, we can now conclude that biomass is the most preferred and promising renewable energy source in the context of the South African electricity sector.

VII. Discussion and Conclusion

The overall aim of this study was to assist decision makers in the South African electricity sector concerning the selection of the most and promising renewable energy sources. To this end, AHP approach as one of the MCDA was applied to different attributes and alternatives, the attributes include the economic, environmental, social, and technical aspects. While, the alternatives considered were biomass, wind, hydro, and solar energy. From the figure 2 above, it can clearly be seen that biomass is the most promising option with 52.6%, followed by wind with 27.2%, hydro 12.9%, and solar energy 6,9%. When computing the priority vector, economic attribute led the raking with 42.6%, followed by social aspect with 23.4%, environmental attribute with 17.5% and in closing technical aspect has had 16.4%. it is therefore believed that the results of this work will help all the parties involved in implementing policy associated with the electricity production.

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Biography

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