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INTEGRATING ENERGY FROM WASTE IN RAPIDLY URBANISING AFRICAN CITIES: A CIRCULAR ECONOMY CASE FOR BIOGAS INITIATIVES

Submitted by

Gamuchirai Mutezo - 1973683

A thesis submitted to the School of Chemical and Metallurgical Engineering, Faculty Engineering and Built Environment, University of the Witwatersrand, Johannesburg, in fulfilment of the requirements for the degree of Doctor of Philosophy.

Johannesburg, 2021

Supervisor: Prof Jean Mulopo

Co-supervisor: Prof Emmanuele Cunningham-Sabot

DECLARATION

I declare that this thesis is my own unaided work. It is being submitted for the degree of Doctor of Philosophy at the School of Chemical and Metallurgical Engineering, Engineering and Built Environment, University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other University.

15th day of *October* 20 *21* at *University of the Witwatersrand, Johannesburg*



Gamuchirai Mutezo

October 2021

PUBLICATIONS

Mutezo G., Mulopo J., Chirambo D. (2020) Climate Change Adaptation: Opportunities for Increased Material Recycling Facilities in African Cities. In: Leal Filho W., Ogugu N., Adelake L., Ayal D., da Silva I. (eds) African Handbook of Climate Change Adaptation. Springer, Cham. https://doi.org/10.1007/978-3-030-42091-8_61-1

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ABSTRACT

African cities are rapidly urbanising, population growth is proliferating and so are waste generation and energy demand. Built environment practitioners play an imperative role in not only managing these proliferations within existing urban morphologies but ensuring a sustainable and efficient supply of services such as waste management and energy access. Considering demographic and waste generation proliferations as well as energy demand, this thesis sought to investigate whether anaerobic digestion technologies can be integrated into African cities for energy production. The work was underpinned by principles of a circular economy. The multi-disciplinary research covered three African metropolitan cities, namely Addis Ababa (Ethiopia), Accra (Ghana) and Johannesburg (South Africa). Mixed Methods Research methods were used, focusing on Concurrent Embedded Design. Quantitative approach comprised of secondary data on existing anaerobic digestion technologies while qualitative approach comprised of primary data collected through interviews with key-decision makers in metropolitan municipalities, using Purposive Sampling. Quantitative data was used to calculate whether anaerobic digestion is circular as a technology to determine its efficiency using urban waste, while qualitative data offered descriptive responses pertaining to factors that can encourage key decision-makers to nurture integration. Circular economic Values (CEV) were calculated for three cases and findings showed that value leaked along the energy generation process. Qualitative findings illustrated that lack of understanding and project synchronisation amongst urban planners, waste management and renewable energy decision-makers negatively impacted anaerobic digestion integration and waste value chain optimisation. Furthermore, urban planners' limited understanding of concepts such as Circular Economy, Anaerobic Digestion and Decentralised Energy play a role to intentionally plan energy access in cities. Findings were similar in each metro-municipality and differed based on unique elements of the city's current morphologies. The researcher's knowledge contribution is a conceptual Approach to Urban Energy Planning and an Urban Biogas Model which African metropolitan municipalities to use as guidance to identify value leakages. Study limitations include lack of recent or limited quantitative

data across the disciplines, use of Mixed Method's Concurrent Embedded Design in the engineering and built environment and overall focus on African urban areas. Urban Energy Planning and Circular Economic Values for anaerobic digestion are emergent disciplines that present opportunities for further research. In conclusion, a multidisciplinary approach to planning, designing and implementing Urban Biogas Systems in African cities is imperative. This study showed that it can improve access to decentralised energy and improve organic waste management in a circular manner.

DEDICATION

Education becomes more relevant once you know what you want to do with it –

Vusi Thembekwayo.

Therefore:

If you are working or you are running a business you have to set aside time and money to invest in your continued formal education and skills acquisition - Strive Masiyiwa.

This study is dedicated to Africa's urban planners, waste management and engineering practitioners as well as researchers and industry champions. May it inspire you to continue exploring collaborative approaches to addressing the continent's urban energy challenges. May it induce innovation as you conceptualise improved waste management and access to clean energy within our current city structures. Lastly, may it inspire you to document those experiences as we aim to churn many sustainability narratives!

A special dedication to my mother, Professor Ashley Mutezo, for being my Muse.

Ndinotenda Amai.

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ABBREVIATIONS

AACA	Addis Ababa City Administration
AD	Anaerobic Digestion
AfDB	African Development Bank
AHP	Analytical hierarchy Process
AMA	Accra Metropolitan Area
APL	Assessment of Circular Economy Strategies at the Product Level
Br	Ethiopian Birr
C	Carbon
C:N	Carbon Nitrogen Ratio
CAQDAS	Computer-Assisted Qualitative Data Analysis Software
CBR	Case-Based Rating
CE	Circular Economy
CES	Circular Economy System
CEV	Circular Economic Value
CH_4	Methane
CHP	Combined Heat and Power
CHP	Combined heat power
CO	Carbon Monoxide
CO_2	Carbon Dioxide
COD	Chemical organic demand
CoJ	City of Johannesburg
CSTR	Continuously stirred tank reactor
CV	Calorific Value
DESAR	Decentralized Sanitation and Reuse
DM	Dry matter

DoE	Department of Energy
EEP	Ethiopian Electric Power
EU	European Union
FW	Food waste
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GW	Green waste
H_2	Hydrogen
H_2S	Hydrogen Sulphide
HHV	Higher Heating Value
HRT	Hydraulic retention times
IDC	Industrial Development Corporation
IEA	International Energy Agency
IPP	Independent Power Producer
ISWM	Integrated Solid Waste Management
kg	kilogram
kg/d	kilograms per day
LCA	Life cycle assessment
LCOE	Levelized Cost of Electricity
LHV	Lower Heating Value
MCDA	Multi-Criteria Decision-Making Analysis
MCI	Material Circularity Indicator
MECI	Material and Energy Circularity Indicators
MFA	Material Flow Analysis
MJ	Megajoule
MMR	Mixed Methods Research
MSW	Municipal Solid Waste

N_2	Nitrogen
NGO	Non-Governmental Organisation
NIUPLAN	Nairobi Integrated Urban Development Master Plan
NPV	Net Present Value
O_2	Oxygen
OECD	Organisation for Economic Co-operation and Development
OLR	Organic Loading Rate
P	Phosphorus
pH	Potential of Hydrogen
PPA	Power Purchase Agreement
PPP	Private Public Partnership
PR-MCDT	Product Recovery Multi-Criteria Decision Tool
R.O	Research Objective
REIPPPP	Renewable Energy Independent Power Producer Procurement Programme
S	Sulphur
SDG	Sustainable Development Goals
SICED	Systems Indicators for Circular Economy Dashboard
SMART	Simple Multi-Attribute Rating Technique
SSA	Sub-Saharan Africa
SWM	Solid Waste Management
t	tonne
tpa	tonnes per annum
tpd	tonnes per day
TS	Total solid
TSS	Total suspended solid
UASB	Up-flow anaerobic sludge blanket

UN	United Nations
UNEP	United Nations Environment Programme
US$	United States Dollar
USA	United States of America
VS	Volatile solid
WtE	Waste-to-Energy
WWTP	Wastewater treatment plant
WWTP	Wastewater Treatment Plant
ZAR	South African Rand

1.INTRODUCTION

"We must continue research into new forms of energy and into more efficient use of existing energy sources" - Mac Thornberry

1.1 Setting the Scene

1.1.1 Rationale for Research Topic

Saunders, Lewis and Thornhill (2009) defined the research process as a multi-stage process carried out in order to complete a project. The number of stages vary but typically include question conceptualisation and clarification, literature review and synthesis, methodology design and data collection, as well as overall write up. It is an ongoing journey whereby researchers find themselves interacting between stages as the research matures (Saunders, Lewis and Thornhill, 2009)[1]. The researcher underwent this process to investigate how biogas can be integrated into Africa's urban areas using a circular economy. Firstly, the study was inspired by personal and first-hand challenges experienced when attempting to integrate anaerobic digestion technologies into urban areas, while capitalising on urban waste material for feedstock supply. Secondly, after extensively reviewing various literature, the themes presented attributes of a relevant and current research topic in terms of capability and appropriateness:

- It is a captivating topic that addresses existing and future phenomenon about access to clean decentralised energy, waste proliferation within urbanising African cities and urban material flows. These phenomena have received great attention from civil society, governments and regional bodies since the early 2000s, namely the United Nations' 17 Sustainable Development Goals. This study complimented goals 7, 11 and 12.
- The topic is not finite. It aims to encourage knowledge sharing, multidisciplinary collaborations amongst practitioners and induce further academic and industry research. Africa's energy demand, proliferating

[1] This study adopted

population and waste beneficiation are expected to remain relevant as far as 2030.

1.1.2 Background

African cities are rapidly urbanising. It is estimated that more than 75,0% of the global population will reside in urban areas by 2050 (United Nations, 2018). Cities will become denser and succumb to various socio-economic and environmental challenges. The continent's population growth rate was forecasted to increase from 11,3% in 2010 to 20,0% by 2050 (United Nations, 2018). It was also forecasted that urban waste generation and urban energy demand would increase and likely strain cities, which are not in a suitable physical state to handle these demands. Globally, cities present 70,0% of the total carbon dioxide (CO_2) emissions (Bautista Angeli *et al.*, 2018). Major contributors include fossil fuels for energy generation and transportation, poor waste management and disposal and limited urban lungs that can take in carbon monoxide (CO). In the context of waste generation, it is driven by factors such as a population growth with a growing middle class, rapid urbanisation, changing consumption and production patterns, global waste trading and trafficking (UNEP, 2018). With regards to the rising energy demand, the international energy agenda favours more renewable energy adoption and environmentally benign initiatives. Emphasis was placed by regional bodies such as the United Nations (UN), which developed a set of 17 Sustainable Development Goals (SDG) in 2015 as a blueprint for such actions.

The International Energy Agency (IEA) identified solar, wind, geothermal and WtE as some resources that can propel renewable energy even further. WtE is a process that converts waste material into a form of energy using biological or thermal processes (Kumar and Samadder, 2017; Mukherjee *et al.*, 2020). Different technologies convert different waste feedstock, based on varying waste quantities, composition and desired energy use. These include but not limited to anaerobic digestion (AD) and gasification for organic waste processing and pyrolysis for plastic waste processing and incineration for general waste. Anaerobic Digestion technology is identified as a key contributor to energy agenda. The digestion process converts organic matter in an oxygen-free environment and produces different energy forms such as biogas, heat or

electricity (IRENA, 2016; Roopnarain and Adeleke, 2017). The organic feedstock includes farm animal manure, offal from abattoirs, fruit and vegetable residue, energy crops such as grass silage, and food waste. Biogas composition depends on the quality and quantity of feedstock but typically comprises of ~60% methane (CH_4) and ~40% carbon dioxide (CO_2), with some minor constituents such as water and hydrogen sulphide (H_2S). Biogas is commonly used directly for cooking, lighting and heating in residential sector or for electricity generation through a combined heat and power (CHP) process, with the electricity being used on-site or injected into the grid (Satchatippavarn *et al.*, 2016; Pla-Julián and Guevara, 2019). Anaerobic digestion has capacity to recover nutrients by beneficiating organic waste to produce biogas and organic fertiliser.

Africa generated an estimated 125 million tonnes of waste in 2012, and generation is projected to increase to 244 million tonnes by 2025 (UNEP, 2018). Considering forecasted population and urbanisation growth rates, it will not be feasible for cities to rely on (1) large scale energy infrastructure to ensure access to affordable clean energy and (2) continued disposal of organic waste through landfilling and incineration. Although West, North and East Africa are increasing energy generation from renewable sources such as solar, wind and hydropower, more than 55,0% of the continent remains unelectrified. South Africa, Nigeria and Egypt are the few odd exceptions who's energy generations still heavily relies on coal, oil and gas, while a greater part of the continent relies on biomass for decentralised energy (International Energy Agency, 2019). Within the energy mix, considering AD technology to address urban energy demand and waste management in a circular manner presents a wealth of new possibilities. Furthermore, it contributes towards a cleaner and healthier environment while technologies such as incineration do the opposite.

1.2 Problem Statement

Over the past decade, there has been an increasing body of literature pertaining to circular economies. The concept evolved from environmental theories and phenomenon such as material flow analyses, sustainable development, waste management, climate change and life cycle assessments (Geissdoerfer *et al.*, 2017; Suárez-Eiroa *et al.*, 2019). A circular economy does not have a fixed definition but is recognised as a new economic paradigm focusing on environmentalism. This paradigm aims to keep materials in use for longer, intentionally designing-out waste (Ellen MacArthur Foundation, 2017). Considering the projected demographic proliferations and resource demands within cities, circularity is becoming more popular as an option to induce environmental benignity while ensuring socio-economic benefits. A sub-field with limited research yet great opportunity is circular economy in the context of waste-to-energy (WtE), namely anaerobic digestion.

Hussain, Mishra and Vanacore (2020)'s study on 'waste-to-energy and circular economy: the case of anaerobic digestion' is the closest reference to this research topic. The authors found that there is value leakage in anaerobic digestion plants. Small businesses in the United Kingdom can play an important role by using technological innovations to capture the value in a circular manner. Chen and Kim (2019) extensively reviewed 'circular economy and energy transition: A nexus focusing on the non-energy use of fuels'. They found that there is a gap in the energy transition framework which impedes detailed investigations for non-energy uses. Using the circular economy, energy transition frameworks can then incorporate non-energy uses – products that are used as raw materials for industrial production. Lastly, Acosta (2019)'s doctoral thesis investigated 'anaerobic digestion of cocoa waste within a circular economy context' in Ecuador. The author found that co-digesting cocoa waste with agricultural residue yielded a high energy recovery and high quality digestate. The best-case scenario entailed anaerobic digestion as the primary technology, then complemented by slow pyrolysis.

Furthermore, a few European cities across Germany, the Netherlands, France, Sweden and England have implemented AD technologies on an urban scale, elongating the duration which organic feedstock is kept in the loop, yielding socio-economic benefits. The integration led to the growth and development of concepts known as Eco-Districts or Eco-Neighbourhoods, which were designed to respond to cities' changing urban morphology, environment and sustainability (Bautista Angeli *et al.*, 2018). In these instances, anaerobic digestion created an opportunity for urban areas to provide decentralised energy or mini-grid solutions to a conglomeration of households. Circular economy principles of reducing, re-using and recycling were included in preliminary designs to ensure 'no waste goes to waste'.

From these studies, it is evident that research focusing on circular economy and WtE is still emergent. Despite the potential to integrate AD into cities' urban fabric, there is a lack of knowledge about the process and actual implementation, particularly within the African context and very few small-scale examples in Europe. The problem statement is summarised as follows: circular economy is a growing economic paradigm that offers socio-economic and environmental benefits. It aims to keep resources in use for longer and capitalise on waste material as feedstock for other activities. Considering rising urban waste material and projected energy demands, there is a need to explore anaerobic digestion for energy recovery using principles of a circular economy specifically in African cities.

1.3 Research Proposition and Objectives

The study is a multidisciplinary in nature and employed both qualitative and quantitative approaches. A research proposition and research objectives are provided below.

Research Proposition:

Anaerobic digestion is a viable circular economy model that may help towards achieving the energy demand in African cities. It is amongst the cheapest WtE methods of energy generation and is socio-environmentally benign.

General Objective:

Using principles of circularity, this study investigates how anaerobic digestion can help improve energy access and integration in African cities by capitalising on urban waste material.

Sub-Objectives:

1. Determine if anaerobic digestion technologies can promote circularity in energy production.
2. Understand who the decision-makers are and investigate factors to assist in their decision-making.
3. Develop an Urban Biogas Model for African metro-municipalities.

1.4 Delineations and Limitations

For novel. contribution to knowledge, Table 1.1 shows the delineations and limitations to the study.

Table 1.1: Summary of Delineations and Limitations

Delineations	Urban	The study focused on metropolitan municipalities because they have higher populations, denser settlements and demand the most service delivery. This includes economic and industrial activities, as well as human settlements with low, middle and high income.
	Decentralisation	Energy that can be generated and accessed on a residential, commercial or institutional level, and is partially or fully independent of grid connectivity.

	Energy	Energy in this study refers to specifically renewable energy sources and in the context of anaerobic digestion, energy output refers to biogas, heat, electricity and/or digestate.
	Urban Waste	The researcher refers to various waste streams generated in urban areas, but focus is on organic waste because of its large presence in Africa's waste composition.
Limitations	Demographics and Study Areas	The study focused on metropolitan cities in Africa which are experiencing rapid urbanisation, population growth, waste generation and a demand for more affordable, accessible and clean energy. Three local metropolitan authorities were selected (City of Johannesburg Metropolitan Municipality, Accra Metropolitan Assembly and Addis Ababa City Government); each contextually different from the other and representing a geographical region. Findings are used for comparison and are not representative of other countries in the region.
	Target Participants	Primary target Participants were decision-makers in local metropolitan authorities, namely in Urban Planning, Electricity and Waste Management Departments. Secondary target Participants were industry associations either key-decision makers or managerial position.
	Selected Technology	The study discusses waste-to-energy technologies, and anaerobic digestion was selected as the technology of choice. It is proven technology suitable for organic waste feedstock, scalable and has extensive technical literature.

1.5 Summary of Research Methodology and Design

Table 1.2 summarises the research methodology and design. An Interpretivism Paradigm was chosen because the multidisciplinary topic shows a complicated and multi-facet reality which presents many perspectives and interpretations.

Table 1.2: Summary of Methodology and Designs

PART A	**Methodology**	
Paradigm	Interpretivism	
Belief	Epistemological	
Reasoning	Inductive	
Nature of Design	Exploratory	
Type of Design	Mixed Methods	
Approach	Concurrent Embedded	
PART B	**Quantitative Methods**	**Qualitative Methods**
Sampling Technique	List of operational AD plants in Africa	Purposive and Snowball Sampling
Data Source	Secondary Sources	Primary Sources
Data Collection Tools	Databases of Existing AD plants	Interviews
Data Analysis	Circular Economic Value	Atlas.ti CAQDAS*
Integration Point	Chapter 4: Results, Discussion and Interpretation	
Ethical Consideration	Ethical Certification Approved	

*CAQDAS: Computer-assisted Qualitative Data Analysis software

The researcher sought to investigate how anaerobic digestion can help improve integration and energy access in African cities by capitalising on urban waste material and underpinning this to principles of circularity. This investigation encompassed technical and non-technical facets which can be interpreted differently from different perspectives. Given that the topic is under-researched, the researcher was able to provide evolving evidence and observe patterns while developing a new theory. Hence, Inductive Reasoning was used.

Mixed Methods were seen as a suitable design for an interpretivism paradigm and inductive reasoning. Quantitative methods determined whether anaerobic digestion technologies promote circularity in energy production. Circular Economic Valuations (CEV) and Exergy calculations were used to understand value leakage for selected anaerobic digestion plants operating across the continent. Qualitative methods investigated factors that can assist decision-makers in their decision-making. Interviews with decision-makers in metropolitan municipalities, industry associations and regional agencies were conducted. Qualitative findings were embedded into quantitative findings and concurrently discussed and interpreted.

1.6 Dissertation Outline

Chapter one provided a background to the research topic, followed by the problem statement, hypothesis and research objectives, delineations, and limitations as well as a summary of the research methodology and methods. The rest of the study is presented as follows:

Chapter 2: Comprises of the literature review, which is divided into four parts. Part One introduces circular economy. The concept is defined, principles of circularity are discussed together with business models required to apply a circular economy in different industries. Tools and approaches to measuring circularity are reviewed and the sub-section is summarised with a literature gap discussion. The focus is on metropolitan areas thus it is important to understand cities and urban space. Part Two presents the urbanisation and demographic trends across African cities, in the context of energy and urban waste. The chapter delves further into the morphology of these cities and how it affects urban metabolism, namely the flow of materials and energy. This is important to review because cities produce urban waste which is feedstock for anaerobic digestion and other WtE technologies. The last sub-section also summarised identified literature gaps. Part Three reviewed waste and energy resource

potentials. This included reviewing current and future waste trends and WtE in the context of international and continental energy agendas. Part Four focused on circular economies and anaerobic digestion. Existing literature and examples where anaerobic digestion plants are integrated into urban areas were discussed, inducing circularity of urban material and urban energy. Literature on measuring circularity in Part One extends to Part Three specifically in the context of anaerobic digestion. A sub-section summarised the relevant literature gaps.

Chapter 3: A detailed research methodology and designs are presented. The chapter begins with a Conceptual Framework, synthesising literature gaps identified by the researcher and linking these to the hypothesis and objectives. A discussion of the research philosophy and strategies follows suite. Subsequently, data sources and collection methods are also discussed, and the chapter is concluded with reliability and validity measures as well as ethical considerations.

Chapter 4: Presents results as well as discusses and interprets the findings. It begins by explaining how quantitative and qualitative data were embedded (Concurrent Embedded Design). It is followed by a Profile of Participants, looking at their designation, industry experience and education. These findings set the scene for the chapter. The rest of the findings were categorised and analysed according to the three research objectives. The chapter continues to embed findings throughout discussions and interpretations. A brief summary of findings were shared as a recap for readers. Discussions were also categorised according to the research objectives, which overlapped due to the Interpretivism nature of the study. It ended with the researcher's contribution to knowledge: interpretation of findings and implications thereof.

Chapter 5: Concludes the study by reflecting on the hypothesis and objectives, then presents the proposed Urban Energy Model that can be used to guide decentralised energy access in urban areas. Recommendations and further research areas are also given.

2.LITERATURE REVIEW

Wisdom does not come overnight ~ Somali Proverb

2.1 Introduction

The literature review chapter is sub-divided into three parts. Part One defines the circular economy – its definition, principles of circularity, areas of application and business models. It provides a fundamental understanding upon which aspects such as urban planning, waste management and energy recovery from waste are reviewed. Part Two explores African cities' urban morphology and metabolism; particularly the impact this has on service delivery. It also includes a review of waste material and energy flows within cities and explores whether cities can encourage a circular economy. Part Three reviews whether circular economy principles have been applied to renewable energy, specifically anaerobic digestion. The sub-section includes a brief description of how anaerobic digestion technology operates. Tools such as Circular Economic Value (CEV), the concept of Exergy and Material Circularity Indicator (MCI) are also reviewed as options to measure material and energy flow. Examples where circular economy principles are used for anaerobic digestion are presented. A chapter summary and identified research gaps then conclude the literature review.

2.2 Part One: Introducing the Circular Economy

A linear economy is one that adopts a take-make-use-dispose model. Along the linear process, large amounts of resources are wasted as well as energy losses experienced (Korhonen, Honkasalo and Seppälä, 2018; Merli, Preziosi and Acampora, 2018).

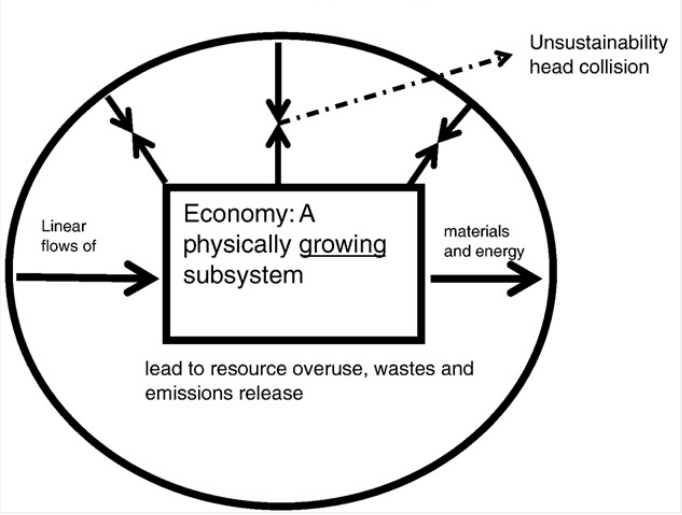


Figure 2.1: A Shrinking Parent System

(Korhonen, Honkasalo and Seppälä, 2018)

The world is shrinking as populations proliferate. Linear flows of materials and energy are contributing towards unsustainable development while trying to meet population demands. Resources are extracted from the natural environment, processed and consumed for human needs, and the harmful waste produced is dumped back into nature – Figure 2.1. Most material end up in landfills or open dumps, resulting in losses of valuable material and energy. Demand for finite resources is increasing exponentially while inducing resource scarcity and depletion (Geissdoerfer *et al.*, 2017). Economic outcomes of a linear system are not sustainable. Many industries are dependent on various natural resources, prices of raw material are significantly high, achieving a positive economic growth becomes difficult, and a growing middle class is expected to catalyse natural resource demand. Similarly, ecological outcomes result in increased pressure on the environment due to depleting natural resources, energy intensive extraction and production processes and large quantities of greenhouse gases (Tisserant *et al.*, 2017; Bocken *et al.*, 2019).

2.2.1 Defining Circular Economy

There are many definitions and understandings of the term circular economy (CE). Much research on the topic has emerged in the past decade, where definitions of a circular economy were probed in different angles. Scholars such as Merli, Preziosi and Acampora (2018) view circular economy as an emerging concept that still needs to develop. The authors systematically reviewed 565 articles and found it was mostly explored with the aim of reducing environmental impacts, waste optimisation and efficiency of processes. Further review indicated that the premise for circularity was linked to many Schools of Thought. These include but not limited to Sustainable Development, Industrial Ecology, Environmental Economics, Biomimicry, Green economies and Regenerative Designs (Nizami *et al.*, 2017; Korhonen, Honkasalo and Seppälä, 2018; Petit-Boix and Leipold, 2018)

The concept was first coined by Stahel (1982) as a self-replenishing system that reduces material and energy input and negative environmental effects. It was popularised by David Pearce in 1990 but the biggest literature boom took place as of the early 2000s. Veleva and Bodkin (2018) define it as a new economic paradigm that requires innovation and new business models; a new system of production. Korhonen et al., (2018) have the most referenced definition for a circular economy. They define it as an approach that "*emphasises product, component and material re-use, re-manufacturing, refurbishment, repair, cascading and upgrading as well as solar, wind biomass and waste-derived energy utilisation throughout the product value chain and cradle-to-cradle life cycle*" (pg 37) which Manavalan and Jayakrishna (2019) resonate with. The term is viewed as an accelerator to achieve the Sustainable Development Goals (Stahel, 1982; Geissdoerfer *et al.*, 2018; Rana *et al.*, 2020).

A circular economy not only promotes economic growth but transitions production from a linear 'extract-produce-use-dump' approach to a cyclical flow that promotes sustainability (Principato *et al.*, 2019). Transformation from the current linear economy to circular economy offers a medley of opportunities to advance natural resources. Numerous economic activities are attainable through re-using, recycling and reducing,

as well as energy and nutrient recovery instead of landfilling (Schroeder *et al.*, 2018). Additional benefits are summarised in Figure 2.2:

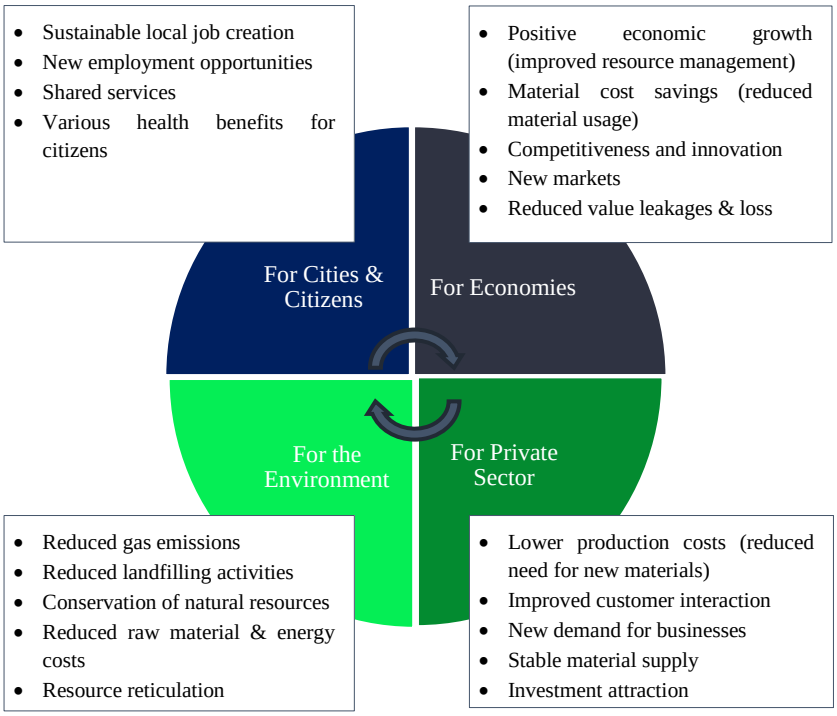


Figure 2.2: Benefits of a Circular Economy

(Schroeder *et al.*, 2018; Ellen MacArthur Foundation and ANSYS Granta, 2019; Principato *et al.*, 2019)

It is not a single organisation's responsibility but of all involved in the supply chain. Earlier research discussed circular economy theoretically but there is a growing trend where organisation are increasingly practicing the approach by looking for opportunities to implement more benign activities, through platforms such as Corporate Social Responsibility or Corporate Social Investment (Manavalan and Jayakrishna, 2019). Amid the benefits attainable from a circular economy, researchers such as Walmsley, Ong, Klemeš, Tan and Varbanov (2019) found circular economy to lack sturdy engineering design methods while Korhonen, Honkasalo and Seppälä (2018) view it as a 'superficial and unorganised'. Six limitations were identified that

need to be addressed before circular economy can be able to fully contribute to global sustainability. These include (Korhonen, Honkasalo and Seppälä, 2018, p. 41):

1. *Thermodynamic limitation*:
    - cyclical systems consume resources and create wastes and emissions.
2. *System boundary limits*
    - Spatial limitation: problems are shifted along the product life cycle.
    - Temporal: short term non-renewables use can build long-term renewable infrastructure
3. *Limits posed by physical scale of the economy*
    - Rebound effect, Jevon's paradox, boomerang effect.
4. *Limits posed by path-dependency and lock-in*
    - First technologies retain their market position despite of in-efficiency.
5. *Limits of governance and management*
    - Intra-organizational and intra-sectoral management of inter-organizational and inter-sectoral physical flows of materials and energy.
6. *Limits of social and cultural definitions*
    - The concept of waste has a strong influence on its handling, management and utilization.
    - The concept is culturally and socially constructed.
    - The concept of waste is always constructed in a certain cultural, social and temporal context and this context is dynamic and changing.

2.2.2 Principles of Circularity

The Ellen MacArthur Foundation (2017) define three principles of a circular economy. Principle one involves preserving and enhancing ‘natural capital by controlling finite stocks and balancing renewable resource flows’, principle two optimizes resource yields ‘by circulating products, components and materials in use at the highest utility at all times in both technical and biological cycles’ and principle three fosters

effectiveness within the system ‘by revealing and designing out negative externalities’ (Ellen MacArthur Foundation, 2015, pp. 5–7)

Circularity can take place in through a Biological Cycle or Technical Cycle – as seen in the Butterfly Diagram -Figure 2.3. The biological cycle involves biological processes such as composting and anaerobic digestion while a technical cycle involves reducing, re-using, recycling and can go further to re-designing and re-manufacturing.

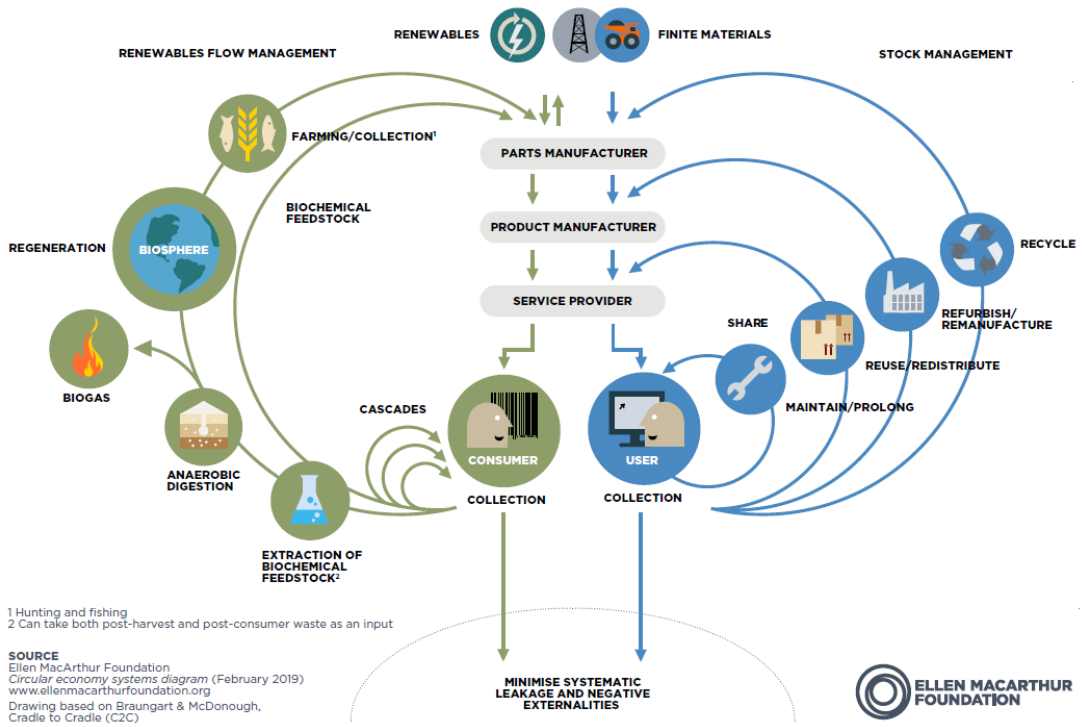


Figure 2.3: The Butterfly Diagram

(Ellen MacArthur Foundation, 2015)

Both biological and technical cycles aim to reduce any waste within the value chain by keeping it in the loop for longer. Waste is not discarded after a single use but rather seen as a resource or feedstock for additional use. The biological cycle views renewable energy as a suitable fuel to drive circularity. Transitioning towards more renewable sources reduces dependence on fossil fuels and improves energy efficiencies (Ellen MacArthur Foundation, 2015). Energy becomes the centre of its

implementation through biochemical feedstock extraction, anaerobic digestion and biogas which are essential for industries and communities. Energy consumption is constantly increasing, and resources are becoming exhausted in the face of growing amount of wastes. The results on the ground show that the current economic model is impractical as available reserves are limited, posing a major risk to economic growth. The collective understanding that resulted in this model is no longer sufficient and circular economy appears as a requisite alternative within the energy sector. The circular economy requires not only a maximum cooperation between all actors within a territory but the collective construction of sustainable balances, by looking for solutions tailored to existing resources and energy needs. Many have argued that the above considerations are similar to the green economy concept, which aims to address environmental problems with economic resources. According to UNEP (2012) it is "*an economy that increases human well-being and social equity, while significantly reducing environmental risks and resource shortages*"(UNEP, 2012). Some researchers emphasize that circular economy cannot be equated to green economy because it is essentially "disruptive" and requires the emergence of a new economic system that based on cooperation between all actors. In a circular economy, resource flows are recirculated to the full, and economic activities are ultimately regenerative.

Furthermore, there are limitations to viewing a circular economy as economic cycle (whatever way it is defined) because it tends to assume a qualitative decline of energy and material used, and this by dissoluteness. It is the concept of Entropy, known as the second law of thermodynamics. Though, the implementation of material and energy cyclical flow may be possible technically, the environmental and financial costs of such an action are likely to be prohibitive due to the thermodynamic degradation of energy and materials. The energy generation activity, which is indeed a linear process, may only be ’circularized’ to a certain extent. However, transformation from the current linear economy to circular economy (even limited) still offers a variety of opportunities to advance natural resources. Numerous economic activities can be implemented re-using, recycling and reducing, as well as energy and nutrient recovery instead of disposing (Schroeder *et al.,* 2018). It may be argued that the concept of

Exergy – which refers to the amount of energy available that can be used – applies more to a linear process when the energy itself is not used in a circular manner. This may refer to heat or gas emitted in a manufacturing process but not used for other energy intensive activities. Leduc and Van Kann (2013) proposed a sustainable urban energy approach based on exergy. Their approach integrated urban functions with renewable and waste resources with the aim of closed cycle energy loops in Dutch cities (Leduc and Van Kann, 2013).

It is not a single organisation's responsibility but of all involved in the supply chain. Earlier research discussed circular economy theoretically but there is a growing trend where organisations are increasingly practicing the approach by exploring opportunities to implement more benign activities, through platforms such as Corporate Social Responsibility or Corporate Social Investment (Manavalan and Jayakrishna, 2019).

2.2.3 Application and Business Models

2.2.3.1 Types of Circular Business Models

Linear production and consumption patterns continue to promote the take-make-use-dispose model. This has negative impacts on social, economic and environmental benefits. Circular economy is imperative for businesses because if they continue to operate 'business as usual', they will not be able to respond to socio-economic and environmental needs in future. Opportunities for businesses include access to new markets, increased profitability along the value-chain, investment attraction, increased productivity and technical capacity (Veleva and Bodkin, 2018; Bocken *et al.*, 2019; Reim, Parida and Sjödin, 2019). Characteristics of circular businesses include:

- Limiting their use of natural resources to positively change production & consumption patterns,
- Collaborative in nature
- Leverage value along value-chains
- Have difference value propositions and sales strategies.

Circular business models can be categorised into five types as shown in Table 2.1:

Table 2.1: Types of Circular Business Models

Circular Supply Model	Renewable, bio-based and recycled materials replace traditional inputs. Material loops are closed and nutrients are cycled within the loop, intentionally designing out any waste.
Resource Recovery	Secondary raw materials from waste streams are produced. Waste is collected and sorted into consistent materials then transformed back into raw materials – therefore closing the loop.
Product Life Extension	This model seeks to extend product life and retain materials in the loop for as long as possible thereby sharing material loops. Products are designed for longevity, direct: reuse, repair, refurbishment and remanufacturing. The revenue model depends on the specific format applied.
Sharing Model	Increases the use of existing products therefore narrowing the resource loop. Products are used more intensively through co-ownership and co-access. This can be facilitated by technologies such as online platforms that reduce transaction costs.
Product Service System	This model combines physical products with a service with the aim of narrowing resource loops. A business would provide a service rather than product and consumers would purchase the service provided by the product. Product ownership would remain with the producer.

(Geissdoerfer *et al.*, 2018; Reim, Parida and Sjödin, 2019; Wainaina, 2020)

Below are examples of where and how the circular economy paradigm has been implemented across the world, across different industries and sectors. A total of 15 publications were reviewed.

2.2.3.2 Circular Economy and Manufacturing

Manavalan and Jayakrishna (2019) analysed circular economy in the context of manufacturing organisations' supply chain. The authors found that Industrial

Symbiosis is a concept that helps supply chain adopt circular economy with the aim of attaining maximum benefits from resources, energy consumption and synergise it to improve sustainability across the value chain. With Industrial Symbiosis as an underlying basis, the study examined a paper manufacturing company in Southern India and identified 6Rs, namely: reuse, recycle, reduce, recover, remanufacture and redesign. Industry 4.0 was discussed as a catalyst for circular economy and Industrial Symbiosis, which brings people together to deliver digitised options that can improve an organisation's sustainability. A case study approach was used. The findings showed that the paper manufacturer produced auxiliary resources that could be used in similar industries. For example, (1) the bagasse residue could be supplied to spirit producers operating in close proximity, (2) the steam harvested from boiling pulp could be used to generate electricity for the operations instead of using coal, or reduce the coal consumption and (3) the fly ash by-product could be sold to nearby cement producers. Using technology, manufacturers are informed of how much waste and where they are experiencing losses within the value chain, thus improving overall efficiency and redirecting waste usage. Big data analytics can equally be adopted and used for raw material supply while Internet of Things (IoT) could be used to determine raw material quality and pre-empt possible wastage.

Mativenga, Agwa-Ejon, Mbohwa, Sultan and Shuaib (2017) explored the circular economy within the composite manufacturing industry in South Africa, specifically the Circular Ownership Models. The study was expanded further in the same year to compare South Africa and the United Kingdom's composite manufacturing companies. Composite waste comprises of fibrous material used to manufacture glass fibre products. According to the authors, adopting the circular economy can redirect composite waste from landfills and create opportunities for further revenue generation. Using a quantitative approach – survey questionnaire of 50 Directors and Senior Managers between the two countries, the study found that manufacturers were driven to reduce, reuse and recycle by the costs involved. Although the role of management is an important driver for sustainable material usage and legislation demands a sustainable approach to business operations, implementing a circular economy should

be cost effective, yield a product of high quality which has a market and give the manufacturers a competitive advantage over others. Interestingly, participants felt local municipalities and consumers should be responsible for end-of-life waste. It is important to contextualise circular economy by considering the local environment to understand participants' views.

2.2.3.3 Circular Economy and Supply Chains

Companies should be including circular economy in their operations to create additional value and make decisions that are less costly to society and the environment (Geissdoerfer *et al.*, 2018). The authors investigated *Integrating Circular Supply Chain Management with Circular Business Models towards sustainable development in organisations*. It was important to comprehend their understanding of business models, which they defined as a simple representation of a complex organisational system. Business models tend to illustrate an organisation's value proposition, creation and delivery, as well as planning, assessment and mitigation strategies in the face of complexities.

Because their research aimed to combine circular economy with business models Geissdoerfer, Morioka, de Carvalho and Evans (2018) budded a new concept known as a Circular Business Model. The term describes "*business models that are suited for circular economy by incorporating elements that are slow, narrow and close resource loop, so that the resource input into the organisation and its value network are decreased, waste and emissions leakage out of the system are minimised*" (pg 713). The main difference between traditional business models and a Circular Business Model is the value creation and delivery element. Using a case study approach to explore this contemporary phenomenon, the researchers identified four companies (furniture manufacturing, aluminium sheet manufacturing, fashion accessory producers who use fibre hoses and a bike sharing service company) using theoretical sampling and administered semi-structured interviews. Findings showed that there is a need for social and technological innovations to fully embrace Circular Business Models in any organisation.

To complement their findings, Manavalan and Jayakrishna (2019)'s study also adopted a case study approach to explore the sustainable supply chain of a paper manufacturing company in South India. The company's supply chain was found to be linear and straightforward. Using the 6Rs – recover, reuse, remanufacture, recycle, redesign and reduce. Figure 2.4 presents the developed circular supply chain model.

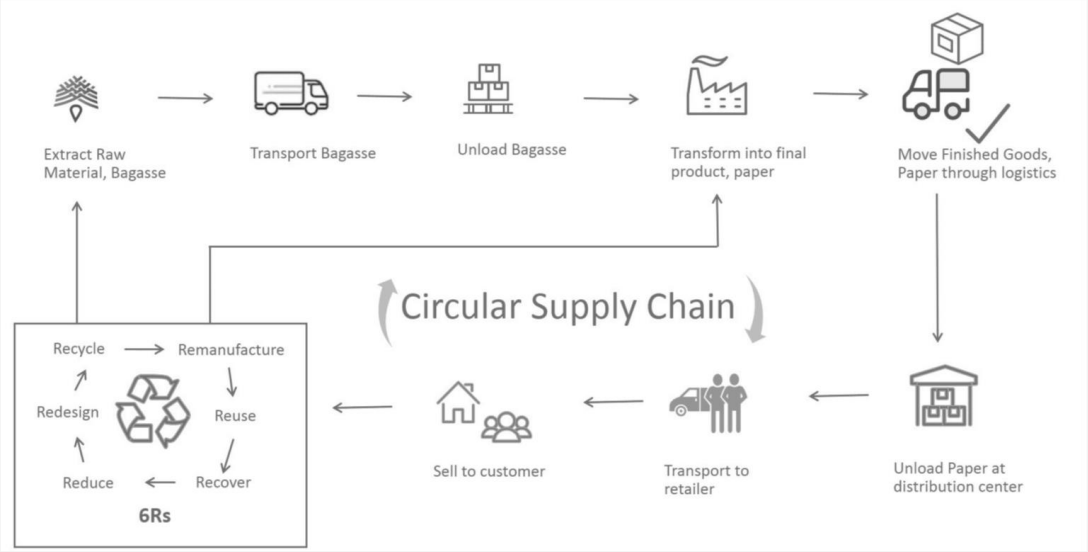


Figure 2.4: Proposed Circular Supply Chain for the organisation

(Manavalan and Jayakrishna, 2019)

Combining Circular Business Models and Circular Supply Chains can yield positive social, environmental and economic impacts. Schroeder, Dewick, Kusi-Sarpong and Hofstetter (2018) address the circular economy and power relations within the Global Value Chains; using circular economy not only for large multi-nationals but small and medium enterprises specifically in low-income countries. They found that low-income countries are circular in their approach compared to their developed counterparts, but the unanswered question is *how can this be turned into a development opportunity that sees low-income countries leapfrog to a more sustainable development path?* The current global value chains use-and-dispose narrative has a negative impact on low-income countries.

Lack of knowledge inhibits these countries from experimenting and exploring circular economy access across the board. There is a need to look at technology as one of the enablers to adoption and implementation (ensuring more efficiency and value add within the value chain) through robotics and additive manufacturing. This can be achieved by "*bringing together interdisciplinary academics and societal stakeholders, industry practitioners, business and government agencies with influence on the broader socio-economic systems*" (pg 78).

2.2.3.4 Circular Economy and Biogas for Electrification

Some intriguing literature on circular economy and biogas was identified in China and Ireland. The development of rural biogas programmes led to great economic, social, economic and environmental benefits. Livestock manure has become one of the biggest carbon emitters in China and there has been an increased use of *circular agriculture* and cleaner production across most animal husbandry activities as a precaution against negative environmental effects while capitalising on resource efficiency and energy recovery (Xu *et al.*, 2018). Using biogas for electricity has become the new and efficient way of using this by-product as well as recycling biofertiliser for circular agriculture. Using a quantitative approach to maximise biogas efficiency, key considerations were the Chemical Oxygen Demand (COD), nitrogen and phosphorus emissions as well as the Net Present Value (NPV).

On the far end of the northern hemisphere, Blades, Morgan, Douglas, Glover, De Rosa, Cromie and Smyth (2017)'s study investigated the application of a circular economy in a rural agricultural setting in Northern Ireland, which was centred around anaerobic digestion technology for potential electricity generation. Agriculture is one of the biggest and important sectors in the region, socially and economically. It provides jobs across the value chain from primary to tertiary agriculture and ensures many households, institutions and businesses are supplied with fresh or processed vegetables and meat. Due to its size, it is also the largest greenhouse gas emitter within the United

Kingdom (28,0%). Emissions are predominantly from livestock (methane) and soils (nitrous oxide). To reduce Northern Ireland's dependence on fossil fuels, incentives and targets were put in place to increase proportion of locally sourced energy, including biogas. Since 2013, 91 applications for anaerobic digestion plants were granted. Most were for electricity generation and some for heat production (Blades *et al.*, 2017). Livestock manure was the main feedstock used, as well as some commercial and industrial waste.

Both sets of authors reiterated the importance of rural farming communities being suited to apply circular economy principles for biogas-to-electricity production. Anaerobic digestion technology could be the centre of *Smart Rural Energy Infrastructure* whereby farms supply the feedstock and local industry supply food waste to generate biogas and electricity. The energy goes back to the local community, providing electricity to homes, businesses and transport sector. Digestate can be used as a fertiliser in crop production and the system continues, achieving SDG 7.

2.2.3.5 Circular Economy and Waste Management

Principato, Ruini, Guidi and and Secondi (2019) investigated the adoption of a circular economy approach to food waste management, particularly pasta production in Italy. The authors identified food loss and waste as one of the biggest challenges with a negative socio-economic and environmental impact. The loss occurs during the initial stages of the Food Supply Chain, from agriculture to industrial transformation as well as final retail and consumption. Furthermore, food loss at consumption phase occurred in Europe, North America and industrial Asia where "*individuals residing in these countries tend to waste much more food than individuals in developing countries*" (pg 82). Principato *et al.*, (2019) used a case study approach, analysing the value chain large European Union food production companies, particularly pasta production companies. They identified the biggest pasta producer in Italy, who was able to avail data and were interested in adopting a circular economy approach for their operations. Results showed that 23,0% of the wastage occurred between the cultivation and consumption phases.

Using a circular economy approach, wasted food during cultivation could be used as animal feed or composting while wasted food at consumption phase could be donated through food banks. Adopting a circular economy approach to sustainable food supply chain is one of many ways to achieving Sustainable Development Goal 12 – Sustainable Consumption and Production. In the same breath, solid waste generation and management is one of many challenges that governments across the world are currently battling to address. This can be achieved through Municipal Solid Waste (MSW) management plans (Marshall and Farahbakhsh, 2013).

The business models for implementing circular economy initiatives need to be feasible and viable for the implementing party (Geissdoerfer *et al.*, 2018), which would be the local municipalities in this instance. Pla-Julian and Guevara (2019) found that circular economy needs to be more inclusive of the social dimensions as a method to identify socio- economic opportunities and achieve social inclusion from an institutional level. This is supported by Ferronato, Rada, Gorritty, Cioca, Ragazzi and Torretta (2019) who stressed the need for developing countries to realise Sustainable Development Goals through effective solid waste management (SWM) strategies. Circular economy can improve current MSW management across the world. The authors found that in Romania, MSW management was driven by circular economy because of the pressure presented by the European Union's (EU) Circular Economy Package. On the other hand, Bolivia which is not an EU member state relied on donor funds and investments to implement MSW strategies centres around the CE. Despite having various circular economy models, implementation and assessment tools available, each is unique to the context (Ferronato *et al.*, 2019). The literature findings affirmed that circular economy can have positive impacts within the municipal solid waste industry. However, there is little to no consideration in MSW plans in developing countries, let alone for urban energy from organic waste.

2.2.3.5 Circular Economy and Entrepreneurship

Veleva and Bodkin (2018) examined the role of small businesses partnering with corporates to advance circular economy. Large companies are not able to fully incorporate the circular economy into their business strategies due to lack of mandates, costs, logistics and inertia. This presents an opportunity for small businesses with innovations to fill the gap, create new business opportunities with socio-environment benefits. This can be achieved by the authors' *Framework for Collaboration to Advance Circular Economy*. In the United States of America, there are no federal regulations for CE, but it has not stopped big companies from partnering with small ones to advance product use and reduce waste. Driving factors include companies' shared sustainability goals, mindset shift towards zero waste and a growing trend to source locally. The research found that there is a knowledge gap between entrepreneurship and innovation in the context of developing a CE within corporate supply chains. New business models are required to address the gap as well as advance redesigning, reusing and remanufacturing within a company's operational system. However, it does not make economic sense for big businesses to reuse or remanufacture when costs are high, profit margins are low, the final product is poor quality or if there is no market.

Entrepreneurs are positioned to deliver social value, contribute massive innovations and reshape the mindsets from linear to circular. It is not easy to transition because of economic complexities of current production systems and lack of measurement tools. Divided attention amongst the stakeholders regarding waste management and climate change and water conservation also impacts the transition. Thus, the framework was based on developing strategic, mutually beneficial partnerships between big and small businesses, focusing on reusing products, repurposing or remanufacturing waste, using technology as an enabler.

Most literature reviewed showed that circular economy research was most prevalent in Europe, Asia and the United States of America (Tisserant *et al.*, 2017; Merli, Preziosi and Acampora, 2018; Walmsley *et al.*, 2019; de Oliveira, Dantas and Soares,

2021). With the odd exception of work by Mativenga *et al.,* (2017) who focused on manufacturing in South Africa and Horváth, Mallinguh and Fogarassy (2018) who reviewed circular transitions for plastic waste management in Kenya, research focusing within an African context remains underexploited and equally present an opportunity for novel work. Mutezo and Mulopo (2021) investigated the use of circular economy principles for energy transition in Africa and also found that continental knowledge is still underexploited.

2.2.4 Measuring Circularity and Material Flows

2.2.4.1 Types of Measurements

There is no generally accepted methodology for measuring circularity in a given context (Ellen MacArthur Foundation, 2015; Saidani *et al.*, 2019). However, it does not rule out the need to measuring circularity because there is a growing need for circularity indicators (Bocken *et al.,* 2019). Indicators are important to monitor, measure and assess progress of a particular system (Saidani *et al.*, 2019; Gonçalves, Freire and Garcia, 2021). It is important to measure it because circularity facilitates and promotes a transition towards resource optimisation; assessing the full scope of material flows within operations. Furthermore, measurement would help to manage risks associated with linear business models, critically evaluate business actions as well as feed back into guiding decision-making (Rana *et al.*, 2020).

There is a plethora of literature addressing circular assessment and measurement at different scales. Decision-makers need assistance to choose the best indicators for assessing circularity because the shift from linear to circular economy is not without unfavourable trade-offs. In a systematic literature review by (de Oliveira, Dantas and Soares, 2021), 61 publications were analysed and 58 indicators explored. Majority of the indicators measured products, focusing on resource recovery. Very few articles addressed measuring circularity at company, government or even city level. Parchomenko *et al.*, (2019) analysed 63 metrics used to measure circularity and confirmed that there are no generally accepted measurement approaches as noted by Ellen McArthur Foundation (2015) and Saidani *et al.*, (2019). Using Multiple

Correspondence Analysis, the authors analysed various contributions by other researchers to provide perspectives on methods and metrics to consider. Figure 2.5 shows some measurements associated with circular economy.

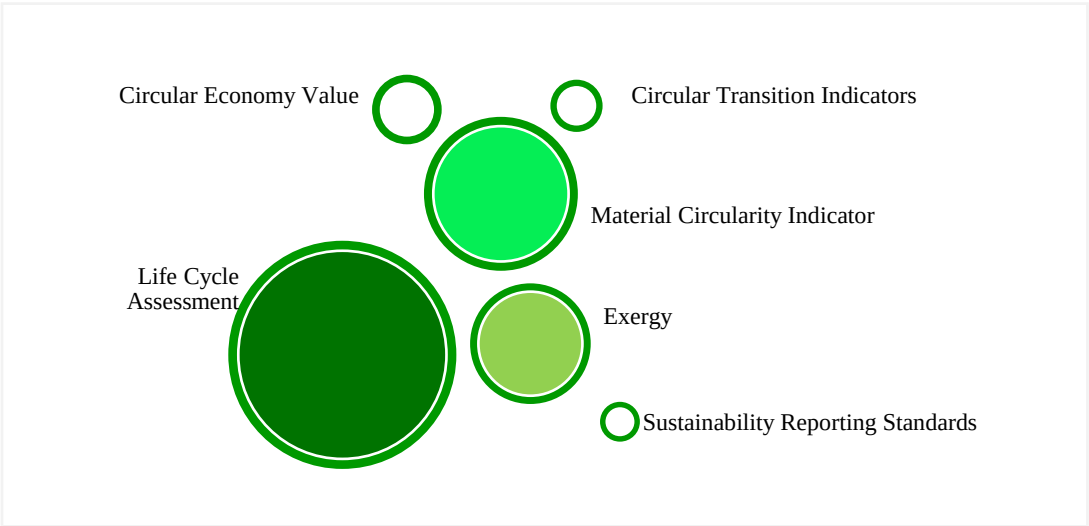


Figure 2.5: Some types of Measurements associated with Circular Economy

Some of the most prominent measurement features relating to circular economy were recycling, resource efficiency, material stock availability and flow, as well as product-centric clustering. These features were eminent in measurement tools such as industrial symbiosis and life cycle assessments, sustainable supply chains, product recycling, exergy extraction and material flow analysis, just to name a few. Other types of indicators include but not limited to Material and Energy Circularity Indicators (MECI), Systems Indicators for Circular Economy Dashboard (SICED), Assessment of Circular Economy Strategies at the Product Level (APL) and Product Recovery Multi-Criteria Decision Tool (PR-MCDT) (de Oliveira, Dantas and Soares, 2021).

The findings complement Saidani *et al.*, (2019)'s work as well, which identified 55 sets of indicators and classified these with the aim to assess, improve, monitor and communicate circular economy performance. An important factor to note from their research is that the criteria used to attempt measuring circularity is not a 'silver bullet' approach. It is differentiated by assessing the levels of implementation (whether a project occurs at a micro, meso or macro level), the type of loops (whether the intention

is to reduce, reuse, remanufacture or recycle), the project's perspective (focusing on the potential for or actual circularity) and lastly the levels of versatility (whether a project is sector-specific or generic).

There is emerging and a growing body of research focusing on circularity measurement, but it is not constant in terms of scope and applications. Some researchers propose more in-depth investigations on the completeness, classification and application of circular economies. However, with the lack of a precise definition, criteria for assessing circularity. Below are three measurement tools discussed in more detail.

2.2.4.2 The Circular Economic Value

Circular Economic Value (CEV) is a method used to measure and identify points where value is lost or to enhance circularity, measure circular efficiency. It relates to aspects of material and energy balance within a circular economy, primarily focusing on energy flows and how materials can be made optimised along a production process (Horváth, Mallinguh and Fogarassy, 2018; Horváth, 2019). This method is used as a universal framework which should be tailored for specific cases while ensuring that principles of circularity are followed. With sufficient data, CEV can be used to conduct a material flow analysis whiles insufficient data leads to material analysis only. In essence CEV is used to determine the circularity of projects. The mechanism of the calculation method is represented by formulae below:

Formula 2.1: Level of Circularity in Plastic Waste Management

$$CEV\% = 100 - \left(\frac{\left(\frac{IM_{rm}}{T_{rm}} + \frac{EX_{mo}}{T_{mo}}\right) + \left(\frac{NR_{pw}}{T_{pw}} + \frac{NR_{rpw}}{T_{rpw}}\right) + \left(\frac{NC_{pw}}{T_{pw}} + \frac{NR_{cw}}{T_{cpw}}\right)}{6} \right) \times 100$$

(MIM, MEX, LCM, CML, WCL, WPL)

Horváth, Mallinguh and Fogarassy (2018)

MIM = ratio of imported plastic raw materials (IMrm) to the total volume of plastic manufacture inputs (Trm);
MEX = ratio of exported plastic products (EXmo) to the total volume of plastic manufacture outputs (Tmo);
LCM = ratio of non-recyclable plastic waste (NRpw) to the total plastic waste amount (Tpw);
CML = ratio of non-recycled recyclable plastic waste (NRrpw) from the total recyclable plastic waste amount (Trpw);

WCL = ratio of non-collected plastic waste

(NCpw) to the total plastic waste amount (Tpw);

WPL = ratio of non-recycled collected plastic waste

(NRcw) to the collected plastic waste amount (Tcpw).

