UNIVERSITY OF RWANDA
COLLEGE OF SCIENCE AND TECHNOLOGY

AFRICAN CENTRE OF EXCELLENCE IN
ENERGY FOR SUSTAINABLE DEVELOPMENT

DECENTRALİSED BİOPOWER & RENEWABLE ENERGY ACCESS-POLİCY IMPERATİVES & MULTİ-STAKEHOLDER CRİTERİA

A thesis submitted in fulfillment to the University of Rwanda in accordance with the requirements for the award of the degree of

Doctor of Philosophy(PhD) in Energy Economics

June Chiaka Levi-Oguike

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UNIVERSITY OF RWANDA
COLLEGE OF SCIENCE AND TECHNOLOGY

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DECLARATION

I declare that this thesis entitled "Decentralised Biopower & Renewable Energy Access-Policy Imperatives & Multi-Stakeholder Criteria" to be submitted for the Degree of Doctor of Philosophy is the result of my own work and has not been submitted for any other degree at the University of Rwanda or any other institution.

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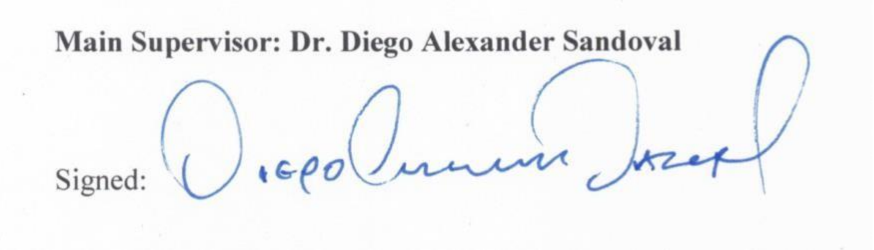
Signed:_____________

Date: 29th June, 2023



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Dedication

To my Children, for your unconditional love and patience.

ABSTRACT

Biomass is a diverse resource as its components are varied and provide the opportunity for its application in diverse facets of both urban and rural living. It is also one of the renewable energy sources for which the term *bio-refinery* has been coined due to the share potential of by-products from its conversion. In this guise and for the purpose of achieving the research objectives, *Biopower*-being electricity generated from Municipal Solid Waste (MSW), is the focus of this research. There are several technologies already in use for generating power using MSW as feedstock and these varying methods have been assessed within the literature comparatively, to determine among others, ease of adoption and adaptability to context, within valid cost considerations and financial constraints, their respective abilities to produce consistent net-energy yields, operate efficiently and related GreenHouse Gas (GHG) emissions, which should be considerably low or non-existent, where feasible. The imperative of this work is further strengthened by relevant stakeholders calling for emphasis in the strategy for the achievement of Sustainable Development Goal 7 (SDG 7-Clean Energy). This particular SDG is deemed pivotal in the achievement of SDGs related to healthcare, education, innovation and gender considerations among others. The SDGs with emphasis on SDG 7 (clean energy) remain at the core of the research activity and propels the investigation into the economics and plausibility of given waste-to-energy (WTE) interventions and application to the sub-Sharan African and in some cases the Nigerian context; given barriers such as regulation, pricing, financing initiatives and eventual challenges in determining the appropriate scale and dissemination of the solution. This research effort seeks to provide a road-map to effectively and efficiently utilise the waste generated by municipalities to simultaneously contribute to solving environmental and energy access challenges currently being experienced in sub-Saharan Africa; with hopes for future dissemination of the assessed frameworks developed in this work, through stakeholder engagement, policy reviews and implementation, for development across the region.

Keywords: Energy; Energy Efficiency; Africa; Blockchain; Sustainable Development; Energy Access; Sustainability; Biomass; DPSIR; Policy; Real Options Valuation; Biopower; Waste; UNSDGs; Biopower; LCC; LCI; Qualitative Comparative Analysis; waste valorisation; waste management; FAHP; GDSS-PROMETHEE; GAIA; Renewable Energy; MSW

TABLE OF CONTENTS

2. CHAPTER 1: BLOCKCHAIN TECHNOLOGY AND RENEWABLE ENERGY ACCESS: A CASE FOR SUB-SAHARAN AFRICA

3. CHAPTER 2: ENERGY ACCESS GAPS, BIOMASS POWER AND SUB-SAHARAN AFRICA: A REMEDIATION MODEL FOR POLICY DEVELOPMENT

4. CHAPTER 3: RISKY BUSINESS: A REAL OPTIONS VALUATION FOR BIOPOWER INVESTMENTS IN SUB-SAHARAN AFRICA

5. CHAPTER 4: A COMPARATIVE LIFE CYCLE INVESTMENT ANALYSIS FOR BIOPOWER DIFFUSION IN RURAL NIGERIA

6. CHAPTER 5: AFRICAN BIOPOWER INVESTMENT AND POLICY SUFFICIENCY- A QUALITATIVE COMPARATIVE ANALYSIS

7. Chapter 6: ALIGNING MULTI-STAKEHOLDER CRITERIA FOR SOLID WASTE MANAGEMENT AND BIOPOWER ACCESS ACROSS SELECTED URBAN SLUMS IN LAGOS, NIGERIA

8. CHAPTER 7: THESIS JUSTIFICATION AND SUMMARY

LIST OF TABLES

Chapter 1

Chapter 2

Chapter 3

Chapter 4

Chapter 5

Chapter 6

LIST OF FIGURES.

Chapter 2

Chapter 3

Chapter 4

Chapter 6

1. Introduction

1.0.1 Background

Technology is accorded as one of the driving forces behind long-term income increases and is credited with being the propelling factor for prosperity increases in rich countries, due to its continuous transmission and the ideas underpinning them. Developing countries can also benefit from technological advancements in the West, through the importation and adaptation of technology to suit local requirements and conditions. The paramount factors in this process aside from the obvious cost and configuration imperatives, are the geographical, political and cultural conditions that may come into play. A combination of investments well attuned to local needs and conditions can enable the economy break out of the current doldrums of power outages and shortages; with these interventions being applied systematically, diligently and cohesively to re-inforce the expected gains and benefits.

The emphasis of Sustainable Development Goal (SDG) 7 (clean energy) cues the imperative for harnessing technological advancement for sustainable energy production and delivery. Renewable Energy (RE) has come to the fore in this regard with several countries such as Sweden, Germany, Austria, Norway and the United States of America already generating a significant portion of energy from these sources for municipal needs.

Nigeria remains Africa’s most populous nation, and Lagos state alone, currently manages an estimated at about 13,000 metric tons daily the waste generated by its estimated 22 million residents. The challenge here is that the current infrastructure retains its constructed capacity in the ’70s, which was for a population of approximately 3 million[1]. However, if Lagos represents the worst-case scenario for most of Africas garbage problems, it also holds the best solutions; as it has an enormous waste challenge that tests the limits of public health and policy, but has simultaneously attracted local entrepreneurs and international businesses to invest in sorting and recycling plants that recover plastics, metals and paper.

The current power situation in Nigeria is also such that most households and commercial entities generate alternative power supply using power generating sets that run on fossil fuels and with the advent of solar and battery powered inverters, autonomy in this regard has also been encouraged. The challenge however, remains in the situation where the urban slums are proliferating due to population explosions and migration, without functional powers supply or even connection to the national grid, what respite exists for the rural areas? some of which remain excluded to this day. A vast majority of these communities have generations that have grown up without electricity and still rely on traditional lighting and cooking methods that contribute heavily to Green House Gas (GHG) emissions. The situation remains a source of deep concern, in view of climate change mitigation initiatives and the overall 2030 SDGs in line with the Paris Agreement to steady global temperatures.

Biomass is a diverse resource as its components are varied and provide the opportunity for its application in the facets of both urban and rural living. It is also one of the RE sources for which the term bio-refinery has been coined due to the share potential of by- products from its conversion. In this guise and for the purpose of achieving the research objectives,

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[1] https://woimacorporation.com/drowning-in-waste-case-lagos-nigeria/

Biopower-being electricity generated from MSW is the focus for operational purposes of this research.

There are several technologies already in use for generating power using MSW as feedstock and these varying methods will be assessed comparatively to decipher which technology can easily be adapted to context within valid cost considerations and financial constraints, produce optimal and consistent net-energy yields, operate efficiently and its Green House Gas (GHG) emissions are relatively low, where feasible.

This work which is essentially a thesis by publications, seeks to provide a road-map to effectively and efficiently utilise the waste generated by municipalities to simultaneously contribute to solving environmental and power problems currently being experienced in Nigeria- from an investor’s perspective; withhopes for future dissemination of the assessed framework’s success and policy across Nigeria. The SDGs with emphasis on SDG 7 (clean energy) will remain at the core of the research activity and propels the investigation into the economics and plausibility of a givenwaste to energy (WtE) technology and its application within the Nigerian context; given barriers such as regulation, pricing, financing the initiative, taxation and eventual challengesto the aspirations of determining the appropriate scale and disseminating the solution.

The argument posed for electrification especially for the rural areas in Nigeria is founded on the need for decentralised energy sources, in simple terms renewable energy that can be generated with feedstock that is unique to that specific region or geo-political zone. This allows for the benefits of price advantages, convenience, reduced carbon emissions (footprints) and certainty of future supply. MSW is one such resource that is practically homogenous to every state, zone or region and thus the necessity to effectively view this current liability as a valuable resource, to aid in solving existing power problems, is the objective.

1.0.2 Aims and Objectives

The purpose of this research therefore is to offer a valid contribution in view of entrenched challenges being experienced across sub-Saharan Africa with some emphasis on Nigeria, regarding waste management and primarily energy access and supply. Some salient points that will be considered in this regard include:

a) Nigeria’s estimated population is over 200 million. Therefore, the waste generated especially in urban areas is sufficient feedstock for WtE technology

b) Converting Municipal Solid Waste (MSW) to energy, provides stable energy while reducing the environmental impacts of poor waste collection prevalent across Nigeria.

c) The economic viability of WTE technologies depends on whether each technology produces firm or non-firm power. Technologies that are non-firm, such as solar PV and wind power, only produce power when the renewable energy source is available

d) Firm renewable energy technologies, on the other hand such as WtE, do not require back-up generation, and therefore should be evaluated according to whether the cost of the power they produce is more or less than the total cost of oil and gas sources.

e) Selection of waste treatment options is the core of MSW management because of related environmental and economic impacts.

f) An optimal waste treatment option attempts to find a reasonable balance between environmental, economic and even social impact.

g) Choosing a sustainable waste treatment strategy requires assessment of various criteria from the point of view of multiple stakeholders.

h) To choose and apply a sustainable waste treatment option, governments generally develop partnerships with other stakeholders such as industries. They negotiate their shares of costs and benefits to reach a mutually beneficial decision. Reaching an agreement for multiple stakeholders with conflicting priorities is often a complicated process.

The literature provides evidence on the extensive use and potential for biomass as a viable fossil fuel replacement, with the potential for refuse derived fuel (RDF) being valuable for commercial purposes. This further improves carbon efficiency and eliminates the need to pay carbon tax (where relevant and in place for industry operators).

The idea of assessing what happens at the smallest unit of control- a decentralised biopower unit or system and not a massive scale, eliminates inherent complexities and introduces a new set of assumptions, challenges and opportunities which this work will assess, analyse and proffer a viable strategy for financial intervention.

It is also imperative to understand that when a new WtE technology is proposed, stakeholders are competing for lesser contribution of costs. These stakeholders include municipality administration, urban households, industrial and commercial operators. In addition, municipality's responsibility toward MSW, results in unequal voting powers among stakeholders. If the stakeholders do not mutually agree on a WtE technology, the project will not be applicable and none of the stakeholders will benefit. Therefore, in proffering a given WtE technology, the stakeholder criteria which will differ for each group, must be defined and factored-in to the proposed intervention, for measurable impact and value.

A study conducted by Scarlat et al (2015) estimates that Nigeria has a gross potential of 8725GWh/year from waste incineration, and 3624GWh/year from landfill gas. However, based on present waste collection efficiency only 3665 GWh/year and 1305GWh/year respectively is recoverable11. Young (2010) states that typically, most organic compounds are thermally unstable and at high temperatures, the chemical bonds of organic molecules break, producing smaller molecules such as hydrocarbon gases and hydrogen gas. At high temperatures, the gaseous mixture produced comprises predominantly the thermodynamically stable small molecules of CO and H2. This gaseous mixture of CO and H2 is called "syngas." This latter stage of the thermal process is known as gasification. This syngas is essentially then channelled for electricity generation.

This short sample of the vast literature, illustrates the variety of options for the utilisation of MSW as feedstock for WtE and is especially encouraging. However, commercial viability is a principal consideration in the design and deployment of any proposed WtE intervention. The need to define objectives in line with current economic realities and viability is essentially a pre-cursor to the success or otherwise of a given project.

This thesis carries the originality of policy prescriptions for augmenting rural and slum dwellers who has no access to electricity, which is an added bonus to rural electrification. It provides a policy blueprint for national planners to alleviate the grave need for cost-effective power supplies for unserved citizens and customers.

1.1 Problem Statement, Research Questions and Hypotheses

Problem Statement

What is the justification, cost and benefits of investing in decentralised Waste-to-Energy (WtE) technology intervention, against readily accessible and commercially attractive alternatives, in order to reduce GHG emissions and improve energy access metrics for Nigeria; in view of the Paris Agreement and in pursuit of SDG 7 by 2030?

Research Questions

1. What is the cost of investment to the private sector investor in WtE-decentralised systems and to what extent using MSW, can current capacities be supplemented to cover suppressed demand in Nigeria.
2. What contributions (outcomes) do the MSW management activities by various actors or stakeholders and their partnerships make to aspects of sustainable development?
3. What policies and regulatory framework need to be in place to create a competitive environment for renewable energy sources and technology, to meet energy access deficits?

Hypotheses

1. If the average investor understands the energy access gaps, alongside the true cost of investment in WtE-biopower generation projects, then measures that ultimately reduce costs and encourage investor uptake of decentralised biopower systems can be implemented.
2. If viable biopower technology is mapped to the current gaps, then developing a policy for effective regulation and compliance is enhanced.
3. If the key stakeholders are identified from inception and their interests and/or preferences are simultaneously aligned, then the success of the WtE scheme can be determined, before scarce funds are sunk.

1.2 Literature Review

Developing countries remain most vulnerable due to their dependence on fossil energy, lack of functional regional electricity and gas markets and high technical and commercial grid losses[1]. It has been shown that the well-being of the poor remains largely disadvantaged, as they spend more income for low-quality energy services, as against the those who can easily afford these services and are rewarded with even higher quality in terms of service delivery [1]. By 2030, cities will absorb in excess of 73% globally generated energy and the expanding urban populations alongside increasing energy demands, signals the urgency for major investment in energy infrastructure and its related interventions.

Sub-Saharan Africa comprises all African countries that are located to varying extents, south of the Sahara. The Africa Millennium Development Gap Report 2015, tags the region as lagging behind, owing to a failure in reducing the proportion of people living in poverty by 50%, including those suffering from hunger. Success in this regard, would have signaled the eradication of extreme hunger and poverty.

In 1990, just over five out of every ten people- 56.5% were living in poverty, 48.4% is the estimated stand, twenty years later. This equates to a 14% fall which should have been at least 28.3%, but still represents 50% of 1990 levels. However, of the thirty African countries assessed, five had increased poverty levels[2][3].

Access to energy finance and investments have also been hampered by inadequate national support systems, inadequate financial capacity for energy investment, slow judicial processes for settling disputes, inadequate strategies for offshore financing, mass transit systems [1]. These proposals are already a reality for most developed nations, with significant renewable energy components recorded in the economic systems of The Netherlands, Norway, Sweden and Germany.

The Sustainable Energy for All (SE4ALL) Initiative was established to galvanise action in support of three interlinked objectives, with a 2030 timeline. They include, providing universal access to modern energy services, increasing the global rate of improvement in energy efficiency and increasing the share of renewable energy in the global energy mix[2].SE4ALL affirms that business-as-usual solutions are ineffective in delivering these objectives, especially for those in the urban slums and rural parts of Africa. In order to achieve the interlinked objectives of SDG 7 and the Paris Agreement, new and innovative mechanisms for energy service delivery that specifically impacts the people and communities currently being left behind, are both essential and imperative [4] [5].

Metrics for sub-Saharan Africa include countries like Ghana aiming to industrialise and thereby providing enhanced economic opportunities for a rapidly expanding population of approximately 28.2 million. Electricity, remains a key constraint to the country’s objectives, due to its unstable and yet expensive supply. Installed generation capacity stands at over 4,000 MW, however, actual availability remains around 2,400 MW due to changing environmental conditions, inadequate fuel sources and supplies and decrepit infrastructure. Households without power is recorded at 1.2 million with a universal access target by 2020. The biggest challenges include inadequate financing of the energy sector, legacy debt, prohibitive generation costs, ambiguous or non- existent procurement framework and ineffective regulatory provisions that would normally encourage competition. Ghana’s SE4ALL targets for electricity access include, increasing effective electricity use in communities with existing on and off-grid solutions through specific programmes, providing universal access to electricity for its island and riverside communities and proliferating access to clean cooking solutions.

Rwanda is also developing rapidly in all sectors and the government aims to take the countryfrom the developing to middle-income category through its sustained effort. The national electrification rate reached 41%- made up of 11% off-grid and 30% on-grid, however, over 7 million people do not have access to electricity. Inherent challenges abound with grid conditions preventing efficient use of power, long- term imbalance of power supply and demand and inadequate or costly financing for off-grid companies. Rwanda’s SE4ALL initiative targets are to provide universal access to improved cook stoves and to extend energy efficiency improvements in the electricity sector by 2030.

Energy generation has been shown to impact climate change and imbued due attention for energy efficiency and energy saving issues. Household energy use remains a pivotal consideration in this discourse, mostly for improved energy efficiency indices. A change in lifestyle patterns remain imperative, for any real intent to achieve low-carbon environments through energy savings. Subsequently, to realise conservation objectives and boost its metrics, a focus on managing household energy consumption is not misplaced [6][7]. One of the strategic objectives of the Economic Community of West African States(ECOWAS) policy is to ensure that all energy policies, programmes and initiatives, comprising large energy infrastructure and investments, remain unbiased and non- discriminatory in all aspects, including gender. The policy aims to target inequalities in the region, especially energy poverty, which has varying impacts on men and women[4]. A change in the average consumers’ investment decisions, reliably reduces domestic energyconsumption and in turn reduces GHG emissions. These investment decisions relate to the purchase and general attitude towards energy- efficient home appliances, as a key determinant of proliferation within a given community or society. The “status quo bias” in consumer behaviour, was introduced to explain and emphasise the aversion to loss instead of focusing on future potential gains [6]. In this context, energy consumers are depicted as avoiding energy efficient investments, because of high initial costs and deeming future savings through energy conservation unreliable. This is due to potential price volatilities, which signal uncertainty for the consumers [6].

An economic reset is expected, as sustainability becomes imperative to harnessing available opportunities, as authorities re-focus and look into boosting electricity generation and distribution, improve transport infrastructure and support a significant reduction in the cost of access to the internet[1]. This poses a unique challenge as Nigerian household incomes fell, considering the rise in the jobless rate from 23.1% in Q3 of 2018[1]. Purchasing power also sharply declined as inflation skyrocketed and the 2019 review in the national minimum wage from N18,000 to N30,000 per month[1] was eroded in value by escalating retail prices.

The World Bank outlines the effects aggregate shocks to economic activity can have on the welfare of individuals and households, they include- the effect on income due to lost earnings and the indirect impact on earnings and employment due to a fall in aggregate demand and disruptions in supply[1]. In view of the current global challenges, the energy discussion is challenges, as governments of developing countries especially, shift focus to public health challenges and economic remedies, targeted at alleviating the strain on the populace.

The case for moving away from a mono-product economy is now stronger than ever, as even though crude oil remains a dominant factor in Nigeria’s economic considerations, only 19% of total primary energy supply in Nigeria came from oil and natural gas (combined). Access to electricity and clean cooking equipment is estimated at 61% and 6% of the population respectively[2] and with increasing evidence of the environmental and economic hazards of dependency on crude oil, the imperatives for pursuing the UNSDGs in the context of clean and affordable energy(SDG7), cannot be overemphasised[8][9].

The advantage of pursuing renewable energy (RE) inclusion in a given energy mix have been outlined in terms of numerous economic, social and environmental benefits, which cover job creation, reduction in poverty and inequality rates, sustainable use of natural resources, reduced greenhouse gas emissions (GHG), enhanced productivity, environmental quality and better health outcomes [9]. The inclination to pursue a viable RE strategy is evident in Nigeria's ratification of the United Nations Framework Convention on Climate Change in 1994, the Kyoto Protocol in 2004, the Copenhagen and Cancun Agreements, Durban Platform for Enhanced Action, and the Paris Agreement (FGN, 2015). Nigeria is alsopart of the West African Power Pool (WAPP) set up to ensure cost competitive, stable and reliable electricity supply for the region, by unifying its electricity market. The Federal Government of Nigeria (FGN) also established the Energy Commission of Nigeria (ECN) in 1979, to plan and coordinate national energy policies and has currently launched various initiatives, programmes and policies to boost RE uptake [2][9].

The above position although positive, is not without its challenges; financing renewable energy is expensive and the huge resource gap, means that for the time being Nigeria will continue to experience a wide variance between energy supply and demand, amidst a burgeoning population, dwindling purchasing power of citizens and resources[2][8], inherent corruption, which increases the cost of RE adoption[9] and the impacts of climate change- causing variations in temperatures, discordant seasons and massive erosion. These factors contribute to the country's energy challenges and have only been exacerbated by the onset of the COVID-19 pandemic. The infrastructure gaps and other structural deficits have become increasingly glaring and therefore demand innovative interventions and implementation support[8][10].

The electricity consumption per capita of a nation is a measure of its economic development and the people's living standard[11].Global energy consumption is said to be increasing by 2% per year[12] with fossil fuels being largely dominant in overall energy generation. As at 2011, about 85% of the global energy supply was from fossil fuels[11]. The attendant effect is the rise of greenhouse gas (GHG) emissions and climate distortion. It is estimated that emissions will increase by 30% in 20 years, if regulatory restrictions are not placed on the use of fossil fuels[8][10][12]. In support of the global action to combat climate change, Nigeria committed itself to cut down its national GHG emissions by 20% unconditionally and 45% conditionally by 2030, with technical support from foreign partners in terms of technology transfer and investments [13].

Globally, there are marked differences in energy supply and access of developing countries, which results in energy inequalities and inequities, as only a third of the African population has access to electricity[10]. The primary energy use per capita in Africa is about 11 and 5 times less than that of the US and EU, which represents only about 5% of the global total primary energy demand[10]. Nearly 80% of the African population depends on traditional biomass for cooking and biomass contributes to half of the total primary energy supply of Africa[10][14].

Nigeria remains Africa's largest economy and with a projected population of 300 million by 2050 and with its current 7566.2 MW electricity generation capacity[8] and only about 30% of the its population with electricity access[11], the socio-economic development of the country appears endangered. Electricity generation capacity in Nigeria from natural gas was about 10,022 megawatts in 2013; where 7,892 megawatts, representing 79%, sourced from gas, 2,040 megawatts, representing 20% from hydro and 88 megawatts, representing 1% from biomass and waste[15]. The gap in the country's electricity supply and demand is significant and roughly pegged at 1:3[15]. Based on the foregoing, Nigeria is engulfed with issues like erratic power cuts and load shedding (power rationing) which results in substantial reliance on private power generators by almost every business and household[11]. Other challenges plaguing the power sector include frequent shortage of natural gas supply,poor maintenance of electricity facilities and an inadequate transmission and distribution network[15].

In Africa, about 590 million people do not have access to electricity which is equivalent to around 57% of the African population[11]. In 2011, Nigeria's primary energy consumption was about 111 Mtoe (1.291TWh) comprising traditional biomass and 83% for waste[11]. Energy poverty, which essentially means inadequate or zero access to electricity, remains a major bottleneck to economic development in Africa and Nigeria in particular. Nigeria is considered among low income (LI) countries and one of the lowest electricity consuming nations in Africa[11]. It was observed that electricity consumption per capita in Nigeria at 107 kWh, was significantly behind South Africa and Egypt with per capita electricity consumption of 4229 kWh and 1331 kWh, respectively[11]. For West Africa, per capita electricity consumption hovers around 14 kWh per capita per year, with an average of 0.29 kWh per day consumed in Nigeria; which is grossly below the required 1 kWh per day to absorb energy demand. The low electricity consumption in Nigeria is attributable to the huge gap in energy demand vs. supply and inadequate capacity[11].

Nigeria’s electricity access rate is roughly 45% and is considered to have one of the lowest rates of net electricity generation[15]. The residential sector consumes about 57% of overall electricity, 26% for the commerce and service sector and 17% for the industrial sector[15]. It is also imperative to state that electricity supply has never matched demand in the history of power generation in Nigeria. Future energy supply therefore, needs to satisfy factors such as sustainability, economy, efficiency and low environmental impact in order to mitigate the global energy crises, climate change and energy poverty[8][15][16][14][17][18]. The uptake and deployment of renewable energy resources (RES) has been recognised as imperative, in alleviating the energy deficit in Nigeria[11].

There are 23 grid-connected generating plants with a total installed capacity of 10,396 MW and an available capacity of 6,056 MW. Nigeria’s transmission network has an actual transmission capacity of 5,300 MW but a theoretical capacity of 7,500 MW. This is below the 6,056 MW available generation capacity in Nigeria, thereby creating an imbalance in power generation and transmission. There are inherent reliability issues with the transmission infrastructure and losses are generally around 7.4 %. The recurrent transmission problems, lack of access to grid electricity, and inadequate power supply, remain key energy poverty markers for Nigeria. Approximately 40 % of Nigerians, about 80 million people, are not connected to the grid and those who are, enjoy electricity on an average of 0-20 hours daily[14][19].

Nigeria while retaining Africa’s largest population, its per-capita on-grid electricity consumption however, is 126 kWh; which is significantly low compared to South Africa (3926 kWh) and Ghana (361 kWh)[19]. The problem in Nigeria’s power sector spreads across generation, transmission and access. Much of the renewable energy (RE) potential in Nigeria remains untapped, while non-renewable energy potential is exploited and exported abroad.

According to a previous study, the predicted electricity load in Nigeria as at 2019 was 16,500 MW, factoring population growth and economic variables, electricity demand by 2030 is predicted to be 19.6 GW[19]. Considering installed capacity highlighted in the text and relevant literature, the current estimated electricity demand for Nigeria is 144.5 TWh/yr[19]. In a 2018 bid to optimise assets in the power sector and diversify its sources of electricity generation, Nigeria set a target to meet 30% of the country's electricity demand by 2030, using RE[11].

Access to electricity remains a marker for industrialisation, innovative technology-driven services and the wellbeing of the populace[14][17]. In Nigeria, the abundance of fossil fuels and renewable energy resources have not visibly translated to affordable and accessible energy for all[14][15][20], as the efficiency of some of the renewable energy technologies- at 15.61%, are not optimised[8][16]. However, the demand for renewable energy (RE) sources has not declined globally due to the characteristics of being clean, sustainable, futuristic, environmentally beneficial and inexhaustible[8][15]. The socio- economic factors that hinder energy access in most developing countries have been outlined as, the remote nature of some communities, low consumption levels in remote areas due to low income and high distribution costs and the lack of human and financial capital[3][14][21]. Energy access has been described as neither a socio-economic problem, nor a resources problem, but a combination of both[21]. The urban-rural energy divide[21] is also a key consideration, since a vast majority of rural households are not connected to the national grid and access to renewable energy systems remains marginal[3][4].

Reducing energy poverty in developing countries has become one of the most pressing priorities at international level, to the extent that it has been recognised as the "missing development goal" by the Food and Agriculture Organization of the United Nations and its consequences have been discussed under the concept of energy injustice[21]. However, conventional energy technologies and deployment approaches are said to be insufficient to eliminate energy poverty in Africa [21].

Access to modern energy services, at affordable cost, is representative of the aspiration to boost the socio-economic wellbeing of people, due to its impact on poverty, quality of life, education, indoor pollution, demographic transition, gender and health [3][5][14][15]. The need to ensure policy formulation and implementation strategies that are able to meet the projected demand for energy and sufficiently address the "energy trilemma" [3][6][22]which encompasses the affordability, security and sustainability of energy supply[3][7][23], is blatantly evident. Failure in this regard will exacerbate the problems inherent in the energy sector [22]. A strong relationship has also been identified between energy access and economic growth, to the effect that economies with higher per capita incomes have higher percentage access to energy[3][20]. This implies thata rise in income equates to a larger share of households with access to modern energy services[20]. The result is evident in enhanced social equity which drives economic growth through productivity and promotes revenue generating opportunities[3].

The unavailability of and limited access to energy services marginalises poor people and impairs their ability to improve their economic conditions[3][4][14][17]. It is usually poor households that bear the brunt of higher energy prices. When prices increase, people with limited income will either have to cut back on their energy consumption and probably become unable to cater for basic needs. They will therefore have to skimp on or forego other essentials like food and healthcare. This leaves poor urban consumers vulnerable to energy price fluctuations and therefore prohibitive tariffs and connection costs discourage them from to seeking Liquefied Petroleum Gas (LPG) or grid-based electricity[3][15]. Access to reliable energy supply at a reasonable price is therefore absolutely crucial in rural and urban poor areas, as evidence also suggests that children of electrified households attain higher education levels, which results in enhanced future earnings[3]. In addition, electrification will enable poor households effectively set up and manage a home business which improves revenue streams.

Modern energy services improve indoor air quality which will improve health conditions for residents and reduce mortality, as in most cases, limited income and access may force poorer households to use traditional fuel and other hazardous and inefficient methods[3][17], which ultimately worsens the current public health crisis, that favours COVID-19 as harbinger.

Economic output in terms of Gross Domestic Product (GDP), is deemed a weak tool for measuring the social progress of a country and for prioritising policy intervention[3]. The human development index (HDI) is posited as a better measurement, since it captures the quality of life and has a direct correlation with adequate energy services[3]. Relevant research supports the fact that significant benefits accrue through modern energy services, but accessibility remains a challenge[4][5][17]. In rural areas, electric power may be available, but inaccessible and unaffordable, while in urban settings electricity is usually available but largely unreliable. Current energy use is not without social and environmental costs, therefore the focus of proposed intervention should be people- focused and based on a locally sustainable economic model which can be operated and maintained by the community[3][6]. Local back-up capacity to guarantee reliability and requisite availabilityis also essential[3].

Based on the above, reliable access to energy is therefore a prerequisite for economic development. The use of RE technology for power generation especially at the local level, is a means to addressing the challenges with the availability, quality and service reliability of electricity in those areas. In cases where the capacity for grid-supplied energy is limited, and further hampered during peak usage hours, transmission and distribution losses are as high as 30%[3], therefore the implementation of on-site power generation technologies using RE sources, are a definite route to mitigating issues of power reliability and quality for a developing countries[15].

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2. Chapter 1

Blockchain Technology and Renewable Energy Access: A Case for sub-Saharan Africa

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Abstract

As the developed world continues to advance technologically and closes the gap in deficiencies of existing economic, financial and environmentally ‘green’ systems, while consequently improving the socio-economic indices of their respective countries and citizens; a measure of introspection is not amiss in considering the challenges that beset their third world counterpart- Africa. The continent still struggles with issues that relate to energy poverty and overall access, as there are indicators that a large majority still have no access to modern, affordable and reliable energy services. The major constraints are identified as inadequate or unavailable financing, invalid or non-existent policies and largely unstable political environments. The SE4ALL mandate in accordance with the Paris Agreement stipulates the need for effective climate change policy, the imperative for improved energy efficiency and the need for inclusion. A dynamic approach is therefore required to provide energy access to the most vulnerable, especially in the rural and urban slums of sub-Saharan Africa. This paper suggests that blockchain technology is potentially that medium and therefore assesses the current advancements, challenges and its potential application within the regional energy context using the diffusion of innovation theory. The results suggest alternative platforms such as Iota being deployed in the near term, due to a lack of requisite network infrastructure and the financial handicap of the region. However, the emphasis on innovative and disruptive business models for harnessing renewable energy sources towards improved energy efficiency and overall socio-economic development, remains. The key is in the adoption of technology that is tailored specifically, towards a sustainable energy future for sub-Saharan Africa.

2.1 INTRODUCTION

The World Bank recently launched its blockchain (BC) operated new debt instrument- "bond-i", which is the world's first bond to be created, allocated, transferred and managed through its life cycle using distributed ledger technology. A$110 million was realised from the two-year bond in August 2018, with the Commonwealth Bank of Australia as lead arranger1. This feat marked the first time investors would support the World Bank's development drive in a transaction fully managed using blockchain technology. The excitement is understandable as this was a real market transaction that adopted the technology on this scale, thus providing considerable credibility to the platform.

Energy remains a major factor in the consideration for social and economic well-being of any society. Improvements in standards of living are evident in increased productivity in terms of food production, healthcare, housing and other desirable amenities. All these require increased energy consumption and statistics show that 80% of the global population living in developing countries consume only 30% of global energy, meaning that by 2030, 1.3 billion people out of the 2.7 billion today [1], would still have no access to modern, affordable and reliable energy services. Therefore, future economic development is largely hinged on a sustainable energy future. The focus consequently, should be to secure policies and programmes that insure our energy future towards sustainable development.

The advancements being made in the developed world towards climate change mitigation and steadying global temperatures invariably means that by 2030, the percentage of the 1.3 billion population without access to modern, affordable and reliable energy services will without a doubt be situated in sub-Saharan Africa[2]. The remedy in the face of inadequate national support systems to attract investment, inadequate financial capacity, dysfunctional judicial and regulatory environments, politically charged environments and inadequate incentives for business investments in deficient sectors such as energy[3], can only be addressed through a disruption in the business-as-usual approach.

The blockchain technology has key characteristics such as decentralisation, persistency, anonymity and auditability[4] and can significantly reduce costs and improve efficiency[5]. The beauty of this technology is that even though it has largely been applied within financial services, its reach is not confined to this space and thus makes it a viable option for solving Africa's energy access, poverty and financing challenges.

Energy Efficiency (EE) indices are largely improved through the financing and proliferation of smart systems and appliances within a given economic space. The paper addresses the inherent challenges and ultimately the modalities for the adoption of blockchain technology within this context. The overall objective is to ensure that the region is included in this wave of innovation and ultimately the fourth industrial revolution. The pertinence of this work is evident in the gap between the advancement of the blockchain technology and its application to the sub-Saharan African environment, with a focus to improve energy efficiency. To the best of our knowledge, the available literature does not address this issue.

2.2 BLOCKCHAIN TECHNOLOGY- OVERVIEW, APPLICATION AND LIMITATIONS

2.2.1 Technology Overview

BC technology possesses revolutionary potential equal to that of the Internet, and could be deployed and adopted much more quickly, given the network effects of current widespread global Internet and cellular connectivity [6].

Blockchains basically enable a given set of users to record transactions in a ledger that can be viewed by those specific users. The recorded transactions cannot be changed once they are published. Participants or users subsequently agree that a transaction is valid by "reaching consensus" [4], [5].

Distributed consensus facilitates agreement between individuals across a peer-to-peer network. Blockchains require this before a validated block is added to the chain. Miners are rewarded when this happens and they therefore compete against each other. This agreement is achieved through distributed consensus algorithms (DCA) [7]. They are as follows:

Proof of Work (PoW) [8,9], This consensus model is designed for cases of minimal trust amongst users of the system. [7], [8][9].

Proof of Stake (PoS) [12,13] operates on the premise that the higher a user's stake is in the system, the propensity to protect and advance the system instead of sabotaging it is higher.

Round Robin Consensus Model assumes a measure of trust exists between mining nodes and therefore eliminates any complicated consensus mechanism, which determines the participant who adds the next block to the chain.

Proof of Burn (PoB) prioritises the next block creating node based on a demonstrable burning of some of their coins by moving them to an unspendable address which is verified [4], [5].

The DCAs are structured to incur a considerable cost to the mining nodes. The completion of a block formation task is rewarded with a payment, comprising fees that each participant is obliged to pay, to secure transaction completion and an amount of the network's cryptocurrency [5].

2.2.2 Applications of Blockchain Technology

Blockchains are able to facilitate enterprise transformations. In the case of postal operators (POs) who act as intermediaries between vendors and customers, their roles can be extended in the provision of services such as, device management, identity services and supply chain management [4], [10]. This provides ample business opportunities for a traditional organisation, using blockchain technology.

Blockchain-based Multiparty Computation (MPC) markets enable the offloading of computational tasks onto a network of anonymous peer-processors[11].

Internet of Things (IoT) is expected to integrate smart objects to the internet and provide users with various services. Common applications of IoT include smart homes, e-health, smart grids, and logistics management with Radio-Frequency Identification (RFID) technology [4], amongst others. Transactions of smart property that are based on blockchain and smart contracts are a new IoT e-business model being proposed. The model adopts Distributed Autonomous Corporations (DAC) as decentralised transaction entities. This allows for exchange of sensor data and obtaining coins without a third party[5], [7].

Blockchains can be applied in public and social services. One typical application is for land registration. This allows land information such as those related to its status and rights, to be registered and publicised on blockchains. This would invariably encourage public service efficiency, as any alterations to the land details such as changes in ownership can be easily recorded and managed on blockchains [5].

Blockchains can also be applied in green energy. The proposed ‘solarcoin’ is expected to promote viable renewable energy (RE) sources. Solarcoin is a digital currency that rewards solar energy producers. The Solarcoin foundation permits mining and grants solarcoins for generating solar energy [10].

Blockchains were originally envisioned to enable currency transactions in minimal trust environments. However, considering learning and teaching processes as currency, BC technology can therefore be valuable to the online education market. Blockchain learning would allow teachers pack and place blocks into blockchains, where learning outcomes and achievements represent coins[5].

2.2.3 Limitations

As an emerging technology, blockchain faces certain limitations. They are enumerated accordingly.

The increasing number of daily transactions ultimately makes blockchains heavy. The Bitcoin blockchain has surpassed 100 GB storage[5] due to all transactions being stored for validation purposes. Bitcoin can only process about seven transactions per second, which is insufficient for real-time transaction processing. The slow transaction speed is caused by original restrictions that were placed on block size and the time required to generate a new block. [5].

Blockchains offer anonymity for users. The transactions are done with addresses that are generated instead of real identity. However, privacy is not guaranteed, as the values of all transactions and balances for each public key are visible to the public. It has also been proven that a user’s Bitcoin transactions can be traced to reveal user information, with an equal method to connect user pseudonyms to IP addresses even when using Network Address Translation (NAT) or firewalls [5].

The use of blockchain technology is not a panacea, and certain limitations must be considered. These include how to manage or penalise malicious users, how to apply controls and the inherent limitations of any blockchain implementation; before a sweeping embrace and adoption of the technology can happen. A blockchain system is effective in the enforcement of transaction rules and specifications, but limited in enforcing a code of conduct [7].

Blockchain technology has enabled a global network of value, that verifies transactions and allows the blockchain to be stored in a synchronised fashion amongst a range of varied users. However, users are tasked with the responsibility of managing their own private keys, as any loss of key would essentially translate into a loss information and mainly digital assets. No “forgot my password” or “recover my account” option currently exists for blockchain systems [7].

Another issue relates to taxation, as a potential shift from an income tax–based system to a consumption tax–based system could herald significant changes and system overhauls for societies, therefore how government regulation unfolds could be one of the most significant factors and risks to whether the blockchain industry flourishes [5], [7].

2.3 BLOCKCHAIN APPLICATION AND USE CASES IN THE ENERGY INDUSTRY

Blockchains can be used to create new business structures and ecosystems within the energy sector, that can compete favourably. BC ecosystems are fuelling new kinds of energy services- such as balancing grid supply and demand, scheduling consumer device operation for Electric Vehicle (EVs) charging remotely and running washing machines[5]. Microgrids enable residents within a given location, to effectively manage their use and even generate and sell power, using solar panels or other alternative renewable energy methods.

Blockchain infrastructure favours products that utilise renewable forms of energy. A portion of businesses in this space, encourage trade in the generated renewable energy, while others support adoption and better utilisation of household-level generation [10].

The emphasis on purchasing energy on a needs basis encourages the user to re-evaluate energy consumption and expenditure. This provides a solid foundation for Energy Efficiency(EE). BC technology is not without its limitations and challenges, in terms of seamless implementation in the energy industry; which is due in part to rigid industry regulation and established monopolies [12]. This is unfortunate considering the attendant benefits which have been outlined.

There remains considerable breadth and depth for the integration of blockchain technology within the energy sector and this is most certainly a welcome development, which should be explored with reasonable fervour.

2.4 A CASE FOR AFRICA – ENERGY IMPERATIVES AND ENERGY EFFICIENCY GOALS

Developing countries remain most vulnerable due to their dependence on fossil energy, lack of functional regional electricity and gas markets and high technical and commercial grid losses [2]. It has been shown that the well-being of the poor remains largely disadvantaged, as they spend more income for low-quality energy services, as against the those who can easily afford these services and are rewarded with even higher quality in terms of service delivery [2]. By 2030, cities will absorb in excess of 73% globally generated energy and the expanding urban populations alongside increasing energy demands, signals the urgency for major investment in energy infrastructure and its related interventions.

Sub-Saharan Africa comprises all African countries that are located to varying extents, south of the Sahara. The Africa Millennium Development Gap Report 2015, tags the region as lagging behind, owing to a failure in reducing the proportion of people living in poverty by 50%, including those suffering from hunger. Success in this regard, would have signalled the eradication of extreme hunger and poverty2. In 1990, just over five out of every ten people-56.5% were living in poverty, 48.4% is the estimated stand twenty years later. This equates to a 14% fall which should have been at least 28.3%, but still represents 50% of 1990 levels. However, of the thirty African countries assessed, five had increased poverty levels3 [18].

Access to energy finance and investments have also been hampered by inadequate national support systems, inadequate financial capacity for energy investment, slow judicial processes for settling disputes, inadequate strategies for offshore financing, political and regulatory risks for investment in energy infrastructure and inadequate or non-existent incentives to businesses encouraging investment in new technologies[3].

Renewable energy is expected to play a pivotal role in satisfying increasing demand for electricity, transport, heating and cooling in urban areas, while equally enabling access to rural energy services[2]. Energy efficiency is a key consideration in this regard, as it potentially delivers faster and evident results in terms of energy savings which contribute in mitigating global GHG emissions and overall energy demand at relatively low costs. Innovative technology-based solutions and focused investment can help to reasonably manage energy consumption, curtail emissions and generate income; especially through conscious lifestyle patterns, improved manufacturing processes, electric vehicles and mass transit systems [2]. These proposals are already a reality for most developed nations, with significant renewable energy components recorded in the economic systems of The Netherlands, Norway, Sweden and Germany.

