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# A Life Cycle Assessment Approach to Electricity Generation from Gishoma Peat Power Plant

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*A B S T R A C T*

Electricity is most often generated at a power plant by electromechanical generators, driven by heat engines fueled by combustion. The combustion of peat for electricity generation is one among the energy contributors in Rwanda as Gishoma peat power plant that provides 15MWh. The aim of this paper is to evaluate the life cycle environmental impacts of peat use for energy generation by using the dried peat for combustion at the power plant. Even though electricity is needed in Rwanda as one among the factors that boost the economy and development, the emission comes from peat has a high effect on the environment they considered impacts are global warming potential, acidification potential, and eutrophication potential. The Lifecycle assessment shows that the level of emission gases emitted and at which level those gases are compared to the international standards organization (ISO) then found that carbon dioxide is the gas which is emitted with the high percentage of 80.30% followed by sulfur 11.23% nitrogen oxides of 4.62% and methane of 3.85%. All those emissions have the different impact on the environment as described by the ISO and International Panel on Climate Change (IPCC). According to the result found the quantity of gases emitted are approximate to the level of standard when consider the other gases emitted in the other stage like extraction it can be too high it is necessary to carry the deep analysis of peat from site extraction to the end use of peat in energy generation process.

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## INTRODUCTION

The first developed peat master plan in 1993 showed the potential to generate around 700MW electricity from Rwanda's peat resources. The master plan showed that Rwanda has estimated reserves of 155 million tons of dry peat spreads over an area of about 50,000 hectares. About, 77% of peat reserves are near Akanyaru and Nyabarongo rivers and the Rwabusoro Plains [1]. The Gishoma peat power plant is located in the Western Province, Rusizi District, Bugarama Sector and is nestled within the Nyungwe Forest National Park, 210km southwest of Kigali City by road. Gishoma Peat Power Plant with a net capacity of 15MW was constructed by RUNH Power Corporation Ltd since 2010 but installed along the way. The plant is owned by the Shengli Energy Group, construction of the plant began in 2010; however, it was completed in 2014. The project cost up to $ 39.2 millions, and it was the first of its kind in Africa. Peat is the surface organic layer of a soil, comprising decomposed organic material, derived from plants, that has accumulated under conditions of water-logging, oxygen deficiency, acidity and nutrient deficiency. In temperate, boreal and sub-arctic regions, where low temperatures (below freezing for long periods during the winter) reduce the rate of decomposition, it forms peat from mosses, herbs, shrubs and small trees. In the humid tropics, it forms it from rainforest trees (leaves, branches, trunks and roots) under near high temperature [1, 2]. Peat provides an effective energy source when dried, comprising a minimum of 30% organic matter. It develops under anaerobic conditions where water-logging slows or prevents the decomposition of dead vegetation. As the vegetation grows in the surface layers, it absorbs atmospheric carbon through the process of photosynthesis. When it dies, it stores this carbon in the accumulating substrate which is peat. Peat as an alternative source that can generate the electricity to support Rwanda national grid but it is better to think also to the negative effect that peat power plant has on the environment because peat fuel result in production of carbon monoxide (CO), Sulphur dioxide ($SO_2$), nitrogen oxides ($NO_x$), which considered as air pollution,

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greenhouse gases emission, Ozone layer destruction result in global warming and climate change. It is better to minimize those effects and keep peat power plant working because electric energy is scarce .
The Life Cycle Assessment (LCA) is a systematic analytical method that helps to identify, evaluate, and minimize the environmental impacts of a specific processor competing processes. It uses material and energy balances to quantify the emissions, resource consumption, and energy use (i.e., stressors) of all processes between the transformation of raw materials into useful products and the final disposal of all products and by-products. This paper provides a systematic overview of life cycle assessment approach to electricity generation from Gishoma peat power plant (Figure 1). By looking at how peat can be extracted and used as fuel to generate power with reduced the environmental performance during electricity production.