Formula 2.2: Implementing solar energy parks using circularity principles

$$CEV\% = 100 - \left(\frac{\left(\frac{M_p}{M_p + M_s} + \frac{M_d}{M_r + M_d}\right) + \left(\frac{E_f}{E_s + E_f} + \frac{E_l}{E_c + E_l}\right)}{4} \right) \times 100$$

(M_{lin}, M_{lout}, E_{lin}, E_{lout})

Fogarassy *et al. (*2017; Horváth (2019)

Mlin: The input side of the material flow (linear),

Mlout: The output side of the material flow (linear),

Mp = The amount of primary raw materials used to create the product,

Ms = The amount of secondary raw materials used to create the product,

Md = The amount of non-recyclable materials after the use of the product (linear),

Mr = The amount of recyclable materials after the use of the product (circular),

Elin: The input side of the energy flow (linear),

Elout: The output side of the energy flow (linear),

Ef = The amount of non-renewable energy used to create the product,

Es = The amount of renewable energy used to create the product,

El = Energy used to displace the product after use (linear),

Ec = Energy used for recycling after the use of the product (circular).

The relationship between input-output shows a systems' level of circularity. Horvath *et al.,* (2018) states that CEV calculations emphasis on linear processes of individual indicators to underline inefficient elements of processes and systems. In their study on plastic waste management in Nairobi, Kenya, the authors calculated a CEV value of 32,7% as the level of circularity. This indicated that plastic waste flow systems were not optimised efficiently to reduce plastic production and consumption. Similarly, Fogarassy, Horvath, Kovacs, *et al.,* (2017) also calculated a high CEV value of 85,5% for a proposed solar park project in Hungary. Solar energy could improve material and energy flows as well as socio-economic and environmental benefits. The authors recommended that pilot projects should serve as an opportunity to identify inefficiencies in input-output flows before medium to large scale projects are implemented. Calculations are based on the ratio of final energy used after the material flow.

2.2.4.3 Concepts of Exergy and Entropy

According to circular economy principles, energy that is not used to fulfil a final function contributes towards a linear production. This is where concepts of Exergy and Entropy equally apply in the context of circularity, specifically energy losses throughout the energy use. Exergy refers to the maximum amount of useable energy (Lucia, 2013; Zanchini, 2015). An example of exergy in a linear process: coal power plants burn their coal to heat water and obtain very high temperature steam. When the steam is passed through a turbine, the thermal energy of the steam (called primary energy) is converted into electrical energy. However, principles of physics state that it is impossible to recover 100,0% of thermal energy in the form of electrical energy. When electrical energy is consumed, 100,0% of the energy cannot be used, even with ideal physical systems. There will always be wasted heat in the process.

When the 'amount of useful work' equals the 'amount of exergy', energy efficiency can no longer be improved despite the remaining heat losses.

Equation 2.1: Exergy Efficiency < 1

"amount of energy" - "amount of energy". exergy "): = exergy efficiency of 1.

On the other hand, when the 'amount of useful work' is less than the 'amount of exergy' (exergy efficiency < 1), energy efficiency can be further improved, theoretically.

Equation 2.2: Exergy Efficiency of 1

"amount of energy" < "amount of energy". exergy " = exergy efficiency of 1.

By definition, the ‘amount of useful work’ cannot be greater than the ‘amount of exergy’.

Equation 2.3: Exergy Efficiency Not Equal to 1

“amount of energy” ≠ “amount of energy”. exergy "

For practicality, researchers such as Lucia (2013) and Zanchini (2015) view energy as exergy plus heat necessarily lost due to insufficiently efficient technology. Unlike energy, exergy cannot be conserved. At each stage of transformation, some of the exergy disappears as waste heat, which has many implications. For example, this means that the notion of circular economy is an aberration from a physical point of view: energy cannot be recycled, it can only be consumed, and any stage of transformation (recycling) very little is consumed.

Entropy is defined as a principle that is applied in closed systems, such as energy flows and resource scarcity (Young, 1991). From an economic perspective, the neoliberal economy creates a notion that resources are unlimited and can be consumed without constraints. From an energy perspective, researchers focus on energy efficiencies in transferring energies from one form to another (Lucia, 2013; Parchomenko *et al.*, 2019) or standalone renewable energy systems (Jiao *et al.*, 2020). Recycling approaches offer a solution that makes it possible to use materials and resources in a circular manner, with benefits of benignity and job creation. However, this ignores the reality of thermodynamics. Consuming a resource destroys an atomic composition. Concomitantly, part of the energy used to extract, produce and transform coal to energy is dissipated in the form of heat, therefore in a state of thermal agitation that is difficult to use. This is the expression of the second principle of thermodynamics, which describes the notion of entropy. In the context of a circular economy, when entropy increases exergy decreases.

2.2.4.4 Material Circularity Indicator (MCI)

The Material Circularity Indicator tool is a spreadsheet that was provided as part of the Circularity Indicators Project by the Ellen MacArthur Foundation and Granta Design Ltd. The first version was published in 2015 and primarily focused on technical cycles and non-renewable material. It was updated in 2019 to include biological cycles as well, maintaining its focus on measuring circularity in companies.

MCI measures how restorative and regenerative material flows of a product are, and how effectively a company is transitioning from linear to circularity. This enables companies to identify circular value in their services and products, reduce risks induced by market price volatility and material supply. Companies can analyse and evaluate regulatory, environmental and supply chain risks in their products or services. The tool can be used by decision-makers to inform design specifications, reporting, procurement and ratings within an organisation. Gonçalves, Freire and Garcia (2021) used MCI to assess the circularity of wood-based plants in Portugal to support a bioeconomy. The authors were able to measure the circularity of material flows such as paper and furniture, and found one to be more circular than the other based on how the products were recyclable.

There are different MCI toolkits available, which cater to both technical and biological materials:

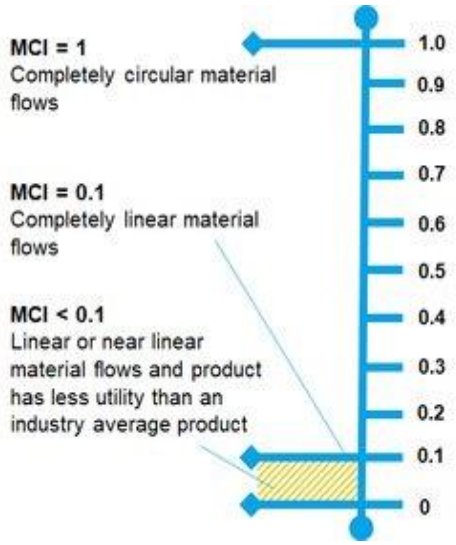
1. The MCI Dynamic Modelling Tool measures circularity at product-level. A range of input data such as virgin feedstock, unrecoverable waste, linear flow index and utility are used to calculate the MCI. The result is used to inform product design, scenario creation and comparison as well as determine product circularity.
2. MCI Company Aggregator Tool focuses on calculating material circularity at company-level. It aggregates a set of product data together using a specific normalising factor. Normalising factors include ‘product mass’ and ‘sales

revenue'. The results are used to inform companies' strategic decisions and future plans, based on their current circularity.

(Ellen MacArthur Foundation and ANSYS Granta, 2019).

The scale ranges between 0 and 1, where 0 means the product is linear and 1 means it is circular or recyclable. This is explained in Table 2.2 below:

Table 2.2: Material Circularity Indicator Scale

	**MCI = 1**: input material would have to be reused or recycled. Any waste generated during and after the production would have to be reused or recycled again; output material being input material – zero waste.
	MCI = 0,1: input material is sources from nature, not reused or recycled. To achieve this rating, the product should have a short life span and intensity of use.
	MCI < 0,1: the product has a linear material flow and lower intensity use than an average product. **MCI > 0,1**: the product has a linear material flow and higher intensity of use than an average product.

(GaBi Solutions, 2020)

Although the MCI are some of the most advanced and widely documented tools for companies to measure circularity at two levels, products or material flows being circular does not necessarily socio-economic and environmental improvements. Regulatory environments, a variety of business models and business risks are just a few metrics that can directly or indirectly affect implementation.

2.3 Part Two: Urbanism Trends and Circularity

Part two reviews circularity in the context of urbanisation. Demographic and urbanisation trends set the foundation for discussions about urban morphology and metabolism. It aims to provide an understanding of African cities' land use patterns and how material and energy flow within. This then leads to aspects of planning for energy in cities, which is recognised as urban energy planning. Urbanisation and population growth are expected to proliferate, thus it is imperative to ensure that cities enable circular flows of material and energy.

2.3.1 Population Growth and Urbanisation Trends

A megatrend such as population presents challenges for effective sustainable development and service delivery. As of 2019, the world population was approximately 7,7 billion. Table 2.3 shows the forecast of Africa's population growth.

Table 2.3: Forecast of Africa's Population Growth

Year:	**2019**	**2030**	**2050**	**2100**
World	7,7 billion	8,5 billion	9,7 billion	10,9 billion
Sub-Saharan Africa	1,1 billion	1,4 billion	2,1 billion	3,4 billion
North Africa & Western Asia	0,52 billion	0,61 billion	0,75 billion	0,92 billion

(United Nations, Department of Economic and Social Affairs, Population Division, 2019)

By 2050, Africa is likely to become a global contributor to the world population Projections indicate that the continent will account for more than half the population growth (52,0%) between 2019 and 2050 while Asia and South America reach population peak by the end of the century. In 2050, population concentrations are projected for nine countries, namely Tanzania, Nigeria, Egypt, Democratic Republic of Congo and Ethiopia (in Africa), India, Indonesia and Pakistan (in Asia) as well as

the United States of America (United Nations, Department of Economic and Social Affairs, Population Division, 2019).

Between 2017 and 2050, rapid population growth is expected to be led by Angola, Burundi, Niger, Somalia, Tanzania and Zambia, which will expand five times in size compared to other countries due to perceived economic growth. (United Nations, Department of Economic and Social Affairs, Population Division, 2017). It will become very difficult for governments to provide basic services. Africa's young population is regarded by multinationals as a continent open to innovation and new ideas. Inhabitants aged between 15-24 years of age accounted for 41,0% of the total population, as well as the lowest aging population bracket (5,0% of the total world population).

Urbanisation is also recognised as a megatrend. It is the concentration of a population and economic activities in an urban area. Its trends are typically induced by rural migration into urban areas, whereby inhabitants are in search of economic activities that are no longer prevalent in rural areas, known as push factors (Madlener and Sunak, 2011; Salim and Shafiei, 2014) as well as fertility, fertility and population growth trends. In 2018, urbanisation estimates were 54,0%, expected to reach 66,0% by 2050 (Bautista Angeli *et al.*, 2018). More recent estimates state that 56,2% of the world's population currently reside in urban areas and will increase to 60,4% by 2030 instead (UN-Habitat, 2020). The difference indicates that urbanisation is occurring at a faster rate than projected.

Economic transformation has led to depleting natural resources and increased energy use due to industrialisation and new technologies as well as production activities. There is a greater reliance on transportation, provision and delivery of public amenities such as bulk municipal infrastructure, and human settlements; all of which are vital to a city's economic development (Salim and Shafiei, 2014). Between 1970 and 2010, it was evident that urbanisation was more prevalent in developing regions than

developed, due to current and estimated population growth (Madlener and Sunak, 2011). There is a link between urbanisation and economic development. As economic and industrial activities expand in cities, resource and energy consumption are expected to increase, seeing a stronger urbanisation-energy relationship (Freire, Lall and Leipziger, 2014).

Although urbanisation presents opportunities for industrialisation and economic growth, it equally presents challenges such as extreme poverty in rural and peri-urban areas. Due to the heterogeneous nature of African countries and its cities in terms of natural resources, cultures and urban morphology, some are urbanising at faster rate than others. One of the synonymous characteristics are the new population's burden on a city's ability to provide affordable and quality services within an already constrained municipal budget (Freire, Lall and Leipziger, 2014; Cobbinah, Erdiaw-Kwasie and Amoateng, 2015; UN-Habitat, 2020). Slow urban policy reforms and inadequate infrastructure investment are likely to place further burden on urban areas that were not designed to accommodate this sudden influx of migrants. This means poor waste management and sanitation services, inadequate access to clean and portable water, and increasing energy demand, among other constraints. In essence, the continent faces four broad development challenges which are (Freire, Lall and Leipziger, 2014, p. 22):

1. Rapid population growth unmatched by levels of economic activity.
2. Low density, sprawl, and informality in peri-urban fringes.
3. Weak access to basic infrastructure and services (water, energy, and sanitation).
4. Weak administration, institutions, and overall planning urban and management capacity

2.3.2 Urban Morphology Trends

2.3.2.1 Defining Urban Morphology

Urban morphology is the science or study of physical spaces, building structures, and formations in urban areas, as well as socio-economic activities within. It is an important aspect of urban planning because of its influence on how the built environment evolves and resources flow. Morphological parameters vary and depend on contexts, for example distribution and distribution of air pollutants, incorporation of solar energy potential from various surfaces in cities as well as urban sprawling and economic inequalities. These include but not limited to types of buildings, land uses, transportation patterns, building energy consumption and densities (Poon *et al.*, 2020; Zhu *et al.*, 2020; Jiang *et al.*, 2021). For example, the absence of appropriate land use planning and poor land use management in the Federal District of Brazilis (Brazil) negatively affected public areas, particularly sustainably they were developed. By understanding a city's urban space, decision-makers are able to make informed decisions and develop supportive tools (Castro *et al.*, 2019).

2.3.2.2 Brief History of African Cities

Africa's towns and cities are shaped by laws imported from British colonial rule from the 1920s (Home, 2015). Urban Planning, interchangeably referred to as Town and Regional Planning or City Planning, is a discipline within the built environment that is concerned with designing and developing land use (Lubida *et al.*, 2019). It was officially recognised as a profession in the latter 20th century (Home, 2015). Key considerations range from transportation, engineered utilities (water, electricity, sewerage systems), infrastructure, communication and social amenities (schools, hospitals, parks, economic activities). Spatial and land use planning are the most predominant specialisations in the field of urban planning. This is a dynamic activity that requires handling social, cultural, environmental and political influences (Lubida *et al.*, 2019).

Land use management decisions pertaining to zoning, subdivision and urban planning are taken by land use authorities, in consultation with different stakeholders (Home, 2015). Amenities such as waste management and energy access have not been deliberate in planning strategies. While there is a global push for cities to become more environmentally responsive and to implement mitigation and adaptation initiatives through policies and strategies – Sustainable Development Goals 11 and13 - current urban systems are not conducive. A large part of African cities remain centred around colonial town planning principles and regulation. Overtime, their spatial structures has been characterised by informalities, such as informal settlements, informal structures, informal economies and informal waste pickers.

Post-independence, there was very little evidence of the evolution of land use planning, especially the form that supports sustainability. Throughout the 1980s and 2000, several academics started to re-invent post-modern planning, one driven by economic development and environmentalism (Okeke and Nwachukwu, 2019) . An increasing body of literature on urban sustainability and innovative planning approaches has begun to shift urban development patterns (Lwasa and Kinuthia-Njenga, 2012). The term ‘green technology’ was identified as a tool for modern urban planning. This includes deliberate coordination of activities that are energy efficient, promote renewable energy, recycling activities and more. There are different technologies that contribute towards sustainable urban planning, such as the implementation of enhanced municipal waste management (Laffta and Al-rawi, 2018). Four types of eco-technologies that urban planners can start implementing more are:

1. Environmental Technology: a range of technologies relating to waste management, access to water and energy.
2. Information Technology: hardware and software coupled with environmental sensor technology to collect environmental data.
3. Geographic Information Systems: collect, share, manipulate geographic data and incorporate with Urban Information Systems to guide design and development of land use and environmental plans.

4. Communication Technology: software to transfer data and knowledge to different environments.

Green technologies are most prevalent and commercialised in Denmark, Sweden, Japan, India, Iraq, Finland, Canada and the United States of America, just to name a few (Laffta and Al-rawi, 2018). Opportunities for African planners to leapfrog are bountiful. Such tools can be used not only for sustainable urban development and waste management but as part of climate mitigation and adaptation strategies. Kenya is not far from realising the benefits of green technologies. Urban planners are responsible for solid waste management. The National Solid Waste Management Strategy is used to incorporate solid waste management and best practices into urban plans. The plans are then subjected to a Strategic Environmental Assessment, which assesses aspects such as sustainability, proposed waste management programmes as well as relevant services and facilities (Ozoike-Dennis *et al.*, 2019). The authors further state that solid waste management (SWM) plans are included in the Nairobi Integrated Urban Development Master Plan (NIUPLAN). The SWM plans focus on 'improving waste collection and transportation system, closing open landfills, and constructing Material Recovery Facilities, where waste material is to be separated to compost biodegradable material, and recycle non-biodegradable material. In South Africa, departments in charge of solid waste management are required to develop Integrated Waste Management Plans as stipulated in the National Environment Management: Waste Act (59 of 2008). The IWMPs include practical aspects of managing waste in municipalities. It is one of the sector plans that feed into and is guided by the Integrated Development Plans (Sango *et al.*, 2014).

2.3.3 Urban Metabolism and Material Flow Trends

2.3.3.1 Defining Urban Metabolism

The concept of urban metabolism offers a framework to help understand how cities function and how resources flow within and across, as well as the complexities affiliated; how energy and materials flow within cities (Pulido Barrera, Rosales Carreón

and de Boer, 2018). Cities are seen as a living organism where urban areas operate as metabolic systems, with social, economic and environmental factors shaping the urban phenomenon. The concept comprises of six elements within cities, namely (1) viewing the city as an ecosystem, (2) material and energy flows, (3) economic-social relations, (4) economic drivers of rural-urban relationships, (5) reproduction of urban inequality, and (6) attempts to re-signify the city through new visions of socio-ecological relationships (Lucertini and Musco, 2020, p. 139) . Currie and Musango (2016) view urban metabolism as "*collection of complex sociotechnical and socioecological processes by which flows of materials, energy, people, and information shape the city, service the needs its populace, and impact the surrounding hinterland*" (pg. 4). Urban metabolism feeds into circular strategies while exploring ways to limit the linear economy in cities.

Cities are an integral part of resource consumption and production, which need to balance phenomenon such as population growth, migration and energy consumption with natural resource usage (Pulido Barrera, Rosales Carreón and de Boer, 2018; Thomson and Newman, 2018). They are spaces for a myriad of socio-economic and environmental pressures. More people are living in cities and the number is still increasing due to high economic and industrial activities. Hence urban metabolism can be viewed from different perspectives. Most research on urbanism focuses on urban planning, formation, function, health and environment (climate change and disaster risk) but very few focus on energy flows (Currie and Musango, 2016). Linkages between material and energy flows and circular economy were seen in measurement tools such as Material Flow Analysis and Material Circularity Indicators.

2.3.3.2 Application of Urban Metabolism

Cities are key actors in the transition towards a circular economy. As more research is done pertaining to urban sustainability, it is becoming clearer that conventional approaches and theories are no longer suitable. Cities are uniquely positioned to catalyse systematic transformation, based on some of the following statistics (Currie and Musango, 2016; Pulido Barrera, Rosales Carreón and de Boer, 2018):

- > 50,0% of the world's population live in cities,
- 85,0% of the global Gross Domestic Product (GDP) is generated by cities,
- 75,0% of natural resources are consumed by cities,
- 59,0% of global waste is produced by cities,
- 60,0 to 80,0% of greenhouse gases (GHG) are emitted by cities,
- 2,0% of the land area is occupied by cities.

Cities therefore represent a population concentration and human activities that yield negative impacts such as pollution and waste. At the same time, cities are also well positioned for innovation. They act as hubs for circular transformation that can support sustainable development - Figure 2.6.



Figure 2.6: Cities as Innovation Hubs

A Circular Urban Framework was proposed by Lucertini and Musco (2020), which applies circular economy with urban metabolism. It is designed to encourage urban planners and policy makers to rethink how waste material and energy flow within cities, and then applying CE principles. Waste material products would be reintegrated into cities' circular system as secondary material. To operationalise and quantify resource flows in urban areas, various metabolism assessment tools would then need to be considered. Some include:

1. *Accounting Approach*: material flow analysis & energy substance flow analysis.
2. *Input-Output Analysis*: measures flow between sectors and their interaction with urban environment.

3. *Ecological Footprint Indicators*: sustainability indicators that show how much land is required to sustain populations in relation to available resources.
4. *Life Cycle Assessment*: evaluate all stages of product life cycle and compare environmental impacts.
5. *Simulation Methods & System Dynamic Modelling*: model system behaviour over time.
6. *Hybrid Models*: a combination of any of the above or more.

Pulido Barrera, Rosales Carreón and de Boer (2018) reviewed urban metabolism in the context of urban energy and proposed a conceptual framework that defines the role of urban metabolism in energy systems. The 'Multi-level Framework for Metabolism in Urban Energy Systems' assesses how dynamics of urban energy differ from ecological systems, highlighting how "*low level resource supply may contribute to increasing energy use efficiencies in cities*" (pg. 230). The Metabolic Theory of Ecology indicates that energy consumption and efficiency increase when systems become larger. The concept is thus largely linked to Material Flow Analysis. An 'Urban Material Flow Analysis Framework and Measurement Method' was developed by Wang, Li, Liu and Zhang (2020) and builds on Pulido Barrera et al (2018)'s work. It provides an accounting template to analyse material flows in cities at different stages.

Faller (2016)'s research studied spatial dimensions of energy flows and transition in the Municipality of Beckerich, Luxombourg. The key finding presented was that it is important to analyse developments in cities, understand their spatial dimensions and context because these influences the transitioning process. Adding to this, role-players' involvement is equally important. These include planners, engineers, politicians, citizens and operators because their decision-making, planning and processes affect whether energy flows occur or not. A valuable consideration for this study because "*a thorough focus on actors and their practices is still missing in this strand of transition literature*" and "*more in-depth studies are needed to understand roles of actors for the*

constitution and transformation of socio-technical systems, such as the energy system" (Faller, 2016, p. 86).

Research focusing on urban metabolism in Africa is still emergent. Assessments of urban material and energy flows in Cape Town were done by Currie and Musango (2016), Currie, Musango and May (2017) while Hoekman (2015) conducted a MFA of Cape Town's material flow. It is not simple to assess waste and energy flows in African cities due of a lack of data at city level, challenges of tracking informal resource flows and a lack of standardised methods (Currie and Musango, 2016).

2.4 Part Three: Waste and Energy Resource Potential

Building from the urban metabolism review, part three reviews waste and energy resource potentials in Africa. Both aspects are defined within the context of this study and their status quo affirm the availability of waste material as a resource and projected energy demand.

2.4.1 Waste Resource Potential

2.4.1.1 Defining Waste

There are various definitions for waste. This is an indication that it is relative to those affected by it as well as the context in which it is found. Waste management researchers concur by stating that there is no single or unified definition of waste but rather it depends on the lens from which it is viewed. UNEP (2018) describes waste as 'stuff that people throw away' due to exhausted economic value. One of the more common definitions is "*substances or objects which are disposed of, or are intended to be disposed of, or are required to be disposed of by the provisions of national law*" (UNEP and Basel Convention, 1989). The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal (known as the Basel Convention) was adopted in 1989. It was in response to a public outcry following the discovery of toxic waste being disposed in Africa and other parts of the developing world.

2.4.1.2 Waste Generation

Waste quantities and composition data are lacking in most developing countries (Fetene *et al.*, 2018). The United Nations Environmental Programme (UNEP) released Africa's Outlook on Waste Management in 2018, a very detailed report aimed at curbing poor availability of data as well as induce improved waste management and energy recovery activities on the continent. This study relied on the report as the primary data source and was complemented by other regional and country-specific reports.

As seen in Figure 2.7, the total MSW generated in Africa (in 2012) was estimated to be 125 million tonnes a year, of which 81 million tonnes were from sub-Saharan Africa (Scarlat *et al.*, 2015). As of 2016, 174 million tonnes were recorded (Kaza *et al.*, 2018). North African countries had a relatively higher per capita waste generation compared to sub-Saharan countries. The average per capita waste generation in 2012 was 0,78 kg per day, which was much lower than the global average of 1,24 kg per day. By 2016 this had increased to 0,46 kg per capita per day (Kaza *et al.*, 2018).

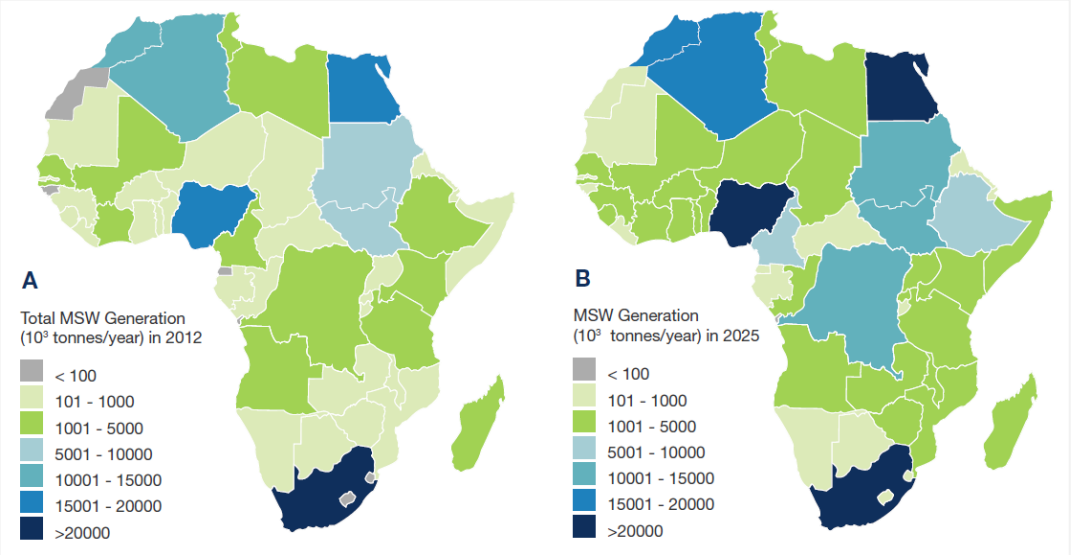


Figure 2.7: Total MSW generation of African countries in 2012 (A) & 2025 (B) (UNEP, 2018)

There are considerable spatial differences in the amount of waste generated, which range from as low as 0,09 kg per day (Ghana) to as high as 2,98 kg per day (Seychelles). South Africa, Egypt and Nigeria, stood out as 'hot spots' of MSW generation, with estimated MSW generation of 23,21 and 17,45 million tonnes per annum, respectively (Scarlat *et al.*, 2015). With specific reference to cities, MSW generation rate vary considerably, from as low as 0,32 kg per capita per day for Addis Ababa, Ethiopia, to 0,95 kg per capita per day in Lagos, Nigeria (Kawai and Tasaki, 2016). The per capita MSW generation rate in developed countries was more than that of developing countries because generation rate depended on economic and social

prosperity of a country. In decades to come, developing countries are forecasted to match MSW generation rates of developed countries (Kumar and Samadder, 2017).

Low-income countries generate more organic waste while high income countries tend to generate a larger share of plastic waste than organic. Factors such as different levels of industrialisation, consumer attitude and consumption patterns, income level and culture, directly impact variations in waste generation (Fetene *et al.*, 2018). An additional consideration is also variations in the information gathered from different sources owing to differences in definitions and the underlying assumptions. Figure 2.8 shows the quantity of municipal solid waste generated in various African cities.

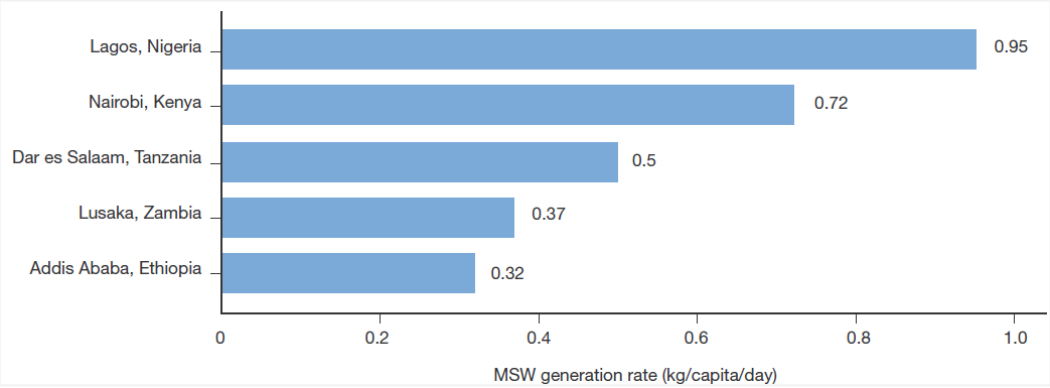


Figure 2.8: Quantity of MSW generated in various African cities

(UNEP, 2018) extracted from (Kawai and Tasaki, 2016)

2.4.1.3 Waste Composition

Waste composition dictates how it is collected and disposed. Composition typically comprises of organic, paper, plastic, glass, metal and other materials. Between 57,0% and 60,5% of the total waste generated in Africa comprises organic waste, which is more than the 30,0% to 32,0% generated by developed countries. This may be attributed to the mass consumption of fresh foods by low-to-middle income countries while high income countries are more diversified, consuming paper and plastic based products (Kaza *et al.*, 2018; UNEP, 2018). Waste composition is also influenced by

income levels, consumer attitudes and economic culture amongst other factors as shown in Figure 2.9.

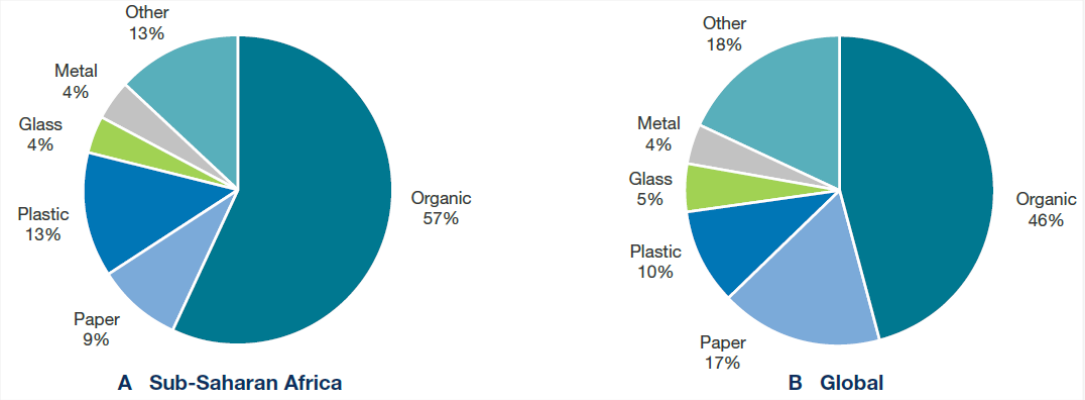


Figure 2.9: MSW composition in sub-Saharan Africa and Global

(UNEP, 2018) extracted from (Hoornweg and Bhada-Tata, 2012)

2.4.1.4 Drivers and Pressures

As stated earlier, waste generation in Africa is driven by population growth, urbanisation, a growing middle-class and changing consumer behaviour, economic development, global trade and economic development. Pressures include weak legislation, lack of enforcement, low public awareness, negative attitudes, the poor state of services, corruption, political instability and conflicts. Other pressures include insufficient budgetary provision for waste collection and disposal, inadequate and malfunctioning operation equipment, lack of effective public participation, and inadequate waste management governance frameworks. Figure 2.10 present the total MSW generation by region.

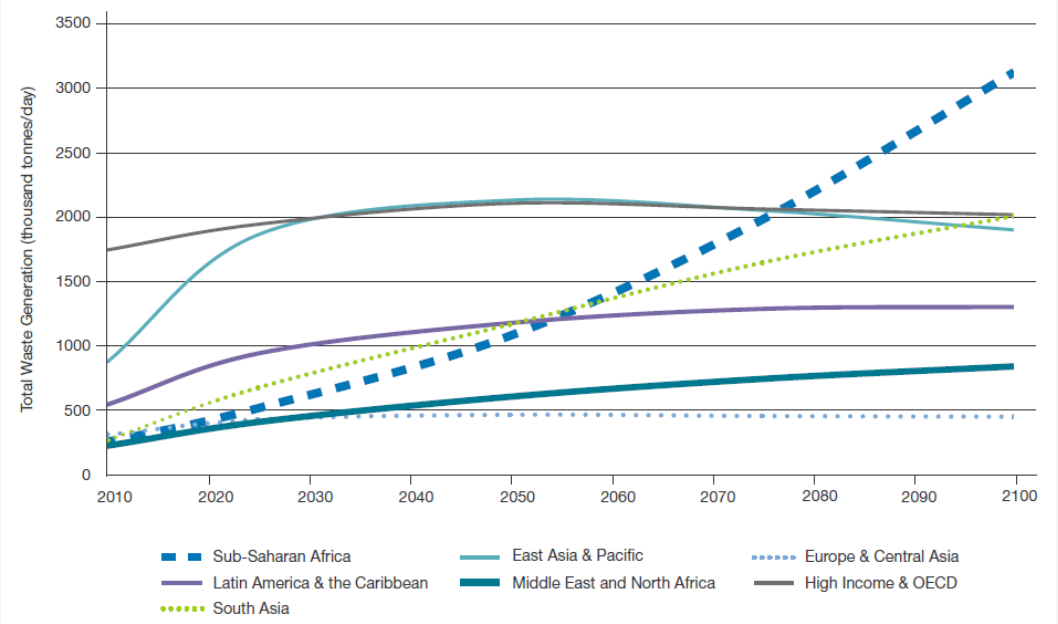


Figure 2.10: Total MSW generation by Region

(UNEP, 2018) extracted from (Hoornweg and Bhada-Tata, 2012)

As seen in the figure above, Sub-Saharan Africa's (SSA) waste generation is expected to proliferate exponentially until 2100. This is attributed to the drivers and pressures discussed earlier. Until 2025 SSA, the Middle East and North Africa will continue to generate the least waste amidst other region (less than 500 tonnes per day). Although South Asia is likely to lead the world population growth, industrial advancements alongside economic growth are just two of many determinates of waste generation. The same may be said for the Middle East and North Africa; equally dubbed as developing regions. High income OECD countries have traditionally been big waste producers (between 1,500 – 2,100 tonnes of waste per day). Europe and Central Asia's waste generation is projected as steady (500 tonnes a day) as of 2030. This may be attributed to a socio-political shift towards environmentally benign activities, financial muscle for project implementation as well as innovations in improved waste disposal, amongst others. Figure 2.11 present the change in composition of wastes in African cities.

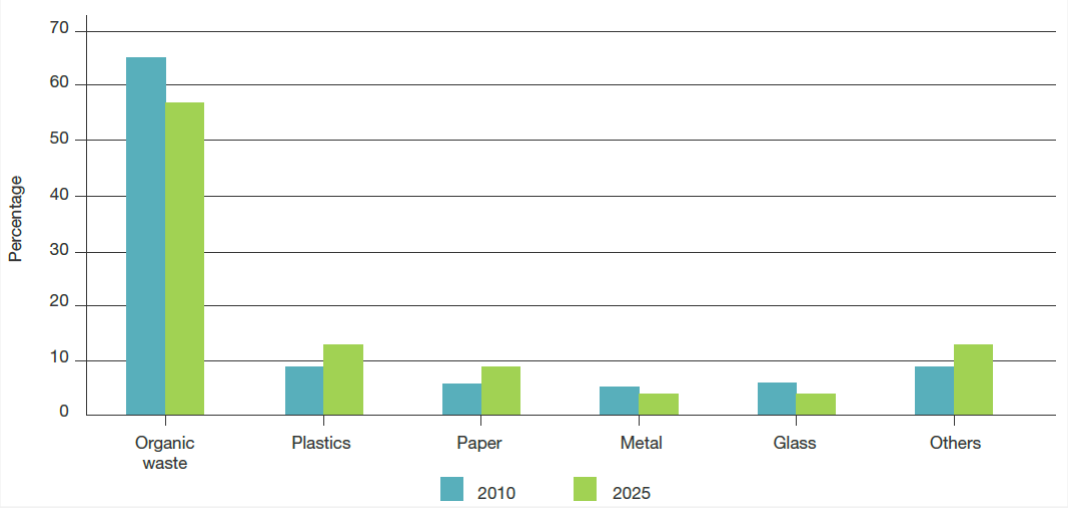


Figure 2.11: Changing Composition of Wastes in African cities

(UNEP, 2018) extracted from (Hoornweg and Bhada-Tata, 2012)

Consumer behaviour, urban morphology and the growth and development of a country's economy affect the type and quantities of MSW generated. From the figure above, it is evident that organic waste will continue to dominate until 2025. Organic waste constitutes of a larger share of the waste composition. More importantly, it is a primary feedstock for anaerobic digestion technologies, meaning that there is scope to adopt more.

2.4.1.5 Waste Management Practices and Value Chains

Counterparts in developed regions have been able to induce technological innovations and improve waste management along the value chain. Biochemical, thermochemical and chemical methods are used to treat waste but in a very efficient manner (Rousta *et al.*, 2017). The European Commission's stance to transition from linear economy to circular economy has been a major contributor. Multi-sector collaborations between academia, private sector and municipalities contributed immensely to ensure that each activity across the waste value chain is efficiently executed. Rousta *et al.*, (2017) systematically reviewed 51 articles focusing on material recycling from MSW in Sweden, particularly collection methods and users' behaviour. The authors found two extremes. On one hand, findings showed that researched focused on optimising

technical aspects only while on the other hand, it focused on user's behaviour. They concluded that waste collection infrastructure is imperative to support separation at source but there was still a research gap combining technical aspects and user behaviour, as this would positively impact how sorting systems were designed, as presented in Figure 2.12.

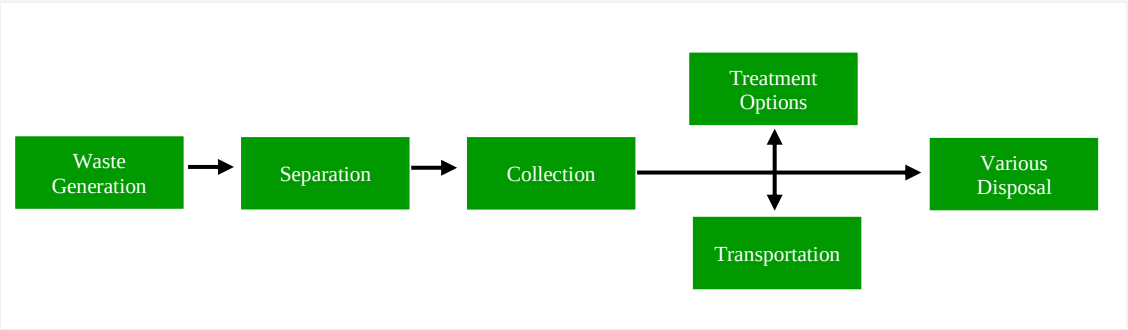


Figure 2.12: Typical Waste Management Value Chain

Adopted from Rousta et al., (2017)

In developing countries, MSW management is an important basic service that is rendered by the local municipalities. Most management and disposal methods are "*unscientific, outdated and inefficient*" (Heeb, 2009, p. 7). The most prominent and cost-effective disposal methods in developing countries are either landfilling, open dumping and recycling (Oakley and Jimenez, 2012; UNEP, 2018; Oduro-Appiah *et al.*, 2019). Over 50,0% of municipal budgets are earmarked for waste management but both municipalities and private sector have not been able to keep up with high generation rates.

Urban settlements with limited to poor road infrastructure barely have their waste collected. Insufficient land within cities limits sorting and disposal areas, thus mass transits out of town to landfills or open dumps. In an article titled 'Working with the Informal Service Chain as a Locally Appropriate Strategy for Sustainable Modernisation of Municipal Solid Waste Management Systems in Lower-Middle Income Cities: Lessons from Accra, Ghana', the researchers collaborated with solid

waste professionals to develop the WasteAware model that includes the informal sector. The aim was to improve management activities across the value chain. Informal service providers increased from 350 to 600 over two years – 2016 to 2018. Their involvement created multiple jobs and saved the Accra Metropolitan Assembly (AMA) approximately US$5,4 million in operational costs (Oduro-Appiah *et al.*, 2019), which improved resource circularity and efficiency. Poor waste beneficiation results in environmental and health related risks and thuds economic opportunities in the waste sector. This reality motivates the need for urban areas to adopt a circular economy approach.

2.4.1.6 Regulatory Environment

Waste management is one of Africa's biggest developmental challenges that needs serious attention and innovation. To address this, several policies, regulations and strategies were developed with a regional focus as well as country-specific challenges. A few regional legislation aimed at guiding sustainable waste management and value chain optimisation are listed below. Each country then uses these to develop and implement strategies or plans suitable for their context.

- African Union Agenda 2063 (2013)
- East African Community Development Strategy (2011)
- Southern African Development Community: Regional Indicative Strategic Development Plan (2001)
- Economic Community of West African States: E-waste regional strategy (2012), regional strategy on chemicals management and hazardous waste (2015) and plastic waste management strategy (2016).

Most of the literature reviewed synthesised that traditional solid waste management practices in developing regions tend to focus on waste collection and landfilling, with limited efforts to explore integrated waste management approaches (Fetene *et al.*, 2018). South Africa is one of a few exceptions. According to South Africa's National Environmental Management Act: Waste Act (2008), local municipalities are required

to develop Integrated Solid Waste Management Plans (ISWMP) which are reviewed annually. The purpose is to reduce financial resources required to manage waste, reduce redundancy by integrating innovative practices and ensure that these practices are environmentally benign (Department of Environmental Affairs, 2009; Sango *et al.*, 2014). Energy recovery from various WtE technologies is a key consideration in IWMPs but municipalities must have adequate data to determine energy potential (UNEP, 2009).

2.4.2 Energy Resource Potential

2.4.2.1 Demand and Supply Profile

2.4.2.1.1 Energy Demand

Energy is the lifeblood of economic development across the globe. All aspects of socio-economic development across multiple sectors such as residential, commercial and industry cannot operate without it. The eminent concerns of the negative impacts of fossil fuels on socio-environment aspects is prompting greater strides towards decarbonisation through energy transition. Renewable energy is an integral driver towards achieving universal access to affordable modern energy. It has three end uses: energy, heat and transport. Global renewable energy for electricity consumption increased to 24,0% in 2016, primarily driven by (1) increased hydrogen power generation in Latin America, (2) China's wind power installations, (3) rapid solar power expansion in China and the United States of America.

Furthermore, Africa is considered to be the world's second largest economy after Asia (Addaney and Cobbinah, 2019; International Energy Agency, 2019). The annual Gross Domestic Product (GDP) is expected to increase from 3,8% (2020) to 4,2 % (by 2024) more than Asia currently at 4,9% (2020) to a projected 5,2% by 2024 (IMF, 2020) due to rapid urbanisation, population growth and industrialisation – drivers for energy demand. The Africa Economic Outlook (2020) forecasted economic growth at 4,0 % in 2019 and 4,1 % in 2020. East Africa region was the fastest growing and North Africa contributed 37,0 % to the total GDP. More than 17 countries achieved real GDP growth

higher than 5,0 %. Sixty % (60,0%) of the world's 10 fastest growing economies are in Africa, namely: Burkina Faso, Ivory Coast, Rwanda, Senegal, Libya and Ethiopia (African Development Bank, 2018a). In 2019 Algeria, Nigeria, Morocco, South Africa and Egypt cumulatively accounted for 55,0 % of the continent's growth and are expected to continue growing between 2020 and 2021. All these fast economies combined are likely to directly impact countries' socio-economic, industrialisation and environmental goals.

Despite ongoing strides towards more clean energy projects, a few countries still largely depended on coal, oil and gas. Fossil fuels represented almost 40,0 % of the overall energy mix in sub-Saharan Africa, coal accounting for 13,0 % and natural gas for 16 % of the mix. Coal is most prevalent in South Africa and parts of Mozambique (International Energy Agency, 2019). Natural gas is most prevalent in Northern and Western Africa, namely Algeria, Egypt, Morocco, Nigeria and some countries in East Africa such as Kenya and Tanzania. Some of the continent's biggest oil producers are along the Western coastline (Angola, Nigeria) and Northern coastline (Algeria). As presented in Figure 2.13, North Africa and Other Sub-Saharan African countries produced close to 100 mega tonnes of oil equivalent (Mtoe) while South Africa produced a similar amount of coal in 2018. These figures may be attributed to oil demands from the transport sector which accounts for up to 60,0% of total energy demand. In 2019 new oil reserves were discovered in Nigeria, Ghana and Angola, a large percentage of which were planned for export outside the continent.

Similarly, the continent is endowed with renewable energy sources such as solar, wind, hydropower, biomass and geothermal. Renewables are increasingly catering to energy demand in regions such as North Africa, East Africa and parts of West Africa where large scale solar and wind projects have been implemented either through the AfDB or increasing presence of Independent Power Producers (IPP) (African Development Bank, 2019).

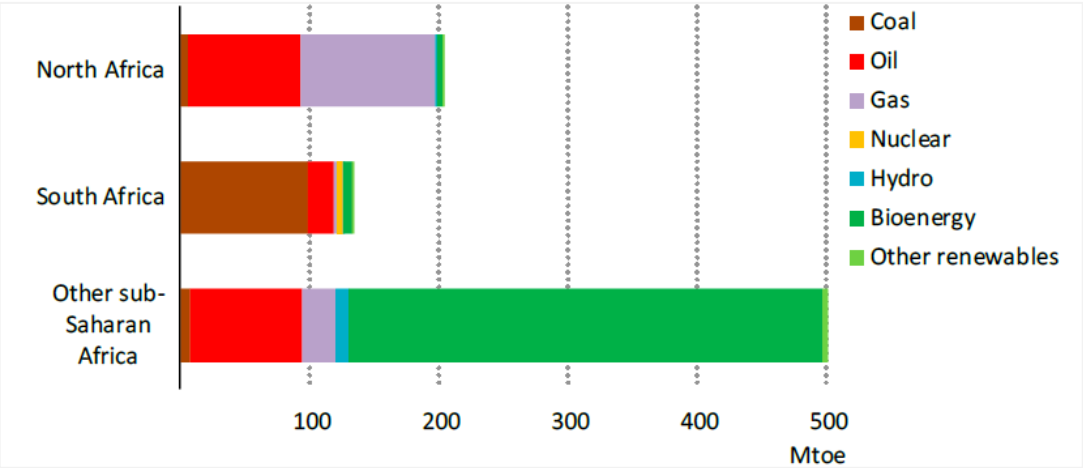


Figure 2.13: Primary Energy Demand by Fuel (2018)

(International Energy Agency, 2019)

2.4.2.1.2 Energy Supply

Globally, renewable energy has gradually contributed towards total power generation over the past decade. By 2017, renewable energy accounted for more than half of the world's new installed capacity, representing 60,0 % (167 GW) (International Energy Agency, 2019). Prices of solar and wind technologies have reduced drastically, spurring many countries to capitalise on renewable energy, subsidies are shifting from fossil fuel projects to clean energy and increased projects by IPPs have also created a competitive environment (African Development Bank, 2019). Hydropower, natural gas, biomass, geothermal and wind resources are expected to dominate capacity additions by 2030, catering to an annual electricity demand increase of 6,0 % per annum on average, and 11,0 % in some regions.

As presented in Figure 2.14, less than 25,0 % of populations in South Africa, Ghana, Kenya and North Africa did not have access to electricity. This was attributed to the counties' energy infrastructure and diverse energy supply sources. On the contrary, more than 75,0 % of populations in 13 countries do not have access to electricity, with equates to 573 million people in countries such as Burundi, Malawi, Chad, Niger and the Democratic Republic of Congo (IEA, IRENA, UNSD, WB, WHO, 2019; International Energy Agency, 2019).

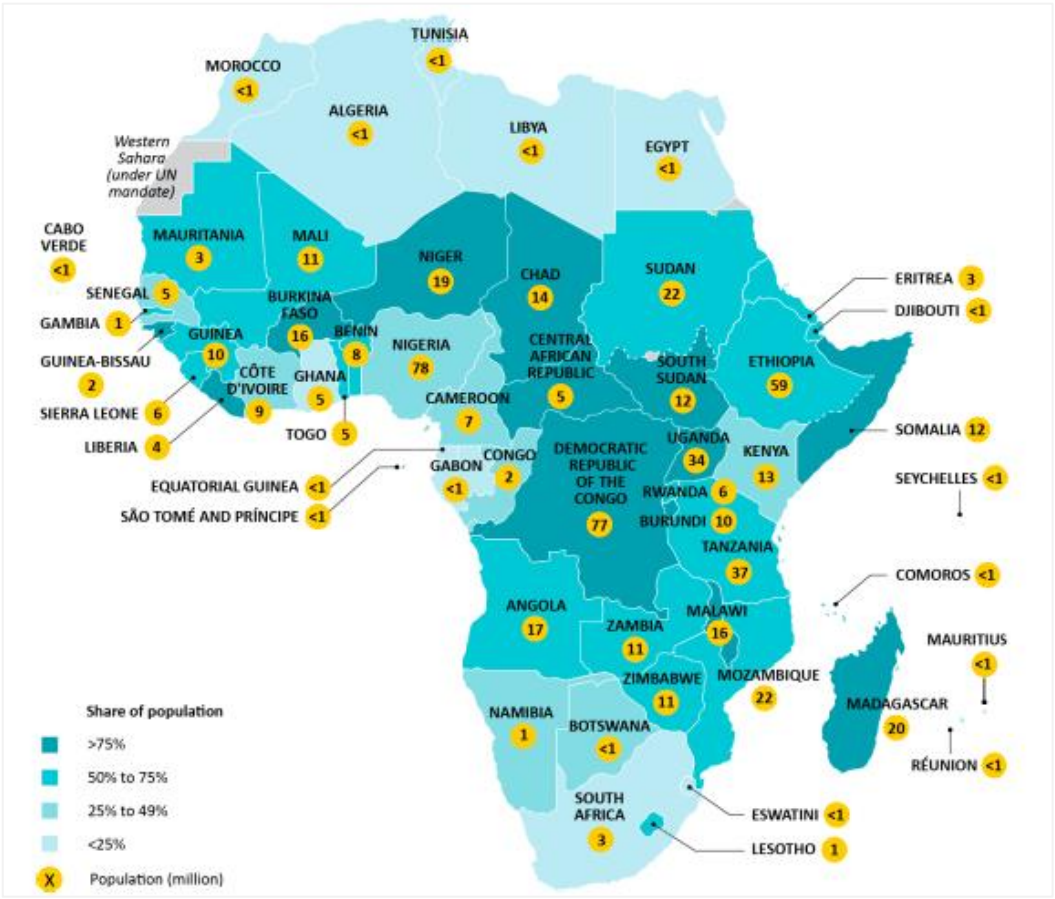


Figure 2.14: Population without Access to Electricity in Africa by country (2018)

(International Energy Agency, 2019)

Although 25,0 to 49,0 % of populations in West Africa did not have access to electricity, many countries made positive strides between 2000 and 2018. Electricity access increased from 40,0 to 60,0 % when countries such as Senegal, Morocco, Ghana, Togo, Ivory Coast and Cameroon increased renewable energy uptake (International Energy Agency, 2019). This is also evident in the number of power generation projects funded in West Africa since 1967 to date (African Development Bank, 2020). East Africa's progression equally increased favourably with Kenya, Ethiopia, Tanzania and Rwanda increasing their capacities in solar, wind, biomass, hydropower and underexploited natural gas reserves. Although power generation investment ranked 5th in the top five sectors that access investment in East Africa, the

region has the second highest number of projects after West Africa (African Development Bank, 2020). The least progressing region was Central Africa, as evident in Figure 2.15, with more than 75,0 % of populations without access to electricity. Impediments include geo-politics, poor existing energy infrastructure and costs affiliated with renewable energy, just to name a few (African Development Bank, 2019).

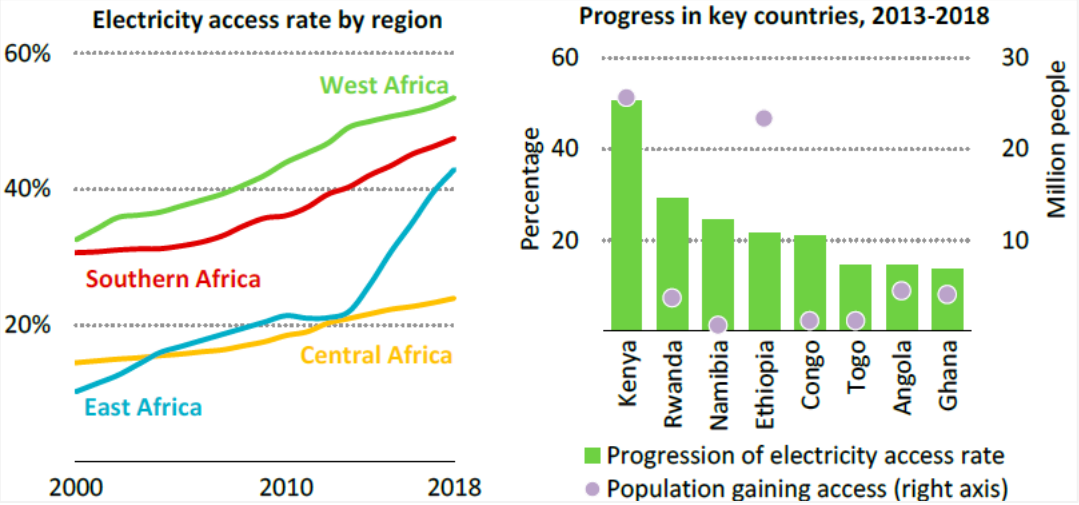


Figure 2.15: Electricity Access Progression by Region (2000-2018)

Energy supply has progressed although not at the same rate as population growth, urbanisation and industrialisation. Literature forecasted continued growth for demographic and economic trends across Africa. The Big Five were Africa's largest economies in 2019 and major consumers of fossil fuels. Similarly, some of the fastest growing economies in 10 to 30 years are in East and West Africa, and currently derive their energy mainly from renewable sources. AfDB's strides not to finance energy projects from fossil fuel further support the need to explore circularity as an enabler for the Big Five's transition. The following sub-section defines energy transition and analyses what the process entails(International Energy Agency, 2019).

2.4.2.2 Energy Access Targets

In 2012 the United Nations developed the Sustainable Development Goals as a response to development challenges facing the world namely: environmental, economic and political. In 2015 UN member countries adopted the 17 goals to be implemented over the next 15 years. Each goal has specific targets that must be achieved, as presented in Figure 2.16.



Figure 2.16: The 17 Sustainable Development Goals

(United Nations, 2015)

This study focuses on Target 7.1: Ensuring access to affordable, reliable, sustainable and modern energy for all. Sub-targets are 7.1.1 the population of people with access to electricity and 7.1.2 the population relying primarily on clean fuels and technologies for cooking. Target 7.2 aims to increase substantially the share of renewable energy in the global energy mix while Target 7.3 is to double the global rate of improvement in energy efficiency.

Focusing on Target 7.1.1: increasing access to energy remains a challenge. Connecting and providing affordable electricity may continue to be challenging because many populations are in overburdened urban areas or very remote areas. To improve access, the report recommended (1) advancing policy planning frameworks (2) increasing private sector financing, (3) decentralising renewable energy and (4) extending electrification that can cope with urban densification. Findings from the report concluded that there is still a lot of work to be done in Africa. Reliability, affordability and urban densification were noted as reasons for poor energy access. Although the report provides a good basis for global tracking but does not discuss waste or biomass as an integral part of decentralising energy access or in the context of using it as a feedstock in urban areas.

Focusing on Target 7.1.2: access to clean fuels, the authors found that the global population's access to clean cooking fuels and technologies increased from 51,0% in 2010 to 61,0% by 2017. A key factor impeding greater access in Africa is that population growth rate is higher than the annual growth in access. It is estimated that more people will continue to rely on clean fuels, but the access growth will only increase by 0,5% per annum. To improve access, the average increase must rise by 3,0%. China and India account for the largest share without access to clean cooking fuels due to their large populations. They are closely followed by the Democratic Republic of Congo, Ethiopia, Uganda, Mozambique, Madagascar and Tanzania. Despite the slow access growth, there has been a tender shift from using traditional fuels such as wood, coal and kerosene, to clean gaseous fuels such as biogas, liquid petroleum gas and liquid natural gas. Greater use of liquid petroleum gas would be appropriate for urban areas while improved cookstoves would be best suited for rural areas.

This particular section reviewed has illustrated that a shift towards clean fuels such as biogas, calls for a business-unusual approach, one that can contribute towards expanding access is necessary. The report suggests liquid petroleum gas for urban areas, however there are access and logistical issues for the African context. Countries

with oil activities can consider petroleum gas but countries without would have to consider an alternative such as biogas, which will not include exorbitant transportation costs. Corresponding to Target 7.1.1, there is no discussion of organic waste material as a potential contributor not only to increase energy access but as a clean fuel.

