THE GLOBAL LPG PARTNERSHIP

BioLPG Production at Scale in Sub-Saharan Africa: key elements needed for its development and efficient use as a clean cooking fuel

Final Report

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MECS is a seven-year programme funded by UKaid (FCDO) which aims to accelerate the transition in cooking away from biomass to modern energy. By integrating modern energy cooking services into energy planning, MECS hopes to leverage investment in clean electricity access, both grid and off-grid, to address the clean cooking challenge. Modern energy cooking is tier 5 clean cooking, and therefore MECS also supports new innovations in other relevant cooking fuels such as biogas, LPG (bio) and ethanol, though the evidence points to the viability, cost effectiveness, and user satisfaction that energy efficient electric cooking devices provide. The intended outcome is a market-ready range of innovations (technology and business models) which lead to improved choices of affordable, reliable and sustainable modern energy cooking services for consumers. We seek to have the MECS principles adopted in the SDG 7 global tracking framework, including integrating access (7.1), renewables (7.2) and energy efficiency (7.3) and promote an informed integrated approach. For more information, visit www.mecs.org.uk

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Tables and Figures

Glossary

AD	Anaerobic Digestion
BCRM	Branded Cylinder Recirculation Model
Biogas	The mixture of gases produced by the breakdown of organic matter in the absence of oxygen, primarily methane (CH4) & carbon dioxide (CO2)
BioLPG	Bio-derived Liquefied Petroleum Gas
BLPGWG	BioLPG Working Group
CNG	Compressed Natural Gas
CT	Transfer Centres
DALYs	Disability Adjusted Life Years
DME	Dimethyl Ether
EPRA	Energy and Petroleum Regulatory Authority (Kenya)
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GLPGP	The Global LPG Partnership
GMP	Global Methane Pledge
GOC	Government of Cameroon
HH	Households
HYSACAM	Hygiene and Sanitation Company of Cameroon
KG	Kilogram
KM	Kilometre
LCA	Life Cycle Assessment
LPG	Fossil-derived Liquefied Petroleum Gas
MINDDEVEL	Ministry of Decentralization and Local Development (Cameroon)
MINEE	Ministry of Water Resources and Energy (Cameroon)
MINEPDED	Ministry of Environment, Protection Nature & Sustainable Development (Cameroon)
MINFI	Ministry of Finance (Cameroon)
MINMAP	Ministry of Public Contracts (Cameroon)
MINMIDT	Ministry of Mines, Industry and Technological Development (Cameroon)
Mio t	Million tonnes
MMECD	Methodology for Metered and Measured Energy Cooking Devices
MRF	Material Recovery Facility
MSW	Municipal Solid Waste
MT	Metric Tonne

NCC	Nairobi City County
NCFC	National Climate Finance Committee
NDC	Nationally Defined Contribution
NDS	National Development Strategy
NEMA	National Environment Management Authority
OFMSW	Organic Fraction of Municipal Solid Waste
RDF	Refuse Derived Fuel
REREC	Rural Electrification and Renewable Energy Corporation (Kenya)
SCDP	Cameroon Petroleum Depot Company
SDG	Sustainable Development Goals
SRF	Solid Recovered Fuel
SSA	Sub-Saharan Africa
TBD	To be determined
tCO_2eq	Tonnes of CO_2 equivalent, a measure of greenhouse gases
WSHW	Waste similar to household waste

1 Introduction

The confluence of Global South development needs, inadequate progress on Sustainable Development Goals (SDGs) and the rapidly evolving "just transition" debate between Global North and Global South has created an urgent need to prioritize objectives which can increase collaboration among North and South and can stimulate consequent mobilization of resources.

A key focus has been on SDG 7 (energy access). **There is relentless pressure on the Global South to achieve decarbonization of energy production while satisfying the energy consumption needs created by the necessary increase of per capita energy consumption, especially for transitioning households to clean cooking.**

The quest for domestic renewable sources of energy is a key focus of the Global South and its international partners. **Recognition of the imperative to realize the latent energy potential in Global South waste generation is now front and centre**. However, realization of that aspiration is in its very early days. Creation of the right analytical frameworks to plan and act is essential so progress can be realized.

A meaningful first step would be to develop a methodology for assessing low-hanging fruit within the universe of waste-to-energy possibilities. **One particularly attractive area of inquiry is a focus on waste and its use as feedstock for industrial scale production of biogas, which can be used directly or transformed into other energy carriers**.

An exciting new possibility is the reforming of biogas into energy dense, easily transported bio-derived Liquefied Petroleum Gas (bioLPG) for clean cooking. The prospect of producing bioLPG (also called renewable LPG or rLPG) from renewable feedstocks such as wastes offers a prospect of delivering high impact economic, environmental and social benefits. **BioLPG is, however, a nascent technology (and sector) which requires (1) nourishment from innovation policy, (2) coordination with other infrastructure policy areas such as waste management, and (3) inclusion in Global North / Global South development programs.**

One important reason for the Global North to provide substantial support for the introduction of bioLPG in the Global South is the "Just Transition". **The Global South aspires to realize the energy potential of its substantial and growing quantities of waste, just as is done by the Global North.** The governments of the Global North, particularly the EU and the US, have been providing, and continue to provide, substantial public monies as subsidies and preferential fiscal policies to support development of their emerging biofuel technologies, companies and infrastructure.

It would be well within the scope of partnership discussions for the Global South to ask the Global North for support of a groundbreaking First-Of-A-Kind (FOAK) bioLPG production project. Such a project would (1) create the learnings necessary to evolve enabling environment policies, (2) develop process cost reductions, (3) create deeper understanding of how to achieve economies of scale so that future projects could attract not only public sector capital but also private sector capital, and (4) advance the development of a potentially impactful contributor to the decarbonization of domestic energy supply.

The Study's main objectives are

(1) to create reader understanding of the ecosystem of issues that must be considered and for which answers and data must be found, in relation to biogas and then for consequent production of bioLPG,

(2) to propose an efficient methodology to proceed logically through stages of inquiry or to reach a determination that further inquiry is not justified

(3) to provide a Techno-Economic Analysis ("TEA") that will stimulate interest in supporting further, detailed assessment of FOAK project development by an African country

Effective visual presentation of ideas and data will be used to increase the effectiveness of the Study presentation.

The case studies of Kenya, Cameroon and Rwanda are summarized in the Study's main text, with appendices providing more detail to specialized interests. The case studies illustrate the presence of a substantial portion of the data needed by the methodology, but also indicate the existence of gaps that would need to be filled for more detailed assessments to be made.

The Kenya case study data, complemented by stated key assumptions, is sufficient to develop and present a TEA and financing plan for a hypothetical project. The key assumptions define domestic decisions and development partner decisions that would create the necessary enabling factors for a FOAK project to be financed, constructed and operated successfully.

The Study is designed to be of interest to readers whose backgrounds and professional responsibilities may vary considerably.

2 Overview

The International Energy Agency (IEA) and others have highlighted the huge potential for the biogas (and related biomethane) that could be produced from organic wastes (IEA, 2020). The world could benefit from using, to the greatest feasible extent, the energy content in municipal solid waste (MSW) and agricultural residues, especially in Africa.

Household and village level African biogas production potential has been studied, but industrial scale production, especially in cities, has not been addressed. There is insufficient, detailed ground-truthing as to what biogas opportunities exist, precisely and where, as well as how and at what cost and schedule. Furthermore, there is a need for exploration of the highest and best use of industrial scale production of biogas.

Use of biogas has been proposed for meeting the urgent need for clean cooking fuel, but scant attention has been given to the possibly greater utility of transforming biogas into other energy carriers, such as renewably-sourced LPG (bioLPG), which is an energy–dense liquid form of fuel in normal handling, is easily transported, stored and used, and is identical chemically to the fossil-derived LPG widely desired by Governments and households for clean cooking.

There is no standardized, efficient, adequate methodology (1) to assess industrial scale biogas production potential at a specific site or in a specific region and (2) to assess economic feasibility of utilizing biogas.

A standardized project appraisal methodology would enable multiple parties at interest (potential project sponsors, government authorities, capital markets and civil society stakeholders) to conduct discussions and negotiations with the adequate body of mutually accepted, credibly derived information needed to reach agreements that result in projects.

This Study focuses in its first section on how to assess industrial scale biogas potential in, or adjacent to, cities, because (1) cities generate large amounts of organic waste in a relatively concentrated catchment area (2) the assessment of urban biogas production potential lends itself to a standardized analytical approach, and (3) urban MSW generation is a significant source of biogas feedstock in an urbanizing Africa.

The Study will not consider agricultural residue biogas feasibility assessment, as that would require complex location screening studies (due to the great variation in aggregation challenges and economics in rural areas) requiring data-gathering for many location-specific variables, which render the delivery of a useful general feasibility assessment framework beyond the scope of study funding presently being provided.

As part of assessing biogas feasibility, a good use of the biogas production must be identified, because biogas "all dressed up with no place to go" is not useful. The Study therefore in its second section uses the emerging technology of Cool LPG (a process for producing bioLPG) as a use case for linking to industrial scale production of biogas.

Though the Study uses a particular selection of countries in Sub-Saharan Africa (SSA) as the focus for its fact-gathering, the methodology proposed by this Study is designed to define the essential questions which should be posed and answered in all geographies, while also indicating how questions and their answers may have to adjust to local conditions.

2.1 Focus on urban MSW, production of biogas and use in producing bioLPG

Biogas is considered an important element of the global and African green transition and Net Zero 2050 development, as the IEA has emphasized in various of its recent reports and recommendations (IEA, 2020) (IEA, 2022). Unexploited urban and peri-urban MSW exists in abundance, as do agricultural residues. The production and use of MSW-based and agricultural residue-based biogas is also an important circular economy practice which can reduce net methane, as part of commitment to the Global Methane Pledge (GMP) Food and Agriculture, and Waste pathways (US DoS, 2022), and CO_2 emissions of human activity.

The latent energy of wastes and residues should be developed where feasible, following the waste management hierarchy (reduce, re-use, recycle, recover). Waste energy exploitation delivers a plethora of co-benefits, including energy import substitution, decarbonization of the overall energy supply and justification of modern waste handling investments and their related contribution to improvements in health and environment which have large, long-term value. As an example of co-benefit value, the World Bank (2022) estimates the cost of Household Air Pollution at $1.67 trillion per year, equivalent to 1.3% of global GDP; much of this pollution comes from use of polluting cooking fuels, for which biogas or its derivatives are clean substitutes.

The potential of MSW-to-biogas-to-bioLPG projects should therefore be a subject of serious inquiry.

This study focuses on urban and peri-urban MSW, as assessments of MSW for biogas potential in those settings are relatively homogeneous in their study and data requirements.

Urban/peri-urban MSW usage for large-scale biogas and its possible linking to bioLPG production have several positive characteristics which make it a priority for assessment: (1) large feedstock availability within a focused area, (2) cash economy households who already spend cash on cooking fuels, and (3) administrative and service sector potential to implement and operate.

2.2 Why bioLPG is a logical complement to biogas development

BioLPG would constitute a direct, “drop-in”, chemically identical supplement to, and eventual replacement of, fossil LPG with expected potential to pass along the benefits of the lower aggregate emissions footprint projected from exploitation of biogas production and use (IEA, 2022; Paolini et al, 2018). BioLPG would immediately fit in to existing local LPG supply chains and cash economy markets, if the necessary enabling conditions exist (policies, regulations, technical and safety standards, and market structures).

A particularly interesting aspect of bioLPG production is its potential to transform biogas into a logistically attractive, dense energy carrier, in contrast to the challenging distribution economics of gaseous biogas, whether used in its raw state or, after upgrading into methane (natural gas), distributed via pipeline or in tanks as compressed natural gas (CNG). There are also obvious advantages of import substitution and reduction of import supply chain risk.

The predominant focus of SSA biogas development to date has been on household level production as part of using small-holder farm waste, with a further view to addressing the climate-smart agricultural opportunity and circularity presented by managing waste and producing biofertilizer (Nzila et al., 2012; Robinson et al., 2023). To date, in SSA there have only been limited efforts to develop industrial scale, commercial production of biogas, especially via industrial scale urban/peri-urban MSW projects.

Meanwhile, further ground-truthing is needed to determine the practicality of sourcing organic feedstocks adequate to enable industrial scale biogas production that could be linked as feed-gas to a Cool LPG plant.

2.3 Key Global South needs addressed by LPG; hence a role for bioLPG

In 2022, the need to address low carbon energy needs, minimizing exacerbation of climate change and its impacts, whilst supporting development, has never been more apparent. The urgency of achieving those goals is compounded by heightened concerns about deforestation and related biodiversity loss, stemming from fuel-gathering of biomass. Achieving implementation of low carbon energy technologies will depend on country priorities and the renewable energy resources available in country (e.g. geothermal, wind, solar, hydro, as well as biomass and wastes). Major changes in global fossil fuel movements and pricing created by the disruptions stemming from epochal shifts in geopolitical factors indicate the value of assessing potential for localised supply chains of energy production which can contribute, at large scale, to increased security of supply.

Dependence on primary biomass (wood and charcoal) as fuel for cooking is a major feature of many countries where access to electricity has been low or unaffordable (World Bank, 2022). Emissions resulting from the use of wood and charcoal as cooking fuel have been identified as a major health risk, killing millions of persons (particularly children) every year (World Health Organization (WHO), 2022). Cooking with wood and charcoal is a major contributor to GHG emissions whose atmospheric accumulation has been causing climate change, especially the short-lived climate pollutant (SLCP) black carbon (25% of anthropogenic black carbon is from household cooking and heating (Garland et al, 2017)). From the sourcing perspective, loss of forest land (also resulting in GHG emissions and loss of carbon stock) and biodiversity are further strong incentives to develop and support access to clean(er) cooking options that reduce biosphere damage.

A substantial body of data and research has enabled the WHO to conclude that LPG, although at present mainly a fossil-derived fuel, is a clean, environmentally friendlier cooking fuel alternative to business-as-usual use of wood and charcoal, which have not been deemed clean by the WHO. LPG has also been found to be faster and cheaper to implement than an adequate universal electricity supply (Floess et al, 2023). The possibility that LPG could be produced from renewables (bioLPG) would enhance global willingness to support and develop LPG use. The important IEA report “A Vision for Clean Cooking Access for All” (IEA, 2023), states very clearly (1) the emerging consensus view that LPG must be a major element in the provision of clean cooking, especially in Africa, and (2) that bioLPG is expected to help decarbonize the footprint of LPG use.

The use of biogas to produce bioLPG creates economic and political externalities which government may value, such as (1) reduction of LPG import supply risk, thus contributing to stabilization of the cost and availability of a politically important consumer good (clean, cooking fuel), (2) increasing certainty of cooking fuel in cities and rural areas which have unstable or insufficient electrical supply, and (3) contribution toward Nationally Defined Contributions (NDCs) by reducing emissions.

2.4 Why this study focuses on the Cool LPG process for bioLPG production

Transformation of biogas into bioLPG might be a highly attractive use of biogas potential which exists at substantial scale in the Global South, particularly in SSA.

The initial desk-top feasibility study led by GLPGP (GLPGP, 2020) indicated the potential benefits of local production of bioLPG (both biopropane and biobutane) in Africa, using waste feedstocks available at scale. Major production routes identified in that study were (a) anaerobic digestion of MSW or agricultural residues to produce biogas, followed by reforming to bioLPG using the proprietary Cool LPG process, (b) gasification of solid wastes, followed by reforming the resultant syngas into bioLPG using the Cool LPG process or the Shell-controlled, IH2 process, or (c) hydroconversion of vegetable oils and animal fats using several available processes.

This Study will only consider the Cool LPG process which produces as its main output both propane and butane. There are few other processes in development for reforming biogas into bioLPG as a principal product and they are far from readiness for demonstration plant decisions (Atlantic Consulting, 2023). T

The IH2 process is based on pyrolysis to produce feedgas, it does not use biogas. It also would not offer LPG scalability, as the process outputs are predominantly jet fuel, gasoline and diesel, although feedstock availability for the process might be adequate.

Hydroconversion processes that use vegetable oil and animal fat feedstocks have been excluded from consideration, as the feedstock availability does not meet the needs of large-scale production and the predominant process output would be biodiesel, with LPG as a minor process by-product. In addition, use of vegetable oils for biofuel production raises “food versus fuel” policy concerns.

Gasification of wastes to provide syngas as feed to the Cool LPG process will not be considered for the following reasons:

(1) Gasification technology at large scale is complex to implement, with many differences in output gas composition arising from the multiple, interactive factors of heterogeneity of waste feedstock, choices of feedstock processing methods and choices in gasification technologies. Specification of a gasification route for MSW to provide syngas for a Cool LPG plant would be highly site-specific and is beyond the scope and budget of this Study;

(2) further research is needed to align feedstock / gasification technology choices with the syngas specification for the Cool LPG process.

As of Q3 2023, Cool LPG technology is expected to reach IEA TRL (Technical Readiness Level) 4 to 5 in mid-2024. Announcement of intentions to develop and commission one or more IEA TRL 7 to 8 demonstration plants by Q4 2026 is expected in one or both of the US and the EU in Q4 2023. Technical development progress continues, supported by the collaboration of a steadily increasing number of large companies in Europe and North America (see GLPGP/BioLPG LLC press releases regarding Cool LPG at http://glpgp.org/resources).

Current Cool LPG research results provide a roadmap to achieving acceptable process economics and indicate that the emissions profile is likely to be attractive. The final development steps needed before financial commitment to a demonstration plant are a set of process design decisions, catalyst stability tests and carbon intensity measurements, due to be completed in Q4 2023. Materials (other than Cool LPG catalysts) for Cool LPG plant construction and operation are general industrial chemical plant items and are assumed to be available, therefore procurement issues, cost variations and risks are not treated in this Study.

Proving feasibility for biogas projects linked to bioLPG plants and then securing the required substantial finance for a pilot plant will require location-specific evidence on feedstocks, enabling environments of policy/regulations/technical standards, cooking fuel demand and local drivers/barriers to investment.

The framework presented in this Study describes how to evaluate biogas production potential and then how to achieve bioLPG production using that biogas in a Cool LPG process.

The Study team did not evaluate in detail a defined project, as that additional work and its cost would have (a) been outside of Study scope and budget and (b) would have required substantial interaction with, and policy decisions by, Governmental authorities with jurisdiction over the proposed project and its site.

To satisfy the need for quantitative analysis which could be used to justify further studies, this Study presents a hypothesized Kenya (Nairobi) project TEA by melding reasonable assumptions with hard data derived from Study ground-truthing. The assumptions are based on a balanced use of third party research findings, market data and statements received by the Study team from relevant Government officials.

3 Framework for establishing if a country/region should engage in detailed studies

The physical MSW potential of a prospective location must be mapped in detail to ensure the viability of biogas-based Cool LPG. The following section outlines the framework of data-gathering and analysis necessary to appraise the physical, technological, logistical, economic and environmental sustainability factors necessary to justify and facilitate a biogas project and a linked bioLPG project. This framework highlights the need for investigation into location-specific availability of sufficient quantities of MSW feedstock having acceptable quality and accessibility on a reliable basis.

3.1 Physical MSW potential: outline of supply chain and key parameters

The following section outlines the framework of data-gathering and analysis necessary to appraise the physical, technological, logistical, economic and environmental sustainability factors necessary to justify and facilitate a biogas project and a linked bioLPG project

3.1.1 Current MSW handling arrangements

The physical MSW potential of a prospective location must be mapped in detail to ensure the viability of biogas-based Cool LPG. This framework highlights the need for investigation into location-specific availability of sufficient quantities of MSW feedstock having acceptable quality and accessibility on a reliable basis.

To make biogas production feasible, necessary logistical capabilities must be in place to aggregate the organic fraction of municipal solid waste (OFMSW). OFMSW management depends on institutional capacities, market structures and local waste characteristics (which may vary according to cultural, climatic and socioeconomic differences). Government waste management policies will impact OFMSW sources, collection mechanisms and economics. Whether organic waste intervention policies (e.g., household organic waste collection) are in place or proposed, or whether OFMSW will need to be separated post-collection, is an important economic and structural matter.

It is essential to identify (1) the business models and goals of the public and private companies controlling MSW or OFMSW feedstock and (2) the competing uses of OFMSW, to understand whether establishment and maintenance of a consistent feedstock supply is economically and physically feasible. This will include identifying the objectives of major waste-handling companies, dumpsite owners and future waste management proposals/stakeholders.

Definition of current MSW flows and disposal sites, whether open dumps or engineered landfills, is necessary to determine the likely locations for biogas production. The suitability of potential plant locations relies on the presence of accessible waste collection and aggregation infrastructure, including transfer stations, recycling plants, and landfills. Additionally, factors such as the labour force availability, proximity to feedstock sources, and closeness to customers will also be considered.

3.1.2 Quantity in region; organic fraction; recoverable resource

The proposed scale of bioLPG production implementation used as an example in this study is a plant producing 10,000 tonnes per annum (tpa). Techno-economic analysis, reported in Chen et al (2021), indicates approximately 270,000 tpa of average organic content-containing MSW would be necessary to produce 10,000 tpa of bioLPG. However, appropriately detailed data gathering about the chemical and physical characteristics (quality) of local OFMSW would be needed to produce more fine-grained quantitative and economic analyses. Careful study of MSW sources and identification of potential contaminants must be carried out, along with a contaminant prevention or mitigation plan, to ensure adequate quality and quantity of feed-gas which can be used in the Cool LPG process.