## MATERIAL AND METHOD

It is the first thermal power plant in Rwanda that uses peat as fuel; it is located at 1.5km from the peatland. It site is approximately 250,000 square meters. Fuel seam thickness is approximately 12 meters, and the reserve is 2.4 million tons meeting the power plant demand fuel. The peat site has been constructed and put into operation and has supplied a small quantity of peat to the surrounding cement plant. It estimates the annual production capacity to be approximately 250,000 tons. The units adopt a condensing steam turbine generator they will supply no outwards steam supply and all power generated to the national grid. The power plant uses 75 tons per hour to generate the power which is 15 MW at high temperature with one steam generator. The moisture content at a harvest (wet basis) is 80%. Moisture at combustion (wet basis) is 35% and Thermal efficiency is 83.3%. The current regulatory framework for LCA is defined by ISO 14040 and ISO 14044 [3, 4]. It generally carries a LCA study out by iterating four phases (goal and scope definition, it) and uses inventory analysis, impact assessment, an interpretation to quantify major potential environmental impacts related to the product. A LCA technique used to assess environmental impacts associated with all the stages of a product's life from raw material extraction through materials processing,

Figure 1. Gishoma peat power plant (captured and edited by author)

manufacture, distribution, use, repair and maintenance, and disposal or recycling. LCAs can help avoid a narrow outlook on environmental concerns by compiling an inventory of relevant energy and material inputs and environmental releases, evaluating the potential impacts associated with identified inputs and releases and interpreting the results to help make a more informed decision. The dried storage of Gishoma Peat shed is shown in Figure 2.

### Types and source of data

Collecting good data was the foundation on which you gather evidence and make sense. It used two general types of data in this study. Quantitative data were any information you can measure and Qualitative data were any information about quality. It's information about how people feel about Gishoma peat power plant. Someone collected the engineering data, environmental data and meteorological data Gishoma peat fired plant. The baseline of peat power plant assessment is summarized in Table 1. The emission quality generated by combustion of peat power plant is summarized in Table 2.

### Meteorological data

The climate in Rwanda is temperate with two dry seasons. The first one from June to September /October and the second from January to February. It expects peat harvesting to take place during these periods known as dry seasons. The rainfall in wet seasons are shown in Figure 3; we see that in the period of January up to the end of March it can extract the peat because the rain is considerably low. from starting of the April, are in the rain season where the quantity of rain is too high about 190 mm, in that period there is no harvesting of peat, from the month of June up to the end of September the rain quantity is too low the harvesting extraction continue then from October up to end of December there is no harvesting. The working period is about seven the other is resting because the rain is too high.


Figure 2. Gishoma peat shed (captured and edited by author)

**TABLE 1**. Baseline of peat power plant assessed

| Parameters | Quantity/hour | Unit cost | Total cost |
|---|---|---|---|
| **Engineering data** | | | |
| Peat burned per hour | 17.632 tonne/h | 273672.5 Frw | 407651.84 Frw |
| Water | 12200 $m^3$/h | 323 Frw/$m^3$ | 39406Frw |
| Natural diesel | 800 kg or liter | 1224.827fw/l | 979856 fw/days |
| Energy generated capacity | 15000kwh | 182 Frw/kwh | 2730000 frw |
| Net energy supplied | 13000kwh | 182 Frw/kwh | 182 Frw/kwh |
| Energy Consumed | 2000 kwh | 182 Frw/kwh | 364000Frw |
| Thermal Efficiency | 83.3% | - | - |
| Peat annually harvested | 2500000tonnes | - | - |
| Moisture at harvest (wet basis) | 80% | - | - |
| Moisture at combustion (basis) | 45% | - | - |

**Environmental data**

| Parameters | Quantity/Unit |
|---|---|
| Ash disposal | 2.5 t/h |
| Fluxes rates ($CO_2$) | 2.5t/h |
| Methane ($CH_4$) | 45 kg/h |
| Sulfur dioxide ($SO_2$) | 77 kg/h |
| Waste (slag) | 1.7 t/h |

**TABLE 2**. Emission quantity

| Measurement parameter | Value for $CO_2$ | Value for $NO_x$ | Value for $SO_2$ |
|---|---|---|---|
| Gas pressure | 190 Kpa | 18.523 Kpa | 16.505 Kpa |
| Gas temperature | 290.65 K | 240.5 K | 193 K |
| Gas volume flow rate | 0.029835 $m^3$/s | 0.0215 $m^3$/s | 0.022 $m^3$/s |
| Gas compressibility | 0.9905 | 0.9958 | 0.9942 |
| Gas fraction | 1 mol/mol | 1 mol/mol | 1 mol/mol |
| Molecular weight | 44 | 30 | 64 |
| Ideal gas constant | 8.3144 J/mol *K | 8.3144 J/mol *K | 8.3144 J/mol *K |
| Burner conversion efficient | 1 | 1 | 1 |
| The obtained quantity of gases | 104.2 g/h | 6 g/h | 14.56 g/h |