The Sustainable Energy for All (SE4ALL) Initiative was established to galvanise action in support of three interlinked objectives, with a 2030 timeline. They include, providing universal access to modern energy services, increasing the global rate of improvement in energy efficiency and increasing the share of renewable energy in the global energy mix[2]. SE4ALL affirms that business-as-usual solutions are ineffective in delivering these objectives, especially for those in the urban slums and rural parts of Africa. In order to achieve the interlinked objectives of the Sustainable Development Goal (SDG) 7-clean energy and the Paris Agreement, new and innovative mechanisms for energy service delivery that specifically impacts the people and communities currently being left behind, are both essential and imperative [20] [19].

2.4.1 Countries in Focus: Nigeria, Ghana, Kenya, & Rwanda

Nigeria is the largest economy in sub-Saharan Africa with a teeming population of approximately 200 million. However, limitations in the power sector constrain growth. Statistics capture installed capacity at 12,522 MW with thermal capacity at 10,142 MW and Hydro at 2,380 MW. A record 20 million households are currently without power and universal access target is currently set for 20304.

The country is an Economic Community of West African States (ECOWAS) member and is committed to implementing the SE4ALL Country Action. The proactive development and formal adoption of the Action Agenda, with the Renewable Energy and Energy Efficiency Action Plans, facilitated the following targets5 as summarised in Table I below:

Table I: Nigeria’s Targets and Statistics

NIGERIA	**Targets and Timelines**
Electricity Access	**Overall**: 75%; **Urban**:90% **Rural**: 60%(2020), 90% (2030)
Installed Generation Capacity	7500MW (2015); 115,000MW (2030)
Energy Efficiency	20%(2020); 50% (2030)
Renewble Energy Targets	**Hydro** (small and large): 9% & 13% contributionby 2015 and 2020 respectively; **Wind**: 1% contribution by 2020; **Solar**: 3% and 6% by 2020 and 2030 respectively

Ghana aims to industrialise, thereby providing enhanced economic opportunities for a rapidly expanding population of approximately 28.2 million. Electricity, remains a key constraint to the country's objectives, due to its unstable and yet expensive supply. Installed generation capacity stands at over 4,000 MW, however, actual availability remains around 2,400 MW due to changing environmental conditions, inadequate fuel sources and supplies and decrepit infrastructure[6]. Households without power is recorded at 1.2 million with a universal access target by 2020. The biggest challenges include inadequate financing of the energy sector, legacy debt, prohibitive generation costs, ambiguous or non- existent procurement framework and ineffective regulatory provisions that would normally encourage competition.

Ghana's SE4ALL targets for electricity access include, increasing effective electricity use in communities with existing on and off-grid solutions through specific programmes, providing universal access to electricity for its island and riverside communities and proliferating access to clean cooking solutions[7]. Additional energy statistics are summarised in Table II below.

Table II: Ghana's Targets and Statistics

GHANA	**Targets and Timelines**
Installed Capacity	Overall: 4,200MW; Hydro: 1,580MW Thermal (Renewable): 22.5MW
Current Access Rate	Overall: 83%; Rural: 50%, Urban: 91%
Renewable Energy Targets	Current contribution: 0.3%; target 10% by 2020

Kenya opened its energy market to Independent Power Producers (IPPs) in the mid-1990s and has leveraged on this to develop one of sub-Saharan Africa's most advanced power sectors. An established reputation as a creditworthy off-taker and abundant renewable energy resources such as solar, wind and geothermal, have enhanced the country's status in this regard. However, inadequate and run-down transmission and distribution infrastructure, scarce financial resources, questionable procurement practice and other innumerable challenges affect growth in the sector8 .

Access to electricity was limited to 23% of the population in 2012, which is approximately 1.97 million households; while over 80% of the population relied on traditional biomass as the core energy source for cooking and heating. Kenya joined the SE4ALL initiative 9 and set the following targets, summarised in Table III below:

Table III: Kenya's Targets and Statistics

KENYA	Targets and Timelines
Electricity Access and Clean Cooking Solutions	100% access target by 2022
Energy Efficiency	2.78% reduction of total energy intensity annually
Renewable Energy Targets	Increase to 80% contribution

Rwanda is developing rapidly in all sectors and the government aims to take the country from the developing to middle-income category through its sustained effort. The national electrification rate reached 41%- made up of 11% off-grid and 30% on-grid, however, over 7 million people do not have access to electricity. Inherent challenges abound with grid conditions preventing efficient use of power, long- term imbalance of power supply and demand and inadequate or costly financing for off-grid companies. Rwanda's SE4ALL initiative targets are to provide universal access to improved cook stoves and to extend energy efficiency improvements in the electricity sector by 2030 10 . Other statistics and targets are summarised Table IV below.

Table IV: Rwanda's Targets and Statistics

RWANDA	Targets and Timelines
Current Generation Capacity	Overall: 209MW; Hydro:110MW; Thermal:98MW
Current Access Rate	Overall: 41%; Urban:72% Rural: 9%
Universal Access Target	52% on-grid; 48% off-grid by 2024
RE Targets	60% of electricity contribution
SE4ALL Target	100% electricity access by 2030 50% of population access, on-grid and off-grid

2.4.2 Discussion

Energy generation has been shown to impact climate change and imbued due attention for energy efficiency and energy saving issues. Household energy use remains a pivotal consideration in this discourse, mostly for improved energy efficiency indices. A change in lifestyle patterns remain imperative, for any real intent to achieve low-carbon environments through energy savings. Subsequently, to realise conservation objectives and boost its metrics, a focus on managing household energy consumption is not misplaced [22], [23].

A change in the average consumers' investment decisions, reliably reduces domestic energy consumption and in turn reduces GHG emissions. These investment decisions relate to the purchase and general attitude towards energy- efficient home appliances, as a key determinant of proliferation within a given community or society. The "status quo bias" in consumer behaviour, was introduced to explain and emphasise the aversion to loss instead of focusing on future potential gains [22]. In this context, energy consumers are depicted as avoiding energy efficient investments, because of high initial costs and deeming future savings through energy conservation unreliable. This is due to potential price volatilities, which signal uncertainty for the consumers [22].

One of the strategic objectives of the ECOWAS policy is to ensure that all energy policies, programmes and initiatives, comprising large energy infrastructure and investments, remain unbiased and non-discriminatory in all aspects, including gender. The policy aims to target inequalities in the region, especially energy poverty, which has varying impacts on men and women [19].

The blockchain technology has been assessed and proven in the West. The key questions now are- in what form should the blockchain technology be employed within the region and what inherent characteristics of this context hamper or promote a blockchain-fuelled energy access objective?

2.5 DIFFUSION OF INNOVATION THEORY AND ANALYSIS

Rogers [24] defines five attributes for the Diffusion of Innovation (DoI), they are as follows:

Relative Advantage- this determines the degree to which an innovation is deemed superior to the its superseding idea.

Compatibility- determines the extent to which an innovation is seen as consistent with existing values, past experiences and the requirements of potential adopters.

Complexibility- assesses the degree to which an innovation is seen as somewhat difficult to understand and implement. A lower complexibility supports adoption, while a higher degree constrains the rate of adoption.

Trialability- represents the extent to which a given innovation may be experimented with on a limited basis; and

Observability- determines the extent to which the results of a given innovation are evident to others. The higher the degree of these attributes, the higher the propensity of adoption for that innovation.

2.5.1 Results

The results of analyses show that the following factors will affect the adoption of the blockchain technology to a large extent within the sub-Saharan Africa region.

Employment and Education: inadequate resources and capacity building opportunities to harness the latent human capital of the region.

Displacement and Resettlement of people due to tribal clashes and insurgent activities; leading to both political and economic instability.

Financing the technology remains prohibitive due to the lack of basic infrastructure, therefore raising the cost of investments exponentially.

Regulatory Provisions which are mostly riddled with inconsistencies and minimal enforceability.

Operational Modalities remain a challenge due to lack of relevant infrastructure and capacity.

The Paranoia and Wariness associated with Bitcoin and blockchain technology is especially evident in the aftermath of significant financial losses experienced by most investors as in the case of Nigeria; where both the Swissgolden cryptocurrency and MMM Bitcoin scams collapsed, causing huge financial losses for at least 10 million people11.

In spite of the above, the objective remains to create conditions that will accelerate socio-economic benefits in terms of improved energy access, reduce energy poverty and overall economic empowerment.[19], [20], [25]. The results are summarised in Table V below.

Table V. DoI Analysis for sub-Saharan Africa

INNOVATION ATTRIBUTES	**BLOCKCHAIN TECHNOLOGY ADOPTION**
Relative Advantage	The BC advantages have been extensively enumerated, but its adoption will be challenged due to a lack of network capacity and infrastructure, including considerable financing constraints. Cloud storage for local blockchains or the implementation of an Iota type platform which requires less computational power for devices, with minimal transaction times and fees may be more realistic in the near term.
Compatibility	Current market frictions with the technology still exist in the West, as regards scalability, costs, security and privacy. Peer-to-peer networks have been proffered to remedy these issues. There is an obvious need for BC adoption, however, due to the novelty of this concept for the region a basis for compatibility based on the defined terminology, is currently non-existent.
Complexibility	There is still a dearth of understanding as regards the technology, and the wariness of investors due to losses from previous BC based schemes, hampers the rate of adoption within the African context. This is attributed to the novelty of the concept in that region, owing largely to lack of skilled technical resources, poor education and awareness, exacerbated by deep financial constraints.
Trialability	The concentration of start-ups that have adopted the technology within the energy industry remains in the West. There is still a lot of room for experimenting with BC in Africa. However, a lot of courage and perseverance will be required to overcome the steep learning curve, in terms of its application to the high risk political and economic environments of the region.
Observability	The results of BC innovation are visible to its direct beneficiaries, i.e. those who have already adopted the technology and have harnessed its efficiencies and cost effectiveness. Inference for the various business models of adoption, can only be drawn from these cases for the African region and are not based off of actual experience. There is a need for experts and the creation of awareness within the target group to be willing to participate or co-operate with a given business model or start-up company/process.

2.5.2 Discussion

Cloud storage especially for local blockchains adopting a prosumer model between neighbours, may be more feasible in the near term, as would alternative platforms such as Iota[10] being adapted to context. This is simply due to a lack of requisite network infrastructure and the financial handicap of the region. A potential remedy is in the use of the blockchain technology to develop a fund, scheme or coin similar to the World Bank's bond-i, to finance the off-take of supply and dissemination of energy efficient heating, cooling and lighting systems to the region; or to generally encourage energy efficient schemes towards climate change mitigation and steady global temperatures.

The rewards could theoretically be based on the PoS DCA protocol, where the miner or node with the largest stake, is also the one able to push these appliances to the remote rural parts of the region or to a larger population of the urban poor. Rewards could equally be in the form of the higher adoption of EE appliances per household recorded on the blockchain, and through smart contracts the investor or supplier could also be the miner with the largest stake; duly rewarded with more of a particular cryptocurrency, similar to Solarcoin [10].

Evaluating the blockchain technology from the diffusion of innovation theoretical perspective, highlights the gap between the region in view and the developed nations who currently possess the advantage in terms of knowledge, skill, expertise and financial capacity to harness and reap the benefits that BC technology offers. However, the results of this analysis should not be considered a deterrent, rather a tool for further innovation in terms of not just adopting the BC technology, but equally developing innovative and customised business models to circumvent the challenges of the regional context and deliver similar, if not enhanced benefits for its people.

2.6 CONCLUSION

The properties, applications and limitations of the blockchain technology have been reviewed extensively and the potential for its adoption within the sub-Saharan African energy context equally presented. Africa requires an innovative adaptation of existing blockchain business models and its proponents, to its unique environment. This paper is presented with the expectation to bridge the gap in this innovative and disruptive technology era, by including Africa’s unique requirements and challenges in the blockchain discussion. It is the World Bank’s expectation that developing economies will gradually embrace and adopt blockchain technology to improve their economies. As much as challenges and risks abound, sub-Saharan Africa’s human, natural and economic resources, remain a pivotal consideration for the total inclusion and complete realisation of a truly interconnected global energy future.

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3. Chapter 2

Energy Access Gaps, Biomass Power and sub-Saharan Africa: A Remediation Model for Policy Development

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Abstract

This paper extends the drivers- pressures-state-impact and response (DPSIR) model to the context of current energy access and waste management challenges for sub-Saharan Africa. The objective is to highlight opportunities for decentralised biopower adoption, while considering the multifaceted environmental and economic challenges exacerbated by the global pandemic. The model is applied to a biopower-related case study and the outcome suggests amongst others, that the presence of requisite infrastructure, environmental legislation, strategic public-private partnerships, policy advocacy, intervention and implementation, all contribute positively to successful waste valorisation and renewable energy-recovery schemes. The DPSIR model is adopted to advance renewable energy, environmental and specifically solid waste management policy efforts in the region, to promote the use of biomass resources in electricity generation.

Keywords: energy access; Africa; sustainability; biomass; DPSIR; policy

3.1 Introduction

Traditional biomass remains a staple for roughly 80% of African households and is used mainly for domestic purposes. With approximately 50% of total energy supply in Africa attributable to biomass[1] [2] and Africa accounting for only about 5% of global primary energy demand, this supports disparities in the energy supply, demand and access within the global south [1] [2].

In 2018, Africa's nominal GDP per capita was estimated at US$2,000 annually and estimates for sub-Saharan Africa remained under US$ 1,600 (2017) [3]. Projections between 100-150% for urban and total population growth is expected between 2015-2050, and waste generation estimates for the same period are expected to increase by almost 200% from 174 million tonnes(2016) to 516 million tonnes(2050) [3]. In spite of this growth trend, low budgetary provisions, inadequate technical and administrative capacities, severely limit the development and structure required for proper waste management systems.

Energy access and poverty deficits remain unchallenged with roughly 57% of African households, a population of approximately 590 million, living without ready access to electricity. This poses a significant and continuous constraint to achieving the United Nations (UN) defined Sustainable Development Goals (SDGs) and Africa's overall economic progress. It is also pertinent to state that electricity supply for the sub-Saharan African(SSA) region has historically remained below demand in terms of power generation and in order to meet future energy supply requirements, factors such as technology and system efficiency, sustainability measures, environmental and economic impact, need to be carefully considered and adequately provided for- as this would aid in mitigating the issues surrounding climate change and energy poverty in general [4] [5] [6] [2] [7].

To gauge the living standard or economic wellbeing and development of a people, electricity consumption per person or per capita is considered an effective metric. This is relevant, as annual global energy consumption continues to expand [8] [9] and electricity access is consequently interpreted as a standard of measurement for economic growth, development, innovation and advancement[2] [7]. The investment in renewable energy (RE) sources has subsequently increased, with total investment initially pegged at US$40billion globally in 2004, peaked at US$279billion in 2011(Hussain et al., 2017). The rapid growth in energy demand pushes the case for RE innovation, with projections for global energy consumption increasing to almost 28% between 2015-2040. In view of the above, RE systems tailored to diverse energy scenarios have been proposed. These include gas storage, electric vehicles, gasified biomass, heating systems and electro-fuel production[9].

The challenge however, remains in the optimisation of RE resources, as most African countries are rich in these sources but lacking in technical and financial capacity. In Nigeria, for instance, the efficiency of certain RE technology interventions are estimated at about 15.61%, which is generally considered sub-optimal[4] [6]. The demand for RE has not declined however, due to its inherent sustainable, environmentally beneficial, clean and inexhaustible efficiencies [4] [5]. Therefore, the socio-economic factors hindering energy access in most developing countries, are summarised as relatively low income capacities translating to low consumption levels, rural and or remote locations and prohibitive distribution costs; in addition to existing deficits in financial and human capital [10] [11] [2]

Energy access has been described as a socio-economic challenge, which is accurate when the rural-urban energy divide is considered, as most rural communities remain unconnected to the national grid or central energy supply [10] [12] [11]. Therefore, the uptake of RE-enabled solutions for electricity generation, based on biomass resources and deployed on various modular scales, provides a viable route to bridging the gaping access deficits in the region and delivers additional benefits for environmental preservation from improved waste management services, behaviours and systems.

3.2 Methods

This paper assesses existing literature to highlight the inherent energy deficits, waste management challenges and practices, in building a case for biomass-power or biopower intervention in the sub-Saharan African energy scene. Relevance to regional context forms the basis for a critical analysis of energy poverty challenges, issues associated with adopting and optimising circular economy principles and the advancement of decentralised biopower interventions based on Municipal Solid Waste(MSW). These factors are assessed through case study and combined to model the problem and policy remedies using the Driving Force- Pressure- State- Impact- Response (DPSIR) framework [13].

The DPSIR framework applies relevant and specific information to determine causality from the dynamic relationship between human, economic and environmental activities, providing a composite structure for analysing problems of the environment, while suggesting viable and sustainable solutions for policy action.

3.3 Energy Poverty Challenges

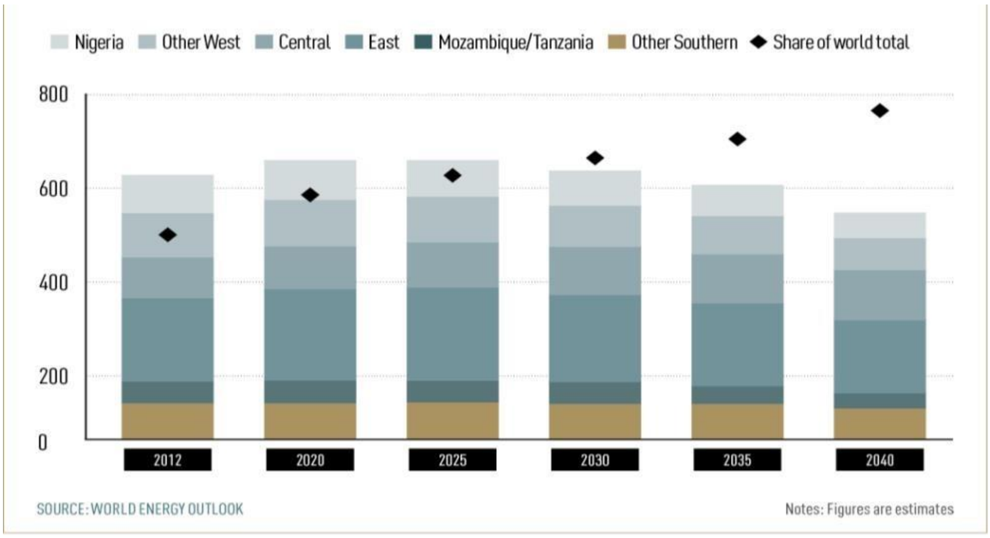

Fig.1 Sub-Saharan African Population without Access to Electricity (Millions)

Reducing energy poverty indices for developing countries, remains prominent at international levels and has been tagged the missing SDG- the import being significant when considered in relation to the statistics illustrated in Fig.1. Its consequences have also been discussed in relation to energy injustice[10], due to the ineffectiveness of conventional energy technologies and implementation strategies; which have failed to deliver tangible reductions in poverty metrics[10].

Access to reasonably-priced modern energy services, is representative of the goal to boost socio-economic wellbeing, due to its impact on education, poverty, indoor pollution and quality of life amongst others [5] [11] [2] [14]. A strong relationship has also been identified between economic growth and energy access, to the effect that higher per capita income economies, have superior energy access statistics [15][11]. This implies that an increase in income, increases the proportion of households that can readily access modern energy services [15]. Hence, the relationship between adequate energy access, economic productivity and income growth becomes apparent- providing a viable pathway to boost economic activity and overall development.

The poor remain effectively marginalised due to impaired access to energy services and continue to struggle with debilitating economic circumstances[12][2] [7][11]. Poorer households typically bear the brunt of higher energy prices, as price hikes force families with meagre incomes to reduce energy consumption, while struggling to cater for basic needs. The urban poor are increasingly exposed and vulnerable to energy fluctuations in terms of pricing, therefore costly tariffs and connection fees often discourage attempts to access grid-based electricity [11] [5]. The impact on rural and urban poor areas extends to children, as evidence also suggests that children raised in households with structured or stable power supply, advance their education significantly and are able to enhance earning capacity in the future [11]. It is therefore imperative that reliable energy sources are harnessed and provided at reasonable cost, to enable the electrification of poor households and the establishment of thriving home businesses for enhanced revenue streams, economic activity and total productivity.

In addition, limited income and access constrain poorer households to continue utilising traditional and other personal and environmentally hazardous and inefficient fuel sources [11] [7]. This consequently exacerbates the current public health crisis and heightens the risk of contagion and mortality within that demographic. Modern energy services are therefore expedient in the current global climate, as indoor air quality is synonymous with improved health and wellbeing for most households, due to the global COVID-19 pandemic.

Empirical support exists for the benefits of modern energy services, however, accessibility for all remains elusive, especially for African policy makers and governments [14] [7][12]. In rural areas, electricity may be available but inaccessible and unaffordable, while in urban settings, electricity is often available but mostly unreliable. This represents the “energy trilemma” which encompasses the affordability, security and sustainability of energy supply [11] [16] [17]. It equally emphasises the need to ensure policy formulation and implementation strategies sufficiently cover projected energy demand and address potential challenges [18] [19][11].

Current energy use is not without social and environmental costs, therefore a proper access strategy should be people-centric and based on locally sustainable economic models, having gained community acceptance and ownership [11] [19]. In addition, the importance of upscaling local support capacity within communities is also paramount to ensuring operational standards, reliability and availability of the installed power source [11].

3.4 Biomass Resources and Waste Valorisation Justified

Fig. 2 United Nations Sustainable Development Goals (UNSDGs)

The general purpose of SDG7, is to achieve effective, efficient and sustainable energy infrastructure [20] [21]. Energy sources include fossil fuels, nuclear resources and other renewable energy sources and account for approximately 24% of global energy demand [22] . Fig. 2 illustrates the SDGs and objectives. The interrelationship between goals is apparent, as achieving SDG7 would impact the achievement and success of related SDGS. Clean and affordable energy has a direct impact on innovation and infrastructure (SDG9) and equally impacts economic growth and poverty indices (SDGs 8-9), through the acceleration of economic activity and productivity. The sustainable exploitation of biomass resources, especially Municipal Solid Waste (MSW), provides the additional benefit of achieving SDGs 3, 11, 12, 13, and 15. This strengthens the argument in favour of biomass resources and provides specific justification for waste valorisation.

Waste valorisation currently appeals to scientific and industrial interests, to effectively manage adverse environmental impact, boost sustainable practice and push for a circular economy [23] [24] [25]. A circular economy model for development, where waste is reduced at inception and subsequently transformed to a resource, is absolutely crucial to achieving sustainable waste management objectives [23].

Biomass maintains its strong potential, in terms of providing an alternative source of energy to stem rising pollution [26] [23]. The rationale for bioenergy encompasses objectives associated with improved efficiency, technological innovation, economic development and climate mitigation [27] [26][28]. MSW, trash or waste are synonymous and its valorisation purportedly injects approximately US$8billion into the economy, annually. This boosts activity in industries such as manufacturing especially at local levels, creates jobs and enhances community wellbeing and cooperation. To this end, an effective biomass or waste valorisation strategy has been suggested, using a combination of low-cost, modular, decentralised and community-championed initiatives and projects [29].

A change in waste management practices and behaviours would also be required, since the activity of inhabitants and informal waste actors impact the quality of waste delivered at valorisation sites. Inadequate and improper waste management services and behaviour in many African countries, have been linked to arbitrary waste disposal on streets, watercourses and open spaces, resulting in, water pollution, stagnation and flooding.

The success of a given resource recovery mechanism or venture will be also dependent on adequate plans, procurement and management of the plant using foreign and local expertise and capacities. Appropriate risk mitigation plans and proper model designs are equally imperative, with the inclusion of operation and maintenance routines governed by technically qualified staff and adequate provision of funds for required supplies and spare-parts.

In view of the opportunities for biomass-to-electricity or biopower using MSW, there is need to advance thinking beyond waste disposal in landfills and the reuse and recycling of waste material. This creates opportunity for decentralised waste management and energy recovery systems [24][1] for rural or marginalised communities. The impact will be evident in the reduction of disparity in infrastructure and networks, enhanced business activity and communal well-being. The informal waste management sector would also benefit in terms of enhanced income generation opportunities using local resources, since trash is a homogenous resource.

3.5 Decentralised Biopower: Charting a Viable Course

Centralised systems for power generation are becoming obsolete, due to the burden of reliance on old systems and equipment, which often require frequent repair and maintenance. This hampers efficiency, in terms of energy production and distribution and also diminishes the ability to meet escalating demand due to urbanisation and increasing populations [7]. To mitigate these risks, the deployment of modular generation and transmission systems is proposed [28].

Decentralised biopower remains a viable route to achieving enhanced energy access and waste management metrics, as it utilises locally available resources to bridge the gap for rural and often remote communities. The adoption of these systems through the use of smart grids, system automation and integration, including advanced forecasting systems, mitigates the challenges posed by older and increasingly obsolete power generation and distribution models. The decentralised model would also be sufficiently practical, where land fragmentation is practiced, as most megacities with space constraints can sufficiently accommodate smaller and less capital intensive projects.

Recent developments in Waste-to-Energy (WtE) technology and plants include improvementin biogas energy, energy recovery and efficiency through plasma gasification, pyrolysis and combustion amongst others [23]. Biomass power or biopower is to be connected to both national and mini grids, using decentralised power stations. These are connected to modular and isolated power line networks to ultimately supply households, buildings or plants [10]. In theory, the system is simple and plausible, however, issues such as design, operation and related biopower supply chain networks determine overall feasibility [28].

The technology is flexible enough to be installed with capacities of up to 10MW, with fast pyrolysis systems being deemed efficient due to long-term electricity generation capacity at reduced cost and higher profit, more than other modular conversion systems [28]. Downdraft gasifier systems, have also been empirically supported as the preferred biomass-to-energy conversion method [28], with some already in operation for close to three decades [28]

Risk is an essential consideration in the selection of a given technology or intervention and empirically favours combustion models, as seen with the Ethiopian Reppie WtE plant- which uses combustion cycles to treat 1,400 tonnes of municipal waste per day, while simultaneously generating 20MW of power. Decentralised systems are largely dependent on public-private partnerships, due to the redistribution of risks, roles and responsibilities between the consumer, service providers and authorities. Therefore, biopower systems should be manageable, discrete but interconnected and the deployment should be governed by factors such as available infrastructure, structured partnerships with defined roles and responsibilities, in addition to other cost and waste transfer considerations. System planning and deployment should also consider socio-cultural specifics, topography, political power dynamics and economic challenges unique to a proposed plant site or location.

It is also pertinent to state that although centralised systems in this specific context are not particularly desirable, they remain valuable in large-scale industrial activities which also provides the bulk of employment opportunities. In addition, it is expected that grid infrastructure and economies of scale with interconnected power systems will be imperative to supplement off-grid decentralised biopower systems, which better serve some commercial loads and mostly residential loads; but industrial load demand will be best met by high quality power supply from these combined sources.

3.6 Ikosi Market Case Study and the DPSIR Framework

Fig.3 Lagos, Nigeria

Lagos State, Nigeria as depicted in Fig.3, is Africa’s largest megacity with an estimated population exceeding 20million. It was up until December 1991, the Federal Capital of Nigeria and remains the country’s commercial live wire.

The Ikosi Fruit Market is located in Ketu, Lagos and is a prime example of the challenges associated with adopting RE-based technology and disseminating RE projects in sub-

Saharan Africa. The market is considered Lagos's hub for fresh fruit produce and an estimated 5,000 tonnes of fruit waste is generated daily, largely due to poor transport and storage facilities.

In 2013, a biogas plant was installed through a partnership between the Lagos Waste Management Authority (LAWMA) and Midori Environmental Solutions (MES), under license from AFRICOM Technology Transfer (Germany), for the construction and installation of a "low-technology" facility. The 26,000-litre plant capacity was expected to generate electricity of up to 10kVA daily.

A biogas fermenter tank (Fig. 4) was fed with bacteria, and the fruit waste generated in the market served as abundant feedstock for the process of producing biogas. The gas was used to generate electricity for security lights and about 50 market shops and stalls, with the project being designed as a pilot scheme, for replication across other markets within Lagos State.

Photo Credit: Temitope Jalekun

Fig. 4 Ikosi Biogas Fermenter Tank

However, within a few months of achieving its objectives, the facility was shut down and the market reverted to status quo. Alleged expropriation by LAWMA, lead to a dispute with the facility contractors and the biogas plant remains abandoned to date.

The traders, being direct beneficiaries of the project, suffered significant losses due to this disruption and vulnerable financial positions, stemming from closed outlets for market-generated fruit waste, income loss from spoiled fruits, fossil fuel costs for operating individual power generators and associated health hazards, all to maintain basic operations and salvage existing stock. Market congestion, air pollution and increasing waste generation, endanger the wellbeing of market actors and considerably defy the tenets of the UNSDGs.

The associated loss of investment for the plant operator is additionally discouraging, considering the increasing difficulty in sourcing adequate funding for business and development projects. While private contractors may successfully operate landfills, the cost of WtE plants are prohibitive and will often require debt and equity financing. This invariably puts such undertakings beyond the capacity of most local private sector operators, in developing countries. This situation remains dire due to the unprecedented economic impact of the COVID-19 pandemic on business sectors and economic agents, worldwide.

3.7 DPSIR Framework for Remediation

The Driving force-Pressure-State-Impact-Response (DPSIR) model is extended to accommodate the lessons from the Ikosi Scenario, including general challenges with poor waste management, services, valorisation schemes, funding and legislation; as a route to suggesting focal areas for policy reform and future development.

The DPSIR model is an extension of the Pressure-State-Response (PSR) framework, initially promoted by the Organization for Economic Co-operation and Development (OECD) and the United Nations Environmental Programme (UNEP); which provided an over-arching strategy for evaluating issues related to the environment, but was later criticised for its narrow interpretation and depiction of the forces responsible for these pressures, which ultimately alter the natural environment.

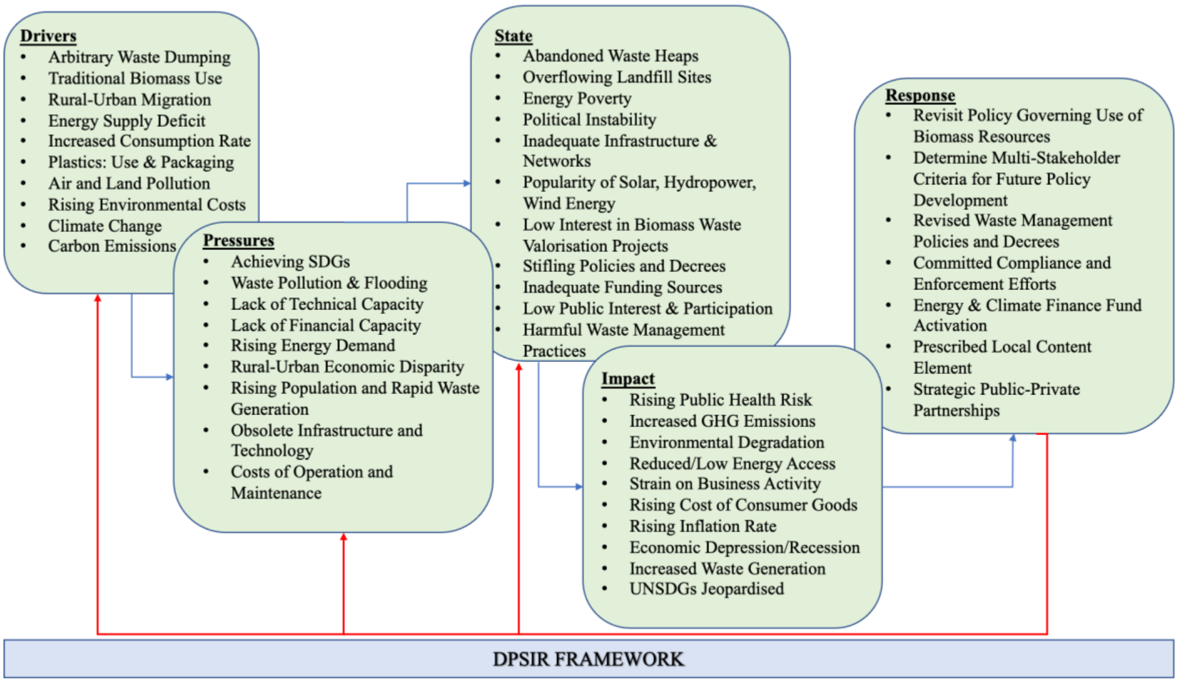

Fig.5 Extended DPSIR Framework

The principle behind the DPSIR model is the understanding that socio-economic human activity catalyses environmental pressure, which alters its natural state and bears significant impact on public health and the ecosystem. The impact in turn, stimulates societal action in response to the issues identified, through “preventive, adoptive or curative measures” [30]. The model has proved effective in determining causality for environmental issues and providing remedies.

Fig. 5 depicts a customised DPSIR framework from the lessons learned in the Ikosi scenario, combined with general waste-related and environmental issues, extended to the socio-economic consequences arising and plaguing developing countries. The biogas plant was necessitated by fruit waste generated in the market and the need for an environmentally sustainable solution. The drivers include open or arbitrary dumping of waste, which causes infestation from vermin and leachate contamination of surface and ground water. Random fires and offensive odours are also common features of this scenario. Uncontrolled dumping sites heighten climate change concerns by releasing methane into the atmosphere from the decomposing organic waste and have also led to overfilled landfills and landslides which have cost human lives [3]. This is in addition to air pollution from the fruit and equipment delivery truck emissions and private power generators run by individual traders, due to energy supply deficits which also hamper adequate storage and lead to increased fruit waste generation amongst others.

The trader demographic mirrors the rising rural-urban migration rate, based on rapid population growth, infrastructure and economic deficits experienced in rural areas. Most traders also engage in farming or belong to rural farming communities and will often migrate to cities in order to enhance income and profits. This increases the pressure on municipalities' limited resources for efficient waste management services amongst other constituted obligations.

'Pressures' have been defined as "anthropogenic factors inducing "unwanted" environmental change" [13]. They have also been defined by the European Environmental Agency as "developments in the release of substances (emissions), physical and biological agents, the use of resources and the use of land by human activities" [13]. The context of this study encompasses human activity, including the challenges environmental pressures induce on economic factors and agents. Pressures often arise from consumption or production activity and have been categorised in terms of abusive environmental practices, excessive use of a specific land area and related emissions. The pressures induced by the identified drivers extend beyond environmental considerations, as open heaps and waste dumping lead to increased waste pollution and flooding due to blocked waterways and drainage systems; with flash floods being notoriously destructive with associated economic losses.

The challenges with scare resources of municipalities translates to inadequate service delivery, which pushes certain communities deeper into poverty and widens economic disparities; creating urban slums, urban poor and rural exclusion. The trader population in Ikosi is representative of not only the Lagos population, but mirrors the challenges experienced in most developing economies across Africa. The scarcity of resources is worsened by a lack of technical capacity to effectively manage available resources. The achievement of the SDGs by the concerned authorities come under pressure as well, as waste management and energy challenges spiral into significantly dire economic and public health consequences.

The state of the environment is altered by these pressures and will be evident in ground pollution due to the leachates from random refuse dumps, due to open dumping and frequent burning of solid waste in particular; before scheduled transfers to open or sanitary landfills. The landfills are often beyond capacity and this leads to increased generation and emission of methane gas, which is often the cause of landfill burns(Anupam Khajuria, 2010). In addition, the state of the environment and related issues also bear economic consequences, by reducing business activity in unsanitary areas or communities and consequently increasing the cost of doing business, which reduces opportunities for enhanced income and revenue generation, especially in disenfranchised communities. This creates socio-economic instability and disparities that often degenerate into class-related or politically motivated upsets. The limited infrastructure, poor waste management behaviour and services, low private sector participation and palpable disinterest in biomass for electricity generation due to the commercial popularity of solar and other RE sources, all contribute to the dire situation and adverse impacts on both the environment and economy.

‘Impact’ relates to socio-economic factors based on human activity and environmental changes occasioned by the identified ‘state’. The energy access deficit, hazardous waste practices, service and funding deficits, degraded neighbourhoods and declining land value are expected impacts, which aside from jeopardising the UNSDGs, strain economic activity and increase the cost of doing business.

The issues identified ideally provoke responses from multiple stakeholders to “prevent, compensate, ameliorate or adapt to changes in the state of the environment” [13]. These stakeholders include policy makers and the government, consumers, private investors and financial entities and other waste management actors such an non-governmental organisations, small and medium scale waste recycling or valorisation ventures and the informal sector, including the wider community. Action would relate to remediation strategies aimed at mitigating ‘impact’ through compliance or enforcement drives, advocacy and community sensitisation to adopt standard waste management practices, enhance private and public funding and participation.

3.8 Considerations

The Ikosi biogas project was a response to the driving forces, pressures and current state of the environment. The private operators provided the technical and financial capacity required and the authorities are expected to support the project with adequate policy and adjustments, tax subsidies, land allocation and required licenses and permits. The authorities’ appropriate action should cover project monitoring for gauging emission standards and regulatory compliance, ensuring proposed technology is suitable based on location or topography, and generally supporting the project by providing a conducive business environment.

In adopting a remediation strategy or response to either the driving force, pressure or states- the stage, timing and appropriate action to be taken, should be carefully considered to achieve expected results and effectively mitigate the impacts identified. The preferred strategy may consist of single or combined solutions by multi-stakeholders, with adequate cognisance of costs, desired effects and the urgency of the impact to be rectified.

The model extension is valid and supported by projected waste amounts. For instance, Table 1 highlights estimated waste amounts for Nigeria up to year 2030 [3]. The rapid population growth and pressures on resources, will see waste amounts increase exponentially by about 22% between 2020-2025, i.e. an additional 11,600 tonnes of waste per day, based on conservative projections of 0.5kgs/person/day. Nigeria has a national policy and budget for solid waste management, but lacks basic legislation and related fiscal policy for waste [3].

Table 1. Projected Waste Amounts

				unit: thousand persons	
Population	**Year**	**2015**	**2020**	**2025**	**2030**
	Total	181,182	206,153	233,692	264,068
	Urban	86,673	107,113	130,312	156,300
				unit: thousand tonne/day	
Waste Amount	Generation Rate	**2015**	**2020**	**2025**	**2030**
	0.50kg/person/day	43,337	53,557	65,156	78,150
	0.75kg/person/day	65,005	80,335	97,734	117,225
	1.00kg/person/day	86,673	107,113	130,312	156,300

Source: JICA

Similar gaps are prevalent across sub-Saharan Africa, with lapses in administrative capacity, abandoning about half of the waste generated [3]. A common feature in most cities is the abundance of scattered waste heaps and overflowing waste skips. Vacant land and alleyways are also popular sites for illegal dumping and contribute to damaging the aesthetics and sanitary condition of most cities in sub-Saharan Africa [3]

Where the waste happens to be collected, it is usually improperly disposed of and managed, as almost 70% of waste in Sub-Saharan Africa ends up in open dump sites [3].

The absence of a structured waste tax system and appropriate waste-related legislation, hinders the drive for compliance or a basis for enforcement. In addition, appropriate waste behaviour is neither induced or encouraged. The major waste component in Africa remains organic waste, providing fitting breeding grounds for household pests, flies and other disease carriers, accounting for outbreaks of cholera, lassa fever and hepatitis, among others.

In addition, plastic wastes which are discarded haphazardly accumulate water and become a breeding source for mosquitoes and increasing spread of diseases such as yellow fever, dengue fever and malaria. These wastes also make their way into rivers and oceans with 5 African countries including Algeria, Egypt, Morocco, Nigeria and South Africa, being named the biggest contributors to marine plastic debris [3]. Blocked waterways and rivers, also aggravate issues of flooding.

Laws can be established at national, state and local levels of to govern the use of plastic bags and packaging. Rwanda provided a model for this, when in 2005, it banned plastic imports and use, and subsequently enacted anti-plastic bag legislation in 2008[31]. Legislation may also apply to electronic waste, with penalties, fines and possible jail terms imposed for harmful practices such as defecation on water ways and open dumping of waste.

The ultimate objective of legislation is to safeguard citizens' health and ensure their wellbeing is prioritised. However, the recurring issue across SSA relates to budgetary constraints and duplication of powers and responsibilities across government and non-governmental structures, which makes enforcement difficult.

Where related law and policy exist, challenges with monitoring, compliance and effective project evaluation due to a lack of institutional capacity, are worsened by persisting handicaps in financial and human capital.

The Human Development Index (HDI) has been lauded over Gross Domestic Product (GDP) in terms of measuring social development and equality, and in prioritising policy imperatives. The HDI encompasses factors related to quality of life, correlated to available and appropriate energy services [11]. The challenges for the government are therefore evident and this provides an opportunity for increased private sector participation and expertise in the treatment and disposal of waste, provision of financial leases to the public sector, and participation in turnkey projects for waste-to-wealth facilities [32]. The case study comprised these factors and delivered the expected results successfully for a limited time. However, the major cause of uncertainty in the study, was the element of alleged government failure- which covers coups, insurgent activity, expropriation and political upturns resulting in new but hostile authorities, with disregard for executed agreements. This impacts private sector interest and future investment in valorisation and waste to energy schemes within context and should remain a focal point for future policy and investment agreements, to hedge risk, uncertainty and loss of investment.

The market case study served as a reflection of Africa’s struggle with waste management, energy access and related environmental challenges, including the economic consequence of these issues, based on the elements identified within the customised DPSIR framework. The model was therefore extended to account for the additional economic impact of related energy and environmental issues.

3.9 Conclusion

The viability of decentralised biopower systems has been assessed and deemed viable to supplement defined energy supply and access gaps; under the right policy conditions. The objective remains to provide affordable energy in a sustainable manner, with minimal environmental impact for the sub-Saharan African region. The commitment of authorities and sustained political will in this regard, will determine the successful adoption of biomass power in mainstream energy mixes. It will also determine future investment and the provision of reasonable tax subsidies, secure and investor-friendly environments, structured regulation, compliance and enforcement, alongside the ability to honour partnership agreements remain imperative to this objective.

Abbreviations
MW- Megawatt
kVA- kilovolt-ampere
RE- Renewable Energy
WtE- Waste-to-Energy
Kgs- Kilogrammes
SSA- sub-Saharan Africa

Declaration of Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could be construed to influence the work reported in this paper.

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4. Chapter 3

Risky Business: A Real Options Valuation for Biopower Investments in sub-Saharan Africa

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Abstract

Adequate electricity supply in many African countries remains unaffordable, inaccessible and unreliable and this paper therefore seeks to assess the value of public-private partnerships in closing this gap. The standard binomial lattice model is extended to include the risk of government failure, as a key determinant of project value and partnership success in developing countries and ultimately guides the investment decision and timing by prospective investors. The results suggest that projects which would ordinarily be executed using traditional valuation methods and the standard binomial model, are significantly affected by the inclusion of government risk as a constant factor of uncertainty and consequently heightens the risk of investing in developing countries. The objective is to highlight imperatives for potential investors, in relation to costs, benefits, and inherent uncertainties surrounding biopower and related renewable energy investments, for enhanced energy access, economic and sustainable development of the region.

