An environmental impact of power supply systems: a comparative analysis Case study of the South African electricity sector

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Abstract

Over the last decade, there has been a growing cognizance concerning the environmental degradation caused by the greenhouse gases emissions release during the production of electricity. This awareness along with the issue surrounding the depletion of natural resources, has led many countries across the world, comprising South Africa to explore the alternatives for mitigating this situation and developing strategies to move away from conventional electricity generating sources towards ‘’low-emissions’’ electricity technologies. However, with the current economic growth and increased of population, ‘’high-carbon emissions’’ electricity technologies are expected to be used for many decades to come, especially in South Africa where roughly 88% of energy are being generated from fossil fuels. Keeping this in mind, this paper aimed at measuring and comparing the environmental impact between coal and biomass-based power plants in the context of the South African energy sector. The assessments were conducted by means of fourteen environmental indicators. The results of the assessments indicate that the coal- fired power plant has significant ecological impacts regarding the global warming, freshwater eutrophication, and fossil depletion categories than the biomass electricity generating source.

Keywords.
Environmental assessment, coal, biomass, South Africa energy sector.

I. Introduction

The deployment of non-renewable energy means is expected to last for several decades in order to support the ever-increasing global people. However, it is important to make use of these means within an effective and efficient manner, which lessens their negative influences over human being health and the ecosystem. Access to adequate provisions of affordable electricity is one of the main requirement for economic growth, and growth is essential for accomplishing the acceptable lifestyle to which several individuals across the world seek. Nevertheless, it is important for policy makers to ensure that both economic growth and improvement of humans’ lives are sustainable.

A largely acknowledged explanation of Sustainable Development (SD) is the one provided in 1987, by the World Commission on Environment and Development (WCED) “the ability of present generation to meet their needs without compromising the ability of future generations to meet their own needs” [1] [2] [4]. To this end, in order to develop sustainable energy decision policy makers should adopt and apply the principles of SD to the power sector. An important principle of sustainable energy is the effective deployment of electricity, society, monetary and natural means. Many nations all over the world are endorsing the concept of SD [9]. The challenge is to conduct appraisals and judgments on various forms of electricity generating sources in the context of SD. Practically, sustainable energy development implies that people health and ecological effects, resource depletion and intergenerational fairness connotations ought to be resolved together with conventional financial and technical matters during the development and employment of electricity generating alternatives. Economic growth and ecological safety ideas must not be viewed equally exclusive, however, must be shadowed as shared and firmly associated objectives. Worldwide worry concerning the extent of ecological deterioration has amplified and community envisages that economic growth must not be shadowed at the cost of deterioration of the Earth's natural means [12].

The production and use of electrical energy cause serious ecological degradation that ought to be taken into account during the decision-making process related to the construction of power plants. The driving-factor to move towards sustainable energy development depends on creating the balance regarding the ecological, financial and social aspects that are viewed the critical sustainability pillars, thus, they should be integrated at the initial phases of project planning, programme development and policy making.

The ecological effects related to electricity generation and consumption should be singled out to deal with and select electricity alternatives and services whilst thinking also about the needs of future generations [3] [12]. Hence, it is crucial to incorporate the ecosystem more efficiently into all phases of power planning and the decision-making process that can assist in making present decisions ecologically careful, financially effective and socially unbiassed, both nowadays and for the coming years [5] [10]. As mentioned earlier, ecological deterioration is a worldwide concern, however, it must be considered on various levels: local, provincial, national and worldwide. To ascertain by what means to meet forthcoming energy supplies, the ecological consequences of several options must be taken into account. All types of energy production technologies, and undeniably all stages of the life cycle are associated with effects, both positive and negative. To this end, this study uses Life Cycle Assessment (LCA) tool to compare the environmental impacts between biomass coal and technologies. In the context of the South African electricity sector.

II. Life Cycle Assessment (LCA)

LCA is a goal process that has been designed with the objective of measuring the environmental problems related to a product, a process, or activity by determining energy and materials employed and wastes discharged into the environment, and evaluation and implementation of initiatives to influence ecological developments [2] [9]. LCA includes four steps as illustrated in the figure 1 below:

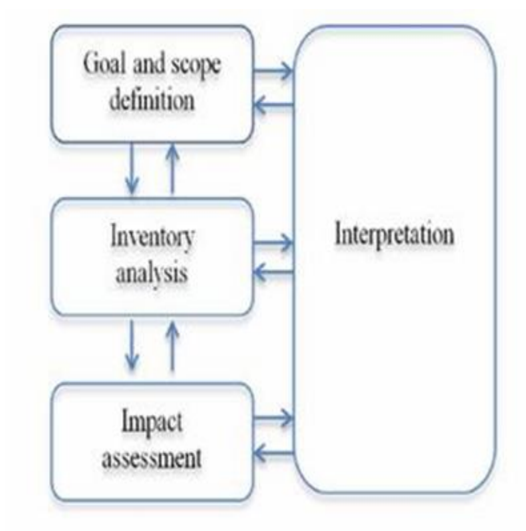

Figure 1. Life Cycle Assessment approach [11]

Over the goal and scope definition phase, all important decisions aim at conducting the LCA study are developed. These decisions should be in line with the envisioned function and comprise the setting of the sequential, terrestrial and industrial margins of the study [8]. Additionally, a functional unit should be determined. It is therefore necessary to point out that LCA is also considered as an iterative method, which enables in redefining the goal and scope with regards to the scrutiny, measurement and the interpretation phase outcomes with the intention of achieving the expected objectives of the study [4] [5] [7]. The more time-consuming stage of the LCA is the inventory analysis that encompasses the compendium and quantification of inputs and yields regarding a specified product system and its mechanisms during its life cycle.

The first reason behind using LCA in order to conduct a comparative risk analysis is to assist the decision policy makers regarding biomass and coal-fired plant with carbon capture, keeping in mind that these two technologies have got the potential to achieve the same desired end. Here, we have taken into account the cleanness of a plant at production stage. Evaluating the ecological burdens linked to various electricity generating technologies by means of the deployment of the LCA approach that enables assessment will allow reliable and fair assessment of these power alternatives. Nevertheless, there is further motive that is as crucial or more crucial: to assist in the understanding of a rare type of risk by comparing, or contrasting, it with a more common type of risk. We performed LCA by making use of a gate to gate method in line with [11] yardsticks. A bottom- up method was integrated with national numerical data concerning product harvest to evaluate the LCI associated with biomass and coal-fired power plants, lessen the ecological burdens throughout the whole life cycle of these power plants, and determining driving-factors for improving the environment. At least three biomass energy generating technologies which were: sewage sludge landfill, MSW landfill, and straw-based energy generating technologies and three coal fired power technologies (sub-critical (400 MW), super-critical (750 MW) were considered in this study.

III. Results

Table I. Environmental assessment results for Biomass-based scenarios

Impact category	Biomass		
	sewage sludge landfill	***MSW landfill***	***Unit***
Fossil	8.05×10^{-2}	8.05×10^{-2}	Kg oil eq
Freshwater ecotoxicity	8.84×10^{-7}	8.84×10^{-7}	Kg 1,4-DB eq
Freshwater eutrophication	6.84×10^{-5}	1.54×10^{-6}	Kg P-eq
Global warming	0.72	6.83	kg CO2-eq
Human toxicity	1.47×10^{-2}	1.47×10^{-2}	Kg 1,4-DB-eq
Land occupation	1.69×10^{-3}	1.69×10^{-3}	m^2a
Marine ecotoxicity	4.46×10^{-5}	4.46×10^{-5}	Kg 1,4-DB eq
Marine eutrophication	7.39×10^{-4}	4.61×10^{-4}	Kg N eq
Metal depletion	3.15×10^{-2}	3.15×10^{-2}	Kg Fe eq
Ozone depletion	1.86×10^{-7}	1.76×10^{-7}	Kg CFC-11eq
Photochemical oxidant	3.19×10^{-3}	3.08×10^{-3}	Kg NMVOC
Terrestial acidification	0.27	1.84×10^{-4}	Kg SO2-eq
Terrestrial ecotoxicity	4.00×10^{-2}	7.56×10^{-4}	Kg 1,4-DB eq
Water depletion	0.21	0.21	m^3

Table 2. Environmental assessment results for Biomass and Coal-based power plants

Impact category	Biomass & Coal		
	Corn straw	***Coal-fired power plant***	***Unit***
Fossil	0.46	0.28	Kg oil eq
Freshwater ecotoxicity	3.78×10^{-5}	7.83×10^{-6}	Kg 1,4-DB eq
Freshwater eutrophication	3.15×10^{-4}	3.18×10^{-5}	Kg P-eq
Global warming	0.72	0.88	kg CO2-eq

Human toxicity	2.36×10^{-2}	2.62×10^{-2}	Kg 1,4-DB-eq
Land occupation	1.27×10^{-4}	2.69×10^{-3}	m^2a
Marine ecotoxicity	6.74×10^{-5}	1.19×10^{-4}	Kg 1,4-DB eq

