A sustainability analysis of the South African power supply systems by means of the weighted sum method

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Abstract

Energy sector is a key player in the economic and social growth of a nation and to the quality of humans' lifestyle. However, considering the way it is being mined, generated and employed, two serious flows have arisen. Foremost, the whole power supply system has become very ineffective. Secondly, important ecological burdens are generated from the activities linked to the power supply system. Thus, over the last decade, the sustainability assessment of electricity technologies has drawn significant attention from scholars and industrial practitioners. Decision regarding sustainable energy development is based on a wide range of indicators. However, in the context of the South African energy sector, there is a paucity of such wide analysis. Therefore, to bridge this gap, we have made use of the weighted sum method, which is one of the multi criteria decision analysis approach to assess and compare 9 different electricity generating technologies on a basis of 7 sustainability indicators (load factor, the operations and maintenance costs, the costs of producing electricity, greenhouse gases emissions, Sulphur dioxide, oxides of nitrogen; and lead. The results of the assessments demonstrate that off all technologies wind and solar thermal are the most sustainable alternatives in the context of South Africa. Additionally, we have noticed that hydropower and geothermal technologies have the potential to provide considerable sustainability developments over conventional power technologies (coal, gas, and nuclear). Lastly, off conventional technologies coal and gas demonstrate a good sustainability performance than coal in most cases.

Keywords.
Environmental assessment, South Africa energy sector, cost of producing electricity, multi criteria decision analysis.

I. Introduction

Since the mid-1700s, electrical energy has been performing a critical role in the betterment of the human being live. This electricity generating resource – clean, affordable, and secured – is estimated at 37% of the global 's overall energy consumption, with universal electricity demand expected to upsurge sharply in the near future [4]. The United Nations argues that easy access to electrical energy is a driving-factor towards the mitigation of poverty and worldwide inequality [2] [11]. Currently, approximately 82% of total global electricity is being generated from fossil fuel and nuclear energy sources [10]. This is in part associated with the current approaches 'superior properties regarding power density, controllability, and historically, outlay. However, the fuels employed for these kinds of electricity production are mostly non-renewable sources and, therefore, create stern ecological burdens. Fossil fuel production is the main producer of greenhouse gases emissions, uncommon metals, and erstwhile atmosphere pollutants [4] [5] [8]. Nuclear power production plant generates radioactive residue, conveys a hazard of nuclear tragedies [11]. Seizing and stowing carbon underground, together with cautious management of nuclear residue, might assist in mitigating some of these ecological issues within the short term [7]. Nevertheless, the activities related to oil, coal, natural gas, and uranium is expected to increase at several times throughout the subsequent 20 decades, off-putting these alternatives 'expediency within a sustainable future [8] [9] [10].

As mentioned earlier, electricity supply system is a key player in the economic and social growth of a nation and to the quality of humans' lifestyle [1] [5]. However, regarding the way it is being mined, generated and employed, two serious flows have arisen. Foremost, the whole power supply system has become very ineffective. Secondly, important ecological and social burdens, at domestic and international level, are being linked to the electricity supply system. To date, 3 decades ago, the worldwide power sector was approximately 37% resourceful, implying that only a third of the globe's electricity means were transformed into valuable electrical energy [1]. Afterward, developments of the effectiveness related to the worldwide power production life cycle have seen this figure growing to approximately 40%. From the thermodynamics perspective, there are serious flows within the system this denotes that there is need for further enhancement regarding the total effectiveness of the entire power supply system [3]. Numerous ecological and social burdens are often generated throughout the plant operation. The burning, conveyance and removal of electricity generating resources as they are being processed throughout the entire life cycle stages ends in causing detrimental greenhouse gases emissions [6]; [13]. These latter in return cause serious ecological burdens, as well as human health threats. The operations associated with electricity production are also socially unsettling– the construction of several electricity generating plants ends in the displacement of publics and worsens differences between social groups. Lowering the ecological and social issues is therefore a critical matter for the power sector. For example, before the industrial transformation in the United Kingdom, the global's economy was fundamentally dependent on agriculture [11]. The demand for electricity was very insignificant and would be met by means of biomass electricity generating source. Afterward, coal fed industrial development and the modern manufacturing company demand continually brought a change into the worldwide power sector. In the mid-1900, the internal burning engine and the deployment of oil altered the transport sector. As the power and industrial sectors kept growing, the whole electricity sector was transformed greatly. In the ''1970'' a sequence of crises concerning the oil sector severely affected negatively the worldwide power supply system, driving nations to reconsider the efficiency of electricity generation and usage, and to seek other options to fossil fuels. Thus, the thoughts of energy efficiency and renewable energy led to the concept of sustainable energy that is currently broadly acknowledged in global energy discourse. Sustainable development implies meeting the nowadays' needs without compromising the capacity of future generations to meet their own needs [14]. Hence, when sustainable development is defined in the context of power sector, it simply means creating a fair balance between electricity production and use by minimising the negative impact on the ecosystem. To this end, in this paper the weighted sum method, which is one of the Multi Criteria Decision Analysis (MCDA) was used to assess different electricity generating technologies based on eight sustainability criteria.