This affects the power plant in case of electricity generation because of the main fuel source become scarce and in case of the economy of the plant because there are workers who assigned contract for a period of years the still get paid even though the power plant is not According to the plan taken to solve that issue, there is an ability to put many extraction machines in peatland so running and other workers who doesn't have contract get rest and they come back in the period of the running. they extract a huge quantity of peat and dry it in all dry season then store so it can help them cover the non-working period due to scarcity of the peat fuel. Flowchart of electricity generation from Gishoma peat power plant is shown in Figure 4.

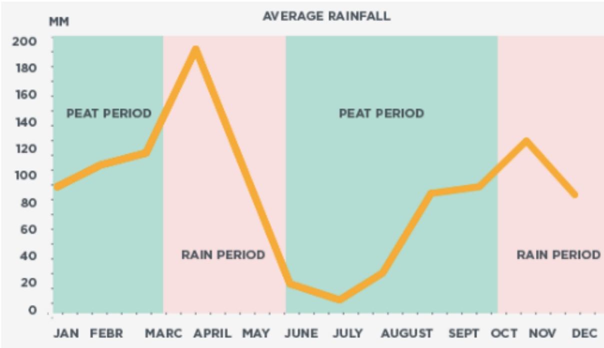

Figure 3. Rainfall rate in Rwanda

## Life cycle assessment of electricity generation from peat

It bases the focal point of the study of the emission of greenhouse gas (GHG) in electricity generation through combustion, which influences global warming. There are many gasses emitted from the peat combustion that has a high potential for global warming, but this potential is different for each gas. To add up all these potentials. It relates the global warming potential (GWP) of a substance to the GWP of carbon dioxide. Methane, for instance research has shown that has about 20- 23 higher GWP than carbon dioxide but most peat about 60% have 20.8. Since on the power plant there is no measure to measure the methane gas emitted, we prefer to use the characterization factors as 20.8 to find the estimate of methane. It means that when considered 1kg of methane and 1kg of carbon dioxide, the result of GWP is equivalent to 20.8kg of carbon dioxide denoted as $CO_2$ equivalent [5]. The impacts considered in our study are

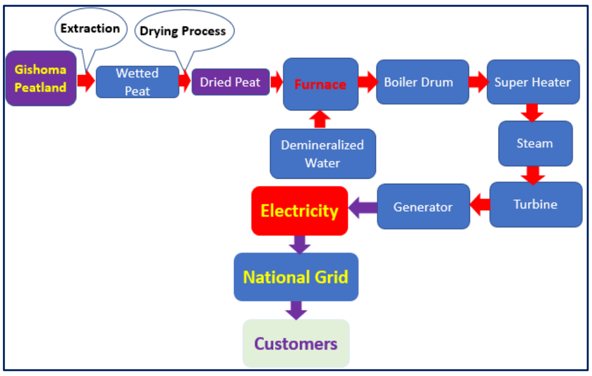

Figure 4. Flowchart of electricity generation from Gishoma peat power plant

The global warming, Acidification, Eutrophication and Solid waste or particulate matter (ash). Once impact categories are chosen for a LCA study, the next step is to link life Cycle inventory parameter to corresponding impact categories based on the Cause-effect relationship. The Functional Unit for this LCA Study is defined as 54,000MJ of electricity is delivered from 17.632 tons of peat per hour, of a 15MW peat power plant.