Impact category	**Biomass & Coal**		
	Corn straw	***Coal-fired power plant***	***Unit***
Marine eutrophication	6.21×10^{-3}	1.19×10^{-4}	Kg N eq
Metal depletion	2.77×10^{-2}	3.68×10^{-2}	Kg Fe eq
Ozone depletion	8.78×10^{-9}	4.31×10^{-9}	Kg CFC-11eq
Photochemical oxidant	1.86×10^{-2}	3.39×10^{-3}	Kg NMVOC
Terrestial acidification	8.42×10^{-3}	4.49×10^{-3}	Kg SO2-eq
Terrestrial ecotoxicity	3.65×10^{-3}	1.56×10^{-3}	Kg 1,4-DB eq
Water depletion	0.74	3.12×10^{-2}	m^3

Table 3. Regularized average results between Biomass and coal power production cases

Impact category	**Biomass**		
	sewage sludge landfill	***MSW landfill***	***Unit***
Global warming	9.01×10^{-5}	7.89×10^{-4}	kg CO2-eq
Ozone depletion	5.46×10^{-7}	1.68×10^{-8}	Kg CFC-11eq
Terrestial acidification	5.76×10^{-3}	3.46×10^{-5}	Kg SO2-eq
Freshwater eutrophication	2.78×10^{-5}	6.16×10^{-5}	Kg P-eq
Marine eutrophication	1.13×10^{-3}	2.37×10^{-4}	Kg N eq
Human toxicity	6.38×10^{-5}	4.21×10^{-3}	Kg 1,4-DB-eq
Photochemical oxidant	3.16×10^{-3}	1.12×10^{-4}	Kg NMVOC
Terrestrial ecotoxicity	1.36×10^{-5}	3.02×10^{-5}	Kg 1,4-DB eq
Freshwater ecotoxicity	$2.14\times 10\text{-}^{5}$	$3.08 \times 10\text{-}^{5}$	Kg 1,4-DB eq
Marine ecotoxicity	3.58×10^{-5}	1.51×10^{-5}	Kg 1,4-DB eq
Land occupation	1.38×10^{-5}	1.49×10^{-5}	m^2a
Metal depletion	5.86×10^{-5}	4.32×10^{-5}	Kg Fe eq
Fossil	5.45×10^{-5}	5.45×10^{-5}	Kg oil eq

Table 4. Regularized average results between Biomass and Coal production cases

Impact category	**Biomass & Coal**		
	Corn straw	***Coal-fired power plant***	***Unit***
Global warming	1.11×10^{-4}	1.78×10^{-4}	kg CO2-eq
Ozone depletion	3.10×10^{-7}	2.66×10^{-8}	Kg CFC-11eq
Terrestial acidification	1.81×10^{-4}	8.66×10^{-5}	Kg SO2-eq
	Biomass & Coal		

Impact category	*Corn straw*	*Coal-fired power plant*	*Unit*
Freshwater eutrophication	8.64×10^{-4}	4.03×10^{-5}	Kg P-eq
Marine eutrophication	8.06×10^{-4}	3.08×10^{-5}	Kg N eq
Human toxicity	2.01×10^{-4}	1.58×10^{-4}	Kg 1,4-DB-eq
Photochemical oxidant	3.03×10^{-4}	1.27×10^{-4}	Kg NMVOC
Terrestrial ecotoxicity	2.22×10^{-4}	1.18×10^{-4}	Kg 1,4-DB eq
Freshwater ecotoxicity	$6.32\times 10\text{-}^{6}$	$5.44 \times 10\text{-}^{7}$	Kg 1,4-DB eq
Marine ecotoxicity	1.91×10^{-5}	1.13×10^{-5}	Kg 1,4-DB eq
Land occupation	3.42×10^{-6}	1.51×10^{-4}	m^2a
Metal depletion	7.31×10^{-5}	2.73×10^{-4}	Kg Fe eq
Fossil	2.45×10^{-4}	1.61×10^{-4}	Kg oil eq