Keywords

Real Options Valuation; Biopower; Africa; Waste; Energy

4.1 Introduction

An estimated 80% of African households continue to rely on traditional biomass as a key energy resource, with attributable energy use currently estimated at 50% [1] [2]. The efficient use of waste generated in municipalities is therefore in focus, as Africa is experiencing unprecedented population growth, with predictions of 1.3 billion additions by 2050. This translates to an extra 3.5 million people a month, or 80 more people every minute [3] and makes Africa the single largest contributor to future global population estimates.

An expanding middle class and related increase in per capita consumption, urbanisation rates and population growth becomes especially troubling when considered in light of inadequate infrastructure to handle the associated increase in solid waste. The cost of providing sound waste management services appears burdensome and poses a challenge to authorities with limited resources and competing priorities. This cues the imperative for strategic partnerships in waste valorisation schemes and especially decentralised waste to energy

(WtE) projects.

Decentralised energy systems have gained traction due to existing centralised models in most developing countries being subpar, difficult to finance and entailing costly operation and maintenance routines with rapidly deteriorating equipment. Distributed grids on the other hand, are largely dependent on public-private partnerships [4]. [4] due to modern technology employed and are governed by the elements of cost, performance efficiency in terms of energy production or recovery and community acceptance due to perceived economic and environmental impact.

An additional consideration of equal importance is the risk element in energy system selection, investment and deployment. A valid distinction between uncertainty and risk is expressed by [5], who asserts that uncertainty varies from risk, as it is resolved through the passage of time, events, and action. Risk however, is usually the outcome of uncertainty and will often remain constant over time. Uncertainty may also increase as time passes and is often confused or used interchangeably with risk. The objective of this paper therefore is to test the element of government failure risk, as a factor that ultimately influences investment decisions. Government failure is defined based on substantive knowledge to include elements of expropriation disputes and attempts, ethnic and political instabilities, policy overturns, insurgency and usurpation of authority and an overall lack or absence of cooperation from the authorities. This risk is deemed constant and empirically modelled in a binomial lattice to ultimately determine the value of investment partnerships with government and adequate system selection in bridging energy access deficits prevalent across the region.

4.2 Literature Review and Justification

The real options framework remains a dominant assessment tool in investment appraisal, due to its value-add to capital decisions affecting the bottom line and the provision of strategic business options for projects riddled with uncertainty and characteristic to developing countries. It also gives the investor the right, but not the obligation to invest in and pursue value-adding technology and strategy; and equally assumes that the investor is both logical and competent and seeks to maximise wealth and minimise the risk of losses.

The traditional discounted cash flow (DCF) valuation method falters in the presence of uncertainty, due to its deterministic approach which potentially and grossly underestimates the intrinsic value of a project. The application of the real options analysis (ROA) is based on the existence of a financial model-usually derived from the DCF method. It also requires the presence of uncertainties which affect active project decisions and the outcome of the financial model [5]. The ROA aids in understanding a project’s true strategic value, where traditional valuation methods make certain projects appear ill-advised due to high implementation costs and no apparent payback timeline for the future [6]. In addition, the ROA provides a justification for the project’s existence and execution and is therefore a valuable extension of the traditional DCF method.

[7] states the characteristics required in an investment scenario for the ROA to be beneficial. First, uncertainty in the future must exist and therefore impacts the outcome of the investment decision. A degree of irreversibility must also apply, such that part of the initial investment will be lost should the investor reconsider the investment or project. Lastly, where the timing of the investment is flexible, the investor has the option to wait as more information becomes available, before making the investment.

ROA has been applied and assessed in diverse contexts across literature. It has been used in assessing the characteristics of renewable energy(RE) investments and its diverse applications [8], including the development of a policy benefit model to analyse China's biomass power production investments [9]. [10] developed a policy planning model using ROA, to determine the impact of uncertainty and technical change on the diffusion of emerging RE technologies; while [11] applied a systematic simulation of scenarios based on defined thresholds and investment parameters, to assess investment appraisal methods based on real options,. [12] developed an investment model to analyse the economic feasibility of waste-to-energy(WtE) projects in developing countries using ROA and suggests that based on energy production and investment costs, incineration or direct combustion is the best technology option for WtE projects, followed by gasification and pyrolysis.

[13] applied the ROA to a case study hydropower project using a compound options model. The authors assessed RE projects using estimates for uncertainties that affect project profits and economic feasibility. The ROA was conducted with the objective of yielding an option value to determine project feasibility. The emphasis was on high volatility and the associated risk of investing in developing countries.

This paper extends Kim’s work to the sub-Saharan African (SSA) RE and WtE scene, using a simple options model to build or defer the projects in question. The stochastic variables defined in past literature are duly acknowledged, however, a definitive constant in the global south is the investment and business risk often determined by the political stability or otherwise of the target region. This has previously been defined in the context of government failure risk, and the authors suggest that it is the key determinant of strategic optionality and overall project feasibility.

4.3 Materials, Methods and Assumptions

4.3.1 Research Questions

What is the justification, cost and benefits of investing in a decentralised biopower plant, considering the risk of government failure and other investor cost considerations? How does this impact the overall decision to invest, abandon or continue in partnership with government?

4.3.2 Theoretical Assumptions and Project Scenario

The literature guides the selection of two irreversible options for investment based on direct combustion and downdraft gasifier technologies in the project scenarios. A decision is considered irreversible once the investment has been made [14]. The downdraft gasifier is also considered the most suitable option for decentralised heat and power generation, because the syngas obtained from it contains minimal amounts of tar and particulates [15].

In this scenario, the agreement to invest in partnership with government (PPP) is considered irreversible, and abandoning the project will bear a related cost element.

The ROA is used to determine not only project feasibility, but the optimal investment timeline. It provides flexibility to postpone an investment until part of the underlying uncertainty is resolved and offers estimates related to the optimal investment time. The investment decisions are regarded as independent and exclusive [6] and government risk is deemed to occur at any time within the projected 5-year horizon.

The project scenarios are based on a company X faced with decisions to build either a US$100million WtE plant based on direct combustion technology(C) or a down draft gasification(G) plant costing US$200million (due to emission concerns leveraged against the popular combustion process). The uncertainty surrounding the investment and project success, leads company X into a public-private partnership(PPP) agreement with the government; and subsequently hedges the risk of losing its entire investment by providing an initial US$10million (for project C) and US$20million (for project G), to cover due diligence, licensing and commitment fees to the government. In exchange, the government provides pioneer status and subsidies for tax obligations, premium land allocation for siting the plant and other support schemes, which would secure a profitable return on investment.

[6] propose a six-step process for determining real options, using the Binomial Lattice method. This is illustrated in Figure.1 below.

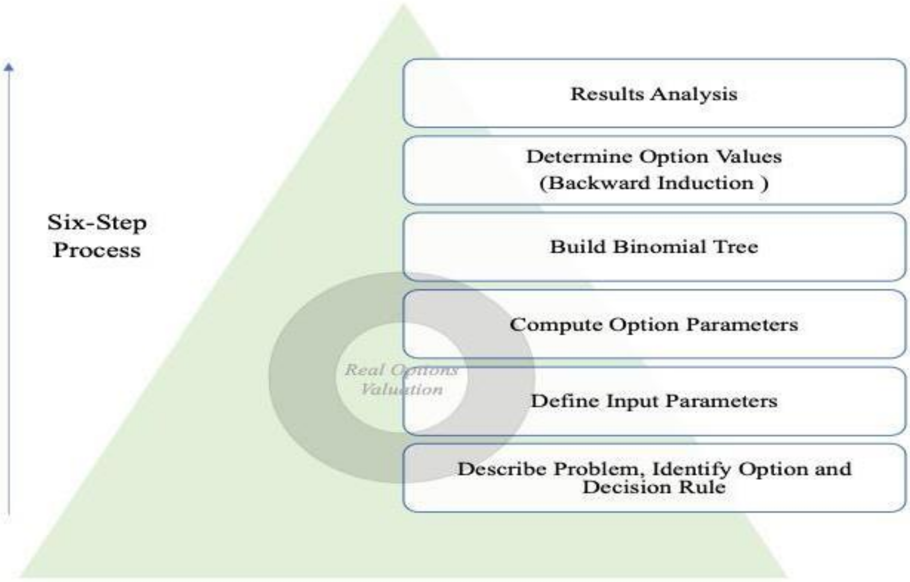


Figure. 1 Six-Step Process for Real Options

A DCF analysis on projected cash flows for both projects is carried out and the Net Present Values (NPVs) of the future cash flows are subsequently determined. An important point here, is that the traditional DCF approach assumes single decision pathways with fixed outcomes and can therefore be deemed a distinct case of ROA, where uncertainty and volatility equal zero [6].

4.3.3 Decision Tree Analysis(DTA)

A Decision Tree Analysis (DTA) is also integrated in the project scenario, as decision trees are considered effective tools in the valuation of projects that involve contingent decisions [6]. Decision trees are strategic road maps, depicting alternative decisions, related costs and possible outcomes, including the probability and payoff of outcomes [6]. The probabilities used in the DTA are subjective and imperative to the valuation process. The The existence of private and market risks to the investor justifies the DTA in this scenario, as it is able to factor in private uncertainty in addition to the ROA; thereby providing a unitary framework for valuation of projects that exhibit elements of private and market risks simultaneously[6].

The DTA in the project scenario is used to determine a build or no build decision for the plants, as a precursor to the ROA. This step may be applied in an investment decision making process, to determine the initial feasibility of the project within defined parameters. It may also be integrated subsequent to the ROA, to illustrate the decision pathways and subsequent course of action, derived from the option values.

4.3.4 *Binomial Lattice and Volatility Factor*

The "cone of uncertainty" is explained through the idea of increasing levels of uncertainty over time, even though the risk remains unchanged. The binomial lattice approximates the "simulation of stochastic processes" and the width of the lattice expands, as uncertainty increases [5]. Therefore, higher uncertainty levels will result in higher option values and higher time steps or increments used in the binomial model, will increase the chances of deriving more accurate option values [5] [6].

Heteroskedasticity, which refers to the volatility factor, is also assumed to change over time. Volatility represents the inherent uncertainty associated with the cash flows comprising the underlying asset value. The Logarithmic Cash Flow Returns Method (Table 1) is applied to derive the volatility factor (σ) in the options model. This represents the volatility of the rates of return, which is measured as the standard deviation of the natural logarithm of cash flow returns [6].

The volatility factor is the square root of (total of squares of deviation/n – 1), where n is the number of values. The return(R_t) is derived using equation 1:

$$R_t = S_t / S_t - 1 \qquad (1)$$

The binomial model is illustrated by the binomial tree (Figures 4-5), with So being the initial or underlying asset value. In the first time step (year 1), the value either goes up or down, and this pattern continues for subsequent time steps, up to the terminal time step (year 5). The up and down movements are represented by the factors u and d, where u is >1 and d is <1 [6] and it is assumed that:

$$d = 1/u \qquad (2)$$

These factors will be impacted by the volatility of the underlying asset. The first time step of the binomial tree has two nodes, showing the possible asset values ($S_o u$, $S_o d$)(Figures.4 - 5) as the time period ends. The terminal nodes at the end of the binomial tree represent the range of possible asset values at the end of the option life (year 5).

Risk-neutral probabilities are also applied within the binomial model by adjusting the cash flows and discounting at the specified risk-free rate. The risk free rate is derived using the difference in the current rates of inflation and government bond yield. The binomial lattice representing the underlying asset value is subsequently modelled below (Equation. 5). It is from this model, that the option values are subsequently derived.

The up and down factors, u and d, are functions of the volatility of the investment or underlying asset and are expressed below:

$$d = 1/u \tag{2}$$

$$u = \exp(\sigma\sqrt{\delta t}) \tag{3}$$

The risk-neutral probability is derived as follows:

$$q = (e^{rt} – d)/ u−d \tag{4}$$

and the option values are derived using the backward induction method, to build the binomial tree accordingly:

$$C = e^{-rt} [qCu+(1 − q)Cd] \tag{5}$$

r represents the risk-free interest rate and Cu and Cd are the option values associated with up and down movements along the lattice structure;

$$C= e^{-rt} [qCu + (1-q)Cd]* (1-Pf) - Pf *CPf \tag{6}$$

represents the extension to the standard binomial model, by incorporating the element of government failure risk; where Pf is the probability of failure risk and CPf is the associated cost of failure, which relates to the initial investment made to facilitate the PPP agreement (i.e. US$10million(C) and US$20million(G)).

3.5 Limitations

The challenges with cohesive data and accurate information related to project parameters, are the key considerations in the use of experimental or theoretical investment scenarios and the benchmark assumptions have been loosely based around active WtE projects across the sub-Saharan African region.

4.4 Results and Analysis

4.4.1 Decision Tree

The project NPV is calculated using the expected value (EV) method (Tables 1 and 2). The EV is simply the product of the probability of the event occurring and the outcome, which is expressed in terms of cash flow value [6]. The project's expected NPV is calculated based on this payoff, by incorporating contingent decisions at various decision nodes in the future. This is where DTA adds value, because the DCF method assumes a fixed path and does not account for the investor's contingent decisions.

The premise of the DTA here is based on the project scenario, where the investor assesses the respective projects on a preliminary basis. The outcome of the DTA based on the probabilities defined, show that the PPP route is the most viable option for the investment, even with a 35% chance of success(Figures. 2-3). The pay-offs are derived as follows: if the project fails, then the loss is equal to the initial amount invested, being the US$10million or US$20million for each project. If the project breaks-even, the total investment sum of US$100million or US$200 million is recouped. Where the projects are expected to yield a profit, the pay-off based on the estimated probabilities would be US$250million or US$300million for projects C and G. The expected NPVs are therefore positive for the PPP nodes and the project is expected to proceed successfully to yield NPVs of US$53million and US$6million respectively. However, a definitive investment decision would be premature based on this outcome, as both projects yield positive NPVs. In order to make a distinction between the exact time to invest and the project to execute, abandon or defer based on available funds and projected success, further analysis is required.

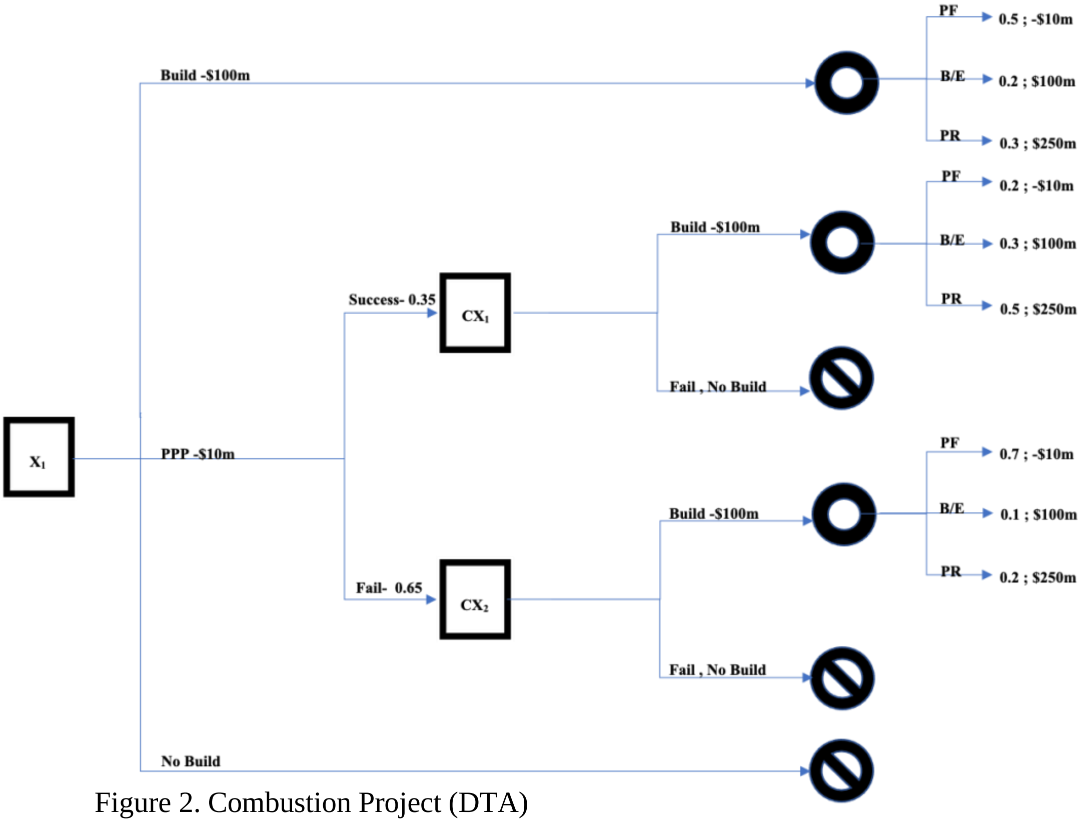


Figure 2. Combustion Project (DTA)

Table 1. Combustion Project (DTA) Expected NPV

DECISION POINT	ALTERNATIVES	EXPECTED NPV CALCULATIONS	EXPECTED NPV ($m)	DECISION
CX1	**BUILD**	0.2 *(-10) + 0.3 * 100 + 0.5 * 250 - 100	**53**	**BUILD**
	NO BUILD	0	**0**	
CX2	**BUILD**	0.7*(-10) + 0.1 * 100 + 0.2 * 250 - 100	**-47**	**NO BUILD**
	NO BUILD	0	**0**	
X1	**BUILD**	0.5*(-10) + 0.2 * 100 + 0.3 * 250 - 100	**-10**	
	PPP	0.35 *53 + 0.65 *0 - 10	**8.55**	**PPP**
	NO BUILD	0	**0**	

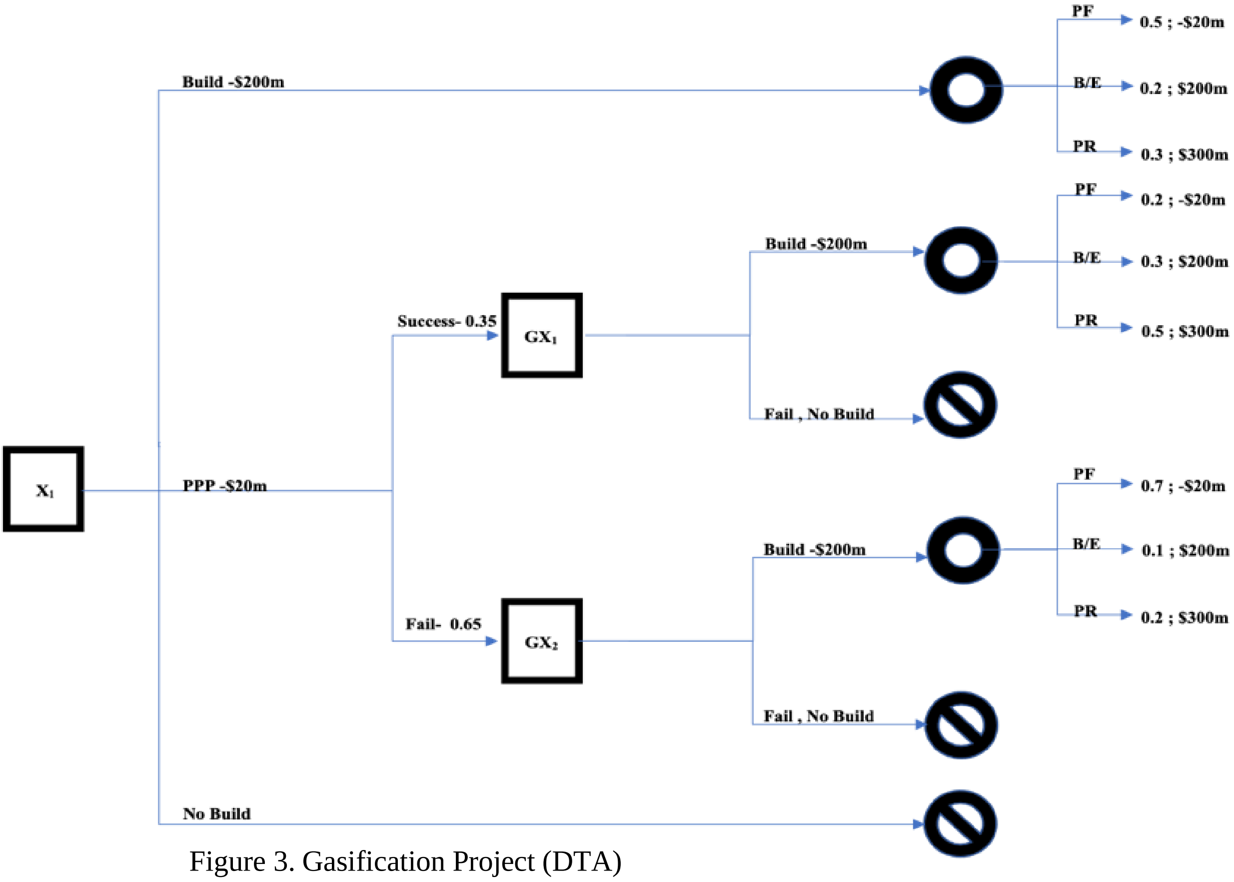


Figure 3. Gasification Project (DTA)

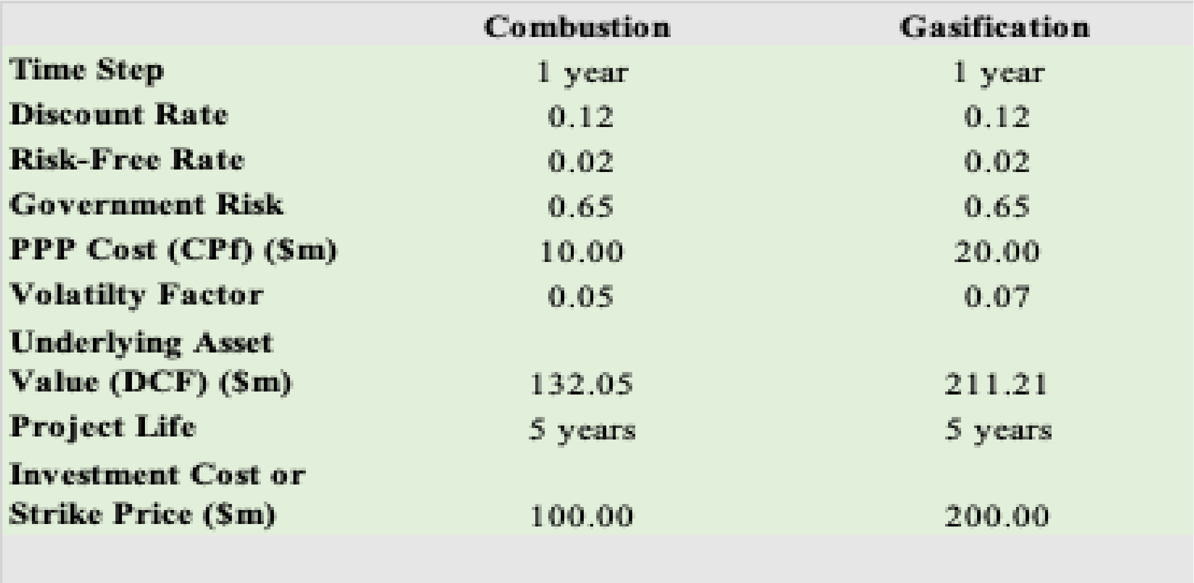
Table 2. Gasification Project (DTA) Expected NPV

DECISION POINT	ALTERNATIVES	EXPECTED NPV CALCULATIONS	EXPECTED NPV ($m)	DECISION
GX1	**BUILD**	0.2 *(-20) + 0.3 * 200 + 0.5 * 300 - 200	**6**	**BUILD**
	NO BUILD	0	**0**	
GX2	**BUILD**	0.7*(-20) + 0.1 * 200 + 0.2 * 300 - 200	**-134**	**NO BUILD**
	NO BUILD	0	**0**	
X1	**BUILD**	0.5*(-20) + 0.2 * 200 + 0.3 * 300 - 200	**-80**	
	PPP	0.35 *106 + 0.65 *0 - 20	**17.1**	**PPP**
	NO BUILD	0	**0**	

4.4.2 Binomial Lattice Model

The projects were evaluated using the six-step process illustrated in Figure.1 and the input parameters to determine the build or wait option are listed in Table 3 below.

Table 3. Input Parameters



	Combustion	Gasification
Time Step	1 year	1 year
Discount Rate	0.12	0.12
Risk-Free Rate	0.02	0.02
Government Risk	0.65	0.65
PPP Cost (CPf) ($m)	10.00	20.00
Volatilty Factor	0.05	0.07
Underlying Asset Value (DCF) ($m)	132.05	211.21
Project Life	5 years	5 years
Investment Cost or Strike Price ($m)	100.00	200.00

The option parameters are mediates to the final option value calculations and are derived from the input parameters. The up movement (u), down movement (d), and risk-neutral probabilities (q) were estimated at 1.055, 0.948 and 0.677 for project C and 1.073, 0.932, and 0.627, respectively for project G, using Equations (2) – (4). The option values were computed using Equations (5) and (6), yielding values for the standard model and the model with the inclusion of government failure risk. The asset values at the varying time steps are also calculated and expressed within the binomial tree.

The investor is expected to make distinct investment decisions at each node of the binomial lattice tree (Figures. 4 and 5). The decision is influenced by the option values and the difference between the asset value and investment cost. In Figure. 4, where the asset value (top number) exceeds the investment cost at node S_0u^5, the expected asset value is US$172.22 million, for a proposed investment cost of US$100 million, this results in a net asset value or profit of US$72million. Therefore, the decision at this node will be to invest or build the plant. However, where the constant risk of government failure is considered, the option value changes from US$72million to US$18million (bottom numbers separated by ;). This is still a positive position and the plant would be deemed a worthwhile investment.

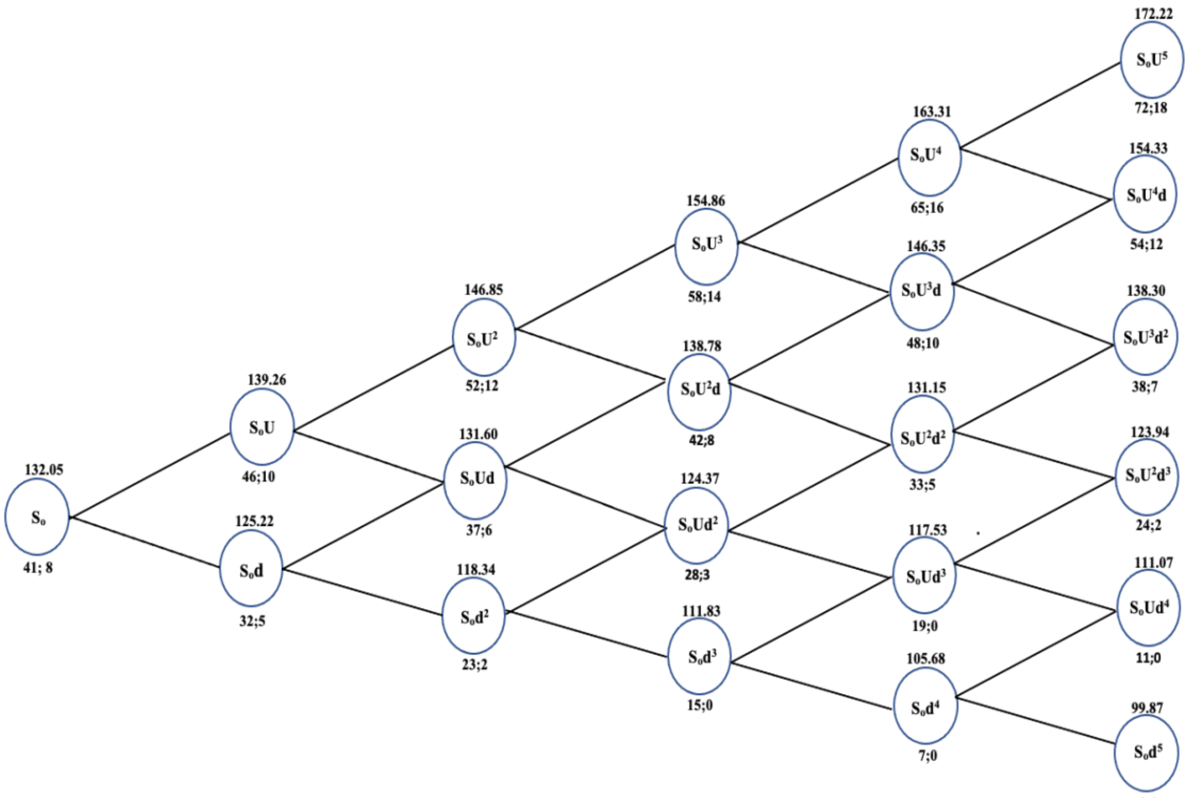


Figure.4 Option Values including Government Risk -Combustion

In contrast, moving to the intermediate nodes, at node S_od^4, the expected asset value for keeping the option open is US$105.68million, which yields a profit of approximately US$6million. The option value or strategic net present value at this node however, is US$7million which indicates that there is some value in waiting to execute the project as a higher payoff is expected. The corresponding value with the inclusion of the government risk factor, yields an option value of US$0 at the same node. This may be interpreted as the project having no perceivable value or is unfeasible at that time step due to active government related risk and related uncertainties. If the investor deems the project risk as being too high, for instance, in reality that particular time (i.e. 4 years from year zero) may be related to an impending political election year, which may produce a different and possibly hostile government. Based on this outcome, the plant construction and entire project and PPP arrangement would either be rescinded or deferred to a time where the uncertainty is expected to have passed. This interpretation assumes that investors are rational, competent and responsive to market movements and general information which affects their bottom line. The cost of the decision to rescind the PPP agreement and abandon the project, would translate to a forfeiture of the initial investment of US$10million for the PPP arrangement and represents the irreversibility element earlier described.

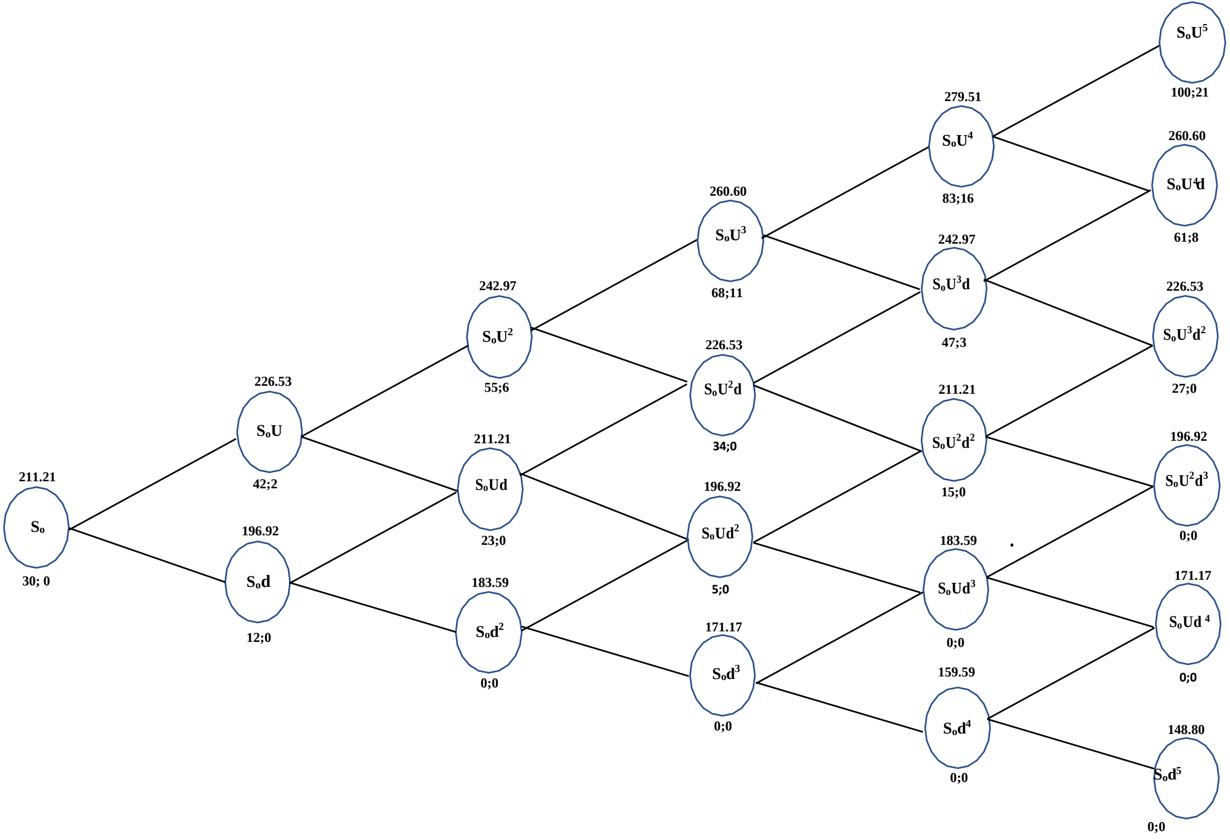
This decision making process is repeated until time 0, corresponding to node S_o. The option value at that node is US$41million which is higher than the net asset value. The corresponding option value adjusted for government risk, yields an option value of US$8million which is less than the US$10million initial investment. At this point, the investor may decide to defer executing the project, to allow the uncertainty resolve. In this scenario, the option value is highest value at year 5, which suggests that it would be advisable to wait and invest at that time, due to the expected pay-off.

The binomial method offers transparency by showing the project values in the future for expected payoffs and the relevant decision pathways open to competent and rational investors. The premise is based on allowing the future uncertainty pass, thus enabling beneficial decisions by comparing the expected payoff with the investment cost, at a given time step.

The value of the ROA when considered alongside the NPV of US$32.05million, would yielda real options premium of US$8.95million. However, the inclusion and adjustment for the government risk or failure, narrows the options in terms of the optimal time to invest and build the plant; as it is only at the nodes where the option value and risk-adjusted option values exceed the net asset value, will the project be executed or deferred in hopes of higherpayoffs.

A similar process is repeated for the values in Fig. 5 and the outcome yields an option premium of US$18.70million from an NPV of US$11.21million. However, the risk adjusted ROA value yields US$0million at node S_o, indicating an unfavourable investment time to build the plant and the only other feasible time along the lattice tree, would be at the single terminal node S_ou^5; where all the values are favourable and exceeding the net asset value and initial project cost of US$20million.

Figure.5 Option Values including Government Risk -Gasification



However, the outcomes do not alter the DCF-NPV decisions to invest in the respective projects, but simply guide the investor on the optimal time to build or invest, considering inherent uncertainties and risk. It therefore provides an investment strategy, such that, though a project may appear favourable for execution, the ROA provides the optimal timeline to do so. The inclusion of the government risk factor, pushes this optimal investment timing decision further into the future, to allow the timing, events or other uncertainty-related actions pass. Empirically, tariffs and energy production have been identified as the catalysts for RE project profitability [13], based on the outcome of numerous Monte Carlo simulations and sensitivity analyses. The authors consider these variable factors which can be resolved within reasonable ambits of the investor's ability, system selection or appropriate negotiations with the authorities. However, the risk of government failure is out of investors' control and will constantly hover over a given venture, holding the potential to completely reverse or overturn related agreements or progress made regarding the investment.

This argument is clearly illustrated, where the project has been given a go-decision based on favourable option values derived from the standard model and optimal time to invest has been determined and adhered to. The plant construction has commenced and the relevant processes are set in motion, however, ethnic violence or sudden disturbance around the plant's vicinity such as insurgent activity which becomes protracted, will automatically void all perceived and or expected benefits from the project. In practice, however, a rational investor is expected to protect all investments and assets legally and equally assumes conscientious authorities acting with integrity, to provide necessary support and compensation where feasible.

It is also pertinent to note that the project scenarios assume zero leakage, i.e. the deferral or wait option does not create a loss in value or erosion by competition. The option to wait or defer a project is applicable and beneficial for projects where the investor possesses "proprietary technology or exclusive ownership rights and the barriers to entry are high". Therefore, the project that yields the most value for the investor at any given time, in light of the risk of government failure, is the option to build the combustion plant. The company may however, exercise caution and stage the project in phases; thus, providing investment outlays in tranches, to minimise losses and hedge risks.

From the above analysis, it is evident that the combustion plant is the favourable option, as the government risk-adjusted option value still yields a real options premium; and the option to invest is observed favourably across a larger horizon, based on the defined time steps. The gasification project is only practical for investment at the terminal node and will require a larger investment. In spite of the significant payoff at this node and the superior or preferred gasification technology, the investment outlay would be considered an irrational decision based on the scenario.

Favourable NPVs are a result of payoffs that exceed project investment and corresponds to the strike price in the ROA. Where the expected payoff is greater than the investment cost, a rational decision would be to invest at that time or forfeit the project entirely.

4.5 Discussion

The advent of covid-19 and the related economic challenges and resource constraints have triggered a strategic divestment of foreign interests within the sub-Saharan African business scene. For example, the South African retail giant Shoprite, announced the conclusion of its divestment from the Nigerian market after 15years of operation and closed the last of its Kenyan stores in February 2021 . This is one of many examples, and the challenge for most SSA governments already grappling with political wrangling, public health crises, currency devaluation, insecurity threats, ethnic conflict, limited economic resources and infrastructure deficits- remains how to attract and retain foreign capital in this case, to the RE scene. This is pertinent to funding and closing energy access and poverty gaps, often requiring technical and financial capacities beyond the ability of these authorities.

The validity of the analysis caried out in this paper, is in its relevance and replicability for actual projects under consideration by potential investors, wary of the afore-mentioned risks in the focal region.

It is also pertinent to state that in spite of the option premium yielded by project C, this outcome is largely attributable to the project parameters defined for the investment scenario. Direct combustion, although a popular method for energy recovery is not without its criticisms. Issues with significant pollution generated from the process, with considerably low efficiency estimates in the region of 5-15% and conversion rates of less than 25% of material energy in municipal solid wastes to “marketed electricity”, makes the technology option expensive and the least efficient energy recovery method [15] [16]. Modern applications however, appear to have overcome some of these challenges, as seen with the Ethiopian Reppie facility which has adopted a modern back-end flue-gas treatment technology, that reduces the sulphur dioxide (SO2), nitrogen oxides (NOx), dioxins and heavy metals produced by the plant during the incineration process. The plant operates in cognisance of the European Union’s (EU) strict emission limits and residues from the process are duly recycled or safely discarded [17]

Gasification entails the conversion of “combustible solids into gaseous fuel mixtures with minimal quantities of char and condensable compounds”[18]. The advantage of the biomass gasification system compared to conventional combustion technology, is the reduction in Green House Gas (GHG) emissions. Biomass gasification systems have been observed as having 2-times the effectiveness in reducing GHG emissions [18], over other RE resource recovery technologies. In addition, the unit cost of electricity for energy generation using this system, is considerably lower than other comparable technologies and it is therefore considered suitable for Village Energy Security Programmes (VESP) and Remote Village Electrification (RVE) schemes [18].

The implementation of bioenergy resources for biopower, using decentralised models or distributed grids requires more focused attention, as the popularity of solar energy and hydropower currently overshadows its potential benefits and relevance. Biopower is considered firm power i.e. it does not require back-up generation or battery storage unlike other RE sources and is derived from a homogenous source which is readily and freely available. The challenges however, relate to the logistics of waste transfer from landfills to plant site, separation and sorting mechanisms and preferred conversion technology based on applicable ISOs and Clean Development Mechanism (CDM) protocols.

4.6 Conclusion

The key objectives of this study were to estimate the risk of government failure, identified as a constant factor in developing countries, determine the optimal investment timeline and the preferred project based on direct combustion or biomass gasification systems. The study also provided a justification for the extension of the standard binomial model, estimated the economic cost and highlighted the benefits of investing in a decentralised biopower plant. It also highlighted the overall impact of the decision to invest, abandon or defer the project, on the potential investor’s bottom line.

The real options valuation using the six-step process was applied to determine a strategic investment roadmap for two distinct project scenarios. The scenarios were based on investment decisions involving two competing renewable energy resource recovery technologies, to determine the optimal timeline for investment in a sub-Saharan African country. The region is characteristically considered to be volatile and investments are largely exposed to heightened uncertainty and risks. The simple wait option model of the ROA framework, grants flexibility to investors to build or defer projects to a future time where the uncertainty may have passed. The decision makers determine the optimal or appropriate investment strategy at defined time steps, bearing in mind prevalent or existing private and market uncertainties. It is evident that the framework and the analysis successfully resolved the research objectives of this study and therefore solidifies the superiority of the ROA in investment appraisals, with the valid model extension for developing countries and contexts.

4.7 REFERENCES

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5. Chapter 4

A Comparative Life Cycle Investment Analysis for Biopower Diffusion in Rural Nigeria

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Abstract: This paper adopts the Life Cycle Investment (LCI) approach proposed by Farinha et al. to assess project viability based on the maintenance and operational efficiency of a proposed biopower plant over its useful economic life. The adoption of ISO 55000:2014, its guidance on management and maintenance policies for physical assets, and its contribution to the achievement of sustaina-ble development goals on clean and affordable energy (SDG7) remain relevant for investment de-cisions regarding waste-to-energy technology systems. Using the parameters defined in a previ-ous biopower feasibility study for Nigeria, the LCI approach is applied to show the change in project profitability over the estimated useful life of the plant, where availability is altered, based on maintenance downtime and overall operational efficiency. The results show positive move-ment in operational efficiency between 85–91%, which correlates with increased profitability in the same period. The project's profitability and return on investment is revised downward from 29% to 8% based on the initial availability adjustment, and the changes in derived profit based on plant availability support the argument in favor of operational efficiency and structured maintenance policies as key performance and investment viability indicators, which ultimately impact the total cost of ownership. The results are also interpreted using Pareto Principles for emphasis. The ultimate goal is to encourage due attention and diligence in relation to latent fac-tors which often erode the perceived benefits of viable projects after completion and potentially hamper future investment, specifically in the broader sub-Saharan African waste management context.

Keywords: UNSDGs; waste; energy; biopower; sustainability; LCC; LCI

5.1 Introduction

Rural electrification rates in developing countries remain considerably low, with an estimated 1.6 billion people still living without access to electricity [1]. Estimates for Nigeria's total installed and operational capacity are pegged at 12,310 MW and 7,788 MW, respectively, with approximately 3,750 MW available annually [2]. These metrics are for 28 on-grid power plants plagued with gas and water shortages, and frequent breakdowns due to commercial and technical grid constraints [2].

The total demand for power is expected to increase by almost 27% in developing countries, from 19,562 TWh to 26,761 TWh between 2012 and 2025 [1], with global capacity projections of up to 8370 GW (2025), about 70% of which would be attributable to enhanced capacity in developing countries [3].The Transmission Company of Nigeria (TCN) forecasts electricity demand to expand at a rate of 6% up until 2035, and with universal access targets for 2030 and roughly 20 million households still living without energy access [4]. Nigeria's current and future energy demand will remain suppressed. This is mostly due to poor electricity supply infrastructure and networks, with attendant illiquidity and significant debt within the energy supply industry [2].

Ezennaya et al. [5] also predicts an electricity demand growth factor of 1.9 × 103 MWh due to technological and economic expansion, and renewable energy (RE) sources are expected to contribute to approximately 10% of required energy cover.