Benefits of increasing access to clean energy are linked to other SDGs focusing on health, gender and the environments. These include better respiratory health due to less usage of fossil fuels, diverting time from fossil fuel collection to social and educational activities, reduction in deforestation and climate change mitigation mechanism. Using organic waste material for urban energy equally complements most SDGs and contributes towards healthier communities. Rodent populations are reduced, water contamination is reduced, the burden on finding land for landfilling is reduced, anaerobic digestion technologies are suitable for hybrid systems and micro-grids, thus encouraging decentralisation and various forms of energy can be used depending on the urban morphology (electricity, biogas, heat, bio-fertiliser) and use bio-fertiliser for urban agriculture. Key terms identified for increasing access are *multi-sectoral partnership, improving supply through decentralisation* and *social acceptability*. These terms motivate for an Interpretivism Paradigm adoption because they explore how participants in a social world construct their world; different decision-makers all working towards multiple realities of energy access.

2.4.3 Energy Recovery from Waste

2.4.3.1 Waste as an Energy Resource

Waste is considered as a renewable source of energy, specifically biomass. It typically comprises of biodegradable material such as agricultural residues, municipal solid waste, animal dung and sewage water (Mas'ud *et al.*, 2015). The global energy demand is expected to increase exponentially, and the current energy supply is lower than energy demanded. Diversifying the energy mix and considering more WtE systems can contribute towards mitigating future energy crisis (Kumar and Samadder, 2017)

specifically in peri-urban areas. The downside is that it requires water and competes with farmers in terms of food security.

About 70,0% of the continent rely on biomass for cooking and lighting (Budzianowski *et al.*, 2018). South Africa, Nigeria and Egypt all have great potential for WtE initiatives, but the feedstock is not used to its maximum potential. Biomass for electricity generation has not been widely exploited in most regions in Africa, except South Africa and Mauritius, both of which use sugar cane in combustion power plants (Wesseh and Lin, 2016).

Africa's urbanisation can have positive and negative implications on sustainable development, depending on the socio-political structures in each region. The continent has the lowest access to sanitation in the world, which is driven by poor disposal methods (Cobbinah, Erdiaw-kwasie and Amoateng, 2015). Similarly, expanding peri-urban settlements pose a serious challenge to electricity provision (Smit *et al.*, 2017). It is "*therefore urgent to overcome the divide between energy and urban planning by elaborating and using new implementation tools*"(Zanon and Verones, 2013, p. 343). The concept of energising Africa has the potential to realise sustainable development positively. Decision-makers need to understand energisation in the context of urban development. Where sets of energy and waste data are available, they can be utilised to develop economic models (Nissing and von Blottnitz, 2010).

2.4.3.2 Motivation for WtE Adoption

It is possible to meet the energy demand because the continent is endowed with natural resources (Mas'ud *et al.*, 2015; Wesseh and Lin, 2016; Budzianowski *et al.*, 2018). However, these are yet to be fully harnessed. Kumar and Samadder (2017) stated that now is the time to realise the potential of WtE as an option for sustainable solid waste management and as one of the most significant future renewable energy sources, which is economically viable and environmentally sustainable. WtE has been greatly modernised and adopted in developed nations. In Europe countries such as Austria,

Belgium, Denmark, Germany, the Netherlands, Sweden and Switzerland divert waste from landfilling to either recycling or composting (Defra, 2013). On the other hand, India, Malaysia and Vietnam have been implementing energy from organic waste at a small scale compared to their European counterparts. AD offers a wide range of social, economic and environmental benefits. It has the capacity to recover nutrients, volarise organic waste and produce various forms of energy such as biogas, digestate and heat (Heeb, 2009; Bautista Angeli *et al.*, 2018). It is accessible in areas where other technologies are not, very cost effective compared to other WtE technologies and relatively simple to maintain. AD technologies can contribute towards a country's energy agenda, specifically the energy mix.

2.4.3.3 Anaerobic Digestion Adoption in Africa

Biogas integration into the energy mix is supported by environmental and socio-economic polities across various European countries. In 2017 more than 17,000 biogas plants were operating across the continent: 10,000 plants in Germany, followed by 1,600 plants in Italy and the remaining 600 plants spread between Switzerland, France and the United Kingdom (EBA, 2018). A number of researchers believe in anaerobic digestion's capability of achieving circular energy supply in cities (Pan *et al.*, 2015; Lindkvist, Karlsson and Ivner, 2019; Suárez-Eiroa *et al.*, 2019; Acharya, 2020; Hussain, Mishra and Vanacore, 2020a)

Most biogas installations in Africa are domestic anaerobic digestion systems which use human waste, animal manure and MSW, as a cooking fuel (Surroop, Bundhoo and Raghoo, 2019). They are positive steps towards increased energy access and security, especially in areas where there is a major reliance on wood fuel. In 2009, the Africa Biogas Partnership Programme was established with the purpose of constructing small-scale bio-digesters in rural and peri-urban areas. In a space of ten years (2009 – 2019) more than 60,000 digesters were constructed across the continent either through the Africa Biogas Partnership Programme or country specific National (Domestic) Biogas Programmes (Surroop, Bundhoo and Raghoo, 2019):

• Burkina Faso	10,310	Rwanda	3,365
• Ethiopia	18,534	Senegal	875
• Kenya	18,560	Zimbabwe	2,000
• Tanzania	6,441	Cameroon	164
• Uganda	7,628	Botswana	15
• Egypt	1,300	Mauritius	10

There is increasing awareness of AD's potential to address energy access and energy security. Countries such as Madagascar, Sao Tome and Principe, Zambia, Comoros, Djibouti, Seychelles and Ivory Coast are exploring small-scale or pilot projects.

On the other hand, there are very few operational medium to large scale WtE projects on the continent. Mauritius generates 20,4GWh of electricity from landfill gas, Kenya has a 2,8MW AD power plant that operates on agricultural waste while Burkina Faso generates 0,28MW electricity from abattoir and brewery waste. South Africa has a 4,6MW plant in Bronkhorstspruit that operates from livestock and agricultural waste (Mutungwazi, Mukumba and Makaka, 2018; Surroop, Bundhoo and Raghoo, 2019). Despite the high potential, very few medium and large scale biogas plants are operational.

2.5 Part Four: Urban Energy, Anaerobic Digestion and Circularity

Part Four review focused on two aspects, urban energy planning and whether principles of circularity have been explored when implementing anaerobic digestion, particularly in cities. Urban energy planning was reviewed to determine the role it plays in ensuring access to energy in cities, then exploring opportunities that anaerobic digestion can be part of energy mixes in cities – inducing circularity.

2.5.1 Urban Energy Planning

2.5.1.2 Motive for Urban Energy Planning

Sixty percent (60,0%) of the continent's urban population do not have adequate access to electricity (Mas'ud *et al.*, 2015; Aliyu, Modu and Tan, 2018). Households depend on harmful fuels such as wood and kerosene for cooking (Kumar and Samadder, 2017; Budzianowski *et al.*, 2018). That is despite large cities consume more than 75,0% of total energy produced, with an annual increase of 7,0% (Cajot *et al.*, 2017; Aliyu, Modu and Tan, 2018).

Jones (1991) states that there is a relationship between urbanisation and energy demand, specifically in Africa. Fay and Opal (2000) and Cobbinah and Amoako (2012) also found that urbanisation on the continent is typically associated with urban poverty which contributes towards the spread of informal settlements that do not have access to municipal services; inducing an increase in energy demand and poor waste management (Jones, 1991; Fay and Opal, 2000; Cobbinah and Amoako, 2012). Poor availability of energy has a negative impact on socio-economic development activities in Africa and it is one of many factors causing Africa to lag behind the rest of the world. Stable energy supply and industrialisation operate concurrently to achieve economic prosperity. Jones (1991) argues that urbanisation proliferates the demand for energy and waste production: within the residential sector, transportation sector, infrastructure, agriculture and manufacturing, amongst other reasons.

2.5.1.2 Components of Urban Energy Planning

Over the past decade, researchers have extensively studied the urbanisation-and-energy use relationship (Todoc, 2008; Madlener and Sunak, 2011; Cajot *et al.*, 2017). There is no single definition of what urban energy planning means. However, it can be borrowed or based on Thery Hetreux and Zaraté (2009) definition of "*energy planning consists in determining the optimal mix of energy sources to satisfy a given energy demand. The major difficulties of this issue lies in its multi scales aspect (temporal and geographical), but also in the necessity to take into account the quantitative (economic, technical) but also qualitative (environmental impact, social criterion) criteria*" (Thery Hetreux and Zaraté, 2009). Some researchers found that urbanisation increases energy consumption while others argued that it can improve energy efficiency across public infrastructure (Todoc, 2008; Madlener and Sunak, 2011).

Madlener and Sunak (2011) analysed the effects of urbanisation on urban structures and energy consumption. During the industrialisation period in North America and Europe, urbanisation was strongly linked to economic development. According to the researchers, such is the case in developing regions however, there has been an increasing imbalance between the two factors. Various opportunities were presented particularly the need for technological innovations, concerning innovative energy technologies. These would increasingly play an important role towards mitigating climate change effects and reducing the scarcity of resources, while fostering sustainable development on the continent. This is illustrated in Figure 2.17 below.

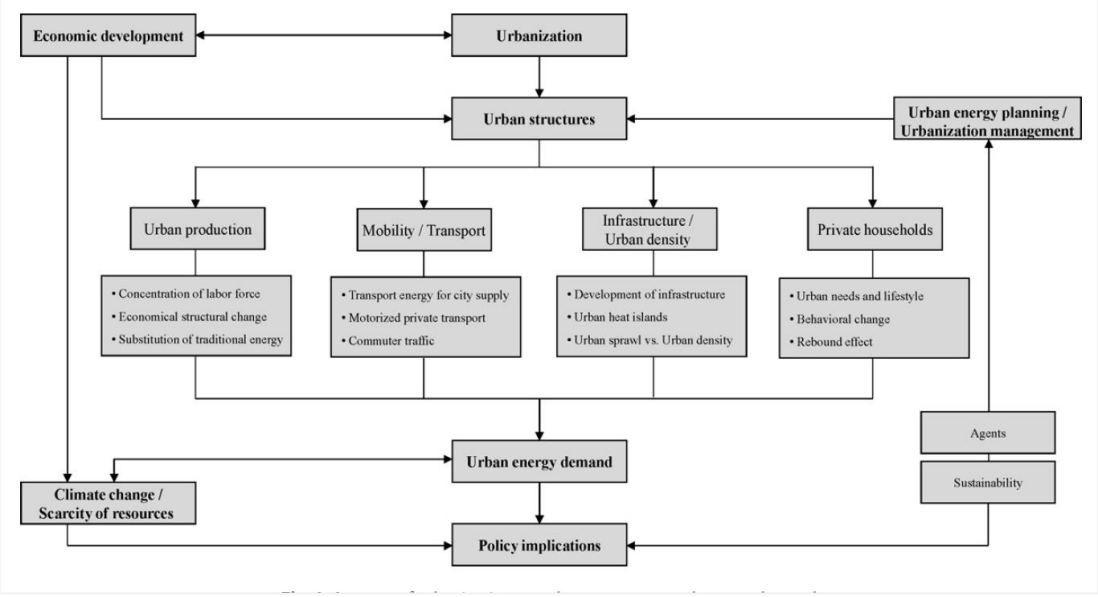


Figure 2.17: Impacts of urbanisation on urban structures and energy demand

(Madlener and Sunak, 2011)

A sustainable urban energy supply scheme includes the usage of renewable energies, such as biomass, solar, wind, or hydro, whereby organic wastes can be used as a substrate in biogas plants. Regarding the problems of waste management in many cities, this implies a double dividend (UNEP, 2009). Despite the supply-related problems of high population and building density in informal settlements, high densities offer a unique opportunity to provide electricity.

Hall and Pfeiffer (2013) stated that urban planners have an integral role to manage energy demand in urban areas because there is an inextricable link between urban energy planning and urban planning. They need to ensure (1) that urban areas are compact and sufficiently dense and (2) prevent urban sprawling as a method to promote sustainable energy consumption. Although developing countries are facing challenges concerning urban and energy planning, the preconditions and preferences differ considerably. "*Hence efficient urban energy planning requires an integrative and multi-disciplinary approach"* (Madlener and Sunak, 2011, p. 51). Thus, a new approach for urban energy planning is required; one that is participatory, multi-

dimensional and multi-sectoral (Todoc, 2008; Hall and Pfeiffer, 2013). Close collaboration and engagement between decision-makers, communities and technology designers is crucial.

2.5.1.3 Planning for Energy Integration in Cities

There is a small yet growing body of literature specifically addressing urban energy planning and the role of not only urban planners but other built environment professionals. Cajot *et al.*, (2015) stressed that "*a better understanding of these frameworks and interactions between urban planning and energy issues is useful not only for the planners themselves, but also for the scientific community who may develop appropriate decision and planning support systems, or for other private actors who may benefit from related economic and social added values*" (pg. 3367).

Available research discuss and explore urban energy planning integration from the perspectives of developed regions such as Canada, Austria, Germany and Switzerland. The Centre for Urban Energy at the Ryerson University in Toronto, Canada, developed a White Paper on Integration of Urban and Energy Planning. The paper recognised cities' important roles as incubators and catalysts for innovative solutions to 21st century challenges. Although the focus was on electrical distribution and grid connectivity, the authors acknowledged the need to integrate and coordinate energy planning with traditional urban planning (Singh *et al.*, no date). The City of Vienna adopted a Smart City Model in 2011, which would be realised through its Urban Development Plan. In the plan, spatial and energy planning were merged and are to be implemented at neighbourhood level. The municipality encourages partnerships with technical experts, private companies and researchers in urban planning and renewable energy to realise the plan (Vienna City Administration, 2014).

African City Energy is an online resource platform that aims to collate information and data about sustainable energy challenges faced in African cities. The initiative is supported by Supporting African Municipalities in Sustainable Energy Transitions

(SAMSET), which comprises of non-profit organisations, universities in Ghana, South Africa and Uganda as well as representatives from municipalities. It is the most centralised database with information ranging from Energy Planning, Renewables, Household Access and Urban Development (African City Energy, SAMSET and ICLEI, 2021). The researcher only focused on energy planning data and found tools and frameworks which can aid municipalities to better plan for energy in African cities. These include but not limited to:

- A Knowledge Exchange Framework for Supporting African Municipalities in Sustainable Energy Transitions,
- An applied methodology for supporting sustainable energy transitions in African municipalities,
- Guidelines to Clean Energy – a Practical Guide for sub-Saharan African Municipalities,
- Sustainable Urban Energy Planning,
- Taking the LEAP in Uganda: Reflections on Developing urban energy baseline and futures models for Kasese and Jinja municipalities,
- Municipality-specific Sustainable Energy Strategies, Energy Future Reports and Energy Agendas.

Although African municipalities have access to these resources, limited research and implementation reports are still emergent.

2.5.2 Circular Integration of Anaerobic Digestion in Cities

2.5.2.1 Anaerobic Digestion Technology

2.5.2.1.1 Technology Types

Energy can be recovered from waste using one of three treatment techniques, thermal conversion, biological conversion and thermo-biological or landfilling. Extensive global research has been conducted on (i) the status of WtE at global level, (ii) need of WtE technologies, (iii) generation, characteristics and compositional requirements for effective energy recovery, (iv) WtE technological options and challenges associated with them in developed and developing countries, and (v) environmental and health impacts of WtE facilities (Curry and Pillay, 2012; Kumar and Samadder, 2017).

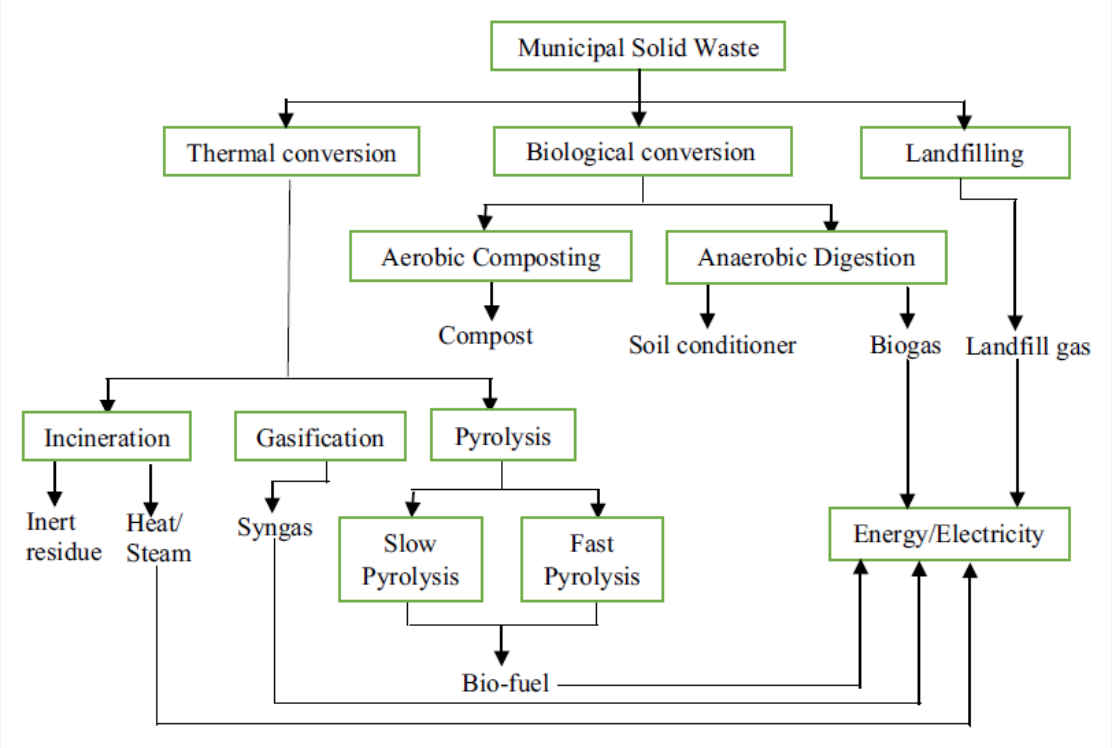


Figure 2.18: MSW treatment techniques and their products

(Kumar and Samadder, 2017)

Figure 2.18 illustrates MSW treatment techniques and their products. Two primary conversion processes are thermal and biological. Three technologies are used for thermal conversion, namely incineration, gasification and pyrolysis. The process entails using heat to convert waste material into a form of energy such as heat, electricity and biofuels. Biological conversion does the opposite and uses a biological process to digest and convert waste material into energy such as gas, heat and organic fertiliser. This can happen through aerobic (presence of oxygen) composting and anaerobic (absence of oxygen) digestion. Lastly, landfilling is considered as thermo-biological conversion but the process takes very long, between 20 to 25 years (Pan *et al.*, 2015; Matheri, 2016; Kumar and Samadder, 2017).

Thermal technologies and landfilling reduce large volumes of waste by 75,0% (Matheri, 2016) however, global disputes about their impact on human beings and the environment, has seen an increase in literature relating to biological conversions – see table below.

Table 2.4: WtE Technology By-products and Emissions

Technology	Waste Type	By-products	Emissions
Incineration	MSW	Flue gas, fly ash, bottom ash	S, N, CO, CO_2, SO, HCl, hydrogen fluid, Chlorine, Florine.
Gasification	Bio-solids sludge	H_2, CO, CH_4	
Anaerobic Digestion	Bio-solids sludge	NH_4 and biofertiliser	N, P, K

(Curry and Pillay, 2012; Pan *et al.*, 2015)

2.5.2.1.2 Anaerobic Digestion Technologies and Benefits

Anaerobic digestion is a matured technology and considered one of the most viable (Mohammed *et al.*, 2017). The biological process digests organic matter in the absence of oxygen. A typical AD technology is illustrated in Figure 2.19:

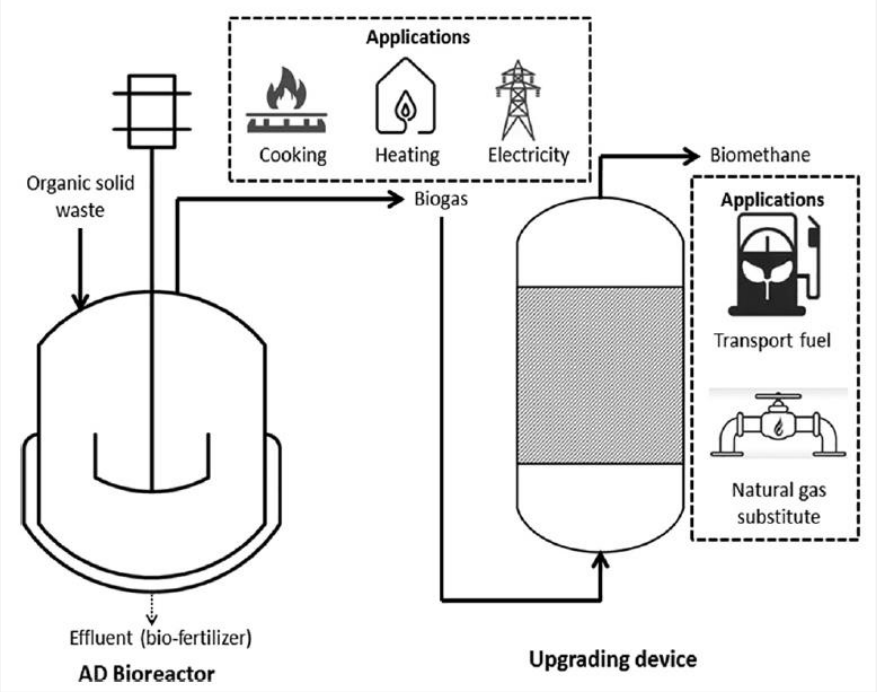


Figure 2.19: Typical Design of an AD Plant and its by-products

(Wainaina, 2020)

The earliest known digestion process was recorded between 1804 and 1808 by John Dalton and Humphrey Davy. From 1881, it was applied to wastewater treatment plants on a large scale. By 1897 India was using anaerobic digestion to supply lighting demands. Intense research and development started in the 1950s and has since increased. This shows that anaerobic digestion is not a new technology and is proven. India and China have some of the world's largest biogas programmes (Baweja, 2017; Ajay, Mohan and Dinesha, 2021). There are different types of anaerobic digestion technologies, designed to operate in different socio-physical environments, using different waste feedstock and climatic conditions. These include but not limited to:

Small Scale Digestors

1. Fixed Dome
2. Floating Drum
3. Bio-bag
4. Plastic roto moulded
5. Tubular or Balloon

Commercial Digesters

1. Lagoon,
2. Plug flow,
3. Complete mix (CSTR)
4. Up-flow sludge blanket (UASB)

(Voegeli and Zurbrügg, 2008; IRENA, 2016; Matheri *et al.*, 2018; Mutungwazi, Mukumba and Makaka, 2018)

AD offers a variety of advantages which are attainable through by-products produced. These include biogas, heat and organic fertiliser, and with combined-heat processing (CHP), electricity can be generated from biogas. Further advantages include improved waste management, reduced greenhouse gas emissions from landfilling, it can be decentralised and contextualised and the energy generated improves quality of life. Disadvantages of AD systems are that it is a very sensitive technology because bacteria require specific digestion conditions. Feedstock supply, quantity and characteristics are very important parameters that determine efficiency and maximum energy output. Incorrect supply can negatively affect the digestion process and technology. It is difficult to re-start the system when this happens. The levelized cost of electricity (LCOE) for waste-to-energy is generally more expensive than other sources. Without subsidies or other financial relief mechanisms, anaerobic digestion may not be feasible in specific contexts. Lastly, safe disposal of digestate is a hurdle which restricts greater adoption in many countries (Antoniou *et al.*, 2019).

2.5.2.1.3 Digestion Process

Biogas is produced when organic waste is broken down using micro-organisms under controlled variables (Matheri *et al.*, 2018). It comprises of a mixture of gases such as methane (48,0-65,0%), carbon dioxide (30,0-40,0%), with some traces of ammonia, hydrogen sulphide, carbon monoxide, oxygen and hydrogen (Baweja, 2017; Jahed *et al.*, 2017; Matheri *et al.*, 2018). The production takes place in four or five stages:

disintegration, hydrolysis, acidogenesis, acetogenesis and methanogenesis (Matheri *et al.*, 2018). A typical system operates as follows:

1. Feedstock is fed into a tank either manually or mechanically. It is broken down into smaller digestible particles for bacteria to react optimally.
2. When mixed with water, feedstock is broken down even into even smaller particles. Hydrolysis can take place in different ways.
3. Acidogenic bacterium further digests the material into fatty acids and produces water and carbon dioxide.
4. At the third stage, acetogenic bacterium creates acetic acids which are digested by methanogens, bacteria responsible for producing biogas.
5. The affluent remains at the bottom of the tank and is sucked out of the tank by gravity, where it is collected and placed in a storage tank. Some systems include a slurry loop design.
6. Biogas rises to the top, where it is trapped in a storage drum. Depending on the design, the biogas can either float directly above the affluent or in a water-ring outside the tank to avoid odour and loss.
7. Using a gas pipe, the storage drum is connected to a scrubber, which is designed purposefully to scrub H_2S in the biogas.
8. Thereafter, the biogas can be used for activities such as cooking and lighting or converted into electricity using the CHP (Combined Heat Process).

The process can either be continuous or batch depending on the feedstock and digester design specifications. The continuous digestion process requires the digester to be fed at regular intervals, and the by-products are also removed regularly.

2.5.2.1.4 Derivable Energy Outputs

In Fetene *et al.*, (2018)'s study, the authors reiterated the importance of valorising solid waste as an opportunity for green city development in urbanising in developing countries. Although the research focused on physiochemical characteristics of solid waste management, the findings supported energy generation and market development

for organic fertiliser. Various studies and experiments confirm that energy can be generated using urban organic waste produced in cities.

Digestate or Bioslurry

Digestate is typically rich in nitrogen, phosphorus and stabilised carbon. The chemical compositions depend on the feedstock characteristics and AD process conditions. Enhancement technologies should be capable of handling large input quantities at a low cost for market penetration. There is a growing trend to further valorise digestate by using pyrolysis to produce biofuels which can fuel CHP systems, biochar as a fertiliser or cooking fuel (Antoniou *et al.*, 2019). The authors investigated a conceptual model for digestate enhancement using downstream gasification. Digestate from an existing anaerobic digestion system was used, co-digesting agricultural waste, pic and cow manure, cereal bran and maize. Digestate from the AD system was used as input for gasification to further valorise the biogas. Findings showed that it is possible to create hybrid WtE initiatives (anaerobic digestion and gasification) which ensures a continued circulation of resources by providing renewable energy and digestate for soil amendment (higher energy recovery).

Electricity Potential

Various literature estimates that anaerobic digestion can produce two to four times more methane per tonne of MSW in three weeks than that produced in a landfill between six and seven years. (Murphy, McKeogh and Kiely, 2004) reported that 1,0 m^3 of biogas produced from anaerobic digestion process can generate 2,04 kWh of electricity taking conversion efficiency of 35,0%. About 150 kg of methane can be generated from anaerobic digestion of one tonne of MSW considering 60,0% organic matter and 40,0% moisture (Scarlat *et al.*, 2015). Figure 2.20 presents the energy recovery potential of different WtE for different municipal solid waste streams.

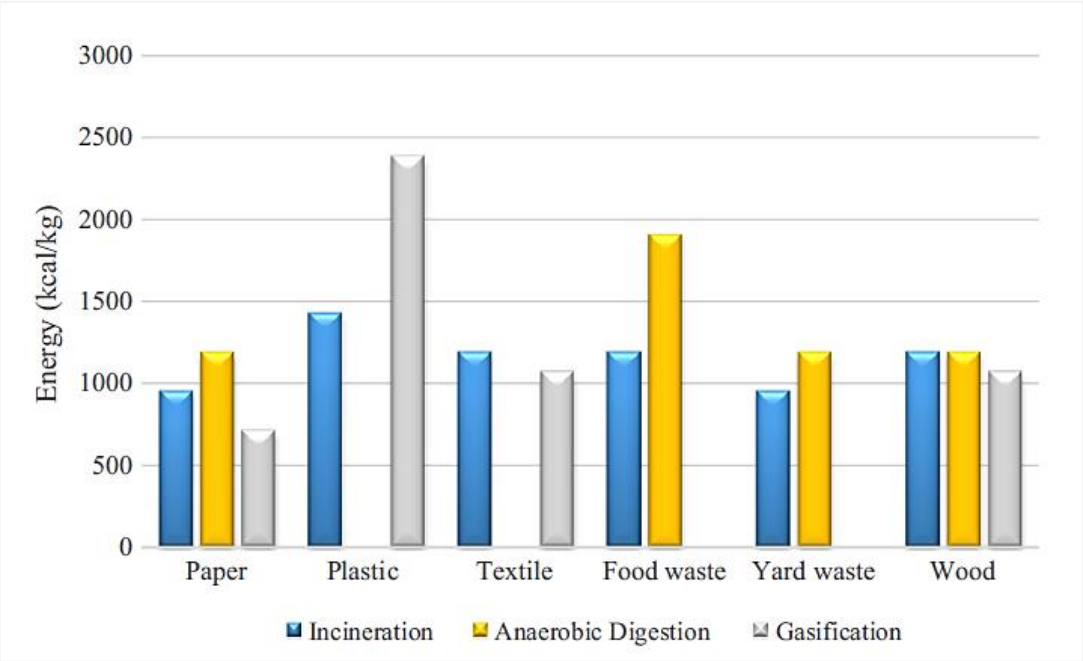


Figure 2.20: Energy recovery potential of different WtE for different MSW stream

(Kumar and Samadder, 2017, pg 405)

The figure above shows that anaerobic digestion systems can yield more energy – 1,900 kcal/kg - using organic waste than any other waste type. Paper, yard waste and wood are considered biodegradable waste material and can be taken through the biological process as well. Although incineration has traditionally been used in most developing countries, generating between 900 – 1,400 kcal/kg of energy using different waste material, the technology has proven to be environmentally devastating. Plastic waste can yield much energy however, the technology is relatively complex and quite expensive for the African context.

Energy Content – also known as Calorific Value (CV) - refers to the amount of heat generated from combusting waste (Fetene *et al.*, 2018). High Heat Value (HHV) and Low Heat Value (LHV) are used to describe energy content. Equation 2.4 is used to determine energy potential (P) of solid waste. Waste generated per day in a given area is multiplied by the LHV and CV.

Equation 2.4: Energy Potential

$$P = \left(Combustible\ MSW\ \frac{generated}{day}\right) x\ \left(LHV, \frac{MJ}{kg}\right) x\ (efficiency)$$

Co-digestion – mixing of different organic material for digestion - has a positive effect on biogas production compared to using a single organic feedstock (Jahed *et al.*, 2017). Mixing household, industrial and agricultural organic waste – dry and wet - also improves efficiency, facilitates a reliable digestion process and balanced nutrients (Jingura and Matengaifa, 2009). Biogas yield is affected by different physical and chemical parameters of organic feedstock. In an experiment conducted by (Jahed *et al.*, 2017) comparing cattle manure and urban organic waste in an Iranian city, the C:N for cattle manure was 13.7 and 18.1 or urban organic waste.

2.5.2.1.5 Considerations and Parameters for Digestor Selection

Waste Quantities and Composition Considerations

Before designing and implementing any WtE technology, it is important to know the quantities of waste, its characteristics and compositions because energy generation is significantly dependent on these base parameters (Mutezo, 2016; Kumar and Samadder, 2017). Furthermore, characteristics such as particle size, moisture content, climate conditions, calorific value and density are equally important for selecting and developing an appropriate anaerobic digestion system (Aleluia and Ferrão, 2016). Consideration should also be given to the varying socio-economic and environmental contexts between developed and developing countries, because it affects access to construction materials, geotechnical investigations and availability of skilled labour. Waste composition varies depending on the level of economic development, geographical location, urban morphology, cultural norms, energy sources and climate of an area (Pan *et al.*, 2015). Feedstock type and quality affect production days and volume.

Techno-Chemical Parameters

Availability of bacteria is critical. There are various parameters that affect the quality and quantity of biogas produced. There are standard technical parameters that must be adhered to during inception, planning and design stages, in any context. Table 2.5 present the parameters required to design an AD technology.

Table 2.5: Parameters required to Design an AD technology

Parameter	Relevance and Discussion
Dry Matter (DM) content	Digesters can be designed for dry, wet or co-digestion. Dry digestion uses solid/dry waste with a Dry Matter (DM) content > 15,0% and wet digestion uses sewage sludge and liquid animal manure (DM substrate < 15,0%).
Climate Conditions	Methane can be produced in different climate conditions. Digesters in warm regions operate optimally at a mesophilic temperature (between 25,0 ^{o}C and 45,0 ^{o}C) while those in cooler regions need a thermophilic environment (temperatures between 45,0 ^{o}C and 60,0 ^{o}C). gas production increases with temperature but if it is too high, then the percentage of methane reduces while the percentage of other gases increases. Psychrophilic environment is the least optimal, peaking 25,0 ^{o}C and lower.
pH Value	Known as the Potential of Hydrogen (pH) value, it represents the level of acidity or alkalinity in a solution. pH between 0,0 and 7,0 indicates acidity in a solution while that between 7,0 and 14,0 indicates alkalinity. For digestion, the ideal value should range between 7,0 and 8,0. pH values are influenced by feedstock characteristics and socio-economic patterns.
Carbon-Nitrogen Ratio (C:N)	Important nutrients required during digestion are: O_2, C, S, P, H_2 and N_2 because they accelerate the digestion rate. The most important nutrients are supplied by C and N. They have to be supplied in correct concentrations because they provide energy and nutrients to the bacteria. An ideal C:N ratio is approximately 30:1, *ceteris paribus*.
Organic Loading Rate (OLR)	The loading rate refers to quantities of feedstock fed into a digester per day. The rate depends on the type of feedstock and size of the technology. Literature recommends 0,2 kg/m^3. Too much or too little loading reduces production.

Parameter	Relevance and Discussion
Hydraulic Retention Time (HRT)	Also known as retention period, this refers to the amount of time the sludge material should be retained inside the digester. This can range from 35,0 to 50,0 days depending on climatic conditions and other physical parameters.
Reaction Period	*Ceteris paribus*, gas can be generated between 3,0 and 4,0 weeks. The digester size also determines the reaction period. Sludge material needs to be thoroughly mixed from inception to ensure that methanogens react optimally – maximising gas production.
Water Content	Water content should comprise of approximately 90,0% of the total weight of feedstock. Too much water content can prevent optimum gas production and too low content can increate acetic acid and thicken the sludge material.

(Baweja, 2017; Matheri *et al.*, 2018; Antoniou *et al.*, 2019)

Methods of Selecting a Suitable Digestor

There are many dimensions to problem solving which call for multi-dimensional tools and techniques. Socio-cultural, economic, technical, environmental and political factors impact the type of decisions made on different levels (Pomerol and Adam, 2004). Simon's model of decision-making is regarded as a rational process to problem solving. It involves three steps: identifying the problem and why a decision must be made to solve it, gather the necessary information required to guide the decision making, then identify alternatives and create criteria for selecting the most suitable decision.

On the premise of Simon's model, there are several methods used to make decisions on choosing a specific anaerobic digestion technology. These include but not limited to: Multi-Criteria Decision-Making Analysis (MCDA), Simple Multi-Attribute Rating Technique (SMART) which is a technique that branches from MCDA, Case-Based Rating (CBR) and lastly the Analytical hierarchy Process (AHP). MCDA is a tool used by decision-makers to identify a set of criteria and assign weighting, in order to make the most suitable decision. Weighting is assigned based on the level of importance then criteria are scored depending on how well the perform. This selection technique was

used by many researchers in selecting AD systems for different contexts. Below are two cases where MCDA was used.

Case One: Matheri *et al. (*2018) carried out a feasibility study to (1) quantify characterisation of waste, (2) determine biomethane potential from organic waste and (3) unpack the process of selecting and designing a bio-digester in Johannesburg, South Africa. The study was carried out in a lab using the batch AD process to determine biochemical methane potential. Using a quantitative approach, the authors used a Multi-criteria Decision Analysis (MCDA) approach to select a suitable technology, they found that biogas can improve energy security and Africa's energy landscape if AD technologies are carefully designed and attentively maintained.

Case Two: A study by Pan *et al.,* (2015) investigated the WtE supply chain in a district energy system by evaluating anaerobic digestion, gasification and combustion. Supply chain optimisation was done using taxonomy criterion, mathematical programming and multi-objective decision-making. The study found that WtE supply chain needs infrastructure (roads and land), water, solid waste and an electrical grid to upload power. In the European case, the WtE supply chain showed that recycling and waste reduction can co-exist in a community where energy is generated through WtE.

2.5.2.2 Business Case for Anaerobic Digestion and Circular Economy

2.5.2.2.1 Business Case to Decentralise Anaerobic Digestion

Wang (2014) proposed decentralising anaerobic digestion to improve its efficiency and socio-economic impact particularly for local communities. It is more useful that way. The author also added that decentralising and localising biogas projects can improve circularity success rates, more-so when supported by multiple role-players – public, private sectors, academia, entrepreneurs, farmers and social groups. Researchers in this sector synonymously agree that it is important for relevant role-

players to identify and know material in-flows and outflows, particularly in cities. In the United Kingdom, Switzerland and Italy, there are different waste management agencies that are responsible for various management activities across the value chain. When responsible agencies have sufficient and accurate material data, they are in a better position to plan for decentralised and localised systems in cities.

If material needs to flow across regional boarders, the required data is clear and well known. Material is then kept in the loop for longer, improving resource efficiency. The Swedish Biogas Strategy motivates "*biogas plants should be located close to waste collection points to increase commercialisation of the BfW scheme, and local municipalities should take overall responsibility for the BfW scheme*" (Swedish Gas Association, 2018).The Government of Scotland's circular economy strategy resonates with this approach and emphasises on the potential for regional biogas hubs (Scottish Government, 2016). The same approach can be taken for peri-urban and rural settlements were smaller communities support the circular economy model by providing the feedstock and being energy offtakers, as well as creating socio-economic benefits for communities (ISABEL, 2018).

This study found Rada et al., (2018)'s study on circular economy and thermochemical waste-to-energy options quite intriguing. The authors investigate consequences that the European Union's circular economy criteria have on the design of WtE plants. Only four criterion and their impacts were reviewed in this study. Firstly, the criteria encourage co-generation or tri-generation compared to electric production only. This affects the choice of location because civil and industrial technicalities relating to the site can affect whether it is suitable to co-generate or not. Secondly, the criteria call for plastic waste to be treated through matter recovery systems. This means plants should be designed with the possibility of input material decreasing over time. The third criteria states that residues should be recyclable. In this regard, vitrification can be used to transform the residue into a product. The fourth criteria call for increased respect for the European Union's waste hierarchy. The design implication is that residual waste would be used as input material and what cannot be processed, as a fuel.

Thermochemical processes can be made more efficient and circular when CO_2 is recovered from flue gases through technologies such as carbon capture and sequestration. Plants can be designed to treat waste with Lower Heating Values (LHV) but material recovery would have to be maximised and optimised during separation.

2.5.2.2.2 The Business Case to include Circular Economy Principles

Pan *et al.,* (2015)'s research found that energy supply from WtE at district level can be a viable method towards achieving circular economy systems at industrial level. The authors reviewed strategies to implement WtE supply chains for circular economy in Denmark, Germany, Sweden, Taiwan and the USA. This was done by evaluating technologies such as gasification, combustion and anaerobic digestion. Regulations and policies were found to be impediment however, eight key tasks were proposed to effectively implement the strategies:

1. Command and control (CC),
2. Economic instruments (EI),
3. Information platform (IP),
4. Technical assistance (TA),
5. Research and development (R&D),
6. Public-private partnership (PPP),
7. International collaboration (IC), and
8. Environmental education (EE).

Similarly, Acharya (2020) found that anaerobic digestion can support circular economy in the United Kingdom. The circular economy paradigm creates socio-economic and technological benefits that minimise waste and promote recycling, making anaerobic digestion the preferred technology. They are viewed as closed cycle systems because value is created from waste material. Various researchers in the biogas sector agree that anaerobic digestion offers a favourable business case for circular economy model and adheres to its principles (Acharya, 2020). The authors motivated that anaerobic digestion should be supported as a viable business case for

energy generation rather than waste management alone. When it is linked to a gas distribution grid or considered for digestate production, it improves the viability of the business case. The benefits of anaerobic digestion enabling circularity is that by-products produced are considered valuable and all waste is a feedstock for one activity or another. Recycling activities play an important role in this regard. Figure 2.21 present the conceptual framework of relationship between environment, WtE supply chains and Circular Economy System (CES).

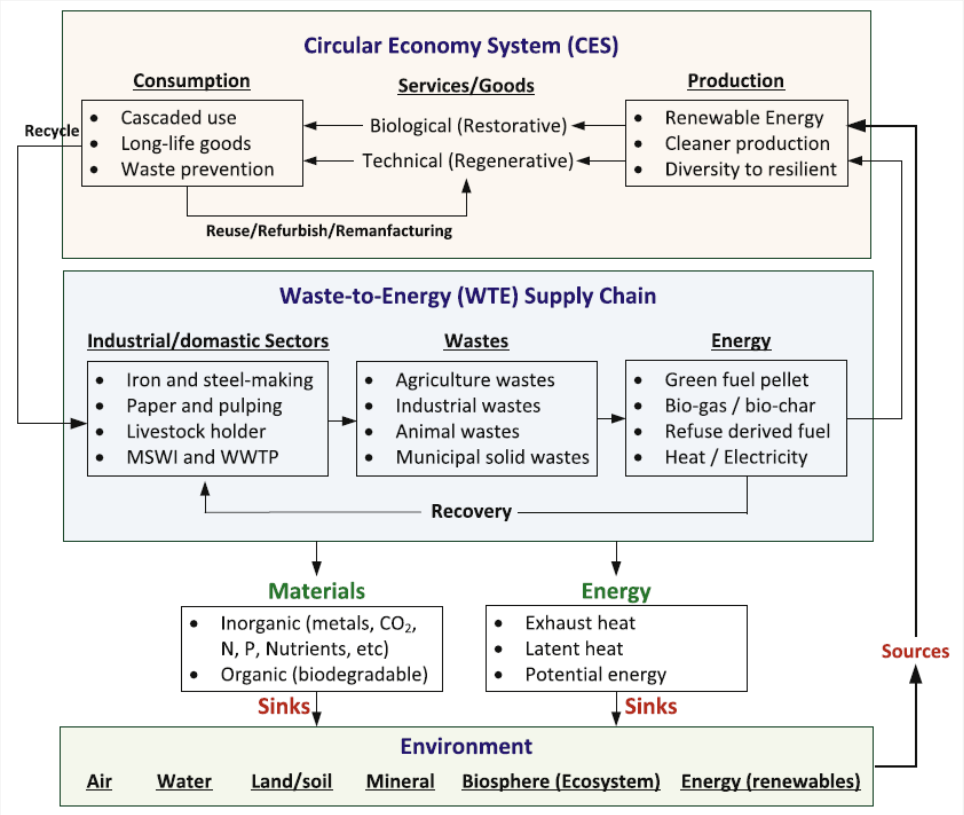


Figure 2.21: Conceptual framework of relationship between environment, WTE supply chains & Circular Economy System (CES).

(Pan *et al.*, 2015)

Pan *et al.*, (2015) present conceptual framework showing the relationship between environment, WTE supply chain and CES. A closed-loop of biological and technical materials flow and exist within the industrial ecology. The natural environment, energy

and carbon emissions are linked so as to achieve the CES. Infrastructure such as road and land access, water availability, waste feedstock and grid connectivity in the event of power generation (depending on the energy need and demand). This has a direct and positive impact on waste collection, sorting and recycling activities where WtE projects are located.

To fully realise these benefits, sustainable and quality feedstock supply is critical within a circular economy. Anaerobic digester operators must have accurate data pertaining to renewable and non-renewable feedstock streams, supply and quality when designing the system (Suárez-Eiroa *et al.*, 2019). This improves the resource efficiency because the focus is on increasing renewable material circulation. However, it is not possible to achieve 100,0% efficiency. When deciding to select the most appropriate technology, a Resource Efficiency Assessment should be done and encompass economic, environmental and energy aspects (Lindkvist, Karlsson and Ivner, 2019). Such an assessment ensures a sustainable supply chain and socio-economic benefits while reducing unwanted materials such as pathogens, metals and other residues.

A most interesting business case identified in the review is the role and importance of small and medium enterprises (SMEs) in using AD for energy generation and decentralisation (Hussain, Mishra and Vanacore, 2020a). Findings from their work illustrated that there is a ‘value leakage’ experienced along the AD process, which equally presents an opportunity for small businesses to capture in a circular manner. Greater participation by SMEs would yield socio-economic and environmental benefits. By adopting circular economy principles across the WtE value chain, businesses can capture the value leakages currently experienced (Hussain, Mishra and Vanacore, 2020a).

Nevertheless, this is not without its fair share of challenges. Conflicting objectives in waste management and energy policies and regulations at various levels, incentives that are more pro incineration-technology than anaerobic digestion, favourable biogas market and poor investment into recycling infrastructure are just a few (Pan *et al.*, 2015; Acharya, 2020). Multi-sector role-players are required to reduce these challenges but prior to that, biogas and circular economy should be viewed from a regional perspective. One such key role-player is the local municipalities who "*can play an active role in regional planning, identifying potential biogas sources and explore new opportunities*" (Acharya, 2020, p. 76). This entails assessing the potential for biogas markets in different geographies and across different socio-economic profiles, increase uptake of biogas by driving market-driven instruments and improved recycling programmes, which result in better feedstock steaming. In doing so, quantities, quality and calorific values are better determined, and efficiency can be maximised.

2.5.2.3 Examples of Decentralised Anaerobic Digestion in Cities

As reflected in previous chapters, the continent possesses immense potential for biogas and bioenergy production for off-grid electricity systems and cooking fuels (Surroop, Bundhoo and Raghoo, 2019). Considering strategies for implementing WtE supply chain within a circular economy simultaneously solves energy demand, waste management and greenhouse gas emission dilemmas (Pan *et al.*, 2015). Anaerobic digestion is an important process for promoting and developing a circular economy because it addresses waste, energy, food production and nutrient recycling challenges in a circular manner (Antoniou *et al.*, 2019). Below are four case studies that examined the integration of AD in cities across different continents and socio-environmental factors.

***Example 1**: A City in the United Kingdom (Europe)*

Research by Hussain et al. (2020) provides the most tangible findings that relate to this study. The authors used a case study approach to explore how WtE can realise circular economy benefits, supported by SMEs. Interviews were conducted with business

owners, technology experts and staff. They were identified based on their involvement in AD design and processes. Their findings contributed towards developing a Circular Anaerobic Process – see Figure 2.22.

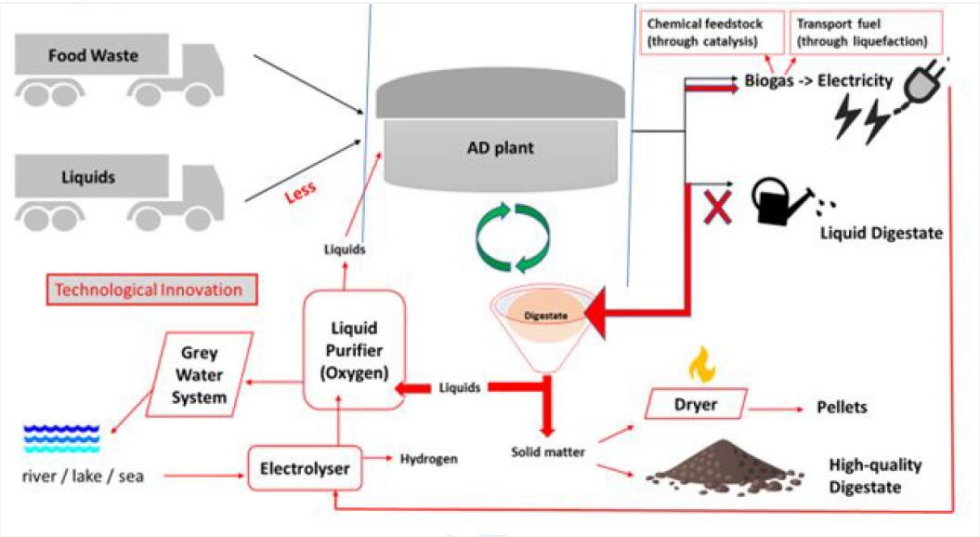


Figure 2.22: Circular Anaerobic Digestion Process

(Hussain, Mishra and Vanacore, 2020a)

The small businesses interviewed had sustainable development and circularity as part of their company vision and offerings. Figure 2.22 illustrates the proposed circular anaerobic digestion process that can be implemented by SMEs going forward. Company A's typical electricity production process comprised of processing 50,000 tonnes of food waste per annum and converting that into digestate and electricity – represented by the grey lines. After conducting a value chain leakage assessment to determine additional sources of revenue and by-products, a circular anaerobic digestion process was proposed – represented by the red lines. Opportunities included liquifying biogas and selling as transport fuel, convert biogas into chemical feedstock for other industries and convert digestate into pellets or high-quality organic fertiliser. Trustworthy and long-term relationships played a pivotal role in achieving efficiencies along the WtE value chain. Without these relationships, value leakage was experienced, thus impeding circularity.

***Example 2**: Germany and Norway (Europe)*

Obereschach, a region in Villingen-Schwenningen district, Germany has had three biogas communities since 2014. A study conducted by Bautista Angeli *et al.*, (2018) analysed the technical processes involved in implementing AD systems at urban scale. A concept known as Eco-Neighbourhoods or Eco-Villages developed in the 1990s. Its purpose was to address MSW at a neighbourhood or village level, assisting inhabitants with improved management and disposal. Socio-environmental and political stances around sustainability and urban morphology were some of the key drivers. The researchers identified 15 AD projects in and ex-situ across Europe – United Kingdom, France, Germany and Sweden. Parameters such as AD technology size, number of urban dwellers, project status (abandoned, operating or developing) as well as start date were considered.

Bautista Angeli *et al.*, (2018)'s findings showed that AD systems varied in size in different cities. In Germany, AD systems were designed for between 2,000 and 5,000 inhabitants from as early as 1985 in-situ. They were designed as part of a concept known as Bioenergy Villages, thus the relatively small number of inhabitants. Swedish cities of Malmo and Sjostad had inhabitants ranging between 300,000 and 10,000. The projects were implemented on a district level from the mid-1990s and continue to operate. They were designed and implemented ex-situ in response to social and environmental ambitions and initiatives. The authors analysed operational and technical elements in order to determine technological sustainability.

Table 2.6: Sample Operational Elements of Valorisation Units

Name	Process studied	Wastes	Collection	Storage	Pretreatment	In flow	Reactor	Condition	Biogas production	Digestate/lixivia	Biogas valorization
Bedzed	Living Machine[1]	Wastewater	By pipe directly from household; district area restricted	–	–	–	–	–	–	–	–
LEAP	AD in situ	Food waste	Transport by inhabitant; collection from local deposits (bike)	Pre-feed tank with grinder		–	2m^3 reactor	–	–	Composting fertilizer	CHP unit
Les Grisettes (Montpellier)	AD in situ	Household waste and green waste	Collection truck; district area extended	Mechanical-biological treatment and heating		140,000 tons/year of household waste (organic + inorganic)	Based on the Valorga® process Dry condition co-digestion		Annual production: 11800000 m^3 of biogas estimated	Composting 33,000 t/year	CHP unit generate yearly 22 GWh as electricity and 12 GWh as heat. Used for local installation and dwellings

(Bautista Angeli *et al.*, 2018, p. 5)

These include:

- Waste (type and description),
- Collection (transported by a truck or pipeline),
- Storage (site and duration),
- Pre-treatment,
- Reactor, condition (dry or wet),
- Biogas production (daily, monthly or annually),
- Digestate (re-use or dispose) and
- Biogas valorisation (conversion to electricity).

It is important to note that the sustainability of WtE technologies is highly contextual, thus the need to investigate these technical parameters in a given context.

Table 2.7: Sample of Characteristics of Deposits identified at Urban Scale

Deposits	Area	Collected from	Quantity	TS	VS	CODt	CODs	pH	TN	NH4-N	TP	Methanogenic potential
Wastewater (typical values)	French	Households	–	TSS: 3.5 g/L (2.1) 0.35%*	–	0.84 g/L (0.34)	–	7.9 (0.4)	–	70 mg/L (22)	12 mg/L (4)	–
Wastewater	Sneek	Vacuum toilets	7.8 L/cap/day 5 L/cap/day	–	–	9.8 gCOD/L (2.6)	3.4 gCOD/L (0.47)	8.8 (0.22) 8.6	1.90 g/L (0.19)	1.4 g/L (0.2) 0.85	0.22 g/L (0.07)	1.8–2.1 m^3 CH_4/m^3 blackwater
						7.7 gCOD/L (2.5)	2.3 gCOD/L (0.81)	(0.53)	1.20 g/L (0.18)	g/L (0.2)	0.15 g/L (0.06)	10–13 L CH_4/ cap/d

(Bautista Angeli et al. 2018, p. 7)

Table 2.7 is more specific, focusing on the chemical parameters of waste on an urban scale. Bautista Angeli *et al.*, (2018) investigated whether the type of waste generated comprised of favourable characteristics that would ensure maximum biogas output within the urban area. Wastewater, grey water and food waste were the key waste produced by households. AD was identified as a suitable technology to treat the waste as well as valorise it. Some of the parameters were considered: Total Solids (TS), Volatile Solids (VS), the pH level as well as methanogenic potential. Methanogenic is derived from methanogenesis, a process of formulating methane gas by methanogen microbes. It is the final step in biomass decomposition. Calculating the methanogenic

potential can assist to determine the maximum biogas yield, subsequently the quantities, usage and quality.

Bautista Angeli *et al.*, (2018) developed urban-specific AD models for three different areas. Model 1: in Flintenbreite (Germany), AD technology was incorporated into the eco-neighbourhood concept. An operational model was specifically developed based on the researchers' findings. Inhabitants in the eco-districts produced two types of waste: wastewater or black water, and food waste. The waste was placed in a conditioning tank before it was pre-treated in preparation for onsite digestion. Two forms of energy were produced, namely biogas which was used for co-generation (heat and electricity) and bio-fertiliser which was recycled into agricultural activities – see Figure 2.23.

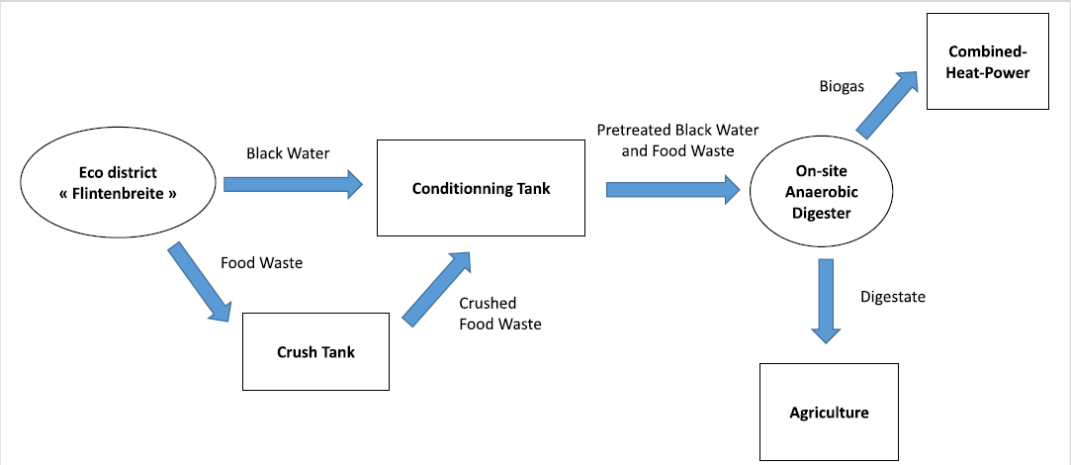


Figure 2.23: WtE system of Flintenbreite

Model 2: the model in Eva- Lanxmeer (Germany) was developed as a mixed use social-geological district with 250. It was also dubbed as a 'biological city farm; due to its sustainable approach. The district planned a 70 m^3 biogas installation to treat black water, organic waste and park biomass. Heat energy was planned for residential use, biogas was cleaned and stored to produce electricity through the CHP process and the leachate for agricultural irrigation. The AD business model was designed to fully

valorise various waste feedstock to maximise energy and nutrient recovery – see Figure 2.24.

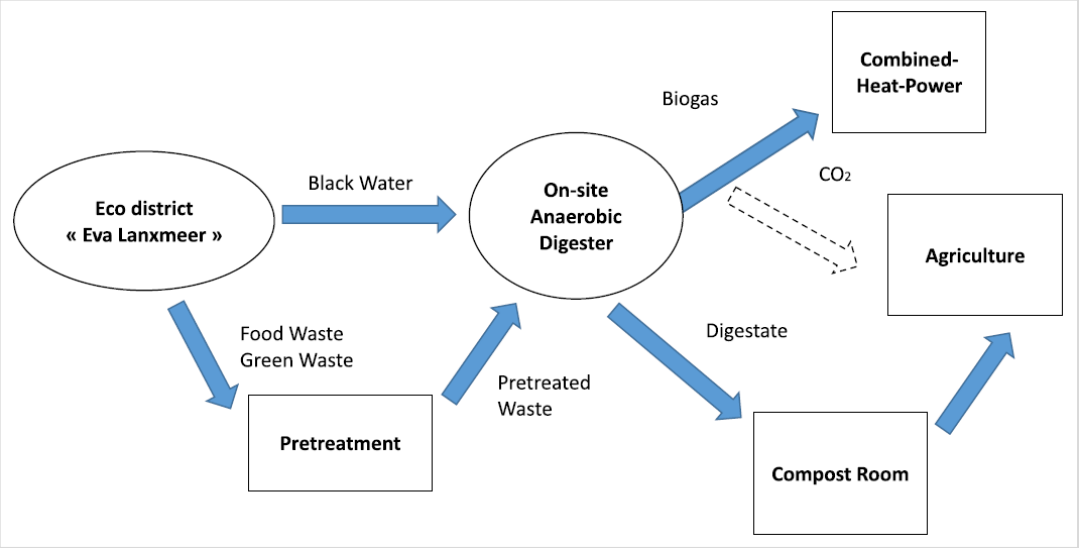


Figure 2.24: WtE system in Eva-Lanxmeer

Bautista Angeli *et al.*, (2018) described the importance of socio-political components. For an AD system to be successful, participation is required from inhabitants from the collection right through to sorting. This also entails sensitising and informing inhabitants about how an AD system works, the benefits and type of maintenance required. Unfortunately, due to poor economic and political will, the system was not implemented. However, the project was extensively studied and documented as it served as a model for other eco-districts.