For AD, the organic, digestible fraction must be separated from indigestible materials such as glass, metals, plastics and construction materials. As discussed in Chen et al. (2021) and elsewhere, waste in Global North countries is often separated at source whereas, in Global South countries, waste tends to be dumped in landfill with little separation (Mmereki et al., 2016). Pre-collection separation of MSW is preferable to avoid financially and time intensive isolation of OFMSW. (Material recovery facility (MRF) is the generic term for the processing and separation stage and “dirty” MRF the term for an MRF processing unsorted MSW.)

Separation at source raises both financial and social concerns, as incentives and education may be necessary to ensure that waste is separated correctly and consistently, and that necessary collection infrastructure is available. Analysis of the structural demands and resulting economics of OFMSW separation at source versus sorting at refuse dumpsites/engineered landfills will indicate attractiveness of any given location.

The framework questions that are necessary to appraise the physical capacity for biogas and Cool LPG production are shown in Figure 1. The questions posed guided the case study investigations reported in section 4 of this Study.

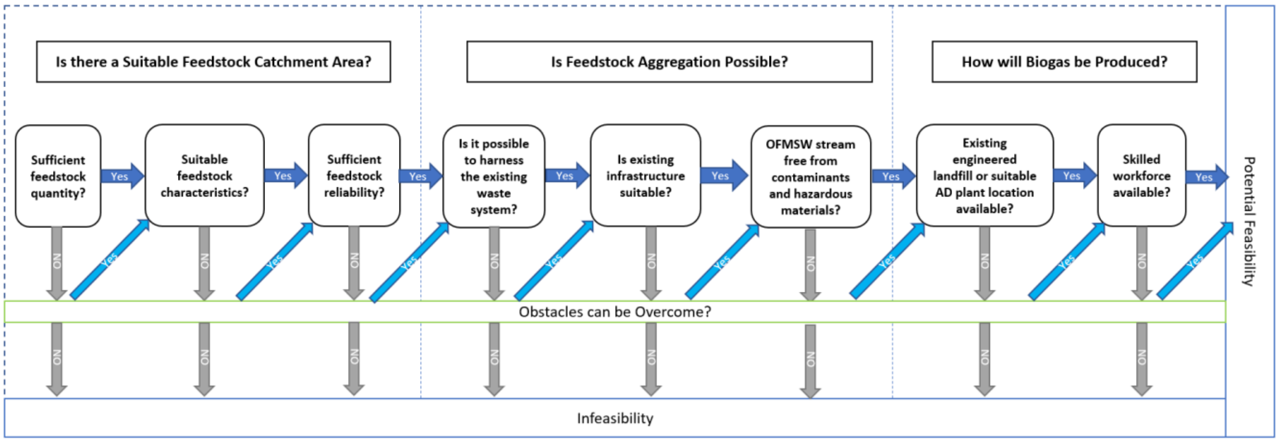


Figure 1 The question flow to investigate physical suitability of a location

3.2 Technical means to convert MSW to energy

The recovery of energy from MSW can be realized through various methods, but as process complexity increases, so do requirements to separate the MSW into its different constituents.

The simplest route to recover energy is by incineration/combustion (mass-burn), with a traditional boiler and generator system to produce electricity.

Pyrolysis (partial thermal degradation) and gasification (thermal degradation to component gases, "syngas") technologies produce gases which can be reformed into various gaseous and liquid energy carriers. However, pyrolysis and gasification require sophisticated management of temperature and pressure conditions, as well as separation and treatment of feedstock and outputs. MSW contaminants and unusable components require investment in separation and disposal. Certain cellulosic MSW components, such as paper, cardboard and wood can also feed 2nd generation biochemical technologies, which, however, are in development and not yet close to being economic (Davis and Bartling, 2022). Intervention at the MSW source to ensure 'clean' feedstock requires design and implementation of modern waste management systems.

The production of biogas has the potential to reduce the environmental impacts of unmanaged MSW, wastewater/sewage and agri-residues. The production and use of biogas from waste and agri-residues reduces GHG emission impact by capturing emissions from otherwise unmanaged waste and residues and by replacing fossil fuels as an energy carrier. Biogas produced via AD also produces a nutrient rich co-product digestate (depending on the nature of the feedstock) which can replace fossil-based fertilizers and is increasingly being considered as valuable water recovery (for irrigation and commerce) in water scarce countries.

Biogas, largely composed of biomethane (CH_4) and carbon dioxide (CO_2) is an energy resource which can be used in all the ways that fossil-derived natural gas can be used – its energy content can be combusted to produce heat and power, used as transport fuel or chemically reformed into other energy products, such as LPG, methanol, dimethyl ether (DME), ethanol and chemical feedstocks such as ethylene, alcohols and various organic acids (Abanades et al, 2022). All these products would be regarded as "green", as they are non-fossil derived.

In the Global North, the development and economic viability of biogas production and use have relied on policy interventions to support commercial operations. The biogas sector in Europe and North America has been stimulated by incentives for landfill gas production, AD biogas production, and biogas use as a renewable energy. For example, in the UK, the development of commercial on-farm and urban AD facilities has been supported by the Renewables Obligation for biogas-electricity (UK Gov RO, 2002); the Renewable Heat Incentive for biogas-heat (UK Gov RHI, 2009; the Renewable Transport Fuels Obligation (UK Gov RTFO, 2007) for the biogas-transport fuel (as biomethane); and the Green Gas Support Scheme (UK GGSS, 2021) for biomethane injection into the natural gas grid.

In the Global South, there is still all to play for. Policies developed and implemented to date have not resulted in industrial scale projects.

3.2.1 Biogas from engineered landfill

Production and harvest of biogas from engineered landfills requires the controlled collection and extraction of landfill gas from the deposited waste, whose organic waste component decomposes in an anaerobic environment. The process involves lining of the waste storage area and installation of gas collection systems and extraction infrastructure. The lead-time on gas production will be several years, as the decomposition process is relatively slow. LCA studies suggest that biogas recovery from landfill is less efficient in terms of energy recovery and GHG emissions compared with AD (e.g. Zarea et al., 2019).

If engineered landfills are already in place or construction of engineered landfills is planned, and if the expected volumes of waste deposition are adequate, those sites may be suitable choices for exploitation of the biogas that is emitted. However, this Study will exclude consideration of biogas from greenfield landfill projects or re-engineered existing landfill sites for the following reasons (1) build-up of adequate biogas production will take years of lead time, and (2) studies have shown that the realization of latent energy in waste is much higher with anaerobic digestion (AD) fed by OFMSW to produce biogas.

3.2.2 Biogas from anaerobic digestion

In the near term, production of biogas via the AD route in countries that do not yet have large-scale, engineered landfills, may be faster and require less investment to be mobilized.

Managed production of biogas in engineered AD systems is now a relatively mature technology. It is a solution that provides both waste management and renewable energy generation. The overall system comprises separation of the OFMSW for AD, with the remaining MSW undergoing further sorting for recovery of other materials and/or disposal of the residual wastes in landfill.

That waste, because the organic fractions have been separated out, will have little biological activity and hence low emissions of GHGs.

The AD technology harnesses the metabolic activity of diverse microorganisms to break down organic matter in the absence of oxygen, resulting in the production of biogas, a mixture primarily composed of methane and carbon dioxide. The process encompasses various stages, including substrate preparation, microbial fermentation, and gas collection, each playing a crucial role in achieving optimal biogas production. For efficient AD, the feedstock must have suitable physical and chemical characteristics.

The precise definition and composition of the OFMSW varies location to location, but it is generally comprised of heterogeneous food waste, yard waste, paper, and other organic materials. Values for key physical and chemical characteristics must be understood to understand the biogas potential of prospective OFMSW flows. Particle size, pH, moisture content and the carbon to nitrogen (C/N) ratio will impact the ease and efficacy of using any stream of biogas production feedstock (Bandini et al. 2022). AD reactor temperatures and moisture levels may need to be controlled depending on the AD technology selected. State-of-the-art biogas plants can carefully regulate internal conditions to maximise efficiency and yield. However, yield is still feedstock dependent and pre-digestion regulation of MSW will be important. For example, Kumar & Samadder (2020) suggest that AD utilising MSW as feedstock will need buffering to prevent acidification, achieved through the addition of alkali reagents or via co-digestion, i.e., mixing another digestible feedstock with the OFMSW with buffering properties, such as cattle manure. Figure 2 illustrates the MSW to biogas system, with key processes, inputs and outputs. For the analysis of LPG production, this system needs to be characterized in terms of the flows of material between each process, which entails estimating the quality of the material (e.g. percentage of organic waste in the input MSW), the process efficiency and yields of each step.

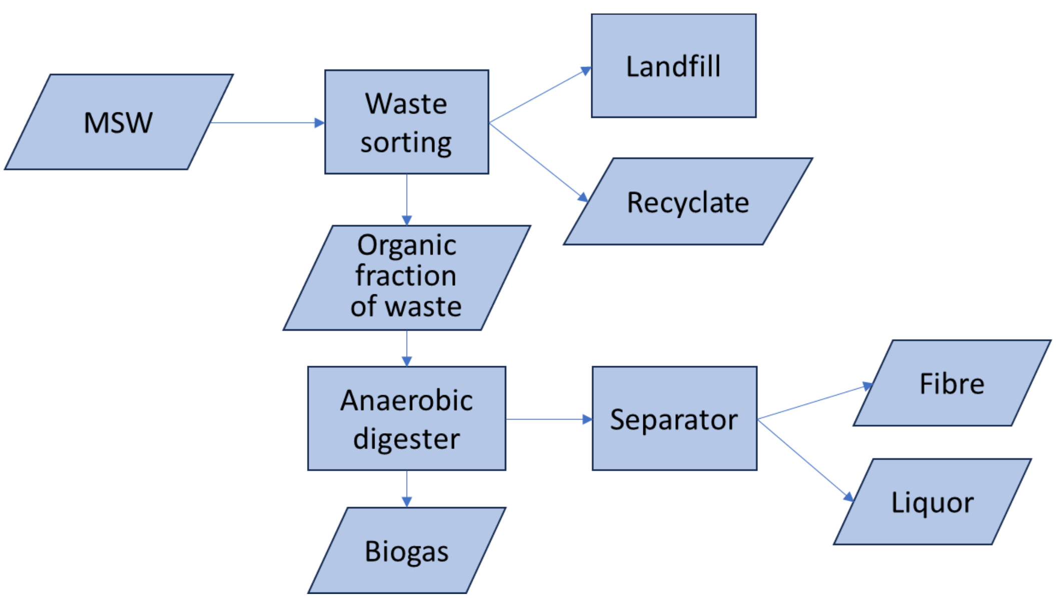


Figure 2 AD system and products

3.2.3 Biogas to bioLPG via the Cool LPG process

The Cool LPG process reforms the two constituents of biogas, bio-derived methane (CH_4) and bio-derived carbon dioxide (CO_2) first into synthesis gas, which is then converted into methanol before upgrading to the mix of propane (C_3H_8) and butane (C_4H_{10}) that comprise LPG. This series of chemical reactions take place in a set of reactors, enhanced via bespoke catalysts. The process diagram is shown in Figure 3.

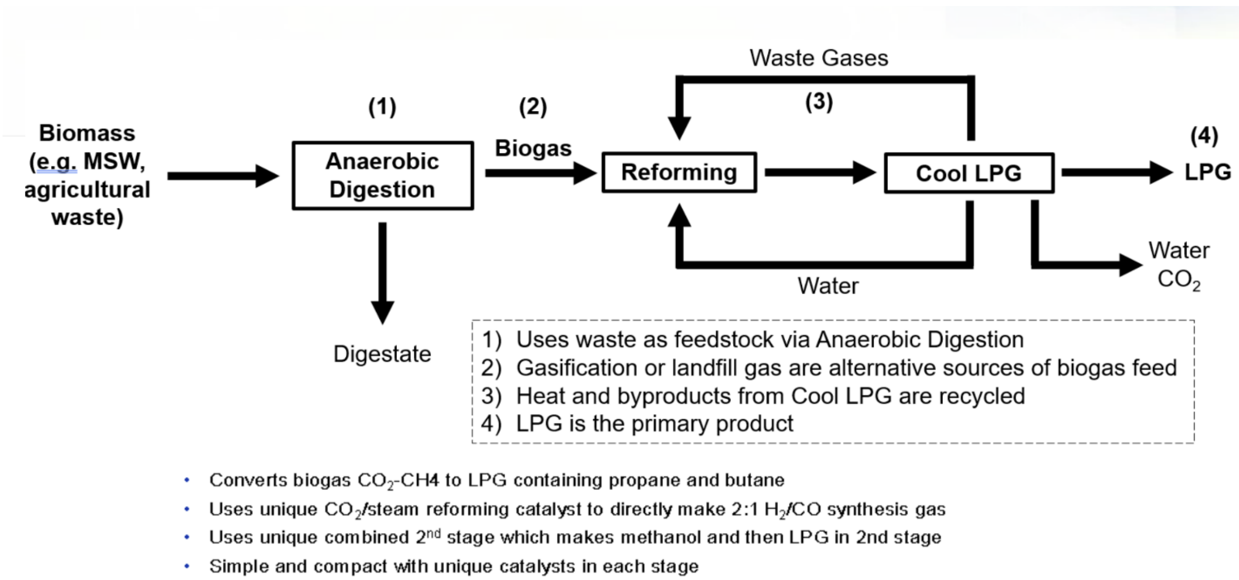


Figure 3 Cool LPG process diagram

It is a self-contained process, able to meet its process energy needs from a portion of the biogas, and recycling some of the byproduct water produced to satisfy the water input needed for the synthesis reactions. As such, the key data required to determine the production potential for bioLPG is the quantity of biogas that will be available, and its proportions of CH_4 and CO_2, which are feedstock and process dependent.

3.2.4 Whether bioLPG could be the highest and best use of MSW latent energy.

This section presents three topics, in order of increasing focus and quantification. (1) A conceptual outline of the key questions that should be addressed by a highest and best use analysis; (2) The methodology of obtaining - and sources for - data that are needed to address the questions; and (3) Quantitative analysis that permits a preliminary judgement to be offered about whether bioLPG could be a preferable use of biogas.

3.2.4.1. General framework for thinking about highest and best use

To make a statement about the highest and best use of waste requires consideration of a sequence of questions, including consideration of informal and undocumented markets.

The first question to answer is whether seeking to recover energy from waste is sensible, including whether resource recovery of any sort is desirable and then whether energy recovery is preferable to material recovery. These are questions well beyond the scope of the current study, and therefore this Study relies on a wealth of existing analysis and policy development, including on the benefits of the circular economy. For the merits of waste to energy, conventional wisdom is reflected in the waste hierarchy, promoting first waste avoidance, then recovery of materials where they are easily accessible and then recovery of energy, with disposal as a last resort (e.g. see the EU Waste Framework Directive

https://environment.ec.europa.eu/topics/waste-and-recycling/waste-framework-directive_en).

The next question is whether anaerobic digestion of the organic fraction of waste is the highest and best use of that feedstock. This is again a large topic, for which Nubi et al (2022) provide a literature review and their own LCA modelling, studying the options for energy recovery from MSW in Nigeria: incineration, AD, gasification and landfill gas. They conclude that AD recovered more energy per tonne of MSW processed and led to the lowest environmental impacts.

A parallel question is whether waste with organic content is available for biogas exploitation. In many countries there are existing markets for certain types of waste produced in certain places. For example, food processor and hospitality sector wastes which are organic and sorted at point of generation are sold to demand for animal feed, not as feedstock for energy production. In contrast, general household waste is unsorted, is only partially organic, and requires processing and separation to collect inorganic components for potential material value and for its organic component to have value as biogas production feedstock. Raw household waste may be cheap to acquire, but requires investment in means to convert it into waste-to energy feedstock.

A final question to answer is what is the best use of biogas? (This assumes that organic waste can be accessed for what in the particular policy and market circumstances would be judged economically viable production of biogas.)

“Best” is not necessarily the most financially profitable. The local definition of “best” may be influenced by public policy priorities, choices and decisions, such as attributed values to the externalities delivered by modern waste handling, improved sanitation and public health, and/or GHG emissions reduction.

The standard buffet of biogas uses are: (1) raw biogas used directly in cooking, heating or lighting; 2) purified biogas distributed in pipelines or in tanks as compressed natural gas, (3) fuel for generation of power, or power and heat, and (4) conversion into a different energy carrier such as methanol or LPG.

What is chosen for implementation depends on a myriad of location-specific and national policy specific factors. Often energy sector investments require enabling decisions about tariffs, buyers of last resort, government guarantees, etc. Financing requires adequate risk mitigation along multiple dimensions, as well as, at the end of the day, a foreseeable stream of positive cash for the project, creditworthiness of the project ecosystem, and reasonable assurances of project technical performance.

The framework outlined in this Section 3 sets forth what must be ground-truthed by a detailed study to answer the questions posed above. Those answers would then yield economic and non-economic inputs which would drive a comprehensive evaluation of the biogas / bioLPG concept that was being studied. The detailed study would be heavily influenced by national and local factors.

3.2.4.2. Best use of biogas energy for cooking

A detailed comparison of all of the possible uses of biogas is beyond the scope of this report. The Study team suggests that the pertinent question to answer is whether MSW, processed into biogas by AD, should be used to generate electricity, or be converted into some other fuel, notably bioLPG. The value of different energy types is dependent on location and national conditions, so this question has no simple answer. However, a specific comparison appropriate for this Study is the amount of cooking that can be delivered by converting biogas to electricity or to bioLPG.

A useful comparison metric is the number of households whose cooking needs can be met by each route, since the delivered energy needed per household will be different in each case.

Preliminary analysis was conducted comparing the number of households whose cooking needs could be served by (a) the electricity that could be generated by use of the feedstock converted by AD, versus (b) the bioLPG produced from the same amount of feedstock. Two AD-to-electricity plants were used for the comparison, a 12.1 MW plant operating in Saudi Arabia (Hadidi and Omer, 2016) and a 4.2 MW plant operating in South Africa (Norfund, undated; Ndlovu et al, undated).

The analysis indicated that the resulting bioLPG would serve a slightly greater number of households for cooking as the resulting electricity, per unit of organic waste input.

Table 1 Comparison of biogas-electricity and biogas-bioLPG plants

	Organic waste input kT/yr	Biogas produced kT/yr	Energy output	HH energy use for cooking	Households served for cooking	HH served per kT biogas feedstock	Assumptions and Sources
Cameroon: AD-bioLPG	185	38	10 kT LPG/yr	0.21 kg LPG/day	133,333	720	System: this report. LPG use in primary cooking HHs: 15kg/capita/yr GLPG (2019), assuming 5 pp/HH
SA Bio2Watt 4.2 MWe AD-electricity	91	?	35,000 MWh electricity/yr	1.5 kWh electricity/day	63,927	701	Biowaste input 200-300 T/day https://www.norfund.no/content/uploads/2020/01/Bio2Watt-case-study.pdf and https://www.cityenergy.org.za/uploads/resource_337.pdf; Cooking energy use from ESMAP (2020), Africa average. LPG= 0.0473 TJ/tonne (IPCC default)
Saudi Arabia 12.1 MW AD-electricity	255	?	91,066 MWh electricity/yr	1.5 kWh electricity/day	166,330	652	Hadidi and Omer, 2016

Additional points in favour of using biomass as feedstock for production of bioLPG include the following: (a) there are many fuel alternatives, both green and fossil, for generating electricity; and (b) there are few feedstock alternatives that can presently be considered for producing economically feasible, green LPG for cooking.

Biogas upgraded to commercial quality methane could also be sold for use as reticulated fuel (that is, gas delivered via piping networks) or as compressed natural gas (CNG). These alternatives have not been widely deployed or planned in SSA countries to date, due to the very high infrastructure costs of piped networks and the high transport and storage costs, and low energy density, of CNG.

It seems appropriate to conclude from the evidence cited above that biogas is a good route to realize energy from waste and that a better use of biogas may be to produce bioLPG which (1) can be dropped into an existing, highly flexible LPG logistics chain and (2) makes more cooking energy available to the household than would be provided if the biogas were converted into electricity.

3.3 Financial performance of MSW-to-biogas-to-bioLPG

The financial performance of a waste-to-energy facility will depend primarily on the capital and operating costs of the constituent parts of the system and then how the necessary investments are financed. This section sets out these two steps in turn.

3.3.1 Techno-Economic Assessment (TEA)

MSW emerged in the 2020 scoping study (GLPGP, 2020) as a key potential feedstock. However, the level of information available on MSW and its management in countries of SSA is generally low, and there is a general lack of country experience on waste management, particularly with waste sorting and treatment. As such, whilst an overall framework was developed for techno-economic appraisal, its use for the 2020 scoping study had to be based largely on secondary information sources and assumptions made based on experience in other regions. The local data collection in this study allows a refinement of the same framework, splitting out some cost items more finely through locally sourced data, ground-truthing some of the assumptions and highlighting issues not identified from the secondary sources.

The framework questions that are necessary to appraise the technology requirements of a proposed waste-handling site and the operating feasibility for biogas and Cool LPG production are shown in Figure 4. This figure does not include the effects of financing structures and costs, or the effects of supportive concessionary finance facilities and grants. Data gathered to answer the framework questions are summarized in Section 4 of this Study.