Biomass energy remains a viable RE resource, and with Nigeria's biomass potential estimated to be around 3.2 EJ (2010), 5.5 EJ (2020), and 29.8 EJ (2050), it provides a viable supplement to cover suppressed energy demand. The popular biomass sources remain as agricultural and livestock wastes, municipal solid wastes (MSW), and forest residues; in order to determine the viability of biomass feedstock for power generation, factors such as the nature of feedstock and its supply, waste conversion processes, and the proposed technology for power generation must be considered.

MSW is in focus because it empirically possesses high capacity factors and is considered an economic source of electricity [6]. The proper management and conversion of MSW to energy still remains a challenge in most developing countries, and in view of current global public health challenges, the import for rural populations in particular in terms of health and general wellbeing is evident; rampant dumping, inadequate collection, and uncontrolled burning of solid wastes remain an unfortunate norm [7,8].

In Nigeria, MSW is generated at an average rate of 0.49 to 0.56 kg MSW/cap/day; this is expected to rise in urban areas by 2025 to 0.80 kg MSW/cap/day, translating to almost 100,000 tons of MSW/day [5]. Waste-to-Energy (WtE) systems are therefore projected to provide about 0.7–1.7% of total projected energy supply and represent up to 9.8–26.2% of indicative energy consumption by 2025 [5].

General MSW thermal treatment processes include incineration, gasification, liquefaction, pyrolysis, curing, and direct combustion [9]. However, only a few of these have proved adequate and economically viable for African cities in the near to medium term, as conventional waste treatment technologies are often technically beyond the capacity of most local and regional municipalities and are therefore challenging to implement. WtE technologies are also costly, and considering the modest economic capacities of the populace, open dumping and burning of wastes remain preferred 'models' for waste management [10].

This provides opportunities for the implementation of decentralized "waste" management [11,12] and electrification systems in order to reduce regional disparity in rural and remote areas, and equally provides the enhanced reliability of energy supply and potential income generation streams, especially for informal waste actors from the use of local resources, as trash is generally homogenous. Centralized energy supply systems are losing popularity, due to fossil fuel depletion and environmental concerns, insecurities surrounding energy transport infrastructure, and investors hedging their risk exposure through the deployment of smaller-scale, modular generation, and transmission energy systems [1,13]. Decentralized waste conversion technology has therefore been proffered as a viable route, using locally available resources for the electrification of rural and remote areas.

Biomass power is expected to be connected to both national and minigrids through decentralized power stations connected to modular power line networks; this will service several households, buildings, or machinery, thereby increasing energy access for rural communities [14].

The funding deficit, however, remains a core challenge for solid waste management in Nigeria, considering related waste volumes. This deficit is enhanced by systemic inadequacies and inefficiencies, especially in operational capacity, as was observed in Umuahia, a South-Eastern Nigerian city with over 1.2 million people; about 50 metric tons of waste is generated daily, with a total waste collection capacity of 76 garbage bins [15].

The Nigerian economy, following the severe aftermath of the global pandemic, has slid into economic recession with attendant unemployment and an overall decline in the standard of living and wellbeing of people. Rural communities in particular require focused intervention to bridge local and regional disparities, and to equally manage the impact of rising populations with increased rural–urban migration rates.

In terms of biopower investment and adoption, investor and consumer willingness to adopt this energy conversion strategy has been linked to the level of education and sensitization among intended users, alongside robust and well executed tax deduction and energy subsidy schemes, which include production tax credits (PTCs)[16,17] among others. Biomass power plant investments have mostly been successful where supportive state and federal RE electricity policies exist, and are implemented rationally and objectively to maximize its inherent benefits for both current and future energy demand. In sufficiently justifying the need for biomass-based energy and outlining its benefits for rural and urban poor communities, which are often marginalized, the subsequent challenge remains hinged on bridging the finance gap to attract private funds in facilitating and actualizing inherent WtE benefits. Therefore, the question of how to successfully commercialize and disseminate this energy source through enhanced private investment persists.

The basis of investment, techno-economic, or technology assessments are often to determine the value of technical efficiency and infrastructure investment required to fulfill project objectives. This often ignores significant elements which impact revenue streams and the entire value of a given project at a future date. Factoring in the time value of costs or ‘variable investments’ and operational efficiencies allows for a comprehensive evaluation of the project in cognizance of the uncertainty and significant financial risk of investment. This paper therefore seeks to highlight the significance of maintenance downtime and the resulting availability of the plant as a key element in investment consideration and project profitability, based on established LCCA results in the focal region.

It introduces the concept of Life Cycle Investment (LCI), especially for physical assets employed in industrial processes, in line with the International Organization for Standardization (ISO) 55000:2014 asset management system and erstwhile Publicly Available Specification (PAS) 55. The standard remains focused on sustainability principles, and provides guidelines on the management of assets through the entire life cycle.

This study is relevant, as Waste-to-Energy initiatives have often been ignored and criticized as lacking commercial viability, particularly in contrast to solar and hydro power modular systems, and have also been deemed technically and financially demanding due to the complexities in the sorting and separation of waste matter. However, the inherent benefits for the environment and overall sustainability objectives cannot be conscientiously overlooked. The overall objective remains to provide guidance and a basis for enhanced investment in terms of adequately assessing the inherent complexities of proposed ventures in politically and financially risky climes, such as Nigeria’s and consequently boost private participation in the general African waste valorization domain.

5.2 Background and Literature Overview

The market for WtE systems is expected to grow by roughly 79% to about US$29.2 billion between 2012-2022[6], another growth estimate forecast puts the figure at around US$80.6 billion[6]. WtE systems are equally projected to treat a minimum of 261-396 million tonnes of waste annually by 2022, with a total estimated output of 283-429 TWh of power[6].

The LCI analysis draws vital conclusions for strategic managerial decision-making and its implementation will be constrained in the real world by factors such as the available funds for investment, energy demand metrics, the nature and availability of required biomass feedstock, changes in cost of plants based on market conditions and changes in subsidies from "incentive schemes"[20]. In this regard, access to energy finance and investment remains imperative and will require national support systems and strategies for managing political and regulatory risks related to energy infrastructure.

The specific WtE conversion process or technology is equally imperative to operational efficiency or availability. Biomass gasification has been empirically observed to possess 2 times the effectiveness in reducing GHG emissions over other RE technologies, with lower unit costs of electricity and has been posited as a strategically viable option for rural electrification[6]. It is also deemed suitable for Village Energy Security Programmes(VESP) and Remote Village Electrification (RVE). It is equally an efficient energy recovery method, for industrial purposes, as it produces less harmful effluents, which often pose severe environmental hazards[6].

Small biomass gasification power plants provide a competitive way to convert diverse, biomass waste to syngas for combined heat and power(CHP) generation and certain gasification power plants have been successfully commercialised, with electrical and cogeneration efficiencies of about 20-80%, with 500-1000 €/kWe, estimated global capital cost[23].

This is evidenced in the Entrade Energiesystems E3 micro-scale biomass CHP plant in Cheshire, United Kingdom which surpassed 1000 hours of operation with minimal human interference in 2015[2].The gasification technology provides continuous baseload power at micro scale, to generate decentralised energy on-site. This boosts the competitiveness of small-scale baseload energy and a maintenance-free, modularised CHP can adapted for local use. The E3 system overcame the challenge of 24/7 maintenance due to regular breakdowns by producing almost no tar, and runs efficiently with roughly 15 minutes of maintenance required weekly[3]. The upgraded E4 model[4] was introduced in 2018 and uses waste to produce high-quality syngas, which powers an internal combustion engine and supplies electricity, heat or cooling, as required.

The E4 model is considered "the world's first modular, series-produced, patented, fully automatic biomass power plant for grid-connected and off-grid power generation"[5]. Each individual E4 power plant has a generation output of 50 kWe and a nominal heat output of

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[2] http://www.renewableenergyfocus.com/view/42637/world-s-smallest-biomass-power-plant-using-biomass-gasification-passes-1000-hours

[3] http://www.renewableenergyfocus.com/view/42637/world-s-smallest-biomass-power-plant-using-biomass-gasification-passes-1000-hours

[4] https://bioenergyinternational.com/technology-suppliers/entrade-showcases-high-performance-micro-biomass-power-plant-at-hannover

[5] https://bioenergyinternational.com/technology-suppliers/entrade-showcases-high-performance-micro-biomass-power-plant-at-hannover

120 kWth, and can be fully operational on a turnkey basis within 2 days[6] . The electric power generated from the system is deemed competitive with or without subsidies compared to other alternatives, and can be used locally as a stand-alone system or fed-in to the national grid. The individual plants can be connected to form larger units, of up to 5 MW and approximately 150 plants have been successfully deployed in 9 different countries worldwide, as at 2018. The E4 system's dimensions are 186cm in length and 156cm in width and can be shipped globally by air freight.

From the above, it is evident that the developed world has sufficiently produced and continues to innovate energy solutions for enhanced well-being and efficiency. The "how? "question in investment terms posited earlier, however, has traditionally been answered by Life Cycle Costing (LCC) methods, as it determines the "probabilistic interdependence of macroeconomic variables over time" [19] and provides a "cradle-to-grave" assessment [18] of the environmental or associated costs of a process, product, or activity by accounting for physical and material resources required to deliver output. It is generally adopted within engineering and business communities, and consists of adding all relevant and **related costs** over a specified period of use, subtracting the terminal value, and ultimately adjusting for inflation [20,21]. This analysis is usually sufficient in economies where certain variables can be predicted with relative accuracy. The economic and political climate of most African countries, however, begs a different approach to ultimately minimize long-term investor exposure and boost economic activity and development in the proposed sectors.

The goal of any LCC analysis is to determine two significant economic metrics, Life Cycle Costs (LCC) and Levelized Cost of Energy (LCOE), for a given biopower pathway [22]. According to Li [23], the LCC of a power plant encompasses the total costs generated throughout the plant's useful life and provides insights into the "lowest long-term cost of ownership", as the expenses that would normally occur during each stage of the project and the concept of present values [16] are considered objectively.

The most suitable method for evaluating the profitability of a potential investment is defined by the project's aims and objectives. In this case, the objective is to present bi-omass, and specifically decentralized systems, as attractive alternatives to solar and small hydropower RE systems, which currently enjoy commercial popularity. Potential private operators and investors remain focused on maximizing profit, and therefore, this study tests an addendum to traditional LCC methods postulated in a previous study to guide investment decisions.

The literature on LCC methodology is vast, however, several authors such as Spickova and Myskova [24] have identified the significance of maintenance and operation costs as part of the main components of an LCC analysis, which seeks to ensure that investment objectives are optimized without sacrificing performance.
Kianian et al. [25] emphasize the importance of quality, productivity, and availa-bility as three key performance metrics which are often overlooked in LCC computations, but remain pertinent in determining the Overall Equipment Efficiency (OEE) measure. Bengtsson and Kurdve [26] suggest that an asset must be analyzed from an investment perspective, and that a low LCC for a project does not automatically imply a significant Life Cycle Profit (LCP); therefore, the LCC must be assessed in tandem with the productivity or project output.

Ljiljana, Dragutin, and Zelimir [27] state that maintenance management was the pre-cursor to asset management, which remains focused on maximizing the life of physical assets and emphasized its importance in the overall performance of a given entity. This is supported by Katicic et al. [28], who emphasized the importance of asset management as evolving from a maintenance focused culture, and states the relevance of asset governance to the implementation of the ISO 55000 standards.

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[6] https://bioenergyinternational.com/technology-suppliers/entrade-showcases-high-performance-micro-biomass-power-plant-at-hannover

Stimie and Vlok [29] developed a strategy for early failure detection to assist asset managers. The "Physical Asset Management Strategy Execution Enforcement Mecha-nism" (PAMSEEM)" provides a system for feedback, decision-making, and execution strategy, all centered around the management of physical assets through their respective life cycles.
The relevance of an asset's operations, management, and entire life cycle to the overall investment, future operational, and related costs are highlighted in Eicher's [30] work, where the imperative of considering the operating life of a given physical asset before its construction or development is equally emphasized.

Maintenance performance indicators are assessed in terms availability, mean repair times and the time between failures, where the asset operates optimally and these metrics are used as tools to determine the correlation between the maintenance schedule, policies, and economic benefit or Return on Investment (ROI) [31,32].

Traditional LCC analyses have been criticized for failing to include income from output or production activity and overall investment in maintenance. By recognizing these factors, the potential investor is able to determine core strategies to optimize plant availability in this case and the overall performance and life of physical assets employed in production activity; this ultimately supports overall investment profitability [33].

5.3 Materials and Methods

This paper adopts the Life Cycle Investment (LCI) approach developed by Farinha et al. [33] to analyze a plant's LCC through its financial life cycle using econometric models. The initial investment in a physical asset, such as a power plant, involves an outflow of economic benefit or resources, and the authors argue that the term 'investment' is erroneously used since an outflow occurs; whereas the financial and related resources employed in the maintenance of the same asset required to deliver economic value are deemed costs. It is this contrast that the LCI analysis bridges; it enables the evaluation of maintenance schedules and structures in terms of the overall effect on the plant's medium to long-term productivity and related profitability; this is especially prevalent in industrial processes or services undertaken for public benefit, such as electricity.

The plant's availability is deemed paramount to the entire analysis, and the key performance indicators within the context of maintenance policy and schedules are determined based on the timeto repair and the maximum availability.

This paper therefore adapts the LCI approach to the feasibility study conducted by Oyegoke and Jibiril [34] for a proposed 5 MW biopower plant in Nigeria. The study outcomes are evaluated to a limited extent, with emphasis on the revised profitability outcome based on the LCI analysis.

A power plant will normally start and remain in operation over an extended period, which inherently involves long-term costs that must be accounted for. The present value (PV) of future costs is determined and discounted at prevailing inflation and interest rates (Ri). In this context, theLCC of the plant is the sum of the present value of total costs (FCi) over the plant's estimated life, as expressed in Equation (1) below:

$$\mathrm{PV} = \sum_{\mathrm{i=0}}^{\mathrm{n}} \frac{\mathrm{FCi}}{\mathrm{(1+Ri)i}} \qquad (1)$$

The lifetime associated costs of developing the power plant include those related to strategic decisions, purchase of plant and office equipment, installation, and operating costs, alongside routine maintenance, commission, and decommissioning costs, which would normally be aggregated.

In contrast to the traditional LCC methodology, Farinha et al. [32] argue for a distinction between project investments and costs, stating that initial costs should be deemed initial investments, while secondary costs should be "variable investments".

The LCI approach adopts a performance indicator for maintenance services at the plant, as the sum of plant processes and productivity metrics are dependent on this factor; this is ultimately captured by the operational efficiency rate or 'availability'. Farinha et al. [32] postulates a direct correlation between profit or benefits and availability, and states that profit calculations must recognize equipment downtime due to routine maintenance; this gives rise to a "Mean Wait Time (*MWT)*" and a "Mean Time To Repair (*MTTR*)". The functional time, i.e., when plant equipment functions optimally, would be represented by a "Mean Time Between Failures (*MTBF*)". A low *MTTR* would signal greater operational efficiency or "maximum availability", and would ultimately bear a significant impact on the calculated profits which would guide the final investment decision based on the evaluation.

Operational efficiency or availability is therefore modelled as follows:

$$E_i = \frac{MTBF_i}{MWT_i + MTTR_i + MTBF_i} \tag{2}$$

i, represents the time period to the *ith* year, while the period of inefficiency, unavailability or non-production is expressed below:

$$U_i = P_i * (1 - E_i) \tag{3}$$

Pi denotes the profit or project benefit.

Adapting the LCI theorem to the standard LCC model, the initial and variable maintenance investments are modelled in Equation. 4 to derive a "global result" or total performance indicator (TP_n) as follows:

$$TP_n = \sum_{i=0}^{n} \frac{P_i * E_i}{(1 + R_i)i} - \sum_{i=0}^{n} \frac{F_i}{(1 + R_i)i} - \sum_{i=0}^{n} \frac{M_i}{(1 + R_i)i} - \sum_{i=0}^{n} \frac{U_i}{(1 + R_i)i} + \sum_{i=0}^{n} \frac{I_i}{(1 + R_i)i} \tag{4}$$

where, for the year *i:*

Pi is the value of benefit or profit
E_i is the efficiency or availability
Fi is the value of functional time

Mi is the value of routine maintenance
U_i is the value of non-production or unavailability, and
Ii is the value of the power plant

Oyegoke and Jubiril [34] developed a detailed feasibility study for the construction of a 5 MW biopower plant in Nigeria, estimated to produce 130 MWh with an initial investment cost of USD 89 million and USD 81 million in operating costs. In their analysis, the duration of power supply, heating value, and energy generation were used to determine the cost of equipment. The plant’s profitability was evaluated based on the total capital invested and operation costs, and was eventually deemed a worthwhile investment to boost development in the Nigerian economy.

Based on the above, the plant was deemed to realize a total net profit of USD 26 million, with an estimated net present worth or benefit of USD 191 million, and a 29% return on investment. The relevant model parameters and estimates derived from their study and tested in the LCI analysis are summarized in Table 1 below:

Table 1. Parameters for LCI Analysis

Parameter	**85%**	**91%**
Plant Investment Value (Ii)	US$200,000,000	US$200,000,000
Annual Runtime (Operational Hours)	7,488	8,000
Useful Economic Life of Plant (Years)	20	20
Benefit Estimate (Pi)	US$50,000,000	US$50,000,000
Functioning (Fi)	US$ 2,500,000	US$ 2,500,000
Non-availability or Inefficiency (Ui)	US$ 3,500,000	US$ 3,500,000
Manintenance (Mi)	US$ 3,500,000	US$ 3,500,000
Rate of Return/Discount Rate (R_i)	17%	17%

5.4 Results and Discussion

From Table A1 (see Appendix A), the benefit which represents the net present value of future flows expected from the plant’s operations, from inception to the end of its 25-year useful life, and duly discounted based on Oyegoke and Jibril’s [34] detailed analysis, is deducted from the accumulated total discounted costs to derive a “global result” or total performance indicator, which essentially represents the plant’s profitability for the defined period at specific availability or efficiency rates.

From the project’s defined parameters and investment estimates, it was observed that at 85% operational efficiency or availability (which is interpreted as minimal MWTs and MTTRs, with maximum MTBFs), positive total performance is observed from the 3rd to the 4th year of the plant’s operational life. This translates to the plant operating profitably for approximately 8% of its useful economic life.

Interpreting this based on Oyegoke et al. [34], if the plant is deemed to be in operation for 355 days, and is only available for 85% of that time, due to MWTs or MTTRs and other maintenance, related challenges such as unavailable technicians or inadequate spare parts, it is therefore operationally efficient for approximately 302 days only. This equally impacts the decision to invest or execute the project, as a recomputed return on investment (ROI) based on the LCI outcome is 8.2% only as against Oyegoke et al.’s [34] 29%.

In Table A2 (see Appendix A), the plant's availability is increased to 91% and this boosts profitability significantly, from the 3rd to 18th years of operation. The return on investment rises proportionately, and this is illustrated in Figures 1 and 2, where the trendline shows the proportion of operational profit based on the defined availability rates.

From Figure 1, the plant is shown to be profitable for only about 8% of its useful life, while in Figure 2, this rises significantly to approximately 64% based on operational efficiency at 91%. The additional 14-year profitability gained at 91% efficiency represents an average 56% increase in total performance by simply increasing availability or operational efficiency due to more detailed attention to a structured maintenance regime.

The 'Pareto Principle' encompasses cause and effect concepts under the '80/20' rule, where at least "80 percent of problems can be traced to 20 percent of the causes"[7]. Adapting this principle to the concept of LCI and the total performance indicators derived, it can then be said that 80 percent of the benefit or profit is derived from 20 percent of the variables; in this case, it is the impact of maintenance on availability and overall profitability.

Pareto principles encompass causality and impact, and therefore allows for the prioritization of strategic responses or solutions to improve the activity, process, or product in focus. From the project's defined parameters and investment estimates, it was observed that at 85% operational efficiency or availability (which is interpreted as minimal MWTs and MTTRs, with maximum MTBFs), positive total performance is observed from the 3rd year up to the 15th year of the plant's 20-year operational life. This translates to the plant operating profitably for approximately 60-65% of its useful economic life.

Increasing the annual plant runtime estimate by roughly 6% to 8000 operational hours- which translates to 91% annual runtime or efficiency, the LCI analysis shows positive movement between the 3rd and 19th years of operation. The plant is therefore deemed profitable for roughly 80-85% of its useful life. The additional 4-years at 91% efficiency, represents an average 24% increase in total performance and therefore profitability.

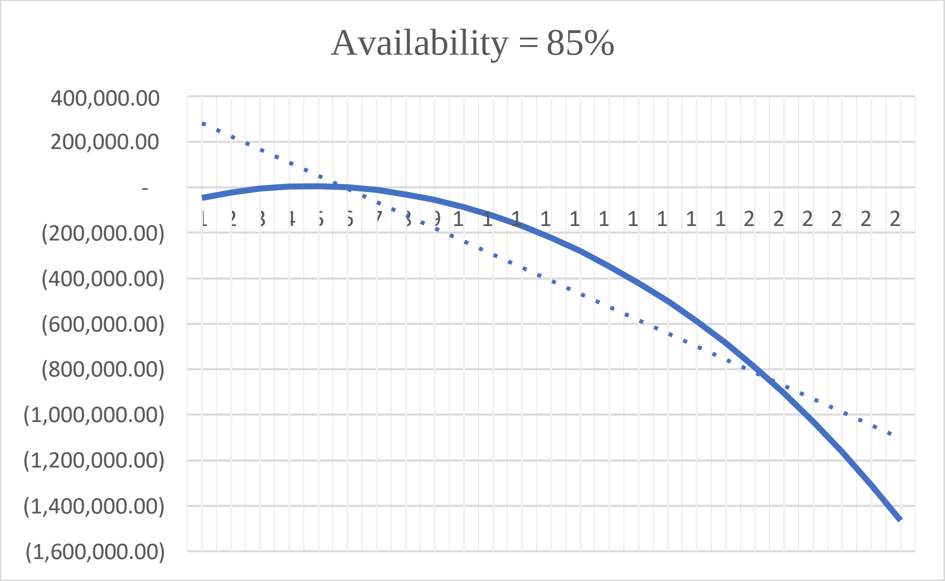

Figure 1. Total Performance Indicator for Investment-85%

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[7] (https://www.mindtools.com/pages/article/newTED_01.htm (accessed on 7 October 2021)).

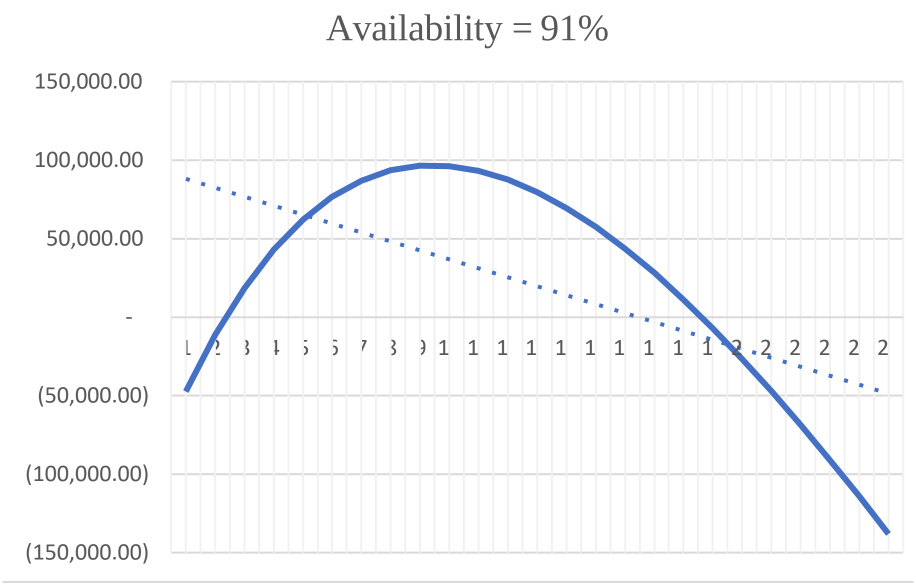

Figure 2. Total Performance Indicator of Investment-91%.

The trend in Figures 1 and 2 suggest smaller profits or benefit as the plant nears the end of its economic useful life, which could be interpreted in terms of aging machinery or equipment and other future unknowns hampering total availability, benefit, and performance.

Although pareto principles are traditionally applied to determine a problem and/or its effects on a given activity or process, in this context, it is used to support and show the impact of an often overlooked or minor but critical variable on the plant's total performance and profits; this ultimately guides the decision to otherwise invest, re-evaluate, or abandon the project. The maintenance policy, schedule, and efficiency of the plant's operations would not typically be a key performance indicator (KPI) or metric for investment decisions under traditional valuation methods. However, the analysis, results, and interpretations lend credence to the conclusion that the real (total) cost of investment is not necessarily a discounted aggregate of determined costs, equipment, products, or employees, but the cognizance of the time, effort, technical ability, resources, and strategy to maintain total plant availability or efficiency at defined levels for maximum profit.

It can therefore be concluded that deriving the true total cost of ownership in project investment or evaluation terms lies in the ability of the investor to adequately consider the equipment, technology, and skilled human capital available or best-suited to manage the proposed venture, based on location and other non-financial or intangible considerations beyond the obvious kWh or electricity price indices usually evaluated in traditional life cycle costing analyses. Therefore, investment decisions in relation to waste valorization efforts, where the success of an RE project is largely dependent on private investor-operator, modular systems, which tend to perform more efficiently due to stronger technical and financial capacities at their disposal [16], should be evaluated in light of potential destabilizing factors, which erode the long-term value of the project.

The basis of investment, techno-economic, or technology assessments are often to determine the value of technical efficiency and infrastructure investment required to fulfill project objectives. This often ignores significant elements which impact revenue streams and the entire validity of a given project at a future date. Factoring in the time value of costs or 'variable investments' and operational efficiencies allows for a com-prehensive evaluation of the project in cognizance of the uncertainty and significant financial risk of investment.

The LCI analysis draws vital conclusions for strategic managerial decision-making, and its implementation will be constrained in the real world by factors such as the available funds for investment, energy demand metrics, the nature and availability of required biomass feedstock, changes in cost of plants based on market conditions, and changes in subsidies. In this regard, access to energy finance and in-vestment mostly for sub-Saharan African countries remains imperative, and will equally require national support systems and strategies to ultimately manage political and regulatory risks related to energy infrastructure projects.

The challenges with data collation, access, and availability in Africa generally results in scenarios where theoretical or proxy data is used for research and inference. The results therefore remain cautious estimates which do not necessarily capture empirical realities, but serve as a guide for decision support and planning processes.

5.5 Conclusion

Rural electrification in parts of Africa has proved challenging due to scattered population sites, low consumption levels, bad roads and networks, and low population densities. Renewable energy is therefore expected to play a pivotal role in satisfying an increasing demand for electricity, while equally enabling access to rural energy services. Therefore, future economic development is largely dependent on the creation of sustainable energy systems through enhanced investment in RE conversion systems for the purpose of electricity generation.

A limited scope analysis has been carried out on a previous study, which proposed the development of a 5 MW biopower plant for Nigeria. The LCI analysis was used to evaluate the viability of the proposed power plant through an assessment of the maintenance schedules, break-downs and repair wait times, and overall operational efficiency of equipment required for energy generation purposes. The results show enhanced total performance of the plant by up to 56% where system availability is increased. It is therefore concluded using pareto principles that the operational efficiency of a power plant, although a minor variable in traditional costing methodology, remains a significant metric in overall strategic investment decisions of this magnitude.

Private participation in the RE-based power sector will also be encouraged through policies and programs which insure investor funds while limiting risk exposure, and it is expected that a committed government will consistently pursue the adoption of RE systems in the mainstream energy mix.

In addition, the provision of tax subsidies, secure and investor-friendly environments, structured regulation, and implementation remain significant in the bid to im-prove Nigeria’s energy access metrics as a pre-cursor to achieving the United Nations sustainable development goals (UNSDGs) and ensuring a sustainable energy future for otherwise disenfranchised communities.

Author Contributions: For research articles with several authors, a short paragraph specifying their individual contributions must be provided. The following statements should be used “Conceptualization, J.Levi-Oguike.; methodology, J.Levi-Oguike.; validation, J.Levi-Oguike.,D.Sandoval and formal analysis, J.Levi-Oguike.; writing—original draft preparation, J.Levi-Oguike.; writing—review and editing, J.Levi-Oguike.,D.Sandoval.; visualization, J.Levi-Oguike.; supervision, D.Sandoval., E.Ntagwirumugara.;

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6. Chapter 5

African Biopower Investment and Policy Sufficiency: A Qualitative Comparative Analysis

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Abstract

This paper seeks to determine the sufficiency of existing waste management and biopower policy that support the proliferation of biopower projects. A Qualitative Comparative Analysis (QCA) using crisp-set analysis (csQCA) methods, is used to answer the question- to what extent existing policy is deemed sufficient based on the success or otherwise of a given biopower project? Empirical testing using proxy data yields a truth table which suggests that the defined causal conditions, hold true for 8 out of the 36 African cases analysed. It is therefore concluded that effective biopower policy focus and implementation initiatives must adapt the elements of public investment, private sector finance, adequate infrastructure and networks and community access and acceptance, to varying degrees. This outcome is further exemplified by case studies of biopower and energy-based projects undertaken in African countries, thus emphasising the imperative for effective policy to enhance investment, specifically in the waste valorisation domain.

Keywords: UNSDGs; Qualitative Comparative Analysis; biopower; waste valorisation; Africa; waste management.

6.1 Introduction

Electricity supply for many African countries remains inaccessible, unreliable and unaffordable [1]. An estimated 600 million people in sub-Saharan Africa [2] [3] remain severely under-powered with zero access to electricity, prompting strategic targets for electricity generation from renewable energy (RE) sources [4]. This applies to a majority of

African countries, with a view to achieving the United Nations defined Sustainable Development Goals (SDGs) within the 2030 timeline.

Renewable energy policy currently focuses on energy security, climate change mitigation and economic development [1] [5]. However, an inherent trade-off exists and it consequently becomes imperative to determine what level of engagement and policy adjustments are required, to achieve defined objectives. This has also encouraged policy considerations of the conditions relevant to enhanced RE generation and consumption in Africa, using several economic and regulatory incentives.

The International Energy Agency (IEA) reports that the Renewable Energy Masterplan (REMP) highlights RE targets of approximately 30% by 2030, for electricity generation in Nigeria. In addition, the South African Integrated Resource Plan (IRP) estimates that RE resources will account for about 26% of total energy by the year 2030 and the authorities have equally introduced the Renewable Energy Independent Power Producer Programme (REIPPP); which is a tender process aimed at enhancing private investments in South Africa's RE generation [6]. The environmental issues related to energy security and fossil fuels, including instability in the price of crude oil for countries like Nigeria, have resulted in increased focus on RE use and investment.

African waste management practices are often characterised by blatant dumping and open burning [7], with minimal disposal to suitable landfills, or diversion to waste valorisation process plants with focus on the 3Rs- reuse, recycling and recovery [8]. Developed countries have recorded greater success in the establishment of structured waste handling, management and recovery intensities; while managing to divert a significant portion of municipal waste away from landfills, than most developing countries [9]. The perception of waste as an environmental bane due to disposal challenges, has evolved into waste becoming a valuable energy resource and therefore justifies investment and infrastructure development in this regard.

The paper therefore examines certain WtE projects to gauge the effectiveness of existing policy, in a random sample of countries across Africa. The causal conditions are defined within the context of structured policy implementation and sustained political will, existing infrastructure and networks, private sector participation and community engagement and access.

6.2 Materials, Methods and Assumptions

6.2.1 Data and Theoretical Assumptions

Data is collated using statistics for 36 African Countries from the International Renewable Energy Agency (IRENA) and World Bank databases for public investment (PUBINV) and private sector participation and finance (PRSF) in bioenergy and energy related investments, for the period 2011-2020. Statistics for final energy consumption and population percentage with energy access for the same period are used as proxies for infrastructure and network facilities (INFRN) and community acceptance participation and access (CEA), while public investment (PUBINV) serves as evidence of government's commitment to defined policy objectives. The raw data is analysed and manipulated to yield cohesive numeric values for further analyses.

The research premise is based on both theoretical and substantive knowledge of the causal conditions or variables that must be present for a given RE or biopower project to succeed. The argument put forward here is that to the extent that these four conditions - PUBINV, PRSF, INFRN and CEA are satisfied, that venture would be successful (PRSUCS) and therefore the existing RE policy governing waste valorisation and electricity delivery for that country would be deemed sufficient for the defined period, all other things being equal.

6.2.2 Data Analysis- Qualitative Comparative Analysis

QCA is based on the concept of 'multiple conjunctural' causation [10], where 'multiple' refers to the number of paths, while 'conjunctural' suggests that each path contains of a combination of conditions. One of the core assumptions of QCA is that the same outcome can be achieved from different paths and its main goal is to explain complex matter in a succinct fashion while simultaneously providing room for causal complexity. This captures the essence of "occam's razor" or the parsimony principle [10].

The methodology adopted to determine relevant factors regarding biopower projects and policy sufficiency, is the Configurational Comparative Methods approach (CCM). This allows cases to be transferred into configurations, which are simply a combination of factors that produce a given outcome of interest [10]. These factors are also referred to as conditions. Therefore, the questions guiding this paper are: to what extent can existing policy be deemed sufficient based on the success or otherwise of a given RE/biopower project? and what measures should be taken to ensure enhanced RE policy implementation and biopower investment?

The specific CCM technique used here is the crisp-set QCA (csQCA). The crisp set analysis [11] uses Boolean Algebra to determine if a case is either in or out of a set. QCA uses binary-coded data, with 1 for membership and 0 for non-membership. A core element of Boolean algebra is the 'truth table', which represents a data matrix based on raw data, that contains all values of the causal conditions and outcomes. A threshold between absence and presence is set for each condition and is subsequently evaluated based on both theoretical and substantive knowledge of cases and variables [12] [11] [10].

Truth tables contain as many rows that correlate with the logically possible combinations of values set for the causal conditions. Therefore, 'each row is not a single case but a summary of all the cases with a certain combination of input values' [11]. 'In this respect, a row of a truth table is like a cell from a multiway cross-classification of several categorical independent variables' [11].

6.3 Limitations

The dearth of cohesive and structured data for most countries in Africa presents a unique challenge and this tallies with a common research problem of 'relatively small Ns' for analysis; i.e. there are usually more conditions or variables than cases. A small sample data size may not necessarily capture or give a true picture of the outcome being tested. In addition, the use of proxies for data also adds a measure of complexity, as the assumptions become largely theoretical and although easy to manipulate for the purpose of research, may not necessarily reflect or capture empirical realities.

6.4 Results and Analysis

Table 1. Outcome Defined for Project Success based on QCA

OUTCOME (PRSUCS)	CASES
Successful Project (1)	Egypt, Arab Rep.,Ethiopia, Ghana, Kenya, Rwanda, Tanzania, Uganda and Zambia
Unsuccesful (0)	Angola, Burundi,Benin, Burkina Faso, Botswana, Cote d'Ivoire, Cameroon, Congo,Dem. Rep, Eritrea, Gabon, Guniea, Guinea-Bissau, Equitorial Guinea, Morocco, Mali, Malawi, Namibia, Niger, Nigeria, Sudan, Senegal, Sierra Leone, Sao Tome and Principe, Chad, Togo, South Africa, Zimbabwe, Tunisia

Project success (PRSUCS) was determined for 8 out of 36 cases as illustrated in Table 1. Project success is defined in this context for cases that satisfy the four conditions PUBINV, INFRN, PRSF and CEA, defined earlier. Therefore countries or cases with the outcome (1) are said to have a suitable combination of these conditions or variables to the extent that allows biopower projects undertaken, be successful. This definition leans on work done by [10] in the exploratory study of 'The Conditions of Successful Renewable Energy Governance. Exploring Qualitative Comparative Analysis (QCA) in Energy Policy Research'; where the author equally relied on previous efforts by [10] to analyse successful RE governance based on European and national goals in energy transition systems. The central point is that a successful outcome of a defined objective is largely dependent on the specific conditions determined at inception and the subsequent framework design. This is also justified with regard to empirical evidence based on country case studies that will be discussed later.

The truth table analysis follows the determination of the logical statement:

$$\text{PRSUCS} = \text{INFRN\&\&PUBINV\&\&PRSF}||\text{CEA} \qquad (1)$$

This is computed in the csQCA using the Quine-McCluskey Algorithm. The model is defined as follows:

$$\text{PRSUCS} = f(\text{INFRN, PUBINV, PRSF, CEA}) \qquad (2)$$

Boolean algebra uses relational operators- the logical 'AND', represented by (&&/ *) and the logical 'OR', represented by the (|| / +) symbols [11] [10]. These essentially hold true i.e.= 1, where both the preceding and the following terms are logically true and numeric terms greater than 0 are treated as true [11]. In Boolean algebra, addition is also indicated by the logical 'OR' and multiplication by the logical 'AND'. The four causes can therefore be expressed as:

$$\text{PRSUCS} = \text{INFRN}*\text{PUBINV}*\text{PRSF}+\text{CEA} \qquad (3)$$

This yields the different combinations of the four causes linked to biopower project success. The analysis of the raw data results in a truth table (Table 2), illustrating the different combinations of the conditions imperative to the outcome.

Table 2. Truth Table

INFRN	**PUBINV**	**PRSF**	**CEA**	**number**	**PRSUCS**	**cases**
1	0	1	1	4	1	*Egypt, Kenya, Rwanda, Uganda*
1	1	1	1	3	1	*Ethiopia, Zambia, Ghana*
1	1	0	1	1	1	*Tanzania*
0	1	1	1	0	0	*No cases*
1	1	1	0	0	0	*No cases*

Based on the above, the logical statement that project success is a function of the four causal conditions, is observed for all cases where the PRSUCS threshold is set to 1[8], i.e. represents a sufficient combination of conditions leading to the outcome. It could also be said the existing biopower policy in eight African countries is deemed sufficient for the proliferation of biopower projects and electricity delivery.

The un-reduced representation of combinations is expressed as follows:

$$\text{PRSUCS} = \begin{aligned} &\text{INFRN, PRSF, CEA, }\sim\text{PUBINV}[9] + \\ &\text{INFRN, PUBINV, PRSF, CEA} + \\ &\text{INFRN, PUBINV, CEA, }\sim\text{PRSF} \end{aligned} \qquad (4)$$

This simply means that a presence of infrastructure, private investment in energy and community access and acceptance is combined with an absence of public investment and so on. It can also be interpreted as project success occurs, if any of these three combinations of the four causal conditions is achieved. Boolean multiplication indicates a combination of presence and absence conditions [11]. However, due to the limited variety of cases, caution is applied in reaching strict conclusions based on combinatorial logic.
Data inconsistencies and numeric approximations may otherwise affect the results and interpretation; and therefore, a holistic approach to analysis is encouraged.

Causes or causal conditions are not to be analysed in isolation, but rather within the context of the presence and absence of other causally relevant conditions.

In minimising the unreduced representations, parsimony is achieved:

$$PRSUCS= INFRN*CEA \tag{5}$$

This is the simplest expression of the logical statement earlier defined and would suggest that in the presence of infrastructure, community acceptance and access, the project remains successful; thereby signalling biopower policy sufficiency to boost sectoral investment- all other things being equal. Interpreting this would be indicative of domestic governments' influence over the WtE (Waste-to-Energy) or biopower plant's siting, operations and management, including evacuation of the electricity generated. It is therefore plausible to conclude that government remains the overarching factor to defined project success and is therefore tasked to ensure that waste management policies and related WtE interventions receive due attention, despite the commercial success and popularity of solar and small hydropower systems.

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[8] The remaining rows of the solution based the possible logical combinations, did not yield any combination of cases and were therefore deleted during the PRSUCS coding stage

[9] ~ represents the absence of the variable or condition

6.5 Discussion

Case studies of current and previous WtE projects across certain countries in Africa are examined in line with the findings of the QCA. The choice of countries is not arbitrary, as Nigeria remains Africa's giant by population and the leading oil producer[10]; South Africa is dubbed Africa's richest country for 2020[11] and Rwanda has been named as one of the world's ten fastest-growing economies in 2020[12]. Ethiopia also gained visibility by successfully installing and operating Africa's foremost and fully-functional WtE facility[13]. These case studies are assessed within the context of existing policy and regulation in electricity delivery and waste management. The literature has sufficiently addressed the deficits in waste management practices and policies and this paper has highlighted policy effectiveness as a corollary to project success.

In 2012, the total Municipal Solid Waste (MSW) generated in Africa was estimated at 125 million tonnes per year, with sub-Saharan Africa accounting for 81million tonnes [13]. The average waste generation per capita in Africa for the same period is captured at 0.78 kg per day and Egypt, South Africa, and Nigeria were identified as the major contributors, with estimated MSW generation of 18.35, 23.21, and 17.45 million tonnes per annum, respectively [13]. This illustrates the magnitude of biopower potential which remains largely unexploited due to cost and pricing barriers where the required investment for new energy infrastructure, including upgrades are rather prohibitive. Most investors especially in developing countries are often faced with one of two challenges which include severely dilapidated existing energy infrastructure and/or non-existent infrastructure for the proposed investment. This affects the initial and subsequent cost of investment, as relates to planning, design, routing and siting of plant locations. Costs also include licensing and agency fees, to gain the relevant permits and comply with existing laws and policy, or risk additional expenses for non-compliance through fines and other penalties.

In addition, the mode of evacuation for the power generated is equally considered. This will be met with additional costs in the form of significant transmission costs, which are equally affected by insufficient transmission infrastructure which for countries like Nigeria, have not been upgraded since the 1980s [4]. Embedded generation has been suggested as a possible solution to overcome this[14].

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[10] https://www.statista.com/statistics/1178514/main-oil-producing-countries-in-africa/

[11] https://www.capetownetc.com/news/south-africa-named-the-richest-country-in-africa/

[12] https://www.bloomberg.com/opinion/articles/2020-11-25/coronavirus-is-helping-african-economies-compete

[13] https://ramboll.com/projects/re/reppie-in-addis-ababa-ethiopia-first-waste-to-energy-facility-african-continent

6.5.1 *Case Study: Nigeria*

Nigeria's estimated population is over 180million. Therefore, the waste generated especially in urban areas is sufficient feedstock for WtE technology. A centralized power infrastructure system is in place, where power generating companies transmit power through about 132 KV lines managed by the Transmission Company of Nigeria (TCN) to the eleven (11) distribution companies providing service for end users nationwide [4]. The Nigerian Electricity Regulatory Commission (NERC) provides and oversees the regulatory framework for the power sector and stipulates feed-in-tariffs (FiT) of up to 10MW for biomass generation. There remain relatively low participation levels of businesses, individuals and international organisations, even with recent renewable energy policy promulgation.

