SUSTAINABILITY IMPACT ASSESSMENT OF UTILIZING SYNTHESIS GAS IN HOUSEHOLD GENERATORS FOR ELECTRICITY GENERATION

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CERTIFICATION

This is to certify that the project titled:” SUSTAINABILITY IMPACT ASSESSMENT OF UTILIZING SYNTHESIS GAS IN HOUSEHOLD GENERATORS FOR ELECTRICITY GENERATION” was carried out under the supervision of Engr Dr. P.E Akhator.

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DEDICATION

We dedicate this project to God Almighty for His love and infinite mercies He has shown towards over the course of this project and in our lives as a whole and we also dedicate this project to our supervisor Dr. Akhator for his guidance over the duration of this project.

ACKNOWLEDGEMENT

We want to thank and sincerely appreciate everyone who in one way or the other contributed to the success of this project, from our supervisor, Engr. Dr. P.E Akhator, to course mates who inspired us and chipped in words of wisdom from time to time.

Much gratitude to our friends and families for their unceasing emotional support, we say thank you. Thanks be to God also, for we could not achieve this without Him.

ABSTRACT

Sustainability impact assessment is a tedious exercise to determine if a project is worthwhile by subjecting it to different methods of analysis. In this project, an assessment was conducted on utilizing synthesis gas as a substitute to conventional fossil fuels such as gasoline, for household power generation.

The methods embarked on in the course of study included the Life Cycle Analysis, Techno-Economic Assessment, and Cost Benefit Analysis. Global warming potential (GWP) of utilizing syngas was checked for and it was seen that it was gotten to be 0.111kg CO_2 equivalent and its acidification potential is 4.4E-4kg SO_2 equivalent and human toxicity potential is 8.86E-2kg, 1-4 DB equivalent. It showed promise of being an eco-friendly method of power generation. In regards to the economic assessment, it was found that the Levelized Cost of Electricity was ₦34.009/kWh and this is seen definitely as a cheaper option than that offered by the current distribution rate seen in the country. The NPV as at the end of 20 years was seen to be -₦157,606.95. Methods of reducing this and making it a positive value was also explored. This included reducing the cost of Operation and Maintenance by 30% and the Biomass cost by 40%. In summary, synthesis gas has a very exciting future in the process of power generation. The findings offer scientific proof for the design and deployment of the hybrid technology to improve energy security, while reducing carbon emissions. Overall, this study brings to light the potential benefits of biomass energy systems and encourages the implementation of sustainable practices regarding energy for a greener future.

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INTRODUCTION

1.1 BACKGROUND TO THE STUDY

Synthesis gas, or Syngas, is a fuel gas mixture consisting of primarily hydrogen, and carbon monoxide. It is a product of gasification that can be obtained from origins such as natural gas, biomass, coal, or basically any hydrocarbon feedstock, by reaction with oxygen (partial oxidation), carbon dioxide (dry reforming), or steam (steam reforming). Originally, such mixtures were obtained by the reaction of steam with incandescent coke and this came to be known as “water gas”. (Reyes, SC., Sinfelt, JH. and Feeley, JS. 2003, pp. 1588-1597) Eventually, steam reforming processes, where steam is chemically combined with natural gas (methane) or petroleum naphtha over a nickel catalyst, found extensive application for the production of synthesis gas. There are mainly three main technologies for conversion and utilization of biomass, physical conversion, thermochemical conversion, and bioconversion. Compared with bioconversion, thermochemical conversion has the advantages of a high conversion rate, fast reaction rate, and good industrial application. It includes combustion, pyrolysis, gasification, and liquefaction, etc., among which gasification is the most practical one for the high-grade utilization of biomass.

Gasification products can be used for the synthesis of chemical products or partially substituting fossil fuels to generate electricity and heat. Gasification offers an alternative to more established ways of converting feedstocks like coal, biomass, and some waste streams into electricity and other useful products. The study of utilizing biomass/biofuels is very crucial due to the rise of prices in fossil fuels and the danger said fossil fuels pose to the environment. Cleaner and renewable energy is much needed in the world and more so in this modern era we find ourselves. The use of municipal solid waste from any source, including household waste, classrooms, restaurants, etc. makes access to materials far easier to come by and quite cheap.

Sustainability Impact Assessment is an exercise to evaluate the environmental, social, and economic impacts of a project or activity to ensure it aligns with sustainable practices and goals. It is a process that helps to identify potential risks and opportunities for sustainable development. This assessment is used in the guiding decision-making and long-term feasibility. The use of synthesis gas in households in Nigeria will help combat improper waste disposal as waste would be properly recycled and utilized to obtain a product, hence, purifying the environment.

1.2 STATEMENT OF THE PROBLEM

According to a survey done by Stears and Sterling, released in June 2022, titled, "Nigeria's State of Power: Electrifying the Nation's Economy", it estimated that over 40 percent of households in Nigeria own and use generators to meet their electricity requirements, showing that an annual expenditure of $14bn is being incurred by those same households. The prices of PMS (Premium Motor Spirit) have skyrocketed in that time making it far harder for households in Nigeria to afford to acquire fuel for movement and talk less of energy to power businesses and the common household.

According to WRI CAIT data, Nigeria's Greenhouse Gas emissions increased by 25% (98.22 MtCO2e) from 1990-2014. As of 2022, carbon emissions from the power sector in Nigeria reached around 11.8 million metric tons of carbon dioxide equivalent. There is a carbon emission problem in the world and it is paramount to reduce our carbon quota as a country by using greener measures that enhance the environment. The adoption of synthesis gas in the household will be a breakthrough in further reducing the CO_2 emissions plaguing the world.

According to a study done by Charles Mba in May 2020, it was seen that Nigeria generates 4.3 million units of 3000W, enough for just 10.75 per cent of all households. According to a report released by The International Renewable Energy Agency, IRENA, in conjunction with the Energy Commission of Nigeria, in 2023, it was revealed that Nigeria is the highest importer of Premium Motor Spirit (PMS) and diesel generators. In concordance with this report, the India-based P&S Intelligence released a report in 2023, stating that the diesel generator market is projected to reach $806.8million by the year 2030. The Nigerian market poses as a wonderful opportunity to generate revenue by providing affordable and renewable sources of electricity

1.3 AIMS AND OBJECTIVES

1.3.1 AIM

This study aims to perform a sustainability impact assessment of utilizing synthesis gas in a household generator for electricity generation.

1.3.2 OBJECTIVES

Specifically, the objectives are to:

1. Identify and assess the environmental impacts of utilizing synthesis gas in household generators. These environmental impacts include air and water quality, greenhouse gas emissions, and land use.
2. Assess the social impacts of using syngas to power households, such as public health, safety, and community well-being.
3. Assess the impact on the economy. This includes the costs and benefits of this technology, as well as its potential impact on local and national economies, Nigeria's economy in particular.

1.4 SCOPE OF THE RESEARCH

The assessment will focus on aiming to inform sustainable energy solutions in Africa, this research analyzes the environmental, social, and economic implications of syngas generators for household electricity generation in developing countries.

1.5 METHODOLOGY

The methodology for this project will involve the following steps:

1. Literature review: A comprehensive review of the existing literature on the sustainability impacts of syngas-based household generators will be conducted. This will include peer-reviewed journal articles, government reports, and industry publications.
2. Data collection: Data will be collected from a variety of sources, including national and international databases, government agencies, and syngas producers and distributors.

3. Life cycle assessment (LCA): An LCA will be conducted to quantify the environmental impacts of syngas-based household generators throughout their entire life cycle.
4. Technoeconomic analysis (TEA): This is an approach for conducting process design and simulation, informed by empirical data, to estimate capital costs, operating costs, mass balances, and energy balances for a commercial-scale biorefinery.
5. Cost-benefit analysis (CBA): A cost-benefit analysis will be conducted to compare the costs and benefits of syngas-based household generators with conventional electricity generation options.
6. Sensitivity analysis: A sensitivity analysis will be conducted to assess the uncertainty in the assessment results.

The specific methods used for each step of the assessment will be tailored to the project's specific circumstances.

1.6 RELEVANCE OF THE STUDY

It is common knowledge by now that Nigeria suffers from severe power generation issues. A report released in March 2023, by the Society for Planet and Prosperity, GCA Capital Partners, and Climate Advisers Network showed that about 75% of electricity consumed in Nigeria comes from diesel and petrol-powered generators, with over 40% of households relying on generators. These petrol/diesel-powered generators, although very vital, also have adverse effects on the nation and the planet at large, such as air pollution, carbon footprint/greenhouse effect, high flammability, and cost. Synthesis gas is a better alternative to fossil fuels for household electricity generation as it is renewable, has lower emissions, and is more versatile and efficient. By assessing the utilization of syngas in generators to power homes, this work will contribute to understanding its impact on all spheres of life as an alternative to fossil fuels in household generators.

CHAPTER TWO

LITERATURE REVIEW

2.1 WHAT IS SYNTHESIS GAS?

Synthesis gas, commonly referred to as "Syngas", is a broad word frequently used to describe the unprocessed gas generated from feedstock that contains a range of different components. Synthesis gas, also known as syngas, is composed of hydrogen, carbon monoxide, carbon dioxide, methane, nitrogen, water vapours, and other hydrocarbons and condensable molecules. When combined, these components produce a synthetic form of natural gas. Synthesis gas, also known as syngas, is widely utilised in various processes such as fermentation and pyrolysis. It is highly regarded as an environmentally friendly method for generating power. Synthesis gas is generated through the gasification of waste items, offering organisations the opportunity to establish an on-site power plant.

In 1780, Felice Fontana made the discovery that when water vapour is exposed to carbon at temperatures exceeding 500°C, it produces flammable gas. The gas combining CO and H_2 was referred to as "water gas" and mostly utilised for lamination applications throughout the 1800s. At the beginning of the 20th century, H_2/CO mixtures were utilised for the production of hydrocarbons, thereby earning the name synthesis gas. In 1910, Haber and Bosch made the groundbreaking discovery of synthesising ammonia from hydrogen (H_2) and nitrogen (N_2). Subsequently, in 1913, the first industrial factory for ammonia synthesis was established. In 1923, Fischer and Tropsch made the discovery of converting syngas into liquid hydrocarbons and oxygenates using iron catalysts. (Abbas, Ibrahim, & Hameed, 2014). Eventually, steam reforming techniques, where steam is reacted with natural gas (methane) or petroleum naphtha over a nickel catalyst, found wide application for the generation of synthesis gas (Reyes, SC., Sinfelt, JH. and Feeley, JS. 2003, pp. 1588-1597). There are essentially three main technologies for conversion and consumption of biomass, physical conversion, thermochemical conversion, and bioconversion. Compared with bioconversion, thermochemical conversion has the advantages of a high conversion rate, fast reaction rate, and good industrial application. It includes combustion, pyrolysis, gasification, and liquefaction, etc., among which gasification is the most feasible one for the high-grade exploitation of biomass.

2.1.1 SYNGAS PROPERTIES

All types of products have some properties that are paramount to its functionality, and the same applies for synthesis gases too. These major properties are the following:

- Syngas flammability limits
- Laminar flame velocity

SYNGAS FLAMMABILITY LIMITS

The flammability of synthesis gas is mostly reliant on its ingredients, i.e., the composition of the combination gases. It defines the range of concentration of the fuel in a fuel-air mixture at a specific temperature and pressure that allows the ignition-initiated flame to propagate and maintain. This feature is mainly controlled by the composition of the fuel, direction of propagation, size and shape of the combustion chamber, temperature and pressure (Kutcha, 1985). The flammability limit is separated into the following limits: Lower Flammability Limit (LFL), and Upper Flammability Limit (UFL); they show the minimum and maximum fuel concentration in the fuel-air combination accordingly. Due to the fact that hydrogen and carbon monoxide are the main combustible elements of syngas, syngas acquires the typical properties of these gases.

A flammability limit for a mixture of gases is established from experiment (Heywood, 1998; Fossum and Beyer, 1998). It can be determined also with the aid of Le Chatelier's law using the following equation (Bjerketvedt et al., 1997, Hristova and Tchaoushev, 2006):

$$\mathrm{LFL}_{\mathrm{mix}} = \frac{100}{\frac{Ci}{LFL1} + \frac{C2}{LFL2} + \dots \frac{C1}{LFL1}} \qquad \text{--}$$

----(2.1)

Where $\mathrm{LFL}_{\mathrm{mix}}$ the lower flammability limit of the mixture LFL_1, LFL_2, ...LFL_i the lower flammability limit of the constituent gases. C_1, C_2, C_i, (vol %) is the fraction of each gas in the fuel mixture without air.

The inclusion of inert gases in the combination will further narrow the flammability limit. Coward and Jones, 1952, have established a means of employing Le Chatelier's law in establishing the flammability limit while adding the effect of the inert gases present in the gas combination. Coward and Jones' combination was mostly constituted of the following gases: Hydrogen, carbon monoxide, methane, nitrogen, carbon dioxide, and oxygen. The technique is seen as indicated below:

1. The composition of the mixture is recalculated largely on an air-free basis; the total amount of each gas is represented as a percentage of the overall air-free mixture.
2. An arbitrary dissection of the air-free combination is formed into simpler mixtures, each of which contains only one combustible gas and part or all of the nitrogen or carbon dioxide.

3. The limitations of any mixture thus split are read from tables or curves.

4. The limits of the air-free mixture are computed using the figures for the dissected mixes given in (3), by means of the equation:

$$FL_{mix} = \frac{100}{\frac{Ci}{FL1}+\frac{C2}{FL2}+\dots\frac{C1}{FL1}} \qquad \text{---}$$

(2.2)

LAMINAR FLAME VELOCITY

The Laminar Flame Velocity (LFV) is the rate at which the flame propagates through quiescent unburned fuel-oxidant mixes in the direction perpendicular to the expansion wave surface under laminar flow condition (Fossum and Beyer, 1998; Kuchta 1985). Due to the fact that LFV is highly sensitive to combustion chamber operations and emission performance, it is particularly significant for the investigation of combustion chamber operations. The composition of the fuel, mixture equivalence ratio, temperature, and pressure affect it.

The composition of synthesis gas can change based on the feedstock being made use of, although with different feedstocks employed, it has been discovered that there is a constant set of ingredients found in synthesis gas. Syngas is basically 30 to 60% carbon monoxide (CO), 25 to 30% hydrogen (H_2), 0 to 5% methane (CH_4), 5 to 15% carbon dioxide (CO_2), plus a lesser or greater amount of water vapor, smaller amounts of the sulfur compounds hydrogen sulfide (H_2S), carbonyl sulfide (COS), and finally some ammonia and other trace contaminants. (National Energy Technology Laboratory, para 1.), The synthesis gas is described as a gas having H_2 and CO as the main components of fuel. Row syngas comprises mostly considerable volumes of CO_2

and H_2O as well. Since syngas is frequently utilised at greater pressures for synthesizing chemicals and fuels, the N_2 concentrations must normally be minimized in syngas. The reason for the removal or decrease of Nitrogen is due to the occurrence of Nitric oxides which can be created in the process. Nitric oxides are pollutants that can contribute to the production of acid rain. Syngas can be a key source of acquiring sulfuric acid which can be marketed and sold, so production of syngas provides numerous alternatives in terms of value for money and benefit. In later sections, it will be seen how syngas can be generated and the different equipment that are made use of in its manufacturing.