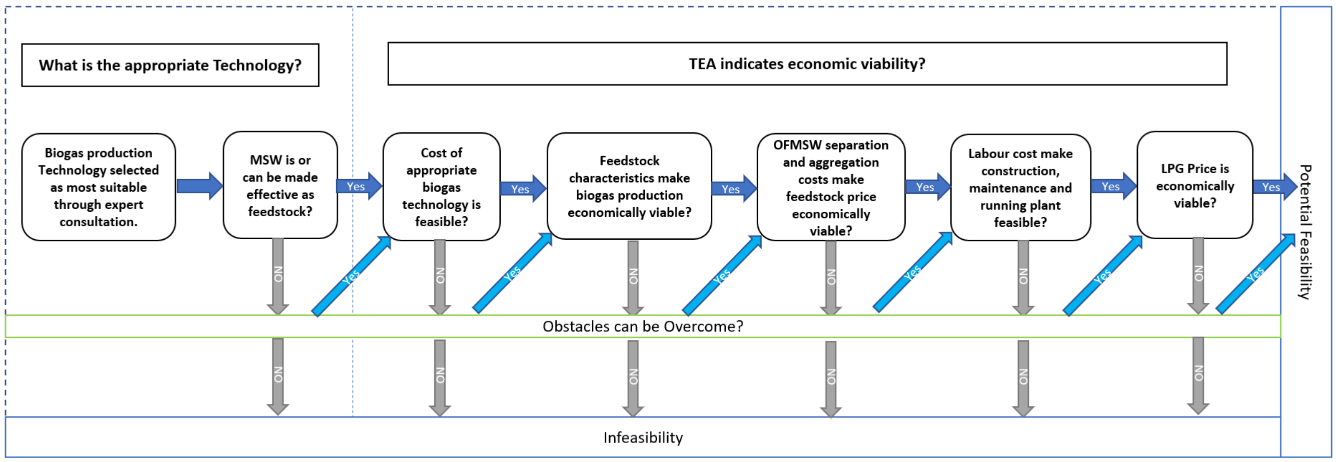


Figure 4 The question flow to investigate technical suitability and economic feasibility

Feedstock: MSW management, feedstock collection

MSW is a changeable mixture of food waste, garden waste, plastics, paper, metals, wood, glass and sometimes construction wastes. Globally, approximately 37 percent of waste is disposed of in some form of a landfill, but just 8 percent of that is disposed of in a sanitary landfill with landfill gas collection. Open dumping accounts for approximately 31 percent of waste disposal, 19 percent is recovered through recycling and composting, and 11 percent is incinerated for final disposal. In low-income countries, 93 percent of waste is dumped, with commercial value recovery through material recycling and energy-from-waste is generally the preserve of high-income countries (Kaza et al, undated). However, there is often an active informal sector comprising waste pickers and merchants. There are strong drivers, economic, environmental and social, to improve waste management practices and increase value recovery in every country, as well as moving waste management more into the formal economy and into the policy thinking of government.

Waste can be collected from households and businesses (or from bins adjacent to them) as mixed waste, or the waste producers can be asked to separate different materials into several categories, such that those materials can be kept separate during collection and transport, facilitating value recovery. Separation at source is becoming the norm in richer countries, underpinning the higher levels of value recovery mentioned above. For the case study countries in this Study, separation at source is a clear government interest, and various initiatives have been pursued, but with limited success (Kabera et al, 2019; Kabera and Nishimwe, 2019; Miezah et al, 2015).

The assumption here is that the majority of waste collected is mixed. For the engineered landfill route, the mixed waste can be deposited without further processing (although formal or informal material recovery may take place to extract valuable fractions), and biogas obtained may require contaminant removal. For AD, sorting is needed to produce an organic waste stream suited to the specific AD technology used (see section 3.3.1.2).

The key element of cost in the waste collection stage is the transport of wastes from where it is generated to where it is processed. It is assumed that MSW is collected from local sites across the city in small-medium sized lorries, which then deliver it to waste transfer stations located adjacent to the city. Bulk waste is then transported inwards, either to a final disposal site or to further processing. The key parameters describing the waste transportation systems are the types of vehicles used (defining cost and other impacts per km) and the distances travelled.

The TEA for a hypothetical project in each case study country is presented in Section 5 below. A key assumption is that the functions of collecting and aggregating MSW and making it available to the project MRF/AD facilities are performed by the government and its contracted agents as a part of public service waste management and therefore are not economic elements that needs to be considered within the project TEA boundary. Government authorities in Cameroon and Kenya have indicated to the Study team that this assumption may be used.

Feedstock: sorting and storage

Mixed collection and transport can be followed by centralized sorting and recycling of appropriate waste fractions, seeking to minimize the residual waste that requires disposal, and to extract value in terms of recycled materials and/or materials going to energy recovery. Metals, glass and construction waste components are incombustible and offer no value for energy recovery; they are thus usually physically separated out (Sipra et al, 2018).

Refuse derived fuel (RDF), Solid Recovered Fuel (SRF) and secondary fuel, are terms used for fuel-type products derived from MSW and which are usually targeted towards combustion (Stapf et al, 2019). To maximize efficiency of use, their preparation may include additional process steps to standardize their composition and form, such as forming into pellets, but essentially these are sorted wastes. Sorting and waste preparation can be undertaken with a mixture of mechanical and manual processes, including refuse bag opening, sorting and shredding into smaller particle sizes.

A generic term for the sorting, processing and recycling stage is a Material Recovery Facility (MRF). Wheeler and Rome (2002) distinguish between a “dirty” MRF that handles unsorted MSW and a ‘clean’ MRF that receives mainly source-separated waste streams. The materials recovered in a dirty MRF will be less clean than those recovered from source separated wastes, largely due to contamination from food waste. MRFs range from low-technology systems mainly using manual hand-picking to high technology facilities with multiple automated stages, which sense and extract individual material types. Pressley et al (2015) developed a process model to represent both clean and dirty MRFs. The cost per tonne input for each MRF type includes costs for the purchase and maintenance of equipment, labour, energy, and the costs associated with land procurement and building construction: land and building costs together make up the largest fraction of the total, ranging from 49% to 62%. Pressley et al (2015)’s estimate of the cost of a “dirty” MRF operation is $23.6/tonne.

A “gate fee” or “tipping fee” represents a payment (usually per tonne) made by the local waste authority to a provider of waste management services (Hogg, 2001). For waste disposal, this would normally represent the fee paid to a landfill site operator to take bulk MSW or residues from other processes. However, gate fees are also used to refer to the fee paid to intermediate service provides in the waste management chain, such as at an MRF or the operator of an energy-from-waste facility.

Hogg (2001) notes that gate fees may be set to cover the costs of treating the waste delivered by the local authority, but it may equally be lower or higher than that, for example, reflecting expectations of other revenue streams. Hence it is difficult to use reported gate fees as a proxy for the cost of a waste management activity. Landfill gate fees are reported for Rwanda, for example, to be approximately $1/tonne but these are estimated to cover only 13% to 23% of the total costs of operating the landfill, with the shortfall covered by the municipality (Rajashekar et al, 2019).

Biogas production

AD plant costs consist of the capital expenditures for the reactors and associated process equipment, plus the fixed and variable operating costs. All of these elements will depend on the specific AD process that is adopted, which will in turn be influenced by the local nature and characteristics of the organic wastes available, their quantities and other local factors. It is possible that such choices will also be influenced by international partner assistance conditions (so-called “tied assistance”).

The fixed operating costs will be dominated by the employment of staff, again influenced by the AD process type. With costs of waste feedstock being considered separately, the variable operating costs are dominated by the energy needed for the process, including heating of the reactors. The heat needed in the digestion process is mainly to raise the temperature of the input feedstock to that of the digestor, and the necessary temperature will depend on the process design and the nature of the feedstock and local regulations: e.g. some regulations require feedstock to be heated to 70℃ for an hour, to kill potential pathogens.

AD plant developers will typically use their own biogas production as the source of energy for the process, and thus treat this as a parasitic load, making a small reduction in the biogas finally produced. In the current application, the bioLPG process is expected to generate a considerable quantity of steam from the synthesis and upgrading: this steam can be used for the AD process, and thus no additional energy costs need be incurred.

Another category of financial costs and benefits relate to the other outputs from the AD: as shown in Figure 5, these include liquid digestate and solid residues. These need to be transported and potentially to be treated, incurring costs, and then they can be used for their high nutrient (nitrogen, phosphorus, potassium (N:P:K) as well as micronutrients, depending on feedstock characteristics) and organic carbon content for agriculture soil conditioning, with potential financial value. Whether these additional costs and benefits need to be taken into account depend on whether these outputs are the responsibility of the bioLPG project, or require further disposal as waste. Contracts could be secured with the municipality or third parties to handle the logistics and to take the revenue from any productive use of the outputs.

BioLPG production via the Cool-LPG process

A high-level explanation of what Cool LPG is and what its advantages are was presented in section 2 and specification of the data necessary for estimation of bioLPG production quantities was presented in section 3.2.

TEA to date suggests that production costs, though presently higher than the global market price of fossil LPG, can be supported by cross-subsidy from the normal profit margin of fossil LPG when bioLPG is blended in. This economic result is why Global North companies are aggressively supporting Cool LPG development, because the presently proposed policy goal of blending green LPG with fossil LPG in a 10% to 20% ratio may be economically feasible for LPG marketers, if regulations require them to buy and blend bioLPG with fossil LPG. Such green blending requirements for gasoline have created bio-ethanol markets in the United States.

The increasing value of emissions credits will also eventually be an important factor in moderating differences between global fossil LPG import prices and the cost of locally produced bioLPG. Subsidy and fiscal benefit programs, such as are offered by Global North governments to their biofuels producers, could also create financial viability for bioLPG projects.

GTI Energy and BioLPG LLC / GLPGP, supported by their 12 European and North American LPG industry corporate partners, are finishing their second year of development tasks, with extended testing of third generation catalyst and process design scheduled to be completed in Q4 2023. Technical presentations will be made publicly in the Q4 2023, with major first plant announcements expected in November 2023. Further announcements are planned to be made at COP 28. Major governments in both the Global North and Global South have expressed interest in bioLPG and the Cool LPG process for producing bioLPG.

BioLPG logistics

The bioLPG logistics and downstream supply chain are the same as for standard fossil LPG, and this is illustrated in Figure 5.

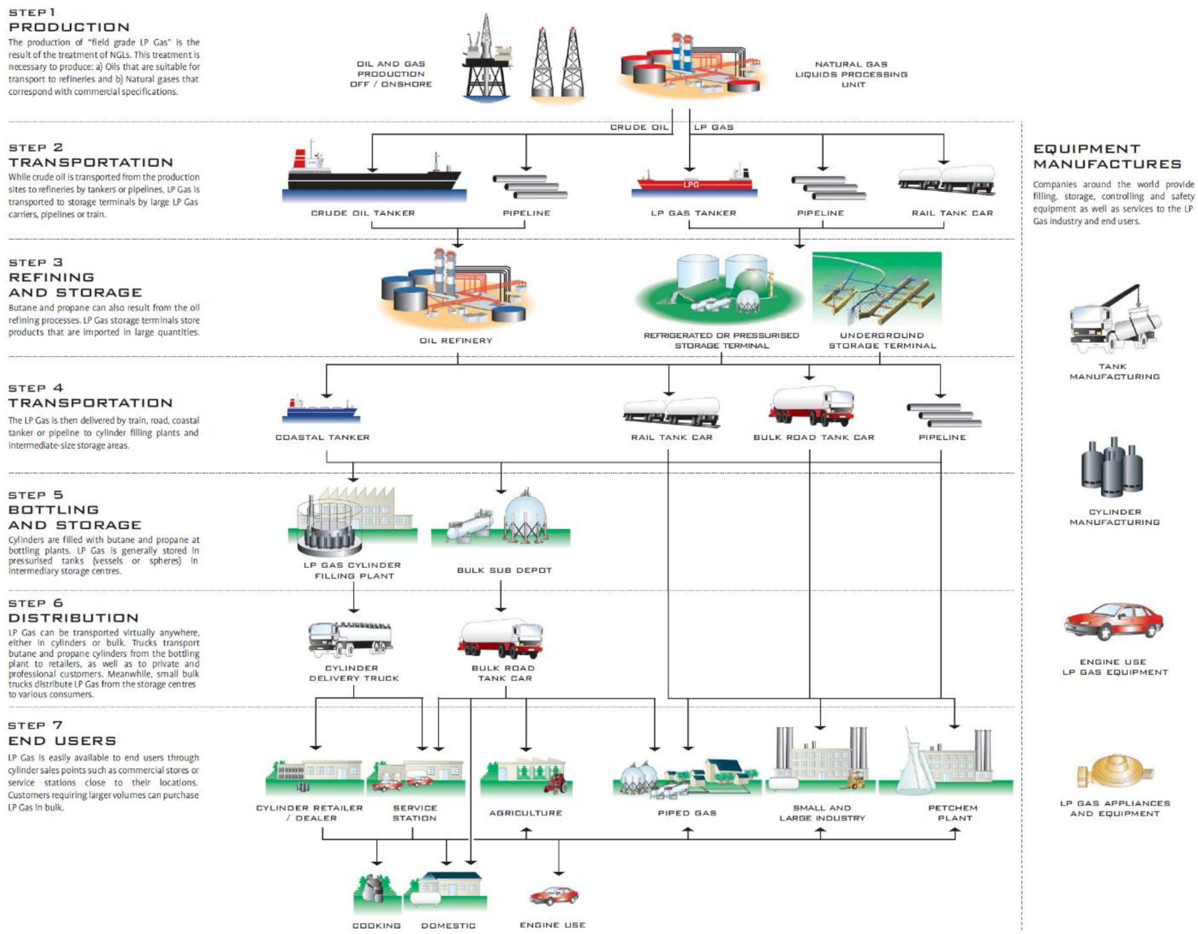


Figure 5 LPG supply chain
Source: WLPGA

3.3.2 Financing options

Financing a waste management project which is then onward linked to a biogas facility and further linked to a bioLPG plant will be complex and project specific. There are many risk factors affecting the variability/certainty and quality of physical operations, the project enabling environment and financial performance. Those factors include feedstock availability, seasonality and cost; government market structures relating to the waste and chemical production sectors; taxation and other fiscal policies; environmental, sustainability, technical and safety standards and their enforcement; assurance that key equipment and specialized consumables such as catalysts can be imported; price control regime; and consumer support policies.

Without a defined project concept and a properly conducted and presented feasibility study, the availability, quantity and terms of financing (debt, mezzanine, equity) cannot be discovered "a priori" from capital markets. Furthermore, finance providers, in general, may or may not have the in-house expertise to form an actionable assessment of a MSW-to-biogas-to bioLPG proposal put before them – they would have to hire outside consultants, which they would ask the project sponsor to pay for. As such, minimal standards of pre-screened hurdles need to be in place for them to take their analysis to the next level. These are specifically operational and financing robustness and viability in order to be "bankable"/"fundable".

Concessional and non-concessional capital sources (Development Finance Institutions (DFI), commercial banks, private debt and equity investors, providers of guarantees) are not the only targets for getting project support.. Various other necessary participants in a finance plan for a project also would have to be approached, educated and patiently brought into play: key insurance brokers and underwriters and qualified contractors with the willingness and capacity to provide equipment and performance guarantees. There would also have to be evidence of government-enabling policy stability and performance capability.

If the information specified in this Study framework is gathered by a properly conducted feasibility study, a project description would be one of the deliverables. Financial projections, proposed financing structures and risk mitigation plans will be necessary materials for use in engaging with potential sources of finance for provision of debt and equity capital and ancillary risk mitigation instruments such as first-loss protections and other forms of insurance. The emergence of substantial carbon credits as a pillar of an emissions reduction-related project needs to be addressed at the project level, because the amount of credit will vary greatly depending on local factors.

Recent publications (IMF, 2019), as well as the meetings and publications of various biogas organizations, demonstrate that there has been substantial attention paid to the challenge of how to stimulate capital to support waste to energy projects. However, a prevailing theme is the need for adequate scope and stability of government policy and supports for waste-gathering both as a public good that must be provided and as an economic system in which resource calls are allocated between the public and private sectors as implementers and bearers of economic risk.

Carbon credits

An additional source of revenue for the bioLPG production program could be finance linked to environmental and/or social benefits. Within the broad framing of Results (or Outcomes) Based Finance, the most obvious route is to seek carbon finance (Bisaga and To, 2021). The recent Saudi purchase of Kenyan carbon credits (Miriri, 2023) should be viewed as positive data about emerging carbon market potential in Africa.

For modern energy clean cooking, the most accessible climate funding source is emission reduction credits via the Voluntary Carbon Market, with development of a project linked to avoidance of emissions for households or others transitioning from using traditional solid biomass fuels to bioLPG for cooking. Value for improvement in other SDGs could be claimed as co-benefits in such a project, or be claimed separately as and when there is sufficient outcome buyer interest.

The bulk of existing clean cooking activities in the voluntary carbon market are certified by the Gold Standard, with domestic biogas activities accounting for more than 80 percent of registered activities (Galt et al, 2023), with biogas treated as a very low or net-zero carbon fuel. BioLPG derived from organic wastes via biogas would most likely be treated similarly, although this would need to be discussed with the carbon credit agencies. As such, the GHG emissions reduction achieved would depend primarily on the traditional fuel displaced from the baseline (e.g. charcoal) and the relative efficiency of bioLPG cooking compared to baseline cooking (typically 65% compared to 10%).

The recommended approach would be to develop a program of activities based on the 'Methodology for Metered and Measured Energy Cooking Devices' (MMECD, The Gold Standard Foundation, 2022). This new methodology has been independently assessed as the most accurate in the sector for climate finance for cooking (Gill-Wiehl et al, 2023), due to its use of data on the actual usage of the project stoves, derived from digital metering or other forms of measurement. Metering of fuel use is well-established for LPG cookstoves (e.g. Shupler et al, 2021). Estimates are made for the carbon credit value achievable for the case presented in section 5.

Other SDG-related benefits (e.g. time savings, gender, health, forest protection) could be factored in as co-benefits, helping secure higher credit prices, or could potentially be developed for standalone impact funding, but the markets for the latter are presently not well developed (Bakhtary et al, 2023).

3.4 Sustainability Framework

The sustainability framework is intended to complement the technical, techno-economic and policy-enabling frameworks developed in the other sections of this Study.

3.4.1 National sustainability priorities and mechanisms

The sustainability framework is intended to further the understanding of the carbon benefit of reducing greenhouse gases (GHG) as CO_2eq, by introducing bioLPG as a replacement cooking fuel for fossil derived LPG, and traditional fuels (charcoal and wood), and of the wider sustainability benefits (environmental and socio-economic) which would support development of the MSW to bioLPG supply chain, via national sustainability priorities and mechanisms.

Solid waste management is also a crosscutting issue that can be linked to twelve out of the seventeen UN SDGs and in each of the three sustainability domains: ecology, economy and society. The affected areas include living conditions, sanitation, public health, marine and terrestrial ecosystem, access to decent jobs, as well as the sustainable use of natural resources. As part of the enabling environment (Section 3.5) the framework review of relevant policies has highlighted that all three countries addressed in this Study have substantial engagement with the climate change agenda of UNFCCC and the SDGs (Appendix D). The specifics of developing a MSW to bioLPG supply chain clearly will require policies supporting waste management and energy.

In addition, understanding of the metrics required to fulfil the carbon assessment required to address the climate change agenda (and the potential for accessing carbon credits or in the carbon trading market) must be developed initially within the Life Cycle Assessment (LCA) framework defined in 3.4.2. Framework questions for sustainability beyond the carbon/climate change agenda have been developed following a benchmarking process of the UNFCCC SDGs (described in 3.4.3). Carbon financing options such as the Voluntary Carbon market defined in 3.3.2.1., and carbon financing options such as the Voluntary Carbon market defined in 3.3.2.1, are also aligned with the life cycle assessment and SDG benchmark approach.

3.4.2 Life Cycle Assessment approach to GHG and environmental impacts

In countries where bioenergy policies have been developed to incentivise the use of non-fossil fuels (solid, liquid and gaseous), these have often been with the purpose of reducing dependence on fossil resources and the intention of reducing GHG emissions. In order to make appropriate comparisons of GHG emission reduction compared to fossil fuels, GHG assessment methodologies have been universally developed following LCA principles and best practice. LCA is also a valuable tool for assessing a wider range of environmental impacts (e.g. resource depletion, land and water use, ecotoxicity, eutrophication, particulate emissions etc.) and offers insight into the benefits and trade-offs which might be seen between a range of different environmental and human impacts, and which cross reference several of the SDGs and inter-link to non-energy and waste management policies. For the purpose of developing a framework of understanding of supply chain GHG emissions and other environmental impacts which may be associated with the development of MSW-to-bioLPG in the Global South, where policy incentivisation may not yet be established, a LCA approach has been taken with a view to informing future policy development. At the current stage of technology development, this study aims to establish: 1) current urban MSW management practices in each of the study countries, following the waste management framework given in Figure 6); 2) provisional systems boundary for the assessment of supply chain emissions of the novel 'Cool LPG' production route to bioLPG (with a view to bioLPG supplementing fossil LPG, or replacing fossil LPG at some point in the future; 3) use-phase emissions of bioLPG compared with other cooking fuels/energy, to inform carbon credit calculations in the TEA (based on current literature); 4) consider how LCA scenarios might address the question of highest and best use of biogas, from an environmental perspective.