Model 3 was based in Malmo - Bo01 (Norway) The project consisted of transforming old ports into sustainable neighbourhoods. A technical approach to waste management and exploration of local renewable energy resources was examined. The neighbourhood was home to 1,303 dwellings with a density of 600 units over nine hectares. It comprised of educational, administrative, cultural, commercial and recreational areas. Figure 2.25 presents the WtE system in Bo01+Fullriggaren.

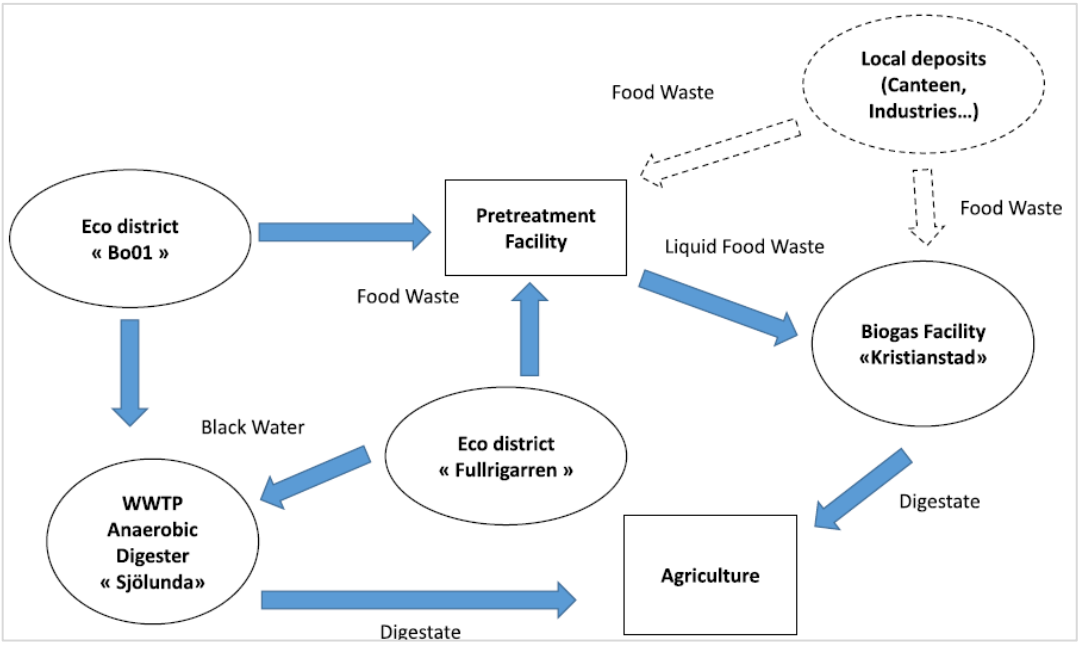


Figure 2.25: WtE system in Bo01+Fullriggaren

The model adopted a co-digestion approach, as did project two. Food waste from residential units and commercial facilities (canteen and industries) was connected to the district's wastewater treatment plant (WWTP) where the co-digestion took place. Inhabitants were equipped with either food crushers or paper bags, which encouraged separation at source and simplified transportation to the Kristiansand Biogas Plant. The plant produced electricity and heat-energy, but it was insufficient for district consumption. Instead, the biogas was deferred as a fuel for public transportation, namely busses. The digestate produced an organic fertiliser for the agriculture sector.

Overlaying the scientific literature and technical information presented in the three projects allowed the researchers to identify the main variables driving the systems. This was highlighted within existing economic, social and political contexts. There is a multitude of processes involved in urban energy and waste management. A summary of considerations is provided in Table 2.8:

Table 2.8: Technical Considerations for AD Selection

Activity	Considerations	
Waste collection	i. the quantity available, the seasonality, and current waste management already realised; ii. the collection points; iii. the physical-chemical characterisation; iv. and the methanogenic potential.	Key waste for AD system in urban areas: i. wastewater (kitchens and toilets) ii. grey water (kitchens and shower/bath) iii. Food waste (vary according to socio – economic & seasonal parameters) iv. Green Waste (garden waste)
Collections	Two ways to collect waste in urban areas: i. Central collection point ii. Decentralised collection points, typically located outside urban areas. This reduces transportation time and costs.	
Storage and Pre-Treatment	For effective AD deployment in neighbourhoods, storage and pre-treatment is crucial. i. Location is important ii. Storage: buried or hermetic tanks iii. Influences: socio-political Depend on waste type and quantities	
AD Process	Co-digestion of dry and wet waste is highly recommended to improve CV and biogas output. i. The AD size is dependent on type of waste being treated ii. Mesophilic temperature is desirable because it is favourable for costs and performance (35^{o}C) Thermophilic is equally good and ensures higher biogas output (55^{o}C)	
Post-treatment, nutrient recovery and energy savings	Digestate valorisation: i. Compared to organic fertiliser which can be used for urban agricultural activities Biogas Valorisation limited by: i. the methane fraction; (ii) the cost of gas	

Activity	Considerations	
	ii. post-treatment such as H^2S removal, or upgrading by CO_2 removal; and iii. the transport of produced energy The quantity of biogas produced by a small unit involves that energy recovery is mainly done by CHP to transform biogas into heat and electricity. Ex situ, the valorisation process seems to have been chosen depending on local users' needs, grid, or energy transition policy.	
District Approach & Conception	To develop AD projects with the aim of treating urban waste, stakeholders must consider: i. technical context ii. social context iii. economic context In case studies: i. government support through MSWM and energy policies ii. technologies are limited by the location a. in-situ projects available for small scale projects b. ex-situ projects available for larger projects c. successful ex-situ projects require a minimum of 100,000 inhabitants residing in a highly dense area iii.	

***Example 3**: India (Asia)*

The first AD system was installed in Bombay, South India in 1859 and has become widespread across Asia. From 1975 various biogas programmes were created by governments in India, China and Nepal. The programmes focused on using animal manure and agricultural residue from farming activities. Changing urban and demographic profile has seen a global migration pattern from rural farming to urbanised industrial and commercial economic activities. In India specifically, municipalities are responsible for waste management and governed by legislation that prohibits landfilling biodegradable waste and encourages separation at source as well as biological treatment options such as anaerobic digestion, composting and

vermicomposting. Ministry of New and Renewable Energy has been promoting biogas systems since the early 1980s, offering subsidies, training and awareness programmes and supporting implementing agencies. (Voegeli and Zurbrügg, 2008) found that AD adoption and use of urban organic material as feedstock in urban settings remains poor. There is little to no knowledge highlighting opportunities, challenges as well as operational and technical feasibilities.

Heeb (2009) investigated decentralised AD for commercial waste. The author focused on a renowned NGO called BioTech which specialised in implementing these technologies. The author concluded that decentralised AD is a promising technology that can handle large quantities of organic waste found in MSW. Parameters assessed were technical, economic and operational, focusing on a commercial scale AD plant in Thiruvananthapuram (South of India). The study found that decentralised AD systems are suitable to treat commercial waste. In order to ensure sustainability, there is a need to improve the economic attractiveness of commercial biogas plants by reducing initial investment costs, selling the bio-fertiliser and implementing CDM projects. The systems comprised of different processing capacities: household (1–5 kg/d), institutional and municipal level (up to 3 t/d). Feedstock ranges from restaurant, abattoirs, markets and ablution facilities (Voegeli and Zurbrügg, 2008). Table 2.9 presents a comparison of different market and institutional level plants.

Table 2.9: Comparison of different market and institutional level plants

Location	In operation since	Volume [m^3]	Feedstock	Pre-treatment	Daily load [kg/d]	Generator power [kW]	Use of electricity	Remarks
Market of the Sreekaryiam grama panchayat, Trivandrum District	2005	25	Fish waste, occasionally small quantities of fruits and vegetables	No Pre-digester available	86	5	Lightning of 12 lamps (2x11W) in and around the market during 3.5 hours in the evening	Subject of the monitoring
Market of the Kottarakara grama panchayat, Kollam District	2007	2 x 25	Mostly fish waste, smaller quantities of vegetable and fruit waste	Pre-digester for vegetable and fruit waste in use	100	5	50 lamps (2x11W) in the market and the surrounding streets, during 3.5 hours in the evening	
Market of the Chdaamangalam grama panchayat, Kollam District	2008	25	Slaughterhouse waste	Pre-digester available but not in use	100	3	24 lamps (2x11W) in the market and the surrounding streets, during 3.5 hours in the evening	
Market of Thrikkarakara, Chdaamangalam grama panchayat, Ernakulam District	2008	25	Fish, vegetable and fruit waste	Pre-digester for vegetable waste in use	80 (fish) 60 (fruit and vegetables)	5	50 lamps (2x11W) in the market and the surrounding streets, during 3.5 hours in the evening	Massive froth formation occurred, probably due to overfeeding
Govt. Ayurveda College, Trippunithura, Ernakulam District	2007	2 x 25	Food waste from the hospital, waste from the production of ayurvedic herbal medicine	Pre-digester for herbal waste in use	200 (food waste)	5	100 Lamps (2x11W) inside the hospitals and 100 at the surroundings. Lamps inside are used as a backup for power cuts.	Excess gas is used for cooking with four biogas stoves

(Heeb, 2009, p. 6)

As seen in Table 2.9, the study explored district-level projects specifically at marketplaces and in some instances, collages. Digestors were fed with a minimum of 80kg/d of feedstock such as food waste, abattoir waste and in some instances, hospital waste. Fish was a popular feedstock due to its abundant availability and economic viability. An average of 3 – 5kW of electricity was generated from 23,0m^3 digestors and used to light the markets at night.

Example 4: *South Africa (Africa)*

In May 2019, the Minister of Environmental Affairs published for public comment, Minimum Standards the Consideration of Environmental Aspects in the Preparation and Review of Spatial Development Frameworks. The Standards aim to provide guidance regarding the identification and integration of environmental aspects within spatial development planning. Furthermore, the Minister also gave notice of her intention to prescribe general requirements for undertaking an initial site sensitivity verification and for protocols for the assessment and minimum reporting requirements of environmental impacts for environmental themes for activities requiring

environmental authorisation (Department of Environmental Affairs, SANBI and Department of Rural Development and Land Reform, 2019).

2.6 Chapter Summary and Literature Gaps

Part One: The Circular Economy

It is evident that circular economy is an increasingly growing trend amongst researchers and organisations especially as an enabler for realising Sustainable Development Goals. The concept is flexible in nature and can be applied across many contexts. Adopting CE offers a plethora of benefits for cities and their citizens, for the environment, for economies and for private sectors. Amongst all authors, there is a call for mindset shifts from linear to circular at levels such as product, company, government and city. Although there is no accepted methodology to measure circularity, researchers are exploring measurement-by-association, considering methods such as Circular Economic Values, Life Cycle Assessments and Sustainability Reporting Indicators to name a few. Some prominent methods used range from systematic literature reviews and case study analyses (Merli, Preziosi and Acampora, 2018; Manavalan and Jayakrishna, 2019), to interviews and survey questionnaires (Mativenga *et al.*, 2017; Geissdoerfer *et al.*, 2018) as well as critical and cost benefit analyses (Korhonen, Honkasalo and Seppälä, 2018; Xu *et al.*, 2018). Two key research gaps were identified:

Gap One: Circular Economy Research focusing on Africa.

Most authors researched the concept (1) on a global theoretical perspective, (2) with specific relevance to European, Asian or North American country, or (4) focused in particular industries such as environmental sciences. Other than Mativenga *et al.*(2017), Mutezo and Mulopo (2021) and Horváth, Mallinguh and Fogarassy (2018) who studied circular economies in specific industries in South Africa and Kenya, there is limited literature that contextualises various perspectives on CE in Africa. Given

that the concept is still emergent globally, an opportunity is equally presented to contribute new knowledge.

Gap Two: Circular Business Model for Energy Recovery

Most literature analysed and explored circular business models from mainly a (1) product, followed by (2) business model perspective, and (3) disciplines like manufacturing industries, environmental sciences and the traditional waste management. Although some existing literature discussed CE and energy intensive industrial activities such as industrial ecology (Petit-Boix and Leipold, 2018; Walmsley *et al.*, 2019) and manufacturing (Mativenga *et al.*, 2017; Cristóbal *et al.*, 2018; Manavalan and Jayakrishna, 2019) as well as agriculture (Blades *et al.*, 2017; Xu *et al.*, 2018), limited reference is made to business models for energy recovery (Blades *et al.*, 2017; Antoniou *et al.*, 2019; Reim, Parida and Sjödin, 2019; Acharya, 2020). This also presents an opportunity to explore CE and energy recovery in a broader perspective, and from an African perspective as well.

Part Two: Urban Trends and Circularity

Literature predicts increasing demographic trends, waste generation and energy demand across the continent. This is expected to exert pressure on existing physical structures in cities. Organic planning and slow spatial transformation over time also exacerbate the pressures. The review noted the importance of cities to address urban waste and energy flows as well as the role of urban planners. Current urban morphologies are still deemed weak and exclusive of intentional planning of waste management and energy particularly in developing regions. However, emerging literature focusing on urban sustainability and innovative planning approaches (Lwasa and Kinuthia-Njenga, 2012; Laffta and Al-rawi, 2018) could catalyse better waste management and more energy planning. These can be included in various development plans. Urban metabolism builds on morphology because it is necessary to then focus on how materials and energy flow in cities. Circular economy was found to complement urban metabolism based on principles of circularity; the need to be

resource efficient and viewing waste products as input material for other activities. Three frameworks to guide design, implementation and assessment of circular metabolism in cities were Circular Urban Metabolism (Lucertini and Musco, 2020), Multi-level Framework for Metabolisms in Urban Energy Systems (Pulido Barrera, Rosales Carreón and de Boer, 2018) and an urban material flow analysis framework and measurement method (Wang *et al.*, 2020). Although concepts of urban morphology and urban metabolism are still (re)emerging, traditional approaches to planning cities are no longer adequate if waste management and energy recovery are to be implemented sustainably.

Gap One: Inadequate Data about Urban Morphology and Metabolism

Although literature explains the need to understand urban morphologies and metabolisms, there were limited studies contextualising these phenomena within an Africa context. Work focusing on the City of Cape Town by Currie, Musango and May (2017) and Hoekman (2015) was acknowledged. Limited data and multidisciplinary planning were also found to contribute towards a lack of consideration for deliberate waste management and renewable energy. Tools such as Material Flow Analysis and Input-Output Analysis are widely researched and used but not from an energy recovery perspective. The gap presents an opportunity for further research and understanding in order to improve access to energy; view waste as a feedstock for energy generation.

Part Three: Waste and Energy Resource Potential

With the expected megatrends proliferations between 2030 and 2050, municipalities will likely remain physically and financially constrained from providing services such as waste collection and energy. Waste management methods such as landfilling and open dumping remain primary disposal methods for most African cities. However, limited space to expand these methods and shifts towards environmental benignity may see more recycling, composting and energy recovery methods, but not at the same rate as waste generation. The global agenda to transition from fossil fuels to clean energy is becoming bigger, with a special focus on Africa. Most of the continent's

energy is generated from renewable sources with a few exceptions such as South Africa, Nigeria, Angola, Algeria and Egypt, who primarily rely on coal, oil and gas.

Despite having an endowment of natural resources that churn clean energy, industry research estimates that more than 600 million Africans do not have access to energy. Above the primary action of managing waste, WtE is recognised as a renewable energy technology. Some technologies are more detrimental to the environment (i.e incineration) while others offer multiple benefits for the environment (i.e anaerobic digestion) (Kumar and Samadder, 2017). The type of research methods used by researchers were both qualitative and quantitative, ranging from secondary data review and case studies (Madlener and Sunak, 2011; Cajot *et al.*, 2017), to interviews and survey questionnaires and some environmental modelling as well as urban system analysis and parametric urban modelling (Amado and Poggi, 2014; Amado, Poggi and Amado, 2016; Singh *et al.*, no date).

Part Four: Anaerobic Digestion and Circularity

Poor access to clean and affordable energy has a negative impact on socio-economic development. These disparities will exacerbate if energy supply is not improved to meet demand in cities. Urban energy planning entails determining optimal energy mixed of various sources to meet a given demand. Different components such as multi-geographic scales, social, technical, economic and environmental factors need to be considered in the process (Thery Hetreux and Zaraté, 2009). Urban planners have an integral role to manage energy in cities because it is linked to their discipline. To successfully achieve this, an integrated and multi-disciplinary approach is required (Madlener and Sunak, 2011). In the context of this study, it entails planning with waste management and renewable energy practitioners. The primary activity requires an understanding of a city's urban form and metabolism so as to integrate energy planning in early stages (Madlener and Sunak, 2011; Hall and Pfeiffer, 2013; Cajot *et al.*, 2015, 2017) as well as identify innovative approaches to assist with the implementation.

With regards to research methods used, researchers such as Rada *et al.* (2018), Chen and Kim (2019), Kalchenko *et al.* (2019) and Acharya (2020) employed qualitative research approaches pertaining to these two concepts. Pertinent methods used by various researchers were more qualitative than quantitative. Some conducted case studies of existing businesses operating within waste and circular economy space, others systematically analysed international databases comprising of peer-reviewed journals as well as conducted semi-structured interviews with participants such as business owners and technology experts (Hussain, Mishra and Vanacore, 2020a). This was followed by thematic analysis indicating that there is a research gap. Key words that were analysed were 'circular economy' and 'waste'. Authors also found that in a 10-year span, publications exploring various aspects of circularity emerged (2015 to 2020). Rata et al., (2018) specifically stated that research about circular economy and waste-to-energy was not present on Scopus. In terms of AD technology selection, researchers investigated and used methods such as MCDA, AHP and SMART.

Gap One: Concept and Implementation of Urban Energy Planning.

Urban energy planning is a recent concept and is still evolving. It is still lacking concrete frameworks and defined methodologies. Like circular economy, the concept has also started garnering traction amongst researchers in academic, private and public sectors. Urban energy planning is even 'newer' in Africa where context-specific research is currently unavailable. Although web-based platforms such as African City Energy provide databased of information, tools and strategies for African municipalities to use for energy planning, it remains unclear how the activities on ground are going. This study views a lack of urban energy planning in Africa as an opportunity for novel and contextualised contributions in the space.

Gap Two: Call for Multi-stakeholder Partnerships.

Multi-stakeholder partnerships are required to intentionally design and realise an urban energy plan. These include but not limited to municipalities, private sector technocrats and universities. Because urban energy planning is still an emerging concept, there is

a research vacuum that investigates which partners are needed and their role. This gap was a key feature across the review.

Gap Three: Combining Anaerobic Digestion and Circularity

Looking at WtE and the circular economy, literature reviewed showed that circular economy is largely linked more to waste management than energy recovery. Literature focusing on circularity and anaerobic digestion is still premature and like the concepts of circular economy and urban energy planning, it is also emerging. Africa-specific research was not found at all. There are countries with waste management and renewable energy policies, but these do not currently detail elements of circular economy or how they can relate to either sector.

3.RESEARCH METHODOLOGY AND DESIGN

"Research is to see what everybody else has seen, and to think what nobody else has thought." - Albert Szent-Gyorgyi

3.1 Introduction

Chapter Three explains the research methodology used. A methodology is a theory of method, the design of the research (Saunders, Lewis and Thornhill, 2009). The chapter provides an understanding of research paradigm, tools and techniques for data collection, interpretation and analysis; all in the context of the literature that was reviewed. Research constructs, methodological approaches, and equations and analyses were also identified. There are five sub-sections: conceptual framework, philosophical approach, research methodology, reliability and validity, and chapter summary.

3.2 Conceptual Framework

Chapter Two reviewed literature pertaining to the flow of materials and energy in urban areas, investigated existing models where anaerobic digestion systems were integrated into urban structures as well as determining circularity within the anaerobic digestion process. Each sub-section summarised gaps and opportunities that support this research as a novel contribution to the existing body of knowledge. These are synthesised in the form of a Conceptual Framework.

A conceptual framework is defined as a blueprint or theory development at the end of literature review; positioning of research within the larger field (Adu, 2015; Michael and Wotela, 2017). Due to the nature of the study, there was no pre-determined or pre-existing theory about integrating energy from anaerobic digestion into urban in a circular manner. These are the aspects that differentiate it from a Theoretical Framework which exists and provides a framework for the research question at the beginning of the study.

It was important to have the framework at the beginning of this chapter because not only does it guide the research, but also serves as a recap for readers as well as compliment the methodological approach. Figure 3.1 is a graphic illustration of the Conceptual Framework for this study which will also be used as a basis for the results and discussion in Chapter Four.

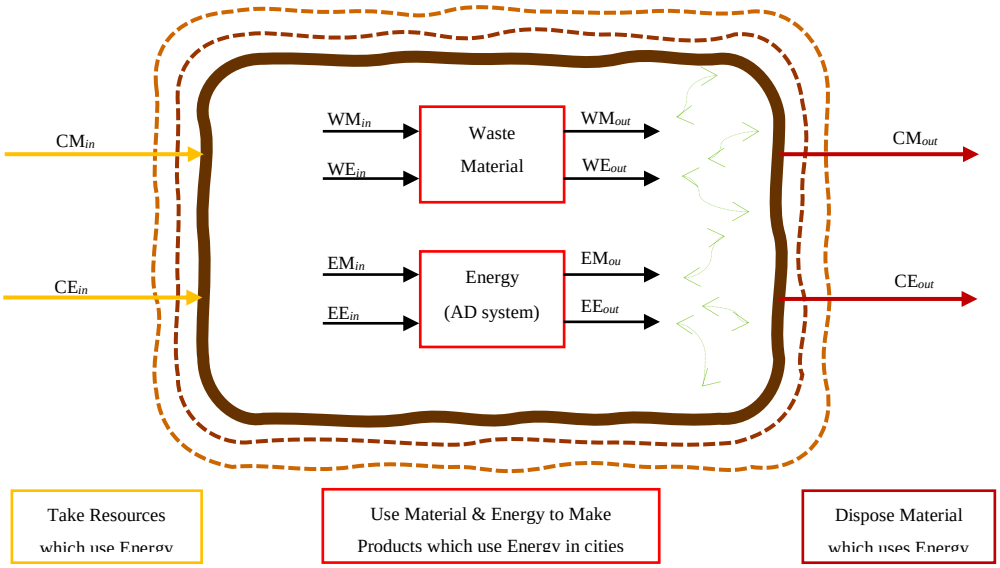


Figure 3.1: The Study's Conceptual Framework

Where:

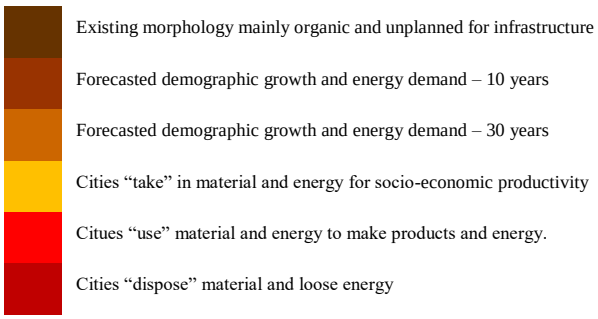
M_{in} = material in

M_{out} = material out

E_{in} = energy in

E_{out} = energy out

Key



Circular economy involves material and energy being kept in the loop for as long and as far as possible. It presents great opportunities for further research and innovation, particularly in Africa. As seen in the framework above, African cities are largely still linear in nature. They "take" resources from the environment and "make" products

required to sustain socio-economic development (CM_{in}). In the process of taking, energy is used; in the process of making, energy is also used (CE_{in}). With specific reference to the flow of waste material in cities (WM_{in}), resources and energy are used to make products that are disposed through unsustainable waste management methods such as landfilling or incineration (WM_{out}). There lies a gap for waste material to be used as a feedstock for energy generation. Energy is required to produce products (WE_{in}) and in the process, energy is lost (WE_{out}).

Looking at energy generation (AD), it is a process that also requires material (organic waste) material to produce various forms of energy (EM_{in}). During the digestion process, energy is used, and energy is lost (EM_{out}). Similarly, energy is used to produce energy (EE_{in}). and due to inefficiencies, energy is lost (EE_{out}). There lies a gap for the material output to be used more for activities such as agriculture and soil regeneration, and energy to be re-used for digestion. Cities' current morphology inhibit sustainable urban metabolism from taking place (CM_{out}). A lot of materials and energy continue to be lost (CE_{out}).

To conclude, urban material and energy flows in African cities are not efficient and sustainable. Waste material is a feedstock for anaerobic digestion, which produces a variety of energies. If the technology is to be integrated in more urban areas, this study needs to show its circularity and how it can improve overall flows.

3.3 Philosophical Approach

3.3.1 Introducing the Research Onion

Designing a research study can be a daunting task. A researcher is required to select and arrange research components to carefully meet research objectives and answer the questions. For this study, the process involved various decision-making actions that were not linear in nature; deliberations about research objectives, suitable literature to review, sampling techniques and data collection, all underpinned by a research paradigm as well as overall analysis and interpretation. This study used Saunders,

Lewis and Thornhill (2009) Research Onion to guide the methodology process in a cohesive manner. Each layer offers various options and leads to a subsequent step. The rest of the chapter is discussed layer by layer, focusing only on elements that relate to the study - Figure 3.2.

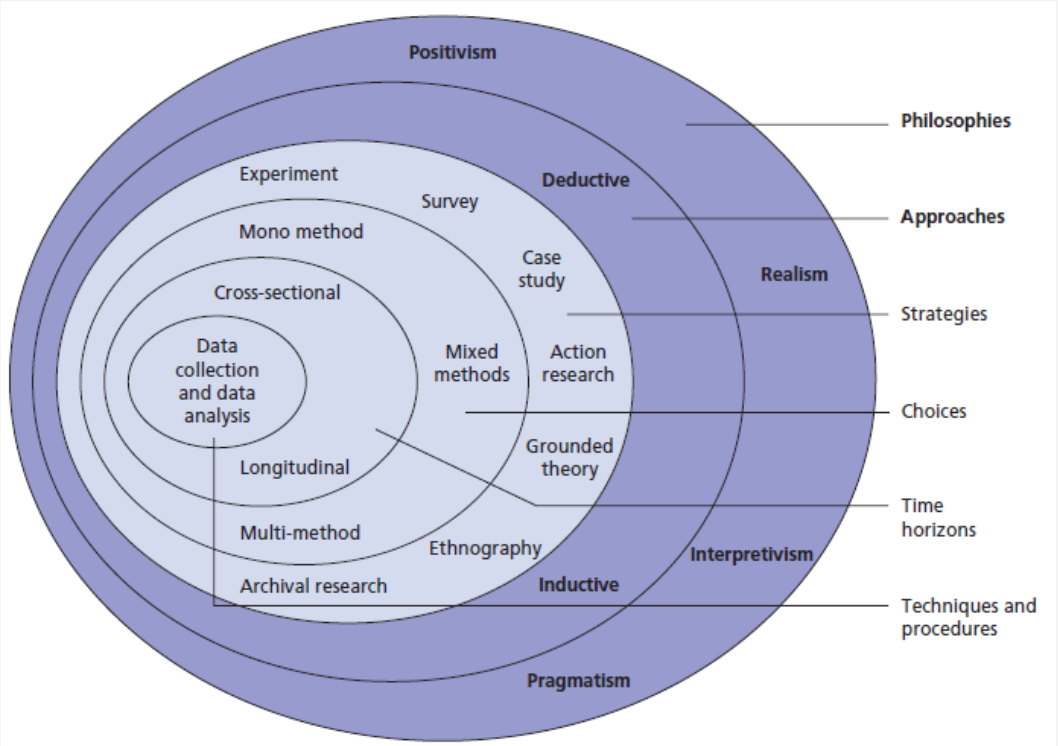


Figure 3.2: Saunders Research Onion

(Saunders, Lewis and Thornhill, 2009)

3.3.2 Paradigm Selection

Before choosing a paradigm (sometimes known as a Research Philosophy), this study to understand and distinguish research assumptions. It is an important step because it shapes a researcher's understanding of the question, objectives as well as methods to use and analysis of findings. Subsequently, paradigms can be understood as a belief system or practice that guides how researchers identify a research question and the key methods (Morgan, 2007). The first layer of the research onion presents four 'traditions of research' which are labelled as: positivism, post-positivism, interpretivism and

critical realism. Kuhn (1970) defined a paradigm as "*a set of social* assumptions that are interrelated. They provide philosophical and conceptual frameworks to systematically study the world or context of interest (Kuhn 1970).

Interpretivism was chosen as the most suitable paradigm. It is a research tradition guided by the author's set beliefs and values about society and how it should be reviewed; meanings and experiences of human beings rather than those of nature (Williamson, 2002). Literature is developed for background understanding without necessarily posing pre-existing expectations. This allows research questions to evolve as the data emerges. Furthermore, interpretivism maintains that it is important for researchers to understand what differentiates humans as 'social actors' (Saunders, Lewis and Thornhill, 2009). Humans interpret daily social roles based on the way they give meaning to these roles. The researcher therefore adopts an empathetic stance by entering the world of research participants to understand the world from their point of view. In this study, it is to understand participants' views about integrating biogas energy into urban areas, underpinned by circular economy principles. Lastly, interpretivism encourages data collection techniques which include a small sample of in-depth interviews that are primarily qualitative.

3.3.3 Paradigm Reasoning

There are two types of reasoning, deductive and inductive. Deductive reasoning is affiliated with theory and hypothesis development and testing. It begins with a general statement that leads to a specific instance or specific statement. Theories and ideas are identified during the literature review process which are used for data testing (Saunders, Lewis and Thornhill, 2009). A positivist approach tends to adopt deductive reasoning to deduce a hypothesis from literature and test it. Inductive reasoning is the opposite. It begins with a specific statement that leads towards generalisation and is often affiliated with Exploratory and Grounded Theory Designs. The reasoning begins with observations or field work then a hypothesis or theory is developed (Williamson 2002). Saunders, Lewis and Thornhill (2009) pointed out that inductive reasoning does not have to start with predetermined theories or conceptual frameworks. These are

developed during the literature review process. In this study, inductive reasoning enabled the researcher to better understand the nature of the problem. During the literature review, a conceptual framework emerged, enabling the researcher to continuously refine the objectives. Lastly, being aligned to interpretivism, inductive reasoning also encourages the study of a small sample and use of various data collection methods to establish different points of views. The inductive process also guided the researcher to consider a Mixed Methods Research Design – discussed later in this chapter. Figure 3.3 presents the interpretivism research process.

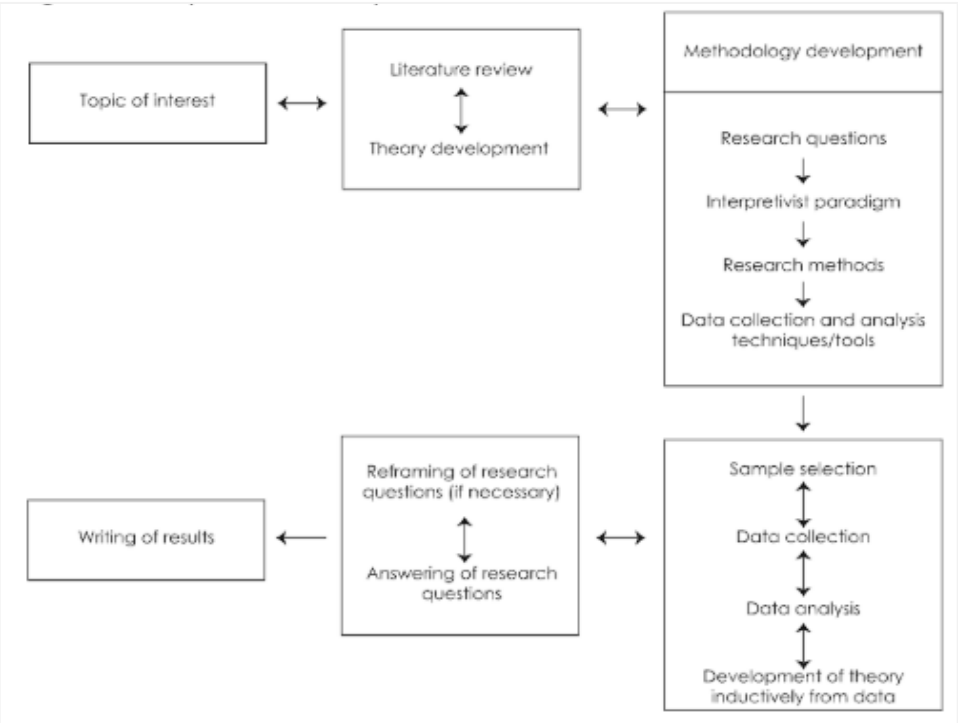


Figure 3.3: Interpretivism Research Process

(Williamson, 2002)

3.4 Research Method

3.4.1 Strategies, Approach and Time Horizons

3.4.1.1 Research Strategy

Research strategies are chosen on the basis that a researcher can meet the objectives and answer the questions. There are seven types of strategies, namely: experiment, survey, case study, action research, grounded theory, archival and ethnographic. Grounded Theory Strategy was chosen for this study because (1) it enabled the researcher to develop and build a theory as part of the data collection process, (2) it is embedded in an inductive approach and (3) constant reference to data (Saunders, Lewis and Thornhill, 2009).

3.4.1.2 Research Approach

There are three types of research approaches: qualitative, quantitative, and mixed methods. **Qualitative research** approach is non-numeric and uses tools such as case studies, personal experiences, interviews, observations, and historical artefacts (Denzin and Lincoln, 2008). Contextual factors such as background and environment they operate in is very important because it influences the participants' behaviour. Qualitative research is guided by inductive reasoning and grounded theory as it allows the researcher to collect data to develop a theory and explain the research problem or phenomenon. Background, experiences might influence what is asked therefore more subjective. **Quantitative research** approaches tend to be used by positivists. Instruments such as questionnaires, surveys and experiments are used to measure variability therefore more objective. Data that is collected and analysed can be generalised to population that was sampled, thus aligning the choice more towards a deductive approach/reasoning. A **Mixed methods** approach is defined as the use of qualitative and quantitative methods in the same study (Williamson, 2002; Creswell, 2013). It is believed to be a good method to attain deeper understanding of issues and experiences. Doyle, Brady and Byrne (2016) appreciate the benefits of mixed methods but warned for the need of awareness that mixing methods may lead to violating

methodological assumptions and done so in a thoughtful manner. Some benefits of adopting mixed methods include (Tashakkori and Teddlie, 2003):

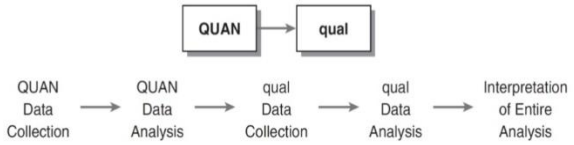
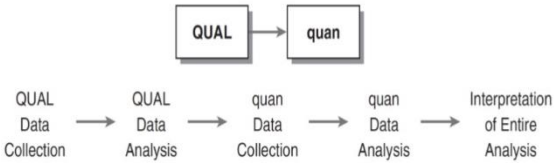
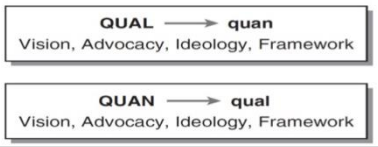
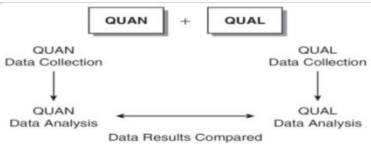
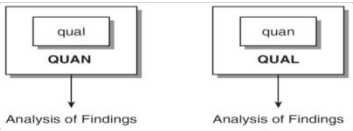
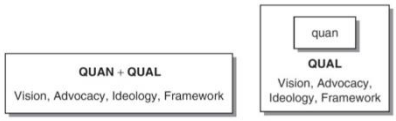
- Enriched findings by using different methods at different levels of the study,
- Increased depth and breadth of phenomenon being studied,
- Theory or Model Testing,
- Improve Trustworthiness and Increased Credibility

This study adopted the Mixed Methods approach which intentionally mixes qualitative and quantitative approaches in a single research. The purpose is to provide an understanding for complex phenomenon that would not have been accessible by using a single approach (Clark and Ivankova, 2016; Shannon-Baker, 2016). The researcher collected, analysed and interpreted qualitative and quantitative data, then integrated the two approaches during the findings and discussion chapter. Moreover, the researcher noted a limited body of literature about and limited use of, mixed methods approach within the context of this study. Most of the literature reviewed either adopted a qualitative or quantitative approach, combining methods case studies with modelling or systematic reviews. Based on this and the conceptual framework in Section 3.2, using qualitative or quantitative methods alone would be insufficient. This study aimed to show a novel approach, one that employs mixed methods within urban planning, waste management, anaerobic digestion and circular economy, and potentially induce future researchers to use it more often, especially for more interdisciplinary research.

3.4.1.3 Research Design in the Context of Mixed Methods

A plethora of Mixed Methods Research (MMR) designs exist and are categorised as concurrent or sequential (Creswell, 2009; Adu, 2015). These are briefly explained below in Table 3.1:

Table 3.1: Mixed Methods Research Designs

Sequence	Design	
Sequential *(data collected at different stages)*	Explanatory	
	Exploratory	
Concurrent *(data collected at the same time)*	Transformative	
	Triangulation	
	Embedded (Nested)	
	Transformative	

(Creswell, 2009)

This study adopted Concurrent Embedded. This design allowed for both qualitative and quantitative data collection at the same time. Findings of one choice were them embedded into another to enhance the findings. In this case, the study's emphasis was qualitative data. Findings were derived and analysed before embedding quantitative data for further enhancement. Concurrent Embedded is suitable for Grounded Theory approach as well as Interpretivism Paradigm because of the exploratory nature of the research objectives and questions(Creswell, 2009; Clark and Ivankova, 2016).

There are different rationales for selecting different designs. They include Triangulation, Complementarity, Development, Expansion, and Initiation. Depending on the nature of the study, more than one rationale can be used. In this study, the rationale for Concurrent Embedded Design was to compliment qualitative with quantitative data and use different analysis methods to analyse various aspects of integrating urban biogas in urban areas and its circularity. Data sets were separately analysed and mixed at the interpretation stage (Adu, 2015).

3.4.1.4 Time Horizon

There are two types of time zones, namely cross-sectional and longitudinal. A cross-sectional time zone is regarded as a snapshot of a specific group of people at a given point while longitudinal time zone is seen as a snapshot of specific people but over an extended period (Saunders, Lewis and Thornhill, 2009). A cross-sectional time zone was chosen because participants were interviewed whilst they were still employed, ensuring no manipulation of variables. The study was able to describe the characteristics that exists within urban planning, waste management and clean energy. The exploratory nature of the study is suitable for cross-sectional time zones because preliminary data provides information about what is happening presently and can be used for further research.

3.4.2 Research Process

3.4.2.1 Step 1: Identification of Study Area and Population

As per the delineations discussed in Chapter One, the study targeted metropolitan municipalities in Africa. The following criterion were used to select the study areas and sample metro-municipalities:

- Urban population.
- Percentage of urban population with access to electricity.
- Percentage of organic waste generated in urban areas.

Only the top 15 cities in each category were chosen in order to narrow the population as much as possible. Datasets were obtained from the Africa Energy Portal and The World Bank's data bank. The most recent data is up to 2018. Figure 3.4 illustrates the top 15 urban areas in 2020, 2030 and 2050. These timeframes were chosen because they offer perspectives on which urban areas will demand more energy in future.

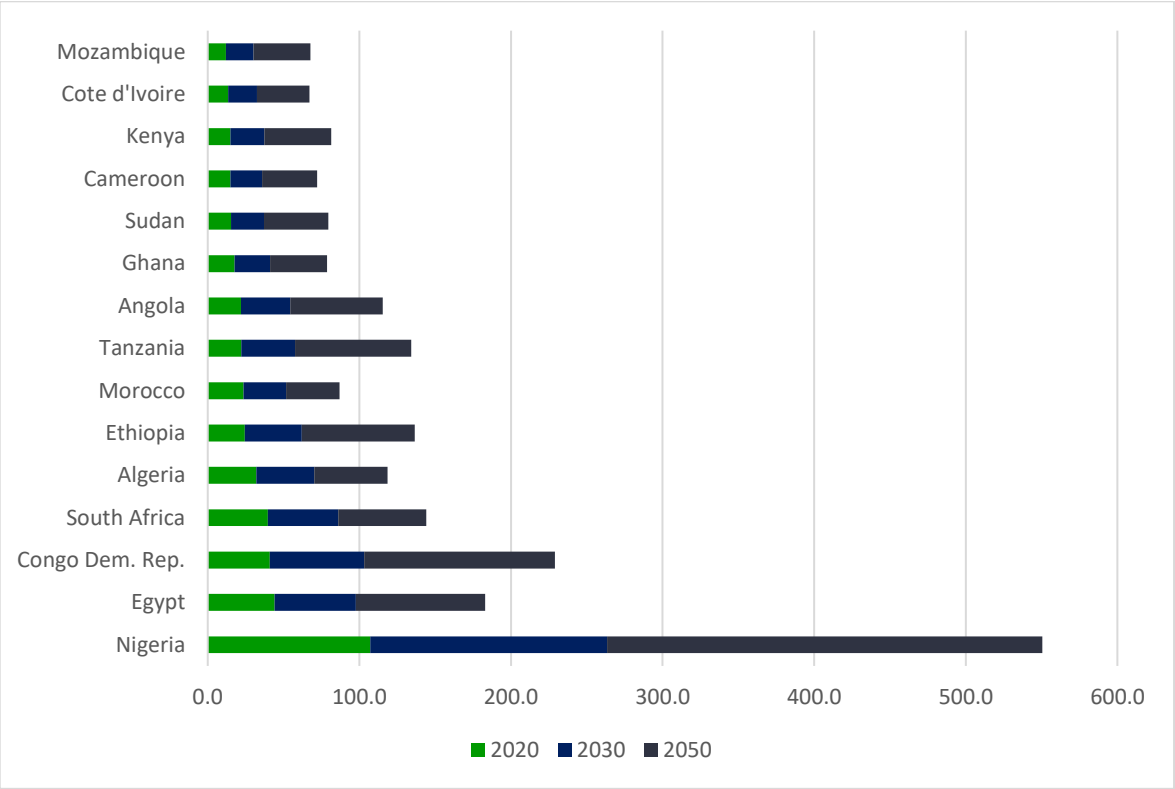


Figure 3.4: Urban Population – 2020, 2030 and 2050

Source: Author's own illustration using raw data from African Energy Portal (African Development Bank, 2018b)

Complimenting Figure 3.4, Table 3.2 provides numeric data which forecasts urban population growth. Nigeria, Egypt and the Democratic Republic of Congo remain competitive urban areas over the 30-year period.

Table 3.2: Top 15 Countries with the Highest Urban Population

	2020	2030	2050
	million		
Nigeria	107,1	156,3	287,1
Egypt	44,0	53,6	85,3
Congo Dem. Rep.	40,8	62,3	125,9
South Africa	39,6	46,5	58,1
Algeria	32,0	38,2	48,5
Ethiopia	24,5	37,5	74,5
Morocco	23,6	28,1	35,3
Tanzania	22,1	35,5	76,5
Angola	21,9	32,4	61,1
Ghana	17,6	23,6	37,5
Sudan	15,3	21,8	42,3
Cameroon	14,9	20,9	36,4
Kenya	14,9	22,4	44,2
Cote d'Ivoire	13,5	18,9	34,6
Mozambique	12,0	18,2	37,5

Source: Author's own illustration using raw data from African Energy Portal (African Development Bank, 2018b)

Noting the above, the researcher sought to understand what the current access to energy in urban areas is, namely electricity. From Figure 3.5 seen below, it is evident that most urban areas are electrified, with a few odd cases were data is limited.

An average of 75,3% of African cities have access to electricity in urban areas. Top ranking countries and their cities are in North Africa (98,6%) with countries such as Algeria, Egypt and Morocco (100,0% electrification each). These are followed by the West African region (with a regional average of 81,6%), represented by countries such as Ivory Coast (100,0%), Gabon (96,7%), Ghana (94,2%) and Senegal (92,4%). The average access in East Africa (regional average of 75,5%) is represented by Ethiopia (92,0%) and Rwanda (89,1%). South Africa's urban areas are the most electrified (92,1%) in the Southern African region (averaging 78,6%).

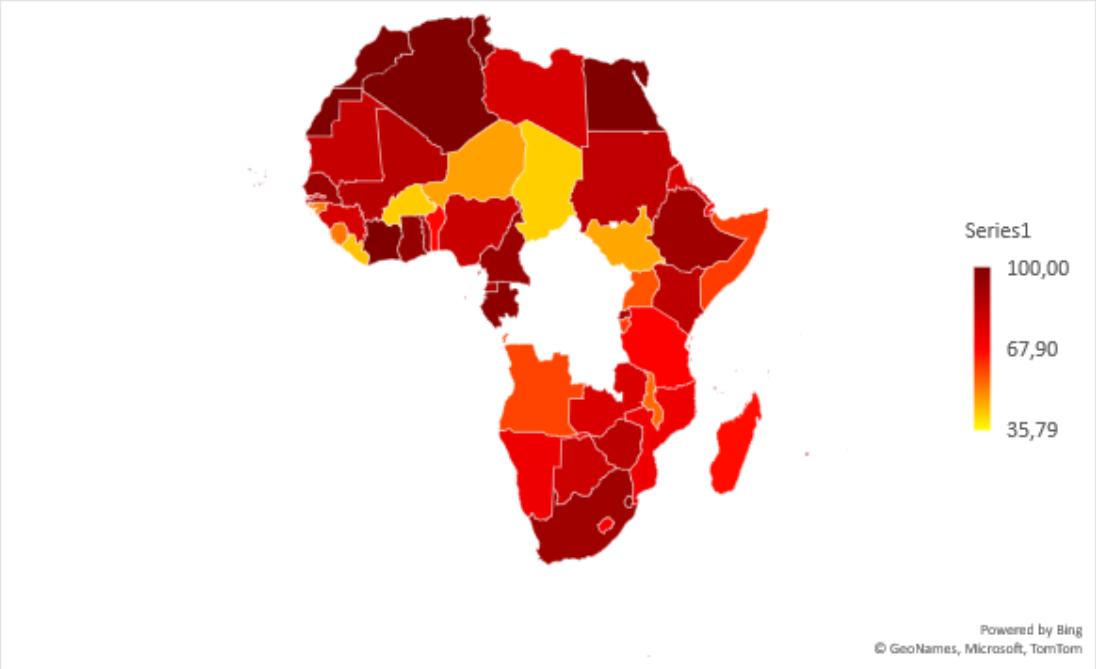


Figure 3.5: Urban Population with Access to Electricity (2018)[2]

Source: Author's own illustration using raw data from African Energy Portal (2018) (African Development Bank, 2018b)

With data on both urban population and energy access, the next step was to investigate the top 15 countries with the highest waste generation. This assisted the researcher to narrow the study area and possible sample, given the study's focus on anaerobic

[2] *Data available for 54 countries I Latest data until 2018

digestion and urban areas. Figure 3.6 presents the top 15 countries with the most waste generated in 2018.



Figure 3.6: Top 15 countries with the most waste generated (2018)

As seen in Figure 3.6 and Table 3.3, Nigeria, South Africa, the Democratic Republic of Congo and Algeria are the top three waste producers on the continent. This is understandable given the high demographic profiles and how big their economies are. Nigeria produced the most waste in 2018, amounting to 27,6 tpa, followed by South Africa (18,4 tpa) and the Democratic Republic of Congo (14,3 tpa).

Despite seeing these high figures, it was imperative for the researcher to only focus on the percentage of organic waste fraction. This is because organic waste is feedstock for anaerobic digestion. The top three urban populations and waste producers have the least organic fraction. Instead, Ethiopia (87,6%), Cameroon (83,4%), Uganda (74,5%) and Ghana (67,0%) rank the highest.

Table 3.3: Top 15 Waste Generators (2018)

	Total MSW (t/y)	% Organic Waste
Nigeria	27 614 830,1	
South Africa	18 457 232,0	16,4%
Congo, Dem. Rep.	14 385 226,0	
Algeria	12 378 740,0	54,4%
Tanzania	9 276 995,0	
Uganda	7 045 049,9	74,5%
Ethiopia	6 532 787,0	87,6%
Kenya	5 595 099,0	57,0%
Ivory Coast	4 440 814,3	
Rwanda	4 384 969,0	
Angola	4 213 643,6	51,8%
Madagascar	3 768 759,2	
Ghana	3 538 275,0	67,0%
Mauritania	3 506 288,0	4,8%
Cameroon	3 270 616,6	83,4%

Finally, the researcher amalgamated all datasets and summarised in Table 3.4. It was used to guide how the study areas and population were selected.

Table 3.4: Summary of Chosen Populations (2018)

Urban Population (in mill)		Urban Population with Access to Electricity (%)			Total MSW (t/y)	% Organic Food Waste
Nigeria	107,11	Algeria	100,0%	Ethiopia	6 532 787,0	87,6%
Egypt	44,04	Egypt	100,0%	Cameroon	3 270 616,6	83,4%
Congo Dem. Rep	40,84	Ivory Coast	100,0%	Burundi	1 872 016,0	81,0%
South Africa	39,55	Morocco	100,0%	Uganda	7 045 049,9	74,5%
Algeria	31,98	Tunisia	99,9%	Libya	2 147 596,5	70,1%
Ethiopia	24,46	Seychelles	99,6%	Chad	1 358 850,5	70,0%
Morocco	23,55	Eswatini	96,7%	Tunisia	-	68,0%
Tanzania	22,11	Gabon	96,7%	Ghana	3 538 275,0	67,0%
Angola	21,93	Ghana	94,2%	Mauritius	-	64,0%
Ghana	17,62	Comoros	94,0%	Morocco	-	60,0%
Sudan	15,34	Cameroon	93,3%	Mozambique	-	60,0%
Cameroon	14,94	Congo Dem Rep.	92,4%	Guinea	596 911,0	58,0%
Kenya	14,94	Senegal	92,4%	Kenya	5 595 099,0	57,0%
Ivory Coast	13,53	South Africa	92,1%	Egypt	-	56,0%
Mozambique	11,97	Ethiopia	92,0%	Algeria	12 378 740,0	54,4%

Top 15 countries are shown in each category but only three were selected as the population study area. Ethiopia, Ghana and South Africa emerged as suitable areas based on the following reasoning:

1. **Regional Representation**: Each country is representative of an African region and are projected to continue being in the top 15 countries with the highest urban populations in 2030 and 2050. The researcher is cognisant that despite the representation, every country has a unique context.

2. **Forecasted Urban Growth & Energy Demand**: All three countries have large urban populations with some form of electrification infrastructure. The researcher acknowledges that although they have high urban electrification, sustainable and affordable supply is different in each context.
3. **Fraction of Organic Waste**: Given the focus on anaerobic digestion, total waste generation figures were considered but a decision was made based on the percentage of organic material. Only Ethiopia and Ghana feature in the top 15.
4. **Available AD Literature, Stakeholders & Ease of Access**: The three countries have the most available research and data on existing anaerobic digestion projects. This serves as secondary data for quantitative analysis in Chapter Four.

Although 15 of the world's fastest growing cities are in Africa, not all of them have fully fletched metropolitan municipalities. Since the study focuses on metropolitan areas, the biggest municipalities were selected: Addis Ababa City Government (Ethiopia), Accra Metropolitan Assembly (Ghana) and the City of Johannesburg (South Africa). In addition, these municipalities have the most data on their administrative and political mandates to guide land use development through urban planning, provide waste management services and energy.

3.4.2.2 Step 2: Sampling Technique and Sample Size

Quantitative Data: An excel sheet comprising of 16,0 anaerobic digestion projects on the continent was developed. During the literature review process, data such as country, operational status, feedstock, size, type of energy produced and owner model, was accumulated. This data is imperative to determine if anaerobic digestion technologies are circular or not, in terms of material and energy input versus output. At least 18,7% of the projects were sampled for calculations.

Qualitative Data: Three countries were identified from a population of 15 countries that fulfilled the criteria: South Africa, Ghana and Ethiopia. Each sample area represents a country in each region of sub-Saharan Africa. Within each country, the following metro-municipalities City of Johannesburg, Accra Metropolitan Assembly and Addis Ababa City Government. Collecting data from a smaller sample meant that more detailed information as well as data that may be considered difficult to access.

There are two types of sampling techniques: probability and non-probability. Probability sampling means that the data can be generalised on statistical grounds. Non-probability sampling means data can still be generalised but not on statistical grounds. Figure 3.7 illustrates the sampling techniques.

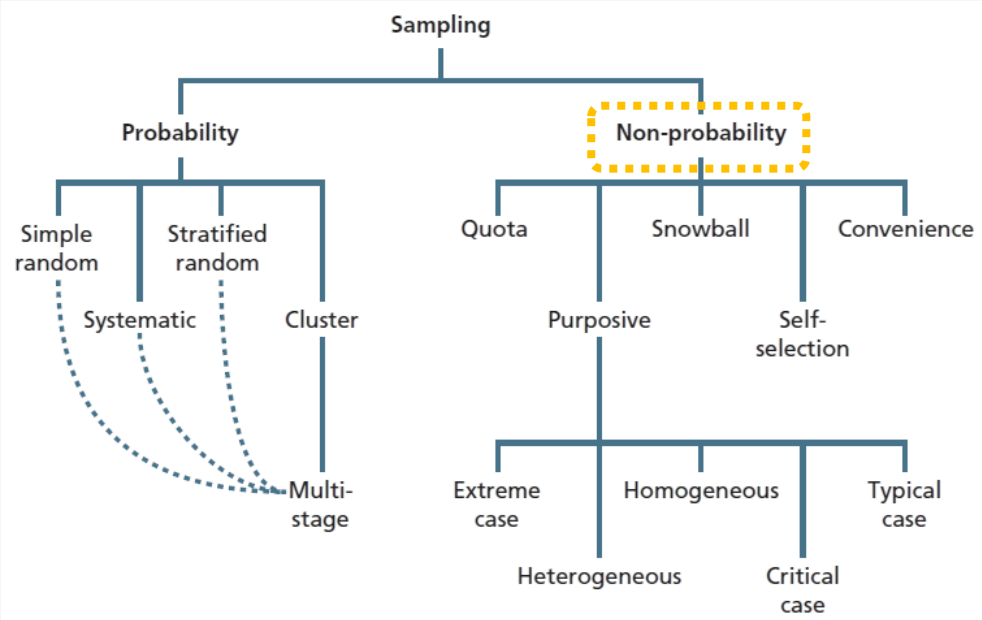


Figure 3.7: Sampling Techniques

(Saunders et al, 2009)

The most popular sampling technique for Interpretivism Research Paradigm and Grounded Theory Strategy is Purposeful Sampling. It is sampling specifically for the purpose of the study, governed by what is important to the study. Purposive sampling allows a researcher to identify Participants who directly impact or drive a mandate and

it is suitable for small samples that require in-depth interviews and understanding. This sampling type has a low likelihood of the sample being statistically representative of all metro-municipalities because they function in different contexts. There are two types of Purposive Sampling, namely: Extreme Case and Heterogenous. Extreme Case sampling focuses on unusual or special cases that yield extreme outcomes while heterogenous sampling focuses on collecting data to identify and explain key themes that the researcher observed (Creswell, 2009; Saunders, Lewis and Thornhill, 2009) – see Figure 3.8 which presents non-probability sampling techniques.