II. Multi Criteria Decision Analysis (MCDA)

MCDA is defined as an integrated sustainability assessment model. It is a functional appraisal and decision support method designed to address intricate issues starring high vagueness, contradictory ideas, diverse types of data and information, various interests and viewpoints, etc [10]. The MCDA method can offer way out to growing intricate electricity management issues. The conventional solo criterion method is typically meant for determining the most effective alternatives at a low cost. Due to increasing ecological cognizance during the 1980s has to some extent altered the solo criterion decision scaffold [11]. Currently, the focus on worldwide ecological burdens has driven MCDA assist in power supply systems. The MCDA approaches are being extensively used for economic, social, agrarian, manufacturing systems in addition to power supply system [15]. Typically, MCDA encompasses four stages which are:

- Identification of electricity alternatives and key sustainability criteria;
- Compilation of criteria information for each option within an akin format;
- Computing the scores of each indicator; and
- Assigning the preferred indicator weights.

This study considers electrical energy technologies that are presently in use in the South African energy sector and feed the national power grid as portrayed in the figure below:

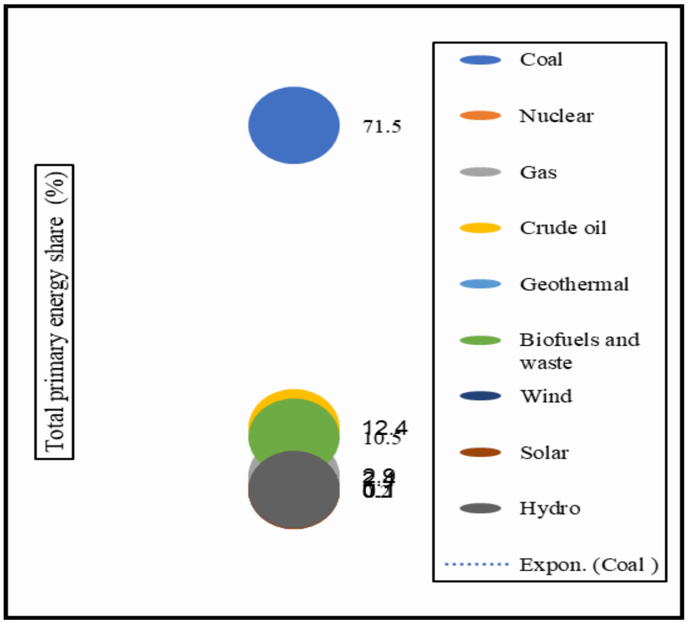

Figure 1. Total primary energy share in South Africa [1]

From the figure 1 above, it can be seen that coal contributes to South African power grid with 71.5%; crude oil is ranked at the second position with 12.4%; followed by biofuels and waste with 10.5%; gas 2.9%; nuclear 2.4%; hydropower 0.2%; wind 0.1%; solar 0.1%; and geothermal 0.1%. In this paper, we used the following equations to compute MCDA scores for each technology as presented in [15]:

$$\beta_{min} = \frac{\beta_i - \beta_{min}}{\beta_{max} - \beta_{min}} \quad (1)$$

$$\beta_{min} = \frac{\beta_{max} - \beta_i}{\beta_{max} - \beta_{min}} \quad (2)$$

$$\begin{bmatrix} k_1 \\ \vdots \\ k_n \end{bmatrix} \times \begin{bmatrix} \beta_{11} & \cdots & \beta_{1n} \\ \vdots & \ddots & \vdots \\ \beta_{m1} & \cdots & \beta_{mn} \end{bmatrix} = \begin{bmatrix} z_{11} & \cdots & z_{1n} \\ \vdots & \ddots & \vdots \\ z_{m1} & \cdots & z_{mn} \end{bmatrix} \quad (3)$$

$$k_f = \frac{1}{\mu} \quad (4)$$

$$k_s = \frac{maximum\ weight}{\mu_p} \quad (5)$$

$$k_o = \frac{1 - maximum\ weight}{\mu_o} \quad (6)$$

Where: m stands for criteria, n electricity technologies, where k is the preferred weights, x stands for the raw scores, and z stands for the weighted scores. Additionally, u stands for the number of criteria; whilst f denotes equal; p is preferred; o is other.