2.2 SYNGAS PRODUCTION TECHNOLOGIES

The development of syngas production technologies has grown over the years and numerous methods for converting feedstock to synthesis gas for diverse uses have been established. The principal form of turning material to synthesis gas is by gasification. Gasification is a thermal conversion process, where carbonaceous material is changed into gaseous products under the influence of temperature and gasifying medium (Tharaka Rama Krishna C. Doddapaneni, Timo Kikas, 2021). Gasification technology depends on a sequence of fundamental reactions such as dehydration, pyrolysis/ devolatilization, and gasification to transform the biological composition of biomass such as carbohydrates, proteins, and lipids into syngas that contains alkane hydrocarbons such as CO, H_2, CH_4, CmHn, etc. Various gasification technologies and techniques are described below

2.2.1 FISCHER-TROPSCH SYNTHESIS

One of the early ways created in converting feedstock to synthesis gas was the Fischer-Tropsch process that was formulated by the German inventors, Franz Fischer and Hans Tropsch in the

1920s. This method proved useful for Germany during World War 2 by supplying liquid hydrocarbons. During the apartheid era in South Africa, due to isolation, the Fischer-Tropsch synthesis method from coal gasification was turned to in order to deliver significant quantities of its hydrocarbon fuel and chemical demands.

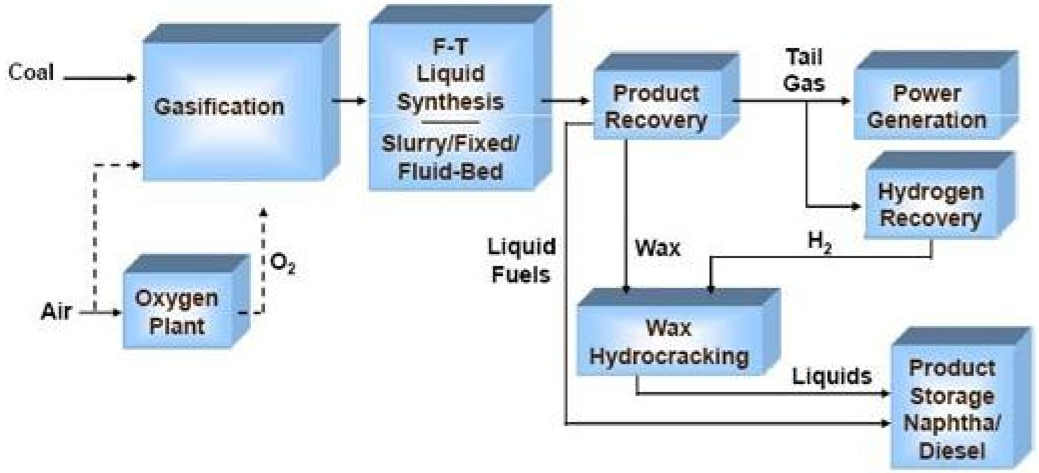


FIGURE 2.1 SIMPLIFIED F-T SYNTHESIS SCHEME (NATIONAL ENERGY TECHNOLOGY LABORATORY, 2010)

The gasification block consists of all supporting stages and processes required to produce clean and excellent syngas. The clean syngas from the gasification island is delivered onto the FT synthesis block, where the clean shifted syngas is transformed into primary products of wax, hydrocarbon condensate, tail gas, and reaction water. The wax is sent on to an upgrading plant for hydrocracking in the presence of hydrogen, where it is chemically separated into lower molecular weight hydrocarbon liquids. A hydrogen recovery machine is used to collect the needed quantity of hydrogen from the tail gas as indicated, or alternatively from the feed syngas stream. The reaction products, together with those from the upgrading stage, are fractionated into the final products of diesel, naphtha, and other light ends, depending on the required product mix.

The Fischer-Tropsch synthesis is a superb application of employing syngas but for the aim of this paper, it is important to examine processes that will aid in power generation. Seeing that the key resources gained from this synthesis process are for other useful materials, it will not offer substantial gain to linger on this.

2.2.2 GASIFIER TECHNOLOGIES

The phrase “Gasification” is needed for synthesis gas to assume shape and form. For gasification to take place, special apparatus known as gasifiers are made use of. In the industry, there are three primary categories of biomass gasifiers:

- Fluidized-Bed Type
- Fixed-Bed Type
- Entrained Flow Type

2.2.2.1 FLUIDIZED-BED GASIFIERS

Fluidized-bed gasification technique is widely employed in the coal gasification area. In a fluidized-bed gasifier, solid fuel is split into small pieces and placed across a gas distribution plate through which oxidant flows upward. Hence, the fuel particles are suspended by the upward-moving oxidant and undergo turbulent movement, including back-mixing (Y. Zhu, H.C. Frey, 2010). Due to the strongly back-mixed operation, the gasifier operates under isothermal circumstances at a temperature below the ash fusion temperature of the coal, thus avoiding clinker formation and possible collapse of the bed. Fluidized bed gasifiers would block if the ash were to melt. The oxidant for this procedure can be either pure oxygen or air. The feedstock is dried and pyrolyzed rapidly to release its volatile stuff., which burns and generates the heat for the endothermic reaction. The low-temperature functioning of this gasifier means that fluidized-bed gasifiers are best suited to highly reactive feeds, such as biomass, or to lower quality feedstocks such as high mineral matter biomass or trash.

Fluidized bed gasifiers have the following characteristics:

1. They may accept a variety of solid feedstock.
2. They have constant, mild, temperature.
3. Moderate oxygen and steam requirements.
4. Char recycling.

Types of Fluidized Bed Gasifiers include the following:

- Bubble fluidized beds
- Circulating fluidized beds
- Double fluidized bed

BUBBLE FLUIDIZED BEDS: Bubble Fluidized Bed gasifier is one of the most popular designs for biomass gasification, mainly due to its applicability to medium-scale systems. It consists of a vessel in which the gasifying agent is supplied upward at a velocity fast enough (0.5–1.0 m/s) to agitate the bed material which sits at the bottom section of the gasifier and to maintain the desired temperature (Bermudez, Fidalgo, 2016). The bubbling fluidized bed has a fairly uniform temperature distribution throughout the reactor, accepts fuel particles of varying sizes, produces a homogenous syngas, and yields a gaseous product with a low tar level.

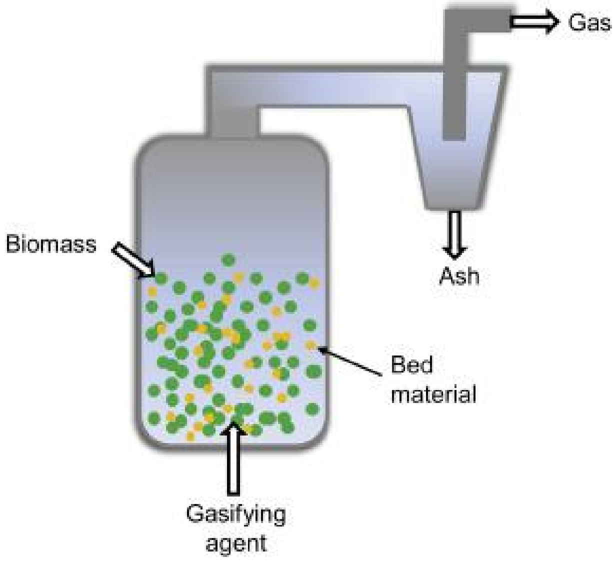


FIGURE 2.2 SCHEMATIC OF A BUBBLING FLUIDIZED BED GASIFIER (Bermudez and Fidalgo, 2016)

CIRCULATING FLUIDIZED BED GASIFIER: This gasifier has fantastic heat transfer thermal qualities, and uniform temperature spread, which can boost the reaction rate and efficiency of conversion of the feedstock. The operational basis of a circulating fluidized bed (CFB) gasifier involves the suspension of feedstock particles in an oxygen-rich gas, generating a fluidized bed within the gasifier. This fluidized bed, working as a fluid, brings about effective heat and mass transmission, thereby speeding the gasification process (Kaneesamkandi et al., 2023). The solid material is commonly sand or some form of catalyst; these particles can allow for a better heat transfer than previous systems. The particles can be removed using a cyclone separator, from which they can be recirculated. The improved gas–solid mixing and longer residence time of the biomass coke are the fundamental distinctions between the circulating fluidized bed and the bubbling fluidized bed; however, the operating expenses and operational complexity of the circulating fluidized bed technology are higher. As wanted properties for the clean phase of future syngas, circulating fluidized bed gasifiers also generate less CO_2, methane (CH_4), and tar.

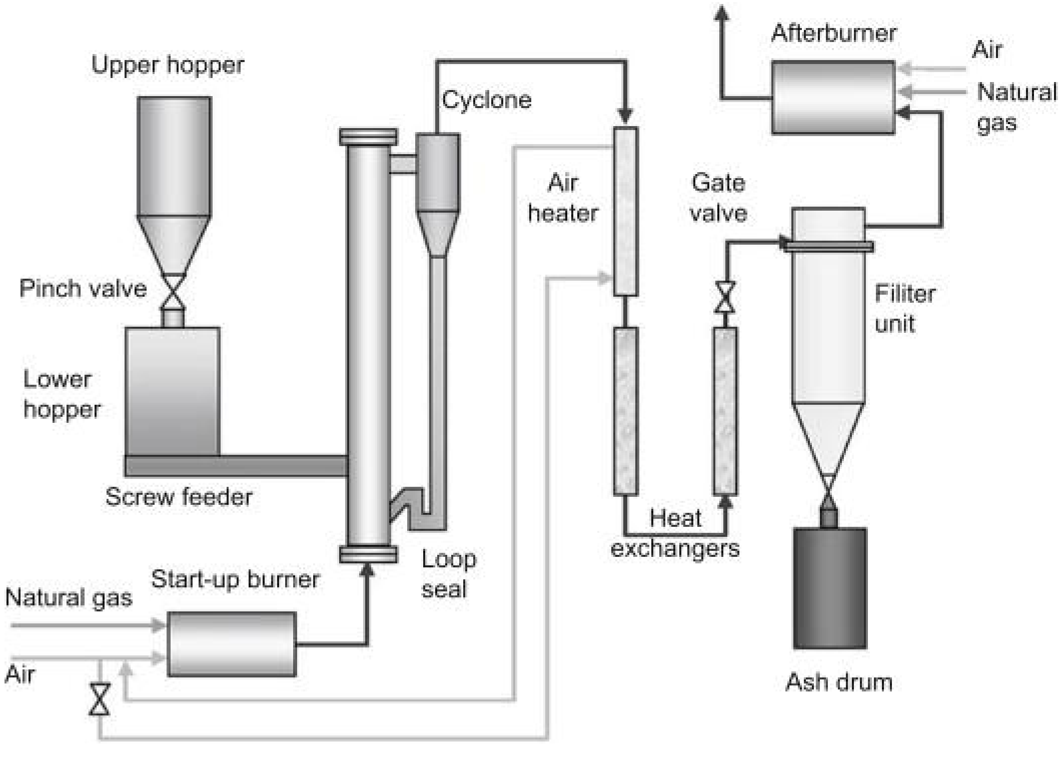


FIGURE 2.3 SCHEMATIC OF CIRCULATING FLUIDIZED BED GASIFIER (Li et al., 2004)

DOUBLE/DUAL FLUIDIZED BEDS: The dual fluidized-bed gasifier is comparable to the circulating bed gasifier, with the exception that the first-stage reactor heats the fluidized medium in the second-stage reactor and the second-stage reactor feeds the first-stage reactor reaction material. A DFB gasifier consists of two interconnected fluidized beds: (1) a bubbling fluidized bed (BFB) gasifier which converts biomass into raw syngas gas/product gas and, (2) a circulating fluidized bed (CFB) or fast fluidized bed (FFB) combustor (riser) which oxidizes the residual char in presence of an oxidizing or a fluidizing agent providing heat for the highly endothermic gasification reactions. The feed (i.e., biomass) is provided to the gasifier with the help of a screw conveyor. The two fluidized beds are controlled individually but interconnected via a non–mechanical valve, such as a loop seal valve, to ensure the circulation of bed material particles. A cyclone separator is employed to separate the heat carrying materials from the flue gases in the riser section. The heat carrying material is returned to gasifier while the flue gases are routed to heat recovery system. The product gas obtained from the gasifier is predominantly made of H_2, CO, CO_2, CH_4, tiny amounts of tar and other unwanted components, which are routed to the purification unit to generate syngas. An additional/excess fuel inlet is delivered to the riser to maintain temperature in the reactor (Schmid et al., 2019).

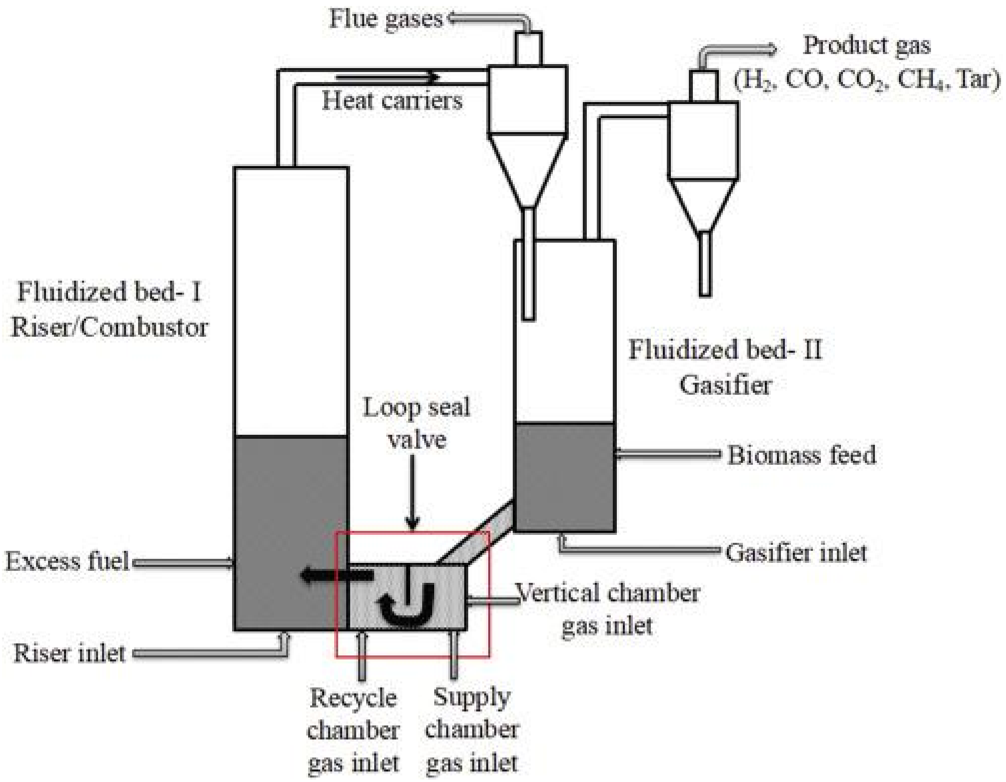


FIGURE 2.4 SCHEMATIC OF A DFB GASIFIER (Hanchate et. al, 2019)

2.2.2.2 FIXED-BED GASIFIERS

Fixed-bed gasification technology has been widely utilised for biomass syngas production due to its advantages such as reduced maintenance, low production costs, and simple structure and operation. s. In fixed-bed gasifiers, the feedstock is put in a stationary bed. Fixed-bed gasifiers can be split into three groups, updraft, downdraft, and cross-draft gasifiers, depending on the flow direction of both the feedstock and the gas.