This is in part is due to poor maintenance and aging infrastructure, vandalisation of existing infrastructure, lack of political will and commitment, conflicting agency roles and responsibilities, political instability and ethnic conflicts. In addition, further pressures such as inadequate service coverage and operational inefficiencies of services, lack of successful public participation and active engagement, inadequate budgetary provisions for waste collection and disposal, malfunctioning and obsolete operational equipment, inadequate landfill disposal, limited utilisation of recycling activities and inadequate waste management governance frameworks, exacerbate the situation [14] [15]. In view of the above, partnerships with private investors and operators have emerged to render more inclusive, affordable and efficient waste services[16] [17].

The Ikosi Fruit Market project is a prime example and was established to convert the waste from the market to electricity. The facility which was situated at the market, produced sufficient biogas to provide electricity for approximately 50 stalls and lock-up shops, through the waste disposed at the market. An estimated 5 tonnes of fruit waste is generated daily at the fruit market, largely due to poor storage and transport facilities and therefore provided sufficient feedstock for the plant. The biogas plant was established based on a license from AFRICOM Technology Transfer (Germany), to build a "low-technology" facility and a partnership between the Lagos State Government and Midori Environmental Solutions (MES) was subsequently established in 2013.

However, four years after the agreement was executed and upon the waste management authority's request that the facility be handed over by the contractors, the project lies abandoned and the market has returned to status quo[15].

In 2016, private investors committed a total of US$2.5 billion to 14 renewable energy projects, and this was intended to contribute about 1,000 megawatts to the national grid [18] . Lagos State currently generates enough waste to produce a similar amount of electricity, however, ambiguous energy policies were cited as a clear deterrent to foreign direct investment in the sector, in addition to a corresponding lack of government commitment and

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[14] NERC signed regulations related to the Independent Electricity Distribution Network (IEDN) and Embedded Generation 2012 to open up Nigeria's electricity sector for more investments in capacity growth, https://businessday.ng/energy/power/article/embedded-power-generation-to-rescue/

[15] https://thediscourse.ca/energy/garbage-solve-nigerias-energy-crisis

attention. Local consumers have also experienced hardships as power generated in excess of one megawatt[16] by existing investors, has to be sold to the national grid without consideration for the energy needs of the surrounding population.

In contrast, a successful project was developed by a team of multidisciplinary researchers, under the Laboratory of Industrial Electronics, Power Devices and New Energy Systems (LIEPNES), at the University of Nigeria Nsukka (UNN). Approximately 500KVA of electricity was successfully generated using a locally-constructed gasification plant. The engineering system which is designed and modelled with locally sourced materials, converts organic solid materials into 'syngas' for electric power generation. The estimated savings to university are calculated in terms of the reduced expenses on national grid supply in the region of USD$ 171,000 to US$196,000 monthly. The same team had successfully generated about 100KVA, using a previous model.

These examples are by no means exhaustive, however a clear distinction is observed in the overall success or failure of biopower or RE projects in general. Major disputes and the threat of expropriation by authorities, often hamper progress and projects that appear to have been initiated and managed on a private investor-operator modular scale, display more favourable outcomes. This summary appears plausible based on the QCA analysis carried out, as the none of the casual conditions and combinations were observed for Nigeria. This could also be explained by data reporting inconsistencies and the inability to effectively measure the impact of disputes and the ultimate cost to investors and projects.

6.5.2 Case Study: Ethiopia

The Reppie project is a waste-to-energy incineration plant where MSW is processed through a combustion chamber and electricity is eventually produced from a turbine generator. The Reppie WtE plant receives approximately 1,400 tonnes of municipal waste daily, which represents an annual waste-disposal capacity of about 420,000 tonnes. This is expected to tackle an estimated three quarters of daily waste generation in the capital city of Addis Ababa, with expected electricity production capacity of 185GWh.

The Facility is expected to eliminate over 80% of the municipal waste delivered to it and has a thermal capacity of 110MWth. It was also designed with a redundant energy generation and evacuation system for added reliability and extended operation. The diversion of waste from landfills and the adherence to strict European environmental standards for WtE, promoted the Reppie Facility as a best practice model for other African countries.

However, The Ethiopian Electric Power (EEP) is expected to restart operations of the Reppie facility after extended disputes with contractors, which caused delays and resulted in the plant ceasing operations after its inauguration[17]. The disputes allegedly involved operational handovers and power generating capacity, with the relevant authorities expected to resolve all outstanding issues. The QCA analysis however, displayed a successful outcome for Ethiopia, being one of the countries for which the four causal conditions were observed. To the extent that the QCA is both experimental and provides a basis to explore causality, certain elements remain stochastic and cannot be adequately captured. However, in spite of the dispute, the QCA accuracy can be evidenced in the commitment to plan, design and inaugurate the Reppie plant. Therefore, for this purpose of

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[16] https://thediscourse.ca/energy/garbage-solve-nigerias-energy-crisis

[17] https://africa-energy-portal.org/news/ethiopia-reppie-waste-power-plant-resume-operations

analysis, the conditions were duly satisfied and Ethiopia's biopower or related RE policy can be deemed sufficient for waste management and valorisation processes and investment based on the defined QCA parameters.

6.5.3 Case Study: South Africa

The Bronkhorstspruit Biogas Plant (BBP), is the first industrial scale biogas-to-electricity plant in South Africa. It was supported by the Agence Française de Développement (AFD) through SUNREF its partner bank[18]. The total project cost was approximately US$9.5million with a US$6million loan element.

The electricity generated is delivered to BMW's Rosslyn factory and an electricity wheeling agreement with the Tshwane Metropolitan Municipality, facilitates this by allowing the electricity generated to be transmitted through the existing grid. The project is in line with Tshwane´s 'Vision 2055' strategy for a "liveable, resilient and inclusive city". The gas from the plant's digesters drives four large engines which are connected to electricity generators and the Eskom grid. Generation capacity at 4.4 MW provides electricity 24 hours daily and the capacity to expand to over 6 MW exists, with a 20-year initial life cycle estimate. The project's use of limited recourse financing is exemplary and uncommon for its size, as BBP was deemed extremely risk sensitive by other banks at the time. Its first output was supplied into the national grid on October 10, 2015 and to date, an estimated 150 total of direct /indirect, permanent/temporary jobs have been created in the once rural community.

Tshwane municipality was named South Africa´s National Earth Hour Capital[19] and announced a large WtE project for its landfill sites and wastewater facilities. Methane gas will be extracted from about seven landfill sites, and biodigesters will be used to generate biogas for electricity generation.

Another successful project is located in Durban, where the eThekwini landfill gas (LFG) to electricity project generates about 7.5 MW of electricity from two of its landfill sites [19]. This is encouraging considering evidence from 2012, where approximately 1,125 PJ of estimated energy potential from LFG recovery and incineration could be derived from Africa's indigenous waste disposal and generation activities [13]. Also in Durban is the The Mariannhill landfill project, which uses some of the gas recovered to generate RE which is subsequently transmitted to the municipal grid The World Bank Group's Prototype Carbon Fund is expected to purchase about 337,000 carbon credits from the project[20]. In 2004, the Mariannhill landfill was also declared a National Conservancy Site, which is a first for landfills, and has since been incorporated as an ecosystem restoration site. As at April 2015, the landfill project provides the municipality with about 3MW of electricity and approximately 181,000 carbon credits have been issued from the project[21]. However, in spite of the evidence above, the QCA did not display a successful outcome for South Africa, which could be due in part to data reporting inconsistencies and a probable lack of co-ordination at national levels; as the projects enumerated have been executed largely at municipal level and issues regarding autonomy and disputes among agencies and levels of government are not uncommon. However, these conclusions are drawn with caution considering South Africa's

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[18] https://www.sunref.org/en/projet/south-africas-first-industrial-biogas-plant-leads-way-for-waste-to-energy-developments/

[19] https://www.panda.org/?256140/Tshwane-waste-to-energy

[20] https://www.worldbank.org/en/results/2015/10/21/powering-electricity-landfill-gas-durban

[21] https://www.worldbank.org/en/results/2015/10/21/powering-electricity-landfill-gas-durban

recent Integrated Resource Plan (IRP) 2019, which outlines renewed commitments to significant electricity generation from renewable and sustainable sources.

6.5.4 Case Study: Rwanda

Rwanda estimates biomass energy availability and utilisation at roughly 85%, making it possibly the most valuable energy resource in the country. The metrics for biomass consumption are enumerated for households-91%, industry-4%, non- energy usage-2% and 1% for both commercial and public sectors [20]. On an industrial scale, biomass is used mostly for drying in small-scale brick making and tea factories. Traditional biomass is therefore relatively commonplace, with small-scale power generation from agricultural residues such as rice husks and bagasse. The use of biogas digesters is also limited, with users citing unreliability and insufficient fuel [21]. In addition, feasibility at minimal capacity has been identified for biomass briquettes made from compacted waste residues or charcoal dust.

In its Vision 2020 strategy document, Rwanda set energy goals to reduce traditional biomass energy consumption from 86.3% to 50% by the year 2020, including electricity access expansion to 70 per cent by 2017 and 100% connection of public institutions by the same year [20]. Electricity consumption in Rwanda is considerably low, at 10kwh for rural households with grid connection. To this end, a key driver of expanding on-grid access has been the Electricity Access Roll-out Program (EARP), as the rural- urban divide is substantial, especially in terms of electrification; where only about 7% of rural areas compared to 61.5% of urban areas are electrified [22].

As Africa's fastest growing economy, a significant element of this development is evident in the rising population and resultant volumes of Municipal Solid Waste; with increases from roughly 400 tonnes to 800 tonnes daily. The majority of waste remains organic and it is estimated that waste generation rates could expand by over 60% in the course of the next ten years, bringing total generation volumes to almost 1,300 tonnes daily, by 2030[23].The Nduba landfill in Kigali- capital city, records several environmental challenges in the form of open-air waste dump sites. This is in addition to vermin, leachate and random combustion, which pose additional management challenges.

The Rwanda Environment Management Agency (REMA) reports that between 1,800 and 2,000 tonnes of solid municipal waste is generated in Kigali city daily and roughly 16-20% of that amount is collected and moved to a single dump site. It has also identified undesirable solid waste management behaviour and custom, as a significant hindrance to sustainable development goals and objectives. This above summary, although not specifically tied to a single identifiable WtE project, highlights sufficient opportunities and potential to cite WtE projects successfully, especially due to the government's apparent commitment evidenced in established policy goals, schemes and implementation structures; which are empirically supported in this context, by the successful outcome of the QCA.

The WtE projects highlighted so far share a recurring theme, being public sector commitment to attract and support private sector investment. Where, government has reneged or rescinded on this commitment, the project becomes moribund as in the case of the Ikosi Fruit Market. A responsible government is therefore expected to create a supportive policy environment and operational structures that attract and retain foreign direct

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[22] https://www.worldbank.org/en/country/rwanda

[23] Theigc.org

investments, of which South Africa has been successful to the value of R53billion[24]. Key considerations for how the energy generated will be evacuated, especially in excess of specified limits and supplied to the end-user, in a manner that factors in the requirements of the plant's host communities and equally allows the investor re-coup initial investment costs are vital to project success. It may also become imperative to adjust generation and transmission capacity limits to allow deprived, under-served or unserved populations benefit from the projects being sited in their communities.

The QCA highlighted the value of public investment among other critical success factors. Government resources can be used to de-risk or reduce the inherent investment risks, subsidise RE energy access for households with limited incomes and access additional financing from the private sector and its development partners; in order to deliver the required RE infrastructure and network systems. This also implies that higher tax rates can be prescribed for fossil-fuel related operations. The subsidising of investment activity in RE technology and energy related operations can also be applied to research and development efforts, in addition to low cost loans and production tax credits amongst other credits, to accelerate sectoral growth. Technology availability and access problems that exclude marginalised populations especially from the consumption of RE generated electricity and related energy applications, should be adequately addressed and managed. A necessary investment by policymakers aside from encouraging and stimulating the availability of RE in commercial forms and related energy policies, should also include public sensitisation to support the acceptance and consumption of RE as a sustainable and environmentally conscious alternative.

6.6 Conclusion

The results of the QCA based on the principles of parsimony, suggest that as long as adequate infrastructure and networks alongside community acceptance and access in relation to a given project are present, the project will essentially be successful; thus indicating the sufficiency of existing biopower policy within the regional or country-specific context.

This in turn, emphasises the importance of government commitment and participation in terms of partnerships with the private sector, through adequate infrastructure provision, support schemes for land availability and allocation for the plant site, ease of licensing acquisition and additional investor-friendly policies among other critical factors imperative to boosting investments in biopower generation projects and its ultimate diffusion.

It is also pertinent to note that in reality, the imperatives for project success and enhanced investment go beyond existing or additional well-intentioned and elaborately articulated policy documents, laws and regulations. Consistent and committed effort in policy implementation and relevant compliance enforcement by the requisite authorities are equally required, to boost investor confidence, attract necessary funding and enhance economic progress in the exploitation of sustainable energy sources for development.

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[24] https://www.gov.za/speeches/energy-releases-state-renewable-energy-sa-report-6-oct-2015-0000

Data Accessibility Statement

The data that support the findings are available upon request from the corresponding author.

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7. Chapter 6

Aligning Multi-Stakeholder Criteria for Solid Waste Management and Biopower Access across Selected Urban Slums in Lagos, Nigeria

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Abstract

Sustainable development criteria, in line with maximising Environmental, Social and Governance (ESG) principles while minimising costs, are defined from the perspective of individual stakeholders, and weighted using the Fuzzy Analytic Hierarchical Process (FAHP). The GDSS-PROMETHEE and GAIA approach are subsequently applied to determine the best case for effective solid waste management and the siting of a modular biopower plant. The underlying research premise and objective of this study, is to determine a consensus approach to tackling significant waste management and slum proliferation challenges in Lagos. The selected slum areas were defined in the Lagos Metropolitan Development and Governance Project (LMDGP) which was supported by the World Bank and closed with “moderately unsatisfactory” outcomes. The results suggest that the defined criteria are reasonably satisfied in 3 out of 7 alternatives, with relative stakeholder consensus, and ultimately provides a strategic roadmap for revisiting previously unsuccessful projects and advancing efforts in slum rehabilitation, particularly for an equitable and sustainable energy future. The relevance of this effort is its practical application in municipal planning and budgetary allocations in view of finite and scarce financial resources and the potential for conflict within key interest groups, to maximise shared prosperity and development of the communities assessed.

Keywords: UNSDGs, FAHP, GDSS-PROMETHEE, GAIA, Renewable Energy, Biomass, MSW

7.1 Introduction

The Lagos Metropolitan Development and Governance Project (LMDGP) was initiated in the 2007 World Bank fiscal year, in a bid to improve the standard and wellbeing of citizens in slum communities through investment and upgrades in critical infrastructure. Access to urban services and basic amenities are often a luxury for marginalised communities, therefore, the World Bank committed a total of US$200 million to a total project cost of US$205.69 million. The project was reported as closed on September 30, 2013, and as of October 31, 2021, a total of US$139.97million had been disbursed, US$12.66million repaid and "moderately unsatisfactory" project outcomes, with "high risk to development outcomes" reported[25].

The focal sectors included other water supply, sanitation, and waste management (19%), other transportation (4%) and waste management (37%) amongst others, under the thematic schemes of private, urban, and rural development, alongside public sector management. The project also brought together key stakeholders including sub-national government officials, international development agencies, the private sector and community representatives, to facilitate dialogue and determine a viable strategy to meet outlined objectives. The participation and acceptance of the communities was also deemed a key sustainability criterion and critical success factor for the LMDGP[1].

The Lagos State Urban Renewal Agency (LASURA)[26] also engaged stakeholders on its improvement plans and projects for slum neighbourhoods in Somolu, Bariga, Ifelodun, Ijora and Badia communities amongst others, to improve the socio-economic wellbeing of its residents. However, the complexities of management and administration in Lagos have not yielded desired results, which is largely due to Lagos' mega-city status, where by 1995, its population had exceeded 10 million. By 2015, an estimated 24.6 million people resided in Lagos, with projections rising to almost 35 million by the year 2020. The city's population is also deemed to be expanding at a pace that exceeds that of New York and Los Angeles tenfold, with aggregate population estimates surpassing that of 32 sub-Saharan African nations combined[2].

Lagos is therefore unsurprisingly expected to be ranked the third largest city in the world behind Tokyo and Mumbai, by 2025[3]. Its commercial significance is also evident in a Gross Domestic Product (GDP) of about 27% of national GDP. In 2016, this figure was estimated at US$145.141billion, with projections by the Lagos Bureau of Statistics of US$157.728billion by 2018, at an average annual growth rate of 4.2%[2]. This expansion is a clear indication of the widening rural-urban divide, due to disparities in basic services, facilities and amenities in most rural areas[4]. The constant quest for improved standards of living, wellbeing and commercially profitable livelihoods and ventures, has seen an unprecedented rate of urbanisation; resulting in overcrowded neighbourhoods and extensive pressures on limited structural and network facilities and related services within the State[5][6].

Due to this population explosion, slums have undoubtedly emerged. This is supported by Morakinyo et al's[7] assertion on the key determinants of slum growth- being population expansion and bad governance. In a 1983 study, about 1,622 hectares was estimated as the blighted community land area within the Lagos metropolis, with related population densities of up to 790-1,240 per hectare[2]. Another survey conducted in 2002 on 1,164 households revealed that approximately 75% of Lagos' residents lived in sub-par housing and environments, and with Lagos being a coastal state-57% were reported as being victims of floods during rainy seasons, while 32% experienced actual flooding within their homes.

In addition, 68% of these households were reported to utilise the services of informal cart-pushers for waste disposal[2][7], while about 11% was collected by the Lagos Waste Management Authority (LAWMA), 10% by private waste collection contractors and roughly 17% deposited at communal waste sites[8]. Poor waste management services in the State, have subsequently encouraged open and uncontrolled waste disposal, especially along waterways, leading to blocked drains, pollution, and eventual flooding. Ojolowo and Wahab[8] state that approximately 27% of the waste generated within Lagos state, end up in waterways and canals, and remains a major cause of flooding, which is commonplace.

About 70% of the entire Lagos population is purported to inhabit these slum neighbourhoods which include Agege, Bariga, Somolu, Mushin, and Apapa, amongst others. The World Bank identified a total of 100 slum communities for rehabilitation in 1995. However, the LMDGP focused on nine specific neighbourhoods-Agege, Ajegunle, Amukoko, Badia, Bariga, Ijeshatedo/Itire, Ilaje, Iwaya and Makoko. The objective was to provide improved infrastructure, solid waste management and drainage inclusive, to ultimately enhance sub-optimal governance and capacities within those communities, which persists due to deficits in urban planning that marginalise the urban poor demographic and proliferates slum growth. Lagos has subsequently earned the tag of a "villagised city"[7], owing to its significant slum population, comprising illegal structures which remain unserved by the authorities. The residents, therefore, remain excluded from the niceties of urban living such as basic water supply, sanitary environments, electricity access and/or supply and basic healthcare facilities, pertinent amongst others.

A major characteristic of slum communities, aside from squalor, is "undulating heaps of refuse"[7] due to poor waste handling and behaviours, inadequate waste management facilities, equipment, funding and technical capacities, especially at municipal or local government levels. Additional information gaps related to waste components and quantities, equally hinder effective planning and budgetary provisions for proper administration[9][10].

In view of the opportunities for biomass-to-electricity or biopower- using MSW, this paper seeks to achieve two objectives- the first being stakeholder criteria alignment as relates to factors captured under Environmental, Social and Governance (ESG) principles, with the inclusion of economic considerations. Stakeholder consensus in this regard, is expected to facilitate the decision to site a decentralised biopower plant, derived using Multi-Criteria Decision Making (MCDM) methods; with this being the second objective.

Opportunities for decentralised waste management systems[11][12] and renewable energy-based power supply, are expected to reasonably reduce the socio-economic disparities within the State, by enhancing energy access metrics and boosting the economy of marginalised communities through employment creation using localised waste resources, especially for informal waste pickers. It is also expected to foster community project ownership, in cognisance of the inherent benefits. This study ultimately provides a strategic roadmap for future policy direction and project success in terms of slum rehabilitation through enhanced renewable energy access albeit it supplementary, while emphasising priority areas where alignment of stakeholder-desired outcomes is evident.

7.2 Contextual Conditions and Relevant Literature

The challenges with waste management generally require a concerted effort to manage issues related to cost, administration and suitable technology to effectively convert MSW, to electricity. This effort is the collective input of key stakeholders, which for the purpose of this study are grouped into 4 categories, namely- government, investors (including donor agencies and international lending institutions), the community and private sector participants (PSPs- private waste collection contractors).

The vast population of Lagos State invariably generate enormous amounts of solid waste estimated to be in excess of 10,000 tonnes daily[2] and is comprised mostly of roughly 45% organic waste, 15% plastic waste and the remaining 40% split between textiles, glass, metals and other perishables[2]. A World Bank study shows that against the 1.3 billion tonnes of MSW generated globally in 2012, an annual expansion to almost 2.2 billion tonnes is expected by 2025[13]. The challenges for Lagos are therefore evident particularly for the Lagos Waste Management Authority (LAWMA), which has been operational since 2005. However, gaining traction in structured MSW management in addition to capacity and funding constraints, has remained challenging due to inconsistencies in government commitment and support for waste management initiatives and projects. Successive administrations often do not share the same focus or vision and often prioritise other equally challenging development areas for intervention.

Resource recovery remains central to MSW management and the challenges with government execution and coverage have largely been due to a lacking involvement of competent PSPs, as was observed with the Cleaner Lagos Initiative(CLI) in 2016; which was designed to tackle challenges of waste management and energy recovery, but ended up being rescinded by the government in 2019, due to residents' complaints, low coverage and other administrative inefficiencies[13], [14]. The required execution rate for appropriate waste management and resource recovery, especially for renewable energy generation in order to reduce emissions[15] and diversify Nigeria's current energy mix- can only be truly derived from a combined effort of the identified stakeholders; particularly the private sector, where entrenched technical and financial capacities abound[14].

Efficient MSW management involves critical decision-making, such as the selection of optimal technology[15], site or location considerations, financing and overall administration[16]. According to Dayton and Foust[17][18], waste management strategy remains specific to each region and will therefore be affected by issues such as waste volumes, available and adaptable technology, available land, regional infrastructure, community acceptance, and relevant regulation relating to waste management, the environment and electricity generation; with cost being the deciding factor, which should ultimately be minimised. Therefore, based on this assertion, it is inferred that the best solution for a given community, will be that which maximises the cross section of environmental, social, and governance considerations while minimising costs[18].

The Lagos State government has estimated a power generating capacity requirement of 15,000MW to secure Lagos's mega-city status and will require approximately US$6.12 billion annually, to achieve this between 2013- 2025[2]. This estimate is indicative for the country, as Nigeria is plagued with significant gaps in power demand and supply, estimated at about 17,520MW combined suppressed and latent demand, compared against a peak

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generation capacity of 5,300MW[19]. This has resulted in an average of almost 90 million residents living without access to electricity, with most of this number in areas where grid-supply is not economically feasible due to the exorbitant cost of providing requisite transmission infrastructure. Extrapolations for Lagos State's requirements are therefore not exaggerated.

The largest consumers of power within the State remain industrial and commercial users, with Ikeja Industrial Area accounting for almost 35%[2]. However, due to constant power supply gaps, shortages and load shedding, most businesses and households rely on fossil-fuel powered generators as an alternative to grid-supplied power. The on-grid renewable energy(RE) target for Nigeria, known as "Vision 30:30:30", aims to enhance generation capacity by up to 32,000MW by 2030, with 30% contributed from RE sources, including 1,100MW from biomass out of the total 9,1000MW nationwide RE target[19][20]. In view of this, the features of a successful RE market for a given country have been described in terms of transparency, clear objectives, appropriate resources and technology, proper incentives, stability, energy market and land use planning reform, in addition to mitigating the risk within communities and appropriately apportioning costs and benefits[21].

Centralised energy supply systems are rapidly losing popularity, due to depletion of fossil fuels, environmental and climate change concerns, insecurities related to energy logistics infrastructure and investors' commitment to minimise financial risks through the use of small-scale, modular generation and transmission systems[22]. The addition of Biomass power or biopower using waste-to-energy systems, will supplement grid supply through decentralised power stations, which are connected to small, isolated power line networks, and will subsequently supply households, buildings or machinery depending on capacity. This will ultimately serve the interests of the marginalised demographic, by enhancing economic opportunities through job creation, rehabilitating current waste management practices and behaviours, while improving overall energy access[23].

The consensus therefore, is that waste management and energy recovery are not solely technical challenges, but remain strongly influenced by government and politics, socio-economic, environmental and cultural factors, while being limited by finite liquid resources[24]. Therefore, the objective in any standard multi-criteria decision-making (MCDM) analysis, is to determine and prioritise actions based on defined decision criteria, to efficiently utilise available resources and achieve desired results. This study combines knowledge garnered from the vast literature on MCDM, ESG investment principles and the substantive knowledge of the authors, based on exposure to the subject matter.

7.3 Materials, Methods and Assumptions

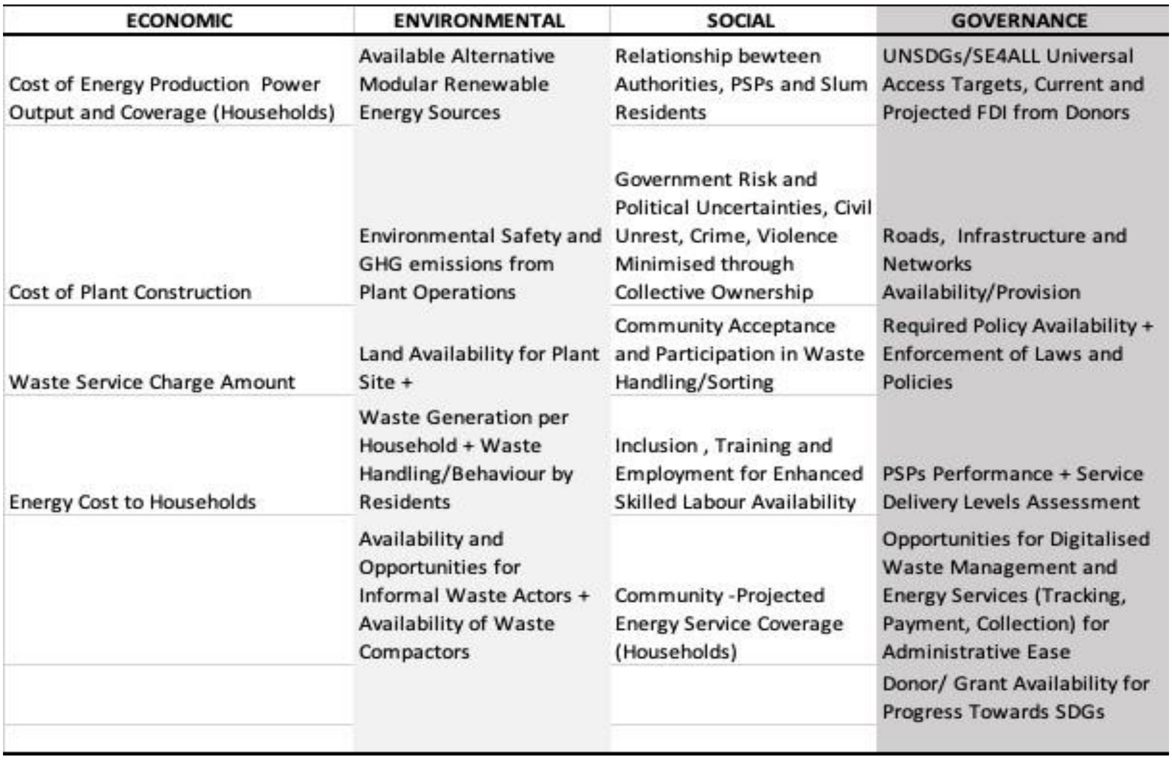
According to Brans and Mareschal[25] a "multicriteria problem is not a mathematically well- stated problem" as it is not possible to derive a single solution which optimises all defined criteria. This perhaps supports Diakoulaki's[26] assertion that conflict remains the underscore in MCDM, due to its being at the core of decision-making. A scenario where all alternatives align with all the evaluation criteria, provides minimal insight or interest as the choice is clear[26]. Krishnan et al[27] describe four key steps in MCDM analysis, which includes identifying the criteria and the alternatives or actions to be evaluated.

A popular MCDM tool is the Priority Ranking Organisation Method for Enrichment Evaluation (PROMETHEE), which is a "pair-wise comparison-based outranking method" used to consider defined alternatives or actions, evaluated by multiple criteria [16][24][27][28]. It is based on ‘positive, out, or leaving’ preference flows and ‘negative, in or entering’ preference flows for each defined action and are subsequently ranked based on the on the net flows or preference weights. The leaving flow illustrates the extent to which a given alternative dominates other available alternatives, while the entering flow depicts an inverse situation[29]. The PROMETHEE tool is able to process both quantitative and qualitative data, to determine a preference ranking of actions, based on defined weights[29].

PROMETHEE I provides a partial ranking of the alternatives- in comparison to each alternative, PROMETHEE II provides a complete ranking from best to worst case for defined alternatives, and the Geometrical Analysis for Interactive Aid (GAIA) complements the PROMETHEE approach, for visualising the result of the rankings. While GAIA illustrates the best alternative alongside determining criteria, the Group Decision Support System (GDSS)-PROMETHEE approach, presents an advanced method to assist a group of decision-makers achieve consensus[30].

The PROMETHEE method has been applied to a variety of assessments, especially in sustainability studies, due to its ability to consider multiple criteria, characteristic to sustainable development issues. Vego et al[24] considered the merits of inter-county cooperation in terms of potential waste management centres and the siting of waste management centres in coastal vs hinterland zones within Croatia. Ogrodnik[31] using sustainable development indicators, applied the method to determine the strength and weaknesses of selected cities in Poland. Mousavi et al[32] ranked appropriate plant location alternatives and Arikan et al[33] determined solid waste management disposal alternatives using a combination of MCDM methods including PROMETHEE.

Table 1. Criteria Groups- Multi-Stakeholder Preferences/Requirements



ECONOMIC	ENVIRONMENTAL	SOCIAL	GOVERNANCE
Cost of Energy Production Power Output and Coverage (Households)	Available Alternative Modular Renewable Energy Sources	Relationship bewteen Authorities, PSPs and Slum Residents	UNSDGs/SE4ALL Universal Access Targets, Current and Projected FDI from Donors
Cost of Plant Construction	Environmental Safety and GHG emissions from Plant Operations	Government Risk and Political Uncertainties, Civil Unrest, Crime, Violence Minimised through Collective Ownership	Roads, Infrastructure and Networks Availability/Provision
Waste Service Charge Amount	Land Availability for Plant Site +	Community Acceptance and Participation in Waste Handling/Sorting	Required Policy Availability + Enforcement of Laws and Policies
Energy Cost to Households	Waste Generation per Household + Waste Handling/Behaviour by Residents	Inclusion , Training and Employment for Enhanced Skilled Labour Availability	PSPs Performance + Service Delivery Levels Assessment
	Availability and Opportunities for Informal Waste Actors + Availability of Waste Compactors	Community -Projected Energy Service Coverage (Households)	Opportunities for Digitalised Waste Management and Energy Services (Tracking, Payment, Collection) for Administrative Ease
			Donor/ Grant Availability for Progress Towards SDGs

Table 1. captures the divergent criteria or interests of multiple stakeholders- Government, Community, Investors and PSPs, under ESG and economic categories. Weights are subsequently assigned to each criterion based on the decision-makers' preferences. In defining the criteria weights prior to the PROMETHEE assessment, Buckley's[34]Fuzzy Analytic Hierarchical Process (FAHP) is employed. The justification for this is due to uncertainties characteristic to developing economies, riddled with equally inconsistent data and imprecise information for decision-making. The FAHP is also a valuable tool where the criteria ranking involves multiple stakeholders or experts.

Buckley[34] using the triangular membership function, employed pair-wise fuzzy ratios in determining a range of values for defined priorities, with the geometric mean approach[35]. A pair-wise comparison matrix is derived, and the final fuzzy weights are used to determine the ranking of criteria from highest to lowest. The criterion with the highest ranking is that which satisfies the defined stakeholder's perspective and remains "undominated"[34].

The criteria weights are the key parameters which reflect a given stakeholder's priorities and the fuzzy weights derived are eventually normalised to crisp numeric values, representing the relative importance of each criterion.

Fuzzy numbers are represented by **Equation (1).**, while **Equation (2)**. determines the reciprocal of fuzzy numbers,

$$\tilde{\mu}_A(x) = \tilde{A} = (1,2,3) \tag{1}$$

$$\tilde{A}^{-1} = (l,m,u)^{-1} = \left(\frac{1}{u}, \frac{1}{m}, \frac{1}{l}\right) \tag{2}$$

These fuzzy numbers are multiplied using the following method:

$$\tilde{A} \otimes \tilde{A} = (l_1,m_1,u_1) \otimes (l_2,m_2,u_2) = (l_1 * l_2, m_1 * m_2, u_1 * u_2) \tag{3}$$

And the fuzzy geometric mean values for the defined criteria are derived as follows,

$$\tilde{r}_1 = ((l_1 * l_2 * l_3 * l_4)^{1/4}, (m_1 * m_2 * m_3 * m_4)^{1/4}, (u_1 * u_2 * u_3 * u_4)^{1/4}) \tag{4}$$

the fuzzy weights are subsequently determined using **Equation (5).** below,

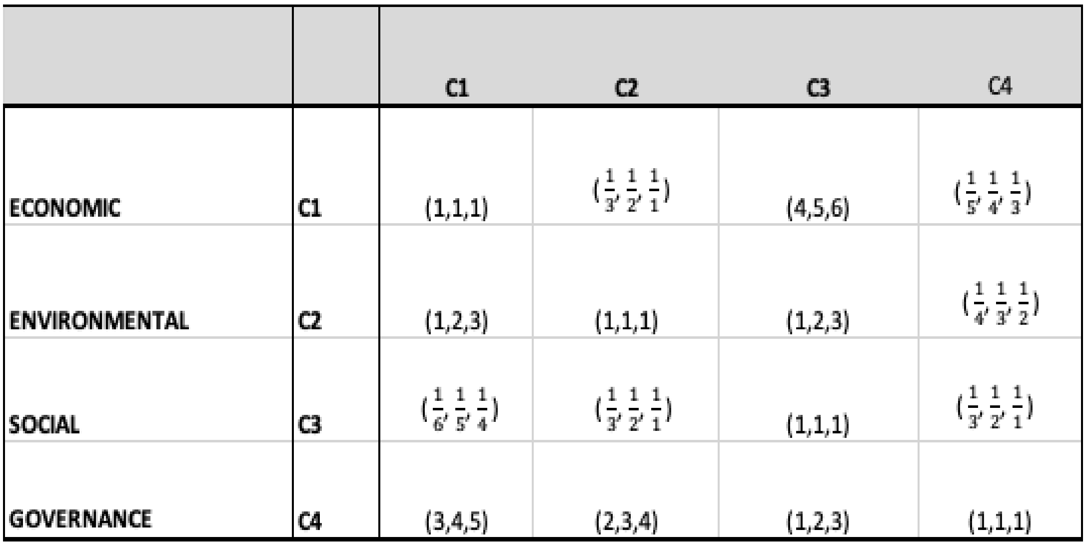
$$\tilde{w} = \tilde{r}_i \otimes (\tilde{r}_1 \oplus \tilde{r}_2 \oplus . . . \oplus \tilde{r}_n)^{-1} \tag{5}$$

Defuzzification to crisp numeric values using the Centre of Area method are derived,

$$w_i = \left(\frac{l+m+u}{3}\right) \tag{6}$$

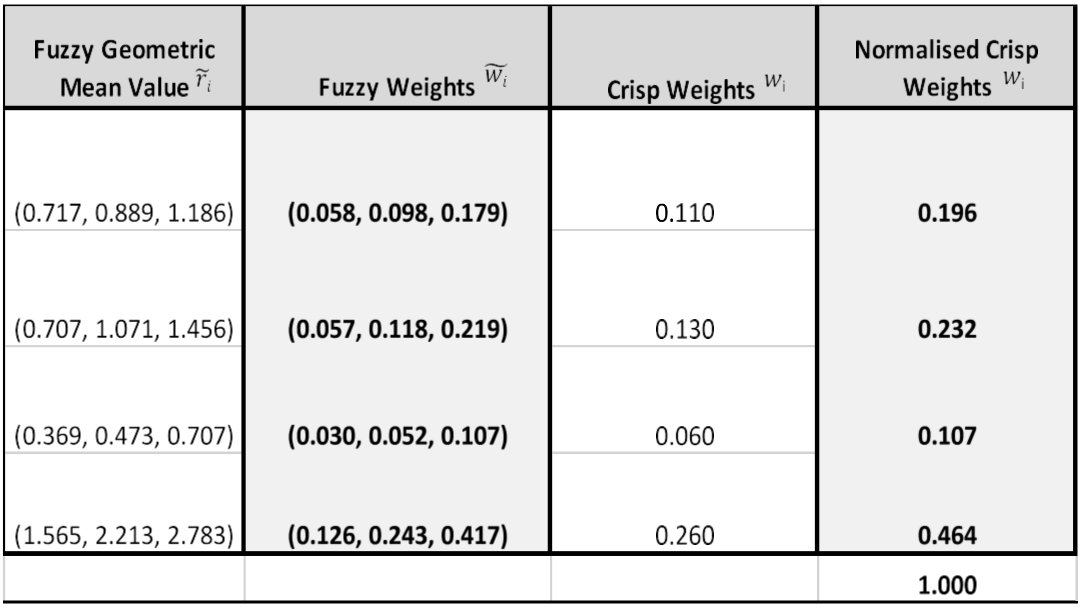
And these crisp values are subsequently normalised. The outcome of the above steps are captured in **Table 2.** and **Table 3.** below:

Table 2. Fuzzified Pair-wise Comparison Matrix



		C1	C2	C3	C4
ECONOMIC	**C1**	(1,1,1)	$(\frac{1}{3},\frac{1}{2},\frac{1}{1})$	(4,5,6)	$(\frac{1}{5},\frac{1}{4},\frac{1}{3})$
ENVIRONMENTAL	**C2**	(1,2,3)	(1,1,1)	(1,2,3)	$(\frac{1}{4},\frac{1}{3},\frac{1}{2})$
SOCIAL	**C3**	$(\frac{1}{6},\frac{1}{5},\frac{1}{4})$	$(\frac{1}{3},\frac{1}{2},\frac{1}{1})$	(1,1,1)	$(\frac{1}{3},\frac{1}{2},\frac{1}{1})$
GOVERNANCE	**C4**	(3,4,5)	(2,3,4)	(1,2,3)	(1,1,1)

Table 3. Criteria Weight-Reference Case Scenario



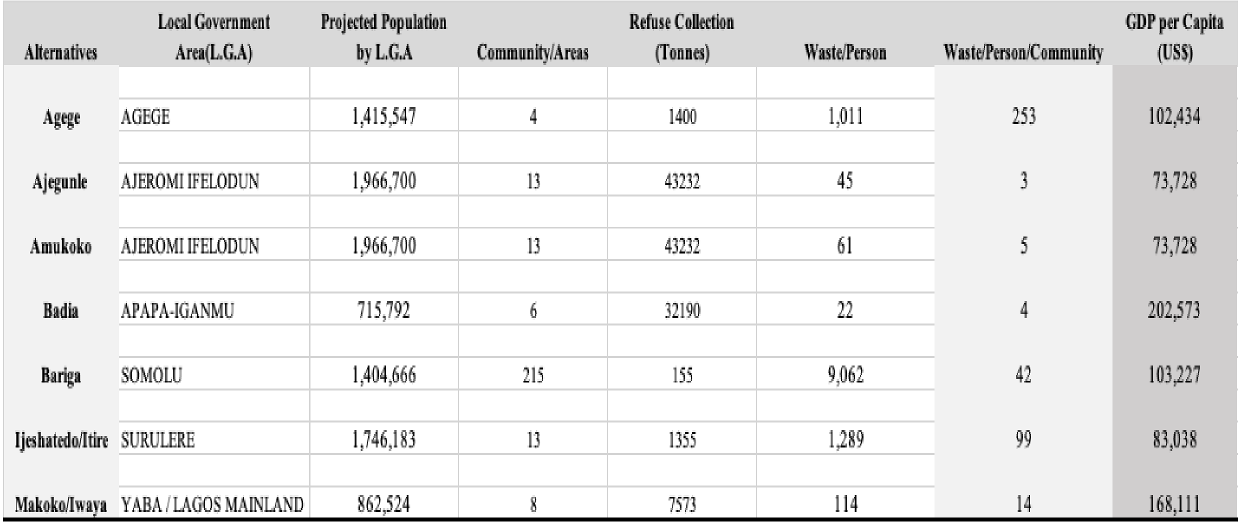
Fuzzy Geometric Mean Value $\tilde{r}_i$	Fuzzy Weights $\widetilde{w}_i$	Crisp Weights w_i	Normalised Crisp Weights w_i
(0.717, 0.889, 1.186)	**(0.058, 0.098, 0.179)**	0.110	**0.196**
(0.707, 1.071, 1.456)	**(0.057, 0.118, 0.219)**	0.130	**0.232**
(0.369, 0.473, 0.707)	**(0.030, 0.052, 0.107)**	0.060	**0.107**
(1.565, 2.213, 2.783)	**(0.126, 0.243, 0.417)**	0.260	**0.464**
			1.000

The normalised crisp weights derived in **Table 3.** represent the weighting for the reference case scenario, being the government stakeholder's perspective. Three additional scenarios are created for analyses, using similar weights which are then varied based on the stakeholder in that specific scenario. That is, in the Community scenario, the social criterion would be weighted 46%, while for the Investor, economic criterion would receive a similar weighting, and so on.

Table 4. captures the input parameters derived for use in the Visual PROMETHEE Academic Edition software. The slum areas for consideration, are adapted from the defunct LMDGP project and the data for projected population, community area and refuse collection are adapted from the Lagos State Government Abstract of Local Government Statistics, 2016[36].