IV. Results

In this section, we analyse the results as calculated with different equations as presented in the above lines.

ANNUAL LOAD FACTOR [16; 17]

Technologies	Annual load factor (%)		
	Minimum	*Nominal*	*Maximum*
Biomass (u=6)	85	85	85
Coal (u=20)	80	85	90
Gas (u=30)	42	85	88
Geothermal (u=7)	73	88	88
Hydropower (u=17)	48	84	91
Nuclear (u=22)	90	90	93
Solar PV (u=36)	19	21	27
Solar thermal (u=12)	33	52	65
Wind (u=91)	25	42	56

ANNUAL OPERATIONS AND MAINTENANCE COST [13; 18]

Technologies	Annual Operations and Maintenance cost (ZAR/kWh)		
	Minimum	*Nominal*	*Maximum*
Biomass (u=6)	0.594	0.689	0.783
Coal (u=20)	0.365	0.378	0.405
Gas (u=30)	0.446	0.473	0.513
Geothermal (u=7)	0.135	0.135	0.311
Hydropower (u=17)	0.067	0.081	0.256
Nuclear (u=22)	0.229	0.243	0.284
Solar PV (u=36)	0.041	0.095	0.594
Solar thermal (u=12)	0.27	0.378	0.459
Wind (u=91)	0.081	0.135	0.324

LEVELISED COST OF ELECTRICITY [1; 13; 17; 18]

Technologies	Levelised Cost of Electricity (ZAR/kWh)		
	Minimum	*Nominal*	*Maximum*
Biomass (u=6)	1.472	1.553	1.647
Coal (u=20)	0.877	0.945	0.999
Gas (u=30)	0.675	0.729	1.121
Geothermal (u=7)	0.743	0.851	0.877
Hydropower (u=17)	0.432	0.688	1.687
Nuclear (u=22)	0.851	1.066	2.201
Solar PV (u=36)	2.052	3.902	5.899
Solar thermal (u=12)	2.214	3.591	4.307
Wind (u=91)	1.134	1.728	3.294

LIFE CYCLE GREENHOUSE GASES (GHG) EMISSIONS [8; 10]

Technologies	Life cycle GHG (gCO2-eq/kWh)		
	Minimum	*Nominal*	*Maximum*
Biomass (u=118)	6	38	46
Coal (u=20)	741	781	1020
Gas (u=42)	312	464	687
Geothermal (u=2)	26	61	106
Hydropower (u=17)	2	8	171
Nuclear (u=61)	6	14	113
Solar PV (u=12)	24	51	186
Solar thermal (u=7)	29	75	75
Wind (u=110)	5	12	47

LIFE CYCLE SULPHUR DIOXIDE (SO2) [3; 7; 9; 11]

Technologies	Life cycle SO2 (mg/kWh)		
	Minimum	*Nominal*	*Maximum*
Biomass	43	493	945
Coal	428	6713	27351
Gas	4	167	328
Geothermal	3	83	163
Hydropower	11	38	63
Nuclear	14	87	160
Solar PV	76	313	561
Solar thermal	38	45	51
Wind	6	49	91

LIFE CYCLE NITROGEN OXIDES (NOX) [1; 4; 6; 10]

Technologies	Life cycle NOx (mg/kWh)		
	Minimum	*Nominal*	*Maximum*
Biomass	294	566	824
Coal	546	3 368	4 241
Gas	103	753	1 410
Geothermal	3	28	53
Hydropower	6	11	16
Nuclear	12	128	243
Solar PV	19	181	343
Solar thermal	57	111	163
Wind	13	46	78

LIFE CYCLE LEAD (PB) [10; 11; 14]