UPDRAFT GASIFIER

Fuel flexibility is the main feature of updraft multifuel gasifiers. These gasifiers may operate on either coal or biomass and fuel switching does not require any adjustments in the reactor. Updraft gasifiers tolerate higher ash content, higher moisture content and larger size variation in fuel as compared to downdraft gasifiers. In this gasifier arrangement, the fuel is put in the upper half of the gasifier chamber, while air or oxygen is injected from beneath, flowing upward through the fuel bed. Gasification processes occur from top to bottom, passing through moisture removal, pyrolysis, combustion, and reduction stages. The fuel that passes through the gasifier from top to bottom touches the hot gases travelling up through the gasifier, and immediately the drying process commences. This is followed by the pyrolysis process during which char production takes place. The char that comes in touch with the combustion products is gasified releasing carbon monoxide. These gasifiers are noted for their thermal efficiency, easy operational procedures, and ability to accommodate feedstock with elevated moisture and ash concentrations (Kaneesamkandi et al., 2023).

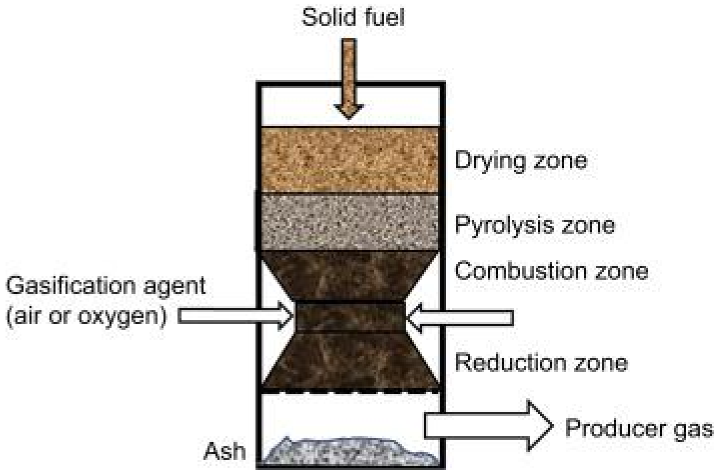


FIGURE 2.5 SCHEMATIC REPRESENTATION OF AN UPDRAFT GASIFIER (Pang, 2016)

DOWNDRAFT GASIFIER

The biomass in a downdraft gasifier goes in the same direction as the gas flows compared to an updraft gasifier. Biomass flows from the top to the drying area, where it removes moisture, and then further to the pyrolysis zone, where the solid fuel is turned to char and gas. During the pyrolysis step, the partially dried biomass undergoes heat decomposition without oxygen, generating volatile gases, tar, and char. As the mixture drops, it enters the oxidation zone, where a precisely controlled amount of oxygen is added. In this location, the volatile gases created during pyrolysis undergo combustion, releasing more heat and generating combustion products. Ultimately, the mixture enters the lower reduction zone, characterized by a bed of hot carbonized material from the original combustion. Here, any remaining oxygen combines with the volatile gases, leading to the generation of syngas that is both clean and energy-rich, largely consisting of carbon monoxide, hydrogen, and methane (Kaneesamkandi et al., 2023). The gas from downdraft gasifiers can be cleaned to a very high purity where it can be made use of by IC engines or for direct heating applications where purity of gas is a vital requirement.

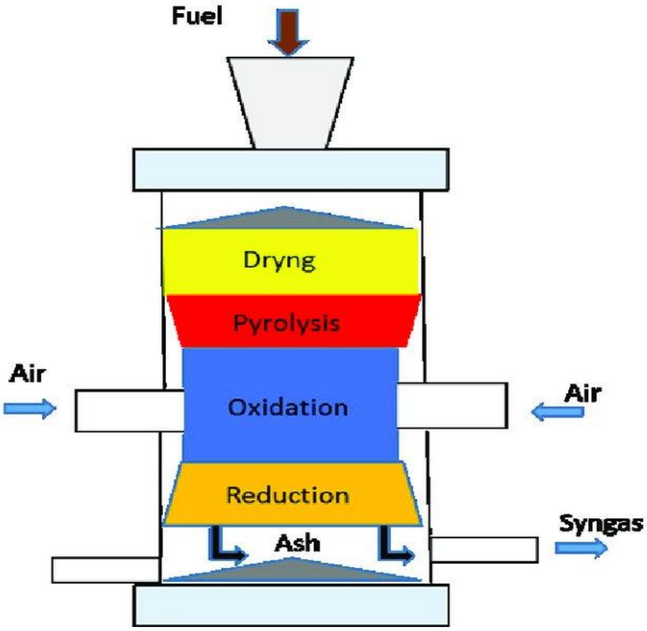


FIGURE 2.6 SCHEMATIC REPRESENTATION OF A DOWNDDRAFT GASIFIER (Gagliano et al., 2017)

CROSS-DRAFT GASIFIER

Like the updraft and downdraft gasifiers, the cross-draft gasifier has its feedstock/solid fuel fed from the top of the device. Air is fed into it through the sidewalls; this is done in order for the air to flow in a cross-wise way, thereby coming in coming in complete touch with the feedstock. This approach employed in furthering thermal decomposition likens the process of the cross-draft gasifier to the thermal decomposition of an incinerator. The synthetic gas produced by this gasifier goes through the opposite side with respect to the air nozzle. This attribute makes the cross-draft gasifier to also be termed as “side-draft” gasifier. This gasifier has a faster startup time when compared to the updraft gasifier and downdraft gasifier.

With the significant advantages the cross-draft offers over the other two, it has its own limitations. These limitations include high exit gas temperature, high gas velocity, poor CO2 reduction among others. These are repercussions of its architecture and it can lead to constraints of what feedstock can be used when harnessing this technology. (EnggCyclopedia, 2012).

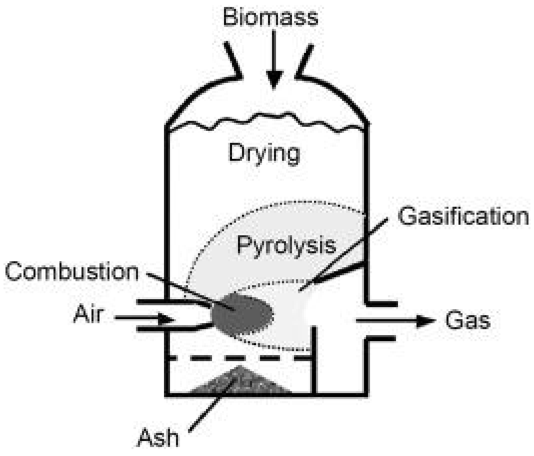


FIGURE 2.7 SCHEMATIC OF A CROSS-DRAFT GASIFIER (BASU AND KASHAUL, 2024)

2.2.2.3 ENTRAINED FLOW GASIFIERS

Entrained flow gasifier is a comparatively recent concept with great efficiency. It is generally applied for large-scale gasification of coal, biomass, and refinery wastes. However, fuel particles should be thoroughly crushed for this form of gasifier, and consequently it is troublesome when biomass is utilised as a feedstock. Due to the high temperature and pressures in the entrained flow gasifiers, the treatment capacity of the entrained flow gasifiers is high, compared with other types of gasifiers with the same bed volume. However, the thermal efficiency is lower, compared with other types of gasifiers. (Kiang, 2018). The gasification reactions in this gasifier occurs at a very quick rate of reaction due to the high working temperature (1200-1600°C) and pressure (2-8MPa), and within a few seconds, the product gas leaves the reactor vessel at the bottom together with the molten slag. (Qin, 2012). The product gas can be cooled by two major methods: (1) Quenching the gas with water or (2) Using a high temperature radiant cooler, while the molten slag falls to a quench chamber for hardening and laves it through a lock hopper. Entrained flow gasifiers have the capacity to handle nearly any coal feedstock and generate a clean, tar-free, syngas.

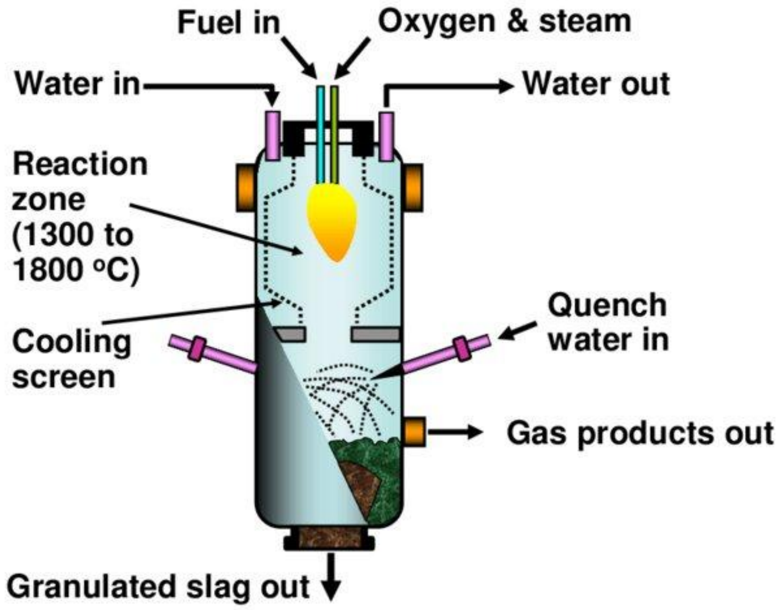


FIGURE 2.8 SCHEMATIC OF AN ENTRAINED FLOW GASIFIER (NELSON, PARK, AND HUBBE, 2018)

2.3 SUSTAINABILITY IMPACT ASSESSMENT

Sustainability impact assessment (SIA) is a systematic process for evaluating the potential environmental, social, and economic impacts of a proposed policy, program, project, or plan. This approach resembles a comprehensive analysis of the advantages and disadvantages, with an emphasis on long-term sustainability. (Hao Zhang et al., 2015).

2.3.1 COMPONENTS OF S.I.A

Sustainability Impact Assessment takes a holistic view of the environmental, social, and economic impacts of a project or product throughout its lifecycle. The key components involved in such an assessment can be summarized as follows:

2.3.1.1 ENVIRONMENTAL IMPACT ASSESSMENT

Environmental Impact Assessment (EIA) is a tool used to examine the important consequences of a project or development proposal on the environment.

EIAs make sure that project decision makers consider about the anticipated effects on the environment at the earliest feasible time and try to avoid, lessen or offset those effects.

Environmental impact assessment is concerned with the following:

- Resource depletion: Examining the project’s use of resources like water, energy, and raw materials.
- Pollution and emissions: Analyzing air, water, and soil pollution generated by the project, including greenhouse gas emissions.
- Biodiversity and ecosystem impacts: Assessing how the project affects ecosystems and wildlife.
- Land use and resource extraction: Evaluating the project’s impact on land use and potential resource extraction needs.

2.3.1.2 SOCIAL IMPACT ASSESSMENT

Social impact assessment (SIA) is a procedure for the discovery, analysis, assessment, management, and monitoring of the potential social repercussions of a project, both good and negative. The social implications of a project are the direct and indirect impacts that affect people and their communities during all stages of the project lifetime.

Social impact assessment is associated with the following:

- Community health and safety: Examining potential impacts on human health, safety, and well-being.
- Cultural heritage: Assessing the project's impact on cultural sites and traditions.
- Livelihoods and economic opportunities: Evaluating how the project affects employment, income, and local economies.
- Social equity and justice: Analyzing whether the project benefits or harms different social groups fairly.

2.3.1.3 ECONOMIC IMPACT ASSESSMENT

Economic Impact Assessment (EIA) studies the influence of an event on the economy in a given area, ranging from a local neighborhood to the entire planet. It usually monitors changes in business revenue, business profits, personal earnings, and/or jobs. The economic event evaluated can include execution of a new policy or project, or may simply be the presence of a business or organization. An economic impact analysis is typically undertaken when there is public concern about the potential implications of a proposed project or legislation.

EIA takes the following into account:

- Costs and benefits: Evaluating the project's financial costs and benefits, including direct and indirect impacts.
- Job creation and economic development: Assessing the project's potential to create jobs and stimulate economic growth.

- Distribution of costs and benefits: Analyzing how the project’s economic benefits and burdens are distributed among different stakeholders.

2.3.2 BENEFITS OF SIA

- Informed decision-making: SIAs provide valuable information to decision-makers, helping them choose options that are more sustainable and have fewer negative impacts.
- Improved project design: By identifying potential problems early on, SIAs can help to improve the design of projects and programs, making them more likely to succeed.
- Reduced environmental impact: SIAs can help to identify and mitigate potential environmental impacts, leading to more sustainable development.
- Enhanced social equity: SIAs can help to ensure that projects and programs are fair and equitable, considering the needs of all stakeholders.

2.3.3 SUSTAINABILITY IMPACT ASSESSMENT INDICATORS

2.3.3.1 Life Cycle Analysis

LCA is a standardized approach for assessing the environmental implications of a given process, technology, system, or service during its complete life cycle. LCA is defined by the ISO 14000 series of international standards, which consists of principles and framework (ISO 14040), goal and scope definition and inventory analysis (ISO 14041), life cycle impact assessment (ISO 14042), life cycle interpretation (ISO 14043), and requirements and guidelines (ISO 14044).

Syngas wood waste gasification for power generation is a promising technology for sustainable energy production and waste management. However, its actual environmental impact might be complex and demands a detailed investigation. This is where life cycle assessment (LCA) comes in.

LCA assesses the environmental implications of a product or system throughout its entire life cycle, from resource extraction and processing to final disposal. In the instance of syngas wood waste gasification for energy, the LCA would typically encompass the following stages:

1. **Cradle:**
    - Wood waste collection and transportation: Including harvesting, pre-processing, and delivery to the gasification plant.
    - Plant construction and operation: Materials and energy used for building and running the gasification facility.
    - Auxiliary materials and chemicals: Consumables needed for the gasification process, such as oxygen, catalysts, and cleaning agents.
2. **Gate:**
    - Syngas production: Emissions and energy consumption associated with converting wood waste into syngas.
    - Byproduct handling: Management of byproducts like char, ash, and wastewater, including potential resource recovery or treatment.
3. **Grave:**
    - Syngas utilization: Emissions and energy generation from using syngas to produce electricity.

- Disposal of residues: End-of-life management of remaining waste streams, including potential landfilling or recycling.

2.3.3.1.1 Cradle-to-Gate vs. Cradle-to-Grave LCA

Two methodologies dominate lifecycle analysis: Cradle-to-Gate (C2Ga) and Cradle-to-Grave (C2Gr). Both offer valuable insights, but with distinct scopes and suitability.