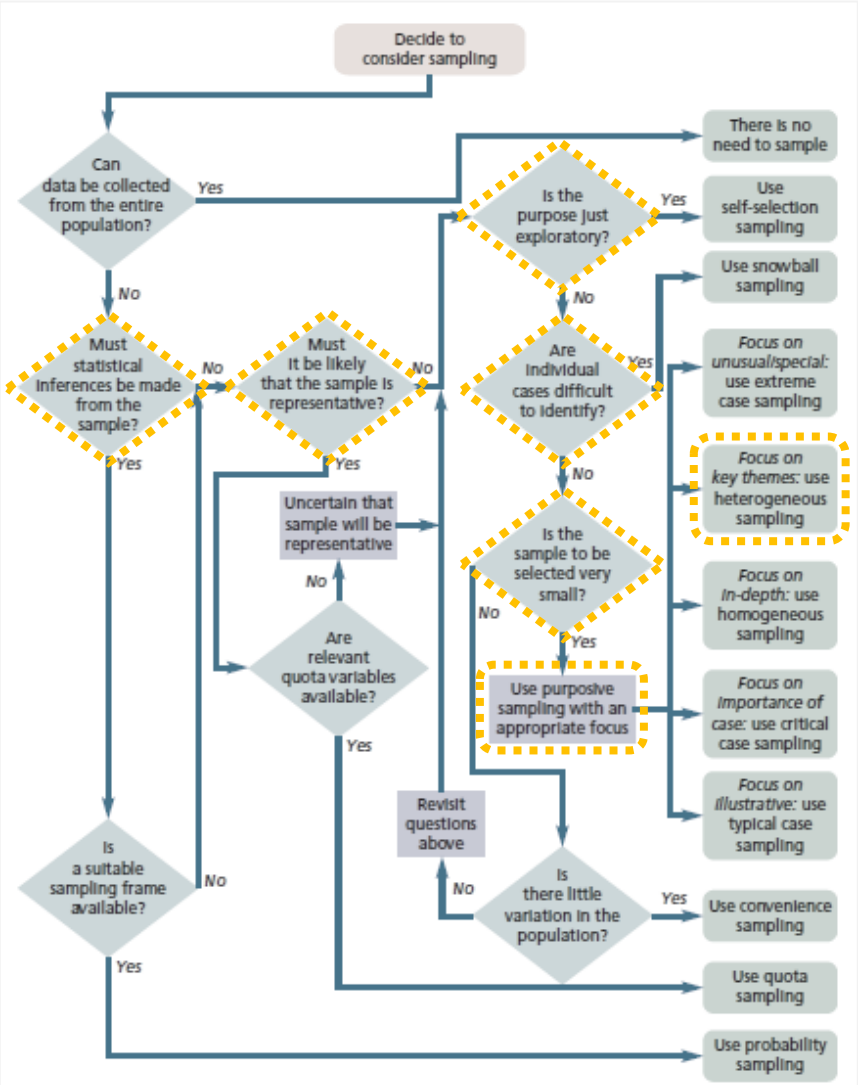


Figure 3.8: Non-Probability Sampling Technique

(Saunders et al, 2009)

In this study, the researcher purposefully sampled the following target group in each metro-municipality:

- Decision-makers (Management, Directorship, Executive positions – having reached these levels within their careers as well as leadership, they are likely to offer deeper insights from which the researcher can build greater understanding)
- Making decision in the following units
    - Urban Planning
    - Waste Management
    - Renewable Energy/Electricity

The participants were required to have at least two years working experience to ensure that their wealth of knowledge and experience is fully capitalised. Furthermore, Snowball sampling was also used to identify additional potential participants. These participants were not necessarily limited to metro-municipality officials but included industry association and research organisations working directly or indirectly with the metro-municipalities.

3.4.2.3 Step 3: Data Sources and Collection Tools

This study used primary and secondary data sources. Demographic, waste generation and energy demand datasets were obtained from various institutions. The data was used to create heat maps to narrow the sample countries and cities. Interviews and observations (were possible) were used to obtain expert information in the selected cities. Secondary data comprising of industry reports, government policies and academic research complemented the primary sources – see Table 3.5.

Table 3.5: Sources of Data

	Sources	Data Extrapolated
Primary	Datasets from: Statistics South Africa, World Bank, UNEP, UNIDO, CSIR, Biogas Association(s)	Population, energy demand and supply, waste generation and characterisation globally, continentally and locally.
	Heat Maps	Using dataset, identify and map: high density urban areas, high population and waste generation.
	Interviews, Observation	Expert Data
Secondary	Reports:UN Habitat Cities Report, World Bank Report, Industry Reports	Urbanisation, socio-economic and renewable energy agenda.
	Government Policies and Regulatory Frameworks	
	Academic Journals, Theses, Conference Proceedings,	

Given the MMR approach, data collection tools were identified and designed for both qualitative information and quantitative data. Interviews and observations extrapolated qualitative information, while a datasets was used to identify three cases that served as a reference. Document review was used as an additional tool – see Table 3.6.

Table 3.6: Data Collection Tools

	Tool	Motivation
QuaL	Interviews	Semi-structured interview questions asked in a face to face to obtain information from participants.
	Observation	Visit existing or planned WtE (AD) projects and examine them in their natural setting, to complement interview and secondary data.
	Documents Review	Policy and regulatory document review and analysis.

	Tool	Motivation
QuaN	Dataset for Case Sampling	Compilation of existing AD projects in urban areas in each municipality.
	Documents Review	Existing anaerobic digestion projects installed in metro areas

Qualitative data was collected using interviews and some quantitative data was collected during literature review as well as interviews and supported by multi-source secondary data recommended by participants. Structured interviews were standardised for each participant and comprise of pre-coded answers. These allowed for in-depth responses. However, the study adopted semi-structured approach because the researcher could (1) create a list of themes and questions guided by the conceptual framework, (2) vary the list depending on the nature of the interview and contextual differences, and (3) vary the flow of the conversation and most importantly (5) can be used for an exploratory study. Participants were probed to explain and build on their responses, which is important for Interpretivism Paradigm. An audio recorder and note pad was used. Multi-source secondary data specifically addressed the existence of AD systems in urban areas and their operational status.

3.4.2.4 Step 4: Data Capturing, Audio Transcription and Data Coding

Audio Transcription

The researcher conducted nine in-depth interviews at three metro-municipalities located in three African cities. Interview durations were between one hour and 1h45 minutes. The audio files were transcribed using a transcription software, followed by manual transcription. The software reduced transcription time to an extent (average transcribing time for one-hour audio was 8 – 10 hrs all being equal). An additional six interviews were administered with agencies, organisations and institutions directly and indirectly working with the metro-municipalities. Ten interviews were carried out in person and five over virtual platforms. Manual transcription ensured that (1) the content was close to verbatim where possible, (2) sentences and expressions hindered

by background noise and accents were reviewed, and (3) most importantly, the researcher began to identify key concepts coming out of the interviews. The researcher created colour coded mind-maps to assist in this regard, listened to audios thrice throughout the process. Continuous reading of transcribed files enabled constant review of alignment between research question and objectives because coding is an iterative process – see Figures 3.9:

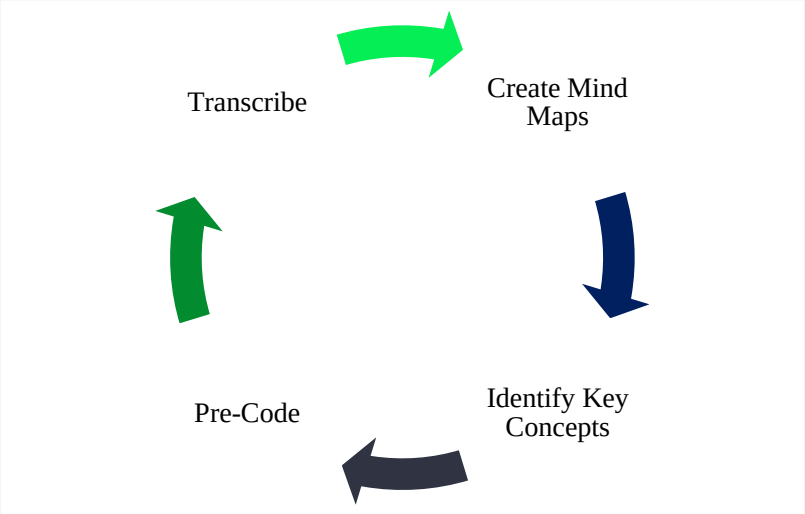


Figure 3.9: Qualitative Data Analysis Process

3.4.2.5 Step 5: Drafting of the Coding Structure

Most Participants provided narrative information suitable for both qualitative and quantitative coding. A working excel document was developed were pre-codes and themes were identified during transcription. Final transcripts were uploaded onto Atlas.ti, a computer -assisted qualitative data analysis software. Atlas.ti was used to further identify and create more codes, themes and network groups that show relationships and influences. More than 250 codes were created then categorised into 11 themes. Figure 3.10 summarises the coding structure:

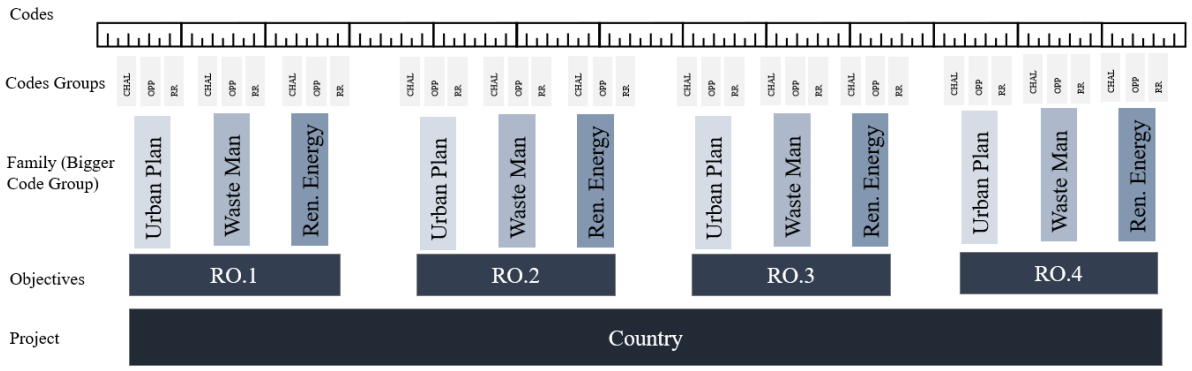
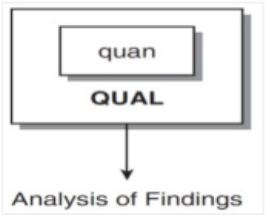


Figure 3.10: Summary of Coding Structure

Relevance of codes was analysed: why particular codes were chosen, whether they answer the research question and to refine as well as expand any properties. A total of 597 codes were identified then later merged to 182 codes. This process is known as inductive coding, whereby codes are generated during interviews, transcription, mindmapping and reporting of findings using Atlas.ti. Free coding, open coding and coding by list were the primary coding processes used. Listing coding is used for deductive reasoning. Finally, data management software was used to organise the large amounts of data and support transparency.

3.4.2.6 Step 6: Data Analysis

As mentioned earlier in this chapter, Concurrent Embedded MM design can prioritise either research approach first and embedding or 'mixing' occurs at the analysis and interpretation stage.



(Saunders, Lewis and Thornhill, 2009)

The researcher analysed quantitative and qualitative data concurrently. Prioritisation was given to quantitative data because that is the essence of this study: to integrate anaerobic digestion into urban areas. Qualitative data was used to support and explain the status of integration. The analysis was carried manually and using Atlas TI for

further guidance and reliability. Themes (Code Groups) were created by clustering codes that are related to each other. Themes were then filtered, which simplified the analysis and interpretation process. These were led by themes identified during the literature review as well as common responses emerging repeatedly from participants – inductive approach.

3.5 Reliability and Validity

There are various data quality issues related to semi-structured and in-depth interviews. Below is a discussion of how the researcher ensured reliability, validity and ethical consideration.

3.5.1 Reliability

Reliability is concerned with obtaining consistent research results when the study is repeated by other researchers. Interpretivist research is rigorous thus reliability and validity are explained in terms of a researcher's candidness to alternative explanations. The rigour speaks to the 'trustworthiness' of the findings, using the following four constructs: credibility, transferability, dependability and confirmability. Here, triangulation plays an important role in establishing the trustworthiness. It is a process that uses multiple data collection methods, constructs, and data sources. Because semi-structured in-depth interviews are not standardised, issues about data reliability arise. Interviewer and interviewee bias (Williamson, 2002; Saunders, Lewis and Thornhill, 2009; Doyle, Brady and Byrne, 2016). This study ensured:

Participant Error	Participants were asked to advise dates and times of their availability as well as neutral spaces (in person or virtual) to meet. By doing this, the researcher wanted to reduce chances of professional or social pressures; allowing participants to engage comfortably.
Interviewer Bias	Prior to the interview, the researcher introduced herself professionally, reiterated the purpose of the study, the layout of

the interview and how the data will be used, to reduce any perceptions interviewees might have had and to make them feel comfortable. During the interview, the researcher posed a question and probed for additional information in line with the theme discussed to avoid any insinuations or belief imposition. Participants were encouraged to let the researcher know if/when they could not answer questions that might cause discomfort.

Interviewee Bias — Adding on to the above, participants were asked to fill in the consent form (and their interest in anonymity) and a list of themes prior to data collection. The interview questions were also designed to be as objective as possible; to answer the research questions considering their daily work deliverables. During data cleaning/ audio transcribing and analysis, the researcher aligned each finding to the research questions.

3.5.2 Validity

Validity can be a threat when findings are biased and constrained by pre-conceived ideas. It is tests whether findings are what they seem to be. Internal validity refers to the extent research instruments measure what they are meant to measure while external validity refers to the extent to which findings can be generalised. Findings from semi-structured interviews cannot be generalised to all metro-municipalities in Africa due to varying contexts and structures (Williamson, 2002; Saunders, Lewis and Thornhill, 2009; Doyle, Brady and Byrne, 2016). The researcher ensured the following:

History — The researcher adopted a cross-sectional time zone. This allowed for data collection at that given time and participants' years of service in the discipline. Furthermore, literature reviewed that all aspects of sustainability, waste management and energy generation are currently and will retain topical in the next three decades. Therefore the themes

were very much aligned to addressing these topical challenges and opportunities.

Testing — Participants' experience in targeted sectors, their years in operation at various organisations and understanding what their roles and responsibilities entail, set the tone to determine whether they would be affected by participating. Their responses in the consent form also indicated the likelihood of a negative impact. They were not negatively affected.

Location — Participants were asked where and when they would be available for interviews. Giving them the space to review their schedules and availability ensured that the date, time and place chosen would make them comfortable.

3.5.3 Ethical Consideration

The researcher drafted and submitted data collection tools and the relevant letters to the Ethics Committee for clearance in August 2019. While awaiting response, potential participants in each metropolitan municipality were identified, as well as other organisations involved in implementing AD systems. They were contacted via electronic mail and telephonically to determine their availability and willingness to participate. Clearance was provided in September 2019 and participants were then e-mailed the Letter of Consent and Letter of Anonymity. They were asked to return signed copies within two weeks if they were still available to participate. The purpose was to allow participants enough time to schedule the interview. Thus, the collection schedule is summarised in Table 3.7:

Table 3.7: Summary of Collection Schedule

Date	Activity	Outcome
Nov & Dec (2019); Jan (2020); June (2020)	City of Johannesburg	• 4 interviews

Date	Activity	Outcome
Jan & Feb (2020); June (2020)	Addis Ababa City Government Accra Metropolitan Assembly	• 4 interviews & 1 observation • 2 interviews

Additional interviews were also conducted with:

- X1 Industry Association
- X1 Regional Agency
- X2 Research Institutes
- X1 Non-governmental Organisation

3.5.4 Limitations to the Study

A total of 15 participants from three countries were interviewed. The researcher experienced the following limitations before, during and after interviews:

- Some participants' availability in terms of date and time were affected by other activities within the organisations as well as global restrictions induced by the corona virus pandemic. Digital video conferencing platforms experienced technical glitches, thus affecting one recording in particular. The researcher took hand-written notes during the interview.
- Some participants were not able to answer all questions because not all applied to their roles, responsibilities, past experiences or current and future mandate.
- One of the biggest limitations experienced throughout the study was the lack of consolidated quantitative data about WtE (anaerobic digestion) projects in metro-municipalities. The most recent and available data was said to be held by non-governmental organisations who were responsible for funding WtE projects – whether operational or not, or by private companies. The researcher relied on industry reports, some data attainable from industry associations and peer-reviewed journals.
- Availability of the researcher's financial, time and data resources limited a greater sample selection.

3.6 Chapter Summary

The choice of philosophical approach and methods selected was informed by approaches and methods identified in the literature review. Given the 'emergent nature' of concepts relating to this study, exploratory approaches comprising of qualitative and quantitative approaches were prevalent. The interpretivism paradigm was selected because the research proposition and objectives included multiple layers and perspectives that can aid in understanding how best to integrate AD in a circular manner. No pre-determined theories relating to the study were identified, hence the inductive reasoning approach.

Because there were multiple layers to the topic, mixed methods research approach was selected, Mixed methods encourage more interdisciplinary research, particularly in cases where one approach is used to expand another. In this study, MM strengthen the findings. Both data sets were merged or embedded at the discussion and interpretation stage. This was achieved by using Concurrent Embedded design, which entails merging one design into another.

This study's primary approach was quantitative. Data about AD operations in African cities was collected and from that, three case study plants to conduct a circularity assessment. CEVs for each study were calculated to determine the plant's circularity. Qualitative information was then embedded into the results to describing challenges and opportunities for integration.

4. RESULTS AND DISCUSSION

He who does not know one thing knows another - Kenyan Proverb.

4.1 Introduction

Chapter Four presents qualitative and quantitative results as well as discussion and interpretation of findings from this study. Results and discussion are themed according to research sub-objectives. As presented in the literature review, much literature is available on anaerobic digestion technologies in general. However, limited literature discusses anaerobic digestion and circularity, biogas integration and market development in African cities. It is at this stage that qualitative data was embedded into quantitative data. Concurrent Embedded Design was adopted, with an unequal bias towards quantitative data. By embedding qualitative data, the researcher ensured that quantitative findings were explained.

The chapter explicitly separates empirical results and discussion of findings to serve both distinct yet interlinked purposes (Wotela, 2018). Presentation of results only summarise the responses collected and analyses these using approaches stated in Chapter Three. Discussion of findings includes the researcher's opinion to interpret what the results mean. A recap of the hypothesis and objectives:

Research Proposition:

Anaerobic digestion is a viable circular economy model that may help towards achieving the energy demand in African cities. It is amongst the cheapest WtE methods of energy generation and is socio-environmentally benign.

General Objective:

Using principles of circularity, this study investigates how anaerobic digestion can help improve energy access and integration in African cities by capitalising on urban waste material.

The chapter outline is as follows:

- Sub-section 4.2 explains how and at what stage results are embedded,
- Sub-section 4.3 presents a profile of participants who were purposefully interviewed,

Sub-sections that follow are themed according to the research objectives:

- Sub-section 4.4 RO 1 – AD promoting Circularity in Energy Generation,
- Sub-section 4.5 RO 2 - Decision-making to promote AD uptake in African Cities,
- Sub-section 4.6 RO 3 - The Ideal Urban Biogas Model for metro-municipalities.

4.2 Summary of Concurrent Embedded Design

Mixed Methods Research (MMR) Design was used to attain a deeper understanding of issues and experiences of ensuring AD is not only a circular technology for energy generation but promotes circular material flows of waste in African cities. Firstly, the researcher found that this design enriched the findings and analyses at different levels, increased the depth and phenomenon of the study and encouraged theory development. This was made possible by adopting Concurrent Embedded Design. Secondly, the research topic is still emergent from different perspectives thus its novelty was enhanced by mixing qualitative and quantitative approaches. Table 18 presents the objectives, approaches, and explains how the embedding occurred. In line with the objectives, the purpose of this table is to help readers see how findings and analyses were mixed throughout the chapter. Table 4.1 illustrates how the researcher embedded the findings.

Table 4.1: Embedding Findings

Objective	Qualitative	Quantitative	Embedding
	Interview Data	**Secondary Data**	
Objective One: Determine if anaerobic digestion technologies can promote circularity in energy production.	Participants' involvement in WtE projects.	Measure Circularity of existing AD Projects in Metro-Municipalities	Determine circularity of existing AD plants and assess current operations to determine if certain parameters need to be changed. Analyses were substantiated with qualitative findings – Objective Two.
		Engineering Design, Urban Waste and Urban Morphology parameters to consider.	
Objective Two: Understand who the decision-makers are and investigate factors to assist in their decision-making.	Challenges and Opportunities		Analyses whether interdisciplinary collaboration and knowledge of sustainability concepts affect (1) how AD systems are designed to be circular and (2) to induce circular flows of urban energy and waste material in cities.
	Inter-disciplinary Involvements		
	Sustainability Concepts		
	Urban Energy Model Design Elements		Qualitative understanding of how model could work then embed quantitative considerations as well.
	Key Considerations		
	Changes in Professions		

4.3 Profile of Participants

A total of 15 participants were interviewed. The first question sought insights into the interviewees' designation at their respective institutions, industry experience and education profile. The aim was to ascertain whether urban planning, waste management and renewable energy practitioners across the three metro-municipalities have or share industry sentiments about what their activities entail.

4.3.1 Participants' Designation

Interview participants were purposefully sampled and selected due to their ability to inform and drive mandates within their portfolios. Key decision makers who held managerial and executive positions were targeted. A few instances of snowball sampling also occurred. As seen in Figure 4.1, most participants (53,3%) held executive positions, followed by managers (26,7%) and professionals (13,3%). One participant was a researcher (6,7%) in urban planning.

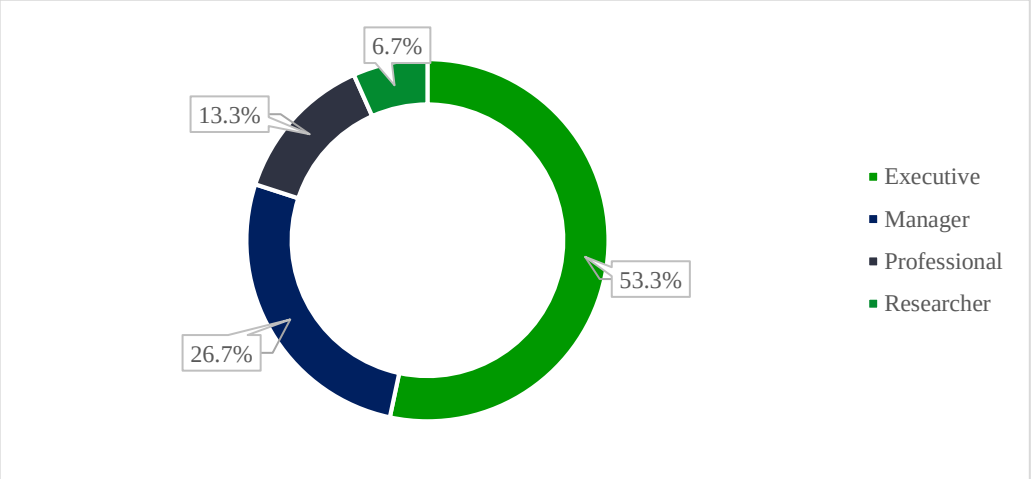


Figure 4.1: Participants' Designation

Roles and responsibilities of participants with executive positions across all three disciplines entailed:

- driving strategy and overseeing departmental and entity performance,

- drafting and implementing policies, plans and strategies,
- explore innovative solutions and programmes to improve service delivery,
- conducting multidisciplinary research and providing consulting services.

These are explained in sector-specific details below:

Urban Planners	• facilitate building permits and review development applications • prepare spatial development plans (schemes) • deal with zoning, land use and land registrations • steer development and spatial planning committee • Green Buildings and Climate Change Adaptation and Mitigation
Waste Management	• advise management about technologies • prepare sanitation and waste management by-laws • solid waste management research and development • science advocacy • landfill site control and monitoring
Renewable Energy	• identify and establish markets for biogas across Africa • sensitise industry participants about biogas • explore appropriate technologies • interact with public and private sector to initiate projects • oversee electricity department and agencies • technology research and development and consultancy

Roles and responsibilities of participants with managerial positions entailed supporting executives, implementing strategies and plans, reviewing impacts, and proposing approaches.

4.3.2 Participants' Industry Experience and Education

The average industry experience was 16,2 years. Participants who held executive positions averaged 20,5 years industry experience across all disciplines. Urban Planning executives (21,0 years) and managers (20,0 years) had slightly more industry experience than waste management and renewable energy participants. Table 4.2 presents participants' industry experience.

Table 4.2: Participants' Industry Experience

	Executive	Manager	Professional	Researcher	Total
Engineering	20,5	15,0	17,0		18,4
Planning	21,0	20,0	5,0	0,0	13,4
Waste Man	20,0	7,0			15,7
Grand Total	**20,5**	**14,25**	**11,0**	**0,0**	**16,2**

Figure 4.2 presents participants' level of education. Nine participants held a master's degree in their disciplines. Urban planning respondents held the most master's degrees while renewable (energy) participants equally held master's (3,0) and bachelor's (3,0) degrees. Only two participants held doctoral degrees. At the time of the interview, one participant with an Electrical Engineering background was pursuing doctoral research in urban design and civil engineering. It is important to note participants' years of experience, education background and area of specialisation because it provides context to how integration and collaboration currently operate.

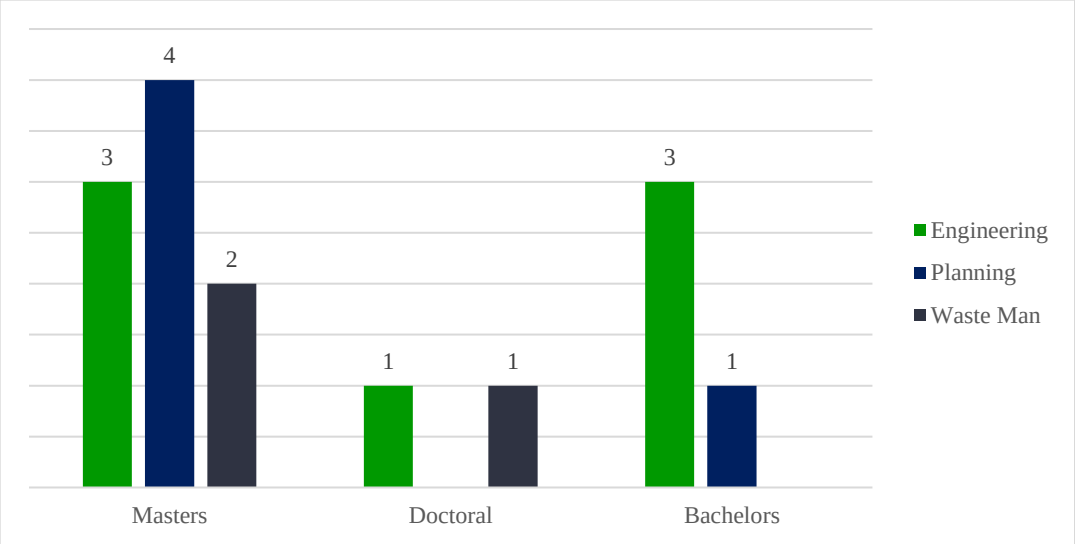


Figure 4.2: Participants' Level of Education

All questions were semi-structured, which ensured that the interview scope was followed while enabling modifications based on follow up questions to interviewees. Some questions were more applicable to specific interviewees than others due to the nature of their job description and activities.

4.4 R.O 1: AD promoting Circularity in Energy Generation

R.O 1: Determine if anaerobic digestion technologies can promote circularity in energy production.

Aim: Firstly, this objective sought to investigate whether existing anaerobic digestion projects in some African cities are currently operating efficiently, in a circular manner. Three operational technologies were selected and the Circular Economic Value for each was calculated. Analyses were substantiated with qualitative findings – Objective Two.

4.4.1 Presentation of Results

4.4.1.1 Participants' Involvement in WtE Projects

Participants were asked about their involvement in any energy or waste-to-energy related projects and if so, to provide details about the project purpose, technology adopted, type of energy expected and its use. Please note the acronyms for participants were footnoted[3].

4.4.1.1.1 Urban Planning Participants

None of the urban planning participants were directly involved in any electricity or energy generation activities. E.P and E.EP mentioned involvement from a consultative perspective, particularly infrastructure engineering but it was not a common occurrence in Addis Ababa. Similarly, G.P's involvement was limited to: engagements held at the steering committees, development applications and building permit issuing required by the utility agency to confirm ownership before electricity connectivity as well as development application reviews. S.DP on the other hand stated development

[3] E.P = Ethiopian Urban Planners; E.WM = Ethiopian Waste Managers; E.E = Ethiopian Energy Practitioners; E.EP = Ethiopian Engineer & Urban Planner
G.P = Ghanaian Urban Planners; G.WM = Ghanaian Waste Managers; G.E = Ghanaian Energy Practitioners; G.RI = Ghanaian Research Institute
S.P = South African Urban Planners Planners; S.WM = South African Waste Managers; E.E = South African Energy Practitioners; S.DP = South African Development
S.RI = South African Research Institute; NGO = non-governmental organisation; RA = Regional Agency

planning's involvement not only in the steering committee but executive management meetings with departments such as waste management, electricity, housing development, economic development and environment. Above land use planning such as reviewing development applications and zonings, other activities include spatial and regional planning of where and how metros should develop. The researcher gathered that urban planning professionals were not involved in energy planning other than reviewing development applications where they are included as a sub-section or engaging with fellow practitioners at exco meetings. The lack of involvement presents a set of opportunities and challenges.

4.4.1.1.2 Waste Management Respondents

E.WM expressed that large energy recovery from waste projects occurred at a national government level – Ministry of Water, Irrigation and Electricity. This also included some small-scale domestic biogas projects. The solid waste management agency does not have biogas projects at a metro-municipality level. Their focus is waste management and does not include biogas generation – "*We're focusing on managing the solid waste, but still we are not converting this waste into biogas. Instead we are flaring this, methane gas*." However, E.WM shared experiences with the Reppie Waste-to-Energy Plant. Being part of the Addis Ababa City Government's Waste Management Division, E.WM's roles and responsibility were to ensure waste is collected and handed to the plant engineers.

G.WM stated that Accra Metropolitan Assembly does not have an electricity utility at local level. The national utility is responsible for all electricity and renewable energy projects. G.WM was aware of two potential incineration projects which the Ministry of Energy was going to partner with private sector through a public-private partnership model. However, as a directorate, they were partnering with a local university to update current data on Accra's waste characterisation. Findings from the report would "*inform technology and landfill management options*". G.WM added that the metropolitan has a material recovery facility which processes 400 metric tonnes per day but it is too small. There were future plans to expand existing operations and

include composting activities and thermolytic cracking, which would be led by a private company. There is a small-scale anaerobic digestion system located in a different municipality due to political demarcations. According to G.WM "*the gas is used for electricity production, less than 1MW but it can be scaled*".

Projects directly or indirectly linked to waste management and energy generation include preparing a Sanitation Masterplan in partnership with the World Bank, prospects of developing a material recovery facility to service Accra, a pilot programme for co-digestion and participating in the Climate-40 group. Despite these efforts, G.WM mentioned the negative influence of politics in realising the full potential of each project.

Lastly, S.WM shared quite a few projects for waste management and recycling as well as concepts under considerations with S.E. Waste management and recycling projects include implementation of Buy-Back Centres and Separation-at-Source in low-to-middle income settlements. S.WM stated that these programmes were "*are part of a mandate to divert waste from landfills*", assist with recovering more recyclable materials and to stimulate job creation. S.WM reiterated working with S.E to diversity Johannesburg's' energy mix because waste was considered as one of the resources. S.WM mentioned that S.E would know more because the directorate focused specifically on electricity and renewable energy generation. The researcher deduced that the participants were more aware and familiar with incineration technologies and it is understandable given the large waste quantities cities produce daily versus highly constrained waste management methods.

4.4.1.1.3 Renewable (Energy) Participants

Due to the large quantities of waste produced in Addis Ababa daily, anaerobic digestion was less viable compared to incineration. E.E mentioned that the electricity utility's involvement was strictly for large scale energy projects. That is why the utility was working together with the metro-municipality on the Reppie WtE Project. The

facility, which has a 25MW electricity capacity, is a first of its kind for Africa, incinerating between 1,500 and 2,400 tonnes of waste per day. Electricity produced is handled by the national utility company, which oversees power generation, transmission and distribution. Other electricity projects include large-scale hydropower, wind, solar and geothermal, with little to no waste-to-energy let alone anaerobic digestion.

At the time of the interview, G.RI was facilitating a biogas plant to generate heat and electricity for a large abattoir in southern Ghana. It was a project initiated by a global regional agency and funded by an Asian government. The first phase was constructed but that it is not operational, and reasons were not clear. There was also a partnership with the Ministry of Energy and a European development agency to explore a 5MW timber-waste-to-energy also in the south of Ghana. Pre and full feasibility studies were being carried out however, its operationalisation remains uncertain "*because the plant wants to feed into the grid, then it gets to the stage where you have to discuss getting PPA and that goes to a lot of political skirmishes*". Getting a power purchase agreement for renewable energy projects is cumbersome and disheartening especially for feed-in projects. Collaborations could be working out well until this stage. However, if there are no intentions to produce electricity specifically for feeding into the grid, then there is very little interferences politically. For example, an agro-industrial company that wants to invest in an anaerobic digestion system to generate energy for onsite-use can do so. The regulations are less complex for such setups. A bottleneck for biogas implementation is financing.

At the southern tip of Africa, S.E shared a few landfill-to-gas and wastewater treatment projects the department was involved in preparing. Some projects started at pilots with the intention of generating on-site electricity for managing waste, while others were firmly for energy generation with intentions of transmitting to the national grid. S.E was not aware of industrial or commercial anaerobic digestion plants other than some which private sector explored. However, the department has plans to explore market waste for biogas production, which would be used to fuel public busses. The researcher

inferred that given the high population and urbanisation, renewable energy professionals focus on large scale energy projects. All participants mentioned that they present a more viable business case due to the large numbers.

4.4.1.2 Measuring Circularity of Existing AD Plants

While participants were not directly involved in any anaerobic digestion projects, the researcher reviewed and collated data from secondary sources. A key limitation experienced during collection was the lack of detailed and publicly available data. Three case studies were selected from a dataset of 16 AD plants. Each is representative of the study areas; Ethiopia, Ghana and South Africa.

4.4.1.2.1 Selecting the Suitable Measurement Tool

In sub-section 2.2.3, a variety of measurement tools used to measure circular economies were discussed. Just with the definition, there is no globally accepted measurement tool. Three tools with the closest relation to circular economy principles were further discussed and the researcher considered two of those.

First Consideration: Material Circularity Indicator (MCI), specifically Product-Level Method.

Equation 4.1: Material Circularity Indicator – Product Level Method

$$MCI^*_P = 1 - LFI \cdot F(X). \longrightarrow \mathrm{MCI}'_P = \max\left(0, 1 - \frac{\mathrm{W}' + \mathrm{V}'}{2\mathrm{M}' + \frac{W_F - W_C}{2} + \frac{W'_F - W'_C}{2}} \mathrm{F(X)}\right).$$

Although the tool was designed to measure circularity in companies, it was considered based on extensive research and case studies available, as well as how it incorporates circular economy principles. By evaluating the performance of a commodity or an entity in a circular sense, this indicator helps you to determine the remaining direction to affranchise the linear model. The 2019 update also consider measuring biological

cycles such as energy recovery and composting. As a result, the Ellen MacArthur Foundation suggests that the MCI be supplemented with "additional indicators" like water, energy, and GES emissions, as well as ‘risk indicators’ like rarity, toxicity, and so on. MCI measures the extent to which linear material flows are minimised and how long they are kept circular. In the case for anaerobic digestion, measuring the extent to which organic urban waste is maximised for biogas production was considered, bearing in mind that technologies differ as well as waste quantities and qualities in each context.

The measurement tool also incorporates products that use raw material but end up in landfills, making it linear production. In the study’s case, the researcher understood how organic urban waste is used as a feedstock to produce some form of energy. If that energy is not used in one form or another - as a gas, electricity or organic fertiliser – then the technology may be considered to discourage circularity. But if the energy is used as a feedstock or input material for another cycle, then it would be seen to promote circular energy production. For example, using digestate for urban agriculture and soil rehabilitation. Lastly, this method calculates circularity using detailed knowledge of product and material flows. Others suggest a circularity analysis based on socioeconomic systems theory to go beyond this debate: Economic activity develops within socio-ecological processes, and its evaluation takes into account both biophysical (ecosystems, flux, natural cycles, etc.) and anthropological (institutions, laws, actors, etc.) factors. This approach makes it easier to see a circularization plan as a social trajectory.

However, MCI was not considered because:

a) the parameters and indicators sway more towards technical cycles and product design within companies,
b) energy recovery and composting (biological cycles) are considered as part of the greater equation; circularity cannot be measured independently,

c) the equation would require input data that is more applicable to production and manufacturing of goods, meaning that input data goes beyond the available AD data.

Second Consideration: Circular Economic Value (CEV) equation used by (Fogarassy, Horvath, Kovács, *et al.*, 2017) to measure the circularity of a solar energy park.

Equation 4.2: Circular Economic Value

$$CEV\% = 100 - \left(\frac{\left(\frac{M_p}{M_p + M_s} + \frac{M_d}{M_r + M_d}\right) + \left(\frac{E_f}{E_s + E_f} + \frac{E_l}{E_c + E_l}\right)}{4} \right) \times 100 \quad (1)$$

(M_{lin}: M_p; M_{lout}: M_d; E_{lin}: E_f; E_{lout}: E_l)

It is the closest reference to measuring circularity and efficiency of an energy system; very specific for energy recovery. This equation was chosen because:

a) the parameters and variables are specific to energy recovery systems because it contains variables which can be translated to any renewable energy technology,
b) it is pro-biological cycles and circularity can be measured independent of technical cycles,
c) the equation handles input and output material and energy flows separately,
d) most importantly, it "*describes the ratio between the linear and circular processes on the input and output sides*." (Fogarassy, Horvath, Kovács, *et al.*, 2017, p. 164)

The equations are not far-fetched from one another. The value of products and materials has to be preserved for as long as possible while keeping waste generation to a minimum. They all incorporate circular economy principles and show readers the different perspectives from which circularity can be measured. As a result there are no uniform indicators for circularity but a few can be combined to measure different

features of a circular economy. Thus the researcher chose the most suitable and applicable option for the given contexts.

4.4.1.2.2 Calculations and Measurement

A circular technology effectively and efficiently uses input material and energy, as well as output material and energy. It means is that the sum of linear flux and circular flux should add up to 100,0%, so the less linear fluxes the higher the circularity index. The conceptual framework of urban energy and waste flows developed in section 3.2 was used and customised it for each case study. For the purposes of this study, not all variables are necessary because the equation was not designed for WtE technologies.

Case Study A: Reppie Waste-to-Energy Plant

In a national survey on current statistics of installed institutional biogas systems in Ethiopia, over 120 biogas plants were identified across different parts of the country. Most were in the Oromia region (34,0 plants), followed by Addis Ababa (24,0 plants), Amhara (22,0 plants) and others. The plants' operatorial and production capabilities were assessed and found that the average capacity ranged between 12,0-350,0m^3. The survey also showed that 53,0% of the plants were operational. The remaining 47,0% stopped being functional in less than three years. Most plants were fixed dome (77,0) followed by vertical floating drums (15,0). These were spread across schools, colleges, and universities, some in prisons, farms and hotels as well as hospitals, abattoirs and churches. Almost all the institutions used biogas for cooking, with very few using it for lighting, organic fertiliser, and waste stabilisation (Chala, 2009). Participants recommended the Addis Ababa University's Industrial Anaerobic Digestor, but its operational status at the time of interviews was unknown and data was insufficient for this study. Thus, the Reppie WtE Plant was recommended. Table 4.3 presents case study A, the Reppie WtE Plant.

Table 4.3: Case Study A – Reppie WtE Plant

Boundary	Reppie WtE Facility was designed with the aim of managing exorbitant urban waste from Addis Ababa households and equally to complement their energy demand. Koshe landfill is the biggest disposal site which has reached its capacity. Due to lack available land for a second facility as well as other socio-political influences for a sanitary landfill, an immediate solution had to be found before the city was riddled in waste. There are approximately 5 million inhabitants within the city and this is expected to increase between 2030 and 2050.
Space Management	Reppie WtE was built on a portion of the landfill to ensure centralised disposal, treatment and generation activities. Approximately 20,0-30,0 collection trucks dispose waste per day. One can literally walk from the landfill to plant. Landfill-to-gas initiatives such as the Fukuoka Method, a Japanese approach to extract methane. Fukuoka transforms methane gas into carbon dioxide, which is then flared due to lack of market demand. Leachate is also managed on site using anaerobic digestion.
Invest Structure	The facility was funded by the government, an investment valued at US$ 95 million or Br 3,9 billion.
Actors	The actors involved include private and public. Cambridge Industries (Ltd) and China National Electric Engineering Co developed the project for Ethiopian Electric Power (EEP) and Addis Ababa City Administration (AACA). The Directorate for Solid Waste Management within AACA is responsible for waste management, namely collection and pre-treatment or sorting (where necessary) and finally disposing at the power plant. EEP is responsible for energy generation, transmission and distribution as well as maintenance. Waste material is collected from mainly households, commercial and industrial sectors.

Policy & Regulatory Frameworks	Addis Ababa's population is approximately 4,9 million as of 2019. The Ethiopian government and various industry reports expect this figure to rise between 2020 and 2030. Noting the currently poor waste management activities and rising energy demand, EEP saw the need to develop Reppie WtE. There are currently no publicly available policies referencing WtE directly. However, the National Electrification Programme 2.0 (2019) recognises WtE as an energy recovery technology and agricultural waste as an energy source. Considerations for mini-grid development are also pertinent in the plan, using resources such as solar and biomass. Improved cookstoves and domestic biogas are equally key features. A greater focus is on the National Biogas Programme which focuses on rural biogas digestors. The programme focuses on addressing energy poverty in rural areas.

Interview Participants, (Cambridge Industries Ltd and China National Electric Engineering Co. Ltd, 2015; Ministry of Water, Irrigation, and Energy, 2019).

Figure 4.3 illustrates Reppie WtE Plant's energy and waste flows.

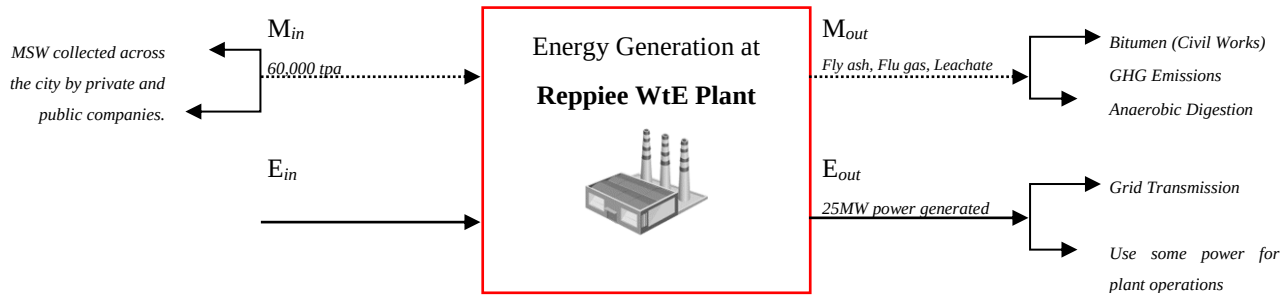


Figure 4.3: Reppie WtE Plant – Energy and Waste Flows Schematic

Where:

M_{in} = material in (linear flux) = 1,400 tpd (60,000 tpa)

M_p = primary raw materials = 1,400 tpd (60,000 tpa)

M_s = secondary raw materials = 0 t

M_{out} = material out (linear flux) = 100,400 tpa

M_d = non-recyclable materials = 0 t

M_r = recyclable materials = 100,400 t

E_{in} = energy in (linear flux) = z MW

E_f = non-renewable energy = z MW

E_s = renewable energy = 0 MW

E_{out} = energy out (linear flux) = 25 MW per month (300 MW per annum)

E_l = energy to displace product = q MW

E_c = energy use for recyling = 0 MW

CEV Formula:

$$CEV\ \% = 100 - \left(\frac{\left(\frac{Mp}{Mp + Ms} + \frac{Md}{Mr + Md}\right) + \left(\frac{Ef}{Es + Ef} + \frac{El}{Ec + El}\right)}{4} \right) x\ 100$$

$$CEV\ \% = 100 - \left(\frac{\left(\frac{60{,}000}{60{,}000 + 0} + \frac{100{,}400}{100{,}400 + 0}\right) + \left(\frac{z}{z + 0} + \frac{q}{0 + q}\right)}{4} \right) x\ 100$$

$$CEV\ \% = 100 - \left(\frac{(1 + 1) + (1 + 1)}{4} \right) x\ 100$$

$$CEV\ \% = 100 - \left(\frac{4}{4}\right) x\ 100$$

$$CEV\ = 0{,}0\ \%$$

Material and Energy In-Flows

Reppie WtE facility is a 0,0% circular technology and its primary objective is energy generation and waste management. As seen in Figure 4.3, M_p of 1,400 tonnes per day (60,000 tonnes per annum) are diverted from Koshe Landfill to the incinerator. There was no significant secondary material identified. The low circularity may be attributed to only having primary material inflow and no pre-sorting. If pre-sorting would take place, this may reduce waste quantities. Having the facilitiy on the same property as

the landfill reduces the amount of energy required to transport from a disposal to treatment site.

∴ M_p = high primary material inflow

M_s = low secondary material inflow

E_f = unknown non-renewable energy inflow

E_s = unknown renewable energy inflow

Energy Generation Process

No pre-treatment takes place but the waste is dehydrated for a few days due to its high moisture content. Once dehydrated, it is incinerated. The plant has a generation capacity of 25MW (E_{out}) of power, which is fed into the national grid. Another factor to consider is the amount of energy used to transmit and distribute the electricity (E_l) The Second Law of Thermodynamics – Concept of Entropy – is considered because during energy transfer or transformation, energy is lost along the value chain. This can make a technology inefficient and less circular.

Matrial and Energy Out-Flows

Given the nature of incineration technologies, material outputs are larger quantities of non-recyclables such as flue gas and fly ash. This may contribute towards a lower CEV. Fly ash residue is taken for landfilling or given to government agencies in charge of public works so as to use for infrastructure projects. Leachate is treated using anaerobic digestion which produces 200 kg of digestate per day (M_{out}). The digestate is then composted using a Japanese composting method known as Takakura. To manage GHG emissions from Koshe landfill, methane gas is extracted using another Japanese method known as Fukuoka. Lack of market uptake of these by-products also affects its circularity. E.WM mentioned that there is no market for the compost hence the city administration was in the process of using it to rehabilitate Koshe Open Dump with trees. A lack of market may result in compost not being reused as input material for urban farming or soil rehabilitation.

∴ M_d = high non-recyclable material outflow

M_r = low recyclable materials outflow

E_l = high amout of energy produced outflow

E_c = unknow amount ofenergy use for recyling outflow

Case Study B: Safisana fixed-dome Biogas Plant, Ashaiman, Accra - Ghana

Biogas technology has been prevalent in Ghana since the 1960s. It is primarily used for cooking and energy generation. Majority of anaerobic digestors were not successfully implemented due to poor processes being followed and immature technology. Since then, researchers such as biogas Bensah and Brew-Hamond (2010) and Osei-Marfo et al. (2018) have conducted case study research to investigate biogas technology update in Ghana. In 2010 Bensah and Brew-Hamond surveyed 50 biogas plants in Ghana, of which "*twenty-nine (58,0%) installations were institutional, fourteen (28,0%) were household units, and the remaining seven (14,0 %) were community plants*" (pg 277).

The authors noted a need for biogas adoption as well as operational knowledge and skills transfer, and thus recommended a National Biogas Programme. Osei-Marfo, Awuah and de Vries (2018) focused on biogas technologies in Central and Greater Accra. The authors identified 120 biogas technologies. Findings showed that most biogas digestors were located in Accra Metropolitan Assembly (55,0), followed by Cape Coast Metropolitan Assembly (30,0) and Tema Metropolitan Assembly (25,0). The authors only surveyed 54,0 of the 120,0 identified (Bensah and Brew-Hamond, 2010; Osei-Marfo, Awuah and de Vries, 2018). The researcher selected one community-based AD plant as a case study: Safisana fixed dome biogas plant. Table 4.4 presents case study B, a fixed-dome biogas plant located Ashaiman, Accra – Ghana.

Table 4.4: Case Study B - Safisana fixed-dome Biogas Plant, Ghana

Boundary	Safisana is a Dutch-owned WtE plant located in Ashaiman, Greater Accra. The nearest disposal site is Kpone landfill site however, it is considered far for producers to travel to compared to their proximity to Safisana. The plant is a fixed dome design that produces biogas for electricity and organic fertiliser onsite. It was commissioned in March 2017 with the aim of generating biogas, fuel for experiments in labs, biogas for cooking, electricity for communal lighting, improving sanitation and producing organic fertiliser for farmers as well as job creation. The multi-purpose facility treats both wastewater and some MSW collected from surrounding households and businesses within and around the area. These include organic produce markets in Ashaiman and Tema, abattoirs in Madina and Accra and food waste from Unilever and Olam biscuit factory. It has a capacity of 2,800 m^3 and generates approximately 2,2 MW of electricity for the national grid (600MWh per annum). Approximately 25,0 tonnes of waste is delivered daily.
Space Management	Safisana offered waste producers a centralised disposal site, with the benefits of time and fuel savings. This ensures sustainable management of various waste streams, co-digestion and generation of various fuel types (biogas, electricity and digestate). The fixed dome, CHP system and waste stabilisation ponds are located on the stie.  **Figure 7** | (a) The Safisana fixed dome biogas plant, Ashaiman, Accra, September 2017, (b) the CHP at the Safisana Ashaiman site, September 2017; (c) Waste stabilisation pond with baffles at the Ashaiman site for treatment of liquid waste from the drying beds, September 2017. Although it is still operational, users who participated in a survey were not satisfied by its performance (29,0%), because their energy needs were not fully met. Issues include insufficient gas production, breakdown of infrastructure.

Investment Structure	Digestion design and implementation have a high initial cost and this impedes greater adoption in Ghana. There are currently no subsidies or investment incentives for biogas production. Costs for different anaerobic digestion technologies depend on site and waste characteristics. Households alone can not afford the costs. Safisana is maintained regularly (monthly and yearly) which has resulted in its continued operation. Waste producing companies pay a fee for Safisana to dispose and handle their waste.
Actors	The facility was developed and commissioned by Safisana together with Ashaiman Local Municipality and the Ministry of Energy and Agriculture. Technology and investment partners comprise of global players such as Draper Richards Foundation, Grand Challenges Canada, Bill & Melinda Gates Foundation, The Stone Family Foundation and Aqua-for-All. "*The initial investment required for the design and construction of the plant is predominantly supported by contributions of donor parties, governmental bodies and loans from international finance institutions or commercial banks*" (Safisana, 2017). Community members have small businesses as well, collecting and sorting the waste. Public sector relations include: Power Purchase Agreement (PPA_ with Electricity Company Ghana, entering a private-public partnership (PPP) and sign memorandum of understanding with Ashaiman Local Municipality.
Policy & Regulatory Frameworks	Ghana's Renewable Energy Master Plan (2019) has a serious and intentional focus on WtE/biomass related projects. The plan forecasts an increased adoption using domestic (200 units), industrial (200 units) and institutional (500 units) waste by 2030. Currently Ghana has 9,000m^3 of installed biogas capacity and 5,6 MW from thermal generation. Based on previous experiences "*existing biogas technologies are not sustainable to provide community-based electrification but may be an ideal technology for sanitation management in relevant institutions*" (Ministry of Energy, 2019, p. 11).

(Safisana, 2017; Osei-Marfo, Awuah and de Vries, 2018; Ministry of Energy, 2019; Okrofu, 2019)

Safisana Plant's business model corroborates with this study's energy and waste flows schematic – see Figure 4.4.

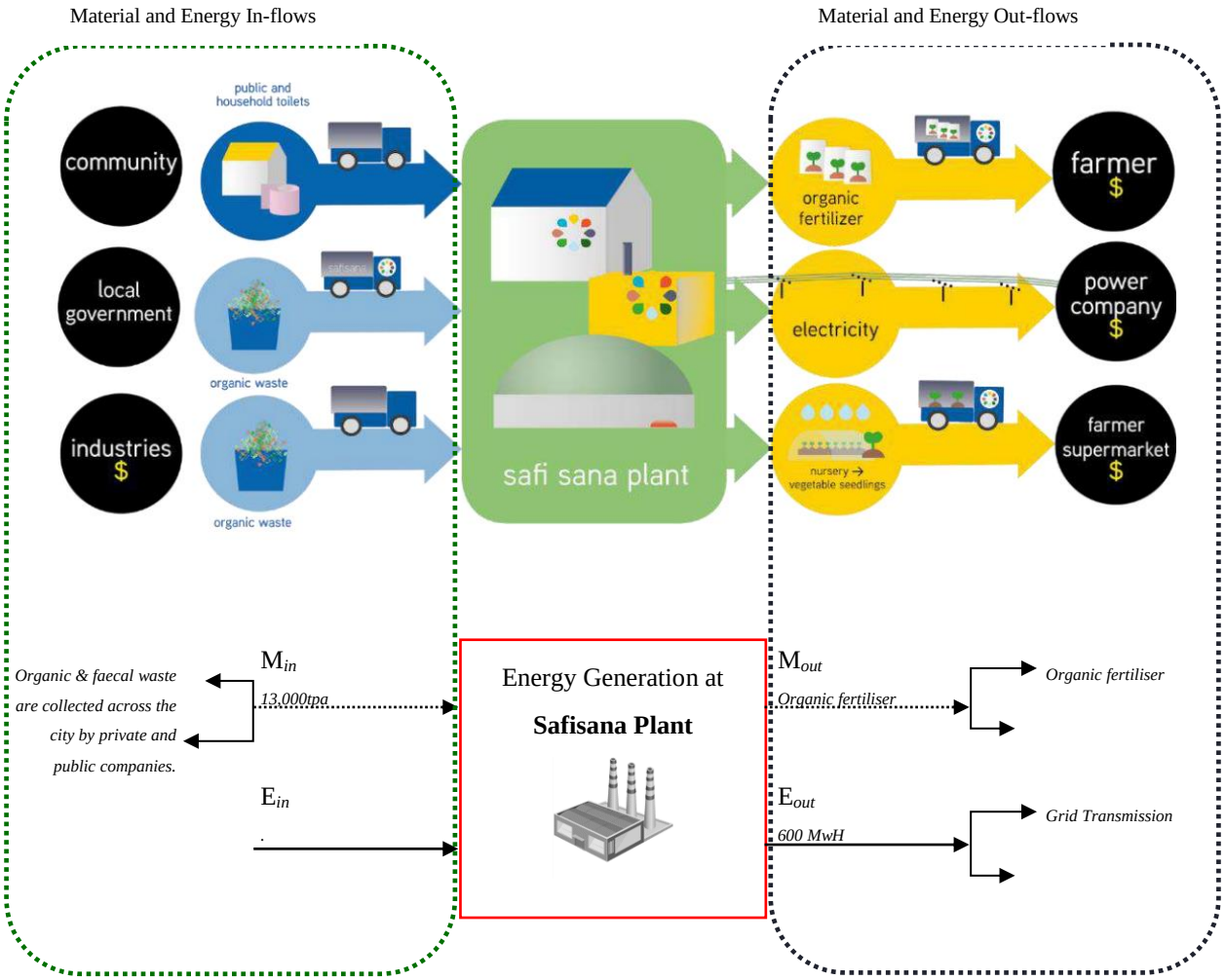


Figure 4.4: Safisana WtE Plant – Energy and Waste Flows Schematic

Where:

M_{in} = material in (linear flux) = 13,300 tpa

M_p = primary raw materials = 9,700 tpa of faecal matter

M_s = secondary raw materials = 3,600 tpa of organic waste

M_{out} = material out (linear flux) = 91 tpa

M_d = non-recyclable materials = 0 t

M_r = recyclable materials = 91 tpa of organic fertiliser

E_{in} = energy in (linear flux) = q MW

E_f = non-renewable energy = q MW

E_s = renewable energy = 0 MW

E_{out} = energy out (linear flux) = z MWh per annum

E_l = energy to displace product = 0 MW

E_c = energy use for recyling = 0 MW

CEV Formula:

$$CEV\ \% = 100 - \left(\frac{\left(\frac{Mp}{Mp + Ms} + \frac{Md}{Mr + Md}\right) + \left(\frac{Ef}{Es + Ef} + \frac{El}{Ec + El}\right)}{4} \right) x\ 100$$

$$CEV\ \% = 100 - \left(\frac{\left(\frac{9{,}700}{9{,}700 + 3{,}600} + \frac{0}{91 + 0}\right) + \left(\frac{q}{q + 0} + \frac{z}{0 + z}\right)}{4} \right) x\ 100$$

$$CEV\ \% = 100 - \left(\frac{(0{,}73) + (2)}{4} \right) x\ 100$$

$$CEV\ \% = 100 - \left(\frac{2{,}73}{4} \right) x\ 100$$

$$CEV = 31{,}75\ \%$$

Material and Energy In-Flows

Safisana's AD plant is a 31,75% circular technology and its primary objective is also energy generation and waste management. Urban waste material comprising of primarily faecal matter (9,700 tpa) and organic waste (3,600 tpa) sourced from households, local government and industries in areas such as Tema, Medina and Ashaiman Local Municipality. There is a lot of organic waste generated in Greater Accra, thus high material inflows. Organic is opportune to possibilities of further beneficiation because of the biological composition. Having a centralised disposal, treatment and energy generation facility reduces the amount of energy required to transport from various waste generators.

∴ M_p = high primary material inflow

M_s = medium secondary material inflow

E_f = unknown non-renewable energy inflow

E_s = unknown renewable energy inflow

Energy Generation Process

It is not clear whether pre-treatment or dehybration takes place, as this may impact the quantity of material inflow. The plant generates 600MWh of electricity (E_{out}) of power, which is fed into the national grid. As with Reppie WtE, the Concept of Entropy is also considered here because energy is lost along the value chain. This can make a technology inefficient and less circular.

Matrial and Energy Out-Flows

An additional material and energy output is digestate and organic fertiliser (91 tpa). The organic material output may contribute towards a higher CEV because of further beneficiation. Unlike the case of Reppie WtE, there is a market to sell organic fertiliser to nearby farmers. PPA's signed with public sector role-players guarantee a market for energy sales.