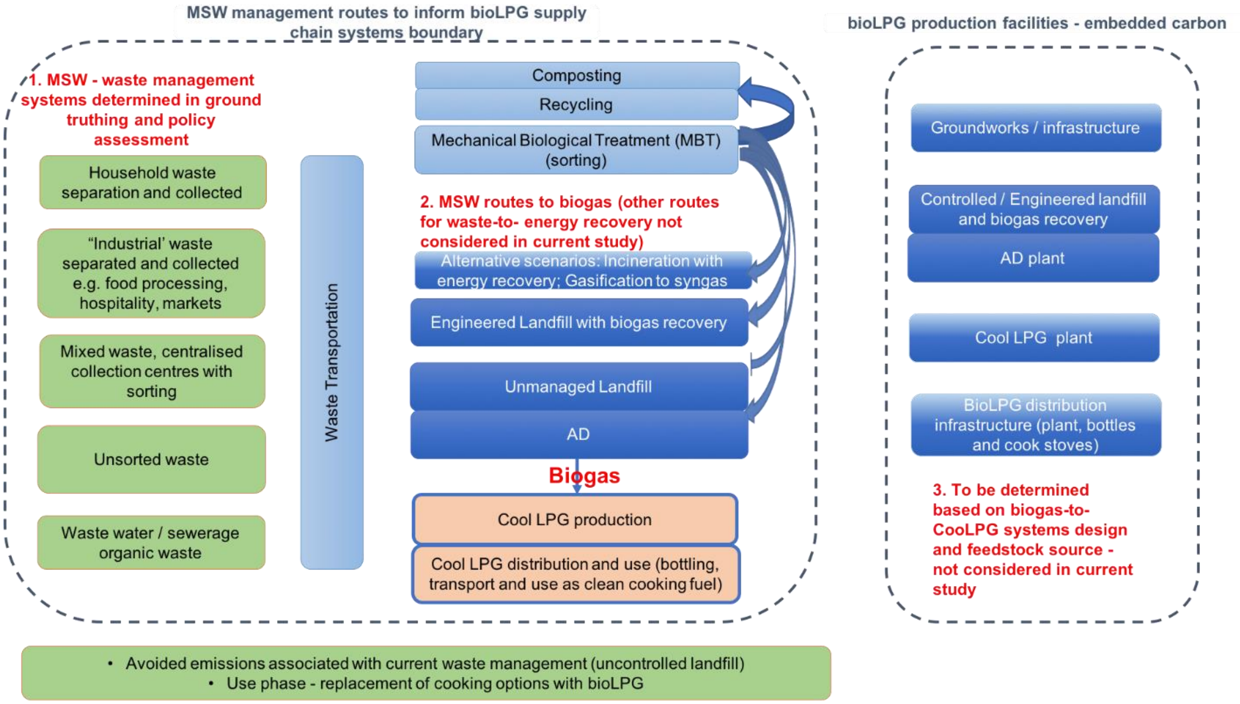


Figure 6 MSW management framework & routes to bioLPG for LCA systems boundaries

Information required for establishing local MSW management activities, data availability and assessment and the information required for establishing LCA systems boundaries were gathered during the ground-truthing activity and reported in the three country case studies, in the following sections. A preliminary quantification of bioLPG supply chain GHG emissions is based on the conditions used for the TEA model, and the potential carbon reduction benefits of replacing traditional cooking fuels with bioLPG. Further iterations of supply chain systems boundaries and routes to bioLPG will be informed by location specific scenarios, considering current MSW management, intended sourcing of OFMSW, according to future MSW management in the countries considered.

The framework scope for LCA studies is consistent with other methodologies which are linked to the developing carbon market and the clean cooking agenda (e.g. Gold Standard for the Global Goals, voluntary carbon market accounting tools); however, further refinement of GHG emissions calculations will require location specific data to inform calculations for the proposed activities surrounding MSW-to-bioLPG. In this Study, carbon calculations are based on current estimates and modelling carried out from literature sources for LPG replacing traditional fuels (wood/charcoal) and avoided emissions from management of OFMSW (Figure 7). GHG calculations for the Cool LPG process are also estimated at this stage, but will be further defined in Q3 2023 by GTI Energy/GLPGP activities.

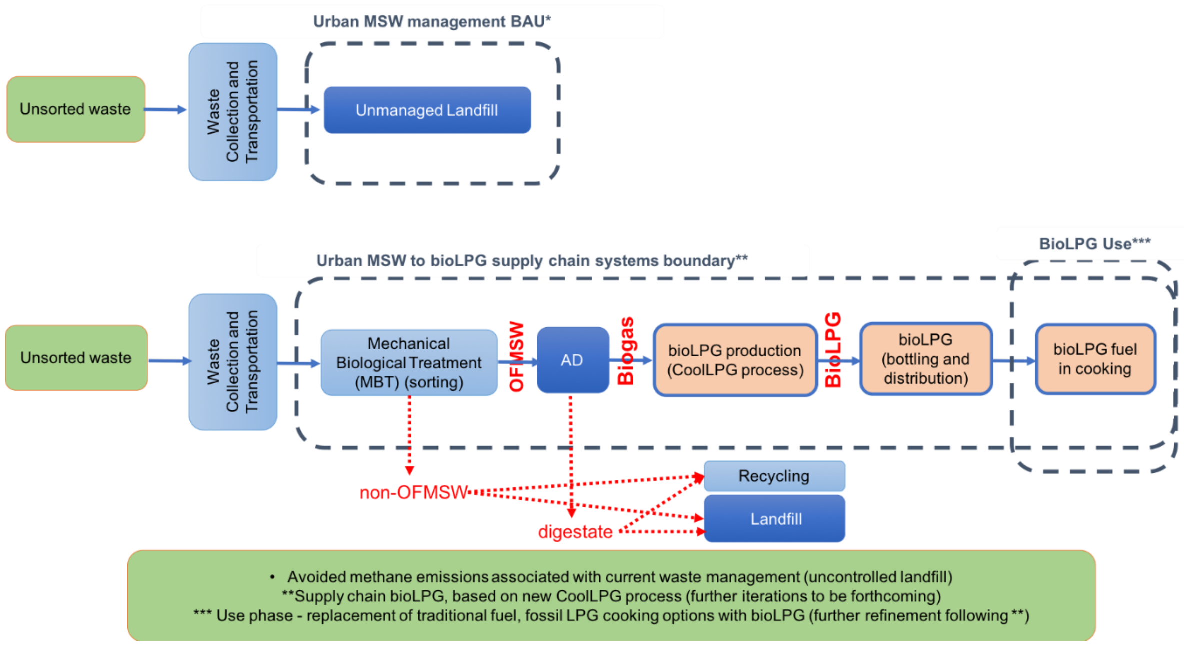


Figure 7 BioLPG LCA GHG emission scenarios

3.4.3 SDG impacts

The SDGs have been used as the basis for assessment of the benefits of implementing bioLPG as a clean cooking fuel. A preliminary benchmark of the SDGs was carried out to identify methodologies available for their assessment. A series of questions were developed to inform a metrics approach to assessing the impact of implementation of a MSW-to-bioLPG chain, considering

1. improved access to clean energy for cooking
2. replacement of traditional charcoal and wood in cooking, with (bio)LPG
3. better waste management

The following SDGs were identified as the focus of assessment methodologies which would be suitable for the application of metrics to define the benefits of bioLPG implementation in the future (actual data gathering at this level is outside of the scope of the current project and its ground-truthing exercise):

> SDG 1 No poverty; SDG 2 Zero hunger; SDG 3 Good health and well-being; SDG 5 Gender equality; SDG 7 Affordable and clean energy; SDG 8 Decent work and economic growth; SDG 9 Industry, innovation and infrastructure; SDG 11 Sustainable cities; SDG 12 Responsible consumption and production; SDG 13 Climate change; and SDG 15 Life on land.

A further benchmark was carried out to overlay polices defined in the policy enabling environment framework, to highlight converging approaches and priorities of the Study countries.

The outcomes of the benchmark are reported in 5.3, considering bioLPG implementation, waste management and enabling policy convergence.

3.5 Enabling environment requirements to create an MSW-to-bioLPG chain

3.5.1 Country-specific social, political and economic conditions

MSW-to-bioLPG plants would address needs for waste management, mitigation of GHG emissions and provision of clean cooking fuel. However, planning for the use of municipal waste to facilitate the transition to clean cooking, particularly through biogas production as feedstock for production of bioLPG, requires careful consideration of country-specific social, political, and economic conditions.

The generation of MSW is influenced by complex relationships among demographic and socio-economic factors which vary over time. Demographic factors (especially population growth, rise in household income and urbanization) are widely used to forecast MSW generation. Generally, a larger population generates a larger aggregate amount of MSW. Population and population density are important variables. For instance, multi-family dwellings generate more MSW compared to single-family dwellings (Monavari et al., 2012). Studies show that the total amount of MSW is influenced by urbanization. Urbanization changes people's lifestyles with a significant impact on MSW generation. Social-economic factors such as income both at the household and city levels are used to explain the variation in MSW generation (Ayeleru et al., 2018). There is also strong correlation between increased wealth and increased energy consumption. GDP growth, which indicates higher economic activity, is also widely used to predict MSW generation.

In the near future, in SSA, the challenges of urban solid waste management are likely to intensify due to ongoing population growth, urban expansion, and increased consumption. As urbanization continues to rise, municipal governments often face financial and institutional challenges. For example, in Kenya, urban infrastructure development is lagging behind demand, resulting in overflowing and poorly managed dumpsites. In Cameroon, uncontrolled urbanization has led to water contamination linked to the poor management of household waste, contributing to waterborne diseases. In Rwanda, waste is primarily disposed of in landfills, with minimal formal recycling of inorganic waste or reprocessing of organic waste. Hence, efficient waste management addresses multiple development and wellbeing challenges confronting nations in the Global South.

Similarly, transitioning to clean cooking energy is crucial for environmentally sustainable development. However, country-specific conditions need to be taken into account when considering the nature and trend of household cooking energy transitions. Some general factors affect both the waste management and clean cooking sectors. For instance, population, urbanization and economic growth are likely to increase energy demand. In contrast, certain drivers of household-level energy transition differ from municipal waste related drivers. As an example, studies have shown a strong correlation between LPG adoption and household socioeconomic levels (Troncoso et al, 2019). Higher-income households are more likely to adopt modern cooking services and technology.

Despite a plethora of programs, announced intentions and heralded priorities, the household clean cooking transition remains very gradual and sometimes non-existent in the Global South. Progress in Africa has been particularly slow, with a large majority of the population relying on polluting and inefficient technologies. This has adverse effects on the environment and public health, counteracting climate change mitigation initiatives. Rapid urbanization can strain existing urban infrastructures, including the supply, demand, and distribution of different fuels. However, the relationship between urbanization and energy consumption varies depending on the stage of urbanization in a country and the adequacy of energy infrastructure. Energy consumption may increase with urbanization due to higher household incomes, but infrastructure must keep pace (Price, 2021).

3.5.2 High-level policy commitment

High-level policy commitment and an accommodating governance framework are crucial for creating an enabling environment. International goals and agreements establish the global agenda for addressing issues like climate change and sustainability. While these goals don't prescribe specific solutions, they provide a framework for countries to work towards common objectives. However, compliance with these goals varies, and nations with different political agendas and ambitions may exceed or fall short of the common goals. Some countries set more ambitious sectoral targets, more specifically focusing on waste and energy sectors, under which biogas solutions are included. However, even in the absence of direct policies, MSW-to-bioLPG is indirectly affected by existing commitments, such as reducing GHG emissions to tackle climate change. The Nationally Determined Contributions (NDCs) of each country provide important insight into the level of interest and commitment as well as incentives for investment in this area.

At national level, environmental concerns are the main drivers of enhanced commitment towards MSW management, followed by the need to tackle public health, urban development, and natural resource management. Environmental concerns also extend to natural resource management, such as curbing deforestation and forest degradation, which often is then linked to the promotion of clean cooking strategies. These commitments are often expressed in national development plans, long and mid-term visions, and other strategic documents that provide a national vision. At the sectoral level, policy level commitments particularly within the energy sector, policies related to domestic energy and clean cooking are relevant for creating an enabling environment for MSW-to-bioLPG. Setting renewable energy targets and recognizing waste-derived energy as a renewable source can encourage the integration of waste-to-energy projects into national energy plans and as part of the overall energy mix (Vassiliades et al., 2022). Policies should align with national energy strategies, climate action plans, and waste management policies.

3.5.3 Governance framework

A conducive governance landscape refers to a set of favourable conditions and practices within the governance framework that facilitates the implementation of specific initiatives or projects.

Implementing MSW-to-bioLPG requires well-designed policies, regulations, and institutional arrangements that promote waste management, renewable energy, and the use of waste as a resource. It benefits from efficient permitting processes, coordinated decision-making among relevant government agencies, and the availability of financial incentives and support mechanisms. Regulatory frameworks should address emissions control, waste feedstock quality, and other environmental and health considerations. These supports provide clarity to investors, project developers, and operators, creating and maintaining their confidence in investing and operating MSW-to-bioLPG projects.

To nourish and grow a clean cooking sector, governments must fully carry out a crucial role in setting policies and regulations that support the adoption of clean cooking technologies. This includes providing incentives, subsidies, and tax breaks for clean cooking solutions, as well as setting emission standards and quality control measures for fuels and appliances. Clear guidelines and regulations are needed that promote market investment competition, ensure consumer safety, and facilitate the availability and affordability of clean cooking options.

The policies influencing biogas solutions, including MSW-to-bioLPG, must be established and coordinated across multiple policy areas, creating an intricate policy and governance landscape. Aligning accountability and responsibility among different departments of government at different levels is crucial. Policy coherence and stability are crucial factors in creating a governance landscape that will induce the making of large investments which require long time periods to succeed (Vassiliades et al., 2022).

Waste management service delivery is typically the responsibility of local authorities, with central governments setting policy and the legislative framework. However, the division of roles and responsibilities is often more complex, with different tiers of government involved. Some governments take a centralized approach, with policy made at the national level, while others adopt a decentralized approach, where waste management decisions are made at multiple levels. In centralized systems, decision-making power is concentrated among a few individuals, while, in decentralized systems, authority is dispersed among various governing bodies. Decentralization also entails higher operational costs.

Additionally, a conducive governance landscape must consider the nature of stakeholders' engagement and public acceptance. The waste sector intersects with informal livelihoods and urban politics, particularly in Africa (Amugsi et al., 2022). It involves both formal and informal actors, such as informal waste pickers, charcoal producers, and traders of both. Any strategy or initiative to improve waste management systems must consider the actors within the informal sector. Similarly, the biomass-based cooking market involves informal actors, and policymakers must balance waste management, social development, and employment goals. Interventions that target and link with various social, economic, and environmental benefits will ensure social and political acceptability, sustainability, and community buy-in for these initiatives (Kubanza and Simatele, 2020).

The framework questions that are necessary to appraise the supporting policy environment and the likelihood of achieving financing for biogas and Cool LPG production are shown in Figure 8. The questions will guide aspects of the case study investigations in section 4 of this Study.

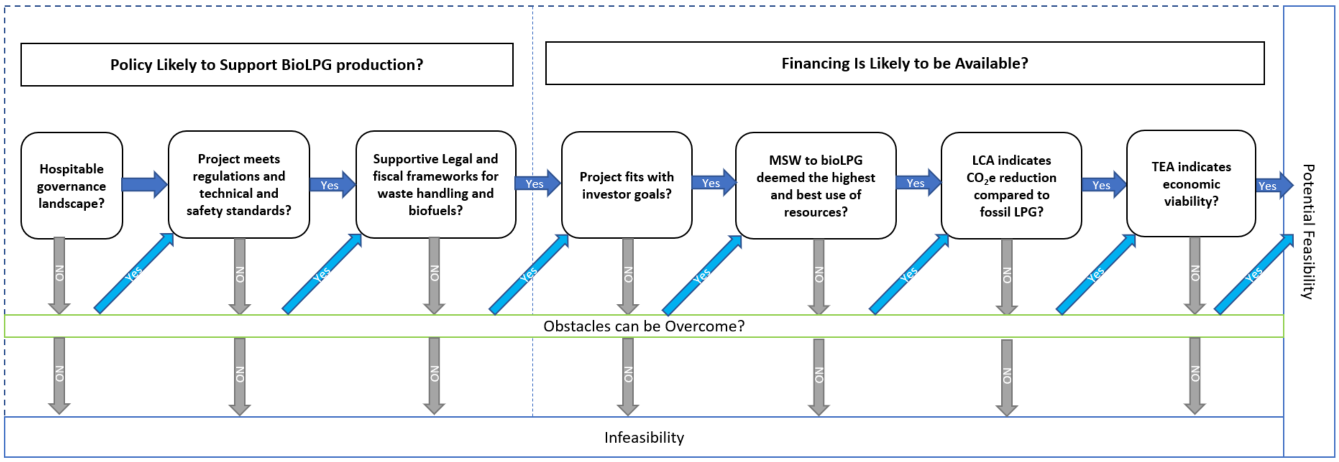


Figure 8 The question flow to investigate supporting policy and financing

3.5.4 Feasibility analysis

A feasibility study for a proposed MSW-biogas-Cool LPG project requires assessment of physical, technical, economic and enabling environment factors. The national enabling environment is the ecosystem of policies, regulations, structures and implementation and enforcement capacities necessary for planning, financing, constructing and operating an MSW-biogas-Cool LPG project. The sequence of information gathering and analysis is shown in Figure 9.

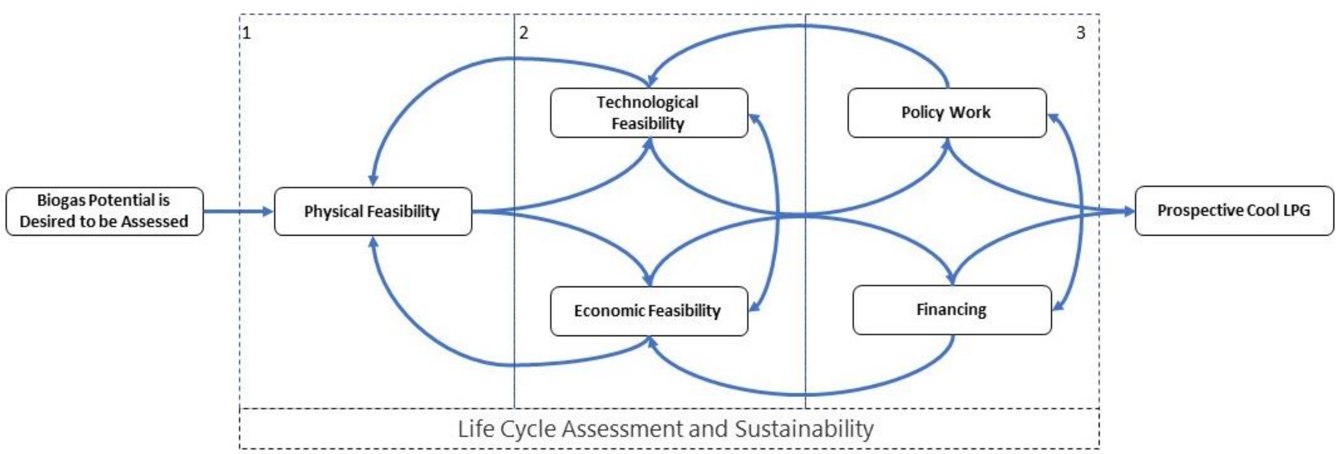


Figure 9 Biogas feasibility analysis and linkage to prospective Cool LPG

4 Country case studies - local answers and gap identification

4.1 Kenya

4.1.1 Kenya Overview

Kenya has a rapidly growing population, with the last census conducted in 2019 indicating a population of 47.653 million people, and a growth rate of 2.2% annually (KNBS, 2019). The study area for this research is Nairobi County in Kenya. Kenya's NDC declarations include commitments to developing a sustainable waste management system and to considering the move towards clean cooking as part of the solution to cutting their GHG emissions by 33% by 2030. Nairobi County in particular, has a dire need for waste management intervention. Nairobi covers 696 square kilometres and has a population of approximately 5 million people. It serves as a national and international business hub for Kenya.

This case study is facilitated by a ground-truthing exercise that aims to serve two purposes: first, to test the efficacy of the framework and second, to further the understanding of the location's physical biogas potential and its enabling environment for biogas production and bioLPG plant installation.

4.1.2 Policy Commitment and Enabling Environment

Kenya has specific policies on energy and waste management that potentially support biogas production and bioLPG. These include:

- Vision 2030, the overarching policy for Kenya's development.
- Kenya Constitution 2010, which created two levels of government, and devolved certain functions.
- SE4All Action Agenda, which aims at ensuring energy affordability, energy efficiency and energy access, with the stated objective of having 100% access of clean energy for all Kenyans by 2030.
- International Commitment, such as the SDG goals, and further committing to ensure access to clean cooking for all by the year 2028, as during the Clean Cooking Conference in Nairobi in 2019, and was recently reiterated during the COP 26 forum.
- The Energy Policy 2018, which aims to ensure an affordable, competitive, sustainable and reliable supply of energy.
- Kenya National Waste Management Policy 2021, which aims to advance Kenya towards a more sustainable and circular economy.
- The Kenya National Environment Policy 2013, which aims to provide a framework for an integrated approach to sustainable management of Kenya's environment and natural resources.