## RESULTS AND DISCUSSION

The predicted emissions measurements method requires measurements of the $CO_2$ concentration and the volume flow rate of the flue gas in the stack using a continuous emission monitoring system (CEMS). The measurements for this method are post-combustion and are therefore direct measurements of the $CO_2$ [6]. This method is hereafter referred to as direct emissions measurements. It can drive the $CO_2$, $NO_x$ and $SO_2$ from the following expression, where the parameters are defined in Table 2.

$$\dot{M}_{gas} = (P * \dot{X} * X_{gas} * \eta_{gas} * Mm_{gas})/(R * T * Z_{gas}) \quad (1)$$

where

$\dot{M}_{gas}$: mass rate of the gas emitted $\eta_{gas}$: burner conversion efficiency

P: pressure gas

R: ideal gas constant

$\dot{X}$: gas volume flow rate

T: temperature of gas

$X_{gas}$: gas fraction

$Z_{gas}$: gas compressibility

Mmgas: molecular weight of gas

Emissions estimates occurred in the peat power plant which can generate 15 MWh are based on the temperature, pressure of gas emission and the volumetric flow rate of the gas. Using Equation (1), it becomes easier to get the quantity rate of the gas emission

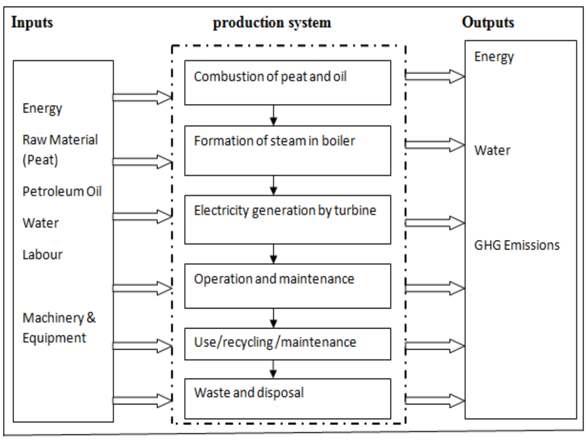


Figure 5. Schematic presentation of the system boundary and the main inputs and outputs Life cycle impact assessment methodology

The mass rate of $CO_2$= (191.857*1*1*0.029835*44)/(0.9968*290.65* 8.3144)

= 104.2 g/h

The mass rate of NOx = (18.523* 1*1*0.0215*30)/(0.995* 240.5*8.3144)

= 6 g/h

The mass rate of $SO_2$= (16.505* 1*1*0.022*64)/ (0.942* 193*8.3144)

=14.56g/h

In Table 3 burning conversion efficiency is a unit because it was assumed that it burns all input quantity, of the gas fraction don't have exact ratio of gases as CO and $CO_2$, $NO_2$ and $N_2O$ that why it was taken as also a unit. About the CH4 it has seen the possibility to be expressed in a term $CO_2$eq (equivalent carbon dioxide). The range of equivalent is between 20-28 depend on the quality of peat used as fuel but 60% of peat in Africa have 20.8 as equivalence as showed by Quick, 2014. Carbon dioxide emission tallies for 210 U.S. peat-fired power plants, it means that 1g of $CH_4$ has 20.8g of $CO_2$. The quantity of $CH_4$ is obtained as the emission of $CO_2$ divided 20.8 as equivalent factors.

## CONCLUSIONS

The peat power plant produces electricity as required energy needed to boost the national economy and development of the country but the green houses gases produced which are harmful. There is some strategy minimizes some of them like $NO_x$ emissions, for the case of peat combustion some catalytic reduction is necessary.

**TABLE 3.** The relation of the emission measured from field to the standard emission specified by ISO

| Emission gas | Impacts Categories | Quantities measured | Percentage emission | Total measured for 15 | Standard Quantities (g/MJ) |
|---|---|---|---|---|---|
| $CO_2$ | GWP | 104.2 g/h | 80.30% | 5617080 | 106 |
| $CH_4$ | GWP | 5 g/h | 3.85% | 270 | 8.7802 |
| $NO_2$ | Acidity | 6 g/h | 4.62% | 324 | 10.999 |
| $SO_2$ | Acidity | 14.56 g/h | 11.23% | 77000 | 20 |