∴ M_d = low non-recyclable material outflow

M_r = high recyclable materials outflow

E_l = high amout of energy produced outflow

E_c = unknow amount ofenergy use for recyling outflow

Case Study C: Bronkhorstspruit Biogas Plant, Pretoria – South Africa

South Africa has approximately 700 digestors installed. The first digestor was installed on a pig farm by John Fry in 1957. (Mutungwazi, Mukumba and Makaka, 2018) provide the most up-to-date data on biogas installations in South Africa. Table 4.5 summarises of some of the prominent installations:

Table 4.5: Biogas Digestors Installed in South Africa

Area	Developer	Substrate input	Power output
Alice, Eastern cape	CAE / University of Fort Hare	4000 m^3 of dairy and piggery manure	2 × 132 kVa electricity generators
	Alrode brewery		
Athlone Industria	Farm Secure Energy, Wastemart, CEA/New Horizon waste to energy	400 t of organic waste per day	
Bela-bela Limpopo	CAE Humphries Boerdery piggery		
Belville		Waste water treatment plant	
Bonnievale	FarmSecure Carbon	> 5 t bovine manure	
Bredasdorp	iBert	4 t abattoir waste per day	100 kW
Cavalter	iBert	20 t abattoir waste per day	500 kW
	EnviroServ/ Chloorkop LFG		
	Cullinan		190 kW
Darling Uilenkraal	CAE/Uilenkraal dairy farm	Bovine manure	600 kW
Darling GrootPost	FarmSecure manure	Bovine manure	
Durban	Bisasar road LFG	3500–5000 refuse per day	6 MW
Durban	Marrianhill LFG	550–850 t per day	1.5 MW
	Ekhurleni LFG		
Grabouw	Elgin Fruit and juices	> 5 t of fruit waste per day	500 kW
	Ibhayi brewery		
Jan Kempdorp	iBert	5.5 t abattoir waste per day	135 kW
	Jacobsdale		150 kW
Johannesburg	WEC/Northern Waste Water Treatment Works	Sewage sludge	1.2 MW
Johannesburg	Robinson Deep		19 MW
Klipheuwel	Reliance Composting	700 t organic waste per day	
Klipheuwel (Zandam)	Farmsecure	> 5 t of manure per day	600–700 kW
Mossel Bay	Biotherm SA, Mossel Bay PetroSA	Refinery waste water	4.2 MW
Newlands	SAB Miller	4500 m^3 of wastewater per day	10% of the plant's energy
Paarl	Drakenstein municipality		14 MW
Pretoria	Bio2watt / Bronkhorst-Spruit Biogas plant	Manure	4.6 MW
	Prospection brewery		
Queenstown	iBert	42 t mixed waste from a piggery per day	
Riverdale	iBert	4 t abattoir waste per day	100 kW
	Robertson		150 kW
	Rosslyn brewery		
Springs	BiogasSA / Morgan Springs Abatrtoir	Slaughter waste and organic waste	0.4 MW
Stellenbosch	Veolia water Technologies / Distell	1000 m^3 wastewater per day	
Stellenbosch Franschhoek	Rhodes Food Group	35 kg per day(testing feedstock)	
	Selectra	Sewage, silage, manure	0.5 MW
	Selectra	Sewage, silage, manure	1 MW
	Selectra	Sewage, silage, agricultural waste	1 MW
Table view	Jeffares and Green / Bayside Mall	0.6–1 t of food waste per day	
KZN	Khanyisa projects	Manure from 2+ cows, school organic and sewage waste	Rural cooking fuel
KZN	SANEDI	Manure from 2+ cows, school organic and sewage waste	Rural cooking fuel
EC (Alice, Fort Corx and Melani villages), WC (Phillipi), KZN	AGAMA	Manure from 2+ cows, school organic and sewage waste	Rural cooking fuel
Gauteng	Zorg	Vegetable pulp + silage plant	7200 m^3 methane

(Mutungwazi, Mukumba and Makaka, 2018)

Table 4.6: Case Study C - Bronkhorstspruit Biogas Plant, South Africa

Boundary	One of the most referenced commercial projects in South Africa is Bio2Watt's Bronkhorstspruit Biogas Project. Inception began in 2007 and generation in 2015. The project is located approximately 40km from Tshwane in an area known as Bronkhorstspruit. Covered In Ground Anaerobic Digestion is used to generate upto 4,0MW of power (35,000 MwH per annum). Primary feedstock is animal manure followed by secondary food waste. The poweris wheeled through the City of Tshwane Metropolitan Municipality and consumed by BMW South Africa.
Space Management	Bio2Watt receives a total of 120,000 tonnes per annum from a nearby cattle feedlot as well as poultry abattoir waste, vegetable and fruit market waste, paper sludge and dairy waste. The operations take place on land covering just over one hectare.
Invest Structure	The ZAR135 million facility was funded by Bio2Watt, the Industrial Development Corporation (IDC), and several funding agencies for various stages of project development. Some include: • Pre-Feasibility Study: ZAR425,000 from the Finnish Development Organisation, • Construction Phase: 70,0% of commercial loan provided the IDC & 30% from private investors as well as mezzanine funding from the Norfund (ZAR14 million), • Development Phase: funding from the Netherlands Enterprise Agency and equity funds from various private investors. The cost per MW installed amounted to ZAR32 million.
Actors	The actors involved include private and public. Bio2Watt are the project owners and developers, the City of Tshwane Metropolitan Municipality and Eskom from an electricity wheeling perspective and BMW South Africa as the offtaker. Other partners include surrounding farmers who provide secondary feedstock.

Policy & Regulatory Frameworks	In 2011, the Department of Energy (DOE) launched the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP). The competitive bidding programme was designed to stimulate renewable energy in country. Although it successfully stimulated industries such as solar and wind, it has not had the same effect for biogas development to date. Various national energy and waste management policies, frameworks and regulations acknowledge WtE technologies. Public and private sector investment incentives such as the Section 12J Income Tax of 1952, are accessible to renewable energy developers but again, not the same effect for biogas development. The National Waste Management Act (2008) encourages waste diversion from landfills. This has a positive impact for projects such as this in terms of sustainable feedstock supply.

(Bio2Watt, 2016; Goemans, 2017; Jordaan, 2018; Ndlovu *et al.*, no date)

Bronkhorstspruit Biogas Plant's business model also corroborates with the researcher's energy and waste flow schematic – as presented in Figure 4.5.

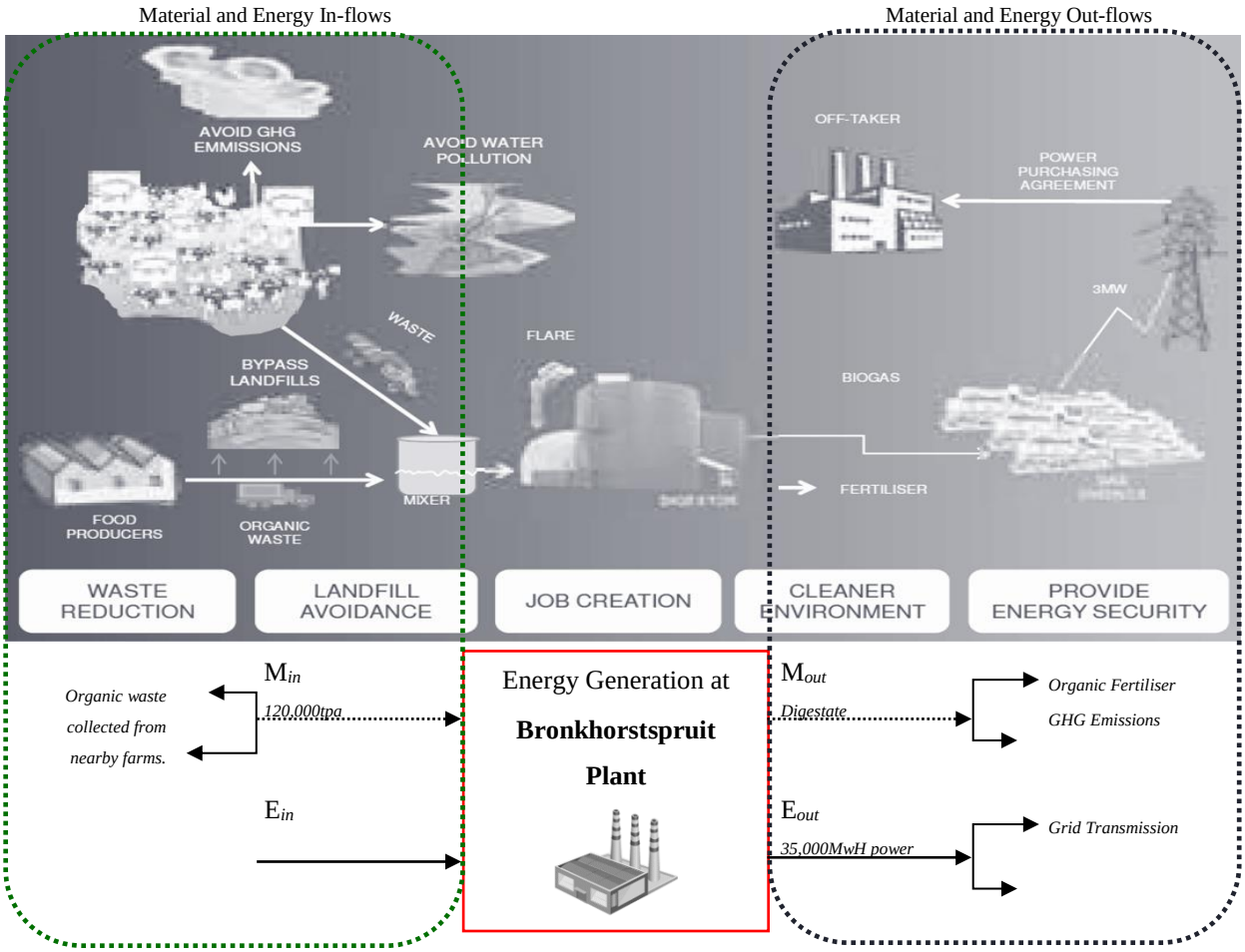


Figure 4.5: Bronkhorstspruit Biogas Plant - Energy and Waste Flows Schematic

Where:

M_{in}	**= material in**	**(linear flux)**	**= 120,000 tpa**
M_p	= primary raw materials		= 120,000 tpa of organic waste
M_s	= secondary raw materials		= 0 tpa
M_{out}	**= material out**	**(linear flux)**	**= 20,000 tpa**
M_d	= non-recyclable materials		= 0 t
M_r	= recyclable materials		= 20,000 tpa of organic fertiliser
E_{in}	**= energy in**	**(clinear flux)**	**= q MW**
E_f	= non-renewable energy		= q MW

E_s = renewable energy = 0 MW

E_{out} = energy out (linear flux) = 35,000 MWh per annum

E_l = energy to displace product = 35,000 MWh

E_c = energy use for recyling = 0 MW

CEV Formula:

$$CEV\ \% = 100 - \left(\frac{\left(\frac{Mp}{Mp + Ms} + \frac{Md}{Mr + Md}\right) + \left(\frac{Ef}{Es + Ef} + \frac{El}{Ec + El}\right)}{4} \right) x\ 100$$

$$CEV\ \% = 100 - \left(\frac{\left(\frac{120{,}000}{120{,}000 + 0} + \frac{0}{20{,}000 + 0}\right) + \left(\frac{q}{q + 0} + \frac{35{,}000}{0 + 35{,}000}\right)}{4} \right) x\ 100$$

$$CEV\ \% = 100 - \left(\frac{(1) + (2)}{4} \right) x\ 100$$

$$CEV\ \% = 100 - \left(\frac{3}{4} \right) x\ 100$$

$$CEV\ = 25{,}0\ \%$$

Material and Energy In-Flows

As with the first two case studies, Bio2Watt's AD plant manages waste and generates energy. The plant's circularity was calculated to be 25,0% circular – the median between the other two. Organic waste material is collected from nearby farmers. It comprises of primarily husbandry and agrarian activities. Secondary material inflow was unknown. However, given the biological composition of the 120,000tpa, further beneficiation is opportune. Centralised treatment and energy generation activities reduce the amount of energy required for transportation.

∴ M_p = high primary material inflow

M_s = unknown secondary material inflow

E_f = unknown non-renewable energy inflow

E_s = unknown renewable energy inflow

Energy Generation Process

It is also unclear whether pre-treatment or dehybration takes place. The plant generates 35,000MWh of electricity (E_{out}) of power. This plant generates more electricity than the other two, meaning a greater use and losses of energy within the value chain - Concept of Entropy.

Matrial and Energy Out-Flows

Two energy outputs are produced, namely electricity and digestate. Electricity is wheeled onto the grid for distribution to the offtaker and digestate is sold to nearby farmers. Further energy losses are likely experienced in the wheeling process, which would negatively impact the CEV. The researcher was not able to determine energy loss and compare to annual organic fertiliser production (20,000t). Nonetheless, organic waste material still has a positive impact on CEV.

∴ M_d = uknown non-recyclable material outflow

M_r = high recyclable materials outflow

E_l = high amout of energy produced outflow

E_c = unknow amount ofenergy use for recyling outflow

4.4.2 Discussion and Interpretation of Findings

4.4.2.1 Mandate and Experience of Targeted Decision-makers

Findings showed that decision-makers in urban planning have an imperative role to drive development physically and strategically across the three metro-municipalities. That is the core the profession. Information and data ranging from demographic profiles, land use management and zoning, economic development and climate change are just a few included in various legislative and regulatory documents. Their work sets the foundation for other professions to build from – see Figure 4.6.

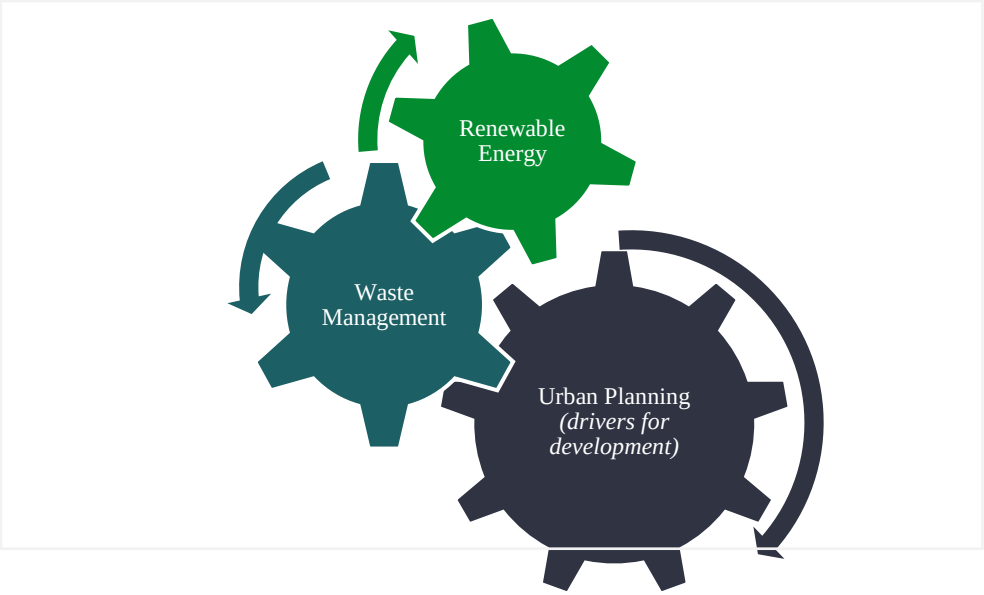


Figure 4.6: Interrelated Disciplines

However, the physical environment and frameworks in which urban planners operate has evolved at a very slow rate, while in some cases it has not evolved at all. Home (2015) alluded to this by mentioning that most African cities did not evolve beyond colonial planning structures. There is a need for intentional urban energy planning as suggested by Thery Hetreux and Zaraté (2009) and Madlener and Sunak (2011) that is inclusive of sustainability aspects such as waste management and renewable energy.

Decision-makers in waste management and renewable energy build on work done by urban planners. Findings showed that roles and responsibilities within these disciplines were very similar across the cities – Addis Ababa, Accra and Johannesburg. Differences are based on each city's political context. Addis Ababa City Government has five directorates for solid waste management while Accra Metropolitan Assembly and City of Johannesburg have one each, but still include relevant activities.

With reference to renewable energy decision-makers, they were all equally qualified and experienced. They all have mandates to ensure that populations are energised. Once again, contexts in which they operate differ because those in Addis Ababa and

Accra deal more with energy from renewable sources compares to Johannesburg where the primary energy source is from a fossil fuel (coal). A few energy plans guiding decision-makers include:

- Ethiopia: National Electrification Program 2.0 - Integrated Planning for Universal Access (2019),
- Ghana: The Renewable Energy Master Plan (REMP, 2019)
- South Africa: Integrated Resource Plan 2019 (IRP, 2019)

4.4.2.2 Participants' Involvement in WtE Projects

Findings explained that urban planners were generally not involved in any WtE projects across the three metro-municipalities. Involvement was limited to executive or steering committee meetings where colleagues in waste management and energy would present their sector plans. This presents an opportunity for urban planners' greater participation in renewable energy generally.

Madlener and Sunak (2011) wrote about urban energy planning and urbanisation management. Urban planners are tasked to ensure that urban structures are compact and to reduce urban sprawling because it affects energy supply. This means balancing growth of informal settlements and informal economies that drive local economic development. Planning for energy in urban areas must be multidisciplinary, multisectoral and participatory. The City of Johannesburg's Development Planning Department has taken strides towards this shift by participating in the C40 Group. The Department was tasked with developing Green Building By-laws for Johannesburg. Although it is not energy generation specific, it does compliment energy efficiency, which has linkages to a circular economy.

A pattern identified amongst waste management and renewable energy decision-makers were more involved in WtE projects focusing on different parts of the value chain. However, large scale WtE projects were most prevalent at national level; initiated and driven my Department or Ministries of Energy in the respective countries.

This is due to countries' policies and plans for electrification and energy diversification. In June 2019, the Government of Ethiopia published their National Electrification Programme (NEP) that details how they aim to achieve universal access by 2025. It refers to biogas projects through the National Improved Cookstove Programme (NICSP) and the National Biogas Programme (NBPE) specifically domestic biogas. In February 2019, the Ministry of Energy in Ghana published the Renewable Energy Master Plan 2030 (REMP) which makes serious provision for domestic, institutional and commercial biogas projects – for cooking and heating. South Africa has a wide variety of electrification and electricity policies, electrification acts and regulations. Some of these include the White Paper on Renewable Energy (2003), the Integrated Resource Plan (2019) and Integrated Energy Plan (2016) – represented under the National Energy Act (2005). Regulation of biogas is mainly governed by Section 28 of the Gas Act (2001), but it focuses on small biogas projects. An example referred to throughout Chapter Four was Ethiopia's 25MW Reppie WtE Facility, which is managed by the national utility.

Projects with capacities of 10MW and below can be implemented within municipalities' mandates. Waste management decision-makers would focus on managing waste by trying to separate it early in the value chain; to ensure suitable management methods are used. Renewable energy decision-makers comprising of mechanical, electrical and chemical engineers would then focus on electricity production. Although decision-makers mentioned that they do have mandates for WtE, the projects were not necessarily developed and implemented by metro-municipalities but through private-public partnerships (PPP). Hence the study also engaged regional agencies, industry associations and research institutions in waste management and renewable energy to obtain different perspectives - see Annexure F – Researcher's Detailed Collation of WtE Projects in Africa

In the same light, the researcher also found that there are very limited country databases of WtE projects generally. Existing data is not centralised or comprise of up-to-date figures. One of the key reasons identified was that metro-municipalities do

not have adequate tools and capacity to collect waste data and trace it to treatment technologies. Furthermore, because of the project ownership models, contractual agreements can stipulate that data belong to project developers who can use it according to their terms. This makes it tough to learn about or improve AD integration in urban areas. When the researcher extrapolated secondary data from various sources, it was evident that indeed it is not centralised. Numerous researchers have contributed much research on AD adoption in Africa, most of which focused on domestic biogas systems in rural areas than commercial or industrial. To name a few: The Africa Biogas Partnership Programme (ABPP), a partnership between Hivos and SNV, USAID and various Universities across Africa.Without accurate and up-to-date data, intentionally planning for anaerobic digestion in urban areas is negatively affected. Therefore, the researcher identified a relationship between data availability and planning for project development. An example shared by a participant in Ghana was of a 5MW timer-waste-to-energy project planning in Southern Ghana meant for heat and electricity.

Regarding the involvement of waste managers and renewable energy decision-makers in metro-municipalities when planning for WtE projects, their roles are very distinct yet complementary. Below is a schematic combining waste management and WtE value chains into a simplified Figure 4.7.

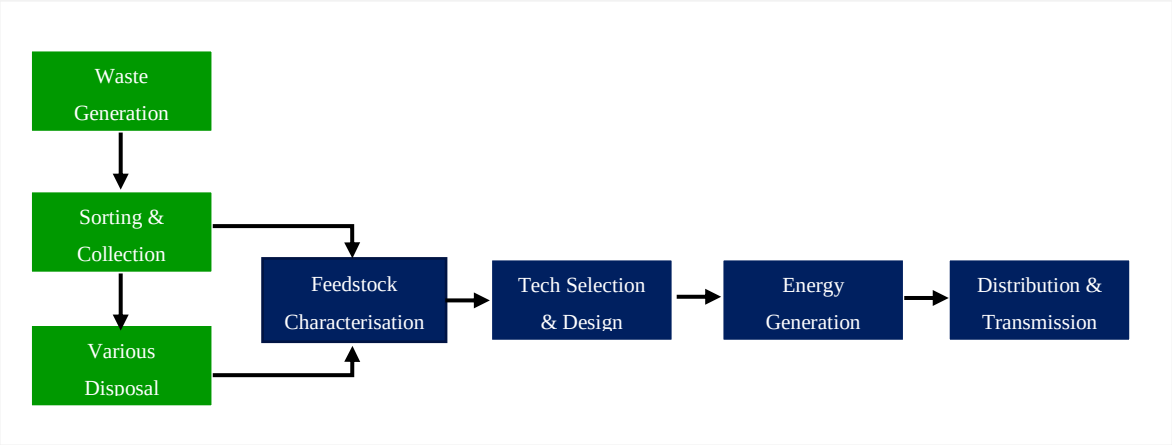


Figure 4.7: Roles and Responsibilities of Decision-makers in WtE Value Chain

Waste management and renewable energy decision-makers were more involved in some WtE project development. Waste management focus on managing waste by attempting to separate it early in the value chain to ensure it is quality feedstock for engineers to then generate energy. In 2009, United Nations Environmental Programme (UNEP) developed a training manual for municipalities in developing countries to upskill their human resources. The manual includes aspects such as waste characterisation, quantification and projections, aimed at developing Integrated Waste Management Plans (IWMP). When the first volume was published, it was noted that developing countries spend between 20-50% of their budget is spend on solid waste management. G.WM, the participant from Accra Metropolitan Assembly confirmed that indeed more than 60,0% of the budget is spent on waste management. Comprehensive waste data is required to develop and implement IWMPs and prioritise material and energy recovery opportunities (UNEP, 2009).

4.4.2.3 Measuring Circularity of Existing WtE Plants

To improve AD adoption in metro-municipalities, it is important to show decision-makers that AD can promote circular economy principles. The research proposition and objective investigated whether anaerobic digestion technologies promote circularity in energy generation. Findings presented in sub-section 4.1 indicate that current technologies are circular to an extent. Three case studies were selected and the CEV calculation was used for three types of technologies as presented in Table 4.7.

Table 4.7: Summary of CEV Calculations

Area	Technology Type	CEV Result
Ethiopia	an industrial incinerator	0,0%
Ghana	community-model fixed dome	31,75%
South Africa	commercial two-stage anaerobic digestor	25,0%

The higher the result, the more circular the technology and vice versa. All three case studies present CEV less than 50,0% which indicates that there are value leakages within their processes. The following reasons may apply:

M_{in} All three plants have an objective to manage waste and generate electricity. Large quantities are processed annually but the quality and composition may contribute towards these low CEVs. Firstly, unknown pre-treatment and recycling activities have an impact on quality of feedstock. Secondly, some feedstocks have higher calorific values than others. Hence co-digestion or multiple feedstock with high calorific values are recommended where possible.

Reppie WtE is an incinerator, and the nature of such technologies is traditionally linear. It can be described as 'garbage in – electricity generation – garbage out'. Material inflow is primarily MSW. Safisana plant's primary material inflow comprises of largely faecal matter and secondary supply of agrarian feedstock. Both types of feedstock have low calorific values and are best used through co-digestion. Bronkhorstspruit plant also has one large feedstock of animal manure and a small supply of agrarian material.

E_{in} E_{out} Primary energy produced is electricity, which is wheeled onto national grids. Energy inflow or use of energy generated for operations and use of renewable energy sources was unknown for all three cases. This presents possible value leakage where input energy may be higher than output energy.

M_{out} This is where the biggest value leakage was identified for material outflow. As alluded to by Hussain, Mishra and Vanacore, (2020). Value is attainable by further valorising by-products and recycling, reusing or redistributing where possible. All three cases have equally centralised their activities. Waste management and energy generation happen on one site. This reduces the amount of resources required as input. However, Reppie WtE's output material

is mainly non-recyclable, meaning no value optimisation. Safisana's material outflow processes 91t of organic fertiliser, which is sold directly to farmers. Bronkhorstspruit's plant produces tonnes of digestate but does not valorise. It was not clear how wastewater was treated or remediated. What these two plants have in common is value leakage for digestate beneficiation. Whether self-valorised or given to small businesses, digestate can be used for (vermi) composting or organic fertiliser. However, environmental limitations on digestate handling impede implementation.

Adding onto the above, literature also illustrated that engineering and urban planning parameters have a direct impact on AD's performance as seen in work by (Rada *et al.*, 2018; Xu *et al.*, 2018; Acosta, 2019; Chen and Kim, 2019; Kalchenko *et al.*, 2019; Hussain, Mishra and Vanacore, 2020). These authors are among a new era who explored circular economy and WtE within different urban environments such as cocoa production, energy transition and livestock manure management. Despite the growing body of literature, there was no focus on the role or impact of urban morphologies as well as urban metabolisms to induce energy flows in cities through AD, which is that this research focuses on. Using the three principles of circular economy from the Ellen McArthur Foundation (2017), the researcher interpreted circularity as follows:

Principle 1 Preserve and enhance natural capital by controlling finite stocks and balancing renewable resource flows.	*Re-Design*: The extraction of organic waste material will require redesigning existing and future waste sorting infrastructure at the beginning of the waste management value chain. Sorting is a critical step to ensure sufficient and sustainable supply of quality feedstock as well as tailored technology design. During this process, feedstock qualities and quantities are expected to vary based on each city's demographic as well as socio-economic profiles.

	This will ensure that what waste management sorts is *circularised* and becomes a feedstock for energy generation. Renewable energy engineers then focus on improving and maximizing technology efficiency, as well as considering a variety of grid options for large-and small-scale transition and distribution for resource optimisation – The Concept of Exergy. Africa's mini-grid sector is still developing and presents opportunity for greater implementation in sprawled settlements. Entrepreneurs can valorise such opportunities along the transition value-chain. Redesigning also ensures socio-economic, environmental and industrialization goals are still met.
Principle 2 Optimise resource yields by circulating products, components and materials in use at the highest utility at all times in both technical and biological cycles	*Re-Use*: The energy produced by AD technologies can be reused either back in the generation process or deferred to energy-intensive sectors in need of additional energy. Example one: large scale hatcheries can generate energy from poultry manure and use output as electricity supply for the hatchery's operation and use the heat to incubate hatchlings. Example two: institutions such as government, schools, universities, community halls as well as off-grid settlements can enjoy biogas for cooking, lighting and heating. Example three: agro-processing and industries can generate sufficient onsite electricity – using the combined heat process (CHP) – to offset their energy bill.

	Sludge material can also be used as a feedstock for small scale agrarian activities such as urban agriculture, or further valorised by using Vermiculture.
Principle 3 Foster effectiveness within the system by revealing and designing out negative externalities	*Reduce*: Traditional consumers become 'prosumers' through Smart Grids and Smart Metering. Technology and innovation make it possible for users to monitor and take charge of their energy demand and, where feed is subject to tariffs, to sell excess energy either to the utility or to nearby demand. Throughout this value chain, human capital development and development of technical and non-technical resources (policy makers, decision makers, investors, government, civil society, professionals and so on) are key requirements.

Limitations identified when calculating circular economic values was that engineering and urban planning parameters are unique to each context. Answers derived are not synonymous but illustrate the principle that circularity can be determined for anaerobic digestion technologies.

4.5 R.O 2: Decision-making to promote AD uptake in Cities

R.O 2: Understand who the decision-makers are and investigate factors to assist in their decision-making.

Aim: The technical aspects of designing anaerobic digestors and assessing their circularity were explained in the previous sub-section. This objective builds from those findings and focuses on qualitative aspects, particularly the role of decision-makers.

The challenges and opportunities they encounter provided context and illustrated the uniqueness of each city. To mitigate these challenges or realise opportunities, their inter-disciplinary activities were also presented because this has an impact on implementation. Lastly, findings of decision-makers' knowledge of sustainable concepts were also presented as this also has an impact on implementation.

4.5.1 Presentation of Results

4.5.1.1 Challenges encountered by Decision-makers

The coding process was two-fold: first-stage, which comprised of preliminary coding and pre-analysis and second-stage which entailed developing themes and sub-categories for each group of participants. In the first-stage the researcher coded a total of 136,0 codes and grounded these at second-stage to 17,0 themes and sub-categories: 6,0 for urban planning participants, 5,0 for waste management participants and 6,0 for renewable energy participants. The term grounded refers to the number of quotations have been associated with the specific code. All participants' quotations were quoted verbatim.

4.5.1.1.1 Urban Planning Participants

A total of 6,0 themes were classified. The most prevalent challenges impeding not just greater anaerobic digestion adoption, but renewable energy projects were policies and parameters (17,0), current urban morphology (12,0) and political influences (10,0). These are discussed in more detail (Table 4.8).

Table 4.8: Challenges Encountered by Urban Planning Decision-makers

Theme	Grounded Quotations
Policies and Parameters	17,0
Current Urban Morphology	12,0
Political Influence	10,0
Skills & Mindset	5,0
Communication amongst Decision-makers	5,0
Funding for Implementation	4,0

Policies and Parameters

Participants shared similar views regarding their cities planning policies and parameters which are taken into consideration during planning stages. There is a lack of sufficient and up-to-date socio-economic data required for development and strategic planning. This affects the type of planning parameters considered, namely density, urbanisation rate and organic sprawling. Participants such as G.P attributed these challenges to planning laws and principles that are still based on British principles while E.EP stated that "*At the end of the day when the implementation is coming, there are certain kinds of variability or variation between what the Local Development Plan says and what the actual settlement is going to be. So, the definitions in the Local Development Plan is a completely different definition of the density (what is coming in a certain period of time) that is a challenge*."

Cities have evolved so much post colonisation and some key policies and regulatory frameworks have not been updated accordingly. The disparities between existing morphology and local development plans becomes more evident because projects are difficult to implements. In the case of Accra and Addis Ababa which have a higher informal urban area, these policies and regulatory frameworks may be considered 'too-formal' for informal areas. G.P alluded to this by mentioning that "*Let me make this point that Accra almost 80% informal. So when I go back to your question, what I can say is that for the informal side, we are not trying to actually integrate them into the system that much*." While E.P expressed "*I do know that the city is formed through organic form of planning system. So the city was formed about 130 years ago, when the king settled. This form of organic settlements have made it hard really for the city to plan. So, we have been trying to modify/trying to fill in things in this kind of regard is very difficult*." With specific reference to waste management and energy generation, it continues to challenge implementation.

Current Urban Morphology

All participants expressed that urbanisation is happening faster than development and with the policy and parameter challenges, it is difficult to keep up with it – "*I think we are going through the same process, but what I can say about urbanization is I think the increasing population is quite fast and developments in terms of infrastructure are not doing that well. Um, development is fast ahead and physical planning, we are not able to match up. So there's always a lack in terms of control and management. So instead of us preparing for development to take place, development is far, far ahead of us.*" (G.P). As stated earlier, Accra and Addis Ababa have more informal growth and planning compared to Johannesburg. This has an impact on waste management and energy generation. Some roads are not tarred while others are too narrow for collection vehicles to access, thus open dumps and litter become prevalent across the city. The economic segregation brought about by urbanisation not only has an impact on development projects, but the type of energy used, especially in informal urban areas. Fossil fuels are widely used because they are cheaper and more accessible.

Political Influence

Participants viewed urban planning as a political tool because it is a profession that is influenced by politics and governance. The mindset of political decision-makers resonated with each participant. When politicians view development within the term they serve and not as an ongoing project, considerations and innovative approaches are limited. One participant mentioned that in their years of experience, they have seen some projects delay or not being implemented because of politics – E.EP "*The communication is very narrow with the government, which is really a problem.*" The ripple effect is that waste management and energy generation are then seen outside urban planning mandates. S.DP expressed that "*To be honest with you, it's a conversation and I don't think we've one into it in detail as executives of the city. We've not really had it and in actual fact I keep on saying, here is that opportunity. It may not affect the SDF per say but because we are in that space and we are trying to get renewable energy practitioners to talk us about all these power lines or land that they have set aside for the power lines*"

Skills & Mindset

Because most African cities' planning policies and regulatory frameworks are still based on those introduced by colonialists, the urban planning profession is also challenged with decision-makers who are not exposed to waste management and energy generation. Thus, when preparing plans and projects, those elements are rarely included. According to G.P "*The main planning school here is so traditional, still into zoning, land use and not much in terms of urban design; doesn't exist at all. Not much in terms of waste; for town planners? No. If we look at our curricula, you'll still see that we are still in British silos: land use, land use...2D plans not even 3D plans are being prepared...no, no, no, no*."

Communication amongst Decision-makers

The limited skills and classical planning mindset extend to how decision-makers in urban planning, waste management and renewable energy relate to one another.

Limited (and in some cases lack of) communication amongst these decision-makers affect access to services as well as the quality thereof, because they have different approaches to the same project. E.EP acknowledged that there is indeed poor communication with waste management and renewable energy departments while G.P and S.DP mentioned limited communication during executive committee meetings or when reviewing development planning applications.

Funding for Implementation

Low revenue collection is a major hurdle for most African municipalities (UNEP, 2018). Key decision makers are then tasked with the challenge of prioritising how and where development is required the most and these are reflected in local development plans. National legislation provides strategic direction of where the country wants to go and what it indents to achieve. Local legislation and regulations are meant to be the implementation vehicle. E.EP expressed that "*Governance is a kind of challenge, and finance even because planning by itself, sometimes it's directly related with the politics. Because it's a kind of political instrument, I can say that; the plan can be political instrument.*"

Current development projects are affected by politics, governance structures and access to finance. Not all municipalities in a state or district have sustainable revenue streams thus some funds can be allocated to smaller struggling municipalities. Citizens are not able to afford their municipal obligations for basic services and still rely on affordable fossil fuels as mentioned by G.P "*You know, it's very difficult to implement property rates within indigenous areas because it's informal. These are about generation four, generation five occupying those old structures. And even that, they can't pay utility bills and some of them their utilities have been cut off.*". This means that preparing a budget for anaerobic digestion projects might not be considered.

4.5.1.1.2 Waste Management Participants

Five (5,0) themes were recognised amongst the participants. The top three challenges were current waste management methods (33,0) followed by political influences and politicians' understanding of WtE technologies (14,0) as well as skills and mindset of technocrats, politicians and waste generators (9,0). Table 4.9 summarises challenges encountered by waste management decision-makers.

Table 4.9: Challenges Encountered by Waste Management Decision-makers

Themes	Grounded Quotations
Current Waste Management Methods	33,0
Political Influences & Understanding of WtE	14,0
Skills & Mindset	9,0
Policy & Regulations	3,0
Communication amongst Decision-makers	1,0

Current Waste Management Methods

The reality that continues to be experienced by the participants is that populations are increasing, waste generation will equally increase and the demand for managing waste will also increase – "*So, our consumer patterns are skyrocketing and growing, that comes with us generating a lot of waste.*" (S.WM). Waste management decision-makers are riddled with many challenges not just to manage and dispose waste but consider WtE technologies as a whole especially in an era where urban populations are forecasted to increase, together with a growing middle class:

1. There is no space in urban areas for more landfills. As mentioned by E.WM "*we have only one landfill, which is open dumpsite, not landfill. This open dumpsite has more than 15 years. So this open dumpsite now it's reach beyond its capacity*" and in Johannesburg "*so, our volumes are not likely to go down.*

But again, our landfill space is completely gone. We do not have landfill space."

2. Current landfills are either nearing their life span, already full or overflowing with waste. In Accra, "*we are taking steps to decommission and cap all the unapproved dump sites. So currently we take our waste far away, about 50 kilometres away from the Metropolis to go and dump at landfill sites elsewhere in other municipalities. This results in open dumping and burning, which results in environmental hazards*" while in Johannesburg "*we have four landfills. Two of the four are in the central belt here. Those two are the biggest and in-between the two they take over a million tonnes per annum. They are going to be closing, the one is closed. We only trying to get height extension, you can only go high up. We're already diverting some of the waste to another two. That will cut the lifespan of those into half if not less.*"
3. Poor sorting at source and old trucks used to transport what can be collected because "*we always use rickety ones/ second-hand vehicles used by Europeans, then they come and dump on us. Every day we incur costs for maintaining them as against you buying brand new trucks to work efficiently. Those are the challenges*." (G.WM). In Johannesburg "*we don't have kind of comprehensive separation at source systems in South Africa. There are some municipalities that are looking at separate collection but again, not comprehensive for paper and packaging waste.*" (S.RI).
4. Poor waste characterisation due to lack of or outdated data because "*first of all, I mean, as you probably know, this is a sector that has got very poor data, very unreliable data, and very old data*." (S.RI). The lack of weigh bridges is also a problem because data is not collected instantly.
5. Waste such as clothing and e-waste are imported from other continents. An example shared by G.WM "*then, we also have the second-hand clothing market, which is also a central hub for the whole of Europe. Europeans bring in their second-hand clothing and most of them turn out to be waste. They get flooded in our market*" while S.RI expressed that "*I think there's a tendency to see increasing electronic waste also entering our waste stream, which is somewhat problematic because it is hazardous.*"

6. Poor road infrastructure contributing towards food waste because "*for Africa, our food waste, as you probably rightly know, is.... our food waste is generated more early on in the supply chain, typically because of poor cold storage and maintaining the cold supply chain of food - sort of from field to warehouse. The state of our roads in Africa means that a lot of produces damaged by the time it gets to market. So that's where most of our wastage happens.*" (S.RI)
7. Limited land for WtE and likely to be time consuming due to lengthy regulatory processes, like the case of Accra "…*because we don't have the land space for the construction of the plant - the plant will be in another municipality*" (G.WM)

Even if AD integration were to increase in urban areas, lack of waste characterisation and assessment hinders environmentalists and engineers from preparing sound calculations. A factor such as determining water content in organic waste is imperative to selecting and designing the technology.

Political Influences and Understanding of WtE

Participants resonated with urban planning participants' responses about the role of politics in service delivery. All mentioned that waste management is influenced by politics because certain decisions must be made or project implemented within a particular political period. In Addis Ababa, technocrats realised an immediate need for an engineered sanitary landfill to divert waste from the over capacitated open dump – "*we established a new sanitary landfill outside Addis, which is a centre for a sanitary landfill. Because of some political issue now, we're not using that sanitary landfill*" (E.WM)

Some political decision-makers also have a limited understanding of various types of WtE technologies. Incineration is more popular and viewed to have a negative impact on the environment while recycling is viewed to be a job creator. Their knowledge and understanding of anaerobic digestion tends to be very limited, if not inexistant. In

Accra, "*we also need to advise our government through our Mayors and Ministers, for them to come to terms with these facts. We pray that our politicians to listen to some of us because we see technically what the issues are*." Because "*irrespective of whatever ideas you have, a politician has the final say and that is it; which is not the best for us Africans*." (G.WM). This affects any sector plans prepared or innovative approaches that waste management technocrats want to implement or pilot. Furthermore, S.WM stressed that "*there is that lacking-support to these projects. Because it's like 'oh, now you think you can generate energy from rubbish? where have you heard of such a thing?'. So that's the attitude we have been getting to say 'this is just the pipeline, it's a dream', until we have to tell people that we are running out of landfill space. It's not a dream, it's reality. There many things also to convince them*."

Skills and Mindset

The skill set and mindset of various waste management professionals (technocrats and politicians included) presents challenges not just for current waste management projects but anaerobic digestion too. With specific reference to public sector, there are limited skills for implementation. Rather, private sector could play a greater role, but they do not. S.WM said "*I think the other problem with us as government, we believe in doing things ourselves. Some of these things we don't have the skill and competency to do them. It's more entrepreneur things. You just need to create an enabling environment for these to thrive, but no...we want to do them ourselves*." Issues of regulation and lengthy processes deter their participation. Because of this, public sector cannot generate maximum revenue from the waste industry, thus stretching allocated resources.

On the other hand, there are waste producers comprising of households and businesses. Their mindset towards waste generally impedes how it is managed. In S.WM's experience "*until we educate our people to be able to deal with that emotional need and psychological need, we will still be heavily consuming resources and we'll be not mindful of our environment. So when it comes to whether we are likely to reduce? I don't think we are likely to reduce until we reach a point where it's not emotional, it's*

about environmental sustainability" and "*they don't necessarily have the capacity in terms of people or skills or infrastructure to collect the data in the municipalities because typically, the municipalities are kind of the coalface of waste management*."

Anaerobic digestion is viewed more as a waste management method than energy generation, thus that kind of mindset may result in limited efforts to expand the technology in urban areas.

Policy and Regulations

The three metro-municipalities have a variety of sector plans, regulations and policies addressing different aspects of waste management. However, these frameworks are not evolving at the same rate at which population and waste generation are increasing. This makes them linear and hinder uptake of new approaches, innovations and even anaerobic digestion – "*you can't have a linear policy and a circular policy. And I don't think we're good at that, in South Africa and getting rid of old policies to make way for new. We tend to just add on to the point where we really are kind of constrained into a box…*" (S.RI).

Communication amongst Decision-makers

"*When we plan the urban activities, we're not seeing the Solid Waste Management, the architect, the water... and it is all not integrated; they're not integrated. That's the big challenge in Addis. So we don't have a plan*". This was the reality of E.WM, who went on to stress that because the different sectors plan in isolation, realising more anaerobic digestion projects in urban areas would not happen effectively.

4.5.1.1.3 Renewable Energy Participants

Six (6,0) themes were also identified amongst renewable energy participants. The most prevalent challenges impeding not just greater anaerobic digestion adoption but renewable energy projects were policies and parameters (17,0), current urban

morphology (12,0) and political influences (10,0). These are discussed in more detail (Table 4.10).

Table 4.10: Challenges Encountered by Renewable Energy Decision-makers

Themes	Grounded Quotations
Political Influences & Understanding of WtE	16,0
Cost of AD project development	15,0
Complexities of AD technologies	9,0
Waste Management Regulations & Disparities	9,0
Urban Material & Energy Flows	7,0
Communication amongst Decision-makers	4,0

Political Influences & Understanding of WtE

As with urban planning and waste management participants, political influences and understanding of WtE technologies was also identified as a big challenge for renewable energy participants. Political decision-makers do not have a sound understanding of all WtE, the benefits and consequences of each. S.E had much experiences to share, in particular:

> "*My problems are that thinkers - which are public servants - seem to have renounced their responsibility and their thinking to politicians. They no longer think smartly. They tend to wait for the politicians to give them instructions rather than them thinking how best to provide good service, good technologies to the people to solve the problems of service delivery. And that is why when we're looking at government...across the government you find that it looks like the politicians are the ones that are the engineers" and the engineers are sitting at the periphery. I'd like you to quote that because I think that is what is messing up this country. Public servants must run the show and politicians must cut ribbons.*"

Political influence and corruption tend to filter through at the engineering, procurement and construction phase of projects. An example shared by E.E was in relation to a large-scale incineration project that saw a planned capacity of 50MW only producing 25MW "*it was supposed to have the capacity of 50MW, but they gave us 25MW*" because "*number one is corruption. That's what slowed the previous government before two years.*" Other instances include wheeling agreements whereby " *because the plant wants to feed into the grid, then it gets to the stage where you have to discuss getting PPA and that goes to a lot of political skirmishes, so I'm not sure what it is. But that's one thing that we also collaborated on. Getting a PPA in Ghana from renewable energy is very cumbersome. Often it requires quite a lot of political connection.*" (G.RI).

Majority of energy related projects are prepared and implemented by a national department, which municipalities do not have control over. The projects tend to be large scale as well but lack of knowledge and skills about WtE possess challenges – "*do you know what the problem? They didn't know about the technology, they didn't know about everything... the investment. They didn't have any knowledge of the sector, that was as the case… and they promised, they just promised.*" In the case of anaerobic digestion, biogas market development was perceived to be contentious amongst the three cities because it is more consumed in some parts than others. One participant argued that it may be regarded non-existent to some extent and one of the reasons shared was the frameworks and processes required to set up anaerobic digestion projects.

Cost of AD project development

In the three metro-municipalities, electricity demands are higher than supply and WtE contributes a very small percentage. Existing projects include the Reppie Waste-to-Energy Plant in Addis Ababa (25MW), a 1MW industrial anaerobic digestion plant

outside the Accra Metropolitan Assembly and wastewater treatment facilities in Johannesburg (capacities ranging between 1MW – 7MW).

Because of the technical complexities and project scale, anaerobic digestion is not regarded as a viable and bankable technology compared to other renewable energy sources. Firstly, the upfront costs to build in urban areas is high – "*it's very expensive building an urban sized biogas plant as well, those are usually huge costs, because you need to construct a very solid plant to be able to manage waste for many years. So institutions it's usually the waste management aspect of it*." (G.RI). Secondly, the price of electricity generated from biogas is higher and cannot compete with other resources. This was the case for the Reppie WtE project whereby "*the investment cost is high, it is three/four times hydro, so the return is… we don't expect a return or payback. So, it has to be money… the… for waste-to-energy, number one the priority, interest is dumping of the waste – managing the waste, not producing electricity, it's secondary*." (E.E). These points were further validated by NGO who stated that costs for biogas development were relative - "*if you chat to me I'll also tell you depends on the context of application. So let me put it in sort of structural basis. If you're looking at it as an energy supplier, only biogas is not viable because it's a non-compete with other renewables in terms of pricing*."

That is why participants expresses that it is more feasible to look at biogas for waste management or just gas production than electricity. When electricity has to be wheeled to the grid, it is complicated and expensive because it requires large capacities, and the space is monopolised by utilities. For the Reppie WtE plant, E.E shared the "*levelised cost of electricity, that means is for the lifetime – 20 to 25 years. So it has to be calculated every… But no, take 130 to $120 or five, almost US$5 million per MW. But for hydro/for wind is almost US$2 million per MW. The levelized cost will be very high*."

Lack of funding and incentives further exacerbate these challenges – *"…but if it was not… the operation and maintenance also expensive. You use many chemicals to treat the biogas. But in other countries, they get from the government incentives, like in China.*" (E.E) whilst in Accra "*going into the larger scale plant, has been a challenge because obviously there are issues to do with investment costs. Most people who have the feedstock resource don't have the, the funding resource to, to set up plants*" and "*you struggle if you want to say generate power from biomass plant and sell to the grid because your cost may not be competitive with what our governments offer to the thermal plants.*" (G.RI)

Complexities of AD technologies

Anaerobic digestion is a proven and simple technology and at the same time, complicated. This is the sentiment shared by the regional agency with years' experience in Africa's biogas industry. Ceteris paribus, the following complexities were identified as impediments to expanding greater adoption especially in urban areas:

1. A lack of quality feedstock – although the most recent waste data mentions that more than 60,0% of waste generated is organic, there are urban attributes which can contaminate organic waste and negatively affect its quality.
2. Then there are limited skills and experiences with different types and sizes of digestion technologies. As noted in the literature review, these range from floating domes to brick-and-mortar as well as commercial. According to G.RI, the biogas market in Ghana generally was underdeveloped because "*obviously, we are not very experienced with large bioenergy plants. A lot of our experience in Sub Saharan Africa, apart from South Africa's... I mean, these have been a little differently from the way they do in other parts of Africa. So maybe I should explain that so that you able to understand where I'm coming from. A lot of the biogas in most parts of Africa are of a small-scale type and only a few industrial plants exist that are a little medium model. And so that has been a challenge."*

3. It is not easy to optimise the plant operations and ensure sustainable as well as affordable energy supply to offtakers. The complexities mentioned above thus position anaerobic digestion as high risk compared to other renewable energy sources. NGO raised important considerations – "*in an urban context, it's a lot harder, because urban contexts are... if it's not an industrial site that has large, organic waste wastewater residues, you're looking at a centralized location. The risk around those projects is that: are they going to have sufficient feedstock security? Are they going to be able to manage the digested produced?*
4. Citizens mindsets towards biogas plants also affect its efficiency. If citizens are surrounded by unpleasant odour or noises, an operation can be stopped. This was the case in I.A's experience where "*because your study's on anaerobic digestion in urban areas... if you look at it, the biggest concern/challenge would probably be public participation in the application of the environmental impact assessment of the anaerobic digestion, concerns on the smell, the impact that if something happens to that plant what environmental impact it would have on surrounding areas. Those sorts of concerns are more than likely to be a high-risk issue for project development. We've seen this within existing plans*."

The researcher acknowledges these challenges and understands that these are inevitable because of the biological process.

Waste Management Regulations & Disparities

Existing waste management regulations were discussed contextually. All three metro-municipalities have some sort of regulatory frameworks and plans, some more than others while those that were existent were regarded as impractical for waste management and biogas development. Because of this, some corporate companies in Accra and Johannesburg began to self-generate energy. However, ripple effects hinder anaerobic digestion because waste management frameworks and plans were created independent of energy frameworks and plans. For example, depending on the resources available, a corporate would explore solar and biogas. Anaerobic digestion

has little representation in energy policies, so it receives little attention while waste management regulations then affect how waste is handled by the corporate. In NGO's experience, "*there are about 11 different regulations streams that need to be addressed when you build a biogas project. That's where the full... and obviously your full environmental impact assessment will address most of these regulation streams. There are few that speak more to the offtake. So for example, if you're going to try and valorise the digestate, then you need to look at a fertilizer act. Unless you're giving it away, you need to register that product. If you selling gas or... just the fact that you're generating gas, you need to register your plant*". R.A affirmed and stated that these disparities and lengthy processes increase project development costs, affecting financial viability.

A synonymous outcome was that there are no guidelines for biogas developers. In Accra and overall Ghana, "*if you speak to the people who implement projects they will tell you how very difficult it is to access some of those support systems that are on paper and supposed to be offered to some of these project developers*" (G.RI). The same sentiments were shared by NGO who stated that "*if you look at that process, it takes anything between 18 months if you are lucky, to two years to complete that process. That's and that's if you do the process correctly, it could take longer if you're not familiar the process. The cost of that is anything between three to 5 million Rand*".

Urban Waste Material & Energy Flows

Responses provided echoed those shared by waste management participants, specifically the challenges they encountered with current waste management methods. These include how urbanisation is happening faster than development, resulting in high logistics costs, higher energy demands and no urban space for additional landfills. The underpinning challenge mentioned was that current urban morphologies are not suitable for large projects: large energy projects and large waste management projects. S.E stated that "*in a changing world, be it of learning, development, infrastructure creation one these kind of things, things are not going to remain in the manner in*

which they are. You have the city that is expanding beyond the available infrastructure - be it sanitation, be it electricity, be it water."

The infrastructure does not encourage waste material and energy flows. In the case of Addis Ababa, urban waste would have flowed to open dumps had Reppie WtE not been set up to divert the waste and convert into electricity – "*so the Addis Ababa waste, the city waste should be dumped somewhere. We have big problem… move to the power plant…we have to dump somewhere. But they are right actually because the City just want to dump it into the bin so the city asked the municipality to arrange something*." (E.E). Bad infrastructure exacerbates flow patterns *"if you have to transport the waste over a long distance, then it becomes very expensive to do that. And it's the same with municipal solid waste*." (G.RI). When looking at energy flows, there is limited infrastructure suitable for electricity generation. Energy flows from outside cities – "*they are mainly out of the city and the electricity is transported into the, into the, into the city centre. So, I think that because of the development of this city, it's difficult to currently find the space to be able to plant renewable energy plants inside the city*.". (I.A)

Communication amongst Decision-makers

Equally complimenting challenges mentioned by urban planning and waste management participants, renewable energy participants specified that there is poor communication mainly between urban planners and renewable energy practitioners in metro-municipalities, thus energy options such as anaerobic digestion are not intentionally planned into development plans because "*well, they communicate very little between or amongst themselves, so the urban planning people well... obviously, because they are not very familiar with some of these modern ways of doing things, and some of them missed that planning their systems without thinking that it's important for them to consult with energy practitioner*."

This is further induced by vertical and horizontal government structures which are designed to operate in silos. According to the participants, these structures also contribute to poor communication and understanding between politicians and technocrats. Based on Ghanaian experiences and "*and some of my colleagues may differ from the stakeholders... is that there's often a feeling that government officials don't communicate efficiently with each other. Whether that be on a municipal level, provincial level, national level or even across the various levels*" based on South African experiences.

4.5.1.2 Opportunities identified by Decision-makers

The coding process was also two-fold. The researcher coded 128,0 codes at first-stage. These were grounded to 12,0 themes at second-stage: 3,0 for urban planning participants, 5,0 for waste management and 4,0 for renewable energy participants. A reminder to readers, the term grounded refers to the number of quotations have been associated with the specific code.

4.5.1.2.1 Urban Planning Participants

Participants shared many opportunities, mostly for the planning profession. Only 3,0 themes related to energy integration in cities – see Table 4.11.

Table 4.11: Opportunities presented by Urban Planning Decision-makers

Themes	Grounded Quotations
Localise Planning of Energy (AD+WM)	19,0
Improve Multidisciplinary Approach for AD	12,0
Involvement of Planners	3,0

Localise Planning of Energy (AD+WM)

All participants shared that they see immense opportunities for urban planning professionals to increase energy generation and improve waste management in cities. This can be achieved by localising the planning process, meaning:

1. Expanding multidisciplinary approaches to waste management and renewable energy professionals so that urban planners can intentionally design-in the necessary infrastructure and determine parameters by including these in local plans. These include but not limited to Local Development Plans and Spatial Development Frameworks as well as Integrated Development Plans. According to S.DP "*we've been a little bit introduced in terms of their bio digester. And now that you're saying this and this conversation, and if those conversations are to be had, this is the time maybe the review of the SDF creates that opportunity for those proper conversations so that when the environmentalists, see the SDF, they engaged with it different*" and in G.Ps opinion, "*it will demand a lot of engagement with the engineers.*"
2. In doing so, a bottom-up approach was proposed for small to medium sized projects; one where energy projects are reflective of energy (and waste) demands across cities and a community ownership model is considered. Localising plans would ensure that the realities on ground are fully considered and necessary infrastructure is planned for – particularly in informal areas. S.DP mentioned "*you know, like when you are engaging with people, instead of just bombarding them, or just dropping a document to them or emailing them the document...*" and similarly in Addis Ababa "*that is why we are starting deviating from the way of looking at the normal/traditional, or what we call the classical planning approach. We call it that the top down approach. Let's start from the bottom-up approaches and that's why we introduced the participation.*" (E.EP)
3. Digitising the planning process was recommended to expedite any applications submitted by citizens and private sector. At the time of the interviews, the researcher noted ongoing research and development for an integrated infrastructure software. The platform "*it looks like a kind of software.*

Currently, we're simply making a plugin with existing softwares, relevant market softwares. This software is demanding a certain kinds of input, its output. But we are also influencing the both sides." (E.E). In Accra, "*the current government is trying to introduce a digitised system and we are still on board. We are discussing seats, we are trying to look out this way*." (G.P)

4. This would lead to anaerobic digestion being considered as part of development application requirements and processes as well as being customised for different settlements. Customisation is important because "*for me, I'm still of the opinion that one, can we learn from the informal sector? and two, can our training accommodate what is actually happening on the ground and see where we come in, in terms of professional skills? But we should not come in as professionals to use this our big-big laws and English to always write them off*." (G.P)
5. A change in tertiary curriculum from 'classical planning theories' to more contextualised Afrocentric theories that include more content focusing on energy generation technologies and waste management. E.EP's view was that "*let's deviate from the classical way of looking at planning, let's look from the specific areas and let's come back to planning analysis. This is our experience here*."

Improve Multidisciplinary Approach for AD

Complimenting the opportunities above, urban planners can focus on the qualitative aspects of anaerobic digestion. E.EP mentioned that "*when thinking about the biogas, it's wonderful in the analysis of a quantitative aspect. When it coming to qualitative, we should making a certain kind of broader and wider approach, and all issues going to be addressed, independently, that also very good, interesting research*". However, until the 'classical planning' approach is revised, their update and understanding will continue to be slow because according to G.P "*for us to carry it forward, planners can come out of planning school where they are taught of waste-to-energy, we are not there yet. I think if we like to look at it, we need to look at it first from the training point of view, from the professionals in the practice, from the organogram of local*

governments systems Ghana. Then we need to look at skills change: what can we do for those already in the system?". These multidisciplinary approaches were deemed necessary by S.DP because if anaerobic digestion is to become a greater reality, "*the conversation for me is it has to happen. It is important. Because first and foremost it will influence even future planning within a city.*"

This can be achieved by having the three departments working together within metro-municipalities. Activities such as 'infrastructure workshops' would encourage knowledge and skills transfer from waste management and renewable energy professionals – "*but if you are a planner, if applicability of a biogas is going to be tested, it is better to look on a wider. Take all the barriers, takes all issues and make that specific analysis and make wider, wider is very good. Because all information will be gathered on for the next researcher or for the person who interested for deep analysis, and going to need these kinds of parameters*." (E.EP).