These policies are implemented through various Acts of Parliament supported by relevant ministries as outlined in Appendix A1.

The government has taken a "zero waste" and circular economy approach, whereby waste generation is minimized or prevented. The Kenya National Waste Management Policy 2021 aims to ensure that waste is collected, separated at the source, reused, and recycled, and that the remaining waste stream is destined to a secure, sanitary landfill. The National Climate Change Action Plan 2018-22 (Government of Kenya, 2018) identifies clean cooking as a priority and as one that presents an opportunity for technological leapfrogging for energy savings, reducing GHG emissions, and delivering health and cost savings.

Kenya is currently developing a national clean cooking strategy aiming to lay out the pathway to achieve the goal of Universal Access to Clean Cooking by 2028 whilst contributing to its NDC target to abate the emission. The Government developed a National Bioenergy Strategy and the Energy Policy in 2018 which demonstrates dedication to utilization of bioenergy, including biogas for cooking. Although the National Bioenergy Strategy recognizes the potential of MSW for large scale bioenergy production, investment efforts are limited due to inadequate data.

These national commitments are operationalized through ministries, policies, acts of parliament and state agencies. Further relevant policies and the governing bodies are detailed in Appendix A1. A list of stakeholders and their importance to a prospective Cool LPG project can be found in Appendix A2.

4.1.3 Ground-Truthing Methodology

The Kenya case study investigates the data necessary to substantiate Nairobi's capacity for MSW derived biogas and BioLPG production.

Stakeholder Sampling

Stakeholders were identified and selected to be part of this Study based on the distance to dump site, volumes of MSW generated, type of business or enterprise and respondents available for interview (Table 2 and Table 4). These stakeholders deliver a snapshot of the various sectors producing potentially viable MSW streams. These include abattoirs, agro-processing firms, dumping sites, health facilities, hotels, malls, open markets, schools, supermarkets, and waste management companies.

Data Analysis Techniques

Data was collated and analysed in the context of the wider literature and the framework questions (sample questionnaire in Appendix A3). Additionally, for exploratory data analysis, Power BI, ArcGIS and IDRISI software were employed to map out MSW flows and specific sites that align with the study's objectives.

4.1.4 Country Data Requirements by the Framework

Physical MSW Potential (Sufficient Feedstock)

Literature highlights the complexity of the waste management sector in Nairobi. The waste collection industry is lucrative and made up of many unlicensed players described as 'cartels' (Muindi et al., 2020). This is accompanied by numerous unofficial dumpsites which the

Government is attempting to control. Because of this, obtaining a complete map of Nairobi's waste flows is complex and the detail below can only provide a snapshot of the system.

Nairobi's MSW feedstock-producing capacity has been analysed through direct investigation into waste producers and waste management stakeholders. The MSW production rate is predicted to rise with the population increase in Nairobi. Table 2 shows measured and predicted MSW generation rates for Nairobi.

Table 2 Observed and projected population and waste generation values (JICA, 2010)

Year	**2009**	**2010**	**2015**	**2020**	**2025**	**2030**
Nairobi Population (thousands)	3,040	3,150	3,760	4,420	5,150	5,940
Waste Generation (t/day)	1,848	1,924	2,353	2,831	3,378	3,990

The amount of waste generated daily by each MSW producer sampled is displayed in Table 3, including the percentage of organic waste.

Table 3 Total daily waste and organic proportion

COMPANY	**Sector**	**Daily Waste (t)**	**Organic Waste (%)**	**Organic Waste (t)**
Woodley Market	open market	15	98%	14.7
Wakulima Market Nairobi	open market	2	98%	1.96
Ruiru Slaughterhouse	slaughterhouse	1	100%	1
Thiani Slaughterhouse	slaughterhouse	1.5	100%	1.5
Dagoretti Slaughterhouses Co.	slaughterhouse	1	100%	1
Sakuu Slaughterhouse	slaughterhouse	1	100%	1
Strathmore University	School	1.2	60%	0.72
Lenana School	School	1	30%	0.3
Sarova Stanley	restaurant	6	25%	1.5
Sankara	restaurant	4	73%	2.92
Village Market	Mall	0.35	47%	0.16
Total		34.05	79%	26.76

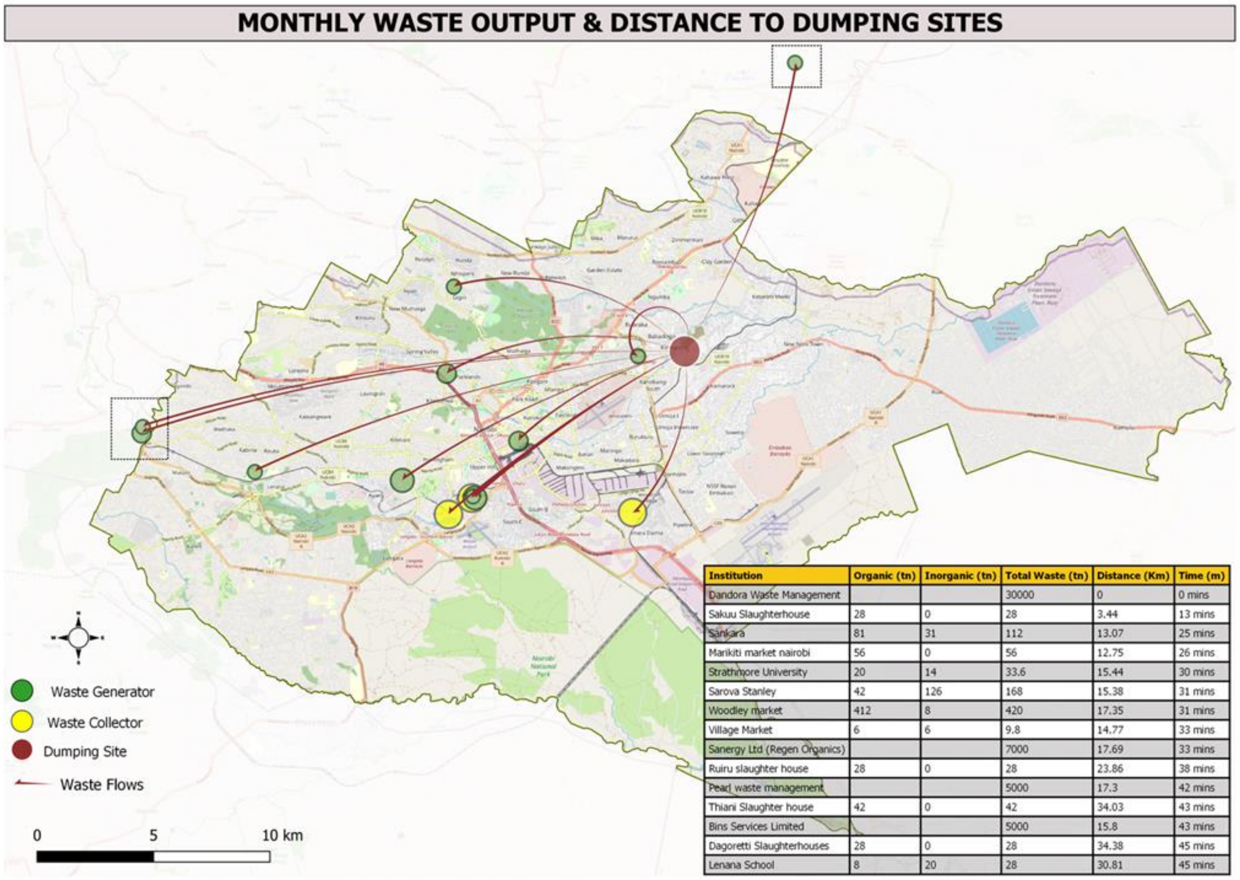
The amount of waste collected daily by each waste management company is displayed in Table 4 including the percentage of organic waste.

Table 4 Daily waste quantities and organic waste proportion for waste collectors surveyed

Company	Sector	Daily Quantities (t)	Organic Waste (%)	Organic Waste (t)
Green Nairobi	County Waste Management Office	3000	60%	1800
Sanergy Ltd	Waste Management Facility	250	100%	250
Bins Nairobi Services Ltd	Waste Collection Company	30	10%	3
Pearl Waste Management	Waste Collection Company	15	60%	9
Total		3,295	63%	2062

In total, the waste management companies sampled collect approximately 3,295 tonnes of MSW daily and, of this, 63% or 2,062 tonnes is organic waste. Based on these collected values and using volatile solid percentage and methane potential values for MSW in Nairobi from Fisher et al (2010)'s, the methane potential for Nairobi is 52,834,626 m^3 per annum and the biogas potential is 80,877620 m^3 per annum.

Direct surveying of government employees working for Nairobi's only official dumpsite, Dandora dumpsite, revealed that approximately 3,000 tonnes of waste are deposited at the site per day. However, these quantities vary with peak seasons, April, August and December when the waste quantities average 2,175 tonnes per day while during the low seasons, the waste collected is approximately 875 tonnes per day. These values are not supported by those found in literature, the most recent available estimate being around 4,000 tonnes generated daily (Njoroge, 2014) with the actual collection rate being between 33% (JICA, 2010) and 80%. This highlights the complexity of accurately estimating the total waste production rates and thus the necessity for a granular investigation into viable waste streams.



Institution	Organic (tn)	Inorganic (tn)	Total Waste (tn)	Distance (Km)	Time (m)
Dandora Waste Management			30000	0	0 mins
Sakuu Slaughterhouse	28	0	28	3.44	13 mins
Sankara	81	31	112	13.07	25 mins
Marikiti market nairobi	56	0	56	12.75	26 mins
Strathmore University	20	14	33.6	15.44	30 mins
Sarova Stanley	42	126	168	15.38	31 mins
Woodley market	412	8	420	17.35	31 mins
Village Market	6	6	9.8	14.77	33 mins
Sanergy Ltd (Regen Organics)			7000	17.69	33 mins
Ruiru slaughter house	28	0	28	23.86	38 mins
Pearl waste management			5000	17.3	42 mins
Thiani Slaughter house	42	0	42	34.03	43 mins
Bins Services Limited			5000	15.8	43 mins
Dagoretti Slaughterhouses	28	0	28	34.38	45 mins
Lenana School	8	20	28	30.81	45 mins

Figure 10 Respondent waste flow in Nairobi including quantities and distance

Suitable Feedstock Characteristics for AD

To determine likely biogas yields and identify specific streams to target for procurement, it is necessary to assess waste stream characteristics. The following information investigates the high-level characteristics of the surveyed stakeholder's waste streams.

Open markets: waste is predominantly fruit, vegetable and food residue which is collected by the city council daily.

Hotels: predominantly kitchen waste, food-soiled paper, expired food, polythene bags, cartons and paper. Waste is collected in bins, drums or polythene bags and is collected by private waste management companies depending on the terms agreed.

Abattoirs: predominantly solid waste from animals including horns and skins. This is stored in drums and manure yards. Ruiru and Dagoretti slaughterhouses use this waste internally as manure, and Thiani and Sakuu slaughterhouses pay to get their waste collected daily by Sanergy and the city council, respectively.

Schools/universities: predominantly kitchen waste, food-soiled paper, E-waste, paper, metal, wood and medical waste which is stored in drums, polythene bags and bins. Strathmore

University pays for daily collection services while Lenana School gives their waste to a local pig farmer.

Malls: predominantly food-soiled paper, polythene bags, cartons and other packaging material, kitchen waste and metallic cans. Organic waste is the highest proportion of the waste collected at the mall and accounts for 30.6%. The village market has a Carrefour branch and 20 to 30 restaurants which produce organic waste only. Waste generated is stored in polythene bags, drums and bins and is collected daily.

Rough estimates of the biomethane potentials (BPM) and biogas yields can be made utilizing literature values for feedstocks; however, to accurately measure the BMP of MSW sources, direct lab measurement and characterisation should be employed.

Current Waste Management Systems

The existing waste system must be harnessed to allow efficient OFMSW aggregation. In particular, the most appropriate method of OFMSW segregation will depend on the existing system in place, which is described below, for the surveyed stakeholders.

Sarova and Sankara hotels separate their waste for storage purposes, as organic waste is stored in refrigerators to prevent unpleasant odours. Lenana School and Dagoretti slaughterhouse use the waste as feed for pig farmers and manure, respectively; therefore, it is also separated. The village market also sells its organic waste, so separation is necessary. A summary of these companies along with their methods of segregation can be found in Appendix A4.

Segregation is often performed by casual laborers. Some collect organic waste to sell to pig farmers and manure producers. Some waste management companies also segregate waste for sale to pig farmers and manure companies before transporting the rest to Dandora dumpsite.

The identification of informal and formal segregation of waste indicates the viability of OFMSW separation for biogas production. However, the interplay between existing systems and potential future procurement should be investigated from both financial and social perspectives.

Adequacy of the Waste Handling Infrastructure Chain

Travel times between waste generators and dumping sites were investigated. These values ranged between 13 and 45 minutes based on direct transfer. Waste is transported by road and waste management companies in general utilize 25-tonne capacity waste trucks.

For the potential locations of AD and Cool LPG plants, current sites of interest and MSW flows have been considered. The location of the current dumping site is considered, as this may facilitate efficient utilisation of existing MSW flows. As well as this, local land zoning policies and the road access network have been investigated. Concerning these factors, three locations have been identified as appropriate: The Industrial area, Athi River and Dandora Sewage treatment works in Ruai. A summary map can be found in Appendix A5.

From the information gathered, it appears that Nairobi has infrastructure available to facilitate the collection and transport of OFMSW feedstock to AD plants.

Economic Characteristics of the Waste Handling Chain

The County waste management office collects waste for free from its citizens, with the help of contractors hired by the government. A constant 'gate fee' of 1,000 KSh is charged to the waste collectors when entering the Dandora dumpsite. Information gathered from literature indicates that unofficial fees may also be charged due to corruption and by 'cartels' so the true cost is hard to define and may be subject to rapid change (Muindi et al., 2020).

A contractor fee is based on the waste transportation distance, quantity, quality and type. Specific cost values can be found in Appendix A6.

Some of the waste generated by open markets, schools, hotels, and slaughterhouses is used internally or sold to a third party. The companies that use the waste collected to create manure utilise all their organic waste. The survey identified companies that sell their organic waste to third parties as shown in Table 5. However, the sellers may offer organic waste to the company that offers the best price. Organic waste prices identified are also summarized in Table 5.

Table 5 Waste generators' willingness to sell waste.

Company	Current Disposal Method	Willingness to Sell
Woodley Market	Organic waste sold.	Yes, unspecified amount
Wakulima Market Nairobi	Paid collection.	Yes
Ruiru Slaughterhouse	Organic waste is used internally.	No
Thiani Slaughterhouse	Organic waste sold to Sanergy.	Yes, at 50 KSh per 100 litres
Dagoretti Slaughterhouses Co.	Organic waste is used internally.	No
Sakuu Slaughterhouse	Organic waste is used internally.	No
Strathmore University	Paid collection.	-
Lenana School	Organic waste is used internally.	No (Have plans to generate biogas)
Sarova Stanley	Paid collection.	-
Sankara	Paid collection.	-
Village Market	Organic waste sold to Green Miles Zero Waste.	Yes, at 250-500 KSh/ Kg

Climate and Sustainability Impacts

The climate and sustainability impacts have not been investigated directly in this ground-truthing work. However, it is evident that the implementation of an MSW-biogas-bioLPG project would contribute towards GHG emissions reduction goals as well as benefit the local environment. The climate change impact and the resultant contribution of the project towards Kenya's NDC may be substantial, but a well-evidenced figure for GHG abatement potential will require an LCA, following specific site and scale determination. For local pollution and sustainability, Nairobi's waste management system currently results in much of its waste being improperly disposed of/leaked and littered into the natural environment which is an unsustainable and ecologically damaging activity. Because a bioLPG project would be an intervention that would reduce the amount of improperly disposed waste, it would likely reduce local pollution.

4.1.5 Conclusions, data gap, remaining issues

The MSW quantity data obtained from the waste management companies satisfies the framework question as to whether sufficient feedstock is produced and available in Nairobi, with over 2,000 tonnes of organic waste being collected per day. The biogas potential of this, based on Fisher et al. (2010)'s methane potential for Nairobi MSW and average volatile solid values, is 80,877,620 m^3 of biogas per annum. This is based on data collected before 2010 and it is likely the characteristics of the waste have changed; therefore, it is important that the methane and volatile solids content of Nairobi's OFMSW is measured directly in the future.

The main issue highlighted by this Study is the complexity of Nairobi's waste management system due to disorganization and corruption. Key challenges include unreliable vehicles, irregular collection, waste fraud, limited labour and storage facilities, excessive waste, lack of waste segregation, and harassment by environmental officers. To succeed in modern waste handling and generation of energy from that waste, substantial work on enabling policies would need to be accomplished, as well as appropriate assignment of implementation, enforcement and accountability to the relevant national and local authorities.

Whilst recent policy enactments and national expressions of intent aim to remedy system shortcomings and defects, they are still not apparent in what happens on the ground. Unsolved, the issues would perpetuate feedstock unreliability and cost uncertainty. However, existing waste management systems work physically on the scale at which they are presently implemented and the necessary quantity and quality of waste appear to be available.

4.2 Cameroon

4.2.1 Cameroon Overview

Cameroon is a central African country on the Atlantic coast between Nigeria and Equatorial Guinea. Its land area is 472,710 sq km. Its climate is tropical except in the far north, which is semiarid. The population is approximately 31.1 million, concentrated in the west and north, growing 2.7% per year. Urbanization is 59%, growing 3.4% per year. GDP was $100.6 billion in 2021 ($3,235 per capita), growing at 3.5% per year.

4.2.2 Policy Commitment and Enabling Environment

The Government of Cameroon (GOC) addresses directly and indirectly the issue of waste handling and access to cleaner fuels for cooking in two of its strategic documents. First, the National Development Strategy (NDS30) (Government of Cameroon, 2020) highlights development of alternative energies to better meet specific needs such as cooking. Second, the NDC, updated in 2021, puts focus on biofuels in its Action 5. Action 5 entails the promotion and popularization of projects to harness biogas for energy, potentially to include bioLPG, with the main target being the city councils in the country.

In accordance with the institutional arrangement provided for in the NDC, a National Climate Finance Committee under the coordination of the Ministry of Finance (MINFI) was established with responsibility for mobilizing and monitoring the use of financial resources for the implementation of the NDC.

In 2022, the GOC established a multi-ministerial bioLPG Working Group (BLPGWG) in partnership with GLPGP under the leadership of the Ministry of Environment, Protection of Nature and Sustainable Development (MINEPDED) to evaluate the feasibility and scale potential of bioLPG production in Cameroon, to assess the potential climate and social impacts thereof, and to recommend follow-on studies for development of a series of bioLPG projects in major conurbations. The national target output of such projects is approximately 60,000 MT of bioLPG per year.

Cameroon has a mixed legal system of English common law, French civil law, and customary law. There is no specific legal text on biogas and bioLPG. Related texts and policies in some portions of legislation are open to revision or reworking for specific support of biogas and bioLPG, per the findings of the BLPGWG. The BLPGWG identified no obstacles to the creation of new bioLPG-supportive policies, given that bioLPG is a high priority sector for the GOC.

Regarding waste management, there are seventeen laws/decrees on the topic of gathering and transportation of waste. Available permits relate to the management of non-hazardous waste, hazardous waste, and electrical and electronic equipment waste. Key laws and decrees are listed in Appendix B1.

More than five hundred environmental permits have been issued by MINEPDED to operators in the waste management sector. Of these, the single largest operator is Hysacam, as described further below.

Waste Management Enabling Environment

Prior to 2019, Cameroon's urban communities took individual responsibility for MSW management within their jurisdictions. As of 16th April 2021, the GOC mandated every municipality to establish a waste hauling program to ensure waste is picked up and processed appropriately. Each municipality has the right to identify potential partners (financial and technical) to develop waste pre-treatment, collecting, and processing, including into any form of energy, which can include biogas and bioLPG.

Government ministries and agencies that have mandates and responsibilities regarding oversight, licensing, permitting, inspections and enforcement relevant to MSW-to-bioLPG include: Ministry of Environment, Protection of Nature and Sustainable Development (MINEPDED); Ministry of Water and Energy (MINEE); Ministry of Mines, Industry and Technological Development (MINDMIDT); Ministry of Housing and Urban Development (MINHDU); Ministry of Finance (MINFI); and the Ministry of Decentralization and Local Development (MINDEVEL) through the City and local Councils.

Approximately 25% of Cameroon's MSW is collected by the private company Hysacam under contracts with 17 municipalities. The remainder is collected by the municipalities themselves (using their contracted operators) or enters the environment.

LPG Enabling Environment

Cameroon's LPG enabling environment practices the Branded Cylinder Recirculation Model (BCRM), the global best-practice model for LPG market design and safety, with deviation from the ideal model by allowing non-exclusive wholesaling of LPG cylinders by market intermediaries. Aside from this deviation, the BCRM is generally well implemented and enforced. A national utility company, SCDP, handles most LPG storage and filling in the country. LPG is subsidized by the government as an essential commodity, resulting in a stable, below-market end-user price nationally.