1. Cradle-to-Gate (C2Ga):

The scope of the Cradle-to-Gate methodology is to assess the impacts from acquiring and processing wood waste to syngas production and electricity generation. It excludes waste management, distribution, use-phase impacts, and potential end-of-life benefits like carbon sequestration. Pros and cons of this methodology are as follows:

- Pros:
  - Simpler and faster to conduct, ideal for initial screening and comparisons.
  - Helps identify hotspots within the production process for improvement.
  - Useful for comparing production efficiencies of different syngas technologies.
- Cons:
  - Incomplete picture, potentially underestimating environmental burdens and benefits.
  - Can lead to misinterpretations if not considering the full life cycle.

2. Cradle-to-Grave (C2Gr):

This methodology encompasses the entire life cycle, including upstream processes, syngas production, electricity generation, waste management, and potential end-of-life benefits (e.g., biochar formation and carbon sequestration). It also takes into account factors such as waste disposal, distribution, and potential environmental benefits beyond direct production. Its pros and cons are as listed below:

- Pros:
    - Provides a more comprehensive understanding of the environmental footprint.
    - Enables comparisons with other electricity generation options considering their full life cycle.
    - Captures potential benefits like avoided emissions and carbon sequestration.
- Cons:
    - More complex and time-consuming to conduct.
    - Requires additional data and assumptions, potentially increasing uncertainty.

2.3.3.1.2 Choosing the Right Method

- Initial screening and quick comparisons: C2Ga offers a streamlined approach for identifying production hotspots and comparing different syngas technologies.
- Comprehensive understanding and full transparency: C2Gr is crucial for a holistic assessment, especially when considering wider environmental impacts and potential benefits beyond production.
- Decision-making and policy development: C2Gr is essential when comparing syngas electricity with other options across their entire life cycles, informing policy decisions and investments.

LCA results are typically expressed in various environmental impact categories, such as:

- Climate change: Greenhouse gas emissions (GHG) throughout the life cycle, compared to alternative electricity sources.
- Human health: Impacts on human health from air and water pollution, noise, and accidents.
- Resource depletion: Consumption of fossil fuels, water, and other resources.
- Ecosystem quality: Effects on biodiversity and habitat loss.

LCA studies of syngas wood waste gasification have shown varied results, with some claiming substantial GHG reductions compared to fossil fuels and others highlighting potential concerns like NOx emissions or soil contamination from landfills.

2.3.3.2 TECHNO-ECONOMIC ANALYSIS

Syngas wood waste gasification is a viable option for sustainable electricity generation and trash management. However, assessing its feasibility involves a comprehensive consideration of both technical and economic aspects. This is where techno-economic analysis (TEA) comes in.

TEA examines the technical feasibility and economic viability of a technology or project, evaluating costs, revenues, performance, and risks. In the context of syngas wood waste gasification for energy, a TEA would typically address the following aspects:

2.3.3.2.1 Technical Analysis

- Gasification technology: Different gasifier types (fixed-bed, fluidized bed, entrained flow) have varying efficiencies, capital costs, and operating parameters.

- Syngas composition and cleaning: The composition of syngas influences its compatibility with different power generation technologies and the need for cleaning to remove impurities.
- Power generation technology: Options include gas turbines, internal combustion engines, and combined heat and power (CHP) systems, each with varying efficiencies and fuel adaptability.
- Grid integration: The potential for grid connection or off-grid operation affects plant design and economic considerations.

2.3.3.2.2 Economic Analysis:

- Capital costs: Investment costs for the gasification plant, power generation equipment, and infrastructure.
- Operating and maintenance (O&M) costs: Expenses for feedstock purchase, transportation, fuel preparation, gasification operation, power generation, and maintenance activities.
- Revenue generation: Income from electricity sales, potential carbon credits, or other product streams (e.g., heat, biochar).
- Financial metrics: Internal rate of return (IRR), net present value (NPV), levelized cost of electricity (LCOE), payback period, and sensitivity analysis to key variables.

2.3.3.2.3 Factors influencing techno-economic viability

Key factors influencing the techno-economic viability of syngas wood waste gasification include:

- **Scale of the project**: Larger plants tend to benefit from economies of scale but can face higher upfront costs.
- **Availability and cost of wood waste:** Reliable and affordable feedstock supply is crucial for long-term operation.
- **Electricity market conditions**: Feed-in tariffs, electricity prices, and grid access can significantly impact revenue generation.
- **Technological advancements:** Improvements in gasification efficiency, fuel flexibility, and emission control can contribute to cost reductions.
- **Policy and regulatory frameworks**: Government incentives, carbon pricing mechanisms, and environmental regulations can affect project feasibility.

2.3.3.2.4 Steps Involved in TEA:

- **Define the System**: Clearly specify the chosen technology for electricity generation (e.g., solar PV, wind turbine, nuclear power plant) and its intended capacity.
- **Technical Analysis:**
  - Resource Availability: Assess the accessibility and long-term availability of resources required for the chosen technology (e.g., sunlight for solar, wind for turbines).
  - Conversion Efficiency: Evaluate how efficiently the technology converts the available resource into electricity, considering factors like solar panel efficiency or turbine design.
  - Environmental Impact: Analyze the environmental footprint of the technology, including greenhouse gas emissions, water usage, and land-use requirements.

  - Operational Requirements: Evaluate the infrastructure, maintenance needs, and operational complexities associated with the chosen technology.

- **Economic Analysis:**
  - Capital Costs: Estimate the initial investment required for building and installing the power plant infrastructure and equipment.
  - Fuel Costs: For technologies using fuel sources like natural gas or coal, factor in the cost and long-term availability of fuel.
  - Operation & Maintenance (O&M) Costs: Include ongoing expenses for personnel, repairs, and regular maintenance of the power plant.
  - Revenue from Electricity Sales: Estimate the revenue generated by selling electricity produced by the system, considering market prices and potential fluctuations.
  - Potential Government Subsidies: Include any financial incentives or subsidies offered by the government for using specific technologies.
- **Financial Analysis:**
  - Payback Period: Calculate the time taken for the project to generate enough revenue to recover its initial investment costs.
  - Internal Rate of Return (IRR): Assess the profitability of the project, considering the time value of money.
  - Levelized Cost of Electricity (LCOE): Calculate the average cost per unit of electricity generated over the lifetime of the project, encompassing all capital, fuel, O&M, and other expenses.
- **Sensitivity Analysis:**

  Analyze how changes in assumptions (e.g., fuel prices, interest rates, electricity demand) can affect the economic viability of the project using techniques like Monte Carlo simulations or tornado diagrams.

2.3.3.2.5 Benefits of TEA

1. **Informed Investment Decisions**: TEA empowers decision-makers with a comprehensive understanding of a technology's technical and economic potential, enabling them to identify the most cost-effective and technically sound options for electricity generation. This ultimately leads to investments that yield optimal returns and contribute to a sustainable energy future.
2. **Policy Development:** TEA provides valuable insights for policymakers crafting energy policies that promote environmentally-friendly and affordable electricity production. By understanding the economic implications of different generation technologies, policies can be tailored to encourage the adoption of sustainable solutions while ensuring affordability for consumers.
3. **Technology Comparison:** TEA facilitates objective comparisons between various electricity generation technologies based on both technical and economic merits. This enables stakeholders to assess the strengths and weaknesses of different options, guiding them towards technologies that align with their specific needs and priorities.
4. **Identification of Challenges and Opportunities:** By meticulously analyzing economic viability and technical specifications, TEA can unveil potential challenges and opportunities associated with specific technologies. This foresight enables proactive planning and risk mitigation, ultimately increasing the likelihood of project success.

TEA studies have demonstrated varying results for syngas wood waste gasification, with some projects showing promising economic potential and others facing challenges. Therefore, it's essential to consider the specific context and assumptions of each study when interpreting the findings.

TEA helps make informed decisions about the implementation of syngas wood waste gasification projects. By evaluating technical feasibility, economic viability, and risks, TEA can support the development of this technology towards a sustainable and commercially attractive solution for waste management and electricity generation.

2.3.3.3 COST-BENEFIT ANALYSIS (CBA)

Cost-benefit analysis (CBA) is a systematic approach to assess the economic efficiency and social desirability of a project or intervention. In the context of electricity production from syngas, it considers both the monetary costs and the wider benefits to society, providing a comprehensive picture of the project's value.

2.3.3.3.1 METHODOLOGY OF CBA

1. **Identify Costs and Benefits:**
    - **Costs:**
        - Capital costs: construction and equipment for the syngas production and power generation facilities.
        - Operational costs: fuel, labor, maintenance, waste disposal.
        - Environmental costs: air and water pollution control, greenhouse gas emissions.
    - **Benefits:**

    - Economic benefits: electricity generation revenue, job creation, local economic development.
    - Environmental benefits: reduced reliance on fossil fuels, potential for carbon capture and storage.
    - Social benefits: improved energy security, air quality improvements, public health benefits.

2. **Quantify Costs and Benefits:**

- Assign monetary values to costs and benefits where possible (e.g., market prices for electricity, estimated social cost of carbon).
- Use non-monetary valuation techniques for difficult-to-quantify benefits (e.g., public surveys for valuing air quality improvements).

3. **Discounting:**

- Future costs and benefits are discounted to present-day values, reflecting the time value of money.

4. **Decision Criteria:**

- Compare discounted costs and benefits using various metrics:
    - Net Present Value (NPV): positive NPV indicates project creates economic value.
    - Benefit-Cost Ratio (BCR): ratio of benefits to costs, with BCR > 1 suggesting potential desirability.

  - Cost-Effectiveness Analysis (CEA): compares alternative projects with similar goals based on cost per unit of benefit.

5. **Sensitivity Analysis:**
   - Assess how changes in key assumptions (e.g., fuel prices, carbon taxes) affect the results.

2.3.3.3.2 BENEFITS OF CBA

- Informed Decision-making: Provides a structured framework for comparing syngas projects with other options, aiding in selecting the most efficient and beneficial projects.
- Transparency and Accountability: Makes decision-making process transparent and accountable by explicitly considering both costs and benefits.
- Stakeholder Engagement: Allows for incorporating different stakeholder perspectives and priorities into the analysis.
- Policy Development: Informs policy decisions around promoting syngas technologies and renewable energy development.

2.4 REVIEW OF PREVIOUS WORK ON SIA OF ELECTRICITY GENERATION WITH SYNGAS

The SimaPro LCA programme, especially version 9, was employed to duplicate the data gathered by Guoqiang Cao et al. The whole life cycle inventory data set was generated using the Ecoinvent version 3.6 database. The reformer feed, originating from the water treatment plant, was mimicked using purified water obtained from the United States. The SMR and rWGS furnaces employed high-pressure natural gas (NG) purchased from the American market as both fuel and process input. The environmental effects of the circulating cooling water (CW) were considered by incorporating the use of fresh river water composition at a rate of 0.07 kg per kilogramme of CW, phosphoric acid at a rate of 0.00004 kg per kg of CW, sodium hypochlorite with a concentration of 15% on a dry basis, and energy consumption of 0.000279 kWh per kg of CW for the CW pump.

The present study proposes the utilisation of a sustainable combination of the S/DR technique to extract syngas from CB. Life cycle assessment (LCA) is a widely accepted approach used to examine the resources and environmental impacts associated with the whole life cycle of a process or product. Hakawati et al. applied this methodology to analyse the usefulness of several strategies for utilising biogas and discovered that direct utilisation of biogas (for energy generation) showed the best efficiency. However, this strategy is limited to areas in close proximity to the anaerobic digestion facility, hence preventing its widespread utilisation. Hajjaji et al. assessed the ecological repercussions of applying biogas reforming for the manufacture of hydrogen. Researchers showed that although the anaerobic digestion process has a deleterious influence on the results of the life cycle assessment, it is still conceivable to cut the greenhouse gas emissions of typical H_2 generating systems by roughly 50%.

G. Chidikofanat et al article intends to analyse the environmental issues related with the tar leaks from a biomass gasifier power plant project for the energy supply of an isolated rural site. Using the LCA approach, it investigates the implications of the power generation from the cotton stalk and rice husk; and two scenarios of disposal corresponding to discharge into the water (river) or on the soil. It analyses the impacts associated to the discharges of tar from the conversion of cotton stalks and rice husks. Based on the Life Cycle Assessment through the ILCD 2011 Midpoint + (V.1.08) method, the environmental impacts are assessed in terms of human toxicity no carcinogenic effect, human toxicity carcinogenic effect and freshwater ecotoxicity. Their analysis reveals that power generation from rice husks is better for the environment than from cotton stalks. The toxicity is substantially higher for discharge into the water than for discharge on soil. The toxicity is substantially higher for discharge into the water than for discharge on soil. The most significant substances contributing to the repercussions of the discharge in water are Naphthalene, Formaldehyde, Phenol in the case of cotton stalk and Pyridine, Fulfural, and Anthracene in the case of rice husk. However, it should be highlighted that most present evaluation approaches, do not or only partially take into consideration the impacts of chemical compounds discharge on soil. For environmental study, these data represent a vital stage in a global environmental assessment of a biomass gasifier power plant.

The environmental feasibility of H_2 production by biomass gasification – by evaluating several feedstocks - has been investigated by Moreno and Dufour (2013). Their results revealed that the key elements contributing to the environmental performance of biomass gasification are yield to gas and requirements of fertilizers and pesticides in biomass growth (Moreno and Dufour, 2013). Their analysis also found that recovery and usage of important products such as non-converted methane boosted the environmental performance of the process. Koroneos et al. (2008) assessed the environmental challenges of H_2 production using varied renewable sources including biomass.

A comparative LCA analysis of two different gasification systems (downdraft gasifier and CFB gasifier) for H_2 production indicated that the downdraft gasifier achieved superior environmental performance than the CFB gasifier (Kalinci et al., 2012). According to the LCA study of hydrogen production by Susmozas et al (2016), direct emission to air, external electricity production, and biomass production are the key processes contributing to environmental impacts, while bio-hydrogen production with CO_2 capture delivers superior environmental performance over conventional processes. Since biomass gasification is an economically interesting solution to produce syngas with low/medium heating value which can be transformed into electricity (González-García et al., 2012), LCA has been applied by different researchers to assess the environmental impacts of electricity generation from biomass. The environmental performance of numerous power-producing systems has also been assessed. A study of environmental consequences of electricity production in Denmark found that GHG emissions might be considerably cut (from 68 to 17 Gg CO_2 -eq/PJ) by better use of residual biomass (Tonini and Astrup, 2012). A comparison research found that electricity production from biomass generated substantially lower CO2 emissions (35-178 g-CO_2/kWh) than coal-fueled systems (975.3 g-CO_2/kWh) (Varun et al., 2009).

Environmental repercussions of electricity production via co-gasification of coal and biomass resulted in much lower CO_2 emissions, in contrast with coal gasification (Hartmann and Kaltschmitt, 1999). IGCC of biomass - with upstream CO_2 adsorption - has been compared with IGCC with chemical absorption of CO_2 at the stack (Corti and Lombardi, 2004). The environmental performance of an IGCC with CO_2 removal - by chemical absorption – has also been examined on the basis of the Eco-indicator 95 approach and compared with a similar energy conversion cycle supplied by coal (Carpentieri et al.,2005). In a different experiment, the environmental assessment of three distinct CHP systems indicated that biomass-based scenarios lowered GHG emissions considerably, but created greater acidification consequences compared with fossil fuel-based scenarios (Kimming et al., 2011).