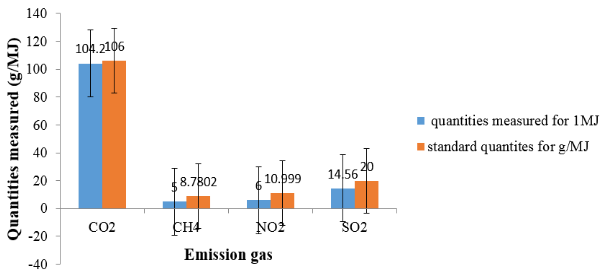


Figure 6. Comparison diagram of field data and standard data

**TABLE 4**. Social assessment data

| Names | Quantity | Risk level | Working hours | Observation made |
|---|---|---|---|---|
| Child employment | 0% | No risk | 8h | The person under 18 are not allowed |
| Force labour | 15% | Very low | 8h | The job require physical effort are few compare to the task handled by machine |
| living wage per month | 20000 frw | No risk | | The accommodation is not on high cost |
| Minimum wage per month | 40000 frw | Very low | - | |
| Labour average wage per month | 74375 frw | No risk | | The salary isenough and accommodation is low cost |
| Weekly hours per employment | 38h | - | 38h | Those maximum working hours per worker in week |
| Gender | 20% | High risk | 8h | The number of women is lower compare to men |
| Health and safety (workers) | 75% | Very low | h | Workers have safety equipment and insurance |

The catalyst reduction for $NO_x$ removal is the process which can help in emission reduction with better efficiency assumed 78% based on International, 1989 and U.S. EPA, 1992. The catalytic reduction can be used to reduce flue gas $NO_x$ emissions from power plants. In this process, ammonia ($NH_3$) is injected into the gas stream before the gas leaves in the stack. The ammonia reacts with the $NO_x$ in the presence of a catalyst to form water vapor and nitrogen. The chemical reaction can be represented as:

$$4NO+4NH_3+O_2 \rightarrow 4N_2+6H_2O \quad (2)$$

the catalyst must be added monthly for better control. In general, catalyst promotes the conversion $SO_2$ formed in emission from peat to $SO_3$ in the presence of $O_2$. The $SO_3$ can then react with any residual NH3 to form ammonium sulfate which will form solid waste then become easy to recuperate. About the carbon dioxide $CO_2$, there is the category of emission which is direct and indirect. In direct effect, greenhouse emissions are produced at the plant while the indirect manner the emission is associated with the processing like site extraction. During a field visit to a data collection process was carried out where we found out that for the case of Gishoma power plant various gases including GHG are emitted from the plant. However, the levels of gas emitted at Gishoma are still below the ISO Standards maximum values, which are a good sign of environmental management design.

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**Persian Abstract**

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**چکیده**

برق اغلب در نیروگاه توسط ژنراتورهای الکترومکانیکی بوجود می آید که توسط موتورهای حرارتی بوسیله احتراق بوجود می آیند. احتراق ذغال سنگ برای تولید برق یکی از منابع انرژی در رواندا به عنوان نیروگاه توریستی گیشما است که ۱۵ مگاوات ساعت را تامین می کند. هدف از این مقاله ارزیابی چگونگی اثرات زیست محیطی استفاده از ذغال سنگ برای تولید انرژی با تمرکز کردن ذغال سنگ ذغال سنگ به منظور احتراق در نیروگاه می باشد. گرچه برق در رواندا به عنوان یکی از عواملی است که اقتصاد و توسعه را افزایش می دهد، برق مورد نیاز از نوعی ذغال سنگ تورب تاثیر زیادی بر محیط زیست دارد که تاثیرات آن را در بر می گیرد، پتانسیل گرم شدن کره زمین، پتانسیل اسیدی شدن و پتانسیل تخریب آب است. ارزیابی چرخه حیات نشان می دهد که میزان انتشار گازهای خروجی و در چه سطحی، این گازها با سازمان استاندارد بین المللی (ISO) مقایسه می شود و سپس ما دریافتیم که دی اکسید کربن گاز است که با درصد بالایی از ۸۰/۳۰ ٪ و پس از آن گوگرد ۱۱/۲۳ اکسید نیتروژن ۴/۶۲٪ و متان ۳/۸۵٪. همه این گازهای آلاینده انتشارآنها تاثیر متفاوتی بر محیط زیست دارند، همانطور که توسط ISO و International Panel on Climate Change (IPCC) توصیف شده است. با توجه به نتایج حاصل شده، مقدار گازهایی که در معرض انتشار قرار می گیرند، تقریبا به سطح استاندارد می رسد، زمانی که گازهای دیگر در مرحله دیگر مانند مرحله استخراج در معرض دید دیگر قرار می گیرند، می تواند خیلی زیاد باشد. تجزیه و تحلیل عمیق ذغال سنگ از استخراج به پایان استفاده از ذغال سنگ در فرایند تولید انرژی رسد.