The GOC adopted a National LPG Master Plan in 2016 (GLPGP, 2016) that sets a national target of 58% of the population using LPG (which can include bioLPG) for cooking by 2030 and provides a roadmap for LPG infrastructure investment, financing, and other measures, with total LPG consumption projected to rise from 170,000 MT in 2016 to between 270,000 MT and 303,000 MT in 2030, based on the growth scenario.

The BLPGWG target of approximately 60,000 MT per year of eventual bioLPG production represents approximately 44-60% of the projected growth in LPG consumption, based on the growth scenario.

4.2.3 Ground-Truthing Methodology

The data and findings were obtained from (a) the COG BLPGWG, and (b) expert review of governmental waste management reports and plans, prevailing waste management contracts, and in-country academic research, in particular with respect to MSW handling in Douala and Yaounde and diverse local biogas development activities and project Stakeholder Sampling.

The BLPGWG was comprised of representatives of, gathered data from, and obtained the policy views of, multiple GOC ministries, as mentioned above. The BLPGPWG reviewed the country's waste management chains, identifying the most significant players and facilities, and reviewed the large number of local, small-scale MSW-to-biogas projects and programs in the country. The project team further studied prevailing, publicly disclosed waste management-related contracts for major conurbations.

In the Cameroon context, only household and market waste flows were considered.

4.2.3.2 Governmental Reports

Among the key GOC documents studied were the NDS30 (Government of Cameroon, 2020), the Cameroon National LPG Master Plan (GLPGP, 2016), the Douala Solid Waste Sanitation Master Plan ("Douala Plan") (Government of Douala, 2020), the NDC (updated 2021), and an unpublished draft of the BLPGWG final report (BLPGWG, 2023).

4.2.3.3 Academic Literature

A germane academic study is a doctoral thesis on Douala waste management that included techno-economic analysis of the potential for generating energy (primarily electricity) from waste via conversion to biogas in centralized facilities (Ngnikam, 2000). Key findings from this study were updated by its author using data from the Douala Plan for purposes of this report.

4.2.3.4 Data Analysis Techniques

Data were collated and analysed based on the BLPGWG's pre-existing workstreams and the framework questions. Techno-economic analysis of the MSW-to-bioLPG supply chain was possible to complete in substantial part, on a preliminary basis, for the city of Douala using a combination of in-country reference data from the Douala Plan, Ngnikam's thesis, and estimates provided by GTI Energy. Potential GHG avoidance and co-benefit impacts were calculated using ratios established in the National LPG Master Plan with reference to peer-reviewed academic studies.

4.2.4 Country Data Requirements by the Framework

Physical MSW Potential (Sufficient Feedstock)

For the year 2021, there were 4,036,147 MT of non-hazardous MSW in Cameroon, which includes ordinary industrial waste (cullet [waste glass], paper, cardboard, wood, etc.) and biodegradable waste (draff [brewing malt waste], kitchen waste, household waste, etc.).

The current MSW feedstock landscape can be divided into four categories:

- Urban centres covered by collection contracts with concessionaire Hysacam, which include households and commercial and public spaces in fourteen urban communities and three other towns (out of a total of 360 cities and towns nationally);
- Departmental capitals not covered by waste collection contracts with Hysacam;
- Commercial markets not covered by Hysacam contracts;
- Industries established on the national territory that create waste similar to household waste (WSHW).

Hysacam handles approximately 1.5 million MT of the total.

Household and assimilated waste includes waste produced by households, craftsmen, traders administrative offices, ordinary waste from food preparation and normal cleaning of homes and offices, broken glass or crockery, ashes, rags, sweepings and various residues, and fermentable waste; waste from small-scale diffuse activities, traders and craftsmen assimilated to waste produced by households and deposited in containers under the same conditions as waste from households; and assimilated waste of the same nature as household waste, disposed of under the same conditions as that from households, but produced by schools, leisure centres, canteens, healthcare establishments and all public establishments and deposited in waste containers.

In the same category as household wastes are cleaning products and rubbish from halls, fairs, markets, places of public celebrations, and bulk waste that has fallen around its container.

Geographically, the primary source of waste is the cities of Douala and Yaoundé, due to their high populations and economic activity. Lesser but still significant volumes of waste are produced in the regional capitals.

Table 6 Quantities of Waste Generated in Yaounde and Douala

	Waste generated			Waste collected	
	Kg/capita/day	Tonnes/day		Tonnes/day	Tonnes/year
City	Households (HH)	HH	Markets	HH + markets	HH + markets
Douala	0.46	1,600	500	1,344 (64%)	547,500
Yaoundé	0.62	2,100	110	1,100 (49%)	395,300
Total		3,700	610	2,444 (57%)	942,800

Sources: Douala Plan (Government of Douala, 2020); Yaounde census projection (Communauté Urbaine de Yaoundé, 2018)

If the biowaste portion of all of the currently collected waste in Yaounde and Douala were utilizable to produce biogas feedstock for transformation into bioLPG, then, applying a working assumption of a 19:1[1] conversion ratio, this biowaste would support approximately 39,000 tonnes of annual bioLPG production.

The following discussion focuses on Douala, for which more current data were available than Yaounde.

Douala MSW forecast

The following table presents the projected growth of Douala MSW to 2040:

Table 7 Douala MSW Growth Projections to 2040

Category	2021	2026	2031	2036	2040
Household Waste	608,542	753,983	938,487	1,187,547	1,433,136
Market Waste	210,092	247,600	291,806	343 247	390 719
Industrial Waste (Non-Valued Part)	33,018	37,655	45,754	53,818	61,282
Hazardous Industrial Waste	8,331	9,501	11,545	13,580	15,463
Hazardous Hospital Waste	13,221	15,078	18,321	21,550	24,539
Hospital Waste Assimilated to Household Waste	4,965	5,662	6,880	8,093	9,215
Sanitation Waste	4,347	4,957	6,023	7,085	8,068
Total	882,516	1,074,436	1,318,816	1,634,920	1,942,422

Based on the determination that 77% of its market waste is biowaste (Ngnikam) and applying the 19:1 conversion ratio to the biowaste, in 2031 MSW from Douala markets can support a bioLPG plant of approximately 9,200 MT per year. Additional waste needed to support a 10,000+ MT-scale plant would require sourcing from households or industrial sources.

Suitable Feedstock Characteristics for AD

Douala household waste

The leading components of Douala household waste are vegetable waste (63.2% of the gross mass and 48.5% of the dry mass), simple and hygienic textiles (10.5% of the gross mass and 15.1 % of dry mass), and soft and hard plastics (7.2% of wet mass and 10.8% of dry mass). Table B1 in Appendix B2 presents the composition of the Douala household waste; Table B2 presents its recoverability.

[1] 4.9:1 digestible biowaste tonnage to biogas tonnage (Ngnikam); 3.8:1 biogas (approximately 50% methane 50% CO_2 by volume) to bioLPG tonnage (GTI Energy).

Douala market waste

The leading component of market waste is fermentable material. In small and medium-sized markets (under 2,000 establishments), the second-largest component is paper/cardboard and flexible plastics; in large markets (over 2,000), it is textiles.

According to the Douala Plan, approximately 72% of the waste produced in the city's markets is biowaste. Table B3 in Appendix B2 presents the composition of Douala market waste.

Market wastes are, generally, not gathered by a waste management system. To utilise them as a feedstock source (as recommended here) will require expansion of the current level of urban waste collection and transportation activity.

Current Waste Management Systems and its adequacy

All waste generated by households, certain markets, and publics services are collected by duly permitted, contracted operators without any sorting. The municipal council fixes the price per tonne in its waste management systems with the participation of the financial stakeholders (City Councils, Municipal Councils, Ministry of Finance, Ministry of Public Contracts). A significant portion of the feedstock value of household or MSW collected by the main operator is currently lost by burying the waste in landfills (waste disposal sites). All known collected waste presently goes to landfills. Waste brought to the landfill may pass through a sorting operation carried out by specific operators (at their option) to remove recyclable materials, store them, and then send them from the landfill site to recycling facilities.

Collection rate of Douala MSW

The present collection rate of waste in Douala is 64% (560,000 MT in 2022), applicable to household wastes and WSHW, but excluding most market wastes. The Douala Plan calls for this collection rate to rise steadily to 93% by 2040.

Notional Feedstock Supply Chain for an Initial BioLPG Project

For an initial bioLPG plant, it is recommended to obtain and process market waste in Douala, because market waste is adequate in quantity, characteristics, and legal and operational accessibility, and because the public authorities may have incentives and/or obligations to support financially its management or transformation. Trucking, sorting and AD might cause bioLPG all-in costs to be higher than the desired targets, prior to any economic optimization of the project. The potential for economic optimization should be a key focus of follow-on study.

To achieve larger-scale bioLPG production in a conurbation such as Douala, household waste must be sourced. Determination of the optimal household waste and biogas supply chains for Douala and other conurbations, the chains' geography, and their economics must be the subject of future study.

Figure B1 in Appendix B3 shows the recommended MSW-to-bioLPG supply chain utilizing Douala market wastes, process yields, and notional costs for each step. Figure B2 in Appendix B3 shows a map of potential consolidation sites in Douala that could facilitate transport optimization.

Economic Characteristics of the Waste Handling and Feedstock Chain

As shown in the feedstock supply chain diagram (Figure B1 in Appendix B3), per 1,000 MT of MSW, the following indicative costs would apply:

Table 8 Feedstock supply chain cost estimates

Item	Quantity		Unit cost	Cost to: Project	Municipality	Purchaser
MSW	1,000	t	$0.0	$0		
Biowaste portion	770	t	$0.0	$0		
Trucking of biowaste	770	t	$32.8	$25,256		
Trucking of non-biowaste	230	t	$35.0		$8,050	
Landfill cost (non-biowaste)	230	t	$10.0		$2,300	
Sorting and anaerobic digestion (AD)	770	t				
Operating cost			$14.7	$11,319		
Capital cost			$11.2	$8,586		
Trucking of rejects and digestate	475	t	$10.0			$4,750
Income from rejects and digestate	275	t	TBD	TBD		
Landfill cost (rejects/digestate)	475	t	$10.0		$4,750	
Biogas produced by AD	158	t	N/A			
BioLPG output from Cool LPG	41	t	TBD			
Total cost*				$45,161	$15,100	$4,750
Cost per t of bioLPG output*				$1,096	$367	$115

* Excludes potential income stream from rejects and digestate and cost to transform biogas to bioLPG

The cost per tonne of bioLPG, whether or not competitive in the local market after LPG subsidies are applied, is highly sensitive to the trucking of biowaste, the sorting and AD step, and the yields from each step. Further study must determine whether the foregoing process can be optimized, which costs can be shared with interested third parties in the public or private sector, and what income streams can be realized, resulting in a lower net cost per tonne of bioLPG produced.

Climate and Sustainability Impacts

The BLPGWG estimated that bioLPG production at a scale of approximately 60,000 MT per annum could contribute an estimated 4.6 million tCO_2eq or more per year toward Cameroon's NDC goals, representing 11% of the country's conditional target of 42 million tCO_2eq of GHG reductions and 33% of the unconditional target of 14 million tCO_2eq.

Key co-benefits as of 2030 include 22-25 million trees saved annually, 1,000-1,400 premature deaths averted, and 54 – 55 million CFA of trade balance benefit. Table B4 in Appendix B4 summarizes the expected range of climate benefits and co-benefits.

4.2.5 Conclusions, data gap, remaining issues

An urban bioLPG plant is dependent on aggregation of adequate biogas, which today can be obtained in Cameroon conurbations from (a) AD of market wastes, which must be gathered from markets, transported, and sorted prior to digestion; (b) numerous household-scale, highly localized projects, in which the biogas is used directly as a local energy source, (c) AD at or near large-scale landfills containing household wastes, and (d) AD of presently uncollected household wastes, which must be gathered, transported, and sorted prior to digestion. Each pathway presents its own questions and challenges regarding cost, scale, practicality, and rights that must be obtained.

Urban market waste is available in suitable quantity and composition in major Cameroonian cities for feeding bioLPG plants. Creating a first MSW-to-biogas-to-bioLPG project would require economic and policy structures to be created. To feed larger-scale plants, household waste would have to be aggregated, processed and linked to AD and bioLPG operations.

Follow-on analysis should include detailed techno-economic evaluation of AD to be built and operated locally and of how to improve the waste and biowaste transport logistics and costs for providing sufficient feedstock to bioLPG plants.

4.3 Rwanda

4.3.1 Rwanda Overview

The population of Rwanda, in 2022, was 13.2 million, with a life expectancy of 69.6 years. Rwanda's capital city Kigali covers 730 km^2 and has a population of approximately 1.7 million. The projected population growth over the next three decades is significant with rapid population growth and urbanisation quickly leading to higher population density and intensifying waste management challenges. To address these challenges, the city government has adopted a public-private partnership (PPP) model, licensing 14 waste collection companies for solid waste collection and transportation.

4.3.2 Policy Commitment and Enabling Environment

Rwanda has made a commitment under its NDCs to address MSW and promote sustainable waste management practices. The NDCs includes the activity "waste as resource" with a high priority level, focusing on the solid waste sub-sector. The purpose of this activity is mitigation within the waste sector.

The regulatory framework and policies in Rwanda pertaining to waste management and environmental protection are designed to address waste collection, treatment, recycling, and disposal, and promote sustainable practices such as circular economy innovations, MSW-to-energy systems, and efficient separation processes.

These laws and policies include Law N° 43/2013 governing land, the National Sanitation Policy (2016), Guidelines on the Management of Waste Disposal Site (2009), Regulation of Solid Waste Recycling (2015), National Environment and Climate Change Policy (2019), Industrial Policy (2011), National Land Policy (2019), Energy Policy (2015), and the Energy Sector Strategic Plan (ESSP) (further details in Appendix C1).

Additionally, laws relating to the environment (e.g., No. 47/2018) provide a comprehensive legal framework for environmental protection including solid waste management. The National Waste Management Strategy (2019-2024) outlines Rwanda's vision and objectives for waste management, while the Ministerial Order on Technical Requirements for Waste Management Facilities (2019) establishes technical standards for waste management facilities. The Rwanda Sanitation Master Plan (2021) recommends the use of sanitary landfills for solid waste disposal, and the Revised Green Growth and Climate Resilience National Strategy for Climate Change and Low Carbon Development (Sept 2022) aims to leverage solid waste as a resource for green growth and climate resilience.

These regulations and policies are complemented by specific initiatives such as the Feasibility Study for Municipal Solid Waste Management in Kigali (WASAC 2021), which assesses the feasibility of implementing a comprehensive waste management system in the city.

Due to the recommendation and potential imminent installation of a sanitary engineered landfill in Kigali, this case study provides an insight into the acquisition of landfill gas alongside AD-derived biogas.

4.3.3 Ground-Truthing Methodology

The methodology for investigation of the landfill gas/biogas production suitability of Kigali followed a systematic approach to gathering and analysing secondary data. The primary focus was on existing documentation, including policies, guidelines, and the Feasibility Study for a Municipal Solid Waste Management System (WASAC, 2021) for Kigali City. Relevant data and information were extracted from the Feasibility Study (WASAC, 2021), including financial projections, cost estimates, and regulatory requirements.

Stakeholder Sampling

To ensure the accuracy and reliability of the collected data, cross-checking was conducted with external sources, market research studies, and other government publications. Furthermore, direct contact with relevant entities such as WASAC, RURA, and Kigali City Council was made to obtain additional information or clarification.

Data Analysis Techniques

This data was then analysed in the context of landfill gas/biogas production and a prospective Cool LPG Project. This analysis included comparing the feasibility study scenario with alternative options, identifying trends, assessing limitations, and drawing conclusions based on the available information.

4.3.4 Country Data Required by the Framework

Physical MSW Potential (Feedstock Quantity Sufficiency)

The waste projections for urban areas of Kigali City from 2020 to 2050 indicate an increasing trend in waste generation. The projections show the quantities of different waste types, including bio-degradable waste, recyclables, and inert and other waste. The total waste generated is expected to increase from the approximate 314,995 tonnes generated currently per annum to 567,000 tonnes per annum by 2050 (WASAC, 2021).

These projections highlight the growing need for an effective waste management system to handle the increasing amounts of waste generated in Kigali City. It underscores the importance of sustainable waste management practices, including proper waste segregation, recycling, and waste-to-energy initiatives, to address the challenges posed by the rising population and waste generation.

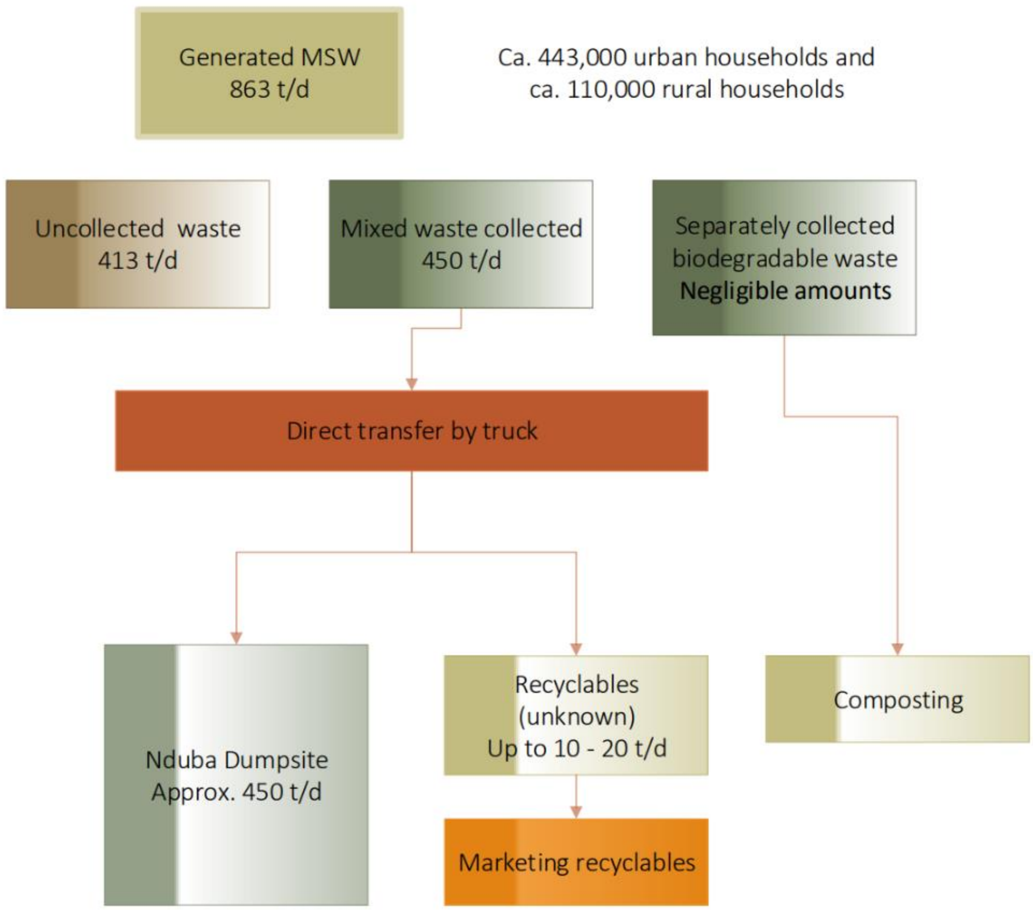


Figure 11 Kigali MSW quantities and flow in 2020
Source: WASAC (2021)

Suitability of Feedstock Characteristics for AD

Solid waste generated in the Kigali service area comes from various sources, including industry, agriculture, and households.

The study identifies three main waste types: biodegradable waste, recyclables, and inert and other waste. Biodegradable waste accounts for the largest proportion of the waste stream at 64%, followed by recyclables at 21%, and inert and other waste at 15%. Based on the SWM Feasibility Study (WASAC, 2021) this equates to around 552 tonnes of biodegradable waste produced in Kigali per day of which a negligible amount is currently segregated as OFMSW.

The laws and regulations in place highlight the significance of managing hazardous and electronic waste responsibly to protect the environment and human well-being.

Current Waste Management Systems

Currently, waste management practices in Rwanda primarily follow a "collect and dump" approach or waste is uncollected as shown in Figure 11. This system lacks any organised waste segregation that could be harnessed to provide biogas feedstock. However, there are currently a number of plans, ranging in investment necessity, to upgrade Kigali's waste management system to one that is potentially very compatible with the production of biogas.