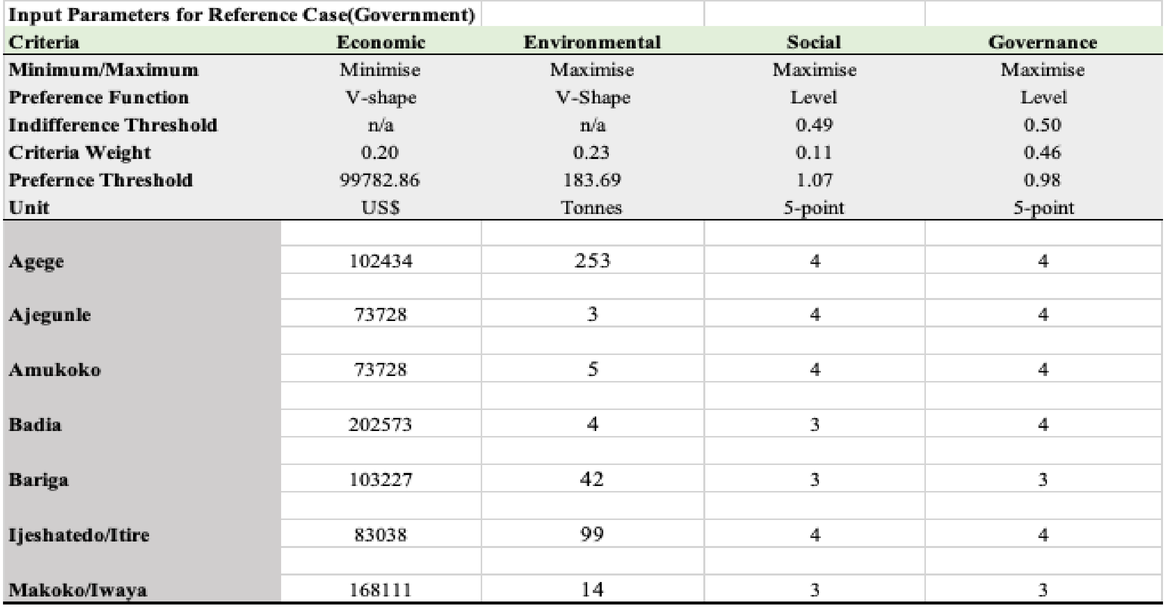
As at 2016, the Lagos Bureau of Statistics reported an estimated GDP of US$145.141billion, this was used to derive the GDP per capita, which is subsequently employed as a proxy for the economic criterion values in the PROMETHEE analyses. The governance and social criteria were analysed for each alternative using a 5-point scale and the values for the environmental criterion were derived from the total refuse collection per person in each community. **Table 5.** provides a summary of the final data used in the analyses, which are then varied per stakeholder perspective and preference.

Table 4. Input Parameters Derivation



Alternatives	Local Government Area(L.G.A)	Projected Population by L.G.A	Community/Areas	Refuse Collection (Tonnes)	Waste/Person	Waste/Person/Community	GDP per Capita (US$)
Agege	AGEGE	1,415,547	4	1400	1,011	253	102,434
Ajegunle	AJEROMI IFELODUN	1,966,700	13	43232	45	3	73,728
Amukoko	AJEROMI IFELODUN	1,966,700	13	43232	61	5	73,728
Badia	APAPA-IGANMU	715,792	6	32190	22	4	202,573
Bariga	SOMOLU	1,404,666	215	155	9,062	42	103,227
Ijeshatedo/Itire	SURULERE	1,746,183	13	1355	1,289	99	83,038
Makoko/Iwaya	YABA / LAGOS MAINLAND	862,524	8	7573	114	14	168,111

Table 5. Input Parameters for Visual PROMETHEE



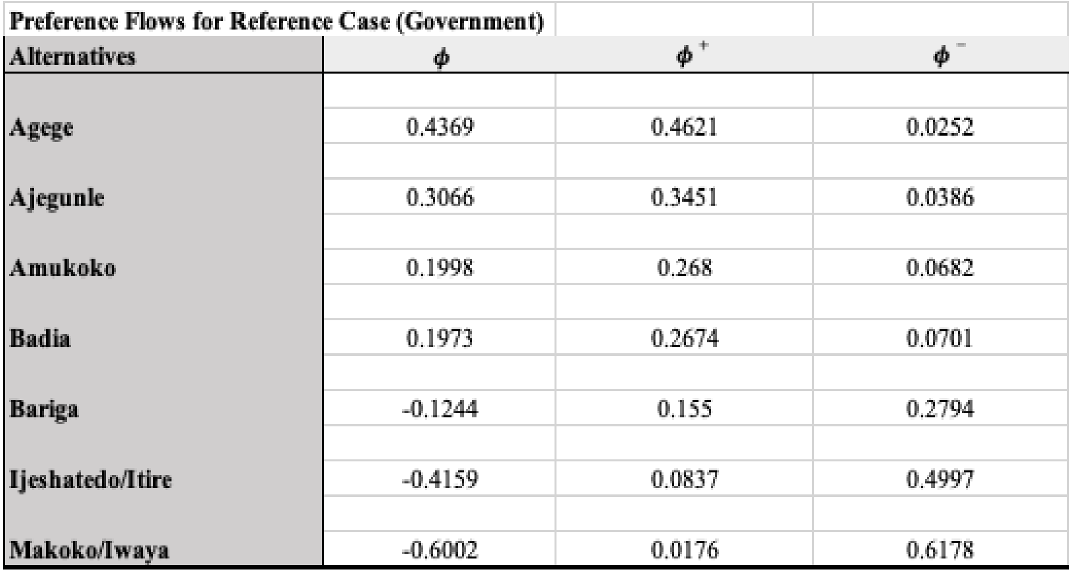
Input Parameters for Reference Case(Government)				
Criteria	**Economic**	**Environmental**	**Social**	**Governance**
Minimum/Maximum	Minimise	Maximise	Maximise	Maximise
Preference Function	V-shape	V-Shape	Level	Level
Indifference Threshold	n/a	n/a	0.49	0.50
Criteria Weight	0.20	0.23	0.11	0.46
Prefernce Threshold	99782.86	183.69	1.07	0.98
Unit	US$	Tonnes	5-point	5-point
Agege	102434	253	4	4
Ajegunle	73728	3	4	4
Amukoko	73728	5	4	4
Badia	202573	4	3	4
Bariga	103227	42	3	3
Ijeshatedo/Itire	83038	99	4	4
Makoko/Iwaya	168111	14	3	3

There are a number of considerations for each alternative, which include the criteria weights, the preference ranking sense- to maximise or minimise, and the preference function which is used to determine the degree of preference based on the pair-wise comparisons[29]. Preference function values are between 0 and 1 and are interpreted as increasing, as stakeholder preference function values approach 1. A strict preference would be denoted by 1, while indifference would have a 0 value. The preference function is therefore an increasing function of deviation, where smaller deviations produce weaker degrees of preference and larger ones equate to more significant degrees of preference[37].

The preference functions selected in the analyses are the V-Shape and Level preference functions. The V-shape is a special case where the Q indifference threshold value is 0, that is even small deviations are considered. The Level preference function is useful for qualitative criteria, where degrees of preference and deviations are monitored on each level of evaluation.[38]. The Q indifference threshold is the largest deviation where the stakeholder or decision maker is indifferent, meaning that “Q is just below that first significant value”; while the P preference threshold is the “smallest deviation considered sufficient to generate a full preference”[38].

The preference flows for the reference case and the other scenarios defined within the PROMETHEE software, for the GAIA and GDSS analyses are summarised in **Table 6.** And **Table 7.** respectively.

Table 6. Preference Flows for Reference Case



Preference Flows for Reference Case (Government)			
Alternatives	ϕ	ϕ^+	ϕ^-
Agege	0.4369	0.4621	0.0252
Ajegunle	0.3066	0.3451	0.0386
Amukoko	0.1998	0.268	0.0682
Badia	0.1973	0.2674	0.0701
Bariga	-0.1244	0.155	0.2794
Ijeshatedo/Itire	-0.4159	0.0837	0.4997
Makoko/Iwaya	-0.6002	0.0176	0.6178

Table 7. Unicriterion Net Flows for Scenarios

Scenario Alternatives	Government ϕ	Investors ϕ	Community ϕ	PSPs ϕ
Agege	0.4369	0.3822	0.4458	0.5298
Ajegunle	0.3066	0.3623	0.3155	0.3361
Amukoko	0.1998	0.2023	0.2087	0.0095
Badia	0.1973	0.1998	0.2062	0.0044
Bariga	-0.1244	-0.0655	-0.1986	-0.0283
Ijeshatedo/Itire	-0.4159	-0.4888	-0.4489	-0.3638
Makoko/Iwaya	-0.6002	-0.5923	-0.5288	-0.4878

The positive outranking flows show the extent to which each alternative outranks the others. The higher the Phi+ or leaving flow, the better the alternative. A negative outranking flow depicts the reverse, where the alternative in focus is outranked by all the others. The smaller the Phi- or entering flow, the better the alternative[25].

7.4 Results and Discussion

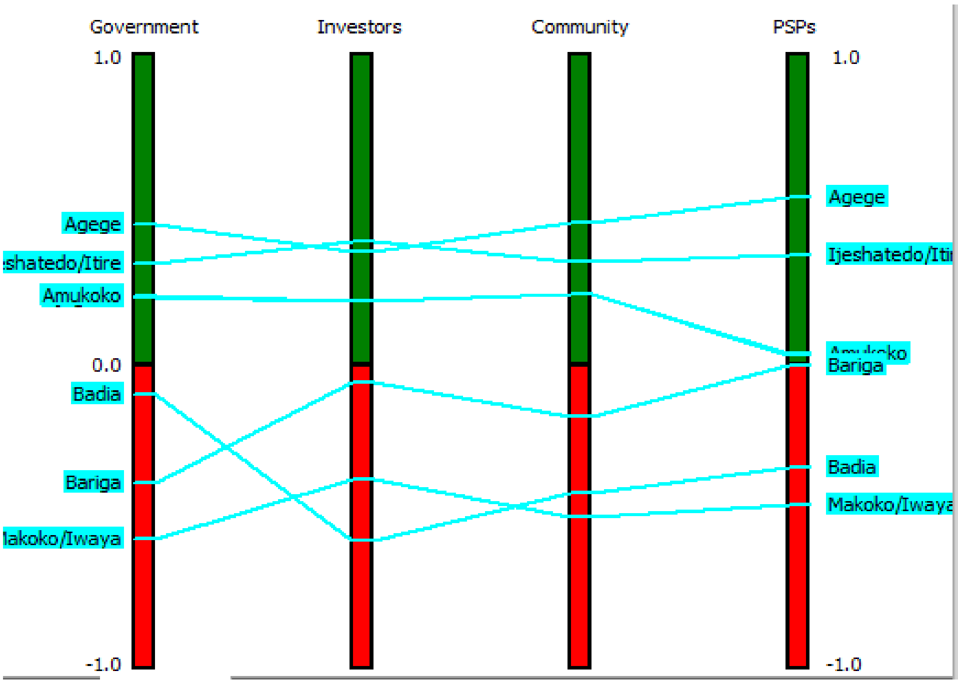


Figure 1. Rankings for Scenarios (GDSS)

Figure 1. represents the results of the GDSS scenario comparison, which is based on PROMETHEE II rankings of the alternatives. This is derived from the difference between Phi+ and Phi-, that is, the net flows (**Table 7.)** The rankings for each scenario are displayed on the vertical green-red bars, with a line connecting each alternative. It identifies the best decision, which indicates stakeholder consensus in terms of solid waste management projects for slum rehabilitation and biopower plant siting. This is positive for Agege, Ijehsatedo/Itire and Ajegunle/Amukoko communities. The alternatives on the red portion of the bars are considered worst cases, based on the input parameters which are largely data driven.

The import of the scenario comparison is its extension to real-life, where Agege community would be the starting point for a proposed rehabilitation project, and this analysis would enable project sponsors or investors successfully phase and appropriately apportion financial and technical interventions, to prevent unavoidable costs and frittered resources. The refuse to be collected would also provide sufficient feedstock for the proposed biopower plant, while encouraging socio-economic development through enhanced businesses opportunities and job creation. The stakeholder consensus also implies a situation where a burgeoning sense of ownership within the community is developed, thus reducing the potential for vandalisation or incidences of larceny, a common threat in slum areas.

Figure 2. GAIA Plot for Scenarios

The GAIA plot illustrates each relevant action, represented by divergent axes from the centre of the GAIA plane. The position of the axes determine how closely each criterion is related. Where the preferences are similar, the axes will move closer together, and vice versa. In **Figure 2.** it is evident that there is convergence among all the stakeholders, except for government or the governance criteria. However, the results generally indicate stakeholder consensus as the orientation of the axes remain similar.

The thick red axis, which is the decision axis, indicates agreement among stakeholders in terms of the defined criteria and alternatives, and means that the results of the PROMETHEE rankings are consistent. Shorter decision axes are usually deemed less reliable and as this is not the case in **Figure 2.**, it is concluded that appropriate weightings have been provided for the criteria and stakeholder scenarios, which is consistent with the value of the FAHP method in cases of imprecise information, data, and multiple stakeholders.

GAIA provides a better indicator of the issues to be resolved before embarking on the rehabilitation project and this plot highlights the often unstable political, business and policy environments in most developing economies. Based on the above, it is evident that the concerned stakeholders will require dialogue and negotiation to achieve significant convergence in preferences and goals, as government remains a key stakeholder and determinant for project success.

Figure 3. shows an aggregated PROMETHEE Rainbow, which is also representative of the PROMETHEE II rankings. It details the gross contribution per criterion based on flow values and weights, in proportion to the Phi net flow of each action; and displays where each alternative performs the best and its weakest features, based on the defined criteria.

The communities are represented by each bar and it is clear that Agege and Ijeshatedo/itire sufficiently satisfy the relevant criteria in varying order. Agege would therefore be the optimal choice for ESG investment, as this is prioritised. Makoko's strong performance in governance is indicative of recent efforts by the Lagos State government to improve the aesthetics and overall structure of the community, following the demolition of illegal structures and settlements.

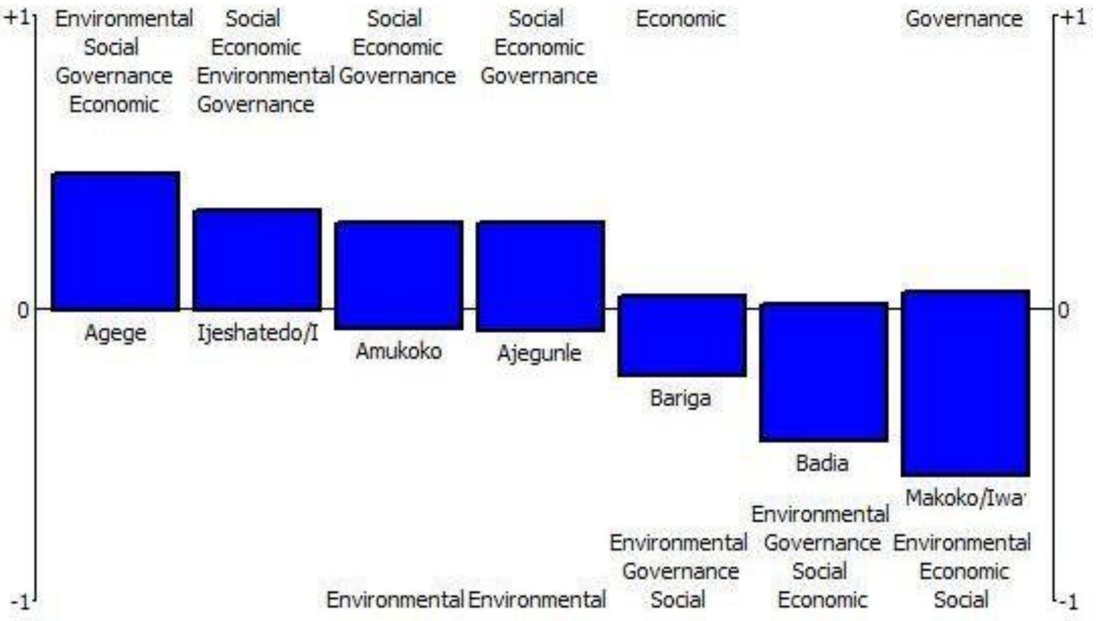


Figure 3. PROMETHEE Criterion Contribution

From the PROMETHEE rankings, although Amukoko and Ajegunle communities, which are in the same local government area, share third place, the PROMETHEE rainbow shows the environmental criterion as not being sufficiently satisfied in these areas. Further investigation would be required to determine the key drivers of this outcome, beyond the available data.

The challenges before the Lagos State government are therefore evident and this creates opportunities for private sector investors and donors to uptake the treatment and disposal of waste and boost turn-key projects for waste-to-energy(WtE) initiatives[39], through the provision of structured or phased technical and financial support to the municipality. However, to the extent that PSPs can collect solid waste, transport them to landfills and operate these facilities, the inherent cost of energy recovery from waste, often excludes local private sector participants. This ultimately broadens the scope for foreign direct investment (FDI) and donors to boost local capacity.

In addition, the decentralisation of these WtE interventions is critical, and is supported by the outcome of the Integrated Sustainable Development Goals (iSDG) Model analysis for Nigeria, completed in 2019. The iSDG is a United Nations Development Programme (UNDP) tool for gauging policy impact on a country’s ability to achieve the SDGs, based on simulated development scenarios. The objective for Nigeria was to strengthen impact and planning for interventions towards SDG attainment, and the results support enhanced investment in decentralised RE, as a catalyst for overall socio-economic development.

In view of the above, the modalities for the enhanced inclusion and dissemination of decentralised modular biopower plants in Nigeria’s RE generation and supply strategy, must be clearly defined and structured, as the true benefit of any system, technology and or intervention, is only derived from its adoption and proper deployment to the target users[40].

RE policy is primarily focused on energy security, climate change mitigation and economic development, however, due to inherent trade-offs in tackling these issues, it is imperative that required policy adjustments and incentives be determined by the State, in order to attract or in the case of the LMDGP, encourage donors and private investors alike to revisit slum rehabilitation projects, as a precursor to significantly contributing to the achievement of the primary UNSDGs on clean and affordable energy(SDG7) and sustainable and inclusive cities(SDG11), amongst others.

Finally, good governance would ultimately be the hallmark of success in any target intervention, as characteristics such as accountability, reliability, quality and decisive leadership based on integrity, proper planning and administration, alongside the provision or commitment to provide basic services which enhance the wellbeing of the masses, all add up to creating an enabling environment for future private investment and overall capacity development, especially for marginalised urban poor settlements and communities.

7.5 Conclusion

The analyses although limited by available data, compared defined alternatives for strategic MSW management and energy recovery through WtE biopower systems. The results also identified the principal areas where relevant stakeholder consensus is achieved, for strategic intervention in Lagos’ blighted communities, as defined in the defunct LMDGP. The PROMETHEE rankings, GAIA and GDSS analyses remain valuable decision-making tools, as they provide key insights and encourage strategic planning of limited resources, while equally highlighting potential conflict areas for consideration, prior to project execution.
Aside from Agege, ijeshatedo/Itire and Ajegungle/Amukoko communities being the clear choice for phased intervention, additional valuable information would be required to make a definitive decision. These include the topography of the ‘best’ areas based on the rankings, land availability, available networks, infrastructure and facilities and the estimated cost of providing these elements where unavailable; prior to determining a strategy for biopower

plant siting or future MSW management facilities. This would ultimately facilitate increased private investment and donor participation in the State.

Globalisation has encouraged greater consumption patterns across the globe, leading to increased waste generation across municipalities and communities alike. Coupled with the rapid expansion in population, the pertinence of a viable strategy to sufficiently manage the unintended impact of burgeoning waste generation on the economy and environment is evident. Although developed countries have devised suitable technologies and strategies for managing waste streams and pioneering RE adoption as mainstream energy sources, the concentration of challenges within the African continent cannot be ignored indefinitely.

WtE or biopower intervention may not be as commercially popular as competing alternatives such as solar or small hydropower systems, however, the imperative to sufficiently utilise trash beyond landfill deposits is a key driver and the underlying value of this study. The objective remains to provide affordable energy in a sustainable manner, with minimal environmental impact. The commitment of a government and its sustained political will in this regard, will remain central to the successful adoption of RE systems in the mainstream energy mix. Stabilising RE energy generation, transmission, distribution and access is a pre-cursor to progress in line with the UNSDGs and a structured approach which considers the above analyses and results, would ensure the effective implementation of bioenergy resources and technology, and secure its relevance in the RE strategy particularly for otherwise disenfranchised urban households.

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8. Chapter 7

Thesis Justification and Summary

8.1 Research Foreground

This research effort commenced in 2018, long before the advent of the Covid-19 Pandemic. In the wake of the economic, social and policy impact of this unprecedented virus, it becomes imperative to consider the consequences for a sustainable energy future in hopes of determining a viable strategy for enhanced renewable energy access not just in Nigeria or West Africa, but across the sub-Saharan African region.

In West Africa, Nigeria remains a major oil producer, whose foreign exchange earnings suffered enormous damage following the advent of the pandemic. Her economic travails were further heightened by a Naira (Nigerian currency) devaluation against the U.S dollar and the attendant freeze of economic activity, which further strained the populace. The slogan “Hunger kills faster than the Virus” was quickly adopted by many, who subsequently flouted lockdown protocols, in search of “daily bread”.
This essentially led to the wide-spread mentality that the pandemic was a falsity, A further lack of co-ordination and a seeming “copy and paste” of European and American lockdown procedures lead to widespread distrust of the figures published by the National Centre for Disease Control (NCDC) and the Nigerian Government in general.
An attendant lack of infrastructure, skilled personnel, inherent injustices and preferential treatment (in terms of availability and accessibility) related to COVID test kits, economic challenges, a devalued Naira, soaring prices for food and medicine without the relevant purchasing power, increased government borrowing without the evident effect on the wellbeing of the citizenry, increased domestic violence and sexual assault cases (minors included) and relentless insurgent activities, lead to countless deaths which either remain unaccounted for, incorrectly captured, or completely ignored and therefore unreported.

In view of the somewhat dismal picture above, the focus of the Nigerian government and indeed most African countries became restoring the economy to a semblance of normalcy, while they endeavoured to keep the death toll from this disease to a “bearable” minimum. This put poverty alleviation and public health at the forefront and somewhat relegated the energy discussion and the achievement of the UN SDGs in certain aspects, across the nation.

SDG 7 (clean energy) discourse, which is the focus of this thesis, was frighteningly ignored and became obvious that Africa may well be “left behind”, if critical factors to boost clean energy availability, access and affordability were not vigorously pursued and effectively implemented. The thesis considers the impact of the pandemic on the Nigerian economy and highlights the danger of the renewable energy discussion for Africa being relegated due to pressing public health and poverty- related issues. It highlights the opportunity for adoption of decentralised biopower as a supplementary renewable energy resource, especially for an overly populated country like Nigeria and equally attempts to chart a way forward, using household, trade, demand and consumption behaviour assessments in the wake of recent economic realities.

The explores the multi-faceted issues highlighted above in line with the opportunities for decentralised biopower adoption (with a focus on MSW), considering that it has been largely ignored due to the popularity of solar and wind sources; but may well be a perfect supplementary and affordable (considering the rising costs of photovoltaic panel elements) source of renewable energy; especially for a major oil producer like Nigeria, as if the African Giant gets it right, the rest of Africa would naturally follow.

Municipal Solid Waste (MSW) has been highlighted as a viable resource, with a double positive impact on both renewable energy access and the environment. Therefore, key considerations in this work assess the economic interactions of the post-COVID-Nigerian and sub-Saharan African economies, while seeking to determine issues such as how businesses will adapt to the new economic climate and the impact on trade and industry, consumers' economic behaviour and investment opportunities and objectives based on spending priorities, the consumption of fossil fuels and general energy behaviour (households); while building a solid case for decentralised biopower, as a viable supplement and/or substitute to other renewable energy sources, in a bid to improve energy access metrics across the focal demographics and geography.

The thesis chapters have explored the nuanced facets of key energy access metrics and factors, including the impact on society, economy and individual wellbeing. The objective remained to chart a viable way forward in view of the inherent opportunities and challenges in adopting a decentralised biopower supplementary system, through the exploitation of Municipal Solid Waste (MSW), as a key renewable energy resource which has largely been ignored.

8.2 Nigeria in Focus: Lessons from Covid-19 (I)

On March 29,2020, a cessation of movement in Lagos and Ogun States was announced, with the inclusion of the Federal Capital Territory in order to reduce the spread of the virus. The lockdown commenced at 11:00 pm on March 30 and was stipulated to remain in place for an initial period of fourteen days. During this time, places of business and offices were mandated to remain closed and people expected to stay at home. The lockdown exemptions included hospitals and healthcare facilities and some commercial establishments in the food, energy, petroleum, and security sectors.

The advent of social distancing, official and often forceful restriction of movement of persons and a virtual halt of economic activity, coupled with the lack of social engagement with family, friends and even mere strangers in the course of daily living -which is a central part of Nigerian culture, was not well received by majority of the populace. Businesses and their employees were affected, with valid fears for economic certainty. Itinerant workers were worst hit, as the struggle for "daily bread" which at best yielded meagre earnings and was only suitable for subsistence living, became considerably non-existent. Most of these workers were forced to break stipulated lockdown protocols and curfews, in search of menial jobs to enable feeding, even if enough for only a day.

For a developing Country like Nigeria, where according to the National Bureau of Statistics (NBS) 40% of people live below its poverty line of 137,430 Naira ($381.75) per year which represented 82.9 million people as at October 2019; and with an attendant devaluation of the Nigeria, that peaked at 460 Naira to the US Dollar (pre-lockdown exchange rate was 360 Naira/US$1), the pre-occupation of the average Nigerian is "daily bread", which in simple terms equals food, clothing and then securing bearable accommodation- all in an final attempt to live a decent life. The economic palliatives introduced by the government, some private organisations and benevolent individuals though laudable, were grossly insufficient and in view of the dismal picture above, the energy discussion clearly disappeared in the fracas, as the national and in fact global focus targeted at the financial, health and mental wellbeing issues arising from prevalent economic uncertainties

The focus of the United Nations Sustainable Development Goals (UNSDGs) and the set 2030 timeline is to ensure the sustainability of the global ecosystem, through innovation and inclusion. SDG 7- clean energy is in focus, as the enhancement of trade and industry availability including the socio-economic wellbeing of the population is largely dependent on energy provision, access and affordability.

The economic interactions and projections for a post COVID-19 Nigerian economy were considered, including how businesses can and will adapt to the new economic climate, the impact on trade and industry, consumers economic behaviour and prioritising spending, the consumption of fossil fuels and general household energy behaviour. These factors were examined as a gateway to facilitate the renewable energy discussion and make a viable case for decentralised biopower.

The case for moving away from a mono-product(hydrocarbon) economy is now stronger than ever, as even though crude oil remains a dominant factor in Nigeria's economic considerations, only 19% of total primary energy supply in Nigeria came from oil and natural gas (combined). Access to electricity and clean cooking equipment is estimated at 61% and 6% of the population respectively[1] and with increasing evidence of the environmental and economic hazards of dependency on crude oil, the imperatives for pursuing the UNSDGs in the context of clean and affordable energy(SDG 7), cannot be overemphasised[2][3].
The advantage of pursuing renewable energy (RE) inclusion in a given energy mix have been outlined in terms of numerous economic, social and environmental benefits, which cover job creation, reduction in poverty and inequality rates, sustainable use of natural resources, reduced greenhouse gas emissions (GHG), enhanced productivity, environmental quality and better health outcomes [3].

The above position although positive, is not without its challenges; financing renewable energy is expensive and the huge resource gap, means that for the time being Nigeria and indeed the SSA region, will continue to experience a wide variance between energy supply and demand, amidst a burgeoning population, dwindling purchasing power of citizens and resources[1][2], inherent corruption, which increases the cost of RE adoption[3] and the impacts of climate change-causing variations in temperatures, discordant seasons and massive erosion. These factors contribute to the country's energy challenges and have only been exacerbated in the aftermath of the pandemic. The infrastructure gaps and other structural deficits have become increasingly glaring and therefore continue to demand innovative interventions and implementation support[2][4].

8.3 Waste-to-Wealth: Key Considerations

Waste Management remains a pervasive problem enhanced by the rapid rate of urbanisation, lack of adherence to sound physical planning and development practices[5]. In Nigeria, especially the major cities like Lagos, it is not uncommon to find heaps of refuse littered casually as part of the scenery, providing sound evidence of mismanaged solid waste, which unsurprisingly culminates in environmental, social and public health challenges.

Trash is commonplace in Nigeria and poses significant public health, environmental health and consequently environmental health law issues. However, the challenges to operating a relatively stable and efficient trash management system, especially for developing countries are highlighted as being due to “inadequate service coverage and operational inefficiencies of services, limited utilisation of recycling activities, inadequate landfill disposal, and inadequate management of hazardous and healthcare waste”[6].

Organized waste collection services are mostly exclusive to urban areas and are usually only provided to the upper-middle income and wealthy residents of the city[6]. The rural areas and urban slums are largely ignored and informal refuse collection by scavengers is not an anomaly across many of these areas. The current rate of waste generation in Lagos is 9,000 tons/day with municipal solid waste collection frequency being either once or twice a week and usually on a door-to-door basis[6]. This is difficult in densely populated areas and therefore collection is irregular, thus allowing the waste generated pile up significantly and dangerously.

The challenges for the government are therefore evident and this provides an opportunity for private sector investors to uptake the treatment and disposal of waste, through the development of sanitary landfills and other facilities, the provision of financial leases to the public sector, and participation in turnkey projects for waste-to-wealth facilities[5]. However, while private contractors can operate landfills, incinerators and waste-to-wealth plants, the costs are prohibitive and usually require debt and equity financing. This invariably puts such undertakings beyond the capacity of most private sector operators in developing countries.

The major challenge in waste management especially in developing countries, is that waste is still considered trash and not an asset and therefore recycling efforts are usually very minimal, limited and lacking in structure[5]. Waste-to-Wealth is an attempt to organise and enhance the serviceable value of wastes that are generated from different sources. This is not without its challenges, as the major issues that impede performance include- sorting, grading, shredding, drying, digesting, pulverising, palletising and gasification[5].

A significant proportion of waste of different types should be salvaged, particularly at household level but due to a lack of sorting at source, a large portion is lost to contamination by the time the wastes reach the dumps and are therefore difficult to retrieve by scavengers. Physical sorting and waste separation at source promote the utilisation of waste at the municipal level and reduces the volume required for transfer to landfill sites. Although this appears straightforward in principle, a lack of political will or enforced regulations has led to an unchanged status quo and it is this lack of enforcement of environmental regulations that emboldens non-compliance by the people.

A funding deficit remains another core challenge for solid waste management in Nigeria, considering the volume of waste being generated. This deficit is enhanced by characteristic system inadequacies and inefficiencies, especially in operational capacity, as most municipal authorities lack the machinery and relevant technology to manage waste volumes effectively.

The behaviour of the people is also a key consideration for any sustainable waste management drive. In a study conducted in Aba, South-East Nigeria from March 2013 to September 2013, two randomly selected communities, Ogbor and Ndiegoro, with a sample size of 443 persons from a population of 4,443 households, it was observed that the majority of respondents were within the age bracket of 35-44 years with about 40% lacking formal education and engaging mostly in trade- displayed four common characteristics as relates to their household waste: ignorance, inadequate sanitary refuse bins at homes and collection centres, poor attitude towards sanitation, and delay in refuse evacuation[6]. This therefore underscores the assertion that the public, especially in developing countries like Nigeria should be educated and encouraged to handle their waste in more responsible ways for the long term benefits of a healthy environment and their consequent wellbeing, while the objective remains to highlight the value of trash as a viable energy asset and expound critical considerations for successful implementation in the RE access discourse.

8.4 The Digital Age for Energy Access: Lessons from Covid-19(II)

During this period, the Federal Government of Nigeria reduced the price of fuel from 145Naira per litre to 125Naira, following lower oil prices and a drop in landing costs for petrol. The fall in oil price and consequently external reserves led to a devaluation of the Naira(N) to N380/US$ in March 2020(FSDH). Nigeria subsequently struggled to find buyers for its crude oil due to a global supply surplus and this led to a drop in crude oil revenues in the first quarter of 2020.

An analysis of the Nigerian economy in the 4th quarter of 2019 showed the average poverty rate increased from 33.1% in 2014 to 46.7% in 2018[7], the dependency ratio of the average elite increased sharply and the level of income inequality i.e. the Gini coefficient went up to 43.3. The key words for most businesses and economies became recovery and survival.
The post-COVID-19 'new normal' presents a new reality where individuals and corporates will redefine their identities and mode of operation in line with the new economic and public health realities.

The World Bank outlines the effects aggregate shocks to economic activity can have on the welfare of individuals and households, they include- the effect on income due to lost earnings where the key earner has to suddenly take care of a sick household member and the indirect impact on earnings and employment due to a fall in demand in aggregate demand and disruptions in supply[8].
A distinction is also made on the impact on non-labour income, attributable to a decline in remittances from family members domiciled in urban areas or internationally, owing to economic stress. This significantly reduces transfers between households and the inclination to magnanimous support.

It is expected that many businesses will remain cautious, as the country slowly transitions out of a recession. Due to a weakened economy, changes in consumer behaviour and spending is evident- as food and medicine are now more than ever considered necessities by a majority of households.
The skills of the workforce will also need to be realigned to meet the changing needs of business and consumers, as a digitally focused objective will require similar skills. This presents an opportunity for Nigeria’s predominantly youthful population where approximately 85% of the population are under the age of 35.

8.5 Core Policy Focus and Objectives for Enhanced RE Adoption

The COVID-19 pandemic presented a unique opportunity for governments to restructure their economies by reviewing sectors that were significantly affected by the virus and assessing policy measures to ensure the protection and survival of the economy. The interventionist policies of government should include amongst others, the diversification of the transport sector – railways and ferries to ease the movement of people, goods and services across the nation, articulating flood management plans to divert the excess flow for electricity generation and an increase in marine activities, that include sanitising the waterways to enhance the quality of marine life and boosting domestic marine transport-as is currently being pursued by the Lagos state government in order to ease road traffic.

Another route to enhancing productivity and efficiency in the economy in order to boost employment metrics, would be to leverage the youthful population and boost their participation in the agricultural sector. This is achieved by making the industry more attractive through enhanced policy efforts, infrastructure and facilities. An improvement in facilities and equipment for domestic production, base warehousing, processing, storage and/or refrigerating[8], would also reduce the risks associated with foreign exchange exposure and improve the ease of doing business.

Enhancing security across the nation would boost the tourism sector, thereby creating additional revenue streams for the country, in the form of non-oil revenue. The infrastructure deficits that effectively constrain economic growth and development are duly identified and should be remedied to improve the education sector and also enhance foreign investment opportunities in other sectors, including agribusiness for produce such as wheat, cocoa, rubber, cashew, cassava, shea butter, oil palm and maize, which have gained demand due to increased international use for the production and manufacture of essential food and drugs.

Several opportunities abound in the mining of mineral resources, as Nigeria is rich in resources such as gold, silica, tar sand, clay, limestone, iron-ore, gold, gemstones, phosphate, gypsum, limestone and kaolin, granite and marbles. Investment opportunities in this regard require encouragement through the provision of requisite infrastructure and policies to safeguard investors and their investments in the event of changing government administrations or future global economic shocks. By restructuring the economy and reducing the size of the informal sector, improving digital communication through infrastructure and skills learning, improved application of technology for micro and small businesses and participants, the government will be able to reduce revenue loss and yield a wieldy informal sector.

A growth in e-governance and electronically based government services is equally imperative to encourage and enhance the above processes as well as ease of doing business in the country, especially in a bid to attract and sustain foreign direct investments.

The government's priority policies going forward, need to be focused on primarily on standard healthcare provision, reforms and expenditure. The situation presented by the pandemic revealed the glaring deficits and defects in the system and therefore valid support for the health care industry is an expedient initiative; considering the number of high-profile deaths recorded in the country due to the inability of most people to travel internationally and access hospitals abroad. This statement does not preclude the masses who do not have the resources to access foreign or expensive private healthcare and are therefore resigned to their fate, positive or otherwise. The coronavirus also presented a special challenge, as most patients with underlying ailments were often sacrificed on the altar of a dearth in specialists to manage their condition under the extremities the virus presented. Therefore the position where health care companies could no longer import critical inputs to manufacture drugs due to flight restrictions, supply shortages and the cash and credit restraints on most pharmaceutical companies may prove no different post COVID-19, if vigorous policy imperatives and directives are not enacted and implemented to improve the system and sector significantly.

The Nigerian government should therefore necessitate required approval, grants and implement much larger healthcare budgets, which would target preventive community-based healthcare services that would deliver the infrastructure and skilled manpower needed to tackle communicable diseases at local government and local community development area levels[8]. Registration and data collection at these levels would make epidemic or pandemic management and eradication significantly easier in the future. In other words, community-based healthcare data collation and analysis would significantly reduce the adverse impact should a pandemic of this nature and magnitude recur. A portion of the healthcare budget should go into medical research that would provide the indigenous capacity to treat and manage infections and disease using locally produced medication, as seen with the Madagascan local remedy as at May 5, 2020, where the country reported 158 cases of COVID-19 with zero mortality, allegedly due to treatments using the local herb combination[8].

One of the features of the palliatives provided by the government during the lockdown period, was to pay an approved amount into the bank accounts of a number of citizens with bank balances below a pre-determined threshold and payment tracking would be done using bank verification numbers (BVN), which is a unique registration number provided to all citizens operating commercial bank accounts. The challenge with this however, is that approximately 65% of the population are unbanked and a significant portion of small businesses operate in the informal sector. Therefore determining the impact and structured measures of disbursement of this approach is considerably challenging. Therefore structured government spending should be at least equivalent to the estimated domestic economic costs of the pandemic and the cash disbursements to small businesses and individuals, in the form of stimulus cheques-as provided by the United States and Canadian governments to their citizens to sustain spending should be traceable and the impact measurable; this would aid and subsequently restore domestic supply chains and reduce the risk of increasing the unemployment rate through lay-offs in both the formal and informal sectors of the economy. COVID-19 has shown clearly that no nation can afford to depend exclusively on foreign supply chains. The new 'normal' economic roadmap would require deeper supply chain relationships within the domestic economy[8]. A forward thinking policy would require an aggressive import substitution strategy.

Larger businesses and potential investors would benefit from tax reliefs, cuts, holidays, and incentives; although difficult to initiate at the moment as an expansion of money supply would lead to rising price levels and strains on the country's foreign currency value. To reduce the severity of the effect of upward price adjustments on fiscal stability, tax rates would have to remain where they are presently and tax reliefs may need to be deferred[8].

To summarise, some of the policy thrusts submitted herein have included higher fiscal spending on healthcare, medical research, pharmaceutical production, and standard digital infrastructure. In addition, upskilling, refocusing and restrategising within the education system, in a bid to align human resource training and development with identified gaps in skilled labour supply remains imperative. Improving productivity and participation in agriculture by scaling up production and infrastructure, through exploiting the teeming

youthful population and the adoption of requisite technology to reduce labour intensity and increase efficiency and investments; have all been outlined and the merits discussed.
A walk through the economic realities of COVID-19 offer up several opportunities for both the federal and state governments to reposition their economies. The same repositioning and resetting remains true for the private sector, the coronavirus pandemic may have its human health challenges but for businesses both small and large that positioned strategically and were swift to react, the pandemic allowed for a gain in market dominance and presented a profitable bottomline. What has proved critical in these unprecedented and challenging times especially in economic terms, is not necessarily what happens to individuals, companies and governments but how they choose to respond. The ability to adapt, react and exploit opportunities are the clear distinguishing and decisive factors between survival and extinction, in the wake of a new normal.

8.6 Decentralised Biopower: An Overview

The takeaway from the assessment of Nigeria and its unique coronavirus experience, is the need to upscale government efforts in the area of infrastructure provision, to support the new normal. A critical success factor to this objective is boosting electricity generation, distribution and access. Energy and its availability in the required form and fashion, remains the pivot and foundation for the seamless functioning of businesses, infrastructure and digital systems in a developing country like Nigeria- where the costs of acquiring, running and maintaining generator sets is added cost of doing business and household maintenance. Without power, a digital future is positively unattainable, as electricity is the bedrock of most telecommunication servers and internet systems. Therefore, stabilising energy generation, transmission, distribution and access is the pre-cursor to progress, in underscoring the points raised and the entire discussion set forth so far.

The singular impact of this resource on the economy and the wellbeing of each household cannot be ignored or over-emphasised. In pursuing this objective therefore, a key consideration is the energy mix of the country, with hydropower being the key electricity generation resource in Nigeria. In terms of other clean energy alternatives, solar remains a popular choice for reasons that have been expounded in countless literature. The success of the Ethiopian Reppie Project however, provides a clear example of the possibilities that lie in the effective harnessing of MSW as a resource for electricity generation and therefore decentralised biopower is assessed as a viable supplementary element for inclusion in Nigeria's energy mix.

There are 23 grid-connected generating plants with a total installed capacity of 10,396 MW and an available capacity of 6,056 MW. Hydro-power is the only renewable energy power plant connected to the grid. It has a total installed capacity of 1,938.4 MW and an available capacity of 1,060 MW. Nigeria's transmission network has an actual transmission capacity of 5,300 MW but a theoretical capacity of 7,500 MW. This is below the 6,056 MW available generation capacity in Nigeria, thereby creating an imbalance in power generation and transmission. There are inherent reliability issues with the transmission infrastructure as it is essentially radial without redundancies. The transmission losses generally are 7.4 %. The inadequate technological infrastructure in Nigeria adds to the power supply issues. The recurrent transmission problems, lack of access to grid electricity, and inadequate power supply evidence the critical energy poverty experienced in Nigeria. Approximately 40 % of Nigerians are not connected to the electricity grid and those connected daily enjoy electricity in the range 0-20 hours on average[9].

Waste valorisation is currently appealing to scientific and industrial interests in order to mitigate environmental damage, achieve sustainability and move towards a circular economy[10]. There have been considerable developments in waste-to-energy (WtE) technologies however, the opportunities to explore and propagate efficient, robust, cost-effective and eco-friendly systems remains[10].Some of the research and recent developments in WtE systems include improvement in energy recovery and efficiencies, biogas energy, thermal arc plasma gasification, optimisation of anaerobic digestion process, and MFC technology[10].

Nigeria remains Africa's most populated country. However, the per-capita on-grid electricity consumption is 126 kWh. This is low in comparison to other developing countries in Africa, such as South African (3926 kWh) and Ghana (361 kWh)[9]. Currently, over 80 million Nigerians (41 % of the population) have no access to electricity and owing to the unmet power demands, most Nigerians often need to endure electricity blackouts and load shedding. The problem in Nigeria's power sector spreads across generation, transmission and access. Much of the renewable energy (RE) potential in Nigeria remains untapped, with the main RE resources being solar, wind, biomass, hydro, and geothermal energy.

According to a previous study, the predicted electricity load in Nigeria as at 2019 is 16,500 MW Considering the population growth rate in Nigeria and other economic variables, the electricity demand by 2030 is predicted to be 19.6 GW[9]. [9] assumed a 200 TWh/yr electricity demand for 2030 to accommodate excess in electricity demand. A typical hourly load profile of Nigeria was used for simulation in their study. The daily, weekly, monthly, and yearly electricity demand profiles based on an electricity demand estimate of 200 TWh/yr[9]. Based on the estimated current electricity and the available supply, Nigeria's electricity situation was analysed and this allowed for a further justification of the need for a 100 % electrification of Nigeria by 2030 and to validate the model used.
The installed capacity of electricity in Nigeria as mentioned is 10,396 MW with an available capacity of 6,056 MW. Based on previous studies reported in the literature, the current estimated electricity demand for Nigeria is 144.5 TWh/yr[9]. In a 2018 bid to optimise assets in the power sector and diversify its sources of electricity generation, Nigeria set a target to meet 30 % of the country's electricity demand by 2030.