IV. Discussion and Conclusion

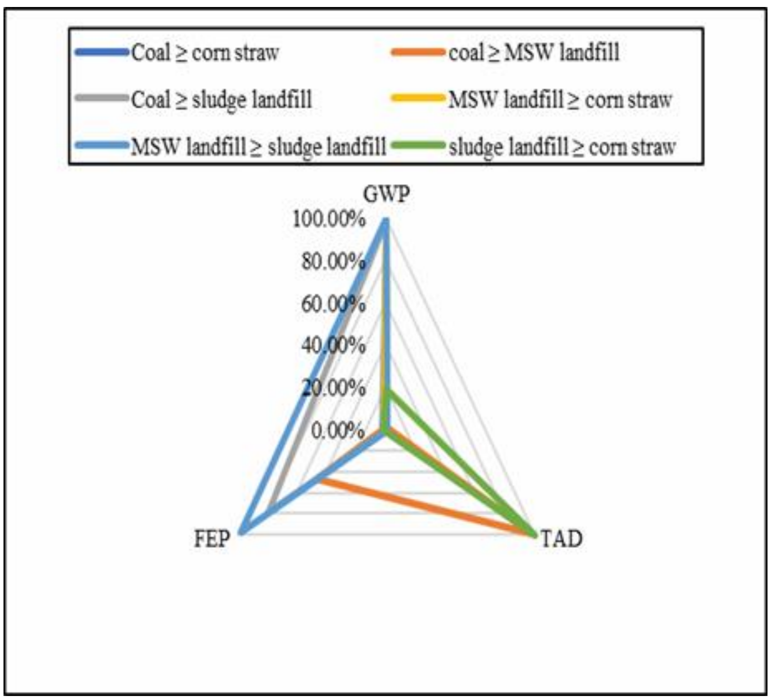

Figure 2. Probability results between biomass and coal power production cases

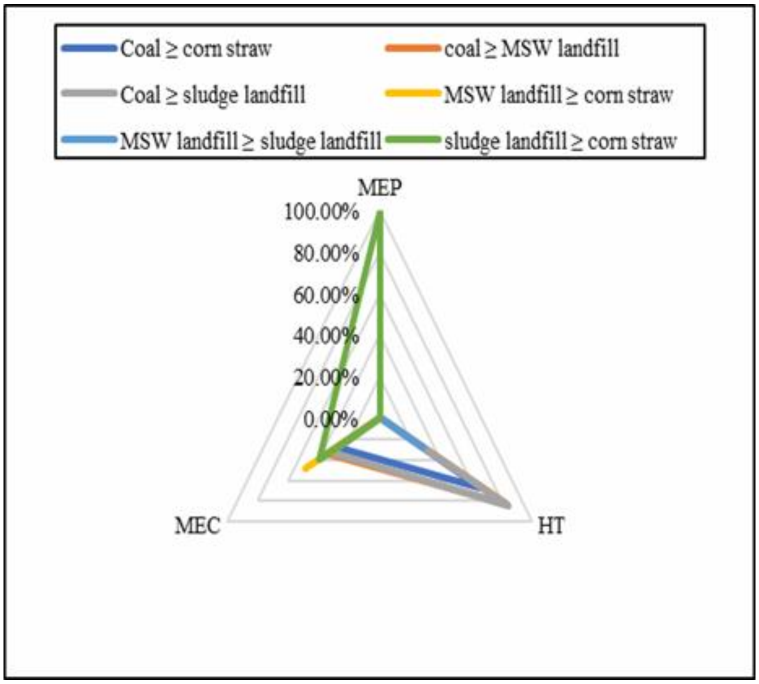

Figure 3. Probability results between biomass and coal power production cases

In this study, we evaluated and compared the environmental impact associated with the coal-fired power plant and biomass electricity generating technology in the context of the South African electricity sector, numerical data were used for this purpose. The results associated with the environmental assessment are presented in the tables (1, 2, 3 and 4) and figures (2 and 3). The results demonstrate that MSW landfills have the utmost effect towards global warming. One possible explanation, it may be due to CO2 generated from methane blazing. Whereas Sludge landfill has emerged to have the uppermost ecological impact over terrestrial acidification and marine eutrophication. The reason maybe as a consequence of NH3 and NOX produced by means of gas emission related to landfill and the transportation of raw material. Additionally, the results display that corn straw considerably impacts on freshwater eutrophication and fossil depletion. This maybe explained due the diesel blazing generated throughout the collection process of corn straw. Furthermore, the outcomes associated with the environmental assessment demonstrate that the electrical energy rated production capacity of corn straw is considerably important than that the one related to MSW and sewage sludge since corn straw is roughly nine times greater in weightiness than that the one associated with sludge and MSW. Furthermore, the results denote that the environmental problem concerning different categories between coal and biomass electricity generating technologies meaningfully fluctuate since the technology and power production efficiency used vary in each case. Particularly, the coal-fired power plant case displays important ecological influences towards global warming, freshwater eutrophication, and fossil depletion categories than in the case of biomass electricity generating source. Nevertheless, the biomass case demonstrates the minimum ecological concern towards the marine eutrophication and marine eco- toxicity categories. Consequently, the biomass power production plants did not demonstrate a considerable generation of ecological issues than the coal-fired power plant case due to the huge volumes of added energy and raw materials used up.

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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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