The electricity that can be obtained from 1 ton of biomass relies on the overall energy conversion efficiency. For the G/CC plant, this parameter is the product of the energy conversion efficiency of the combined cycle calculated by the so-called cold gas efficiency (CGE, η_{CG}), where the numerator refers to the chemical energy of the syngas and the denominator is the chemical energy of the biomass as raw material.

$\eta_{CG} = M_{syngas} \cdot LHV_{syngas} / M_{biomass} \cdot LHV_{biomass}$

The CGE is obviously dependent on the conversion efficiency of the gasification process, which can vary substantially. It is generally influenced by the gasification conditions, i.e., the quantity and quality of the oxidizing agent. For example, the use of pure oxygen instead of air leads to qualitatively better syngas generation, with a higher LHV. Different η_{CG} values have been suggested in the literature. In this experiment, the η_{CG} was fixed at 0.414.

The use of LCA to evaluate the environmental impacts of converting biomass to bioenergy, including electricity, has been studied intensively in recent years (Cherubini and Stromman 2011; Sebastian et al 2011; Steubing et al 2011; Field et al 2013; Hertwich et al 2013; Pierobon et al 2014; Stephenson and MacKay 2014). In specifically, Stephenson and MacKay (2014) from the UK Department of Energy and Climate Change did a scenario assessment using North American woody biomass for the United Kingdom's electricity in 2020. They showed that the lowest GHG impact can be attained by using forest or mill residues or trees died by natural disturbance, which is the feedstock that would otherwise be burned as rubbish (<100 kgCO_2 -eq/MWh). Pierobon et al (2014) applied radiative forcing analysis to analyse the environmental impact of woody-biomass-based bioenergy conversion. Pierobon et al (2014) incorporated the dynamics of carbon sequestration, decomposition of residues, and biomass processing in the life cycle analysis framework of bioenergy and concluded that the adverse global warming (GW) impact associated with biomass collection and burning from industrial forests can be fully offset by the carbon sequestration during forest growth within about 18 yr.

To put biomass (wood) electricity production into context, according to the US Energy Information Administration (USEIA), wood-powered electricity is estimated to be 43.4 million MWh for the year 2016 which is a considerable value for many countries but it is only about 1% of the US electrical grid (USEIA 2016). Regardless of the existing value for the United States, there is great potential in increasing wood-powered electricity (USDOE 2016). Thus, as it is in this situation, it is crucial that LCAs continue to examine new technologies as they are generated. LCA can focus on components of the lifetime of the technology that may not be considered until a method gets commercialized. It can do this while the process is still in the development phase to evaluate what-if possibilities.

From the review of LCA work for bioenergy systems by Cherubini and Stromman (2011), it was found that the net GHG emissions from biomass-generated electricity are usually 5-10% of those from fossil-fuel-based electricity, and GHG emissions could be lower if the feedstock biomass is derived from residue streams such as logging slash and small-diameter trees. All the studies reviewed by Cherubini and Stromman (2011) assumed neutral climatic impact from biomass combustion in terms of CO_2 emissions. Steubing et al (2011) conducted a cradle-to-grave LCA of a poly-generation unit that produced synthesis gas (syngas) for heat, electricity production, and transportation fuel. They contrasted the findings with a fossil-fuel-based system. Their analysis suggested substantially less influence on climate change when syngas were replaced with fossil fuel, but these benefits were largely compensated by new environmental problems linked to human health and eutrophication. They saw syngas from wood used for transportation fuel as a viable technology in light of the rising demand for sustainable transportation fuels. Field et al (2013) did a case study on a Colorado regional coproduction of biochar and bioenergy from biomass residue feedstock. Their financial investigation indicated that the returns were typically bigger when biochar was employed for energy (coal) than when used for soil amendment (biochar), while biochar application had greater GHG reduction value than coal. The goal of this study focused on the down-stream process of burning syngas produced from a distributed-scale advanced biomass pyrolysis system which will be referred to as the Tucker (developed by Tucker Engineering Associates, Inc., Locust, NC) renewable natural gas (RNG) unit to generate electricity. The authors will answer the question of how much environmental damage can be minimised if woody-biomass-derived syngas energy is substituted for fossil-fuel-based power. Applying LCA can help to examine the processes or technologies for energy and environmental advantages and locate the environmental “hot spots” (highest points) of the major impact categories.

CHAPTER THREE

RESEARCH AND METHODOLOGY

The steps outlined below were undertaken to perform the analysis in this study:

- Collation of general performance data of various gasification technologies in small scale production.
- Performing down selection process with developed criteria to identify the most suitable technology.
- Sizing and costing of equipment
- Determining the cost of syngas production
- Determining capital investment and performing discounted cash flow analysis
- Performing sensitivity analysis on process and economic parameters.

3.1 DOWN-SELECTION PROCESS

This can be defined as a process of choosing the best option for a certain activity when presented with different criteria. There are criteria to be met when selecting the right option for a project. In this case, we intend to select the right gasification technology to be incorporated to this project. The technologies considered are shown below:

1. Fluidized Bed Gasifier
2. Entrained Flow Gasifier
3. Cross-Draft Gasifier
4. Updraft Gasifier
5. Downdraft Gasifier

3.1.1 PRELIMINARY CRITERIA

The following criteria are employed during the selection process of this project:

I. The gasification technology selected should be easily reproducible and low cost in its construction.
II. The gasification technology should have tolerance for a range of biomass fuels.
III. The gasification technology shouldn’t require extraneous biomass processing before feeding can occur.
IV. The technology employed should be able to produce syngas devoid of tar, so as to avoid unnecessary post-processing cost.
V. Suitability for small scale power production

3.1.2 TECHNOLOGY SELECTION

Downdraft gasification technology was selected due to it meeting the criteria given above. It is very suitable for use in small scale production. As seen in Chapter 2, it was shown that downdraft gasification produces highly clean syngas which can be utilized by internal combustion engines and also produces little tar and char.

3.1.3 TECHNOLOGY NOT CHOSEN

Entrained flow operates at high temperatures which gives room for complete cracking of tar and it has low residence time of biomass in the unit and have been seen to be useful in large scale plant (Wang et al, 2013). These are promising features but it has certain drawbacks as it requires fine pulverized feed within the range of 0.1-1mm which means higher pre-processing cost

(Molino et al, 2016), high energy cost for biomass reduction (Siedlecki et al, 2011) and it also requires biomass with very low moisture content.

Fluidized bed has a process that is complex thus requires well-trained personnel to operate which goes against the concept of simplicity for the average household. Other drawbacks include instability of the bed, high tar content of produce gas.

The fixed bed gasifiers which were not selected, i.e., Updraft and Cross-Draft gasifiers, both share some similar characteristics with the downdraft but were knocked off due to the high level of tar formed with syngas produced.

3.2 COST-BENEFIT ANALYSIS

The Net Present Value (NPV) approach was used to examine the economic viability of the proposed Downdraft Gasifier Generator (DGG) technology. All cash flows of the proposed Downdraft Gasifier Generator (DGG) system are studied over 20 years and resolved to their equivalent present worth (PW) cash flow. Revenues were thought to represent positive cash flows while costs were seen as negative. The NPV of the DGG system was estimated by the following equation:

$$NPV = CAPEX + PW(O\&M) + PW(BCT) - PW(ES) - SV \qquad \text{--------------------------}(1)$$

where CAPEX is the capital cost that included the initial investment cost of constructing of the Downdraft Gasifier Generator system (DGG), O&M is the operation and maintenance cost, BCT is the cost of procuring the biomass, ES is the incomes from selling electricity to customers and

SF is the salvage value of the project after its useful life. The PW is the present value, which is calculated with annual value (AW).

$$PW = AW\frac{(1+i)^{N}-1}{i(1+i)^{N}} \quad \text{---}(2)$$

where i denotes the interest rate (an interest rate of 18.75% was used based on CBN's Monetary Policy Rate, January 2024), and N denotes the assumed operation years (N = 20 years in this study).

3.2.1 CAPEX AND O&M COST

The capital cost (CAPEX) was determined by the Bills of Engineering & Materials which was meticulously drafted out (Table 3.1). The Downdraft Gasifier Generator has been fabricated and the cost of production for the fabrication process was determined to be ₦551,600. O&M cost refers to the cost it will take for operation and maintenance of running the device.

TABLE 3.1 BILL OF ENGINEERING MEASUREMENT AND EVALUATION (BEME) FOR THE GASIFICATION SYSTEM

S/N	DESCRIPTION	QUANTITY	UNIT PRICE (₦)	TOTAL PRICE (₦)
1	2.5″ galvanized pipe	4 lengths	18,000.00	72,000.00
2	2″ galvanized pipe	1 length	13,000.00	26,000.00
3	1″ galvanized pipe	1 length	7,000.00	7,000.00
4	Drum	2	18,000.00	36,000.00
5	Blower	1	17,000.00	17,000.00

6	Flexible copper wire	10 yards	700.00	7,000.00
7	High temperature rubber hose	3m	13,000.00	13,000.00
8	Galvanized clips	18	500.00	9,000.00
9	Cast iron plug adaptor	6	2000.00	12,000.00
10	Paint cup	3	2,500.00	7,500.00
11	Bolts	23	600.00	13,800.00
12	Nuts	23	600.00	13,800.00
13	2mm sheet metal	3	25,000.00	75,000.00
14	2" angle bar	1 length	6,000.00	6,000.00
15	Square rod	1 length	8,500.00	8,500.00
16	12 volts battery	1	38,500.00	38,500.00
17	High temperature silicon gel	2 tubes	2,000	4,000.00
18	Jam bottles	2	500.00	1000.00
19	Weighing scale	1	4,500.00	4,500.00
20	Pocket size digital multimeter (MAS830)	1	12,000.00	12,000.00

21	High Temperature Type K thermocouple block ceramic kiln probe	1	14,000.00	14,000.00
22	Digital K type thermocouple (TM-902)	1	16,000.00	16,000.00
23	3” stainless steel pipe	1 length	22,000.00	22,000.00
24	Cylindrical tank	4	4,000.00	16,000.00
25	Labour		100,000.00	100,000.00
	Total			**551,600.00**

*1 Length = 18 feet.

It has been determined that a 5kVA generator will be required to produce the required power and that has been determined from market prices to be ₦415,000 which brings up the capital cost to a sum of ₦966,600. According to the standard practices put out by the International Renewable Energy Agency, IRENA, in 2018, it has been stated that for gasifiers, the operation and maintenance cost ranges from 3-6% of the original capital cost. An optimum value of 4.5% was taken for the operation and maintenance cost.

3.2.2 ELECTRICITY UNITS SALES REVENUE AND SALVAGE VALUE

The parameter, ES, refers to the benefits gotten by the producer from selling units of electricity gasifier. The electricity selling price was obtained through the LCOE (Levelized Cost of Electricity). The DGG has been rated to produce 2000W per hour. The salvage value has been taken to be 10% of the initial investment cost.

3.2.3 BIOMASS COST

According to research conducted by Akhator et al., 2016, it was determined that the availability of wood waste in Benin City was 335,460.04 tons per year. It has been determined that the specific biomass cost was N6.00/kg after adjustment for inflation (Iyamu et. al., 2019). This is helpful in determining the biomass cost.

3.3 LIFE CYCLE ANALYSIS

3.3.1 GOAL AND SCOPE

The purpose of this Life Cycle Assessment is to examine the environmental implications of the project from the wood chips transportation to the power generation, and all the activities in between.

The scope encompasses analyzing energy generation, emission of pollutants and potential environmental repercussions to inform decision-making towards more sustainable solutions. The Cradle-to-gate technique was utilised for this study, in order to measure the power produced from the syngas of the downdraft gasifier. Due to the fact that this study focused on the generation of electricity from syngas, all environmental burdens were allocated to the syngas as the product of interest. Residues encountered in the course of gasification such as char, H2S and others took zero environmental load from the system, but its role for the long-term storage in the soil was examined for carbon sequestration advantages in the LCA in offsetting the syngas power impacts.

Primary data was acquired from the functioning of the downdraft gasifier. The feedstock was wood chips acquired from sawmills across Benin City. The wood of choice was Cordia millenii, with moisture content of 9.84% and energy content of 19.78 MJ/kg. (Akhator P.E et al, 2017).

The values of the different input and output flows for the different processes were calculated first, and then the system was modeled using the OpenLCA software, a powerful free and open source LCA modelling software, while the ecoinvent version 3.10 Allocation at Point of Substitution (APOS) unit processes database was used to provide additional data and processes for this research, The impact method used for the calculation was the Centrum voor Milieukunde Leiden (CML) version 2001, and the allocation method of choice was physical.

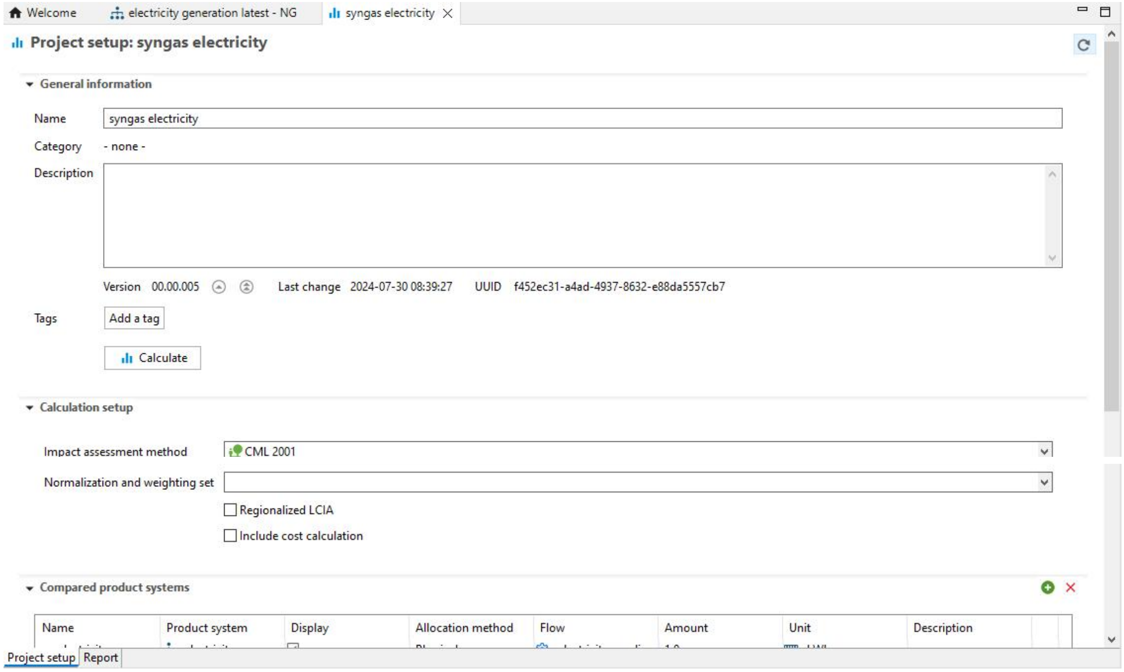
3.2.4 LCA FOR EXPERTS

In today's eco-conscious world, the openLCA software has emerged as a cornerstone for experts navigating Life Cycle Assessment (LCA).

Its key features include an extensive list of databases which can be gotten from the openLCA Nexus website, advanced modeling capabilities, and customization options. By enabling detailed scenario simulations and precise parameter adjustments, OpenLCA enhances the accuracy and efficiency of environmental assessments.