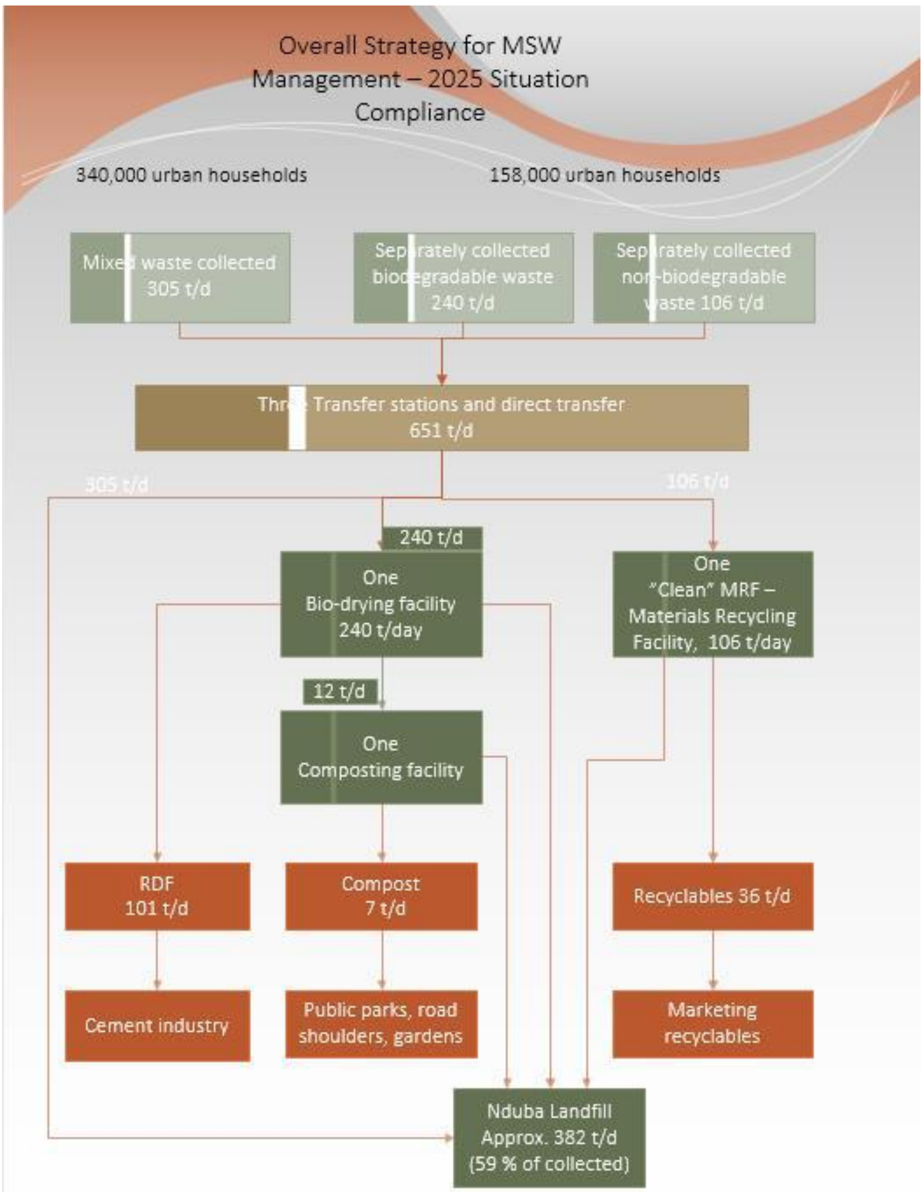


Figure 12 Waste flow diagram 2025-2035
Source: WASAC (2021)

One scenario includes the incineration of waste whilst another would involve the development of a sanitary landfill with advanced waste separation and recycling. The later scenario would be highly suitable for a bioLPG project due to the proposed separation of OFMSW for compost production and the potential to source landfill gas from the engineered landfill. Figure 13 shows the hypothetical replacement of composting facilities with AD and Cool LPG production.

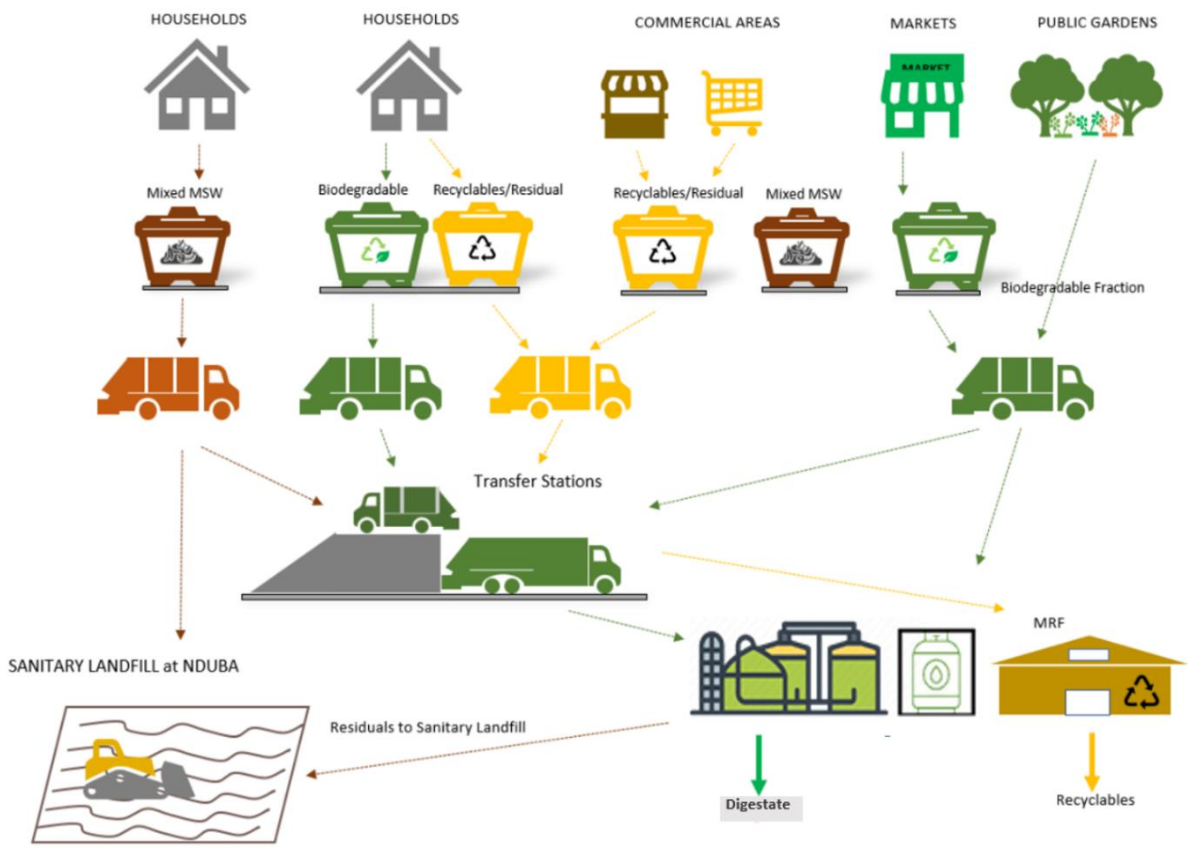


Figure 13 Integration of AD and Bio LPG plants in the proposed MSW Management Plan
Source: WASAC (2021)

Adequacy of the Waste Handling Infrastructure Chain

The Nduba landfill is projected to reach its limit by 2036-2037 without waste diversion initiatives. To support the waste management system, plans are underway to improve the access road to the landfill area and pave access and neighbourhood roads in high-density areas of Kigali.

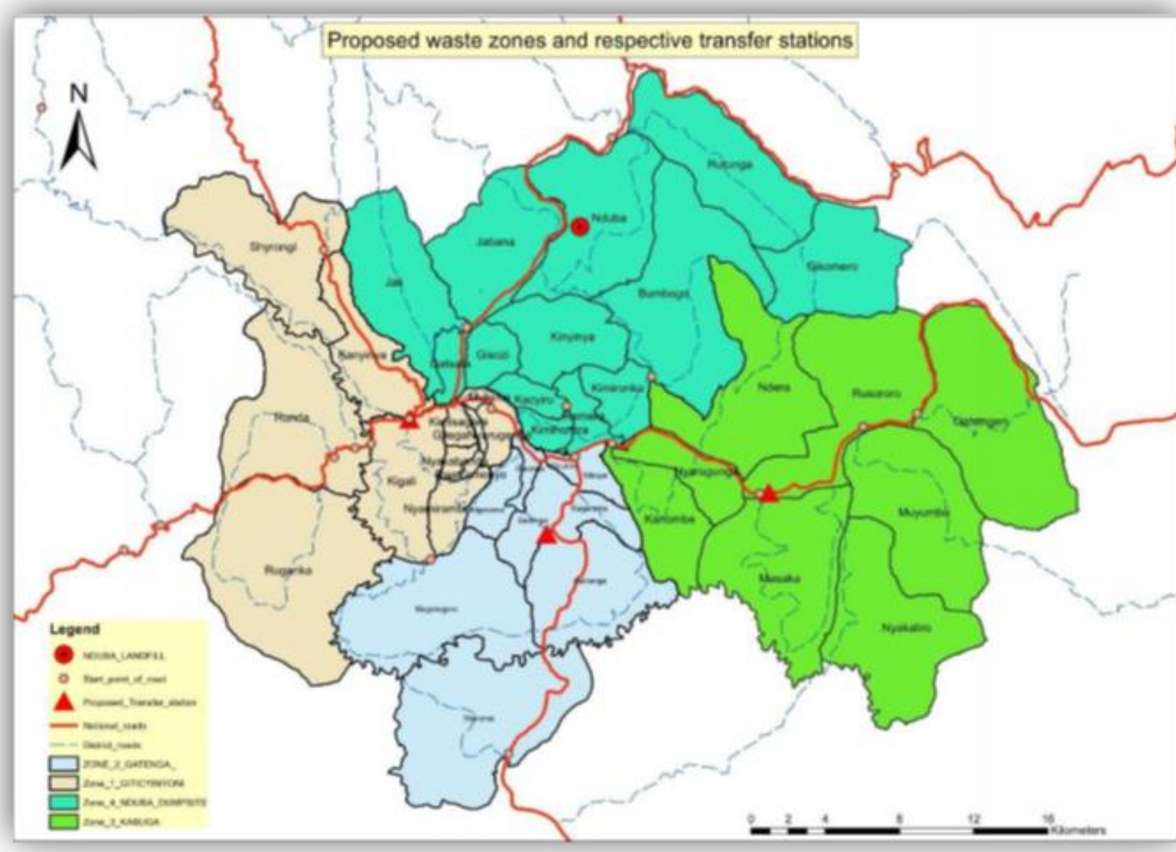


Figure 14 Catchment areas for three transfer stations in Kigali
Source: Kigali MSW Feasibility Study (2021)

Climate and Sustainability Impacts

Reduction of GHG Emissions: The proposed waste management system is expected to contribute significantly to the reduction of GHG emissions. Over the period from 2025 to 2050, it is estimated that approximately 6.9 million tons of CO_2 equivalents will be avoided.

Occupational Health and Public Health Improvements: The implementation of the proposed waste management system is expected to lead to significant improvements in occupational health and public health. Proper waste management practices can reduce health hazards associated with waste handling and disposal, leading to a healthier and safer working environment for waste management workers.

Surface and Groundwater Conditions: The proposed waste management system is likely to have positive effects on surface and groundwater conditions. Proper waste disposal practices can prevent leaching of harmful substances into the soil and groundwater, reducing the contamination of water resources and protecting ecosystems.

The implementation of the proposed waste management system is expected to have positive effects on various other environmental conditions. This includes improvements in litter control, reduced dust and odour emissions, and overall enhancements in the local environment's cleanliness and aesthetics.

Table 9 CO_2 emission reductions and replacement, Kigali 2025-2050

CO_2 emission reduction	2025-2050
Total CO_2 emissions without project	11,292,178
Total CO_2 emissions with project	4,044,531
Displaced emissions through generation from clean sources	266,112
Total avoided CO_2 emissions	6,981,535

4.3.5 Conclusions, data gap, remaining issues

The current MSW management systems in Kigali presents challenge, including high population density, pollution, land degradation, and inadequate waste treatment. The lack of waste segregation, low recycling rates, and non-compliance with waste management guidelines further exacerbate the issues.

The Kigali urban and peri-urban region generates sufficient quantities of OFMSW, but the study was not able to source adequate data to characterize the potential feedstock in terms of composition and biogas yields. Additionally, at present the current waste management system cannot effectively be harnessed to provide organic feedstock to ADs. However, near-term plans put forward by the Rwandan government would, if implemented, result in a system highly compatible with the requirements of an AD system.

The integration of AD and a Cool LPG facility in the planned MSW management system in Kigali would help achieve waste reduction, renewable energy production, and improved environmental sustainability, supporting the city's transition to a circular economy.

5 Techno-Economic Analysis (TEA) of bioLPG production and its financing considerations

5.1 Introduction

The detailed analytical framework presented in Section 3 and the ground-truthing data from Kenya, Rwanda and Cameroon presented in Section 4 will now be integrated into a model TEA scenario for a hypothesized "First Of A Kind" (FOAK) project in Kenya (Nairobi). The TEA combines reasonable assumptions and hard data to generate a projected investment case which can be replicated in methodology to model other cases.

Assumptions will be stated in detail, together with sources and justifications. The financial model will use stated structure and cost of capital assumptions to present an estimated project net present value and cash flow (CFL). Key parameters, project risks and risk mitigations will be identified and defined and presented in standard terminology.

Sensitivity analyses will be offered, to illustrate the impact of changes in key variables. Project cost data are generic, but project LPG sales revenue is projected from Nairobi data. The expected trend of key costs will be toward cost reduction, as learnings from the FOAK are used in design, construction and operation of following plants. Carbon prices are expected to rise over time and this possibility is conservatively illustrated.

The TEA makes clear that subsidy support for biofuel production, possibly at or near the level presently extended by the EU and the US to their biofuels producers, is needed to make the financial feasibility of the hypothesized project viable. The finance structure and costing of each finance component proposed in the TEA deliver the needed subsidy effect, but alternative structure and pricing combinations can be devised to deliver the same overall financial result.

The implication for African countries is that, in their ongoing discussions with Global North development partners, support of nascent African biofuels industry projects (as represented by waste-to-bioLPG) would be an important and impactful collaboration topic.

The appropriate perspectives to be taken in planning and arranging financing are threefold:

a. The Government of Kenya (GoK) and its international development partners should view the development of a waste-to-energy facility as a FOAK integrated waste/biogas/bioLPG project that demonstrates innovative technology in real world continuous operation.
b. GoK and its international development partners should view the project goals as (1) creating technology improvement and operating learnings that enable future commitments to larger plants offering improved economic results, (2) creating the policies and policy coordination capacity that will enable future waste-to-bioLPG projects to be developed efficiently and to be financeable in domestic and international capital markets, and (3) creating a set of linked public goods that collectively represent a new path, if implemented more widely, to achieving significant improvement in citizen quality

of life (sanitation, health, domestic renewable energy supply, clean cooking fuel, and circular economy)

c. In the financing of an actual project, the GoK should seek from its international partners funding assistance in magnitude and nature which mimics the effectiveness of the support structures that those partner governments offer their own energy companies to help bring to life their nascent industries. This assistance could include grants and concessionary loan or guarantee facilities which, in turn, might encourage other funders to offer attractive long-term finance facilities and equity investment.

5.2 Production system from waste generation to bioLPG

To present waste-to-bioLPG to providers of financing and risk mitigation and to engage their interest, it will be necessary to communicate the goals which the project is addressing. The feasibility and financing analysis must define "what is being financed, and why." The range of partners for funding includes local and national governments, development finance institutions (DFIs), impact/ESG/SDG funds and commercial investors/lenders.

The Study team has taken the view that the project might be organized as a GoK project and that GoK might communicate to international development partners a FOAK project is being proposed to achieve the following goals:

a) Demonstrate circular economy production of bioenergy from waste by an integrated waste-to-biogas-to-Cool LPG project, with demonstration of co-benefits from GHG emissions reductions and reduction of unhealthy air pollution.

b) Plan, finance, construct and operate a robust integrated waste-to-biogas-to-Cool LPG FOAK, SSA demonstration project whose learnings will stimulate replication as well as continued process and operational improvements that will reduce cost.

c) Evolve the municipal waste handling policies, structures and enabling environment in Kenya.

d) Evidence GoK capacity to plan and carry out a FOAK technology project of scale.

e) Create a new and sizeable biofuel sector that can advance Kenyan credibility on NDCs and African renewable energy leadership.

f) Persuade international development partners that the project addresses important priorities for them: Sub-Saharan Africa development, renewable energy, clean cooking fuel, import substitution, modern waste management, public health, deforestation mitigation, and circular economy use of wastes.

The projected project revenues and operational costs over a 25-year period demonstrate adequate amounts of positive operational cash flow, but also a clear inability to amortize the projected capital investment if financed at market rates and maturities. The Study concludes that concessional finance is required, such as domestic government fiscal preferences and international institution long-term "soft" loans on concessionary terms, subsidies, guarantees and pure grants.

The text below Table 10 presents the assumptions used in the TEA and its accompanying model financing plan. Table 10 presents the key assumptions in table form.

Table 10 Key economic variables

Key Financial Data

REVENUES	**Year 1**	**Yrs 2-25**	***TOTALS***
Revs from Ops	$6,292,500	$201,360,000	$207,652,500
			$111,227,738
Carbon Offsets	$3,370,538	$107,857,200	
	$9,663,038	***$309,217,200***	***$318,880,238***
EXPENSES			
Variable Costs	($2,539,046)	($159,873,480)	($162,412,526)
Fixed Expenses	($2,710,739)	($65,057,726)	($67,768,465)
Start-Up Costs	($12,882,196)		($12,882,196)
	($18,131,981)	***($224,931,206)***	($243,063,187)
EBITDA	***($8,468,943)***	***$84,285,994***	***$75,817,050***

CAPEX			
Total Capital Requirement	**Construction Period 1**	**Contruction Period 2**	***TOTALS***
a) AD Plant	($10,362,689)	($15,544,034)	($25,906,723)
b) Cool Plant LPG	($15,544,034)	($23,316,050)	($38,860,084)
Costs (AD+CoolLPG)	***($25,906,723)***	***($38,860,084)***	***($64,766,807)***

Cash Flow Sensititivites

	25 Years		**25 Years**
	Discounted EBITDA (CFL)*		***Discounted EBITDA (CFL)****
8.0%	($34,674,050)	8.0%	$22,629,915
9.0%	($36,692,154)	9.0%	$19,783,237
10.0%	($38,323,441)	10.0%	$17,343,897
11.0%	($39,634,486)	11.0%	$15,244,620
12.0%	($40,679,497)	12.0%	$13,430,527
13.0%	($41,502,793)	13.0%	$11,856,656

** Includes all CapEx*

** Excludes CapEx*

Key Assumptions:

A. Revenue is two-fold.

1) **<u>Operational Revenues</u>** are derived from the sale of bioLPG in the marketplace, and they are expected to occur in the form of offtake contracts from the bioLPG plant. The Study uses as its pricing benchmark the fossil LPG wholesale price in Nairobi of $839/tonne. Thus a 10,000 tonne/year Cool LPG plant would generate $8.4 million revenue per year.

2) **<u>Carbon Credits</u>** can be derived from switching household energy use from biomass, such as wood and charcoal, to bioLPG. Urban Kenyan households would save the CO_2 equivalent of 18 tonnes per year for each tonne of bioLPG they use, leading to a reduction of 180,000 tonnes of CO_2 equivalent.

The carbon credit assumptions include:

- baseline cooking uses the urban Kenyan mix of fuels; in the project period, the household transitions to LPG, using 80kg/year, at 60% cooking efficiency (Bailis, 2015, Kenya average).
- applying the MMECD calculator, which implements IPCC default values for emission factors, the baseline emissions are 1.9 tCO2e/household/year;
- project period emissions are assumed to be zero, as bioLPG is treated as a renewable fuel. A credit price range of $8 to $30 per tonne is proposed, based on recent market trends and evolution of the Paris article 6 mechanisms. The Study used $25/tonne, which would yield additional revenue of $4.5 million per year.

B. Operating Expenses

TEA uses generic estimates, not country specific estimates. The most significant expense categories impacting economic feasibility include the following:

1) **<u>MSW Sorting and AD</u>**. The waste is assumed to be delivered to the AD facility at no cost to the project, which then bears the expense of separating the organic component from the inorganic component and then converts the organic component into biogas. This shows up in the model as feedstock cost.

2) **<u>Cool LPG Catalyst.</u>** This cost is governed by two factors: (a) the unit cost of the catalyst; (b) the frequency of catalyst replacement, which is presently projected every other year.

3) Start-Up Costs. The major item is initial catalyst fill.

C. Capital Expenditures (Capex):

1) **<u>The cost of the AD facility</u>** is estimated at $25.9 million, or 40% of the cost of the integrated plant.

2) **<u>The cost of the Cool LPG</u>** plant is estimated at $38.9 million, or 60% of the integrated plant.

3) **<u>The Capex</u>** includes direct and indirect cost as well as a 15% contingency.

4) **<u>The Phasing of the bioLPG plant investment</u>** assumes 40% in construction year 1 and 60% in year 2.

These revenues, expenses, and capital costs are summarized in Table 10.

D. Net Cash Flow Analysis

Operational revenue handily covers projected yearly operational expenses, but not the annual outflows necessary to service the market rate debt and equity that would be needed to provide the initial $65 million plant capital investment. The capital investment can only be amortized if financed by non-commercial soft financing from DFIs, donors, development partner governments, impact investors and blended capital sources. Indirect financial support in the form of first-loss guarantees from DFIs, donors, foundations, and impact investors might also be able to mobilize primary capital.