Technologies	Life cycle Pb (mg/kWh)		
	Minimum	***Nominal***	***Maximum***
Biomass	32	57	82
Coal	20	9 213	9 784
Gas	21	79	136
Geothermal	4	29	53
Hydropower	3	16	28
Nuclear	3	7	10
Solar PV	9	311	613
Solar thermal	10	20	29
Wind	4	11	17

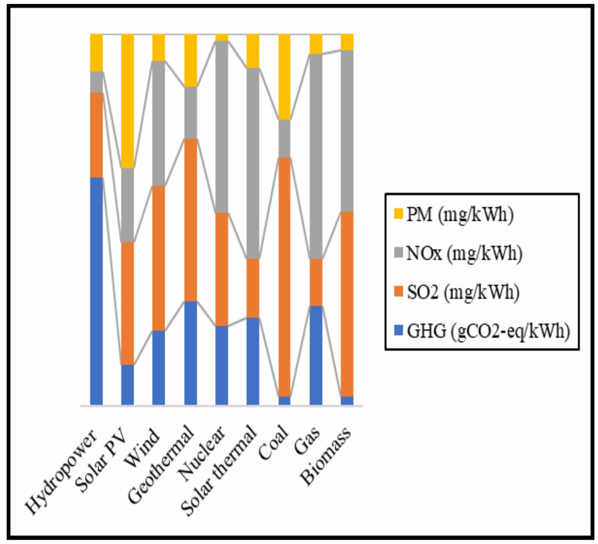

Figure 2. environmental indicators

V. DISCUSSION AND CONCLUSION

Here, will discuss the results as presented in the previous section.

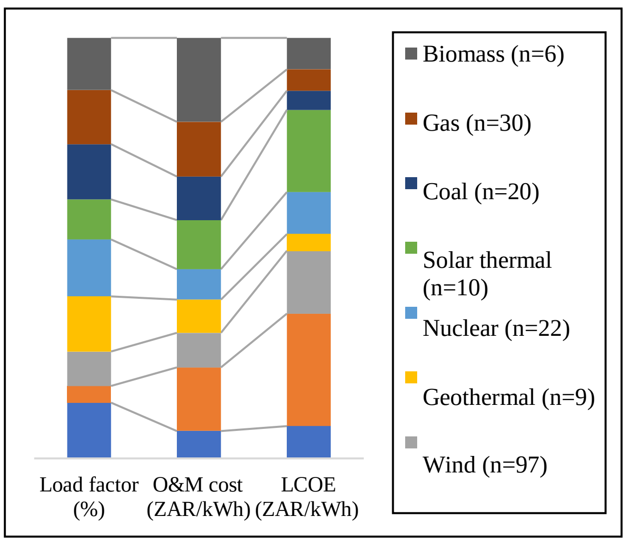

Figure 1. Techno-economic indicators

In this paper, we have made use of MCDA to assess and compare different electricity generating sources, including thermal and renewable energy sources on a basis of 7 sustainability indicators comprising technical, economic, and environmental making use of quantitative minimum, nominal, and maximum values. As far as far as the author is aware this study is the first example in the context of the South African energy sector. To this end, energy policy decision makers may make use of these findings in order to assist in choosing the technology meeting an acceptable set of sustainable development requirements. As it can be seen from the figure 1 and 2, the results demonstrate that off all technologies wind and solar thermal are the most sustainable alternatives in the context of South Africa as a whole. Additionally, we have noticed that hydropower and geothermal technologies have the potential to provide considerable sustainability developments over conventional power technologies (coal, gas, and nuclear). Off conventional technologies coal and gas demonstrate a good sustainability performance than coal in most cases. These outcomes insinuate that policy makers should encourage the adoption and implementation of renewable energy sources. Though, these latter still not competitive to conventional electricity technologies in terms of the load factor and cost of producing electricity. It should be pointed out that the results of our sustainability assessments do not take geographical boundaries into account. Since the results presented in this work are the South African-based and might therefore not be relevant to a worldwide extent. Nevertheless, an akin approach used with whereabouts-particular data might be suitable to decision-making process from a global scale perspective.

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Biography

Ndala Yves Mulongo is currently conducting a PhD degree in the Faculty of Engineering and the built environment, University of Johannesburg. He holds bachelor of engineering in extraction metallurgy and master of engineering in engineering management from University of Johannesburg, South Africa. His research interests involve life cycle approach, cost of electricity production, energy efficiency measures, green supply chain management, impact of mining operations on environment, mineral processing, manufacturing processes.

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