Moreover, OpenLCA's reporting and visualization tools facilitate effective communication of assessment results, fostering stakeholder engagement and informed decision-making.

In essence, OpenLCA represents a significant leap forward in sustainability efforts, empowering organizations to make informed decisions and drive positive environmental change, and is the LCA software of choice for this study because of its extensive features, and reliability.



Project setup: syngas electricity

General information

Name: syngas electricity
Category: - none -
Description:
Version 00.00.005
Last change 2024-07-30 08:39:27
UUID f452ec31-a4ad-4937-8632-e88da5557cb7
Tags

Calculation setup

Impact assessment method: CML 2001
Normalization and weighting set:
☐ Regionalized LCIA
☐ Include cost calculation

Compared product systems

Name	Product system	Display	Allocation method	Flow	Amount	Unit	Description

3.2.5 LIFE CYCLE INVENTORY (LCI)

Within the LCA approach, the LCI phase measures all the raw materials and energy inputs for creating 2 kWh of electricity from the syngas produced by the downdraft gasifier within the set system boundary. The emission profiles covered activities linked with feedstock (wood chips) transportation, wood chips gasification (syngas generation), and lastly the syngas transportation and combustion for generating power.

ASSUMPTIONS

The following assumptions were taken in order to carry out this LCA:

- Generator was already on site.
- Syngas was used to produce electricity as soon as was produced.
- Mass of char is 10% of the mass of syngas produced.
- The energy generated = 2 kWh.
- Functional unit = 1 kWh.
- Emission reduction (E.R.) = 0.25.
- $1\ kg\ of\ wood = 2.02\ kg\ of\ syngas$
- Ratio of mass of air to wood for consumption = $5.8 kg\ air\ per\ 1 kg\ wood$.
- Lower Heat Value (LHV) of the syngas is the Calorific value.
- Distance of wood waste to syngas production site = $100\ km$.
- Gasification reaction: $\mathbf{CH_aO_bN_cS_dAsh + yH_2O + x\ (O_2 + 3.76N_2) \Rightarrow z_1H_2 + z_2CO + z_3CH_4 + z_4CO_2 + z_5N_2 + z_6H_2O}$ **+ char + Ash + impurities (tars, H_2S, dust).**
- Mole fraction of syngas = 16.642% H_2, 28.15% CO, 2.538% CH_4, 6.132% CO_2, 45.418% N_2.

LCI CALCULATIONS

MASS OF AIR REQUIRED FOR GASIFICATION

$$Emission\ Reduction\ = \frac{Actual \frac{Air}{Fuel} Ratio}{Schoichiometric \frac{Air}{Fuel}\ ratio}$$

$$Actual \frac{Air}{Fuel}\ Ratio = 0.25\ \times 5.8$$

$$Actual \frac{Air}{Fuel}\ Ratio = 1.45$$

$$Recall\text{: } 1\ kg\ of\ wood = 2.02\ kg\ of\ syngas\ (basis\ of\ the\ calculation)$$

From the reaction:

$$mass :: \ wood\ (moisture\ included) + air = syngas + char + residue\ (particulates)$$

LHV = 10.78 H_2 % + 12.63 CO % + 35.88 CH_4

$LHV = (10.78\ \times 0.16642) + (12.63\ \times 0.2815) + (35.88 \times 002538)$

LHV = 6.26 MJ/m^3

Density of syngas = 0.95 kg/m^3

LHV = 6.59 MJ/kg

$Generator\ rating = 2kWh = 7.2\ MJ/kg$

To produce 1 kWh of electricity, 0.5463 kg of syngas will be required, and to produce 2 kWh of electricity, 1.0926 kg of syngas will be required.

$$Efficiency\ of\ Syngas = 21\%$$

$$Actual\ amount\ of\ syngas\ for\ 1\ kWh\ of\ electricity = \frac{0.5463}{0.21} = 2.6\ kg$$

$$Mass\ of\ wood\ waste\ = \frac{2.6}{2.02} = 1.287\ kg$$

$Required\ mass\ of\ air = 1.866$ kg

$$Mass\ of\ char = 0.26\ kg$$

Mass of residue = (1.287 + 1.866) – (2.6 + 0.26) = 0.293 kg

$$1\ mole\ of\ syngas\ (100\ \%\ mole\ fraction) = 2.6\ kg$$

TABLE 3.2 MASS FRACTION OF SYNGAS

Constituent	Mole fraction	Molar mass	Mass	Mass fraction
H_2	0.16642	2	0.333	0.0138
CO	0.2815	28	7.882	0.328
CH_4	0.02538	16	0.406	0.0169
CO_2	0.06132	44	2.698	0.112
N_2	0.45418	28	12.717	0.529
TOTAL			24.035	

Mass of H_2 = 0.0138 × 2.6 = 0.0359 kg

Mass of CO = 0.328 × 2.6 = 0.853 kg

Mass of CH_4 = 0.0169 × 2.6 = 0.0439 kg

Mass of CO_2 = 0.112 × 2.6 = 0.291 kg

Mass of N_2 = 0.529 × 2.6 = 1.375 kg

NOTE: The remaining 1.12 % (0.0012 kg) mole fraction of the syngas are the impurities.

MASS OF EMISSION GASES

When the syngas combusts with air in the generator, the oxygen in the air reacts with the various constituents of the syngas except **N_2 and CO_2**.

The different balanced chemical reactions are as follows:

- **Hydrogen combustion**

$2H_2$	+	O_2	$2H_2O$	(reaction)
2 moles	+	1 mole	2 moles	(number of moles)
4	+	32	36	(molar mass)
1	+	8	9	(moles fraction)
0.0359	+	0.2872	0.3231	(mass in kg)

- **Carbon monoxide combustion**

2CO	+	O_2	$2CO_2$	(reaction)
2	+	1	2	(number of moles)
56	+	32	88	(molar mass)
1	+	0.571	1.571	(moles fraction)

0.853 + 0.487 1.34 (mass in kg)

- **Methane combustion**

CH_4 + $2O_2$ CO_2 + $2H_2O$ (reaction)

1 + 2 1 + 2 (number of moles)

16 + 64 44 + 36 (molar mass)

1 + 4 2.75 + 2.25 (moles fraction)

0.0439 + 0.1756 0.1207 + 0.0988 (mass in kg)

$TOTAL\ MASS\ OF\ OXYGEN = 0.2872 + 0.487 + 0.1756 = 0.9498$ kg

By weight, Oxygen = 0.23 × mass of air

Mass of air = $\frac{mass\ of\ O2}{0.23} = \frac{0.9498}{0.23}$ = 4.13 kg

Mass of N_2 in air = 4.13 – 0.9498 = 3.1802 kg

MASS OF EXHAUST GASES

The exhaust gases CO_2, H_2O, N_2, residual gases and their respective masses are as follows:

- **Mass of CO_2**

Mass of CO_2 = unreacted CO_2 in the syngas + CO_2 produced after combustion

CO_2 = 0.291 + 1.34 + 0.1207 = 1.7417 kg (after the combustion of 2.6 kg of syngas)

- **Mass of H_2O**

  Mass of H_2O = total mass of H_2O after combustion

  H_2O = 0.3231 + 0.0988 = 0.4219 kg (after combustion of 2.6 kg of syngas)

- **Mass of N_2**

  Mass of N_2 = unreacted N_2 in the syngas + N_2 in the air

  N_2 = 1.375 kg + 3.1802 = 4.5552 kg (after combustion of 2.6 kg of syngas)

- **Mass of Residual Gases**

  Mass of residual gases = unreacted residual gases in the syngas

  Residuals = 0.0012 kg (after combustion of 2.6 kg of syngas)

INVENTORY TABLE

The inventory table (Table 3.1) is shown below:

TABLE 3.3 LIFE CYCLE INVENTORY TABLE

INPUT	AMOUNT	UNIT
Wood Chips (10% moisture content)	1.287	kg
Air (for gasification)	1.866	kg
Syngas	2.6	kg
Air (for combustion)	4.13	kg

Diesel (additional for transport)	0.005	kg
Transport (for wood)	260	kgkm
Generator, 5KVA	1	pcs
OUTPUT		
Electricity	1	K Wh
Carbon dioxide	1.7517	Kg
Nitrogen	4.5552	Kg
Water Vapour	0.4219	Kg
Particulate Matter	0.0012	kg

LIFE CYCLE IMPACT ASSESSMENT (LCIA)

The lifecycle impact assessment would involve evaluating the environmental impact associated within the stages within the system boundary. All the different input and output flows of the different processes, from wood chips transportation to electricity generation will be modeled in the OpenLCA software and the Centrum voor Milieukunder Leiden (CML) impact methods was used to analyze relevant environmental impact categories which include:

- Global warming potential: This is a measure used to compare the potency of greenhouse gases in trapping air over a period of time (in this case 20 years), relative to carbon dioxide.

- Acidification potential: This is a measurement of the ability of a substance to contribute to the acidification of the environment through emissions of acidic pollutants (SO_2 is the pollutant measured in this study).
- Human health impacts (respiratory issues): this impact category assesses the potential harm that can be caused to human health (in this case 20 years). It considers factors such as toxicity, persistence, and bioaccumulation to quantify the impact on human health.

3.3 TECHNO-ECONOMIC ASSESSMENT

The system's economic performance is initially proved by many common economic indicators, such as the levelized cost of energy (LCOE), internal rate of return (IRR), and net present costs (NPC). The LCOE stands for the unit electricity cost in systems generated during the complete life cycle of the system. The computation for LCOE is illustrated in equation (1) as stated by Evans et al. (2009).

$$LCOE = \frac{\sum_{n=0}^{N} C_n(1+r)^{-n}}{\sum_{n=0}^{N} E_n(1+r)^{-n}} \qquad \text{---(3)}$$

An economic sensitivity analysis was undertaken to evaluate how uncertainty in capital and operating cost predictions can influence fuel prices.. The capacity estimated for the gasification unit is 2kW input, based on the biomass lower heating value of 19.78MJ/kg. This guarantees the fuel synthesis facility takes use of the benefits of scale while being unrestricted by feedstock availability where

$\sum_{n=0}^{N} C_n(1+r)^{-n}$ represents the total cost of the year, CNY;

$\sum_{n=0}^{N} E_n (1+r)^{-n}$ represents the total Power consumption in kWh; and r is the discount rate. The above formula can be further simplified to:

$$LCOE = I_{t,e} + F_{c,e} + O\&M_{c,e} \quad \text{---(4)}$$

The present value of all the expenses a system incurs over its lifespan less the present value of all the money it generates is the system's total net present cost (NPC). Costs include fuel costs, pollution fines, replacement costs, O&M costs, capital expenditures, and grid power purchase costs. Salvage value and grid sales revenue are examples of revenues.

The following equation, equation (3) calculates NPC :

$$NPC = \frac{C_{ann,tot}}{CRF_{\left(r,\ R_{proj}\right)}} \quad \text{---(5)}$$

where $C_{ann,tot}$, is the total yearly cost; $CRF_{(r,\ Rproj)}$ is the capital recovery factor ; r, interest rate, %; R_{proj} represents the project lifetime. The capital recovery factor is a ratio that can be used to assess the present value of a sequence of equal annual cash payments. The formula is stated using equation 4:

$$CRF = \frac{i(1+i)^n}{(1+i)^n - 1} \quad \text{---(6)}$$

Internal rate of return (IRR) is the discount rate when the net present cost (NPC) is zero in the life of the system, which is calculated by equation. (5).

$$\sum_{t=0}^{n} (CI - CO)_t \left(\frac{P}{F}, IRR, t\right) = 0 \qquad \text{---(7)}$$

where $(CI - CO)_t$ represents the net cash flow of the n-th year; P is the principal, and F is the end value.

The reliable operation of a power plant over its lifetime heavily relies on adequate maintenance. However, the duration of maintenance periods is directly tied to the plant's annual operational hours. The operation and maintenance (O&M) cost requires precise information on variables such as maintenance personnel costs, replacement parts, and repairs, which can be challenging to obtain. Nevertheless, according to IRENA (2018), gasifiers typically incur an O&M cost between 3-6% of the total plant cost per year. For this calculation, an average O&M cost of 4.5% of the total plant investment cost (I_{tot}) was used, as shown in Equation 8.

$$O\&M_{c,\,a} = 0.045C_{ann,tot} \qquad \text{---(8)}$$

The specific O&M cost is obtained from Equation 8,

$$O\&M_{c,\,e} = \frac{O\&Mc,a}{Et} \qquad \text{--(9)}$$

$$I_{t,\,e} = I_t \div E_t \qquad \text{--(10)}$$

Where E_t , is the yearly total electrical energy (kWh/yr).

Annual cost of biomass (Fc,a in N/yr) was calculated by multiplying the biomass consumption rate (kg/h), biomass specific cost (Fc,s in N/kg), and annual operation time ($t_{o,\ yr}$) together as shown in Equation 11.

$$F_{c,\ a} = m_f \times F_{c,\ s} \times t_{yr} \qquad \text{---}(11)$$

The annual specific cost of biomass $F_{(c,\ e)}$ was determined by relating annual cost of biomass with the energy generated per year using Equation 12.

$$F_{c,\ e} = F_{c,\ a} \div E_t \qquad \text{---}(12)$$

The reliable operation of a power plant over its lifetime depends immensely on adequate maintenance.

3.3.1 NUMERICAL INDICATORS

A unique approach must be used to integrate all of the economic and technical evaluation indices that must be taken into account simultaneously in order to make an efficient assessment (Chambers et al., 2012). In this work, evaluation indices selected are combined into a comprehensive evaluation indicator via multiple index assessment approach.

The comprehensive benefit evaluation index of renewable energy power generation system constructed in this paper is shown in the table below. Evaluation indicators are classified into two sorts of positive and negative indicators.

TABLE 3.4 EVALUATION INDICATORS

S/N	*Evaluation Index*	*Property*
1	Levelized cost of energy	-
2	Internal rate of return	+
3	Net present Value/Costs	+
4	Avoided carbon dioxide emissions	+
5	Renewable fraction	+

A better system performance is indicated by higher values for positive indicators like internal rate of return, return of gain, net present value, avoided carbon dioxide emissions, and renewable fraction; higher system performance is indicated by lower values for negative indicators like levelized cost of energy.

3.3.2 ECONOMIC PARAMETERS

An economic sensitivity analysis is undertaken to evaluate how uncertainty in capital and operating cost predictions can influence fuel prices. An environmental LCA study assesses the environmental implications of biofuel production from biowastes. The capacity estimated for the gasification unit is 2kW input, based on the biomass lower heating value of 19MJ. This guarantees the fuel synthesis facility takes use of the benefits of scale while not being limited by feedstock availability.