Involvement of Planners

Urban planners' high-level understanding of some technical terms can better equip how they intentionally design in anaerobic digestion and spaces for material recycling facilities. A fundamental opportunity that also resonated with other participants was urban planners' role in identifying various land parcels for various waste management technologies. as suggested by G.P "*get the collection points within municipalities, for some people to take their waste there. In some of the well organized areas we have the waste truck.*". In doing so, S.DP recommended a set of questions that urban planners would need to ask during the site selection process, "*because we're having the most growth here it means that we also have an increase of construction in the site... Where are our construction or our rubble-type of landfill sites? where should people be dumping? Is there a way that we can start encouraging people to use their rubble. You know, like reusing the material that is on site… from a planning and transport point of view, if we are picking up waste from these different areas, how is this waste getting to these particular areas?... Or are we going to have many landfill sites that support those two big ones, which we are going to be utilising for waste-to-energy?*"

4.5.1.2.2 Waste Management Participants

The researcher summarised opportunities into 5,0 themes as shown in Table 4.12. The benefits of anaerobic digestion (17,0) presented the most opportunities, followed by strengthening multidisciplinary decision-making (16,0) and optimising the waste value chain (10,0).

Table 4.12: Opportunities presented by Waste Management Decision-makers

Theme	Grounded Quotations
Benefits of AD	17,0
Communication amongst Multi-disciplinary Decision-makers	16,0
Optimise Waste Value Chain	10,0
Involvement of Planners	9,0
Drivers for Change	4,0

Benefits of AD

Participants reaffirmed findings presented in the literature review. The benefits offered by anaerobic digestion are opportune not just for managing waste but energising urban citizens. With a conducive environment and intentional planning, more composting for regenerative agriculture and more recycling activities can take place at the collection and sorting stages. The solid waste management directorate in Addis Ababa has plans to continue diverting organic waste and doing so with rigour. The growing population and middle class are also increasing waste generation – "*we have a big projects especially the... it has not started but is in the process – biogas and composting projects*" and "*still we are not starting the construction but we are on the feasibility study. We are selecting two areas, 2.1 hectares each. So our planning is to take this organic waste into the composting in the biogas facility and changing into compost and also simultaneously into biogas*" (E.WM). At the time of the interview, there were more than 600 known unions, 40 private companies and 6,100 small

companies that were collecting and recycling plastic waste. E.WM advised incorporating these companies in the value chain to streamline organic feedstock supply for anaerobic digestion.

Biogas capacities can vary and be applied for uses such as bus rapid transit systems, heating and cooking in various institutions. Depending on the type and quality of waste, treatment technologies such as thermolytic cracking and incineration could be considered to complement anaerobic digestion. A notable opportunity for the researcher was treatment solutions can be developed close to landfills, which would encourage circularity. S.WM mentioned that "*treatment technologies were the solution because we can still house them in locations where our operational landfills are*" meaning that waste does not go to waste. Lastly, with a conducive environment, anaerobic digestion can induce job creation across the waste value chain. Existing waste management practices can be expanded to include anaerobic digestion. In Johannesburg, "*we established those source separation programmes, and supported with some infrastructure that helps us to sort even further and a little bit processing like baling and chipping because these are at buy-back centres so that it is this material can be of a better quality for the people who recover and to make better money*." (S.WM).

Communication amongst Multidisciplinary Decision-makers

Municipalities in South Africa are required to have Integrated Waste Management Plans. Similar sector plans are required in Ethiopia and Ghana. Participants felt that communicating with urban planners and renewable energy professionals would assist to induce innovation and with implementation, as well as enhance principles of circularity. Municipal Think Tanks were also proposed as a suitable platform to improve multidisciplinary communication and sector understanding. According to G.WM, the African Union could play an important role from a regional perspective because "*it is up to us and our leaders to also think: once we have a body like AU, we form a Think Tank. It would include an institution of engineering, institution of*

planners, an institution of architects to come together, and then they got a common policy and legislation framework for all the countries to follow."

Politicians, built environment technocrats and other decision-makers would benefit immensely and have regional perspectives on technologies such as anaerobic digestion. S.RI stressed this point as well based on experiences "*I think if we start to take this more holistic view of how a city functions, everybody has to sit around the table. From the CFO to the Planning to the Environment to the... because otherwise, you're going to... our municipalities are going to continue to work in silos.*" More communication and understanding can have a positive outcome for anaerobic digestion uptake. A Municipal Think Tank was also presented as an opportunity and a few questions posed –

> "*Do we have like think tanks? Do we have like a Municipal Think Tank? somewhere that's like a testbed for innovation where you can try things and fail and no one holds you accountable kind of thing. But that's only where you learn, get to experiment… It's kind of like a virtual city. Just experiment on a virtual city and see what you can actually produce.*"

Optimise Waste Value Chain

Physically, there is no more land to build new landfills in the metro-municipalities. Available land has to compete with other development activities. Strategically, waste management decision-makers can make a strategic decision not to explore circular opportunities along the value chain and divert waste from any dumping. By doing so, the following aspects are optimised:

1. Up-to-date waste data and profiles by capitalising on block chain, drone technology, smart meters, which were proposed by S.RI – "*there other systems that we could put in place, like drones, or, you know, smart meters or whatever…Could you use blockchain? The plastic waste that we produce, can you use that as raw material in 3D printing?*"

2. Improved collection and sorting by involving other players such as "*private sector and informal waste collectors… that we needed to be pulling them towards us, towards assisting us in extracting as much resources from the waste stream as possible" (S.WM)* and at Koshe landfill *, "there are there are more than 2000 waste pickers"(E.WM).*
3. More small-to-medium sized anaerobic digestion plants that capitalise on urban waste because the thinking should be "*can you actually utilize this waste as a resource within the boundaries of your city?*".
4. More market development for biogas usage in urban areas because in Addis Ababa, tonnes of methane gas could be extracted and used by nearby industries but presently, it is being flared. Currently "*this project is helping us to reduce the volume of the waste and help us to manage the methane gas by installing the venting pipe to extract the methane gas and convert to carbon dioxide. And also this project helps us to manage the leachate, which is generated from the waste*."

Involvement of Planners

As skills set and knowledge become more multidisciplinary, waste management and renewable energy projects can feature more in strategic and local development plans. This would streamline development processes. Urban planners' activities can include site selection and assessments for waste transfer stations, conversion of landfills to eco-parks and socio-economic activities required to support the waste value chain. Based on E.WM's experiences with the proposed sanitary landfill that is yet to be operationalised, "*before we go to the centre for sanitary landfill, there was a plan to convert this open dumpsite into a Scientific Park. So once the conflicts started to happen, we're just back again and we're using this open dump site for waste disposal*". A notable opportunity mentioned by G.WM is that:

> "*…the town planners too should come in when it comes to layout and scheme of a particular area. Once we identify a site for a waste-to-energy process plants, then the town planners come in to be able to look at a topographic area*

such that there will not be problems and challenges with regards to NIMBY syndrome where people will say 'don't bring the plant near my backyard or something'"

and

"… this is where town planners should come in. Whenever they are going to approve of any plans for such physical infrastructure, they should insist on the right is to be done by tapping from the engineers who matter and then advise them on what to approve so that the energy dependency ratio will be curtailed."

Drivers for Change

Organic waste fraction for two cities were estimated to be over 60,0% - "*solid waste management in Addis… 3,200 tonnes waste generated daily. So from this the composition of the waste is 64.5% is organic waste that is interesting. So it's organic waste and 5.3% is paper and cardboard, 5.2% plastics*" - while in Johannesburg it was estimated to be 20,0-40,0% of total waste generated – "*I think South Africa like many other developing countries, kind of... in terms of general waste has a very high organic waste content. Both organic fraction municipal solid waste, but also industrial biomass*." (S.RI). There is a vacuum for more and greater adoption between 2030 and 2050 due to population and urbanisation growth rates. This vacuum can be viewed as a driver for mindset shifts required. Most importantly, ongoing conversations about the circular economy in Africa was seen as an important driver.

"*the circular economy is not something new, the circular economy is something that we've lost to make way for a linear economy. I think Africa has not lost it as much as Europe. So I think we've still got one foot heavily implanted in a circular economy driven by poverty and need as opposed to policy design*" (S.RI)

The 2019 African Ministerial Conference on the Environment (AMCEN) for the first time discussed about and Ministers to "*this idea of the circular economy and the opportunity*" (S.RI). South Africa has taken the lead in this regard through the Ministry of Science and Innovation that developed Africa's first policy document - White Paper - on circular economy "*makes specific reference to the term circular economy*." (S.RI). Further drivers mentioned were Addis Ababa City Administration, Accra Metropolitan Assembly and City of Johannesburg's participation in the C40 Cities Climate Leadership Group. It is a network of megacities that are committed to addressing climate change issues in cities,

4.5.1.2.3 Renewable Energy Participants

A summary of opportunities identified by renewable energy decision-makers are presented in Table 4.13. Opportunities communicated across the top three themes - benefits of anaerobic digestion (24,0), communication amongst decision-makers (10,0) and policy and mindset shift (7,0) – resonate with those shared by urban planning and waste management professionals. At this stage, the researcher was able to confirm key themes that can aid greater adoption of anaerobic digestion in urban areas.

Table 4.13: Opportunities presented by Renewable Energy Decision-makers

Theme	Grounded Quotations
Benefits of AD	24,0
Communication amongst Multi-disciplinary Decision-makers	10,0
Policy Changes & Mindset Shift	7,0
Infrastructure Planning for AD	6,0

Benefits of Anaerobic Digestion

A large percentage of urban populations in Addis Ababa, Accra and Johannesburg have access to electricity. The national electricity utility currently produces 5,300MW countrywide, while in Accra alone, "*access to electricity for households is about 85%*." However, access and affordability were contextualised to each metropolitan because of different socio-economic and demographic profiles. Participants mentioned that the benefits of anaerobic digestion present opportunities to expand access and cities' energy mixes as E.E mentioned "*it's a blessing to have energy mix from different resource*" and biogas can compliment technologies such as photovoltaic, batteries and mini-grids.

1. The energy by-products serve as a feedstock for other activities and this speaks to a principle of circularity because according to G.RI "*I mean, for a lot of Sub Saharan Africa you know, we have a lot of biomass resources from municipal solid waste, liquid waste into crop residues, etc. And because we have such a plethora of resources, I think that is our number one opportunity to want to do biogas or bioenergy generally*."
2. Participants acknowledge the large quantities of organic waste in each metropolitan and how biogas can assist waste management professionals reduce the negative environmental effects, for example intentional waste diversion from landfilling. S.AI highlighted that biogas is the only renewable energy source that can resolve waste management challenges. *Ceteris paribus*, biogas can supplement energy at peak demand – "*biogas itself is... if you have a good solution to peak demand in a situation where there's not much capacity installed, biogas can come in handy to 'do' peak demand. So if you're selling your biogas or power from biogas at peaking power rates, it's viable*."
3. Opportunities for digestate to rehabilitate soil within and outside urban areas, whether it is urban farming or green public spaces such as parks. An opportune example shared by NGO "*So for example, a site that's producing agricultural residues suitable for biogas plant that has a high "utility" and water need, that is more suitable for biogas projects. Because they can then treat that*

agricultural residues and reduce the disposal cost of those residues, clean up some of the wastewater generated and provide them an energy output as well as a solid "answer" for the digestate"

4. Participants mentioned that underutilised land can be identified in urban areas but not for large scale projects. These can be considered rather for small to medium sized anaerobic digestion and waste transfer stations. Centralised activities would reduce transportation costs – which is where most waste management departments spend most of their budget.
5. If projects are customised based on the type of energy required – biogas, heat, electricity or digestate – it can be engineered to meet the energy users' desired energy demand. Centralising and customising energy generation would contribute towards reducing energy poverty particularly in peri-urban areas. S.IA highlighted that anaerobic digestion is "*something that need to be implemented very quickly in the urban areas. I believe that is important but to be completely honest and open, it will be very challenging to implement a circular economy concept in areas out of the unique cities, where the main problem is still the waste collection*."

In summation, "*the benefit in terms of job creation and their greenhouse gas, energy production is clearly demonstrated in every county. So, there is no need to discuss, prove or show the benefits*." (S.IA) and "*you're diverting waste from landfill sites or diverting waste from being a nuisance wherever it might have been something which is really a resource. So by so doing, you are ticking many boxes... hitting many birds with one stone*." (R.A)

Improve Multi-disciplinary Approach

If metro-municipalities provide supportive business and legislative environments, private sector can catalyse the following opportunities:

1. Feasibility studies and project development that are more reflective of urban, waste and energy needs as well as promote small scale anaerobic digestion –

"*if you are, if you don't intend to sell to the grid, then there's very little impact from politics. If you are, let's say you have an industrial plant, you have your money you want to build your biogas plant to use within your plant. There's very little -by way of regulation - that would stop you*" (G.RI)

2. Strengthening of biogas industry associations that can drive activities at Municipal Think Tanks and knowledge-share industry trends because "…*one of the tasks, one of the responsibilities of our association is to try to reduce these boundary between different offices and to allow people to understand that resource...*" (S.IA)
3. Sustainable Development Committees in metro-municipalities intentionally and strategically executing anaerobic digestion projects, as alluded to by S.E:

> "*Somebody feels that 'no, electricity is not as important', he's thinking of giving them water. But why can't we together as that unit we call the Energy Management Committee, come together and say John, if you are giving these guys electricity, I as Jim will build a bio-digester so that these guys can throw their dirt there. Then the guy from water says I will be able to put this small reservoir for these guys*."

Policy Changes & Mindset Shift

As mentioned under challenges, large scale energy projects tend to be politicised and sometimes riddled by misaligned regulatory frameworks. One – reviewing sector plans, standards and frameworks for waste management and energy is imperative. There is an opportunity to streamline activities across the value chain as well as knowledge share technology design, operation and maintenance as well as reviewing licencing and permitting processes. The opportunity to be realise here is exemplary in South Africa where biogas standards *"... are currently under development, some standards that are still not approved but it will be approved in the next few years and they will... by South African Bureau of Standards ... and they must be considered when there will be a actual design or commissioning or operational biogas plant*." Two – the knowledge sharing then leads to mindset shift amongst all built environment

decision-makers and technocrats. That presents an opportunity to intentionally design-in anaerobic digestion. Three – Think Tanks were policy reviews, mindset shifts, and training take place. G.RI mentioned that there should definitely be skills training but "*lot on the mindset because I've seen very brilliant people who don't really do much… we often think that the guys at the top aren't really serious, they're messing up our resources, they're corrupt people. People wonder why they should work hard/they should do their best*."

Infrastructure Planning for Anaerobic Digestion

Where existing infrastructure can be upgraded, there is an opportunity to physically integrate waste management and energy activities. Different treatment technologies can be considered depending on the energy need in that jurisdiction. According to E.E, "*every city in Ethiopia, they need to have this facility. Even at suburbs, needs to have this facility but they don't know it. That's the case. If they know it, I don't think… But for this case, it's also my recommendation that it is good to expand. A lot of things are already there.*"

Africa's uptake of the smart cities concept is still evolving and that presents a variety of prospects to optimise the waste value chain and streamline feedstock for digestion plants. The opportunity here is that biogas-to-electricity projects under 1MW – small scale embedded generation – can be popularised because "*depending on the type of technology and resources organised, it could be cheaper than accessing energy from the electricity grid*." (G.RI). This is an area where South Africa is leading with regards to project development. An experience shared by NGO:

> "*For example, currently in the renewable space, opportunities lie within the small-scale embedded generation space, that's below one megawatt. If a company implements a renewable technology such as, a good example solar PV, and they are a net-user, they can sell the excess energy back into the grid*

under the tariff of the municipality. The municipality has a tariff structure for small scale embedded generation."

4.5.1.3 Current Collaboration Amongst Decision-makers

4.5.1.3.1 Current Collaboration

In light of the sector specific challenges and opportunities shared by participants, they were also asked about their (1) current collaboration within and beyond the metro-municipality as well as (2) which sectors should be working together and the reasons thereof. A total of 52,0 codes were identified and quotations were grounded as seen in Table 4.14.

Table 4.14: Frequency of Interdisciplinary Involvement

Collaborations	**U.P**		**W.M**		**R.E**		**Total**	
	Grounded Quotations and Percentage Representation							
U.P & R.E: No	0	0,00%	0	0,00%	4	7,69%	4	7,69%
Other & R.E: Yes	0	0,00%	0	0,00%	15	28,85%	15	28,85%
U.P & W.M & R.E: No	7	13,46%	0	0,00%	0	0,00%	7	13,46%
Other & U.P: Yes	12	23,08%	0	0,00%	0	0,00%	12	23,08%
U.P & W.M: No	0	0,00%	4	7,69%	0	0,00%	4	7,69%
Other & W.M: Yes	0	0,00%	10	19,23%	0	0,00%	10	19,23%
Totals	**19**	**36,54%**	**14**	**26,92%**	**19**	**36,54%**	**52**	**100,00%**

As part of the planning process, all urban planning participants mentioned that they do not work in much with (13,5%) waste management and renewable energy departments other than participating in executive and spatial planning and (sub)committee meetings

which take place on a monthly or quarterly basis. On the other hand, participants do work with (23,0%) other departments and outside organisations in some way or another. Waste management and Renewable energy participants work did not involve much collaboration urban planning (7,7% each) compared to working with other organisations (19,2% and 28,9% respectively). These include but not limited to research institutes, quasi government organisations, corporate and regional development agencies as well as non-governmental organisations. R.A mentioned that "…*the interactions with urban planners are minimum*…" because in a practical example provided by E.EP

> "*after the houses were completed, it took around eight months to provide any energy/electric line for these households. So you can clearly see that there is a very deep/ very big gap in the planning how the energy is coming… there's not really communication between the planners and the energy sector. So the planners we plan houses, the streets and everything and we give it to the engineers.*"

As alluded to under challenges and opportunities, urban planners should work with waste management and renewable energy to have a high-level understanding of their technical work. This way, they can realise the opportunity to begin identifying suitable land within and around urban areas for such projects. It will also allow them to explore qualitative aspects of biogas as well as participate during the feasibility study stage. The proposed approach would strengthen relations within municipalities, which in term encourages better planning processes and guides incremental development.

4.5.1.3.2 Improving Interdisciplinary Approach to enhance AD and CE Uptake

Participants were asked 'how' collaboration could be improved and what would need to be done by whom. Table 4.15 presents participants proposed approaches to improve interdisciplinary engagements.

Table 4.15: Improving Interdisciplinary Approaches

	U.P		W.M		R.E		Totals	
	Grounded Quotations and Percentages							
1. Knowledge Sharing & Understanding	3	8,57%	0	0,00%	4	11,43%	7	20,00%
2. Understand Urban Metabolism: Waste & Energy Flows	0	0,00%	4	11,43%	0	0,00%	4	11,43%
3. Amend Development Regulations to Include WM & RE	0	0,00%	6	17,14%	3	8,57%	9	25,71%
4. Intentionally Design-in AD in Sector Plans	1	2,86%	1	2,86%	2	5,71%	4	11,43%
5. Support Technical Designs (WM & RE)	0	0,00%	1	2,86%	4	11,43%	5	14,29%
6. Identify Suitable Land & Transport Routes	0	0,00%	2	5,71%	2	5,71%	4	11,43%
7. Holistic Project Management	0	0,00%	0	0,00%	2	5,71%	2	5,71%
Totals	4	11,43%	14	40,00%	17	48,57%	35	100,00%

Approaches to improve interdisciplinary approach for better uptake of anaerobic digestion and circularity were shared. These approaches resonated with challenges and opportunities identified. Majority of the proposed approaches were targeted towards urban planners because they are drivers for development – "*I'll start with the urban planning. I think urban planning is crucial to waste management, but to date, it has actually had a very small role*" (S.RI) and "*I think they've got more role... in fact, they've got more power, because they can influence the development right from its conceptualization. The problem: we come in when developments are already in the advanced stages and trying to demand sustainable power and etc, it's already too late*" (S.WM). Improvements were summarised into six themes.

Knowledge Sharing & Understanding: renewable energy participants (11.4%) highly recommended that urban planners expand their current knowledge and skills to include waste management and anaerobic digestion and urban planning participants concurred (8,6%). This would be followed by 'Understanding Urban Metabolism: Waste & Energy Flows' whereby waste management participants (11,4%) indicated that as drivers for development, urban planners should understand how waste and energy flow within cities, in lieu of increasing urbanisation rates. This would lead to 'Amending Development Regulations to Include WM & RE' with both waste management (17,4%) and renewable energy participants (8,6%) encouraged. Renewable energy participants (5,7%) then stressed that it would assist urban planners to 'Intentionally Design-in AD in Sector Plans'. Waste management and renewable energy professionals would then build on the plans prepared and lead while urban planners 'Support Technical Designs'. Waste management (5,7%) and renewable energy participants (5,7%) encouraged urban planners to then 'Identify Suitable Land & Transport Routes', which are cognisant of urban and energy flows. Though these recommendations sway towards urban planners, it would improve the interdisciplinary approach because they offer a 'Holistic Project Management' as alluded to by renewable energy participants (5,7%).

4.5.1.4 Decision-makers' Knowledge of Sustainability Concepts

Knowledge and understanding impact how decisions are made. The same principle can be argued when making decisions on the mechanics of waste treatment and energy generation technologies. These factors permeate through concepts such as Circular Economy and Technology Design, Urban Waste Material Flow and overall Sustainable Development. In the previous sub-sections, participants shared challenges and opportunities they encounter when it comes to implementing anaerobic digestors in urban areas, as well as current collaborative efforts to do so.

Conceptualising, designing and implementing anaerobic digestion technologies is the responsibility of an engineering professional but other built environment and natural sciences professionals are involved. Their activities are guided by key considerations during the conceptualisation and design phase; looking at aspects such as land – where the technology will be developed and how energy will flow to offtakers, waste feedstock supply and digestate use. The researcher asked participants about their knowledge of circular economy and relatable principles because to improve circularity, the necessary knowledge is required. All professionals involved in the anaerobic digestion value chain would need to understand basic elements of circularity so as to intentionally design them in. Below are the findings:

4.5.1.4.1 Urban Planning Participants

Literature identified multitude of concepts that are prominent within SDG 7 and SDG 11. These concepts relate to improving access to energy, which is possible through different clean energy sources, and ensuring it is sustainably accessible in cities and communities. Participants' knowledge/understanding/familiarity of these concepts aim to highlight whether there is a need to know them and the impact they may have on conceptualising, planning and implementing decentralised energy initiatives such as biogas. Table 4.16 summarises' participants understanding of key concepts.

Table 4.16: Urban Planners' Understanding of Concepts

	Addis Ababa	**Accra**	**Johannesburg**
Anaerobic Digestion	Highly Familiar, mentioned failed examples.	Some Familiarity	Not Familiar
Biogas	Highly Familiar, mentioned failed example	Some Familiarity	Some Familiarity

Circular Economy	Familiar	Not Familiar	Not Familiar
Energy Poverty	Highly Familiar, engineering project experience	Not Familiar	Not Familiar
Decentralised Energy	Familiar	Some Familiarity	Some Familiarity, different energy mixes.
Urban Energy Planning	Familiar	Not Familiar but said it includes solar energy.	Highly Familiar, the need to plan for energy in cities
Waste-to-Energy	Highly Familiar, engineering background	Familiar based on observation of one site.	Highly Familiar, based on Energy Manag. Committee

E.EP indicated high familiarity and experiences with anaerobic digestion, biogas, decentralised energy and waste-to-energy because of an engineering background and knowledge of failed projects initiated by corporate companies as well as international donor agencies. E.EP also indicated familiarity with circular economy, stating the principles of extending the life span of waste material and harnessing by-products such as biogas and bio-fertiliser – "*the biogas is directly related to what we call it circular economy concept*." Familiarity with Energy Poverty and Urban Energy was also high. E.EP shared experiences where AD systems were used to provide energy in rural and peri-urban areas as well as how these initiatives were intentional energy projects that were planned – "*because the city is failing to provide the kerosene, the kerosene is getting very expensive, and the government is failed to provide a continual energy sources.*" With specific reference to urban energy planning, there is an increase in wood and charcoal fuel utilisation within urban areas. Biogas was emphasised as a cleaner option that could be emphasised in poverty alleviation strategies. On the other hand, E.P who's background and experience were in classical urban planning stated familiarity with these concepts because of working together with E.EP, and was not able to provide further details.

G.P stated understanding of anaerobic digestion, biogas and waste-to-energy based on seeing a small-scale operation in a different province. G.P mentioned basic knowledge of how the system worked but no relation to ever working on any of these projects. Furthermore, G.P was not familiar with Energy Poverty and Urban Energy Planning (referring to solar home systems and solar water heaters prevalent in some high-income Ghanaian households) but had heard of circular economy principles and decentralising energy.

S.DP's knowledge of energy sources were mainly fossil fuels, primarily coal. Waste-to-energy was relatively new and based on knowledge shared during Energy Management Committee meetings – "I'm *actually glad we're having this conversation even for myself, because like I said, we're just about to review our SDF... We have been a little bit introduced in terms of the biodigester… this is the time maybe the review of the SDF creates that opportunity for those proper conversations*". S.DP went on to share experiences of reviewing development applications and not understanding some concepts – say environmental – and why certain aspects need to be prioritised over others and the rationale from a planning perspective.

It is important to note that urban planners' knowledge or familiarity of concepts such as circular economy is relative. This is because its definition and context vary from region to region. When the researcher explained circularity principles and shared examples of where they are implemented, participants understood it from an element of resource efficiency (financial and non-financial) particularly in households that need to maximise their resource – putting nothing to waste.

4.5.1.4.2 Waste Management Participants

There are different methods of managing waste as well as ongoing research and innovation. Disciplines such as environmental sciences and engineering expose technocrats to these methods, research and innovation. Thus as shown in Table 4.17,

it is evident that these decision-makers had a more knowledge and familiarity of sustainability concepts compared to their urban planning counterparts.

Table 4.17: Waste Management Practitioners' Understanding of Concepts

	Addis Ababa	Accra	Johannesburg	S.RI
Anaerobic Digestion	Familiar, though not part of agency	Highly Familiar, part of work	Highly Familiar, part of work	Highly Familiar, part of work
Biogas	Familiar, though not part of agency	Highly Familiar, part of work	Highly Familiar, part of work	Highly Familiar, part of work
Circular Economy	Familiar, through Life Cycle Assessment	Familiar with concept	Familiar with concept	Highly Familiar, part of work
Energy Poverty	Some Familiarity	Familiar with concept	Familiar with concept	Familiar with concept
Decentralised Energy	Some Familiarity	Highly Familiar, part of work	Highly Familiar, part of work	Familiar with concept
Urban Energy Planning	Not Familiar	Familiar with concept	Familiar with concept	Familiar with concept
Waste-to-Energy	Highly Familiar, Reppie WtE Plant	Highly Familiar, part of work	Highly Familiar, part of work	Highly Familiar, part of work

E.WM's academic background and experiences are environmental management and climate change. The participant expressed familiarity of concepts such as anaerobic digestion and biogas but not from any project experiences. The researcher linked this to a challenged shared whereby the solid waste management directorate's mandate was strictly managing waste and not converting it into a form of energy. Circular economy was also a familiar concept because of its relationship with Life Cycle Assessment processes. As alluded to in the literature review, circular economy relates greatly to a

number of environmental assessment and measurement tools (Ellen MacArthur Foundation, 2015; Mativenga *et al.*, 2017; Cremiato *et al.*, 2018). Energy Poverty, decentralised energy and urban energy planning were expressed as high-level understanding – thus complementing the challenge alluded to, that urban planners and waste management professionals have a weak relationship.

G.WM expressed high familiarity and knowledge of anaerobic digestion, biogas, decentralised energy and waste-to-energy based on industry experience and projects underway within Accra Metropolitan. This may also be attributed to G.WM's profession as a sanitary engineer. Familiarity of and knowledge about Circular Economy, Energy Poverty and Urban Energy Planning concepts were guided by visits to developed countries for conferences as well as working on local projects with regional organisations such as the World Bank and C40 Group. S.WM shared the same responses, and understood circular economy as an approach that '*looks at waste as a commodity that gives multiple income streams, not as a burden to get rid of alone*', and anaerobic digestion as '*a very sensitive technology*' but with great potential. The only concepts S.RI was familiar with and had limited interaction in daily operations, were Energy Poverty, Decentralised Energy and Urban Energy Planning. This speaks to the challenge identified whereby communication and collaboration with urban planners remains weak. S.RI understood circular economy as '*keeping resources in flow for as long as possible at high value*', Decentralised Energy as '*a community taking control of their energy generation and top-up from national utility*' and Biogas as '*an unharnessed opportunity*'.

4.5.1.4.3 Renewable (Energy) Participants

Like the waste management participants, renewable energy decision-makers were also highly familiar with technical concepts such as anaerobic digestion, biogas, decentralised energy and waste-to-energy. This may be attributed to their professions as electrical and mechanical engineers as well as project experiences – see Table 4.18.

Table 4.18: Renewable Energy Practitioners' Understanding of Concepts

	Addis Ababa	Johannesburg	R.A	S.IA	NGO	G.RI
Anaerobic Digestion	Highly Familiar, part of work	Highly Familiar, part of work	Highly Familiar, part of work	Highly Familiar, part of work	Highly Familiar, part of work	Highly Familiar, part of work
Biogas	Highly Familiar, part of work	Highly Familiar, part of work	Highly Familiar, part of work	Highly Familiar, part of work	Highly Familiar, part of work	Highly Familiar, part of work
Circular Economy	-	Familiar with concept	Highly Familiar, part of work	Highly Familiar, part of work	Highly Familiar, part of work	Familiar with concept
Energy Poverty	Familiar with concept	Familiar with concept	Highly Familiar, part of work	Highly Familiar, part of work	Highly Familiar, part of work	Highly Familiar, part of work
Decentralised Energy	Highly Familiar, part of work	Highly Familiar, part of work	Highly Familiar, part of work	Highly Familiar, part of work	Highly Familiar, part of work	Highly Familiar, part of work
Urban Energy Planning	Familiar with concept	Familiar with concept	Familiar with concept	Familiar with concept	Familiar with concept	Familiar with concept
Waste-to-Energy	Highly Familiar, part of work	Highly Familiar, part of work	Highly Familiar, part of work	Highly Familiar, part of work	Highly Familiar, part of work	Highly Familiar, part of work

E.E's background as a mechanical engineer and experience being a key decision maker at the national energy utility contributed to high familiarity with most technical concepts. Circular economy was not applicable, while energy poverty and urban energy planning were familiar concept through interactions with some staff and project team members. They were not concepts used profusely within the utility. S.E echoed the same sentiments as the Ethiopian counterpart and was more familiar with circular economy. This familiarity was a result of engagements during executive management and sub-committee meetings where different departments present their sector plans.

Decision-making participants at the regional agency, industry association, non-governmental organisation and research institute all expressed knowledge and experience with anaerobic digestion, biogas, energy poverty, decentralised energy, and waste-to-energy.

R.A provided the most descriptive responses about each concept, stating the following:

- Anaerobic Digestion "*it is a living system that is difficult; it is not viable and needs special conditions to be viable, such as skilled professionals"*
- Biogas "*a good solution for peak demand where there is limited demand"*
- Circular Economy "*brings the value & sequestrating carbon but economy should point at a tangible value"*
- Energy Poverty "*household, community or national level…."*
- Decentralised Energy "*can exist in the form of a mini-grid where no grid is available and seen as a stand-alone model; participants should be part of the ownership model"*

Similarly, S.I.A provided the most descriptive responses about each concept, stating the following:

- Anaerobic Digestion "*500MW potential"*
- Biogas "*solution to manage organic waste"*
- Circular Economy "*need to be implemented quickly in urban areas; it should be in big cities at a mini-grid level"*
- Energy Poverty "*we have the solution: decentralised energy; it can be addressed by solar photovoltaic and biogas mini-grids"*
- Decentralised Energy "*many areas that are not connected to the grid can be decentralised using sources mentioned in energy poverty; we can use feedstock available in that area"*
- Urban Energy Planning "*should be included in waste management regulation"*

- Waste-to-Energy "*it is a mature technology; some say technology is not proven so it limits access to energy; rather, there are not enough experts especially in financial institutions"*

G.RI's expressions were as follows:

- Anaerobic Digestion "*managing waste to produce energy as an added bonus*"
- Biogas "*gas that you can produce from biological resources that have similar properties to natural gas*"
- Circular Economy "*managing resources so that there's little waste; so we are to use the output of one system as an input to another system*"
- Energy Poverty "*it's a situation where people do not have access to enough energy as they should have. So if you need to have say 400 kilowatt hours of energy a year and you have access to only 15 kilowatt hours then you are energy poor*"
- Decentralised energy "*Energy that is somewhat independent of the grid.*"
- Urban Energy Planning "*It is not something I've thought about very much. But I would think of planning energy systems in urban areas which would be a little different from rural planning*"
- Waste-to-energy "*That's energy, whether it's electricity or some form fuel generated from some waste resource (agro-industrial waste, municipal solid waste, municipally, good waste, etc.)*"

From these descriptions, the researcher deduced that waste management and renewable energy participants were more familiar with circular economy concept compared to urban planning participants. Although the familiarity related to aspects such as resource efficiency and life cycle assessments to name a few, it is a starting point to contribute towards integrating more anaerobic digestors in urban areas.

4.5.2 Discussion and Interpretation of Findings

4.5.2.1. Challenges Experienced and Opportunities Identified

Challenges within the urban planning profession not only affect how urban planning mandates are achieved but the adoption of renewable energy within cities. In the context of adopting and integrating renewable energy sources generally, the researcher induced the following:

Challenges	Political influences and mindset, understanding of WtE technologies, let alone anaerobic digestion was the primary challenge experienced by all participants. Change, integration and implementation are further affected by political interests because as all three participants mentioned, 'planning is political' and "*it is a political instrument*". It is political because it involves land: how it is used, what it is used for and why whom. Limited knowledge and understanding of what anaerobic digestion is and its socio-economic and environmental benefits, contribute towards the poor strategic inclusion in urban areas. This is exacerbated by the secondary challenge: costs and technical designs of not only anaerobic digestion but urban waste management. In examples shared, some plants did not operate efficiently because the costs and designs were not cognisant of the urban environment. All participants stressed the need for urban planners' greater involvement so that they can assist with morphology aspects which have a direct impact on how waste is managed as well as access to services.

Opportunities	All participants were synonymous about improving the multi-disciplinary approach to project development and decision-making. The role of urban planners came out strongly between waste management and renewable energy participants. (Ferreira, Sykes and Batey, 2009) argued that there is a need to evolve urban planning curriculums to be more multidisciplinary in practice, not just theory. When urban planners are given practical projects to work on with engineering students and room to think out of the box, they can become better practising professionals. Urban planners' current planning theories need to evolve from classical planning to that which is more cognisant of sustainability issues in cities. Waste management and renewable energy participants shared how Municipal Think Tanks could serve as a platform to workshop ideas, prototype and test models, knowledge share, review sector plans and regulations as well as intentionally design-in circularity. Biogas benefits were seen to help optimise opportunities along the waste value chain – secondary opportunity. This would then lead to the tertiary opportunity, localising and intentionally planning for anaerobic digestion and improved waste management.

The SDG 7 Report states that the entire world is behind and will likely not meet full implementation of goal 7 targets. This study identified that despite different contexts, decision-makers across the three cities and disciplines share similar sentiments about challenges and opportunities, as well as the impact it can have on future plans for more decentralised biogas projects and optimal urban material flow in cities. These resonate with reasons identified in the SDG 7 report. Irrespective of decision-makers' discipline, background or experience, cognisance of existing challenges assists with better and intentional planning, risk identification and mitigation and provides room for innovative solutions, amongst others. Table 4.19 presents a ranking of top three challenges per discipline.

Table 4.19: Ranking of Top Three Challenges per Discipline

	Discipline	Ranking
Policies and Parameters	UP	1
Current Urban Morphology	UP	2
Political Influence	UP	3
Current WM Methods	WM	1
Political Influences & Understanding of WtE	WM	2
Skills & Mindset	WM	3
Political Influences & Understanding	RE	1
Cost of AD project development	RE	2
Complexities of AD technology	RE	3

The data presented in Table 4.19 suggest that political influences are a base challenge for all decision-makers, a lot more for waste management and renewable energy decision-makers than urban planning. This may be attributed to their experience or familiarity with WtE as a whole. Furthermore, the researcher found that the challenges experienced by urban planning professionals directly and indirectly affects waste management and renewable energy professionals.

For urban planners, political influences related more towards development and spatial planning matters. Interferences by politicians who do not have a technical understanding or have an opposing mandate affects project implementation, more-so energy projects. Building on this, the rate at which development is happening is at a faster rate than urban planners can plan for. This results in major service delivery backlogs and some projects not being implemented at all. Private sector has a bigger budget to implement projects compared to public sector that has to stretch their budget across multiple commitments. This in turn exacerbates spatial disparities which negatively affects how cities' morphologies evolve. Consideration for decentralised renewable energy project then experiences the domino effect. Adding to this, the

analysis also found that the rate at which development policies are reviewed or amended in relation to evolving morphologies also make it tough to intentionally design in biogas projects or encourage material flow within the city.

These challenges permeate into those experienced by waste management decision-makers in each city. Current management methods were found to be ineffective due to higher waste generation rates compared to management activities. City structures make it difficult to identify and locate decentralised transfer stations, lack of separation earlier in the value chain induce 'easier and cheaper' methods such as open-air dumping or landfilling, and collection trucks are hindered by varying road typologies in terms of access. Lack of skilled capacity to effectively manage the waste as well as mindset of stakeholders exacerbates this even further because waste is viewed as finite material through linear a lens.

Keeping Figure 4.7 (Roles and Responsibilities of Decision-makers in WtE Value Chain) in mind, renewable energy professionals become more technically involved with waste as a feedstock for energy generation either during the sorting stage or disposal. Quantifying and characterising the feedstock are required as primary factors to guide technology selection and design, as well as transmission and distribution. This is where the cost of AD project development ranks second for energy engineers. The study affirmed that WtE remains a more expensive option compared to its counterparts; more-so biogas. Investor appetites for a proven yet biologically sensitive technology are weaker as a result. Coupled with urbanisation and high waste generation rates, anaerobic digestion presents higher financial risks. Lack of updated data required to calculate realistic engineering parameters thus catalyses both technical and biological complexities.

Challenges provide a platform to learn what not to do or where to improve. By understanding and combining with the opportunities too, the analyses contributed towards exploring innovative solutions – see Table 4.20.

Table 4.20: Ranking of Top Three Opportunities per Discipline

	Discipline	Ranking
Localise Planning of Energy (AD+WM)	UP	1
Improve Multidisciplinary Approach for AD	UP	2
Involvement of Planners	UP	3
Catalyse Benefits of WM	WM	1
Multidisciplinary Decision-making	WM	2
Optimise Opportunities in Value Chain	WM	3
Benefits of Biogas	RE	1
Multi-disciplinary approach - decision-makers	RE	2
Policy Changes & Mindset Shift	RE	3

Referencing the table above, the researcher found that decision-makers in each discipline noted distinct yet interrelated opportunities. Starting with urban planners, the top-ranking opportunity is to localise energy planning; intentionally planning-in anaerobic digestion and waste management activities in spatial and urban development plans. Due to limited exposure as well as participation within these sectors, it is imperative to improve the multidisciplinary approach where urban planners are more involved. Although some involvement was deemed at departmental meetings or approval of development plans, there is room for much more involvement. As mentioned by a WM participant in the previous chapter, Municipal Think Tanks where public officials - representative of various departments and leadership ranks – can actually collaborate, create prototypes and test solutions is imperative. This was ranked second by both waste management and renewable energy decision-makers.

Through this approach, there would be a better approach to catalyse multitude benefits identified across literature such as those presented by anaerobic digestion, while

ensuring that the waste value chain is optimised further. Lastly, there is an opportunity to encourage energy policy changes and a mindset shift of policy makers.

4.5.2.2 Current Collaborations and Interdisciplinary Involvement

The study found that interdisciplinary collaboration was prevalent but weak and, in some cases, weaker than others. Urban planning decision-makers tend to collaborate with waste management and renewable energy at a very high level in terms of conversing, not in the actual planning process (communication to collaboration) as depicted in Figure 4.8.



Figure 4.8: Urban Planners' Collaborative Levels

This has a direct impact on development and quality service delivery. The analyses showed that collaboration was stronger between waste management and renewable energy and this may be attributed to common familiarity with organic waste. It is imperative for urban planners – as drivers for development – to be more involved. This can be achieved through establishment of Municipal Think Tanks and a change in the tertiary curriculum change (where waste management and renewable energy professionals are involved in preparing spatial and urban development frameworks. Achieving this as a primary base is as important as relations and networks established with research institutions, corporates, NGOs and regional development agencies. As an urban planning participant alluded to in the in the findings, poor communication led to a housing project being completed without access to electricity. The planners were not familiar with electricity engineers' work hence engagements were not simultaneous.

This poor collaboration and communication are directly linked to decision-makers' understanding and familiarity with various sustainability concepts. The concepts identified include: anaerobic digestion, biogas, circular economy, energy poverty, decentralised energy, urban energy planning and waste-to-energy. Although some concepts may be related, one's understanding and context in which they apply differ. A common thread that was evident during the analysis placed emphasis on urban planning as a discipline that requires the most change to cater for more decentralised energy projects and circularity. Urban planning decision-makers' familiarity with some of the concepts was noted to be weaker than that of waste management and renewable energy decision-makers. The fact that their knowledge and tangible collaboration is limited was identified as a key contributor. For example, the urban planning respondent in Addis Ababa with civil engineering training was more familiar with concepts presented than decision-makers trained in Classical Planning.

4.5.2.3 Impact of Sustainability Concepts on Decision-making

Anaerobic digestion and circular economy were not popular concepts amongst urban planners, including energy poverty and urban energy planning as presented earlier in Table 4.16: Summary of Urban Planners' Understanding of Concepts. The researcher noted that much needs to change theoretically and practically before urban planners can comfortably or intentionally plan in integrate more AD projects in cities.

There is an opportunity for urban planning professionals to be more exposed and upskilled about these concepts and improve interdisciplinary collaboration within as well as across the three disciplines. The researcher builds on seven proposed approaches shared by waste management and renewable energy participants which can aid in adopting more anaerobic digestion and circularity in cities. Figure 4.9 summarises the approaches into four high level themes.

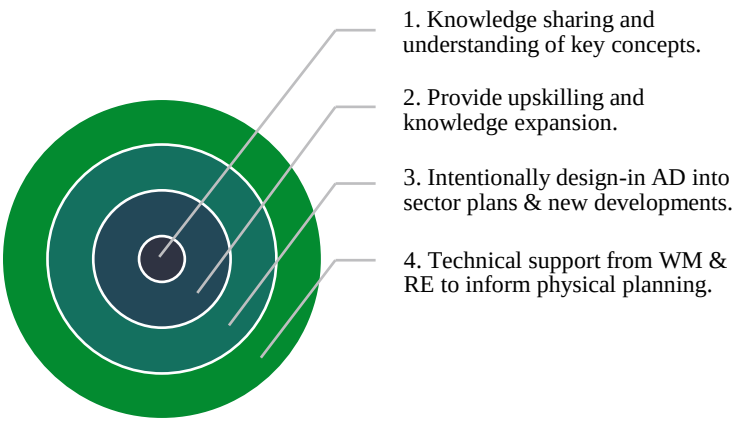


Figure 4.9: Summary Approaches to Improve Urban Planners' Collaboration

These approaches are mainly proposed for urban planning professionals:

1. Improve knowledge sharing and understanding of anaerobic digestion as a technology, and familiarising with circular economy is imperative to improving decision-making at the early stages,
2. Upskill and expand knowledge about urban metabolisms in African cities, specifically waste and energy flows,
3. With improved knowledge and understanding, amend current development regulations to include more aspects relating to waste management and renewable energy,
4. Then intentionally design-in anaerobic digestion projects into sector plans and new development applications,
5. Engage waste management and renewable energy professionals about the technical parameters and how they are impacted by urban parameters,
6. Which would lead to identifying suitable land and transport routes within cities to optimise logistics along the value chain, and lastly
7. Offer holistic project management.

Noting that urban planners are primary drivers for development, they are able to plan in activities from the conceptual stage. They would be able to guide waste material and energy flows towards socio-economic and environmental benignity. This would result in waste management and renewable energy professionals as well as decision-makers being able to realise benefits of biogas for urban citizens.

4.6 R.O 3: The Ideal Urban Biogas Model

R.O 3: To develop a generic Urban Biogas Model for Africa's Metro-Municipalities.

Aim: Objective three is a culmination of the first and second objective that illustrates what the ideal urban biogas model would look like. The aim was to show how quantitative and qualitative aspects of biogas projects could be embedded in development projects.

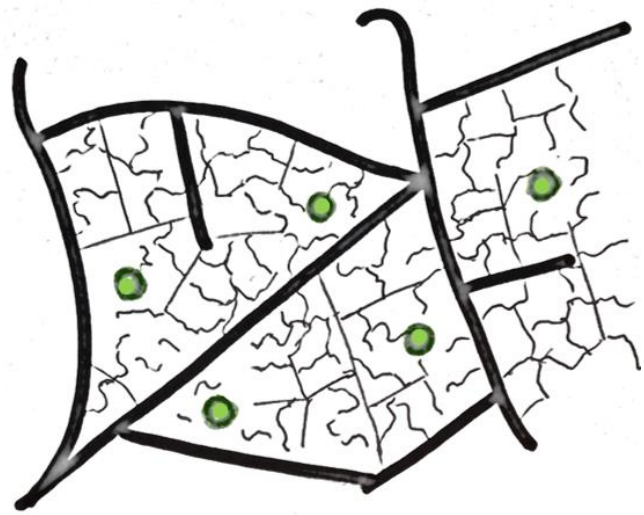
Having calculated how circular different types of anaerobic digestion technologies can be and having understood decision-makers' experiences as well as synthesis of sustainability concepts, participants were asked to describe what an (1) ideal urban biogas model would like. In this description, they shared (2) how it would ideally operate and (3) role-players that would be involved. Participants responded and engaged with excitement.

4.6.1 Presentation of Results

The researcher graphically illustrated what these ideal models would look like for each participant. Once again, findings are presented from a sector perspective.

4.6.1.1 Urban Planning Participants

E.P mentioned that the Integrated Planning Strategy tool which their institution was in the process of developing can guide future projects in Addis Ababa. It would encourage built environment professionals to share insights, exchange parameters and improve implementation. Figure 4.8 illustrates the researcher's interpretation of a proposed Urban Biogas Model for Addis Ababa.



(●) Decentralised AD Systems integrated into existing organic morphology

(-) Planned Areas

(~) Organic Areas

Figure 4.10: Proposed Urban Biogas Model for Addis Ababa

Source: Researcher's Interpretation during Interview

E.EP stressed that any models identified would need to "*find ways to integrate into existing morphology which comprises of organic settlement*". Furthermore, E.EP suggested the model should consider community ownership models and payment technologies which not only allow citizens to be part of the process but pay as they go. Biogas can be metered thus citizens use what they can afford. The integration should also include "*incremental implementation of infrastructure*" which will assist to manage resources and provide what the community needs at a specific point. Although property developers are building more structures that are self-sustained and use grid infrastructure or municipal water supply as a fall-back, their approach ensures sustainability. E,P concluded by stating that these properties are currently for the very wealthy, but the same approach can be applied using a simulated model to plan properly. Addis Ababa is traditionally known for being mixed use – no physically defined spaces for different income groups – thus feeding into surrounding settlements can be an option too.

S.DP expressed that from a planning perspective, there is an opportunity to have more interactive workshops when preparing various development frameworks. These interactions would have all the metro-departments participating, thus improving how

development planning happens in future. Interactions would also offer metro-departments to understand planning parameters such as densities, land uses proposed, design capacities and many others. Then, development can take place and all department can identify whether new bulk infrastructure needs to be implemented or existing infrastructure can be used or upgraded. The finances saved by developers could be directed to upgrading service infrastructure in other parts of the city. If the metro-municipalities improve their energy mixes, electricity and gas could be reticulated to households were possible, instead of having gas cannisters.

The researcher found that urban planning participants were not able to share much about how anaerobic digestors can be included in cities, what this ideal model would graphically look like nor outline key players. E.EP's contribution was guided by an engineering background and experience working across multiple disciplines.

4.6.1.2 Waste Management Participants

E.WM did not have granular information about energy and biogas related technicalities but conceptually believed that energy decentralisation could happen in cities – *"Yeah, of course it work. But I don't have any information."* A Master Plan was proposed, one set by different agencies and directorates, showing a shared vision for Addis Ababa. In this plan, an additional incineration plant would be necessary to improve disposal, composting and recycling initiatives – "*We have to set a Master Plan. Different organisation has to set common plan and we need to also set the responsibility/obligations in order to implement the activities for sustainable development of the city*". There is a need for additional disposal sites because the population is increasing, and more waste is expected. Land is becoming more costly and scarce in Addis Ababa. A master plan will also guide agencies to use land for different activities, specifically another incineration plant that can handle large waste volumes, recycling, and composting because "*because this open dumpsite is beyond its capacity*."

G.WM started by reiterating how highly urbanised Accra is, then said "*yes*" renewable energy in general can be decentralised in urban areas as means "*to power immediate surrounding areas particularly where the waste-to-energy plant is located*". Figure 4.11 illustrates the researcher's interpretation of a proposed Urban Biogas Model for Accra.

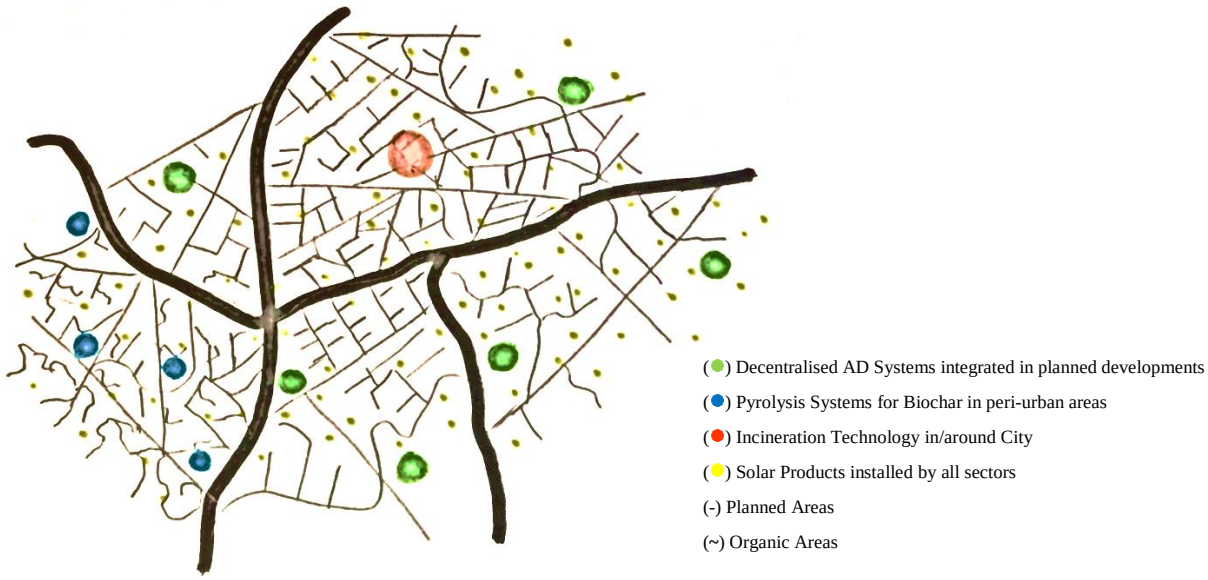


Figure 4.11: Proposed Urban Biogas Model for Accra

Source: Researcher's Interpretation during Interview

G.WM suggested different waste-to-energy technologies at a small scale for different energy outputs. Pyrolysis was suggested to produce biochar because "*it is a useful by-product*". Incineration was suggested to produce electricity and dispose material that is too large in quantity. By-products such as bottom ash could we used for road construction. G.WM also made a call for co-digestion projects with wastewater treatment for more energy productions. With organic fertiliser as a by-product from such projects, "*there needs to be a good balance between nitrogen, potassium and phosphorus*" specifically for farmers who may offtake it. Furthermore, biogas produced can be bottled and sold for use in institutions such as schools and hospitals. A point stressed was the need for a mindset shift by politicians and technocrats; to understand each technology's impact and the sustainability agenda. G.WM saw this as

an imperative point that can improve access to electricity in urban areas, which is supported by the following statements: "*high urbanisation growth can be advantageous to harness waste resources for green energy*", "*also consider solar for hybrid systems in urban areas by having dedicated residential roofs for solar and street lights*" and lastly, due to Africa's hot climate, "*consider thatch roofing that can help with cooking*".

In terms of roles and responsibilities, G.WM rather emphasised on the role of urban planners and mentioned that "*whenever town planners approve plans for physical infrastructure, they should insist on the right things to be done by tapping into advice from engineers so that energy dependency ration will be determined*". By doing so, urban planners would know the exact energy capacity they are planning for. To realise all of this, policies aimed at developing Think Thanks for built environment practitioners was suggested. It would include urban planners, all engineering disciplines, architects and more, operating in public and private sectors. S.WM exclaimed "*Yes! It is possible*" to integrate anaerobic digestion in urban areas but at residential estate levels – see Figure 4.10.

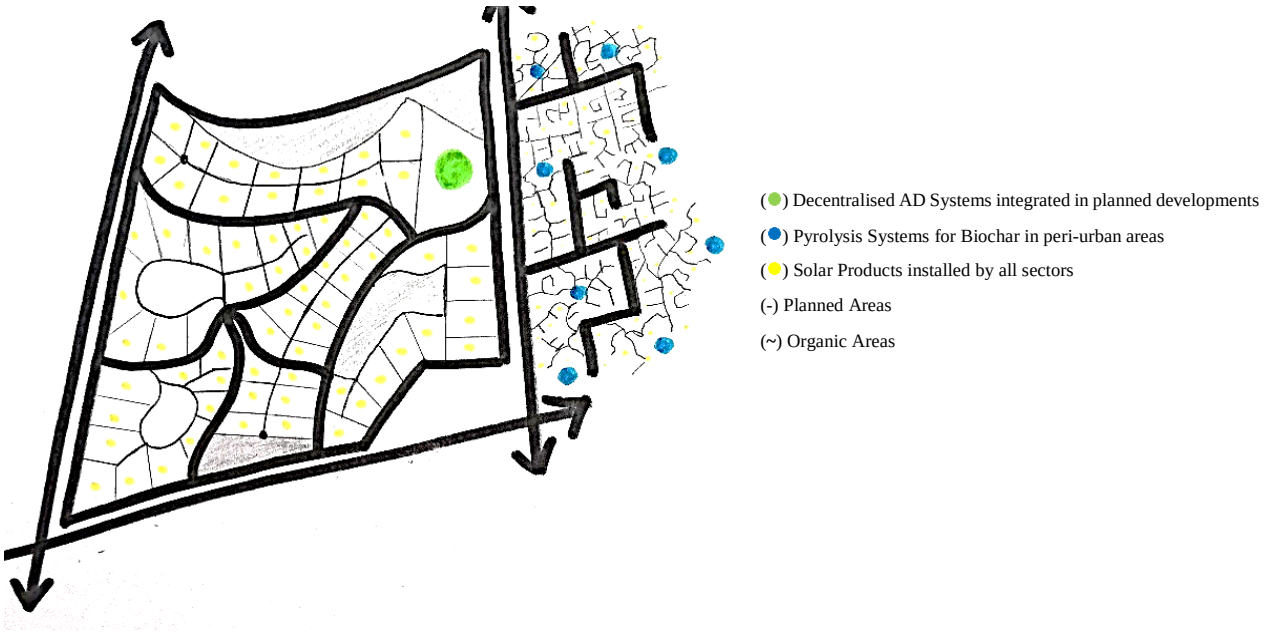


Figure 4.12: Proposed Urban Biogas Model for Johannesburg

Source: Researcher's Interpretation during Interview

S.WM stated that "*we should consider integrating small digestors in estates and use the energy generated in schools*". In peri-urban areas, decentralised energy should be in the form of biomass, which can be used to create biochar. With improved clean cooking fuels, those settlements would be off-grid and decentralised too. "*Wood waste can be used as feedstock for biochar but we would have to make sure it produces good heat energy for cooking*". S.WM mentioned it would result in reducing electricity theft while managing waste in many informal settlements. Solar should be considered for the mix as well. S.WM stressed various opportunities for entrepreneurs can be exploited when energy is decentralised; when the value chain is unpacked, and that is how circular economy is further achieved. The circular economy can improve decentralisation and access. S.WM concluded by stating that entrepreneurs can drive these opportunities but "*government needs to be an abler through integrated plans*" that are clear from the beginning.

S.RI mentioned that "*anaerobic digestion enables decentralisation*". It is a waste management solution that provides energy solution. It is a scalable technology, whether household or community level, within industrial parks or within a city. However, "*not all anaerobic digestion should lead to decentralised energy, it should be contextualised*" by making sure it is "*part of an available market*" in the area where waste is collected, and that some areas only manage waste and in others, energy can be generated. In terms of who should be involved and how, S.RI reiterated the sensitivity of anaerobic digestion technology and due to this, its need for expertise. SR.I then stated the importance of urban planners in planning to decentralise the technology because they need to understand that "*infrastructure in big cities is failing and crippling municipalities therefore there is a need to look at cities of the future*" – see Figure 4.13, an ideal Urban Biogas Model modelled proposed for Municipal Think Tanks.