Biomass is one of the primary potential sources of generating alternative energy to mitigate fossil-fuels related environmental pollution. Biogas as an energy vector can be produced from biomass and other organic waste streams. However, there are many challenges, potential for exploring new waste streams, and gaps for further optimisation of the concerned processes. Furthermore, the economic feasibility has been studied to estimate the production cost, capital cost, revenues and net profit value and it was discovered that the production of both heat and electricity by co-digestion of milk whey and potato stem has positive net economic benefits, but with limits in raw material costs and digestate (biofertilizer) selling prices. It is therefore very important to make favourable governmental policies, such as to reduce the logistics costs and ensure the participation of producers in supply chain as some European countries have already developed. another stepping stone towards developing more advanced waste treatment technologies and sustainable energy systems that will lead to enhanced economic opportunities and a healthier and safer environment[11].

The growing concerns about the effect of greenhouse gas emissions(GHG) on climate change is pushing national governments and the international community to achieve sustainable development in an economy that is less dependent on carbon emitting activities is a vision that is usually termed a "low-carbon society". Electricity is conceivably the most multipurpose energy carrier in modern global economy, and therefore primarily linked to human and economic development as well as the environment[11].

Energy sector reform is critical to sustainable energy development. Global dependence on fossil fuels has led to the release of over 1100 Gt CO2 into the atmosphere since the mid-19th century. Currently, energy-related GHG emissions, mainly from fossil fuel combustion for heat supply, electricity generation and transport, account for around 70% of total emissions including carbon dioxide, methane and some traces of nitrous oxide. This multitude of aspects play a role in societal debate in comparing electricity generating and supply options, such as cost, greenhouse gas emissions, radiological and toxicological exposure, occupational health and safety, employment, domestic energy security and social impressions[11].Through the different stages of development, people have experimented with various sources of energy ranging from wood, coal, oil and petroleum to nuclear power. In recent years, public and political heightened awareness to environmental issues and energy security have led to the promotion of renewable energy resources. Better access to modern energy sources and electricity is mandatory for improving living standards and reducing poverty in rural areas of developing countries like Nigeria.

An estimated 1.6 billion people (85% of the world population) living in rural areas have no access to electricity. Electrification rates in rural areas of developing countries are substantially low. Even when electricity supply is available, the service is unreliable and expensive. The electricity issue in rural areas cannot be solved as a simple problem of demand and supply or as a mere logistic problem to provide electricity services. There is significant debate over the best means to carry out the electrification process. Most developed countries rely on a centralized electricity generation and distribution systems. Electricity is generated at scale in large central plants and then distributed to end users through a transmission network. These networks can be expensive and in most cases take many years to fully develop. In addition, these centralised energy supply systems are gradually losing appeal due to a number of frustrating factors which include but are not limited to the depletion of fossil fuels and their climate change impact, the insecurities affecting energy transportation infrastructure, and the desire of investors to minimise risks through the deployment of smaller-scale, modular generation and transmission systems[11]. An alternative for electrification of rural and remote areas, is the introduction of decentralised conversion technologies using locally available resources.

Decentralised electrification can provide a more reliable supply and generate income derived from the use of local resources. Decentralised electrification using local resources can reduce regional disparity in rural and remote areas in terms of supply reliability and cost, as well as promote income generation.

A careful social impact-assessment showed that decentralised energy systems opened a social as well as microeconomic dilemma and the acceptance and adoptability of distributed networks in developing countries is still debatable, when the social aspects are considered due to this social dilemma and human cooperation; owing to inherent culture, practices and behaviours.

Local conditions, social and political power relations and economic circumstances must be rigorously assessed, before a project is undertaken[11].

This human element cannot be overlooked in the realisation of how a decentralised biopower generation and distribution system, could lead to a long-term sustainable future in rapidly developing parts world. These social and related policy facets provide room for further research, which the authors will explore in subsequent articles.

The focus and one of the most important and challenging aspects on decentralized electricity generation (DEG) from biomass is its design and operation and related biopower supply chain networks. Supply chain modelling and supply chain system optimisation have received a lot of attention. Several models and solutions that can be used as decision support tools for strategic analysis as well as tactical planning of the energy systems have been proposed. But no remarkable work has been done for decentralised bio-power systems. A general decentralized energy optimization model for developing countries is developed by Bazmi et al[11] and enables the selection of biomass conversion technologies, capacities, biomass conversion plant locations, and the logistics of transportation from the biomass sites to the conversion sites; which subsequently deliver electricity to specific demand locations.

Access to electricity is an important component of rural development. Better access to electricity has been correlated to the improvement of living conditions in several aspects, such as education and income generation. Electrification in rural areas of developing countries, and in particular in the case of remote areas, is difficult due to low population densities, highly dispersed location of populated centres, low energy consumption levels per capita and poor road infrastructure which constrains transportation. This makes conventional rural electrification programs based on extension of the electricity grid and decentralised schemes with foreign fuels expensive or even economically impossible. Rural electrification programmes often require interventionist government policies and support in the form of subsidies. In rural areas where energy resources are widely available in the form of agricultural wastes, forest biomass and household waste, DEG using local resources is more suitable as an alternative for electrification. DEG avoids the necessity of extending transmission lines to dispersed populated centres, reduces the dependence on foreign fuels within these areas and promotes local development through the introduction of the production chain of biomass energy[11].

Biomass is a viable RE resource that potentially enhances the emergence of diverse and sustainable energy mix. Biomass was a major source of energy in the world before industrialisation, which lead to the prominence of fossil fuels for economic activity; remains an important renewable source of energy and various literature have proven its viability for large-scale production over time[11].

DEG utilizing biomass is garnering increasing interest for the electrification of rural areas in developing countries.
Decentralized energy systems have also been designed by means of multi-criteria and multi-objective methodologies. The analytical approach generally used in these models is single-period optimisation. In addition to optimisation, there are studies deploying simulation and geographic information systems methodologies that give more emphasis to supply stability and optimal allocation of resources.

Energy conversion technologies included in the system are combustion, gasification and pyrolysis. The demand-side of the energy system only considers the total amount of electricity demanded in the residential, industrial, and commercial sectors at specific demand locations. The possible routes for production of electricity from biomass through these selected technologies are illustrated in six major types of bio-power systems: direct-firing, co- firing, gasification, pyrolysis, anaerobic digestion/fermentation and small, modular systems. Most of the bio-power plants use direct-fired systems. Through gasification, solid biomass can be converted into a gaseous form, known as syngas. The syngas can run through “combined-cycle” gas turbine or other power conversion technology.

In addition, gas and liquid fuels can be produced from biomass through pyrolysis. In pyrolysis biomass is heated in the absence of oxygen, The biomass then turns into a liquid called pyrolysis oil, which burns like petroleum to generate electricity. Several bio-power technologies can be installed in small, modular systems which can generate electricity at a capacity of 5 MW or less. Fast pyrolysis systems were observed as having great potential to generate electricity at a profit in the long term, and at a lower cost than any other biomass-to-electricity system at small scale[11]. The downdraft gasifier design, being well developed and demonstrated, is the most feasible technology for biomass to energy conversion[11]. A few gasifiers have already been in operation for thirty years and a number of gasification processes are under industrial development at pilot and demonstration scale. Gasifiers are available from Foster Wheeler and Bioneer in Finland, Lurgi in Germany, Vølund in Denmark, TPS in Sweden, PRM Energy in the USA and Repotec in Austria[11].

A number of authors have posited that biomass-based power generating technologies are still not mature enough to provide high amounts of feedstock and satisfy the higher electricity demands. Research and development in this regard is progressing at a reasonable pace and more effective plants with improved efficiency and higher capacities are expected to be developed on a commercial scale in the foreseeable future.

Risk is often a very important factor is system selection and would tend to favour the combustion option being more developed, as seen with the Ethiopian Reppie waste-to-energy plant, which uses combustion cycles to treat 1,400 tonnes of municipal waste per day, while simultaneously generating 20 MW power to the grid . This in turn provides electricity to approximately 30% of the residents in the capital city of Addis Ababa, while conforming to global standards on air emissions . In future systems, fast pyrolysis which has only a slight advantage over the gasification and combustion options especially at small scales, due to decoupling options that are not available in combustion or gasification based-systems. De-coupled fast pyrolysis systems may be more cost-effective than the alternative technologies in particular circumstances. Thus in future systems the fast pyrolysis option can be expected to face stiff competition from alternative systems[11].

Suberu et al analysed the potential of municipal solid waste (MSW) for renewable power generation in the Lagos metropolis of Nigeria. They reported probable added benefits of financial recompense, efficient waste handling and freed up land for other productive uses[12].

In a comprehensive review of green energy potential, applications and renewable energy policies in Nigeria, Giwa et al. presented solar and biomass resources due to their huge availability. They elicited that the techno-economic feasibility and viability of utilising these resources for sustainable development is location-dependent and contingent on key aspects. These aspects included financial, institutional, cultural, educational, political and social imperatives. Given Nigeria’s geography, it is not economically viable to supply electricity to remote rural communities by extending the national grid. This would require enormous financial commitments to procure high voltage transmission lines and medium or low voltage distribution lines. Some studies have reiterated that off-grid systems are the most economical routes for delivering electricity to rural dwellers and these systems would be based on RE resources. It has also been proved that the productivity of rural businesses was impacted by electrification to the extent that, rural business owners were willing to pursue alternative electrification options irrespective of the associated costs[12].

8.7 Energy Challenges: Africa in Focus

The electricity consumption per capita of a nation is a measure of its economic development and the people's living standard[13].Global energy consumption is said to be increasing by 2% per year[14] with fossil fuels being largely dominant in overall energy generation. As at 2011, about 85% of the global energy supply was from fossil fuels[13].The attendant effect is the rise of greenhouse gas (GHG) emissions and climate distortion. It is estimated that emissions will increase by 30% in 20 years, if regulatory restrictions are not placed on the use of fossil fuels[2][14][4]. In support of the global action to combat climate change, Nigeria committed itself to cut down its national GHG emissions by 20% unconditionally and 45% conditionally by 2030, with technical support from foreign partners in terms of technology transfer and investments [15].

Globally, there are marked differences in energy supply and access of developing countries, which results in energy inequalities and inequities, as only a third of the African population has access to electricity[4]. The primary energy use per capita in Africa is about 11 and 5 times less than that of the US and EU, which represents only about 5% of the global total primary energy demand[4]. Nearly 80% of the African population depends on traditional biomass for cooking and biomass contributes to half of the total primary energy supply of Africa[4][16].

Nigeria remains Africa’s largest economy and with a projected population of 300 million by 2050 and with its current 7566.2 MW electricity generation capacity[2] and only about 30% of the its population with electricity access[13], the socio-economic development of the country appears endangered. Electricity generation capacity in Nigeria from natural gas was about 10,022 megawatts in 2013; where 7,892 megawatts, representing 79%, sourced from gas, 2,040 megawatts, representing 20% from hydro and 88 megawatts, representing 1% from biomass and waste[17]. The gap in the country’s electricity supply and demand is significant and roughly pegged at 1:3[17]. Based on the foregoing, Nigeria is engulfed with issues like erratic power cuts and load shedding (power rationing) which results in substantial reliance on private power generators by almost every business and household[13]. Other challenges plaguing the power sector include frequent shortage of natural gas supply, poor maintenance of electricity facilities and an inadequate transmission and distribution network[17].

In Africa, about 590 million people do not have access to electricity which is equivalent to around 57% of the African population[13]. In 2011, Nigeria's primary energy consumption was about 111 Mtoe (1.291TWh) comprising traditional biomass and 83% for waste[13]. Energy poverty, which essentially means inadequate or zero access to electricity, remains a major bottleneck to economic development in Africa and Nigeria in particular. Nigeria is considered among low income (LI) countries and one of the lowest electricity consuming nations in Africa[13]. It was observed that electricity consumption per capita in Nigeria at107 kWh, was significantly behind South Africa and Egypt with per capita electricity consumption of 4229 kWh and 1331 kWh, respectively[13]. For West Africa, per capita electricity consumption hovers around 14 kWh per capita per year, with an average of 0.29 kWh per day consumed in Nigeria; which is grossly below the required 1 kWh per day to absorb energy demand. The low electricity consumption in Nigeria is attributable to the huge gap in energy demand vs. supply and inadequate capacity[13].

Nigeria’s electricity access rate is roughly 45% and is considered to have one of the lowest rates of net electricity generation[17]. The residential sector consumes about 57% of overall electricity, 26% for the commerce and service sector and 17% for the industrial sector[17]. It is also imperative to state that electricity supply has never matched demand in the history of power generation in Nigeria. Future energy supply therefore, needs to satisfy factors such as sustainability, economy, efficiency and low environmental impact in order to mitigate the global energy crises, climate change and energy poverty[2][17][18][16][19][20]. The uptake and deployment of renewable energy resources (RES) has been recognised as imperative, in alleviating the energy deficit in Nigeria[13].

Access to electricity remains a marker for industrialisation, innovative technology-driven services and the wellbeing of the populace[16][19]. In Nigeria, the abundance of fossil fuels and renewable energy resources have not visibly translated to affordable and accessible energy for all[17][21][16], as the efficiency of some of the renewable energy technologies- at 15.61%, are not optimised[2][18]. However, the demand for renewable energy (RE) sources has not declined globally due to the characteristics of being clean, sustainable, futuristic, environmentally beneficial and inexhaustible[2][17]. The socio-economic factors that hinder energy access in most developing countries have been outlined as, the remote nature of some communities, low consumption levels in remote areas due to low income and high distribution costs and the lack of human and financial capital[22][23][16]. Energy access has been described as neither a socio-economic problem, nor a resources problem, but a combination of both[22]. The urban-rural energy divide[22] is also a key consideration, since a vast majority of rural households are not connected to the national grid and access to renewable energy systems remains marginal[24][23].

Reducing energy poverty in developing countries has become one of the most pressing priorities at international level, to the extent that it has been recognised as the “missing development goal” by the Food and Agriculture Organization of the United Nations and its consequences have been discussed under the concept of energy injustice[22]. However, conventional energy technologies and deployment approaches are said to be insufficient to eliminate energy poverty in Africa [22].

Access to modern energy services, at affordable cost, is representative of the aspiration to boost the socio-economic wellbeing of people, due to its impact on poverty, quality of life, education, indoor pollution, demographic transition, gender and health [17][23][16][25]. The need to ensure policy formulation and implementation strategies that are able to meet the projected demand for energy and sufficiently address the “energy trilemma” [26][27][23]which encompasses the affordability, security and sustainability of energy supply[23] [28][29], is blatantly evident. Failure in this regard will exacerbate the problems inherent in the energy sector [26]. A strong relationship has also been identified between energy access and economic growth, to the effect that economies with higher per capita incomes have higher percentage access to energy[21][23]. This implies that a rise in income equates to a larger share of households with access to modern energy services[21]. The result is evident in enhanced social equity which drives economic growth through productivity and promotes revenue generating opportunities[23].

The unavailability of and limited access to energy services marginalises poor people and impairs their ability to improve their economic conditions[24][16][19][23]. It is usually poor households that bear the brunt of higher energy prices. When prices increase, people with limited income will either have to cut back on their energy consumption and probably become unable to cater for basic needs. They will therefore have to skimp on or forego other essentials like food and healthcare. This leaves poor urban consumers vulnerable to energy price fluctuations and therefore prohibitive tariffs and connection costs discourage them from to seeking LPG or grid-based electricity[23][17]. Access to reliable energy supply at a reasonable price is therefore absolutely crucial in rural and urban poor areas, as evidence also suggests that children of electrified households attain higher education levels, which results in enhanced future earnings[23]. In addition, electrification will enable poor households effectively set up and manage a home business which improves revenue streams. Modern energy services improve indoor air quality which will improve health conditions for residents and reduce mortality, as in most cases, limited income and access may force poorer households to use traditional fuel and other hazardous and inefficient methods[23][19], which ultimately worsens the current public health crisis, that favours COVID-19 and other equally deadly diseases.

Economic output in terms of Gross Domestic Product (GDP), is deemed a weak tool for measuring the social progress of a country and for prioritising policy intervention[23]. The human development index (HDI) is posited as a better measurement, since it captures the quality of life and has a direct correlation with adequate energy services[23]. Relevant research supports the fact that significant benefits accrue through modern energy services, but accessibility remains a challenge[25][19][24]. In rural areas, electric power may be available, but inaccessible and unaffordable, while in urban settings electricity is usually available but largely unreliable. Current energy use is not without social and environmental costs, therefore the focus of proposed intervention should be people-focused and based on a locally sustainable economic model which can be operated and maintained by the community[23][27]. Local back-up capacity to guarantee reliability and requisite availability is also essential[23].

Based on the above, reliable access to energy is therefore a prerequisite for economic development. The use of RE technology for power generation especially at the local level, is a means to addressing the challenges with the availability, quality and service reliability of electricity in those areas. In cases where the capacity for grid-supplied energy is limited, and further hampered during peak usage hours, transmission and distribution losses are as high as 30%[23], therefore the implementation of on-site power generation technologies using RE sources, are a definite route to mitigating issues of power reliability and quality for a developing countries[17].

To effectively gauge the living standard, wellbeing and economic development of a people, electricity consumption per person or per capita is considered an effective metric, especially as global energy consumption is said to be increasing at 2% per year [13][14] with fossil fuels being largely dominant in overall energy generation. As at 2011, about 85% of the global energy supply was from fossil fuels[13].The attendant effect is the rise of greenhouse gas (GHG) emissions and climate distortion. It is estimated that emissions will increase by 30% in 20 years, if regulatory restrictions are not placed on the use of fossil fuels[2][14][4]. In support of the global action to combat climate change, Nigeria committed itself to cut down its national GHG emissions by 20% unconditionally and 45% conditionally by 2030, with technical support from foreign partners in terms of technology transfer and investments. [15] [13][14] [2][4][13].

Disparities in the energy supply and access of the global south are glaring, as an estimated third of the entire population of Africa can access electricity; this ultimately translates to approximately 5% of the total primary energy demand, globally. Nigeria remains Africa’s largest economy and with a projected population of 300 million by 2050 and with its current 7566.2 MW electricity generation capacity[2] and only about 30% of the its population with electricity access[13], the socio-economic development of the country appears endangered. Electricity generation capacity in Nigeria from natural gas was about 10,022 megawatts in 2013; where 7,892 megawatts, representing 79%, sourced from gas, 2,040 megawatts, representing 20% from hydro and 88 megawatts, representing 1% from biomass and waste[17]. The gap in the country's electricity supply and demand is significant and roughly pegged at 1:3[17].

Based on the foregoing, Nigeria is engulfed with issues like erratic power cuts and load shedding (power rationing) which results in substantial reliance on private power generators by almost every business and household[13]. Other challenges plaguing the power sector include frequent shortage of natural gas supply, poor maintenance of electricity facilities and an inadequate transmission and distribution network[17].

Nigeria's electricity access rate is roughly 45% and is considered to have one of the lowest rates of net electricity generation[17]. The residential sector consumes about 57% of overall electricity, 26% for the commerce and service sector and 17% for the industrial sector[17]. It is also imperative to state that electricity supply has never matched demand in the history of power generation in Nigeria. Future energy supply therefore, needs to satisfy factors such as sustainability, economy, efficiency and low environmental impact in order to mitigate the global energy crises, climate change and energy poverty[2][17][18][16][19][20]. The uptake and deployment of renewable energy resources (RES) has been recognised as imperative, in alleviating the energy deficit in Nigeria[13].

Nigeria remains Africa's largest economy, with an estimate of almost 300 million people by 2050. Electricity generation capacity is currently 7566.2 MW electricity [2] and with only about 30% of the its population with electricity access[13], the socio-economic development of the country appears endangered. Electricity generation capacity in Nigeria from natural gas was about 10,022 megawatts in 2013; where 7,892 megawatts (79%), sourced from gas, 2,040 megawatts (20%) from hydro and 88 megawatts (1%) from waste and biomass [17]. The gap in the country's electricity supply and demand is significant and roughly pegged at 1:3[17]. Based on the foregoing, Nigeria still struggles with issues like power cuts and load rotation, which results in substantial dependence on individual power generators by almost every business and household[13]. Other challenges plaguing the power sector include, poor maintenance culture in terms of existing facilities, inadequate networks for transmission and distribution and erratic natural gas supply [17].

About 57% of African households do not currently enjoy or readily have access to electricity. Energy poverty, which essentially means inadequate or zero access to electricity, remains a major hindrance to Africa's development. Nigeria is considered one of the lowest electricity consumers on the Continent, with an estimated 107 kWh electricity consumption per capita[13]. The estimate for West Africa, is placed at 14 kWh per capita annually and Nigeria accounts for around 0.29 kWh of that figure, daily. 111 Mtoe (1.291TWh) was equally estimated as the primary consumption metric for Nigeria in 2011, which comprised traditional biomass and 83% for waste[13]. This is grossly below the required 1 kWh per day to absorb energy demand. The low consumption rate in Nigeria can be is attributed to the huge gap in energy demand versus supply and also inadequate capacity[13].

The electricity access for Nigeria is estimated at about 45%, and this is considered to be a relatively low rate in terms of electricity generation capacity [17]. The electricity consumption rates for the industrial, commerce and service, and residential sectors are estimated at 17%, 26% and 57% respectively[17]. It is also imperative to state that electricity supply has historically remained below demand, in terms of power generation within Nigeria. Therefore, to meet energy supply requirements for the future, factors such as efficiency, sustainability and impact on the environment and the economy need to be carefully considered and adequately provided for in order to mitigate issues surrounding climate change, the looming energy crises and energy poverty [2][17][18][16][19][20].

This in turn will boost the uptake and deployment of RE systems and resources; an absolute imperative to bridging the gaping energy access deficit in Nigeria[13].

Nigeria while retaining Africa’s largest population, is also estimated to have about 126 kWh of grid electricity consumption per capita; significantly less than South Africa’s 3926 kWh and Ghana’s 361 kWh [9]. This is largely owed in part, to issues related to access, generation and transmission, which leaves the RE potential in Nigeria largely under-exploited and unutilised; while non-RE sources remain key export-activity focus.

The reduction of energy poverty in developing countries, especially in Africa, is now considered one of the salient imperatives at international level and a missing SDG. Its consequences have also been discussed in relation to energy injustice[22], as it has been determined that conventional energy technologies and implementation strategies will remain ineffective in this guise, while deployment approaches remain insufficient to eliminate energy poverty in Africa [22] . Access to reasonably-priced modern energy services, is representative of the goal to boost the socio-economic wellbeing of people, due to its impact on education, poverty, indoor pollution and the quality of life amongst others [17][23][16][25]. The need to ensure policy formulation and implementation strategies that are able to meet the projected demand for energy and sufficiently address the “energy trilemma” [26] [27][23]which encompasses the affordability, security and sustainability of energy supply[23] [28][29], is evident. Failure in this regard will exacerbate the problems inherent in the energy sector [26]. A strong relationship has also been identified between economic growth and energy access, to the effect that higher per capita income economies, have greater access [21][23]. This implies that an increase in income, increases the proportion of households that can readily access modern energy services[21].

When prices increase, people with meagre incomes are forced to cut back on energy consumption and usually become unable to cater for basic needs. They therefore have to ration or forego other essentials like food and healthcare. The urban poor are increasingly exposed and vulnerable to energy fluctuations in terms of price and therefore costly tariffs and connection fees discourage attempts to access grid-based electricity[23][17]. It is therefore absolutely crucial that rural and urban poor areas are able to access reliable energy sources at a reasonable price, as evidence also suggests that children raised in households with structured or stable power supply, advance their education significantly and in turn, enhance earning capacity in the future[23]. In addition, electrification will enable poor households effectively set up and manage a home business which improves revenue streams. Modern energy services are therefore expedient in the current global climate, as the air quality indoors is improved and thus the health and wellbeing of households, being secured ultimately reduces harmful practices and mortality rates. Limited income and access usually constrain poorer households to continue with the use of traditional fuel and other hazardous and inefficient sources and methods[23][19], which consequently worsens the current public health crisis.

Relevant research supports the fact that modern energy services provide significant benefits however, accessibility remains a challenge[25][19][24]. Based on the foregoing, reliable energy access is imperative for economic advancement. Implementing RE technology in power generation especially at rural levels, is a means to addressing the challenges with the availability, quality and service reliability of electricity in those areas. In cases where the power supplied by the grid is hampered or limited, or capacity is lacking and perhaps worsened during hours of maximum use, transmission and distribution loss estimates are in the region of 30%[23]; therefore the implementation of on-site power generation technologies using RE sources, are a plausible route to mitigating issues of power quality and reliability for developing countries[17].

8.8 Biomass Resources and Waste Valorisation

The focus of the United Nations Sustainable Development Goals (UNSDGs) and the 2030 timeline, is to ensure the sustainability of the global ecosystem, through innovation and inclusion. SDG 7- affordable and clean energy is in focus, as the enhancement of trade and industry including the socio-economic wellbeing of the population is largely dependent on energy provision, access and affordability. The entire purpose of the SDG is to achieve an effective, efficient and sustainable energy infrastructure across board[15][30].

Energy sources can be divided into three main categories: fossil fuels, nuclear resources, and renewable energy sources[31]. RE sources currently supply about 23.7% of the total world energy demand, up from 2% in 1998; and this includes 7 exajoules of modern biomass, and two exajoules of all other renewable sources[31]. The power sector has recorded the most gains in sustainable energy as global capacity exceeded 1560 GW[31]. The investment in RE sources has been on the rise, as a total of 40billion USD was invested by global investors in the field of renewable energies in 2004; this peaked at 279billion USD in 2011[31].

The rapid growth in energy demand pushes the case for innovative intervention and in this case through RE uptake; as currently, over 1.4 billion people globally have no electricity access, the majority being located in Africa[24]. Worldwide energy consumption is expected to rise up to 28% between 2015 and 2040, and Asia is projected to see a 51% increase in energy consumption, being the largest in the world[24]. In view of the above, smart renewable energy systems considering several energy scenarios, including gasified biomass, gas storage, electric vehicles, electro-fuel production, and heating systems[14] have been proposed.

Biomass provides the largest share of renewable energy in the world today, accounting for an estimated 10% share of all energy use, compared to less than 4% for other renewables. Most of this biomass is still used in developing countries in traditional, solid form in households and small-scale industries. Modern avenues for bioenergy include solid, liquid and/or gaseous fuels, and traverse various sectors including, combined heat and power, transport and industrial applications. Although there are grey areas in the definition of traditional vs. modern bioenergy, in general, modern bioenergy has higher efficiency and energy service levels, with lower environmental impact. Fuelwood is primarily used for traditional biomass applications, while charcoal and biogas can be classified as traditional or modern depending on the scenario. The rationale for bioenergy encompasses objectives associated with improved efficiency, technological innovation, economic development and climate mitigation[32][33][11].

Biogas is a reliable and sustainable form of energy and will help not only in producing an alternative source of energy, but in maintaining the environment and improving the health of the populace[23][21][16][27]. The reality for bioenergy (biofuel and biogas) production in Nigeria however, is that the resources are readily available but the necessary infrastructure and technical skills for large scale deployment are lacking[17]. The strategy to overcoming these challenges is a detailed analysis of the existing gaps and the development of a detailed strategy for exploitation. Though the emissions from bioenergy sources are less than the fossil fuel sources, it is much larger than the other RE resources; with estimated GHG emissions from dedicated biomass and waste to energy were 14e650 gCO2-eq/kWh and 97e1000 gCO2-eq/kWh respectively[24].

This thesis has primarily focused on biomass of which Municipal Solid Waste (MSW) is a component. It is also referred to as trash and urban solid waste and is mostly household or domestic waste[34]. MSW includes biodegradable waste, such as kitchen food waste and food packaging; clothing and toys; recyclable materials such as paper, plastics, and metals; appliances and furniture; and debris. It is usually diverted to landfills or incinerated to make electricity. The remnants that are not incinerated can be converted to syngas through gasification for co-firing in boilers with coal, to produce electricity[34].

The major challenge in waste management especially in developing countries, is that waste is still considered trash and not an asset and therefore recycling efforts are usually very minimal, limited and lacking in structure[5]. Waste-to-Wealth is an attempt to organise and enhance the practical value of wastes that are generated from different sources. This is not without its challenges, as the major issues that impede performance include- sorting, grading, shredding, drying, digesting, pulverising, palletising and gasification[5][35].

A significant proportion of waste of different types need to be salvaged, particularly at household level; but due to a lack of sorting at source, a large portion is lost to contamination by the time the wastes reach the dumps and are therefore difficult to retrieve by scavengers. Physical sorting and waste separation at source promote the utilisation of waste at the municipal level and reduces the volume required for transfer to landfill sites. Although this appears straightforward in principle, a lack of political will or enforced regulations has led to an unchanged status quo and it is this lack of enforcement of environmental regulations that emboldens non-compliance[36][5][37].

The reuse, recycling and recovery of end-of-life products has the potential to create significant socio-economic opportunities for Africa. Growing a secondary resources economy in Africa could inject at least an additional US$8 billion every year into the economy from secondary resources that are currently being thrown away as waste to dumpsites and landfills. To achieve this, secondary resources should be released into the economy, to grow and strengthen local manufacturing, create jobs, address unemployment and build local and regional economies. While there is currently limited understanding or agreement on the appropriate waste technology roadmap to achieve this vision, a combination of small- scale, low-cost, decentralised, community-driven initiatives and larger-scale, higher-cost, centralized public-private initiatives may be required to address current and expected future solid waste management challenges[35]. Solid waste management (SWM) has direct links to many global issues such as public health, climate change, ocean plastic, poverty, food security and sustainable production and consumption. And therefore, environmentally conscious SWM provides a viable pathway for Africa's achievement of the SDGs[35].

The current challenge is to find the balance between development, resource conservation and environmental and human-health protection. "Making progress in addressing waste management issues will contribute directly to 12 out of the 17 Sustainable Development Goals" and "the Sustainable Development Goals cannot be met unless waste management is addressed as a priority [35]". In addition, SDG 11 (Sustainable cities and communities) and SDG 12 (Responsible consumption and production) are particularly pertinent for SWM in Africa. It is therefore expedient to recognise that Africa will achieve the SDGs much more effectively, once waste management is understood as a powerful driver of sustainable development[35].

Waste valorisation is currently appealing to scientific and industrial interests in order to mitigate environmental damage, achieve sustainability and move towards a circular economy[10][38][39]. Moving to a circular development model, which works to reduce

waste before it is produced and treats it as a resource when produced- is crucial; therefore holistic and integrated sustainable waste management remains essential[10].
There have been considerable developments in waste-to-energy (WtE) technologies however, the opportunities to explore and proliferate efficient, cost-effective and eco-friendly systems remains[10].Some of the research and recent developments in WtE systems include improvement in energy recovery and efficiencies, biogas energy, thermal arc plasma gasification, optimisation of anaerobic digestion process, and microbial fuel cell (MFC)technology[10].

The reality for bioenergy (biofuel and biogas) production in Nigeria however, is that the resources are readily available but the necessary infrastructure and technical skills for large scale deployment are lacking[17]. The strategy to overcoming these challenges is a detailed analysis of the existing gaps and the development of a detailed strategy for exploitation. Though the emissions from bioenergy sources are less than the fossil fuel sources, it is much larger than the other RE resources; with estimated GHG emissions from dedicated biomass and waste to energy were 14e650 gCO2-eq/kWh and 97e1000 g CO2-eq/kWh respectively[24].

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Biomass remains one of the primary potential sources of generating alternative energy to mitigate fossil-fuel related environmental pollution[33][10]. It is therefore expedient for policy makers to focus on reducing the cost of logistics and court the investment and participation of private producers in developing more advanced waste treatment technologies and sustainable energy systems, that will provide enhanced economic opportunities, healthier and safer environments[11][33][40].

8.9 The Business of Waste: Bioenergy Opportunities

Developing countries have made significant progress since the 1990s, when controlled waste disposal rates were often 0%. It is expected that lower income cities in Africa and Asia will double their municipal solid waste generation within 15-20 years and since MSW per capita increases with income level, globalisation gains will result in industrial and hazardous waste generation shifting to developing countries[41][42].

The average waste generation rate is about 237 kg per capita per year in sub-Saharan Africa. The organic fraction consists of about 57% of the total waste generation in sub-Saharan Africa, compared to the global MSW composition which stands at about 47%[13]. The reason for this is owed to agriculture, with many farmers involved in food crops. Due to the poor facilities for food storage and low electricity generation for food preservation, more foods end up in landfills as waste. Plastic wastes and papers are responsible for about 13% and 9% of the total MSW composition in sub-Saharan Africa, respectively[13].

The implementation of bioenergy technologies can have varied implications for reducing carbon emissions, changing landscapes, or generating environmental and community impacts[40][43]. WtE supports the overall objective of sustainable urban livable cities, such as landfill diversion, resource efficiency, energy recovery, greenhouse gas avoidance and a high level of public service[38]. Most African mega-cities such as Lagos, Nigeria are witnessing increasing waste quantities, which is suitable feedstock for treatment and energy recovery. The gap in affluent vs less affluent areas in most cities determines the waste mix, facilitated through source separation and recovery, to attain a calorific value in the range of 8–11 MJ/kg, which is considered suitable for energy conversion. It is therefore possible in most fast-growing African mega-cities to establish WtE facilities that can contribute to much needed landfill diversion, electricity generation for the city and support waste treatment[16][38][19].

Waste incineration plants based on older designs and standards of the European Union caused unacceptable emissions, which have to a large extent pushed significant improvements in combustion and flue gas cleaning technology. This means that WtE facilities built according to current European Union standards have no local environmental consequence, other than traffic and visual impacts[38]. The adoption of WtE technology or practice provides a 95 per cent volume reduction of waste and the bottom ash (flue gas cleaning technology by product), which is the largest part of the solid residue, can in many instances be recycled or used for road construction[38].

WtE is capital intensive, typically requiring an initial investment in the range of US$800–1,100 per tonne of annual plant capacity (i.e. a 500,000 tonne per year plant would cost in the range of US$400–550 million, all-inclusive)[38]. Annual operation and maintenance(O&M) costs are also significant and highly dependent on the revenue from sale of energy. The critical issues and risks to consider include: “i) waste quality and quantity risk, ii) gate fee payment risk, iii) permitting and planning risks, iv) change of legislation and policy risks, v) cost of residue disposal risk, v) revenue from energy sale risk, vi) plant availability risk, vii) currency exchange risk, viii) technology risk including obsolete technology risk and viii) political risk”[38]. Successful planning and procurement of WtE facilities requires international and local experience to ensure that the business case is sound and robust, all business case risks are managed well and that excellent design choices are made. Successful O&M requires access to skilled and qualified staff, as well as access to supplies and spare parts of suitable quality.

Waste for the purposes of WtE technology, should also be well-defined and of reasonable quality, in terms of calorific value. This is important for the required functioning of the plant, available plant capacity, energy yield and overall business viability. Waste flow and quality need to be fully comprehensible and controllable[38]. The calorific value must be greater than or equal to 6 MJ/kg throughout all seasons and should preferably be higher than 7 MJ/kg. In Central and Northern Europe, the calorific value of the residual MSW is typically in the range of 9–12 MJ/kg, with residual refuse- derived fuel typically having a calorific value in the range of 11–15 MJ/kg[44][21]. These figures are important especially for developing economies, where the informal waste management sector is a critical component and must therefore be understood, due to its impact on the quality of residual waste arriving at the WtE facility.

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Waste generation is rapidly increasing in Africa beyond current structural and administrative capacities, and following the estimates by the United Nations Department of Economic and Social Affairs (UNDESA 2017a, 2017b)-that the African Continent will see a population explosion from approximately 1.2 billion inhabitants in 2015 to almost 2.0 billion by 2040, pro-active measures are glaringly imperative. The urban population is also projected to expand from an estimated 470 million in 2015 to over 1.0 billion in 2040. Based on these projections, a generated model for future urban MSW generation for Africa based on assumed per capita waste generation rates of 263 kg/capita/year in 2015 to 358 kg/capita/year in 2040, results in an annual waste generation for urban Africa of 124 million tonnes in 2015, growing to 368 million tonnes in 2040[38][35].

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8.10 Selected African Cases: Critical Considerations

Developing countries with a population of about 80 % of the world’s population, face complex challenges relating to environment, health, deforestation and energy. An increase in population density and continuous dependence on rationally high priced fossil fuel enhance these challenges which are major constraints to economic growth. Insufficient environmental regulations in these countries have also led to improper management of waste generated from agricultural, municipal and industrial activities.

Over 90 % of these waste streams are often disposed in unregulated dumps or openly burned and are sometimes treated by composting. The environmental impacts of these common methods of treating such waste include, damage to the ecosystem and natural resources critical to the health and wellbeing of people. There is a deficiency to electricity and clean energy supply in developing countries especially in the sub-Saharan Africa region, where more than 600 million people are without access to electricity[45].The African experience with WtE has only up until recent times been relatively limited and considerably negative, due to poor and mostly obsolete facilities, outdated technology or non-existent flue gas cleaning systems. WtE remains a viable and necessary alternative waste treatment technology where the status quo of collect-and-dump is increasingly unsustainable, due to shrinking landfill capacity, further transport distances and the rising cost of land[38].

Biogas technology was implemented in Africa through the African Biogas Partnership Program. A number of biogas digesters have been installed in Burundi, Botswana, Burkina

Faso, Cote d'Ivoire, Ethiopia, Ghana, Guinea, Lesotho, Namibia, Nigeria, Rwanda, Zimbabwe, South Africa and Uganda. Biogas potential in Nigeria is estimated at 6.8 million cubic meters per day from animal manure and 913,440 tons of methane from MSW, which is equivalent to 482 MW of electricity. An estimate of 171 TJ of energy could potentially be generated from biogas in Nigeria, by 2030 [45]. Despite the potential of biogas in African countries and the demonstration its viability, the technology is not being proliferated and implemented as expected, mostly due to cost constraints, technical and infrastructural challenges[45].

Developing countries have a long way to go in biogas production compared with their developed counterparts. The implementation of biogas in developing countries varies significantly among countries due to climate conditions, technologies, level of development, natural resources endowment and socio-economic status [9], [21], [22]. Small scale and domestic biogas plants for household use common in developing countries [18], with China having the highest number of household biogas plants in the world [19]. However, most developing countries are accelerating their pace to increase biogas production, by developing medium and large-scale biogas plants. Establishing sustainable technology-based systems, continues to remain a major challenge for biogas implementation in developing countries. In addition, the extent to which users understand the technical rudiments of the biogas systems, determines implementation success[45][46].

The electricity generation potential of hydrogen gas produced by steam reforming of biogas, was undertaken in six locations across south-west Nigeria. From the results, an estimated total of 0.411 million tons of H2 gas could be obtained from the selected locations. This amount of hydrogen gas could provide a total of 19.46 million kWh per year of electricity, in those specific areas[13]. An ecological efficiency of 94.33% is achievable and preferred in consideration of biogas steam reforming process. The use of fuel cells powered by the generated hydrogen gas, could avoid the use of 7.446 million litres of diesel fuel in all the selected cities resulting into the prevention of about 16.031 million kg of CO2 and 45.477 thousand kg of CO, due to the combustion of diesel fuel for electricity generation[13]. An earlier study conducted on the viability of MSW for electricity generation in Nigeria also revealed that anaerobic digestion (AD), is the best technology option for energy extraction from MSW in south-western Nigeria. The best fuel from an ecological point of view, is that which produces the minimal amount of pollutant when combusted[13].

In 2017, the Lagos State Government (Nigeria) issued a call for investors, for a new waste management programme tagged "Cleaner Lagos Initiative". The programme would enable the local government establish a 10-year concession plan based on a public-private partnership, encompassing improved waste collection services and waste treatment, recycling and energy generation from waste. The estimated cost was pegged at US$136.38 million[38]. The project was unfortunately set-back, due to some operational and administrative challenges.

For advanced waste treatment infrastructure such as WtE facilities to be an economically viable option, it is necessary not only to compare the cost of the WtE option with the cost of operating a non-compliant dump (where all costs have been sunk), but to also calculate the actual costs of the complete current waste management system, including the avoided costs of long-distance waste transfer and well-engineered distant landfills, complete with leachate collection, landfill gas collection and treatment systems. There is also a need for careful planning of plant capacity and ensuring that waste avoidance, resource recovery and energy recovery complement and support each other rather than competing[44][35].

A waste management system that prioritises waste avoidance, resource recovery and energy recovery is complex and requires fitting regulation in terms of permitting, planning and fiscal measures, as well as capacity planning and mechanisms that support a circular economy demand for high quality recovered materials. Establishing a sustainable technology continues to remain a major challenge to biogas implementation in developing countries compared to their developed counterparts[45].

The potential for MSW power generation in the Lagos metropolis of Nigeria, has been assessed and the results show probable added benefits of financial reward, efficient waste handling and more free land available for other productive uses[12][46]. Given Nigeria's geography, it is not economically viable to supply electricity to remote rural communities by extending the national grid. This would require enormous financial commitments to procure high voltage transmission lines and medium or low voltage distribution lines. Some studies have reiterated that off-grid systems are the most economic efficient route for delivering electricity to rural dwellers and these systems should be based on RE resources. It has also been proved that the productivity of rural businesses was impacted by electrification to the extent that, rural business owners were willing to pursue alternative electrification options irrespective of the associated costs[12].

Developing countries with a population of about 80 % of the world's population, face complex challenges relating to environment, health, deforestation and energy. An increase in population density and continuous dependence on rationally high priced fossil fuel enhance these challenges which are major constraints to economic growth. Insufficient environmental regulations in these countries have also led to improper management of waste generated from agricultural, municipal and industrial activities. Over 90 % of these waste streams are often disposed in unregulated dumps or openly burned and are sometimes treated by composting. The environmental impacts of these common methods of treating such waste include, damage to the ecosystem and natural resources critical to the health and wellbeing of people. There is a deficiency to electricity and clean energy supply in developing countries especially in the sub-Saharan Africa region, where more than 600 million people are without access to electricity[45].

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The Bio2Watt plant is a 4MW industrial-scale biogas project in Bronkhorstspruit, South Africa. It is a commercial anaerobic digester that treats organic waste and produces biogas that is converted to electricity on-site. The power produced by the plant is purchased by

BMW for its Rosslyn production facility in Pretoria, South Africa. Organic waste is fed from a receiving tank towards primary and secondary digesters. Bio2Watt estimates that as much as 120,000 tonnes of organic waste (cattle manure and mixed organic waste) per year is fed into the plant, to produce the biogas feedstock for a combined heat and power application. The plant is fed with 160 tonnes of manure per day, plus another 340 tonnes of waste from other sources. The plant has an installed electrical capacity of 4.6 MW and 3 MW of heat available for beneficiation. Its modular design means that it could be scaled up to around 8 MW. The project cost R150 million or R34,090/kW (US$2,456/kW) was financed through a debt and equity mix[38]. An arrangement between the Bronkhorstspruit biogas plant and the City of Tshwane, as well as Eskom, allows the plant to connect to the grid and facilitate the sale of electricity between Bio2Watt and BMW. BMW pays a slightly higher premium for the "greener" power and Bio2Watt pays a monthly fee to Eskom for use of the grid and a wheeling fee to the city. Through this agreement, 25-30 per cent of BMW Rosslyn plant's electricity requirements are generated from renewables[38][35].