For the economic study, the net present value of the plant and the breakeven selling price are computed using the discounted cash flow rate of return methodology. The values for the economic parameters used in the economic analysis are shown in the table below

TABLE 3.5 ECONOMIC INDICATORS IN THE ECONOMIC ANALYSIS

Plant Operation Time	
Daily (hrs/day)	14
Yearly (days/year)	360
Generator Power Output (kW)	2 kW
Daily Generator Power Output (kWh)	28
Annual Generator Power Output (kWh/year)	10,080
Fuel	
Biomass Consumption Rate	3.704 kg/hr
Efficiency of Generator	21%
Specific Biomass Rate	₦3.00/kg

Gasoline Consumption Rate	1.11L/hr
Specific Cost of Gasoline (Market Value)	₦600.00/L

By giving costs or values to specific flows or inventories, all input-output inventories in a particular system boundary for a certain functional unit in environmental LCA should be taken into account for LCC in terms of granular level data.

TABLE 3.6 COST VARIABLES

Cost Variables	
Capital Expenditure Cost (CapEX) (₦)	452,166.00
Annual Fuel Cost (₦)	56,004.40
Operation & Maintenance Cost (₦)	20,347.00
Discount Rate (%)	18.75

For the variable costs, the maintenance and repair costs are estimated at 4.5% of the total capital investment.

TABLE 3.7 VARIABLE COSTS

Variable Costs	
Operation & Maintenance Costs	₦20,347.47

Biomass Cost/year	₦56,004.48
Total	₦76,351.95

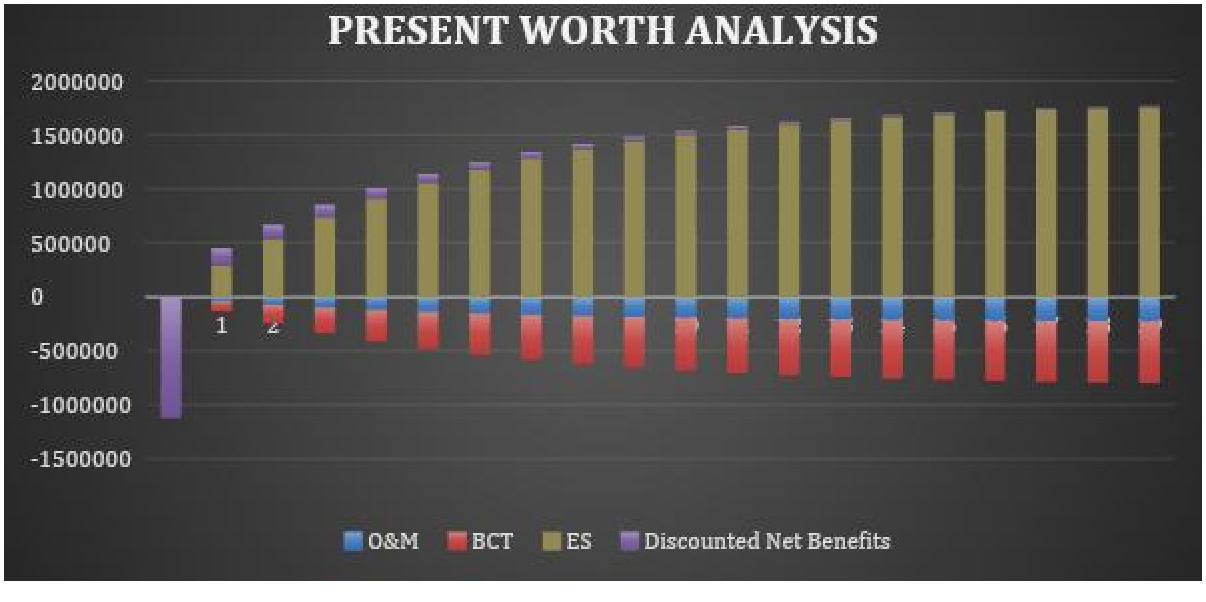
CHAPTER FOUR

RESULTS & DISCUSSION

4.1 COST-BENEFIT ANALYSIS

4.1.1 PRESENT WORTH ANALYSIS

The following results were obtained after running an extensive cost-benefit analysis for the Downdraft Gasifier Generator system, these results are displayed in Fig 4.1. It was found from economic evaluation that the Levelized Cost Of Electricity was ₦34.009kWh. The total NPV as at year 20 was -₦157,606.95. The cumulative present worth of the O&M cost in year 20 was ₦3217667.08. The PW of the biomass cost was ₦574493.956 in year 20. The sources of revenue for the DGG system were the ES and salvage value at the end of its total lifespan with the cumulative PW value of electricity selling revenue being ₦25359080.26.



4.1.2 PAYBACK ANALYSIS

From analysis, it has been determined that the project will yield a negative net present value after the projected useful life. Analysis shown on the chart in Fig 4.2 showed that there was steady growth in the net present value. For the project to be economically viable, i.e., to produce a payback in 10 years, it has been determined that the following conditions should exist:

1. The O&M cost of the system needs to be reduced by 30%
2. The biomass cost needs to be decreased by 40%

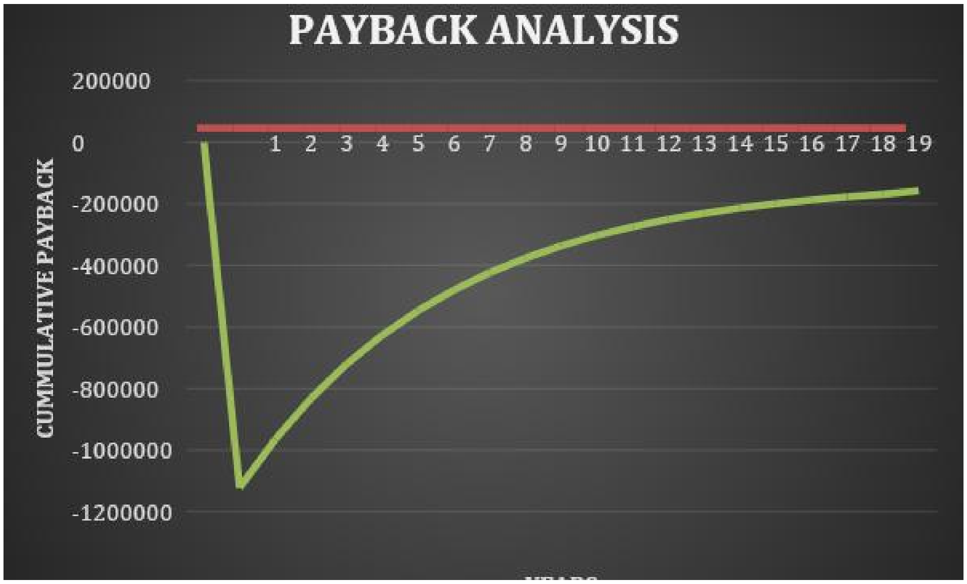


FIGURE 4.2 PAYBACK ANALYSIS CURVE

4.1.3 SENSITIVITY ANALYSIS

The impacts of four factors towards NPV were studied via sensitivity analysis and these factors include the Electricity Selling revenue, Operation and Maintenance Cost, Salvage Value after its useful life, and Biomass cost, the impact is represented on the chart as seen in Fig 4.3. It can be seen from the chart that the least sensitive parameter is the O&M cost as a large difference in it will impact the Net Present Value. However, it can be observed that very little changes in the values of the other parameters can cause a change in the Net Present Value of this project with the most sensitive parameter being the electricity selling revenue. From calculations, it has been a 9% change in its value can have large effect on the success of the project. Hence, it can be said that the profitability of the project can be greatly increased with the sales revenue of electricity rising with the costs such as O&M cost and Biomass Cost, reducing.

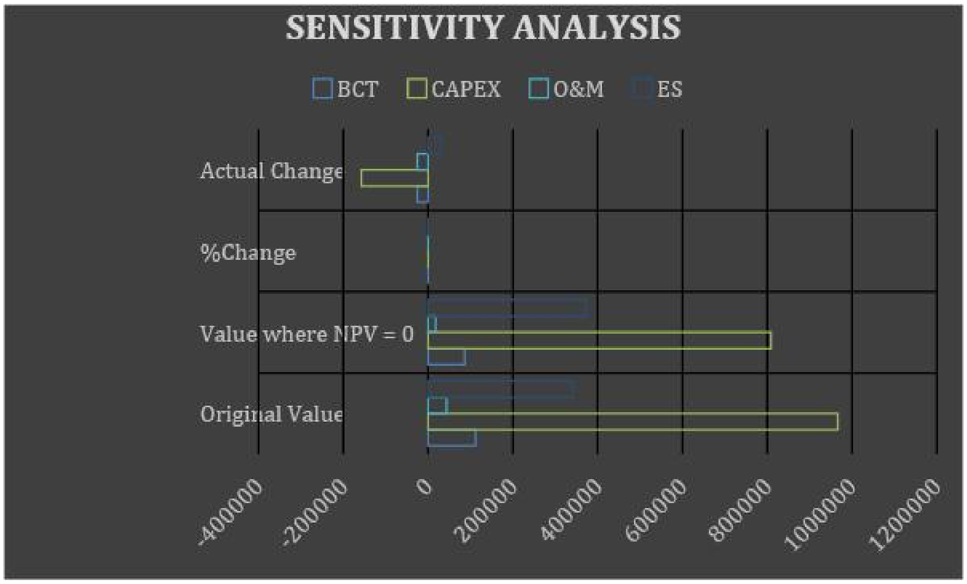


FIGURE 4.3 SENSITIVITY ANALYSIS CHART

4.2 ECONOMIC ANALYSIS

4.2.1 ECONOMIC ANALYSIS RESULTS

The following data were calculated using the methodology described in Chapter 3, and the following results (Table 4.1) were obtained

TABLE 4.1 ECONOMIC ANALYSIS

Cost Parameters	Generator with Biomass Gasifier	Gasoline Generator
Capital Expenditure Cost (CAPEX) (₦/kWh)	18.577	7.976
Annual Fuel Cost (₦/kWh)	11.112	357.5
Operation & Maintenance Cost (₦/kWh)	4.315	1.852
LCOE (₦/kWh)	34.009	367.028
WACC(%)	18.75	18.75
IRR (%)	16%	

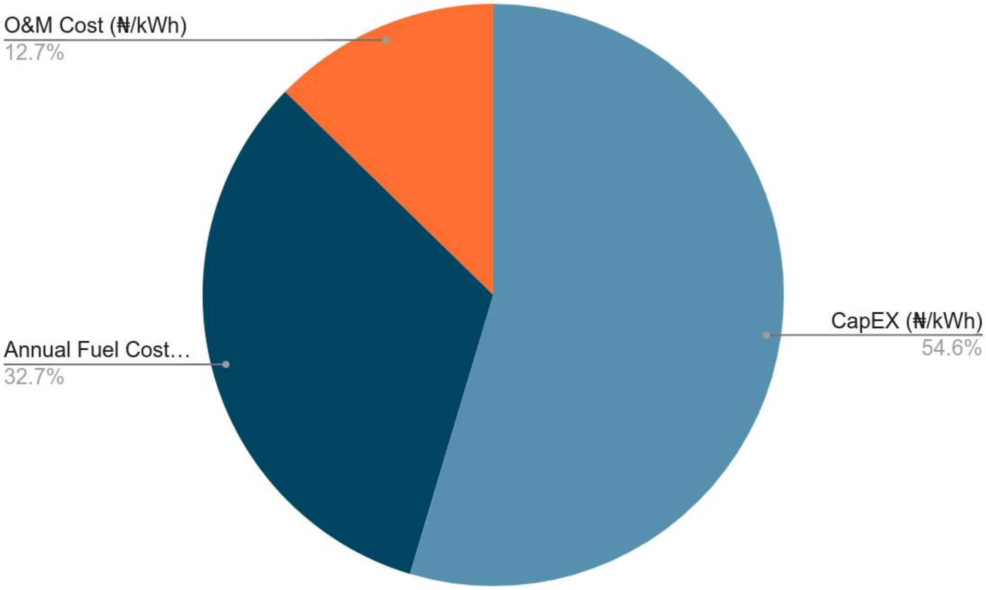
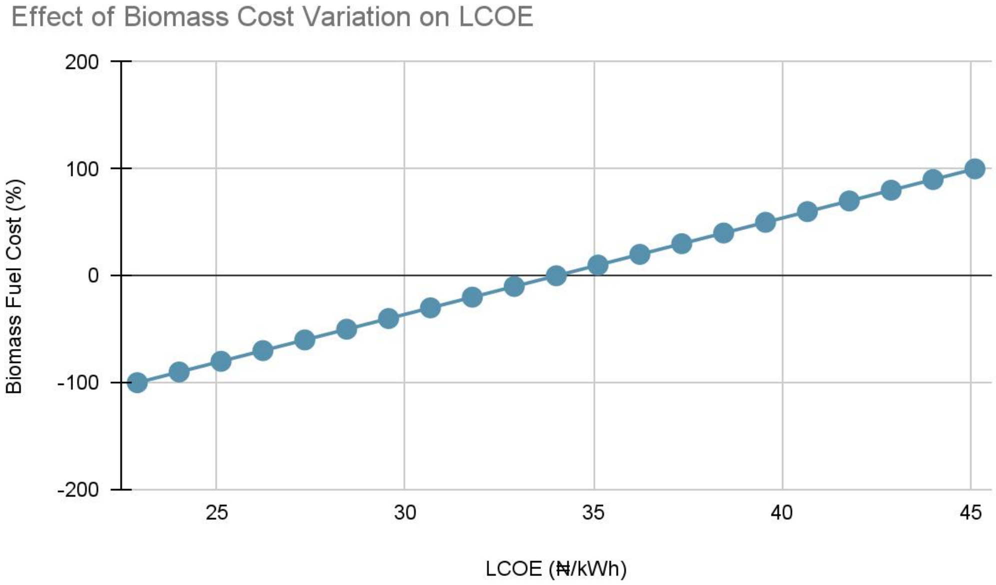


FIGURE 4.4 CHART SHOWING COMPOSITION OF THE LCOE RESULT

4.2.2 EFFECT OF BIOMASS COST ON L.C.O.E

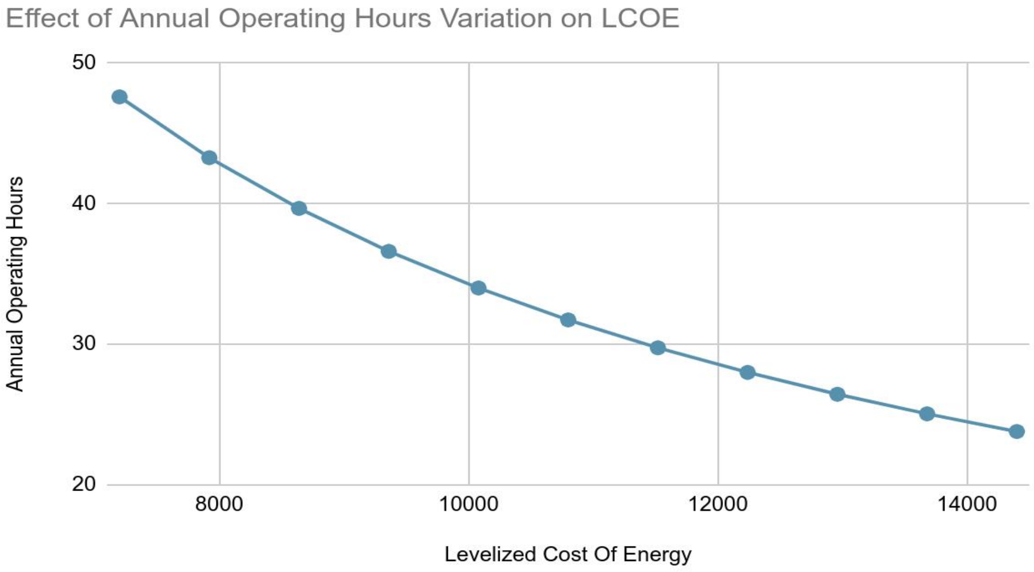


The analysis shows that the price of biomass fuel and the Levelized Cost of Energy (LCOE) are directly correlated. Biomass accounts for a sizable portion of total operating costs, changes in its cost have a direct impact on the LCOE.