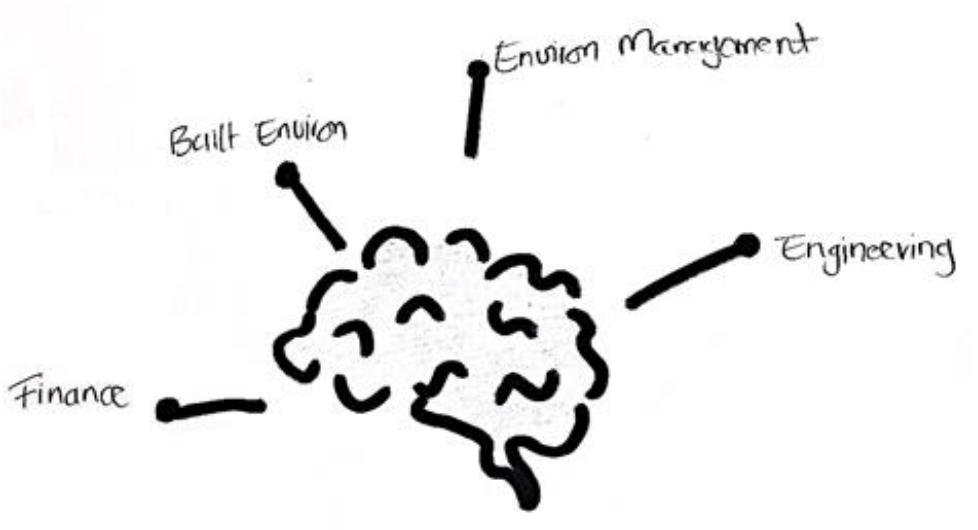


Figure 4.13: Ideal Urban Biogas Model modelled in Municipal Think Tanks

Source: Researcher's Interpretation during Interview

A second consideration S.RI mentioned is the need for key departments in metro municipalities to drive this change. It can be in the form of "*Municipal Think Tanks*" where officials such as Chief Financial Officers, environmental department and built environment experiment as well as try & test solutions and challenges with no barriers. S.RI further emphasises how these Municipal Think Thanks would encourage a "*mindset shift to promote energy integration and futuristic*…". City Metabolism and circular economy are achieved when metro municipalities begin to "*reduce the cost of service per citizen if the approach is integrated because the process is a more efficient use of the budget. Generating value for citizens and co-digestion reduces waste management costs and that money can be re-directed*".

4.6.1.3 Renewable Energy Participants

E.E responded to this question expressing "*That's good. That's the plan of the Prime Minister*". There is a need to diversify energy supply sources and reduce the monopoly for grid electrification – see Figure 4.14.



Figure 4.14: Proposed Urban Biogas Model for Addis Ababa

Source: Researcher's Interpretation during Interview

Micro-hydro plants are one of the approaches being considered for future use because they can provide access to electricity in areas where the grid cannot. Small decentralised systems are manageable and relief national utilities from technical complexities and financial pressures of existing infrastructure as well as expanding. The Reppie WtE project was referred to as a good start to decentralising access to energy in Addis Ababa. E.E suggested that the facility should be expanded.

> "*Every city in Ethiopia, they need to have this facility. Even at suburbs, needs to have this facility but they don't know it. That's the case. But for this case, it's also my recommendation that it is good to expand. A lot of things are already there.*"

The facility is fitted with all the equipment required for expanding. However, with an additional two boilers, it can process almost double the daily tonnage of waste (up to 3,000 tonnes of waste per day). Presently, it is operating at two-thirds its capacity. Some of the largest WtE facilities in the world average between 50 MW and 100 MW capacity. The 25 MW is not the maximum for Addis Ababa because so much more

energy can be generated. For smaller cities, E.E suggested they also consider incineration but for waste management and not electricity generation because it will be very expensive for them. They can ways to use the biogas or heat output even if the quantities are small; maybe used on-site. Overall, challenges faced from inception to date should be reviewed to improve technical designs and funding models, which in turn improve overall efficiency. G.RI earlier suggested a hybrid model comprising of solar and biogas systems for large residential estates as means to ensure sustainable waste management and energy generation. Solar lamps or streetlighting for lighting, solar water pumps for borehole water and biogas co-digesting faecal and food waste for cooking gas.

> *"When it comes to biogas I don't believe in very small plants. I do not know how would rather go for a centralised system for some enclave. I mean, it is still a decentralized system but centralised for different enclaves. So when you have a small neighbourhood that has a number of facilities that you can put together to have your plant that is bigger - so you bring all the resources into a central point to have a bigger plant - then it's easier to manage the plant, it's easier to... if you have to do some further treatment to the energy to the gas to use it... it's much easier when you have a lot of small plants scattered all over the place".*

Figure 4.15: illustrates a proposed Urban Biogas Model for Accra from a research institution's perspective.

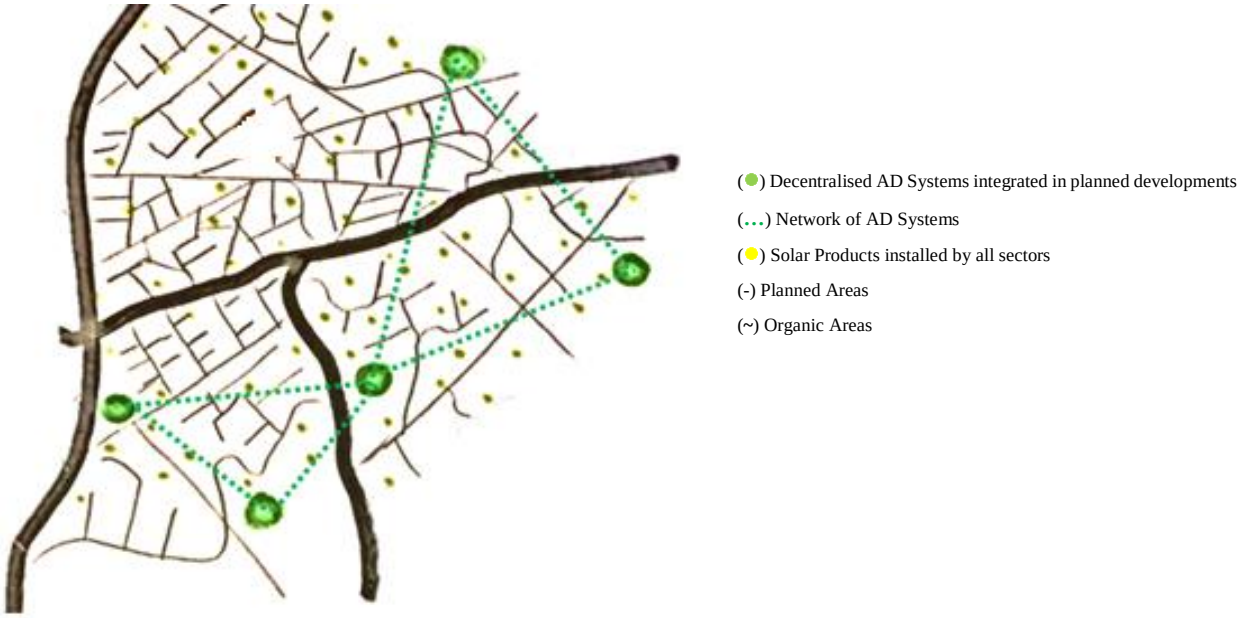


Figure 4.15: Proposed Urban Biogas Model for Accra

Source: Researcher's Interpretation during Interview

Furthermore, solar can be added as a centralised system for lighting and electrification on both a community or household level. It can complement biogas during maintenance or low feedstock supply or other glitches because it is not as complex as biogas. Solar could also be popularised in the commercial sector, where buildings and parking spaces are created using solar panels to generate electricity for onsite consumption. The model was proposed for new residential, commercial and industrial developments because current physical planning and land-use does not allow for massive changes especially in peri-urban areas where planning is poorly done. Given how Accra's planning is organic and informal, finding physical space to implement decentralised anaerobic digestion systems may prove more challenging than for solar – "*What I see in most of West Africa, most peri-urban communities are not really well organized to have especially biogas system. Solar systems I mean, they can be anywhere even on a thatch roof…*".

To realise this model, G.RI suggested that the Urban Planning and Environmental Health Departments within municipalities should lead the projects: model designs and location., responsible for development and housing projects, infrastructure planning and sanitation, liquid and solid waste. With regards to where and how these different planning professions can change, G.RI's experiences suggest that many built environment professionals study abroad and return with innovative ideas but find themselves in a mediocratic environment that is set in specific ways of thinking. Hence a mindset shift was suggested more than skills development. Tying in with perceptions about leadership and their conduct as well, mindset shift would be required at leadership perspective too, a shift that allows for new ways of thinking and promotes an integrated approach.

S.E mentioned that during a strategic session a few years back, a question similar the interview question was asked – 'what do you think of the City in 2050?' S.E answered as follows:

> "*We will probably have a situation whereby the sanitation is not taking the waste to a wastewater treatment plant. The treatment plant is about 20-30m from houses. The waste gets into an enclosed structure, which then biodegrades the waste. The water that is a by-product of that biodegradation is then utilised to water gardens and aquaculture establishment in those areas so that nothing goes to waste. Everything is in a closed loop, whereby not only that the water goes towards the activities but is then recycled for use in your toilet again. But the waste for the toilet is therefore taken to generate electricity and the by-product is utilised as your fertiliser or whatever form of utility you want*" – see Figure 4.16.

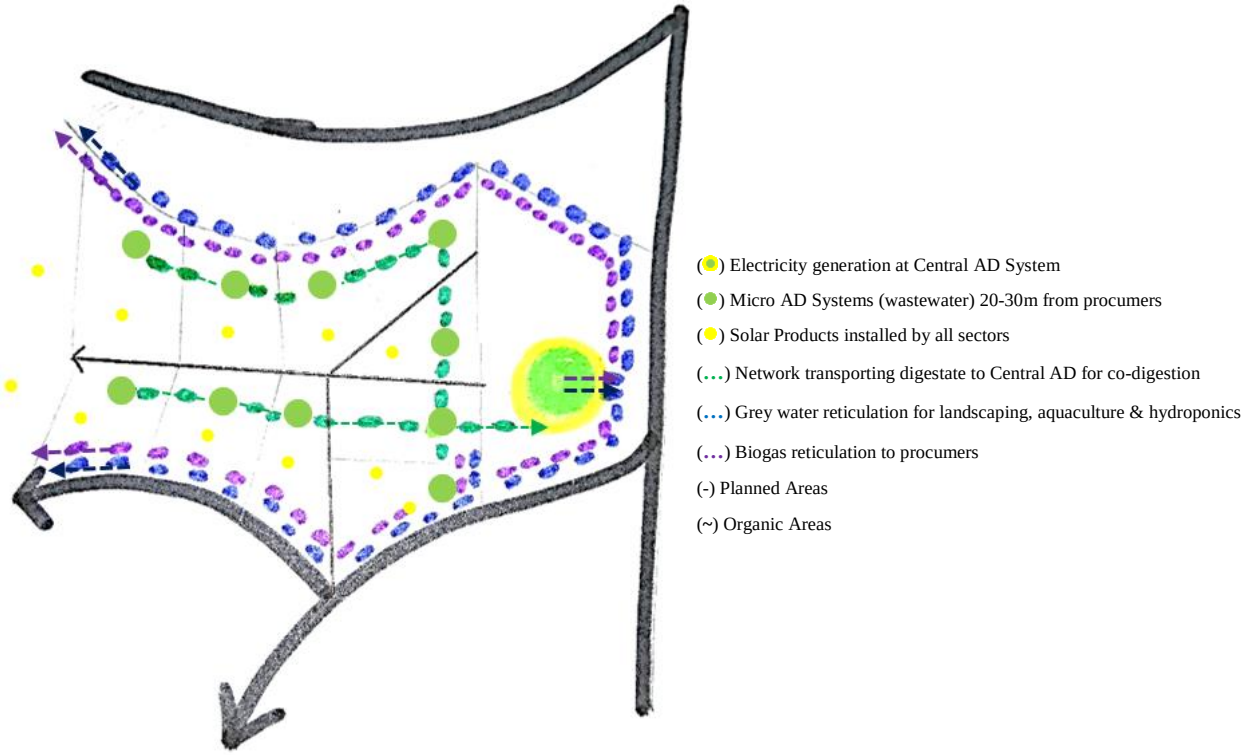


Figure 4.16: Proposed Urban Biogas Model for Johannesburg

Source: Researcher's Interpretation during Interview

Furthermore, S.E proposed small-scale hybrid systems; solar energy generation combined with liquid petroleum/ liquid natural gas and biogas reticulation into residential, commercial and industrial sectors. The systems would have to be tailored for settlements, with input from community participation – "*Why don't you utilize the thinking that the people are having of how to improve their lives as part and parcel of your service provision?* ". Electricity generated can be channelled using mini-grids, especially in areas that are far from grid connection.

Complimenting S.E, R.A said that "*it should be natural in a community or neighbourhood*" to integrate and decentralise anaerobic digestion because "*it improves efficiency*". Furthermore, R.A emphasised that biogas can be integrated into existing systems such as aquaponics and hydroponics, where the digestate would act as feedstock for fish and plants, or even soil rehabilitation within the mining industry.

"*This would achieve a circular economy*" because digestate is an issue most biogas producers grapple with, finding benign ways of disposing it. Stand-alone systems are a lot more efficient due to having a common energy source that can aggregate their needs and buffer different households (who demand different energy). The national utility would be on standby for peak time energy demand. "*it is actually better for a utility to be on standby while the community is smart*". R.A added the following characteristics to consider: the infrastructure layout and interference with utility should be synchronised with frequencies to manage fluctuating demand. Safety is a very important aspect when any energy independently. If not managed well, it can affect grid supply. With regards to suitable role players and their responsibilities, R.A mentioned that "*metros are best suited for decentralisation*". Their role entails planning in the integration from the start "*and look at the opportunity cost of not doing it*".

Current legislation and regulation prevent the use of coal and wood for some household activities, but the reality is those sources are accessible and affordable. Including and introducing decentralised technologies such as improved cook stoves or wood pallets continues to meet households' energy demand in a benign manner. Small businesses can service these decentralised needs. S.E concluded that this model would reduce the metro-municipality's infrastructure budget in terms of extensions, operations and maintenance. By decentralising infrastructure, it would be a more efficient manner of re-centralisation because those systems need to be interconnected and maximise optimisation as well as economies of scale, "*Symbiotic Relations*". This is the type of thinking S.E stressed that public servants should have. This way, action plans and frameworks such as Agenda 21 and the Sustainable Development Goals are met.

Solid waste management, wastewater treatment and electricity departments in metro municipalities should be responsible for implementation and urban planners should drive it. However, there would need to be a common understanding amongst all of them. R.A provided two scenarios of how and where this can apply. Firstly, in residential estates, households could "*convert all their waste into energy if they are*

not linked to a grid or receive waste collection services". Urban planners would need to plan it in development guidelines early enough: "*they should be driving urban energy and research what needs to be put in plan*s". R.A also said these integration projects should occur more in highly populated areas, especially where illegal connections and electricity theft are rife. There is a greater demand for sustainable energy provision in dense areas. Lastly, R.A called for greater private sector participation to "*relieve metros*" because their "*processes are too long, and legislation affects greater biogas uptake*". Models such as Build, Operate, Own or Build, Operate, Transfer can be considered and improve efficiency.

"Yes!" was S.IA's response. "*Anaerobic digestion technology can be considered for decentralising energy in urban areas, for biogas and for heat*". However, it would need to be mixed with other sources such as solar and grey water reticulation. S.IA said the model is suitable for urban areas because there is no space for big renewable energy plants in the city. Since most fossil fuel plants are outside cities, maybe industrial anaerobic digestion plants can be considered, especially near industrial areas which "*require a lot of energy for production and manufacturing activities*". Renewable energy/electricity and waste management departments in metros and beyond should work together to ensure efficiency but "*this must be done from the beginning before any implementation*".

Lastly, NGO also agreed that anaerobic digestion can be integrated into urban areas but emphasises two key factors. Firstly, private sector participation should be included, and each project should be tailored to "*fit into the development plans for that area*". By doing this, it reduces energy generation monopolies and increases competition along the value chain of generation, distribution, and transmission, resulting in improved implementation. To achieve this, NGO suggested greater adoption of public-private-partnerships. Secondly, government's role is to regulate and create a favourable environment for more private sector participation in energy generation and waste management.

4.6.2 Discussion and Interpretation of Findings

4.6.2.1 Consider Current Urban Morphological Structures

Not all urban planning decision-makers were able to share specific models in relation to anaerobic digestion. Despite limited knowledge about the technology and circular economy, the decision-makers were able to share features in relation to renewable energy in general. For them, it would include an Integrated Planning Strategy Tool designed to encourage knowledge sharing and improve implementation. In terms of its operation, the model would need to consider existing organic morphologies – informal settlements. Doing so would ensure that energy is also accessed in areas with little to no infrastructure. Incremental infrastructure implementation would need to be factored in as well, to provide energy resources needed at a particular point.

Waste management decision-makers collectively agreed that anaerobic digestion can be integrated at city level and achieve circularity, but from a 'managing waste' perspective rather than energy generation. The model would need to include additional disposal sites to match increasing population. Material Recycling Facilities (MRF) where waste materials are sorted and separated were suggested to improve recycling and composting opportunities. As one participant mentioned "*anaerobic digestion enables decentralisation*" but not all technologies should lead to decentralised energy, they have to be contextualised to a surrounding market's demand. It should also include designs that are customised to service a demand. For example, a settlement in need of biogas energy instead of electrical energy should have their needs catered to. Hybrid energy solutions such as anaerobic digestion, solar, pyrolysis for briquette making, and incineration, were proposed.

All the renewable energy participants concurred that it is great to diversify energy supply sources. "*It should be natural in a community or neighbourhood*" because "*it improves efficiency*". The ideal model should feature a hybrid system of these sources, namely anaerobic digestion, incineration, small scale hydro-plants, solar, and wastewater. Equally important is the use of mini grids not only to physically decentralise access but technologically centralise through energy networks. This

would relief national utilities from technical and financial pressures presented by existing infrastructure as well as future plans. Generation activities should be located close to waste generators and energy demanders. Noting rapid urbanisation across the three cities and current city structures, participants stressed that there is no physical space for big renewable energy projects. Residential, industrial and commercial sectors all demand energy that is accessible and affordable.

4.6.2.2 Physical Connection Routes and Logistics

A greater presence and consideration for bulk infrastructure and urban planning parameters such as densities, land uses, design capabilities would aid in intentionally designing-in renewable energy technologies. Participants encouraged a community ownership model where citizens are part of the process. Incorporating payment technologies would ensure efficiencies because citizens use what they need and can pay for at a given point.

Customised energy demand profiles would offer a better understanding of energy output. Operationally, WtE ought to feature in a City's Master Plan. This allows decision-makers to review available technology options that can manage large quantities of non-recyclable material and keeping up with high waste generation rates. Although incineration technology is viewed to have massive negative environmental impacts, by-products such as fly-ash can be used for road construction – particularly in organic peri-urban areas. Co-digestion with wastewater from treatment facilities can aid biological process while balancing potassium, phosphorus and nitrogen. Participants viewed this model being implemented either at residential estate or settlement level with the aim of reducing feedstock and energy transport costs. Where demand is biogas, it can be reticulated through pipe infrastructure or bottled in cylinders for local demand. Within this value chain, participants believed a circular economy can be achieved for both energy and waste.

According to renewable energy participants, this model would operate primarily as a network of anaerobic digestion systems. It would be cognisant of formal and informal settlement, and the decentralised network approach can improve gas reticulation efficiencies. Liquid and solid feedstock would be transported to a central location where energy is generated. Various output energy can then be customised for local needs. This includes but not limited to:

- digestate for land scaping and soil rehabilitation
- grey water reticulation for aquaponics, hydroponics

The approach promotes a closed loop system because digestate is one of the key challenges for developers. Additional operation considerations include:

- reticulation biogas straight into households and institutions
- consideration for min-grids which are not dependent on grid connection but rather use it for back up energy or during fluctuating demand
- a serious consideration for infrastructure layout will be necessary so that frequency interferences are managed.

4.6.3.2 Technology Engineering, Procurement and Construction

Interactive workshops with waste management and renewable energy professionals were proposed as an imperative activity to prepare development frameworks. The anticipated result would improve development planning that is cognisant of energy and circularity.

Major emphasis was placed on the role of urban planning decision-makers and professionals. Their role should be to improve development plans by catering for decentralised energy and urban waste material flows. Key responsibilities include but not limited to (1) reviewing whether new development are pro-sustainable development, (2) review data and circular flows of energy and waste material, (3) in order to determine capacities to plan for. Establishing Municipal Think Thanks can expedite their mindsets to shift from linear to circular. Other role-players to consider are entrepreneurs because they have the tenacity to innovate and exploit opportunities

in the waste value chain as well as realise circularity. Activities include but not limited to (1) waste collection and sorting services, (2) energy production – biogas and briquettes, and (3) logistics. needs.

Renewable energy decision-makers proposed that energy planning should be done beforehand. Urban planning and waste management decision-makers were proposed as key project leaders who should: review development guidelines, design the spatial model, identify suitable land within existing city structures, consider the use of existing infrastructure, review solid and waste flows from waste generation to energy generation site, data collection and characterisation of waste profiles within cities and so forth. The model should happen in metropolitan municipalities and be accompanied by upskilling and mindset to realise it. Lastly, entrepreneurs together with well-established private sector role players equally need to be part of the value chain especially in the early stages; be the project developers and implementation champions.

5. SUMMARY, CONTRIBUTIONS AND CONCLUSIONS

Science knows no country, because knowledge belongs to humanity, and is the torch which illuminates the world - Louis Pasteur.

5.1 Introduction

To recap the problem statement, numerous industry reports and academic journals forecast rapid urbanisation and population growth to proliferate between 2030 and 2050. With this comes a range of opportunities and challenges relating to quality service delivery. Delivery of amenities such as waste management and energy, just to name a few, will likely experience severe strain. Two systems can be combined to prepare accordingly for the decades ahead, namely anaerobic digestion and circular economy. Anaerobic Digestion is a well-researched and proven– sometimes biologically complex – treatment technology that offers a solution to manage waste and generate energy, inducing environmental sustainability. In the same breath, circular economy has and continues to garner traction as economic paradigm that offers socio-economic and environmental benefits. It aims to keep resources in use for longer and capitalise on waste material as feedstock for other activities. This study investigated the possibility of integrating anaerobic digestion technologies into African cities in a circular manner. The research proposition and objectives were as follows:

Research Proposition:

Anaerobic digestion is a viable circular economy model that may help towards achieving the energy demand in African cities. It is amongst the cheapest WtE methods of energy generation and is socio-environmentally benign.

General Objective:

Using principles of circularity, this study investigates how anaerobic digestion can help improve energy access and integration in African cities by capitalising on urban waste material.

Sub-Objectives:

1. Determine if anaerobic digestion technologies can promote circularity in energy production,
2. Understand who the decision-makers are and investigate factors to assist in their decision-making,
3. Develop an Urban Biogas Model for African metro-municipalities.

The research was multidisciplinary and used a mixed methods research design, which combined both quantitative and quantitative approaches. Quantitative data was mainly secondary data and qualitative data was collected through interviews with key decision-makers from three metropolitan municipalities – Addis Ababa, Accra and Johannesburg. Participants' experiences and qualifications were in urban planning, waste management and renewable energy. Concurrent Embedded design was used to amalgamate the approaches. Key decision-makers in three metro-municipalities were purposefully selected. They have (1) mandates for development, (2) powers to inform the direction of development, and (3) how it can be implemented. Participants were chosen from urban planning, waste management and renewable energy departments because they are interlinked where development is concerned. A city requires physical and strategic planning to ensure that amenities such as waste management and energy are provided. Hence one is not independent of the other. Objective two sought to understand who these decision-makers are and what factors assist in their decision-making.

5.2 Research Summary

The aim of this study was to investigate how integrating energy from waste in rapidly urbanising African cities can be done in a circular manner. Results were presented and findings discussed and interpreted in Chapter Four. The key findings are presented below:

R.O 1: Determine if anaerobic digestion technologies can promote circularity in energy production.

The study found that anaerobic digestion has the potential to promote circularity. Three existing and operational AD plants were used as a base to calculate the Circular Economic Value. An exception included in this calculation was Reppie WtE Plant. It is an incinerator facility and was chosen due to limited available data on AD operations in Addis Ababa (Ethiopia). It also allowed for technology comparison. The other two were Safisana community AD plant in Accra (Ghana) and Bronkhorstspruit Biogas Plant in Tshwane (South Africa). All three cases presented low circular values. Reppie WtE plant was 0,0%, Bronkhorspruit Biogas Plant was 0,25% circular and Safisana had the highest with 31,75%. Low circularity was attributed to linear fluxes along the value chains. This resulted in value leaking, resulting in missed opportunities to further reduce, reuse, recycle and remanufacture where possible.

Although some AD plants were identified in urban areas, decision-makers in urban planning were not aware of such energy generation technologies compared to waste management and renewable energy counterparts. It was found that limited knowledge about or involvement in planning such projects does have a direct impact on adoption and integration, i.e. recent data required for project planning and development. The researcher interpreted how circular economy principles can be considered to improve value optimisation:

Principle 1 Preserve and enhance natural capital by controlling finite stocks and balancing renewable resource flows.	*Re-Design*: The extraction of organic waste material will require redesigning existing and future waste sorting infrastructure at the beginning of the waste management value chain. Sorting is a critical step to ensure sufficient and sustainable supply of quality feedstock as well as tailored technology design. During this process, feedstock qualities and quantities are expected to vary based on each city's demographic as well as socio-economic profiles. This will ensure that what waste management sorts is *circularised* and becomes a feedstock for energy generation. Renewable energy engineers then focus on improving and maximizing technology efficiency, as well as considering a variety of grid options for large-and small-scale transition and distribution for resource optimisation – The Concept of Exergy. Africa's mini-grid sector is still developing and presents opportunity for greater implementation in sprawled settlements. Entrepreneurs can valorise such opportunities along the transition value-chain. Redesigning also ensures socio-economic, environmental and industrialization goals are still met.
Principle 2 Optimise resource yields by circulating products, components and materials in use at the highest utility at all times in both technical and biological cycles	*Re-Use*: The energy produced by AD technologies can be reused either back in the generation process or deferred to energy-intensive sectors in need of additional energy. Example one: large scale hatcheries can generate energy from poultry manure and use output as electricity supply for the hatchery's operation and use the heat to incubate hatchlings. Example two: institutions such as government, schools, universities, community halls as well as off-grid settlements can enjoy biogas for cooking, lighting and heating. Example three: agro-processing and industries can generate sufficient onsite electricity – using the combined heat process (CHP) – to offset their energy bill.

	Sludge material can also be used as a feedstock for small scale agrarian activities such as urban agriculture, or further valorised by using Vermiculture.
Principle 3 Foster effectiveness within the system by revealing and designing out negative externalities	*Reduce*: Traditional consumers become 'prosumers' through Smart Grids and Smart Metering. Technology and innovation make it possible for users to monitor and take charge of their energy demand and, where feed is subject to tariffs, to sell excess energy either to the utility or to nearby demand. Throughout this value chain, human capital development and development of technical and non-technical resources (policy makers, decision makers, investors, government, civil society, professionals and so on) are key requirements.

R.O 2: Decision-making to promote AD uptake in Cities

The first objective illustrated that AD has the potential to induce circularity. Objective two investigated elements needed for decision-makers to intentionally plan for it particularly in cities.

The study found that urban planning, waste management and renewable energy decision-makers experience similar issues in their respective metro-municipalities and organisations. These all relate to providing affordable and efficient services to citizens, specifically development, waste management and access to energy. Differences were primarily based on the demographic profile of each city. Shared challenges and opportunities specifically for anaerobic digestion integration include:

Challenges

- Political influences and mindsets about WtE and what it entails,
- Costs of waste management and energy development projects,

Opportunities

- Multi-disciplinary approach to project development,
- Need for a strong role by urban planners to guide development,

- Unfavourable land structures to incorporate waste and energy activities,
- Limited knowledge and data relating to AD systems.
- Use of Municipal Think Thanks that are resources with the latest data,
- Prospects of intentionally designing-in AD into plans.

Furthermore, decision-makers' understanding of various sustainability was a key finding. The study identified various concepts that emergent and driving energy access and sustainability agenda. These included: circular economy, urban energy planning, anaerobic digestion, waste-to-energy, energy poverty and decentralised access to energy. Urban planners were found to be least knowledgeable or aware of these concepts compared to their scientific and engineering counterparts.

R.O 3: The Ideal Urban Biogas Model

This objective amalgamated objective one and two. Having shown circular prospects of AD and investigated opportunities to improve adoption and integration, participants were asked to share what their ideal urban biogas model would look like. The study found urban planners across the three metro-municipalities had less input and could not visualise. The researcher graphically interpreted models shared by waste management and renewable energy participants. A key finding was that they all visualise a model that is cognisant of current morphologies and where:

1. Urban planners lead physical planning and identify land within cities for waste sorting as well as AD development,
2. They have access to the same data for sector-based planning (technical plans required from each department)
3. Intentional energy planning that mixes different energy sources such as solar, palletisation, pyrolysis and incineration where necessary,
4. Intentional plans that cater to both planned and organic settlements (key focus on informal settlements)
5. Indicates were and how value can be extracted along the AD process.

5.3 Knowledge Contribution and Recommendation

A wide range of research is available on urban planning, waste management and renewable energy. It covers different continents, including technical, social, economic and environmental issues, as well as micro and macro scales. Building onto that, there has been emergent research starting to combine these disciplines in a multi-disciplinary approach. These include circular economy, urban energy planning and considerations for circular anaerobic digestion technologies in cities. However, the emergence lacks an Afrocentric perspective, one that equally investigates and explores within the current context. Noting the many demographic and environmental proliferations in the next decade and beyond, this study added to the emergence, particularly from an African perspective.

Firstly, CEV calculation is not widely used generally. It is mailable for different contexts and can be used to pre-determine value leakages across the AD process. This study showed that more CEV calculations can be considered to pre-determine an AD's circularity as part of the design process. Renewable energy practitioners, particularly electrical, mechanical and chemical engineers can review these sections of development applications.

Secondly, this study shows that as the world aims 'not to leave anyone behind' in terms of accessing energy, urban planners, waste management and renewable energy professionals need to strengthen their collaborations. Collective expertise require intentional urban energy planning where anaerobic digestion technologies are considered in development planning applications. Research on urban planners' roles and responsibilities did not include aspects of waste management and energy generation.

Thirdly, to achieve this multidisciplinary and intentional integration, there is a need for upskilling and knowledge sharing. Concepts such as circular economy, urban energy planning, anaerobic digestion and ought to be more prevalent amongst decision-makers. This approach also encourages circularity

because role-players become more aware of where within and how to capitalise on along the WtE value chain.

Lastly, this study highlighted the need for an Urban Biogas Model to specifically support African metro-municipalities. Noting their responsibilities to provide services to their citizens, they require an innovative approach which is circular and sustainable.

Based on the knowledge contributions, an Approach to Intentional Urban Energy Planning and an Urban Biogas Model were designed to be contextualised to different cities and guide decision-makers – see Figure 5.1. Insights were considered from examples of similar approaches in Europe.

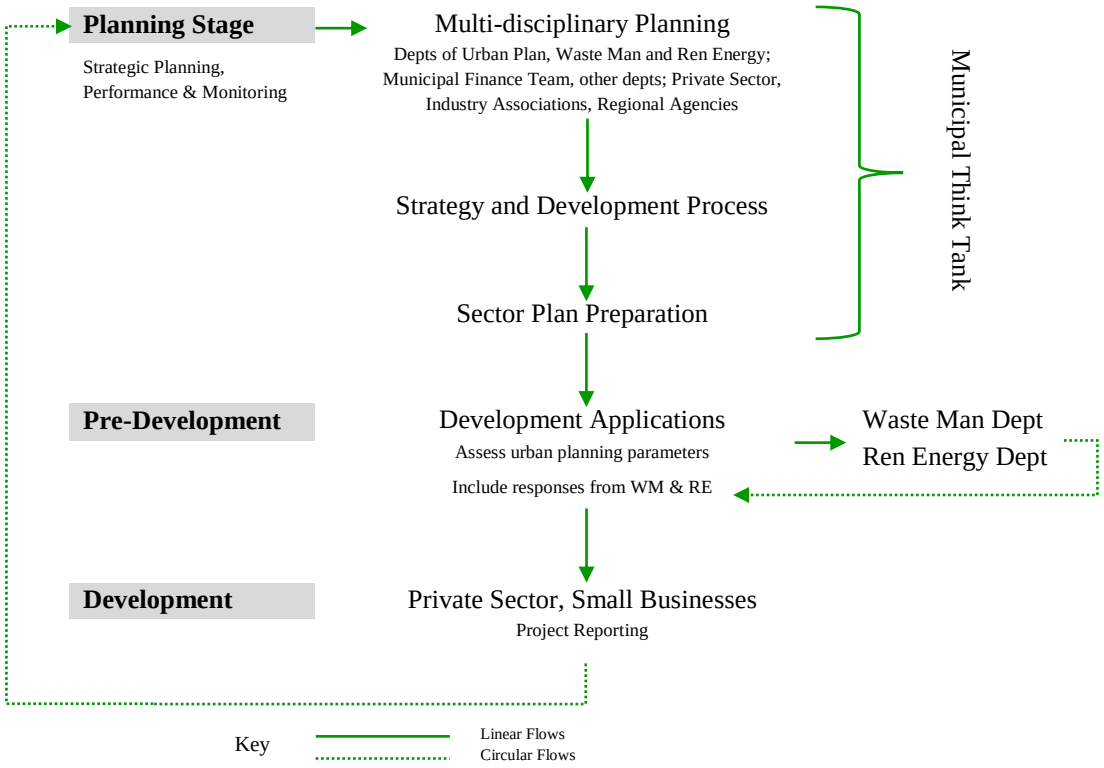


Figure 5.1: Approach to Intentional Urban Energy Planning

At the planning state, municipal executives and management teams set the vision and strategic planning for the municipality collectively and for each department. Any demographic or land related needs are made aware to urban planners by waste management and renewable energy departments. A more detailed and multi-disciplinary planning process follows where engagements take place. Intentions to include anaerobic digestion in new developments, whether public or private, are discussed. Comments are then incorporated into departmental strategic planning, consequently informing sector plans. All these activities take place under the umbrella of a municipal think tank.

Urban planners continue to receive development plans but would have made provision for public energy projects as well as new private sector development. Urban parameters are reviewed in the context of waste management and renewable energy considerations – Value Leakage Assessment and Optimisation. Based on the circularity of the proposed anaerobic digestion technology, a development application may be accepted or rejected. Private sector and small businesses then develop anaerobic digestion projects on that premise. Project reporting becomes mandatory in order to keep track of value optimisation and establish an information database.

A future recommendation is the need for innovative waste management and energy recovery in cities. The Urban Biogas Model is specifically designed for waste management and renewable energy professionals to achieve the most circularity and efficiency as possible. It aims to assist these decision-makers with Value Leakage Assessment and Optimisation. Figure 5.2 presents the researcher's proposed Urban Biogas Model.

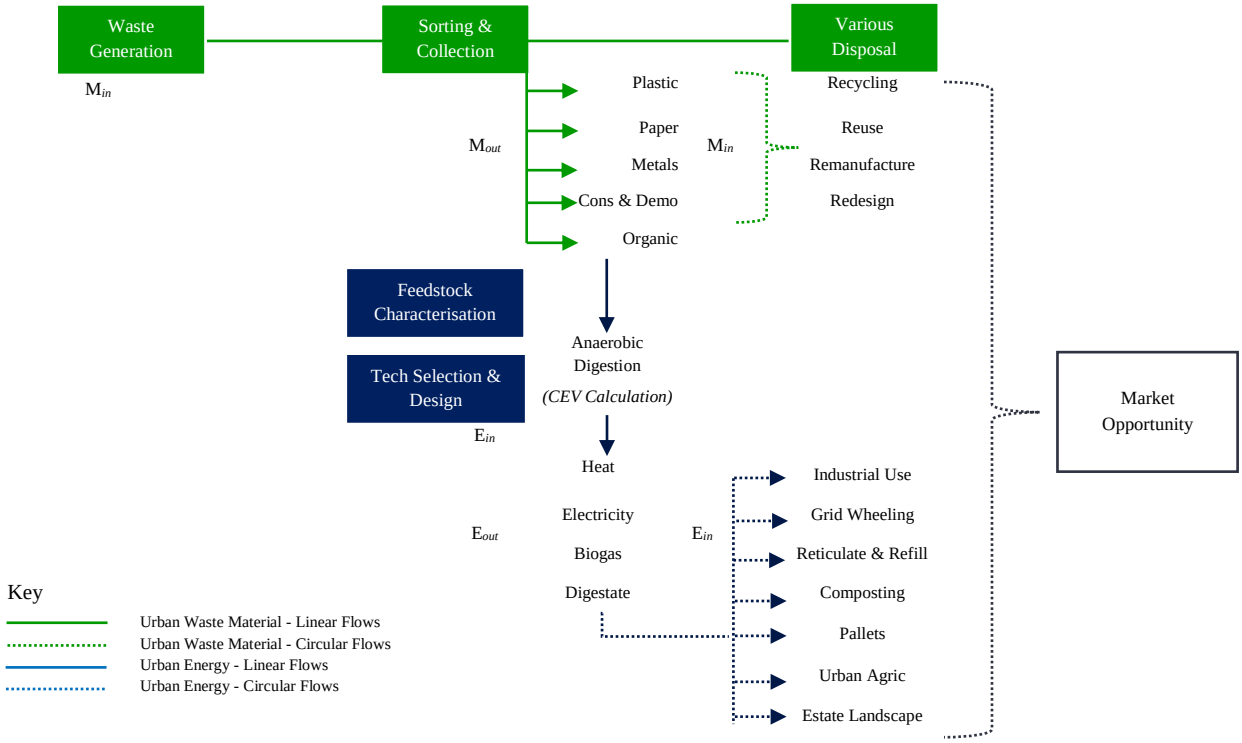


Figure 5.2: Urban Biogas Model

Waste Management and Renewable Energy decision-makers receive either public or private sector development applications from the Urban Planning Department. Waste Management decision-makers would review accordingly. The waste management process remains the same where waste generated is viewed as material inflow (M_{in}). Special attention is given to any value leakages or optimisation opportunities. During collection and sorting, materials such as plastic, metals, construction and demolition and organic waste can be viewed as material outflow (M_{out}) however, their value lies in them being viewed as material inflow (M_{in}) for recycling, reusing, remanufacturing and redesigning purposes.

Organic waste (M_{out}) sorted is then taken as feedstock (M_{in}) for anaerobic digestion. CEV calculations will pre-determine whether an identified technology will induce circularity or not. Energy (E_{in}) is required to treat the waste and various energy outputs

(E_{out}) are produced, such as electricity, heat, biogas and digestate. These are also viewed as energy input (E_{in}) for other activities.

Ceteris paribus, available land in cities would encourage more material recycling or waste transfer stations were separation and sorting occurs. Organic waste material is then transported to the nearest AD plant – if activities are not happening on one site. For private sector development, their waste management approach would need to be reviewed as well as AD incorporation. Furthermore, there is a market opportunity for private sector and small businesses optimise value and ensure circularity.

5.4 Study Limitations

Given how novel the research topic is, limitations and delineations were certainly prevalent. As presented in chapter one, the study was undertaken within the following parameters:

Delineations

Urban	The study focused on metropolitan municipalities because they have higher populations, denser settlements and demand the most service delivery. This includes economic and industrial activities, as well as human settlements with low, middle and high income.
Decentralisation	Energy that can be generated and accessed on a residential, commercial or institutional level, and is partially or fully independent of grid connectivity.
Energy	Energy in this study refers to specifically renewable energy sources and in the context of anaerobic digestion, energy output refers to biogas, heat, electricity and/or digestate.
Urban Waste	The researcher refers to various waste streams generated in urban areas, but focus is on organic waste because of its large presence in Africa's waste composition.

Limitations

Demographics and Study Areas	The study focused on metropolitan cities in Africa which are experiencing rapid urbanisation, population growth, waste generation and a demand for more affordable, accessible and clean energy. Three local metropolitan authorities were selected (City of Johannesburg Metropolitan Municipality, Accra Metropolitan Assembly and Addis Ababa City Government); each contextually different from the other and representing a geographical region. Findings are used for comparison and are not representative of other countries in the region.
Target Participants	Primary target Participants were decision-makers in local metropolitan authorities, namely in Urban Planning, Electricity and Waste Management Departments. Secondary target Participants were industry associations either key-decision makers or managerial position.
Selected Technology	The study discusses waste-to-energy technologies, and anaerobic digestion was selected as the technology of choice. It is proven technology suitable for organic waste feedstock, scalable and has extensive technical literature.
Data Collection	Some participants' availability in terms of date and time were affected by other activities within the organisations as well as global restrictions induced by the corona virus pandemic. Digital video conferencing platforms experienced technical glitches, thus affecting one recording in particular. The researcher took hand-written notes during the interview. Some participants were not able to answer all questions because not all applied to their roles, responsibilities, past experiences or current and future mandate.
Lack of recent and complete data	One of the biggest limitations experienced throughout the study was the lack of consolidated quantitative data about WtE (anaerobic digestion) projects in metro-municipalities. The most recent and available data was said to be held by non-governmental organisations who were responsible for funding WtE projects – whether operational or not, or by private companies. The researcher relied on industry reports, some data attainable from industry associations and peer-reviewed journals. Lastly, the researcher's financial, time and data resources limited a greater sample selection.

5.5 Recommendations for Future Research

This study was underpinned by principles of circularity. Circular economy principles were evident in urban metabolism, urban energy planning and anaerobic digestion. Chapter two provided a summary of research gaps identified. Incorporating the findings and recommendations proposed to decision-makers in metro-municipalities, the researcher recommends the following for future public and private multi-disciplinary research:

1. More researchers to investigate CE and its current or future implications in African cities,
2. Explore circular business models for energy recovery,
3. Experiment with digital innovations to collect demographic data and build a database of urban waste and energy flows at a city level,
4. Conceptualise the need and impact of Municipal Think Thanks for collaborative project development and data knowledge sharing.
5. Investigate further use of CEV as part of AD technology design and selection.

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7.APPENDICES

Appendix A: Ethical Clearance

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

Research Office

HUMAN RESEARCH ETHICS COMMITTEE (NON-MEDICAL)
R14/49 Mutezo

CLEARANCE CERTIFICATE	**PROTOCOL NUMBER: H19/09/38**
PROJECT TITLE	An integrated approach to addressing waste management and clean energy provision in rapidly urbanising African cities - A case for waste-to-energy initiatives
INVESTIGATOR(S)	Ms G Mutezo
SCHOOL/DEPARTMENT	Chemical and Matallurgical Engineering/
DATE CONSIDERED	13 September 2019
DECISION OF THE COMMITTEE	Approved Permission letters are required before data collection can commence
EXPIRY DATE	09 October 2022

DATE 10 October 2019 **CHAIRPERSON** J. Knight
(Professor J Knight)

cc: Supervisor : Prof J Mulopo

DECLARATION OF INVESTIGATOR(S)

To be completed in duplicate and **ONE COPY** returned to the Secretary at Room 10004, 10th Floor, Senate House, University. Unreported changes to the application may invalidate the clearance given by the HREC (Non-Medical)

I/We fully understand the conditions under which I am/we are authorized to carry out the abovementioned research and I/we guarantee to ensure compliance with these conditions. Should any departure to be contemplated from the research procedure as approved I/we undertake to resubmit the protocol to the Committee. **I agree to completion of a yearly progress report.**

_____ **Signature**

_____/_____/_____ **Date**

PLEASE QUOTE THE PROTOCOL NUMBER ON ALL ENQUIRIES

Appendix B: Letter of Permission

UNIVERSITY OF THE
WITWATERSRAND,
JOHANNESBURG

LETTER OF PERMISSION

School of Chemical and Metallurgical Engineering
Faculty of Engineering and Built Environment
1 Jorissen Ave
Braamfontein
Johannesburg
October 2019

Dear Sir/Ma'am,

PERMISSION TO PURSUE RESEARCH AND INFORMATION GATHERING.

In reference to the above, Gamuchirai Mutezo is registered as a post-graduate student (Doctor of Philosophy) at the School of Chemical and Metallurgical Engineering, Faculty of Engineering and Built Environment, University of the Witwatersrand.

Name:	Gamuchirai Mutezo
Programme:	Doctor of Philosophy
Email:	1973683@students.wits.ac.za
Contact:	+27 76 574 0796

Gamuchirai Mutezo is conducting research on 'An Integrated Approach to addressing Waste Management and Clean Energy Provision in Rapidly Urbanising African Cities – A case for Waste-to-energy initiatives' under the supervision of Professor Jean Mulopo from the School of Chemical and Metallurgical Engineering.

She is in the process of data collection. The Faculty of Engineering and Built Environment believes that the knowledge, expertise and data that your organisation hold would be suitable in completing the research. Thus, we would appreciate if you could assist her to conduct the research at your premises and avail information she may need.

The research findings and results can be made available to your organisation upon request to the Faculty. All information obtained pertaining to the research will be treated with strict confidentiality, kept anonymous and be used for academic purposes only. Should you require additional information, you are welcome to contact me on the following: jean.mulopo2@wits.ac.za and +27 11 717 7005.

Sincerely yours,

.....

Professor Jean Mulopo
Supervisor

Appendix C: Participant Information Sheet

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

PARTICIPANT INFORMATION SHEET

School of Chemical and Metallurgical Engineering
Faculty of Engineering and Built Environment
1 Jorissen Ave
Braamfontein
Johannesburg
October 2019

Dear Sir / Madam,

INTERVIEW PARTICIPATION LETTER

My name is Gamuchirai Mutezo. I am a PhD student in the School of Chemical and Metallurgical Engineering, Faculty of Engineering and Built Environment, at the University of the Witwatersrand in Johannesburg. Professor Jean Mulopo – Associate Professor in the same school – is supervising the study.

The research is titled 'An Integrated Approach to addressing Waste Management and Clean Energy Provision in Rapidly Urbanising African Cities – A case for Waste-to-energy initiatives'. It aims to investigate whether anaerobic digestion technologies can be integrated into urban areas as means of decentralising access to energy, particularly in metropolitan municipalities.

I would like to invite you to participate in an interview. This activity will involve probing for qualitative and quantitative data, using a set of semi-structured questions. You were selected based on your experience and decision-making capabilities within the disciplines of urban planning, waste management and renewable energy (biogas). The interview will take between 60 and 90 minutes at your workplace/project site or a mutually agreed venue. With your permission, I would also like to record the interview using a digital device, hand-written notes and possibly interview software.

You will not receive any direct benefits from participating in this research, and there are no disadvantages or penalties for not participating. You may withdraw at any time or not answer any question if you do not want to. The interview will be completely confidential and to a small degree, anonymous, as I will not be asking for your name or any identifying information, and the information you give to me will be held securely and not disclosed to anyone else. I will be using a pseudonym (false name) to represent your participation in my final research report. If you experience any distress or discomfort at any point in this process, we will stop the interview or resume another time.

If you have any questions during or afterwards about this research, feel free to contact me on the details listed below. This study will be written up as a research report which will be available online through the university library website. If you wish to receive a summary of this report, I will be happy to send it to you once it has been examined. If you have any concerns or complaints regarding the ethical procedures of this study, you are welcome to contact the University Human Research Ethics Committee (Non-Medical), telephone +27(0) 11 717 1408, email Shaun.Schoeman@wits.ac.za. Should you wish to participate, please find attached the Consent Form and Interview Questions Guide, kindly complete and revert by October 2019. Interviews are scheduled from October 2019 to January 2020.

Yours sincerely,

Gamuchirai Mutezo (Ms)

Gamuchirai Mutezo, 1973683@students.wits.ac.za , +27 76 574 0796
Professor Jean Mulopo, Jean.mulopo2@wits.ac.za , +27 11 717 7005

Appendix D: Consent Form



CONSENT FORM

Title of project: An Integrated Approach to addressing Waste Management and Clean Energy Provision in Rapidly Urbanising African Cities – A case for Waste-to-energy Initiatives

Name of researcher: Gamuchirai Mulezo

I, _____ agree to participate in this research project. The research has been explained to me and I understand what my participation will involve.

Please circle the relevant options below:

I agree that my participation will remain anonymous	YES	NO
I agree that the researcher may use anonymous quotes in his / her research report	YES	NO
I agree that the interview may be audio recorded	YES	NO
I agree that the information I provide may be used anonymously by other researchers following this project	YES	NO

_____ (signature)

_____ (name of participant)

_____ (date)

Appendix E: Interview Questions – Urban Planning Participants

RESEARCH INSTRUMENT: INTERVIEW QUESTIONS

Dear Participant,

Thank you for availing time to participate in this interview. It comprises of semi-structured questions spanning across three disciplines: *Urban Planning*, Waste Management and Renewable Energy/Electricity.

Urban

1. Could you please tell me more about your roles and responsibilities?
2. In your line of work, what are some of the challenges and opportunities you experience daily?
3. In the city's current urban morphology and spatial planning, could you please share your experiences of:
   - 3.1. Industries or sectors shaping the current and future morphology
   - 3.2. Current approach to spatial planning
4. What are the main factors influencing urban morphology and spatial planning? E.g. socially, environmentally, economically, etc
5. Are familiar with the policies and regulations guiding urban planning? If possible, please share examples of how they are being used.
6. As part of your daily planning process and deliverables, do you work with other departments within/at the municipality and other organisations?

Waste & Energy

1. What is your opinion on the involvement of urban planners in (1) waste management and (2) renewable energy planning at municipal level?
2. From an urban planner's perspective, can you describe the challenges and opportunities presented by waste management and renewable energy
3. Which sources of energy are you familiar with?
4. In your opinion, are there urban characteristics that generally affect energy demand in urban areas? If so, how would they affect energy demand?
5. Please share your understanding of the following concepts. Feel free to skip those which you are not comfortable with.
   - Anaerobic Digestion
   - Biogas
   - Circular Economy
   - Energy Poverty
   - Decentralised Energy
   - Urban Energy Planning
   - Waste-to-Energy
6. Are there any projects you are currently involved in relating to electricity or energy generation and access within the city?
7. How do you think access to energy can be improved?
8. As a waste management practitioner, what do you think about integrating and decentralising renewable energy in urban areas, inclusive of anaerobic digestion technology?
   - 8.1. How would it look like?
   - 8.2. Engineering design specifications to consider.
   - 8.3. Urban characteristics to consider.
   - 8.4. Waste characteristics to consider.
9. In your opinion, which departments within the municipality or beyond should be involved and how?
10. Which parts of the city require access to energy the most? E.g. peri-urban, urban, rural, sub-urban
11. Coming back to the role of urban planners, where can they play a role together with energy practitioners, waste management practitioners and the likes? (aligned to question 8 & 9).
12. What would need to change within the profession for urban planners to be more involved in energy planning?
13. Last question, what do you think urban energy will look like for African cities in the next 10 years?

**Please feel free to share additional comments/input.*

Appendix F: Interview Questions – Waste Management Participants

RESEARCH INSTRUMENT: INTERVIEW QUESTIONS

Dear Participant,

Thank you for availing time to participate in this interview. It comprises of semi-structured questions spanning across three disciplines: Urban planning, *Waste Management* and Renewable Energy/Electricity.

Waste Management

1. Could you please tell me more about your roles and responsibilities?
2. In your line of work, what are some of the challenges and opportunities you experience daily?
3. In the city's current waste profile, could you please share your experiences of:
   - 3.1. Industries or sectors generating the most waste
   - 3.2. The most prevalent type of waste generated
   - 3.3. Current waste management methods
4. What are the main factors influencing waste generation and management? E.g. socially, environmentally, economically, etc
5. Are you familiar with the policies and regulations guiding waste management in your city? If possible, please share examples of how they are being used.
6. As part of your daily planning process and deliverables, do you work with other departments within/at the municipality and other organisations?

Urban & Renewable Energy & Electricity

1. What is your opinion on the involvement of waste management practitioners in (1) urban planning and (2) renewable energy at municipal level?
2. From a waste management practitioner's perspective, can you describe the challenges and opportunities presented by urban planning and renewable energy?
3. Please share your understanding of the following concepts. Feel free to skip those which you are not comfortable with.
   - Anaerobic Digestion
   - Biogas
   - Circular Economy
   - Energy Poverty
   - Decentralised Energy
   - Urban Energy Planning
   - Waste-to-Energy
4. Please share your general opinion about waste-to-energy as a technology.
5. Literature shows waste-to-energy as a waste management method in the waste hierarchy. In your opinion, is it possible to consider waste-to-energy, particularly anaerobic digestion, as an approach to decentralise or improve access to energy in the city specifically?
6. Are there any projects you are currently involved in relating to waste-to-energy in the city, specifically anaerobic digestion?
7. How do you think access to energy can be improved?
8. As a waste management practitioner, what do you think about integrating and decentralising renewable energy in urban areas, inclusive of anaerobic digestion technology?
   - 8.1. How would it look like?
   - 8.2. Engineering design specifications to consider.
   - 8.3. Urban characteristics to consider.
   - 8.4. Waste characteristics to consider.
9. In your opinion, which departments within the municipality or beyond should be involved and how?
10. Which parts of the city require access to energy the most? E.g. peri-urban, urban, rural, sub-urban
11. Coming back to the role of waste management practitioners, where can they play a role together with energy practitioners, urban planners and the likes? (aligned to question 8 & 9).
12. What would need to change within the profession for waste management practitioners to be more involved in energy planning?
13. Last question, what do you think urban energy will look like for African cities in the next 10 years?

**Please feel free to share additional comments/input.*

Appendix G: Interview Questions – Renewable Energy Participants

RESEARCH INSTRUMENT: INTERVIEW QUESTIONS

Dear Participant,

Thank you for availing time to participate in this interview. It comprises of semi-structured questions spanning across three disciplines: Urban planning, Waste Management and *Renewable Energy/Electricity*.

Renewable Energy/ Electricity

1. Could you please tell me more about your roles and responsibilities?
2. In your line of work, what are some of the challenges and opportunities you experience daily?
3. In the city's current energy profile, could you please share your experiences of:
   - 3.1. Industries or sectors demanding the most energy
   - 3.2. Current generation sources meeting the demand
   - 3.3. Current share of renewable energy versus fossil fuels
   - 3.4. Current or future role and impact renewable energy has made/is making?
4. What are the main factors influencing energy generation and access (demand and supply) in the city? E.g. socially, environmentally, economically, etc
5. Are you familiar with the policies and regulations guiding generation and energy access in your city? If possible, please share examples of how they are being used.
6. As part of your daily planning process and deliverables, do you work with other departments within/at the municipality and other organisations?

Urban Planning & Waste Management

1. What is your opinion on the involvement of energy practitioners in (1) urban planning and (2) waste management at municipal level?
2. From an energy practitioner's perspective, can you describe the challenges and opportunities presented by urban planning and waste management?
3. Please share your understanding of the following concepts. Feel free to skip those which you are not comfortable with.
   - Anaerobic Digestion
   - Biogas
   - Circular Economy
   - Energy Poverty
   - Decentralised Energy
   - Urban Energy Planning
   - Waste-to-Energy
4. Please share your general opinion about waste-to-energy as a technology.
5. Literature shows waste-to-energy as a waste management method in the waste hierarchy. In your opinion, is it possible to consider waste-to-energy, particularly anaerobic digestion, as an approach to decentralise or improve access to energy in the city specifically?
6. Are there any projects you are currently involved in relating to waste-to-energy in the city, specifically anaerobic digestion?
7. How do you think access to energy can be improved?
8. As an energy practitioner, what do you think about integrating and decentralising renewable energy in urban areas, inclusive of anaerobic digestion technology?
   - 8.1. How would it look like?
   - 8.2. Engineering design specifications to consider.
   - 8.3. Urban characteristics to consider.
   - 8.4. Waste related characteristics to consider.
9. In your opinion, which departments within the municipality or beyond should be involved and how?
10. Which parts of the city require access to energy the most? E.g. peri-urban, urban, rural, sub-urban
11. Coming back to the role of energy practitioners, where can they play a role together with urban planners, waste management practitioners and the likes? (aligned to question 8).
12. What would need to change within the profession for energy practitioners to be more involved in energy planning?
13. Last question, what do you think urban energy will look like for African cities in the next 10 years?

**Please feel free to share additional comments/input.*

Appendix H: Researcher's Collation of Operational AD Projects In Africa

Table 7.1: Summary of AD Projects across Africa

Country	Location	WtE Tech	Feedstock	Size (MW)	Energy	Owner Model
Ethiopia	Addis Ababa	Incineration	MSW	25	Electricity	National Gov
Ghana	Accra	AD	Faecal and Organic	<1	Electric	
	Kumasi	AD	Abattoir	0	Electric & Heat	International Donor
	Kumasi	AD	Timber	5	Electric	International Donor
	Adeiso	AD	Fruit waste	96 kWe		International Private Enterprise
	Ashaiman	AD	Market, toilet, abattoir	100 kWe		International Social Enterprise
South Africa	Johannesburg	AD	Animal Manure	25MW		
		Landfill gas to electricity	MSW	7MW		
	Mandini	AD	Napier Grass	18 kWe		Local Private Enterprise
	PMBurg	AD	Horticulture Waste			
Senegal	Dakar	AD	Abbatoir	100 kWe		Government Agency
Nigeria	Ogun State	AD	Poultry manure	5,5 kWe		Local Social Enterprise
Uganda	Kampala	AD	Abattoir	30 kWe		Academic Institution

Country	Location	WtE Tech	Feedstock	Size (MW)	Energy	Owner Model
Kenya	Kericho	AD	Spent tea	160 kWe		International Private Enterprise
	Naivasha	AD	Crop waste	2,300 kWe		International Private Enterprise
	Murang'a	AD	Avocado skin & stone	445 kWe		International Private Enterprise
	Kilifi	AD	Mango & cattle manure	150 kWe		International Private Enterprise