The Reppie WtE facility is located within a vacant brown-field site currently used to dump, burn and dispose of waste in Addis Ababa, Ethiopia. It handles roughly 1,200 tonnes of waste per day and is in a 7-hectare area, within the 37 hectare dump site. This is to avoid the additional cost of transporting waste from the transfer station and also to mitigate the environmental impacts by averting waste sent to landfills or open dumpsites[38]. The cost of the waste combustion with energy recovery was estimated at US$120 million, including transmission line. It possesses capacity for waste throughput of 350,000 tonnes per annum and energy output of 50MW; which should process approximately 80 per cent of the city's waste and supply the city of Addis Ababa with 30 per cent of its household electricity needs[38][35].

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8.11 Decentralised Biopower: Charting a Viable Course

Electricity is conceivably the most multipurpose energy carrier in modern global economy, and therefore primarily linked to human and economic development as well as the environment[11].
Energy sector reform is critical to sustainable energy development, as dependence on fossil fuels has led to the release of over 1100 Gt CO2 into the atmosphere since the mid-19th century[11]. Currently, energy-related GHG emissions, mainly from fossil fuel combustion for heat supply, electricity generation and transport, account for around 70% of total emissions including carbon dioxide, methane and some traces of nitrous oxide. This multitude of aspects play a role in societal debate in comparing electricity generating and supply options, such as cost, greenhouse gas emissions, radiological and toxicological exposure, occupational health and safety, employment, domestic energy security and social impressions[11].

The power infrastructure in Nigeria remains vulnerable to disruptions because it has a centralised model [78]. Distributed generation model involves generating electric power close to customers or in locations that would enable connection to the distribution network [124]. Power generation plants in Nigeria are sited close to oil producing states (Rivers, Abia, Ondo, Edo, Akwa Ibom, Bayelsa, Imo and Delta), because of the presence of natural gas. The advantage of proximity to raw materials is often faced with the challenges of power transportation to other regions since the transmission and distribution infrastructures are not capable and reliable. The power sector structure after the reforms, and series of privatisations have resulted in a new generation, trans- mission and distribution model; and transaction dynamics as shown[2].

Centralised design and models have been criticized, as it lacks the fundamental principles of complexity in organic compounds that allows for malleability. Bulkeley, Powells explain that centralised power generation systems still rely on the old and obsolete equipment and layout; hence, they require regular maintenance and repair. Their layout means that they are challenged when it comes to expanding to meet the ever increasing demand warranted by urbanisation and population increase The designs and layout also mean that their efficiency, especial in terms of production and distribution of energy is compromised[19]. As such, it is shown that centralized systems can pose a risk to the liveability levels of cities, as entire cities can be rendered without electricity if one single component malfunctions. Hiremath, Shikha underscore that opting to transport these resources and raw materials to site would prove very expensive, and this would impact on the pricing of electricity, which in turn would affect those fed by the power plant.

The challenge of distribution losses still looms, causing economic drawbacks. Bhatti and Danilovic, for instance, explain how such challenges could be addressed by adopting decentralised power systems, using smart grids, and by system automating by integrating advanced forecasting systems and technologies. All these challenges could be reduced significantly if the decentralisation of power production is adopted].

In particular, allowing for energy diversification so that cities can capitalize on Renewable Energy sources contextualized and abundant in the area. By so doing, they would benefit from sufficient and even, in some cases, excess production. This would promote environmentally friendly practices and management structures, like P2P [With diversified production, the entire energy network would become stable as cases of breakdowns, insufficient production, power loss and insufficient production would be checked [Diversification also has the potential to increase innovation; hence, more resilient components that are cheaper and reliable are produced and utilized in the small-scale power plants[19]. the diversification dimension is the best suited in situation where land fragmentation is possible and practiced. This is so because Megacities provide these opportunities since available free spaces are not always sufficient for large scale project but could accommodate different types of small-scale power plants that are not capital intensive. diversification is deemed relevant since it would allow for a regular supply of energy, since, when one form of production is affected, the other one could be up and running as is emphasized by Zhang, Wu [19].

Distributed grids involve breaking the centralized grid down into smaller autonomous cells known as microgrids, which allows a community to operate its systems in an autonomous manner. These microgrids are then connected to other microgrids and to the main grid, to form distributed grids. The renewable energy sector, e.g. solar, is a case in point, decentralizing electricity generation from a central, large-scale power plant towards many rooftop mini-plants. The opportunity now is to extend distributed grids into other infrastructure sectors where existing services and technologies are proving inadequate for meeting the needs of consumers. In the MSW sector, shifting the thinking away from waste disposal to landfill, to waste reduction, reuse, recycling and recovery in line with the waste hierarchy, provides opportunities for the implementation of decentralized “waste” management models[38][4].

In addition, these centralised energy supply systems are losing appeal due to a number of frustrating factors which include but are not limited to the depletion of fossil fuels and their climate change impact, the insecurities affecting energy transportation infrastructure, and the desire of investors to minimise risks through the deployment of smaller-scale, modular generation and transmission systems[11]. An alternative for electrification of rural and remote areas, is the introduction of decentralised conversion technologies using locally available resources.

Decentralised electrification can provide a more reliable supply and generate income derived from the use of local resources. Decentralised electrification using local resources can reduce regional disparity in rural and remote areas in terms of supply reliability and cost, as well as promote income generation.
A careful social impact-assessment showed that decentralised energy systems opened a social as well as microeconomic dilemma and the acceptance and adoptability of distributed networks in developing countries is still debatable, when the social aspects are considered due to this social dilemma and human cooperation; owing to inherent culture, practices and behaviours.

Local conditions, social and political power relations and economic circumstances must be rigorously assessed, before a project is undertaken[11][26].

Biomass power, upon generation is expected to be connected both to the national grid and to mini-grids—through decentralised power stations connected to small isolated power line networks supplying several households, buildings or machinery—thus increasing energy access of the rural population[22].The focus and one of the most important and challenging aspects on decentralized electricity generation (DEG) from biomass is its design and operation and related biopower supply chain networks. Supply chain modelling and supply chain system optimisation are currently in focus[11].

Access to electricity is an important component of rural development. Better access to electricity has been correlated to the improvement of living conditions in several aspects, such as education and income generation. Electrification in rural areas of developing countries, and in particular in the case of remote areas, is difficult due to low population densities, highly dispersed location of populated centres, low energy consumption levels per capita and poor road infrastructure which constrains transportation. This makes conventional rural electrification programs based on extension of the electricity grid and decentralised schemes with foreign fuels expensive or even economically impossible. Rural electrification programmes often require interventionist government policies and support in the form of subsidies.

In rural areas where energy resources are widely available in the form of agricultural wastes, forest biomass and household waste, DEG using local resources is more suitable as an alternative for electrification. DEG avoids the necessity of extending transmission lines to dispersed populated centres, reduces the dependence on foreign fuels within these areas and promotes local development through the introduction of the production chain of biomass energy[11].

A more comprehensive review of model applications for designing rural energy systems is provided by Nakata et al. [11], where a decentralised energy system for rural electrificationin developing countries was designed using LP optimization model. In this guise, the authorsfocused on the regional disparity incorporated by disaggregating electricity demand intourban, rural and remote areas. It is pertinent to note that among these studies, a completeassessment of DEG encompassing from source renewable energy fuel, technology selection,optimal site selection, market assessment and distribution network for final product;electricity is not yet explored.

The authors equally suggest a complete DEG system for biopower with distribution network. The model is formulated as a mixed integer nonlinear programming (MINLP) optimization problem. The MINLP represents decisions regarding- the optimal number, locations, and sizes of various types of processing plants; and the amounts of biomass transported, electricity to be transmitted between the selected locations over a selected period, and minimises the objective function of overall generation cost[11].

The performance of the energy system is evaluated according to the net costs of the system. The design of the energy system provides the most suitable conversion technology (or combination of technologies), suitable locations to install conversion plant of selected technology to meet a certain quantity of electricity demand under a set of goals and constraints. Being widely available in target area, palm oil biomass is considered as renewable energy source. Energy conversion technologies included in the system are combustion, gasification and pyrolysis[47]. The demand-side of the energy system only considers the total amount of electricity demanded in the residential, industrial, and commercial sectors at specific demand locations. The possible routes for production of electricity from biomass through these selected technologies are illustrated in six major types of bio-power systems: direct-firing, co- firing, gasification, pyrolysis, anaerobic digestion/fermentation and small, modular systems. Most of the bio-power plants use direct-fired systems. Through gasification, solid biomass can be converted into a gaseous form, known as syngas. The syngas can run through "combined-cycle" gas turbine or other power conversion technology.

In addition, gas and liquid fuels can be produced from biomass through pyrolysis. In pyrolysis biomass is heated in the absence of oxygen, The biomass then turns into a liquid called pyrolysis oil, which burns like petroleum to generate electricity. Several bio-power technologies can be installed in small, modular systems which can generate electricity at a capacity of 5 MW or less. Fast pyrolysis systems were observed as having great potential to generate electricity at a profit in the long term, and at a lower cost than any other biomass-to-electricity system at small scale[11]. The downdraft gasifier design, being well developed and demonstrated, is the most feasible technology for biomass to energy conversion[11]. A few gasifiers have already been in operation for thirty years and a number of gasification processes are under industrial development at pilot and demonstration scale. Gasifiers are available from Foster Wheeler and Bioneer in Finland, Lurgi in Germany, Vølund in Denmark, TPS in Sweden, PRM Energy in the USA and Repotec in Austria[11].

Biomass integrated gasification combined cycles (BIGCC) based on pressurised biomass gasification, coupled with economical acceptable hot gas clean-up systems, are one of the most promising options with a high overall conversion efficiency up to 40-50%. The first BIGCC running on 100% biomass (straw) has been successfully operated in Sweden. BIGCC offers the opportunity for both performance and environmental advantages, providing a flexible alternative to conventional technologies. Bazmi et al submit that biomass-based power generating technologies are still not fully mature enough to provide high amounts of feedstock and satisfy the higher electricity demands. It is envisaged that DEG biopower systems will contribute a considerable portion to the RE mix.

More established systems present a lower risk to potential developers of biomass-to-electricity systems. Risk is often a very important factor is system selection and would tend to favour the combustion option being more developed, as seen with the Ethiopian Reppie waste-to-energy plant, which uses combustion cycles to treat 1,400 tonnes of municipal waste per day, while simultaneously generating 20 MW power to the grid. This in turn provides electricity to approximately 30% of the residents in the capital city of Addis Ababa, while conforming to global standards on air emissions. In future systems, fast pyrolysis which has only a slight advantage over the gasification and combustion options especially at small scales, due to decoupling options that are not available in combustion or gasification based-systems. De-coupled fast pyrolysis systems may be more cost-effective than the alternative technologies in particular circumstances. Thus in future systems the fast pyrolysis option can be expected to face stiff competition from alternative systems[11].

Distributed grids redistribute roles and responsibilities between the consumer and service providers, and so depend on partnerships between the public and the private sector. Concerns have been raised that small-scale, decentralized technologies may not be able to cope with the expected increase in waste generation in Africa. However, large-scale, centralized technologies in Africa are difficult to finance, operating and maintenance costs are often restrictive and facilities, where they do exist, are increasingly failing. A combination of scales provides the opportunity to distribute costs and activities across a range of players and scales, increasing the resilience of African cities in managing their waste. A decentralized model can however increase the risks associated with waste management, by dispersing the environmental impacts across multiple sources that are difficult and could become costly to monitor with enforcement officers. This will require appropriate legislation, monitoring and enforcement. Such models would be predicated on decentralising single grids into discrete, manageable, but interconnected microgrids, supported by new and emerging technologies and processes, smart grids, blue/green infrastructure, an understanding of the city as a complex ecosystem, and the building of strong public/private partnerships with differentiated roles and responsibilities[35].

However, apart from MW-level centralised generation, decentralised generation of RE has been shown to have several social, economic, and environmental benefits. Furthermore, with the advent of modern power control systems, a mini- grid can provide more benefits by avoiding transmission losses associated with central generation. The development of decentralized RE (small RE program) is also a part of the Government targeting economic development to ensure that small and medium enterprises owned by the minority are able to participate in the green economy. The DRE system can be operate via interactions with the local grid when extended to rural communities, whereby it feeds surplus power generated to it, or alternatively it can be a stand-alone isolated energy system[48].

Smart policy support for distributed generation can help achieve a cost-effective RE future [49]. To unlock DG's potential to facilitate demand-side and wholesale DG deployment in a way that maximizes benefits to consumers, the following policy options may be pursued: Net energy metering (NEM), which ‘‘runs the meter backwards’’ for utility customers who generate onsite power, has attracted significant retail customer investment in DG. 2. Shared renewables programs should be developed so that the three-quarters of retail customers who currently cannot participate in on-site renewable energy programs can invest in DG. 3. Wholesale procurement programs, which allow utilities to buy and run DG, be developed and expanded to provide for stable, cost-effective investment in wholesale DG, with an emphasis on siting DG in locations that can defer transmission and distribution (T&D) system infrastructure costs. 4. State-level interconnection standards and procedures and local permitting processes based on best practices should be developed and maintained to support cost-effective DG development. 5. States and utilities incorporate realistic assumptions regarding DG in their T&D planning processes, to ensure that the T&D benefits stemming from investment in DG are not lost to utilities and their customers, and to ensure that lower-cost DG opportunities are not ignored in planning the electric grid of the future. When developers, regulators, and policymakers have a full sense of the costs and constraints of each option, DG can serve as an effective complement to large-scale renewables and bulk transmission.

Energy sector reform is essential to achieving sustainable energy development objectives, as dependence on fossil fuels has led to the release of over 1100 Gt CO2 into the atmosphere since the mid-19th century[11]. Energy-related GHG emissions primarily from fossil fuel combustion for heat supply, transport and electricity generation, account for around 70% of total emissions including carbon dioxide, methane and some traces of nitrous oxide. This lays the foundation for the debate over electricity generation and supply options- with factors to consider including cost, GHG emissions, radiation and toxic exposure, employment, occupational health and safety, domestic energy security and social impressions[11].

An estimated 1.6 billion people, living in rural areas have no zero access to electricity[11]. Electrification rates in developing countries especially in the rural areas are considerably low and where supply is available, the service is unreliable and expensive, considering the income capacity of the people in those communities. Most developed countries rely on centralised electricity generation and distribution systems, where electricity is generated in large plants and then distributed to the end-users through a transmission network. The networks are expensive and require considerable time to fully develop. In addition, these centralised energy supply systems are losing popularity, to the depletion of fossil fuels and the environmental impact, the insecurities related to energy transport infrastructure and investors' drive to minimise risks through the deployment of smaller-scale, modular generation and transmission systems[11]. solution, using locally available resources for the electrification of rural and remote areas.

Bulkeley, Powells explain that centralised power generation systems rely on old and obsolete equipment and therefore require regular maintenance and repair. This hampers efficiency, in terms of production and energy distribution; and also diminishes the ability to meet escalating demand due to urbanisation and increasing population[19].

The challenge of distribution losses remains pervasive and its economic drawbacks evident. The adoption of decentralised power systems, for instance, through the use of smart grids and system automation which integrates advanced forecasting systems and technology; could effectively mitigate the challenges posed by older, obsolete power generation and distribution models. To further harness the potential gains of decentralised systems, energy diversification- where cities utilise RE sources abundant in a given area; would guarantee sufficient and even excess production in some cases.

It has been reported that the number of non-electrified people in the world decreased from 1.7 billion in 2000 to 1.1 billion in 2016[48]. This is attributable in part to renewable-based decentralised energy systems, which account for nearly 6% of electrical connection since 2000[48]. It has been shown that decentralised (or distributed) generation of RE, possesses social, economic, and environmental benefits and these systems can be synchronised to operate with local grids, for extension to rural communities; whereby surplus power generated is channelled to it, or alternatively it operates as a stand-alone isolated system[48]. The use of RE sources in this context would invariably promote environmentally friendly practices and management structures, like P2P and this would enhance the stability of the energy network as breakdowns, inadequate production and power loss would be sufficiently mitigated. There is also room for increased innovation under this model, and would therefore create significantly cheaper, reliable and more resilient components for use in small-scale power plants[19]. The decentralised model would also be sufficiently practical, where land fragmentation is possible and practiced, as most Mega-cities can adequately accommodate smaller scale projects, that are not capital intensive.

Distributed grids involve breaking the centralised grid down into smaller autonomous cells known as microgrids, which allows a community to operate its systems in an autonomous manner. These microgrids are subsequently connected to relevant microgrids and finally to the main grid- this forms distributed grids. The challenge now is to extend distributed grids, where existing services and technology are insufficient for consumers' requirements.

In view of the opportunities for biomass-to-electricity or biopower- using MSW, there is need to advance thinking beyond waste disposal to landfill- waste reduction- reuse, recycling and recovery in line with the defined waste management hierarchy. This provides opportunities for the implementation of decentralised "waste" management models[38][4] and decentralised electrification through this medium, reduces regional disparity in rural and remote areas, provides enhanced reliability of supply and income generation (especially for the informal waste management sector) from the use of local resources- as trash is a homogenous resource.

Biomass power or biopower will be connected both to the national grid and minigrid, through decentralised power stations connected to small isolated power line networks, which will supply several households, buildings or machinery; thereby increasing energy access for the rural population[22].In theory, the system is simple and plausible, however, a major challenge to consider in decentralised electricity generation from biomass especially MSW, is the design, operation and related biopower supply chain networks[11].

The performance of the energy system is evaluated according to the net costs of the system. The design of the energy system provides the most suitable conversion technology or combination thereof, suitable locations to install conversion plant of the selected technology- to meet a certain quantity of electricity demand, given a set of goals and constraints. Energy conversion technology included in the system are combustion, gasification and pyrolysis[47]. The demand-side of the energy system only considers the total amount of electricity demanded in the residential, industrial, and commercial sectors at specific demand locations. The possible routes for production of electricity from biomass through these options are captured in six major categories of bio-power systems: direct-firing, co- firing, gasification, pyrolysis, anaerobic digestion or fermentation and small, modular systems. Most biopower plants use direct-fired systems. Gasification processes allow for solid biomass to be converted into gaseous form, referred to as syngas. The syngas can run through "combined-cycle" gas turbines or other power conversion technology[47][11][38].

In addition, gas and liquid fuels can be produced from biomass through pyrolysis. This method allows for biomass to be heated in the absence of oxygen. It is transformed to a liquid called pyrolysis oil- which burns like petroleum, to generate electricity. Biopower technology is flexible enough to be installed in small, modular systems, with a capacity of 5 MW or less. Fast pyrolysis systems have been observed as having the potential to generate electricity at a profit in the long term, and at reduced cost than any other biomass-to-electricity system at small scale[11].

The downdraft gasifier design, being well developed and demonstrated, is considered the most feasible technology for biomass-to-energy conversion[11], with some already in operation for almost three decades and a number of gasification processes still undergoing industrial development, at pilot and demonstration scale. Gasifiers are identified as being available from Foster Wheeler and Bioneer in Finland, Lurgi in Germany, Vølund in Denmark, TPS in Sweden, PRM Energy in the USA and Repotec in Austria[11].
Biomass Integrated Gasification Combined Cycles (BIGCC) based on pressurised biomass gasification, coupled with economically acceptable hot gas clean-up systems, are among the more promising options, with a high overall conversion efficiency up to 40-50%[11]. The first BIGCC running on 100% biomass (straw) has been successfully operated in Sweden. BIGCC offers the opportunity for both performance and environmental advantages, providing a flexible alternative to conventional technology.

Distributed grids redistribute roles and responsibilities between the consumer and service providers, and so depend on partnerships between the public and the private sector. Concerns have been raised that small-scale, decentralised technologies may not be able to cope with the expected increase in waste generation in Africa. However, large-scale, centralised technology are usually difficult to finance, with operation and maintenance costs being restrictive and facilities, where they exist, increasingly deteriorating. A combination of scales provides the opportunity to distribute costs and activities across a range of participants and scales, thereby increasing the resilience of African cities in managing waste. A decentralised model can however increase the risks associated with waste management, by dispersing the environmental impacts across multiple sources that are difficult and costly to monitor. This will therefore require appropriate legislation, monitoring and enforcement[35].

When developers, regulators, and policymakers have a clear understanding of the costs and constraints of each option, decentralised systems can serve as an effective complement to large-scale renewables and bulk transmission.

Electricity access is an important component of rural development, which has been correlated with the improvement of living conditions and standards in relation to education and income generation. Electrification in rural areas of developing countries, and particularly remote areas, is challenging due to low population densities, highly dispersed location of populated centres, low energy consumption levels per capita and poor road infrastructure which constrains transportation. This makes conventional rural electrification programs based on extension of the electricity grid and decentralised schemes with foreign fuels expensive or even economically impossible. Rural electrification programmes often require interventionist government policies and support in the form of subsidies. In rural areas where energy resources are widely available in the form of agricultural wastes, forest biomass and household waste; decentralised systems using local resources are a better-suited alternative. This bypasses the need to extend transmission lines to dispersed populated centres, reduces the dependence on foreign fuels within these areas and promotes local development, through the introduction of the production chain triggered by biomass-induced electricity generation[11].

8.12 Conclusion

The review and assessment of literature in the domain of waste management and the subsequent analyses of Nigeria's COVID-19 experience, with a view to determining a way forward and the imperatives for the economy to achieve and sustain recovery- with energy generation, distribution and energy poverty reduction as the pivot underpinning the achievement of the outlined goals and policy measures. This paves the way for the adoption of a decentralised biopower generation strategy to act as a viable supplement and fulfill defined energy supply and access gaps.

This work has duly identified areas where attention should be focused on by both domestic governments and potential private sector participants and investors, in the wake of a new normal; owing to the new structures, behaviours and systems that have emerged and are expected to emerge following the rigors of the COVID-19 pandemic.

The takeaway from the assessment of Nigeria and its unique coronavirus experience, is the need to upscale government efforts in the area of infrastructure provision, to support the new normal. A critical success factor to this objective is boosting electricity generation, distribution and access. Energy and its availability in the required form and fashion, remains the pivot and foundation for the seamless functioning of businesses, infrastructure and digital systems in a developing country like Nigeria- where the costs of acquiring, running and maintaining generator sets is added cost of doing business and household maintenance. Without power, a digital future is positively unattainable, as electricity is the bedrock of most telecommunication servers and internet systems. Therefore stabilising energy generation, transmission, distribution and access is the pre-cursor to progress, in underscoring the points raised and the entire discussion set forth so far.

The singular impact of this resource on the economy and the wellbeing of each household cannot be ignored or over-emphasised.

Trash never disappears and remains an integral part of our ecosystem, therefore the ability to manage it responsibly and efficiently in an environmentally conscious manner, will expedite the achievement of the objectives outlined in SDG7, within set timelines. However, in the near-term, larger and more expensive centralised systems, managed on a public-private partnership basis may remain the norm; as the cost of financing infrastructure upgrades or overhauls remain prohibitive, especially for developing countries like Nigeria, with limited resources and capacity. It is expected that the analyses provided herein, based on experienced researchers' efforts and the authors' assessments and analyses, provides a stable foothold for domestic governments and potential investors venturing into Nigeria's and indeed sub-Saharan Africa's testy business environment.

The review and assessment of literature in the domain of waste management and the analyses of Nigeria's COVID-19 experience, has been carried out with a view to determining a pathway and the imperatives for achieving and sustaining economic recovery. This has also been done with the objective of considering energy generation, distribution and energy poverty reduction, as a pivot to the achievement of outlined goals and proposed policy measures. This thesis essentially provides a roadmap for the adoption of a decentralised biopower generation strategy, to act as a viable supplement and fulfill defined energy supply and access gaps and it is expected that the data, results and analyses, provided herein, based on experienced researchers’ efforts and the author’s proprietary research and assessments, provides a stable foothold for domestic governments and potential investors’ venture into the testy energy business waters of the focal region.

The core areas for both domestic governments and potential private sector participants and investors have been identified; bearing in mind new structures, behaviours and systems that have emerged and are expected to emerge in a post-COVID-19 world.

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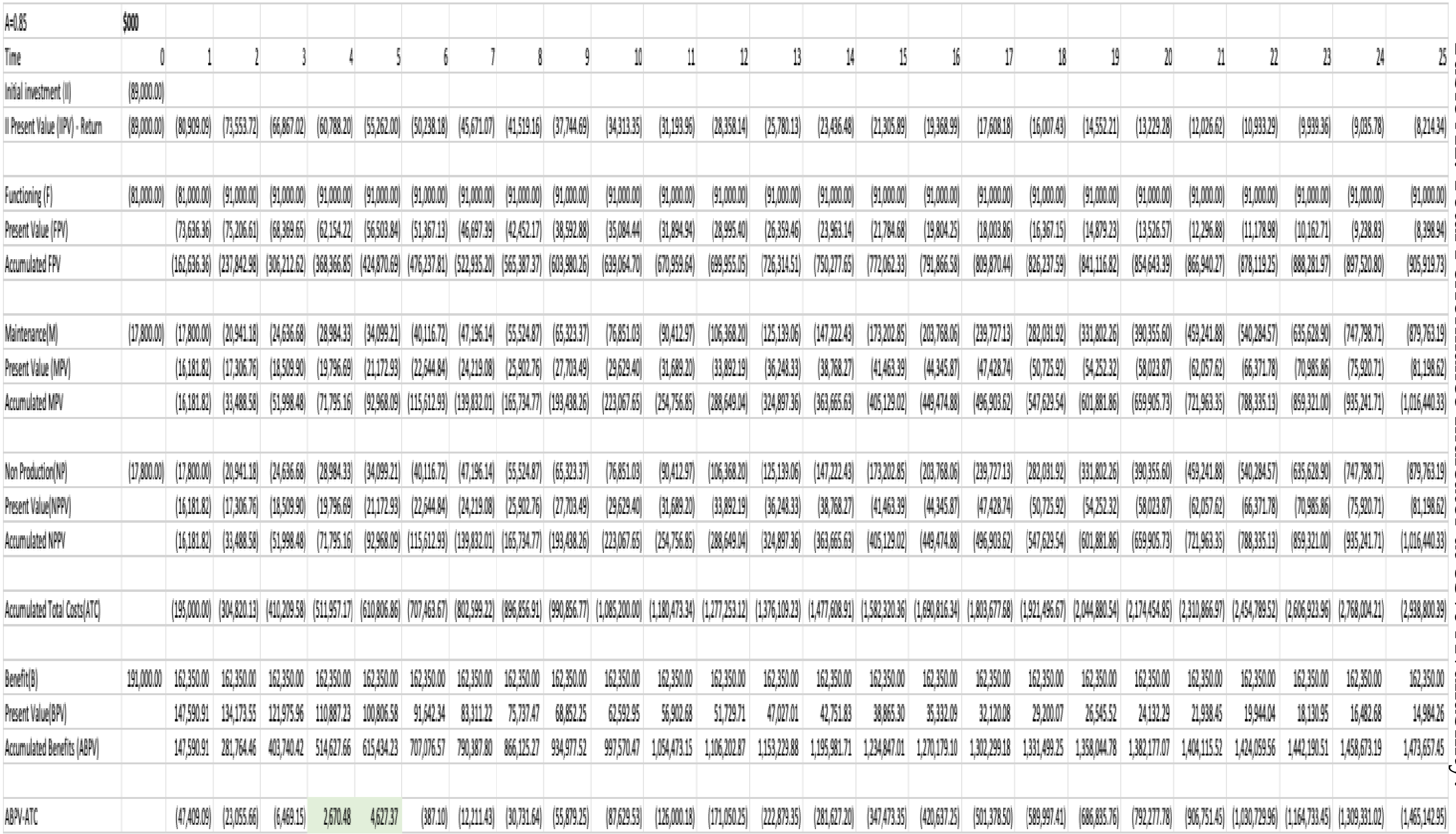
Appendix I

Table A1. Total Performance Indicator at 85% Availability.



A=0.85	$000																									
Time	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Initial investment (II)	(89,000.00)																									
II Present Value (IIPV) - Return	(89,000.00)	(80,909.09)	(73,553.72)	(66,867.02)	(60,788.20)	(55,262.00)	(50,238.18)	(45,671.07)	(41,519.16)	(37,744.69)	(34,313.35)	(31,193.96)	(28,358.14)	(25,780.13)	(23,436.48)	(21,305.89)	(19,368.99)	(17,608.18)	(16,007.43)	(14,552.21)	(13,229.28)	(12,026.62)	(10,933.29)	(9,939.36)	(9,035.78)	(8,214.34)
Functioning (F)	(81,000.00)	(81,000.00)	(91,000.00)	(91,000.00)	(91,000.00)	(91,000.00)	(91,000.00)	(91,000.00)	(91,000.00)	(91,000.00)	(91,000.00)	(91,000.00)	(91,000.00)	(91,000.00)	(91,000.00)	(91,000.00)	(91,000.00)	(91,000.00)	(91,000.00)	(91,000.00)	(91,000.00)	(91,000.00)	(91,000.00)	(91,000.00)	(91,000.00)	(91,000.00)
Present Value (FPV)		(73,636.36)	(75,206.61)	(68,369.65)	(62,154.22)	(56,503.84)	(51,367.13)	(46,697.39)	(42,452.17)	(38,592.88)	(35,084.44)	(31,894.94)	(28,995.40)	(26,359.46)	(23,963.14)	(21,784.68)	(19,804.25)	(18,003.86)	(16,367.15)	(14,879.23)	(13,526.57)	(12,296.88)	(11,178.98)	(10,162.71)	(9,238.83)	(8,398.94)
Accumulated FPV		(162,636.36)	(237,842.98)	(306,212.62)	(368,366.85)	(424,870.69)	(476,237.81)	(522,935.20)	(565,387.37)	(603,980.26)	(639,064.70)	(670,959.64)	(699,955.05)	(726,314.51)	(750,277.65)	(772,062.33)	(791,866.58)	(809,870.44)	(826,237.59)	(841,116.82)	(854,643.39)	(866,940.27)	(878,119.25)	(888,281.97)	(897,520.80)	(905,919.73)
Maintenance(M)	(17,800.00)	(17,800.00)	(20,941.18)	(24,636.68)	(28,984.33)	(34,099.21)	(40,116.72)	(47,196.14)	(55,524.87)	(65,323.37)	(76,851.03)	(90,412.97)	(106,368.20)	(125,139.06)	(147,222.43)	(173,202.85)	(203,768.06)	(239,727.13)	(282,031.92)	(331,802.26)	(390,355.60)	(459,241.88)	(540,284.57)	(635,628.90)	(747,798.71)	(879,763.19)
Present Value (MPV)		(16,181.82)	(17,306.76)	(18,509.90)	(19,796.69)	(21,172.93)	(22,644.84)	(24,219.08)	(25,902.76)	(27,703.49)	(29,629.40)	(31,689.20)	(33,892.19)	(36,248.33)	(38,768.27)	(41,463.39)	(44,345.87)	(47,428.74)	(50,725.92)	(54,252.32)	(58,023.87)	(62,057.62)	(66,371.78)	(70,985.86)	(75,920.71)	(81,198.62)
Accumulated MPV		(16,181.82)	(33,488.58)	(51,998.48)	(71,795.16)	(92,968.09)	(115,612.93)	(139,832.01)	(165,734.77)	(193,438.26)	(223,067.65)	(254,756.85)	(288,649.04)	(324,897.36)	(363,665.63)	(405,129.02)	(449,474.88)	(496,903.62)	(547,629.54)	(601,881.86)	(659,905.73)	(721,963.35)	(788,335.13)	(859,321.00)	(935,241.71)	(1,016,440.33)
Non Production(NP)	(17,800.00)	(17,800.00)	(20,941.18)	(24,636.68)	(28,984.33)	(34,099.21)	(40,116.72)	(47,196.14)	(55,524.87)	(65,323.37)	(76,851.03)	(90,412.97)	(106,368.20)	(125,139.06)	(147,222.43)	(173,202.85)	(203,768.06)	(239,727.13)	(282,031.92)	(331,802.26)	(390,355.60)	(459,241.88)	(540,284.57)	(635,628.90)	(747,798.71)	(879,763.19)
Present Value(NPPV)		(16,181.82)	(17,306.76)	(18,509.90)	(19,796.69)	(21,172.93)	(22,644.84)	(24,219.08)	(25,902.76)	(27,703.49)	(29,629.40)	(31,689.20)	(33,892.19)	(36,248.33)	(38,768.27)	(41,463.39)	(44,345.87)	(47,428.74)	(50,725.92)	(54,252.32)	(58,023.87)	(62,057.62)	(66,371.78)	(70,985.86)	(75,920.71)	(81,198.62)
Accumulated NPPV		(16,181.82)	(33,488.58)	(51,998.48)	(71,795.16)	(92,968.09)	(115,612.93)	(139,832.01)	(165,734.77)	(193,438.26)	(223,067.65)	(254,756.85)	(288,649.04)	(324,897.36)	(363,665.63)	(405,129.02)	(449,474.88)	(496,903.62)	(547,629.54)	(601,881.86)	(659,905.73)	(721,963.35)	(788,335.13)	(859,321.00)	(935,241.71)	(1,016,440.33)
Accumulated Total Costs(ATC)		(195,000.00)	(304,820.13)	(410,209.58)	(511,957.17)	(610,806.86)	(707,463.67)	(802,599.22)	(896,856.91)	(990,856.77)	(1,085,200.00)	(1,180,473.34)	(1,277,253.12)	(1,376,109.23)	(1,477,608.91)	(1,582,320.36)	(1,690,816.34)	(1,803,677.68)	(1,921,496.67)	(2,044,880.54)	(2,174,454.85)	(2,310,866.97)	(2,454,789.52)	(2,606,923.96)	(2,768,004.21)	(2,938,800.39)
Benefit(B)	191,000.00	162,350.00	162,350.00	162,350.00	162,350.00	162,350.00	162,350.00	162,350.00	162,350.00	162,350.00	162,350.00	162,350.00	162,350.00	162,350.00	162,350.00	162,350.00	162,350.00	162,350.00	162,350.00	162,350.00	162,350.00	162,350.00	162,350.00	162,350.00	162,350.00	162,350.00
Present Value(BPV)		147,590.91	134,173.55	121,975.96	110,887.23	100,806.58	91,642.34	83,311.22	75,737.47	68,852.25	62,592.95	56,902.68	51,729.71	47,027.01	42,751.83	38,865.30	35,332.09	32,120.08	29,200.07	26,545.52	24,132.29	21,938.45	19,944.04	18,130.95	16,482.68	14,984.26
Accumulated Benefits (ABPV)		147,590.91	281,764.46	403,740.42	514,627.66	615,434.23	707,076.57	790,387.80	866,125.27	934,977.52	997,570.47	1,054,473.15	1,106,202.87	1,153,229.88	1,195,981.71	1,234,847.01	1,270,179.10	1,302,299.18	1,331,499.25	1,358,044.78	1,382,177.07	1,404,115.52	1,424,059.56	1,442,190.51	1,458,673.19	1,473,657.45
ABPV-ATC		(47,409.09)	(23,055.66)	(6,469.15)	2,670.48	4,627.37	(387.10)	(12,211.43)	(30,731.64)	(55,879.25)	(87,629.53)	(126,000.18)	(171,050.25)	(222,879.35)	(281,627.20)	(347,473.35)	(420,637.25)	(501,378.50)	(589,997.41)	(686,835.76)	(792,277.78)	(906,751.45)	(1,030,729.96)	(1,164,733.45)	(1,309,331.02)	(1,465,142.95)

Table A2. Total Performance Indicator at 91% Availability

A=0.91	$000																									
Time	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Initial investment (II)	(89,000.00)																									
II Present Value (IIPV) - Return	(89,000.00)	(80,909.09)	(73,553.72)	(66,867.02)	(60,788.20)	(55,262.00)	(50,238.18)	(45,671.07)	(41,519.16)	(37,744.69)	(34,313.35)	(31,193.96)	(28,358.14)	(25,780.13)	(23,436.48)	(21,305.89)	(19,368.99)	(17,608.18)	(16,007.43)	(14,552.21)	(13,229.28)	(12,026.62)	(10,933.29)	(9,939.36)	(9,035.78)	(8,214.34)
Functioning (F)	(81,000.00)	(81,000.00)	(91,000.00)	(91,000.00)	(91,000.00)	(91,000.00)	(91,000.00)	(91,000.00)	(91,000.00)	(91,000.00)	(91,000.00)	(91,000.00)	(91,000.00)	(91,000.00)	(91,000.00)	(91,000.00)	(91,000.00)	(91,000.00)	(91,000.00)	(91,000.00)	(91,000.00)	(91,000.00)	(91,000.00)	(91,000.00)	(91,000.00)	(91,000.00)
Present Value (FPV)		(73,636.36)	(75,206.61)	(68,369.65)	(62,154.22)	(56,503.84)	(51,367.13)	(46,697.39)	(42,452.17)	(38,592.88)	(35,084.44)	(31,894.94)	(28,995.40)	(26,359.46)	(23,963.14)	(21,784.68)	(19,804.25)	(18,003.86)	(16,367.15)	(14,879.23)	(13,526.57)	(12,296.88)	(11,178.98)	(10,162.71)	(9,238.83)	(8,398.94)
Accumulated FPV		(162,636.36)	(237,842.98)	(306,212.62)	(368,366.85)	(424,870.69)	(476,237.81)	(522,935.20)	(565,387.37)	(603,980.26)	(639,064.70)	(670,959.64)	(699,955.05)	(726,314.51)	(750,277.65)	(772,062.33)	(791,866.58)	(809,870.44)	(826,237.59)	(841,116.82)	(854,643.39)	(866,940.27)	(878,119.25)	(888,281.97)	(897,520.80)	(905,919.73)
Maintenance(M)	(17,800.00)	(17,800.00)	(19,560.44)	(21,494.99)	(23,620.87)	(25,957.00)	(28,524.17)	(31,345.24)	(34,445.32)	(37,852.00)	(41,595.61)	(45,709.46)	(50,230.17)	(55,197.99)	(60,657.14)	(66,656.19)	(73,248.56)	(80,492.93)	(88,453.77)	(97,201.94)	(106,815.32)	(117,379.47)	(128,988.43)	(141,745.53)	(155,764.32)	(171,169.58)
Present Value (MPV)		(16,181.82)	(16,165.65)	(16,149.50)	(16,133.37)	(16,117.25)	(16,101.15)	(16,085.07)	(16,069.00)	(16,052.94)	(16,036.91)	(16,020.89)	(16,004.88)	(15,988.89)	(15,972.92)	(15,956.96)	(15,941.02)	(15,925.10)	(15,909.19)	(15,893.29)	(15,877.42)	(15,861.56)	(15,845.71)	(15,829.88)	(15,814.07)	(15,798.27)
Accumulated MPV		(16,181.82)	(32,347.47)	(48,496.97)	(64,630.34)	(80,747.60)	(96,848.75)	(112,933.81)	(129,002.81)	(145,055.75)	(161,092.66)	(177,113.55)	(193,118.43)	(209,107.32)	(225,080.24)	(241,037.21)	(256,978.23)	(272,903.32)	(288,812.51)	(304,705.81)	(320,583.22)	(336,444.78)	(352,290.49)	(368,120.37)	(383,934.43)	(399,732.70)
Non Production(NP)	(17,800.00)	(17,800.00)	(19,560.44)	(21,494.99)	(23,620.87)	(25,957.00)	(28,524.17)	(31,345.24)	(34,445.32)	(37,852.00)	(41,595.61)	(45,709.46)	(50,230.17)	(55,197.99)	(60,657.14)	(66,656.19)	(73,248.56)	(80,492.93)	(88,453.77)	(97,201.94)	(106,815.32)	(117,379.47)	(128,988.43)	(141,745.53)	(155,764.32)	(171,169.58)
Present Value(NPPV)		(16,181.82)	(16,165.65)	(16,149.50)	(16,133.37)	(16,117.25)	(16,101.15)	(16,085.07)	(16,069.00)	(16,052.94)	(16,036.91)	(16,020.89)	(16,004.88)	(15,988.89)	(15,972.92)	(15,956.96)	(15,941.02)	(15,925.10)	(15,909.19)	(15,893.29)	(15,877.42)	(15,861.56)	(15,845.71)	(15,829.88)	(15,814.07)	(15,798.27)
Accumulated NPPV		(16,181.82)	(32,347.47)	(48,496.97)	(64,630.34)	(80,747.60)	(96,848.75)	(112,933.81)	(129,002.81)	(145,055.75)	(161,092.66)	(177,113.55)	(193,118.43)	(209,107.32)	(225,080.24)	(241,037.21)	(256,978.23)	(272,903.32)	(288,812.51)	(304,705.81)	(320,583.22)	(336,444.78)	(352,290.49)	(368,120.37)	(383,934.43)	(399,732.70)
Accumulated Total Costs(ATC)		(195,000.00)	(302,537.92)	(403,206.57)	(497,627.53)	(586,365.88)	(669,935.31)	(748,802.83)	(823,393.00)	(894,091.77)	(961,250.02)	(1,025,186.74)	(1,086,191.91)	(1,144,529.15)	(1,200,438.13)	(1,254,136.74)	(1,305,823.03)	(1,355,677.09)	(1,403,862.61)	(1,450,528.43)	(1,495,809.83)	(1,539,829.83)	(1,582,700.23)	(1,624,522.70)	(1,665,389.66)	(1,705,385.13)
Benefit(B)	191,000.00	173,810.00	173,810.00	173,810.00	173,810.00	173,810.00	173,810.00	173,810.00	173,810.00	173,810.00	173,810.00	173,810.00	173,810.00	173,810.00	173,810.00	173,810.00	173,810.00	173,810.00	173,810.00	173,810.00	173,810.00	173,810.00	173,810.00	173,810.00	173,810.00	173,810.00
Present Value(BPV)		58,009.09	143,644.63	130,586.03	118,714.57	107,922.34	98,111.21	89,192.01	81,083.65	73,712.41	67,011.28	60,919.34	55,381.22	50,346.57	45,769.61	41,608.73	37,826.12	34,387.38	31,261.26	28,419.32	25,835.75	23,487.04	21,351.86	19,410.78	17,646.16	16,041.97
Accumulated Benefits (ABPV)		147,590.91	291,235.54	421,821.56	540,536.13	648,458.47	746,569.68	835,761.69	916,845.34	990,557.75	1,057,569.03	1,118,488.37	1,173,869.59	1,224,216.16	1,269,985.77	1,311,594.50	1,349,420.62	1,383,808.00	1,415,069.26	1,443,488.58	1,469,324.33	1,492,811.37	1,514,163.23	1,533,574.01	1,551,220.18	1,567,262.14
ABPV-ATC		(47,409.09)	(11,302.38)	18,614.99	42,908.60	62,092.59	76,634.37	86,958.86	93,452.34	96,465.98	96,319.01	93,301.63	87,677.69	79,687.01	69,547.63	57,457.76	43,597.59	28,130.91	11,206.64	(7,039.85)	(26,485.51)	(47,018.45)	(68,537.00)	(90,948.69)	(114,169.48)	(138,122.99)