This sensitivity emphasizes the importance of reliable and affordable fuel sources to maintain long-term economic sustainability. Fluctuations in the price of biomass can strongly impact the competitiveness of syngas generation among alternative energy sources.

4.2.3 EFFECT OF OPERATING HOURS ON LCOE

As the operation time which signifies the number of years the biomass generator runs, decreases, The LCOE of the system increases and vice-versa. Hence, while reducing operation time might seem like a cost-saving measure initially, the effect leads to an increase in the LCOE of the system thus potentially impacting the economic viability of the system.



4.2.4 EFFECT OF O&M COST VARIATION ON LCOE

The variation of the operation and maintenance costs has a linear effect on the LCOE value as shown in Fig 4.6 below. It shows that as the operation and maintenance costs increase it increases the LCOE value.

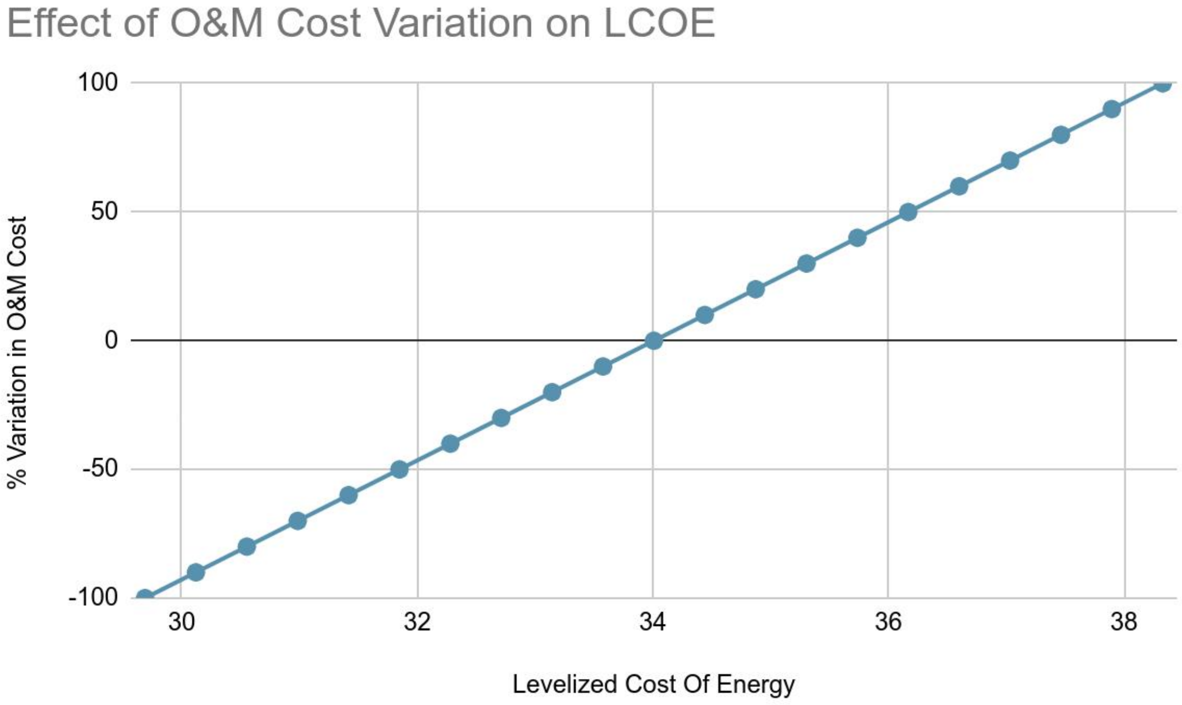


FIGURE 4.7 CHART SHOWING EFFECT OF O&M COST VARIATION ON LCOE

4.2.5 DISCUSSION OF RESULTS

The LCOE was obtained as 34.009 (₦/kWh) for the fixed bed downdraft gasifier fueled by wood waste and 367.028 (₦/kWh) for the gasoline generator. The results showed that the small-scale downdraft gasifier is more beneficial economically.

The LCOE was calculated for a 2kWh system that would supply electricity to household residences. It was observed that the LCOE of the biomass system was less than the current electricity tariff of Maximum Demand (MD1 and MD2) areas which have an electricity tariff range of 45.29 (₦/kWh) to 225 (₦/kWh) across all bands. It is also less than non-MD areas across Band A to Band C which are 45.80 (₦/kWh) to 225 (₦/kWh). The tariff rates of non-MD areas in Band D and Band E are higher than the LCOE.

Tariff Class	A	B	C	D	E
Min. Supply Hrs	20	16	12	8	4
(Tariff) Non MD N/KWh	225	68.56	56.91	41.2	41.21
(Tariff) MD 1 N/KWh	225	63.88	54.98	46.64	46.64
(Tariff) MD 2 N/KWh	225	63.88	54.98	46.64	46.64

FIGURE 4.8 CHART SHOWING TARIFF RATES ACCORDING TO BENIN ELECTRIC DISTRIBUTION COMPANY

4.3 LIFE CYCLE ASSESSMENT

4.3.1 LCA RESULTS INTERPRETATION

After modeling the lifecycle inventory using Gabi software, the LCIA was conducted using the CML method that was mentioned in the previous chapter. The impact categories measured are shown in the graphs below:

- Global Warming Potential 20: From this analysis, the GWP was found to be 0.111kg CO_2/kWh of electricity generated.

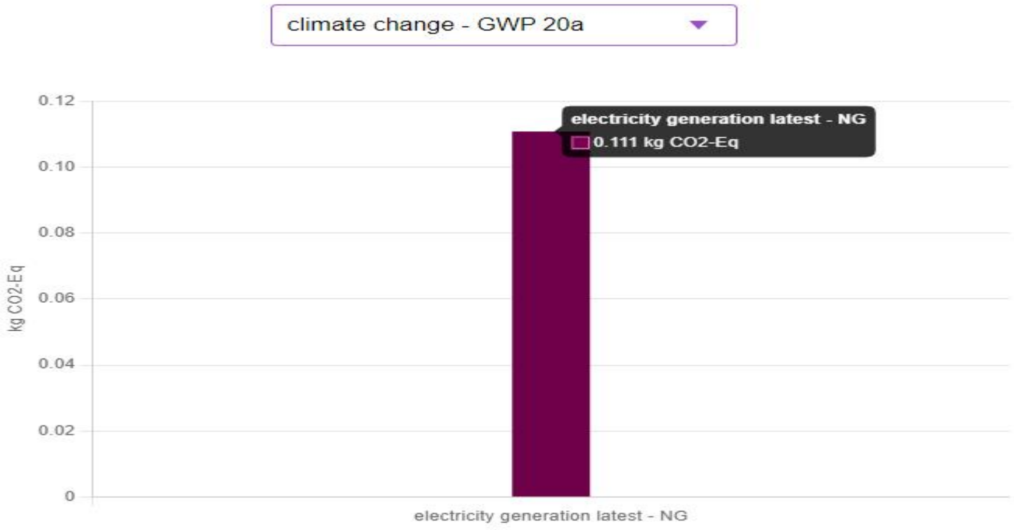


FIGURE 4.9 GLOBAL WARMING POTENTIAL 20 (KG CO_2/KWh)

- Acidification Potential: After calculations within the OpenLCA software, the AP for the syngas power plant was found to be 0.00044 kg SO_2/kWh.

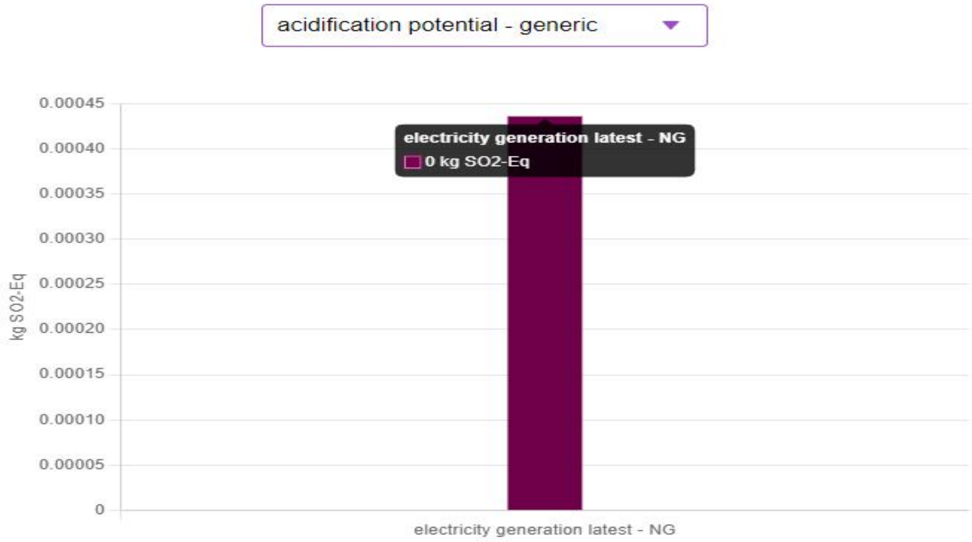
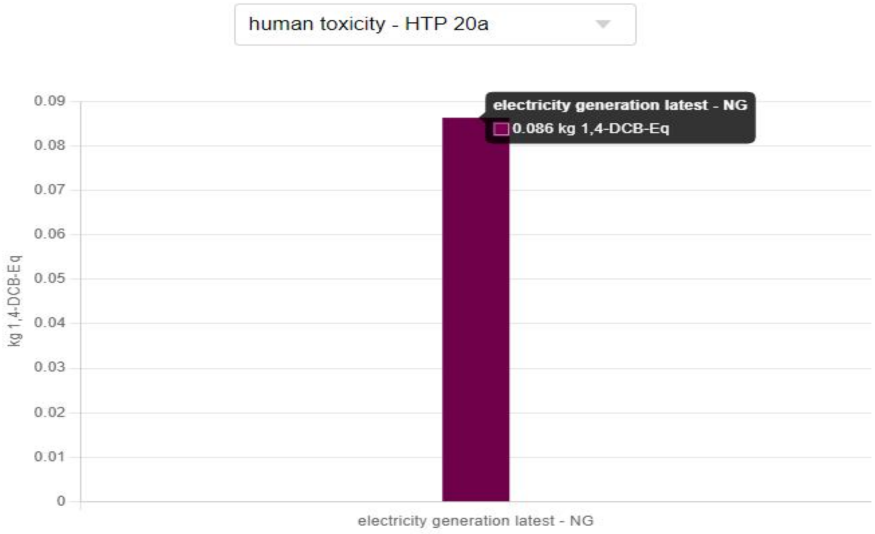


FIGURE 4.10 ACIDIFICATION POTENTIAL (KG SO_2/KWh)

- Human Toxicity Potential (HTP): The HTP gotten from the LCA was 0.0886 kg 1-4 DB/kWh.



IMPACT CATEGORIES RESULTS AGAINST OTHER ENERGY SOURCES

The table below shows a comparison between the syngas power plant, an Integrated Gasification Combined Cycle Power Plant (IGCC), and a Natural Gas Combined Cycle Power Plant (NGCC) (Yan et al., 2021), another biomass gasification power plant and a natural gas power plant (Shuangyin et al., 2020).

TABLE 4.2 IMPACT RESULTS COMPARISON AGAINST OTHER ALTERNATIVES

FIGURE 4.11 HUMAN TOXICITY POTENTIAL 20 (KG 1-4 DB/KWh)

	Unit	Syngas	IGCC	NGCC	Biomass Gasification	Natural Gas
Energy Efficiency	%	21	42	64	22	39
Global Warming Potential	kg CO_2 eq	0.111	0.813	0.459	0.0839	0.423
Acidification Potential	kg SO_2 eq	4.4E-4	3.79E-4	4.53E-4	3.36E-4	3.33E-4
Human Toxicity Potential	kg, 1-4 DB eq	8.86E-2	2.87E-3	1.39E-3	3.31E-2	4.83E-2

From the table above, the syngas power plant is compared to other power plants, including a biomass gasification plant, across three impact categories: Global Warming Potential 20 (GWP), Acidification Potential, and Human Toxicity Potential 20 (HTP). The syngas plant has a lower

GWP than most systems, except for the biomass gasification plant, due to differences in feedstock and the absence of Carbon Capture Systems (CCS). Acidification potential is generally similar across plants, with the syngas plant and NGCC having the highest values, while the Natural Gas plant has the lowest. The syngas plant has the highest HTP, primarily due to the large amounts of nitrogen gas released during electricity distribution.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

In conclusion, it can be said that the Downdraft Gasifier Generator plant has the capacity to be a game changer in the energy generation sector in Nigeria. However, the LCA also identifies areas for improvement before it can reach its full potential. As this technology is in its early stages, further research and development are crucial. This will determine its viability as a large-scale contributor to the energy grid. While the initial assessment is encouraging, focused efforts are required to address current limitation. Overcoming these challenges will pave the way for its successful integration into the energy sector as a substantial and sustainable fuel source.

The study examines the existing biomass gasification technologies and showcases the fixed bed downdraft gasifier as the technology to be adopted for a generator to produce small-scale power generation. Results from the study revealed the LCOE was obtained as 34.009 (₦/kWh) for the fixed bed downdraft gasifier fueled by wood waste and 367.028 (₦/kWh). The results showed that the small-scale downdraft gasifier is more beneficial economically. The LCOE was calculated for a 2kWh system that would supply electricity to household residences. It was observed that the LCOE of the biomass system was also less than the current electricity tariff of Maximum Demand (MD1 and MD2) areas which have an electricity tariff range of 45.29 (₦/kWh) to 225 (₦/kWh) across all bands.

The analysis has shown that this system can be a major player in the energy market but with a touch of increased revenue parameters, it can yield even greater returns and the payback period can be attained at a closer time. The sensitivity analysis showed that reducing capital investment, sourcing for cheaper biomass options, and increasing operation hours while reducing downtimes will increase the LCOE and achieve higher revenues from selling electricity from the plant. It also showed that the electricity selling revenue is the most sensitive parameter for the plant's success.

5.2 RECOMMENDATIONS

1. Cheaper biomass options should be sourced for the generator to reduce the annual biomass cost, this would increase the LCOE of the system and aid its economic viability.
2. It is recommended that the syngas should be made more efficient in order to reduce the quantity required to produce a unit value of electricity, as the quantity of syngas required is directly proportional to the amount of CO_2 emissions.
3. Syngas purification techniques should be put in place in order to reduce the acidification potential, and emissions capture should be installed in order to regulate the amount of harmful substances that gets exposed to the environment.
4. Further sources of revenue can be gotten from the plant, such as incorporating the heat generated from the exhaust to dry fish feed, drying clothes, etc.

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