Cash Flow analyses:

1) The cumulative, non-discounted Net Cash Flow before financing costs is approximately $75.8 million ($3.5 million per year in the final 24 years of the 25-year plant life). This analysis assumes that all years during the 25-year life after commissioning are cash flow positive, steady-state operations with the exception of Year-1 negative cash flow due to start-up costs. The Year 1 negative cash flow is assumed to be financed by a debt facility secured by the project assets.
2) Discounting the Net Cash Flow using a range of discount rates from 8% to 13% produces the results seen in Table 10 – presented in two scenarios: (1) with Capex payments included and (2) without Capex payments included.
3) Excluding the Capex cost results in a positive net discounted cash flow of $22.6 million at an 8% discount rate.
4) However, including the Capex cost results in a negative net discounted cash flow of $34.76 million at an 8% discount rate.
5) A tax holiday on the investment is assumed to be provided to the project.

E. Potential Financing Terms

To analyze Capex financing options, the Study team determined the strength of operational cash flows of the integrated plant, excluding coverage of Capex. Plant operations as modelled demonstrated the capacity for continuous positive operational cash flow generation over the assumed 25-year project life span. As seen in Table 10, the projected EBITDA is approximately $76 million, taking into account Year 1 start-up cost.

To handle the projected capex of $65 million, external funding would need to be amortizable by the positive cash flow from operations. Finance sources will focus on key levers of cash flow: on the revenue side, LPG sales price and carbon credits; on the operational expense side, most importantly, the catalyst cost. The impact on Net Cash Flow of changes in these variables are illustrated in the sensitivity analyses presented in Table 12 and Table 13.

The modelled operational Net Cash Flow can support (1) debt that covers 65% of required financing if concessional terms of 6% fixed interest rate and 25 year loan tenor are provided, and (2) GoK or some other source provides 35% of the capital as equity or grants (with no imposition on operating cash flows).

The Study team would suggest a focus on funding sources that are mandated to support projects that offer one or more of the following characteristics: impactful energy sector innovation, climate change mitigation potential, environmental preservation, Africa-focused. The first set of organizations to be approached would be leading DFIs which are mandated and equipped to fund the transaction size and terms proposed in this TEA. Publicly available institutional information and transaction data suggests that this project might be of interest, if properly presented.

The proposed Plant financing model:

a) GoK provides 35% of the Capex.

b) The project seeks guarantees or first loss options from funders who have experience in providing these types of facilities which would lower capital costs.

c) Borrow the remaining 65% of the Capex requirement, with (i) a 25-year maturity, (ii) a concessionary interest rate of 6% , (iii) a three-year grace period before principal repayment. Loan amortization is modeled as equal principal/ declining interest payments for the final 22 years (Development Finance Institutions have extended loan facilities on such terms).

Table 11 below presents the cash flow over project life according to the foregoing model terms:

Table 11 Cashflows

Sources & Uses Analysis						
	Financing Scenarios	***Govt Pays***				
CapEx Total	$64,766,807	35.0%				
			Terms on Remaining Financed Piece			
Govt Pays %	**Piece Funded by Govt**	**Remaining Piece for Fundng**	**Grace Period Years**	**Repayment Periods (Yrs)**	**Interest Rate**	**Straightline Amort/Yr**
35.0%	$22,668,382	$42,098,424	3.0	22.0	6.0%	$1,913,565

Debt versus CFL Analysis

Year	Beg Balance	Principal Pmt	End of Period	Interest	TOTAL Pmts	EBITDA	Remaining CFL After Pmts
1	$42,098,424	$0	$42,098,424	$0	$0	($8,468,943)	($8,468,943)
2	$42,098,424	$0	$42,098,424	$0	$0	$3,511,916	$3,511,916
3	$42,098,424	$0	$42,098,424	$0	$0	$3,511,916	$3,511,916
4	$42,098,424	($1,913,565)	$40,184,860	($2,468,499)	($4,382,063)	$3,511,916	($870,147)
5	$40,184,860	($1,913,565)	$38,271,295	($2,353,685)	($4,267,249)	$3,511,916	($755,333)
6	$38,271,295	($1,913,565)	$36,357,730	($2,238,871)	($4,152,435)	$3,511,916	($640,519)
7	$36,357,730	($1,913,565)	$34,444,165	($2,124,057)	($4,037,622)	$3,511,916	($525,705)
8	$34,444,165	($1,913,565)	$32,530,601	($2,009,243)	($3,922,808)	$3,511,916	($410,891)
9	$32,530,601	($1,913,565)	$30,617,036	($1,894,429)	($3,807,994)	$3,511,916	($296,077)
10	$30,617,036	($1,913,565)	$28,703,471	($1,779,615)	($3,693,180)	$3,511,916	($181,264)
11	$28,703,471	($1,913,565)	$26,789,906	($1,664,801)	($3,578,366)	$3,511,916	($66,450)
12	$26,789,906	($1,913,565)	$24,876,342	($1,549,987)	($3,463,552)	$3,511,916	$48,364
13	$24,876,342	($1,913,565)	$22,962,777	($1,435,174)	($3,348,738)	$3,511,916	$163,178
14	$22,962,777	($1,913,565)	$21,049,212	($1,320,360)	($3,233,924)	$3,511,916	$277,992
15	$21,049,212	($1,913,565)	$19,135,647	($1,205,546)	($3,119,111)	$3,511,916	$392,806
16	$19,135,647	($1,913,565)	$17,222,083	($1,090,732)	($3,004,297)	$3,511,916	$507,620
17	$17,222,083	($1,913,565)	$15,308,518	($975,918)	($2,889,483)	$3,511,916	$622,434
18	$15,308,518	($1,913,565)	$13,394,953	($861,104)	($2,774,669)	$3,511,916	$737,248
19	$13,394,953	($1,913,565)	$11,481,388	($746,290)	($2,659,855)	$3,511,916	$852,061
20	$11,481,388	($1,913,565)	$9,567,824	($631,476)	($2,545,041)	$3,511,916	$966,875
21	$9,567,824	($1,913,565)	$7,654,259	($516,662)	($2,430,227)	$3,511,916	$1,081,689
22	$7,654,259	($1,913,565)	$5,740,694	($401,849)	($2,315,413)	$3,511,916	$1,196,503
23	$5,740,694	($1,913,565)	$3,827,129	($287,035)	($2,200,599)	$3,511,916	$1,311,317
24	$3,827,129	($1,913,565)	$1,913,565	($172,221)	($2,085,786)	$3,511,916	$1,426,131
25	$1,913,565	($1,913,565)	$0	($57,407)	($1,970,972)	$3,511,916	$1,540,945
TOTAL		***($42,098,424)***		***($27,784,960)***	***($69,883,384)***	***$75,817,050***	***$5,933,666***

F. Financing Plan

1) The targeted funders to be approached would be developmental institutions, governments of development partners, impact investors and the project host country government.
2) Assemble complementary sources of capital which can as a group offer (a) the right mix of grants, guarantees, debt and equity, and (b) long-term facilities at concessionary interest rates, with helpful moratoria and risk mitigation mechanisms.
3) GoK and its development partners could consider creation and funding of financial support structures which mirror Global North government biofuel sector programs.

G. **The value of sensitivity analyses in preparing for further projects after the FOAK**

The Study has described the variables which have the most influence on project cash flows. The trajectory of process and cost improvements can be envisaged clearly. The possible magnitude of future changes in key variables can indicate the potential financial case for considering future iterations of bioLPG production.

The study team identified the following potential upsides in the cash flow/EBITDA. These include:

1) Expected optimization of the bioLPG process will resulting in lower Capex and Opex per unit of production capacity.

2) Expected progress in lowering catalyst utilization and cost. Catalyst costs presently represent approximately 50% of the variable cost of Cool LPG production .
3) Expected economies of scale from increasing plant size. GTI Energy has modelled increases in plant size and the results indicate the probability of substantial decreases in unit production costs.
4) A higher carbon credit (increasing from $25 to $30 per tonne of CO_{2eq}).
5) An increase in the selling price of bioLPG if LPG marketers are required to blend a certain percentage of green LPG in their product (see Global North policies requiring blending of green fuels with fossil fuels and the price consequences for green fuels of such policies). An increase in the price of bioLPG from a fossil LPG price of $839/tonne to $1,200/tonne would increase EBITDA from $3.5 to $7.1 million per year.

Table 12 and Table 13 show the impacts of changing key variables

The first table shows the impacts of price increases while the second demonstrates the positive impact of catalyst cost savings.

Table 12 Sensitivity results, pricing

	Sensitivity Variables			Results		
					NPV @ Discount Rate	
Rev/Pricing Increase Scenarios	LPG Price/ton	Carbon Price	Catalyst Cost	EBITDA	8%	13%
Base Case	$839.0	$25.0	Nominal	$3.5	($34.7)	($41.5)
W/ Carbon Price Increase	$839.0	$30.0	Nominal	$4.4	($26.6)	($36.5)
LPG Price Increase	$1,200.0	$25.0	Nominal	$7.1	($2.3)	($21.4)
w/ Carbon Price Increase	$1,200.0	$30.0	Nominal	$8.0	$5.7	($16.4)

Table 13 Sensitivity results, reduced cost

	Sensitivity Variables			Results		
					NPV @ Discount Rate	
W/ Reductions in Catalyst Exp	LPG Price/ton	Carbon Price	Catalyst Cost	EBITDA	8%	13%
Base Case	$839.0	$25.0	-30.0%	$4.5	($24.5)	($35.0)
w/ Carbon Price Increase	$839.0	$30.0	-30.0%	$5.4	($16.9)	($30.2)
LPG Price Increase	$1,200.0	$25.0	-30.0%	$8.1	$7.4	($15.1)
w/ Carbon Price Increase	$1,200.0	$30.0	-30.0%	$9.0	$15.5	($10.1)

Expected improvements in some or all of the illustrated operating factors will enable future projects to access a wider and deeper range of public and private capital sources.

5.3 SDG benefits for the whole supply chain system

Section 5.2 presented the financial costs, revenues and GHG benefits (in the form of carbon credits) for a FOAK 10,000 tonnes/year demonstration plant.

This section 5.3 estimates the wider set of environmental, social and key economic benefits that would be associated with bioLPG production and use at significant scale for Kenya.

In the earlier analysis, GHG emission benefits are restricted to the end-use emissions avoided by substituting a renewable fuel for the mix of traditional fuels, as these are the emissions that can be monetised through carbon credit markets. This section includes a first estimation of the changes in the wider supply-chain emissions for the introduction of waste to biogas to bioLPG. The appropriate methodologies and system scope were discussed in section 3.4.2, including the uncertainties in this type of analysis.

Table 14 sets out the scenarios for comparison: the existing position with cooking needs met by a mix of traditional fuels and waste being dumped, and an alternative scenario with substitution of bioLPG for cooking, and associated diversion of waste into the production of biogas as feedstock.

Table 14 GHG emissions across the full supply chain

Project scenario: Waste-Biogas-BioLPG	**Counterfactual: waste to dump; cooking with traditional fuels**	**GHG difference**
CO2eq from transport of waste to plant at dumpsite	CO2eq from transport of waste to dumpsite	None
Captured biogas from rapid digestion of waste via AD	Released biogas from slow natural decomposition of waste at landfill (1)	Net avoided: amount of captured biogas (CO2 + CH4)
Waste gas (CO2) from Cool LPG process	CO2eq from production of equivalent energy-quantity of traditional fuels (e.g., charcoal) that will be displaced (2)	Net addition: amount of waste gas from Cool LPG - the GHG from production of rival biomass fuels (small, hard to quantify)
CO2eq from the packaging and transport of bioLPG in cylinders to market	CO2eq from the packaging and transport of equivalent energy-quantity (at point of end use) of charcoal and firewood etc. to market	Expected to be small; not easily quantified
CO2eq from end-use combustion of bioLPG, mainly for cooking (3)	CO2eq from end-use combustion of the displaced biomass fuels, mainly for cooking (4)	Net avoided: end-use GHG from traditional fuels displaced

(*1) This assumes that the biowaste, if not used for bioLPG, will not be used for anything else*

(2) GLPGP's national reports on Cameroon, Kenya and Rwanda quantify the amounts and mix of the displaced fuels but not the CO2eq involved in their creation

(3) BioLPG will be regarded as a renewable fuel (as biogas is), as the emissions are biogenic carbon: carbon that is stored in biological materials

(4) Displaced emissions only from the fraction of fuel that is from unsustainable biomass sources

The methodologies used to calculate the various impacts include:

- Net CO2eq benefits are computed in two parts:
    - At point of combustion, such as for cooking, when displacing the existing non-LPG fuel mix, following the MMECD standard as discussed in section 5.2. This part may be

monetized; a credit price of $25 per tonne is used, following the approach in section 5.2.

  - In the AD stage of the bioLPG facility, where MSW that would otherwise be in a landfill and emit GHG into the atmosphere is used instead to create captured biogas as feedstock to the Cool LPG process. This additional part may not be readily monetised but this is included in the results to demonstrate the additional social value.
  - The AD stage benefits were determined from the biogas mix (CO2 and CH4) and amounts presently created per tonne of urban MSW in the country, using Paris Agreement weighting factors. It was assumed that the GHG created by the AD as Cool LPG feedstock would equal the amount eventually released into the atmosphere from landfill, if the MSW had gone there instead.

- All co-benefits are calculated based on the findings of the GLPGP National LPG Feasibility and Investment Report for Kenya (GLPGP 2019b)
- The GLPGP report used published research data on the prevailing mix of non-LPG fuels that would be partially displaced by LPG for cooking (it is partial due to continued fuel stacking) based on LPG's economic viability and other factors, and the anticipated rate of LPG adoption growth and consumption growth under a business-as-usual and interventional scenario.
- The benefits and costs/harms of LPG taken from the literature and from large-scale national survey datasets were compared at the household level with the benefits and costs/harms of the displaced fuels similarly obtained, and then the differences scaled according to the LPG growth scenario.
- By comparing the co-benefit quantities across the two scenarios and the difference in LPG consumption (in tonnes) across the two scenarios, one may ascertain a per-tonne value for each co-benefit from the additional LPG—in this case, bioLPG—that enters the market for cooking.
- Once the per-LPG-tonne values were determined, they were scaled to 10,000 tonnes per year of bioLPG output. These data are shown in the results.

Table 15 presents the GHG benefits, and the set of co-benefits for a plant producing 10,000 tonnes/year bioLPG. The first row shows the end-use stage emission reductions, and at the bottom of the table are the full supply chain estimates. In practice it may not be feasible to fully monetise the total supply chain emission reductions, but they represent social economic value.

Table 15 SDG benefits for bioLPG in Kenya

Annual impacts of 10,000 tpa from bioLPG plants	
tCO2eq residential emissions averted [a]	179,869
Potential price per tCO2eq in 2030 [b]	$25.0
tCO2eq economic value [a,b]	$ 4.5 mio
BCeq emissions averted [a]	7.9 mio
Trees saved [a]	84.8 mio
Averted premature deaths [a]	115
Avoided Disability Adjusted Life Years (DALYs) [a]	6,088
Consumer net energy spending savings [a]	$ 1.4 mio
Value of labor time saved [a]	$ 0.3 mio
Trade balance benefit, vs importing all LPG as fossil LPG [a]	1,677 mio KSh
tCO2eq emissions averted from MSW repurposing to bioLPG [c]	348,866
CO2 waste emissions from Cool LPG process [d]	28,074
Total tCO2eq emissions averted (cooking + MSW - CoolLPG)	0.5 mio
Total tCO2eq economic value (cooking + MSW- CoolLPG)	$ 13 mio

Sources:

[a] GLPGP (2019). National Feasibility Assessment: LPG for Clean Cooking in Kenya. New York: The Global LPG Partnership. http://glpgp.org/s/GLPGP-Clean-Cooking-for-Africa-Kenya-National-Assessment-2019.pdf. At the time of this report, the exchange rate was 1 Euro = 113.2 KES.

[b] EY (2022). Essential, expensive and evolving: The outlook for carbon credits and offsets. Australia: Ernst & Young. https://assets.ey.com/content/dam/ey-sites/ey-com/en_au/topics/sustainability/ey-net-zero-centre-carbon-offset-publication-20220530.pdf

[c] GLPGP (2020). Assessing Potential for BioLPG Production and Use within the Cooking Energy Sector in Africa, p. 56. New York: The Global LPG Partnership. 1.pdf

[d] GTI Energy (2022) pers. comm. Assumes no injection of H2 to neutralize waste CO2.

6 Conclusions

This Study has posited a framework of key questions whose answers would inform a necessary and sufficient analysis of whether an African FOAK, urban MSW-to-bioLPG project concept is plausible and worthy of detailed feasibility analysis. The Study team determined what information would be needed to:

a. describe the nature and scope of a project opportunity, in its identified geography
b. analyse the project's physical, economic, enabling environment, technical and sustainability requirements
c. identify the categories of economic data that would have to be the foundation of a project financial projection and plan that would be needed to get financing indications
d. identify the project risks that would have to be mitigated

A concise summary of operational implications resulting from the country ground-truthing in Kenya, Cameroon and Rwanda would be the following:

1. Enough suitable MSW is available for large-scale urban biogas production and linked bioLPG production in all three countries.
2. The cost of LPG from a MSW-biogas-bioLPG FOAK project could be estimated on a preliminary basis in a TEA. Sensitivity analyses illustrate the positive effect on financeability of expected future changes in key operating and technical variables.
3. Carbon credits could be achievable at the levels indicated by the market.

One crucial finding of the Study work is the complexity of the public sector decision-making that is required to render MSW-to-bioLPG possible. The economic and non-economic benefits of modern waste management must be valorised in government policies to support and make use of the energy potential of that waste.

The Study notes that Africa in general lacks adequately evolved waste management policies linked to energy production and circular economy principles. The advent of carbon emissions credits is increasing the incentive for governments to pay attention to the MSW-to-energy challenges and opportunities.

Overall, the three country case studies lead consistently to the following important findings:

4. the framework questions can be answered
5. data and policy gaps were identified and, in the judgement of the Study authors, can be filled in a satisfactory way once sufficient funding for more detailed studies are made available.
6. A FOAK project will require concessionary financing, but the learnings from that FOAK will enable great progress to be made toward achieving widespread economic feasibility for a bioLPG sector to evolve. There is justification to support doing detailed feasibility studies for a FOAK MSW-to-biogas-to-Cool LPG project in the TEA focus city (Nairobi).

The Study authors emphasize that detailed studies that produce detailed project economic projections will require identification of a specific site; without a site nomination, only general statements can be made. Detailed data gathering and analysis for a candidate project, with a specific site nominated to focus the data acquisition and modelling, were out of scope for the budget available to this Study.

In each case study country, the major urban/peri-urban areas that were researched present adequate waste quantity and quality potential for industrial-scale MSW-to-biogas-to-bioLPG projects. The macro quantitative assessment of urban MSW indicated meaningful physical potential for energy production.

An advantage to note is that use of domestic energy feedstock (waste) to produce bioLPG would reduce national hard currency use to import LPG, the same advantage as that offered by solar, wind and geothermal resources. The production of LPG energy from domestic resources also provides incremental supply security advantages in relation to the politically important, fundamental clean cooking fuel need which has been expressed by African governments, including the three case study countries.

A moderate risk to manage is exposure to hard currency needs to pay for goods and services imported to realize and maintain a project, similar to the hard currency needs often created by necessary imports for solar, wind and geothermal projects. To the extent that financing is provided by non-domestic sources, there will be the need to manage risks of interest rates, currency exchange rates and cross-defaults created by other transactions.

At a conceptual level, the multi-dimensional requirements for establishing an industrial scale, urban MSW-to-biogas-to-bioLPG chain have been defined and the potential of such an integrated project and its advantages has been characterized.

However, as with all innovation, there is need for a carefully selected FOAK project to be studied in depth with an expectation of possible implementation if the study finds feasibility. Therefore, this Study team respectfully urges consideration of funding of the necessary order of magnitude to conduct such a feasibility study (or studies). The current estimate of the funding to conduct such a study in any one of the three case study countries is US $ 3-5 million.

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8 Study Team

8.1 The Global LPG Partnership

Kimball Chen, Chairman
A global industry statesman in the LPG and LNG sectors, with more than 40 years of experience as a CEO, investor, former President of the World LPG Association (the global LPG industry association), and senior LPG and LNG sector advisor to governments and international institutions. He founded GLPGP in 2012, at the request of the UN.

John Hauge, CFO
A senior international finance expert. Previously served as Chief Financial Officer of the Inter-American Development Bank, Deputy Assistant Secretary in the U.S. Treasury, and senior positions in global investment banking and major companies.

Alex Evans, Senior Advisor to the Chairman
In the past 30 years, CEO, COO/CFO and other senior roles in the energy, technology and distribution sectors. Served for 12 years on the Industry Council of the World LPG Association; co-authored the industry textbook on LPG sector development in emerging markets; and led LPG master planning in multiple African countries.

Bessem Enonchong, Director, Central Africa
Led GLPGP in-country national LPG plan project work for Cameroon and was part of GLPGP senior team that delivered the Rwanda national LPG plan. Broad business development experience in the LPG industry in Cameroon and West and Central Africa. Formerly Senior Sub-Saharan Africa sales executive of multinational LPG equipment manufacturer MAKEEN Gas Solutions (formerly Kosan Crisplant).

Elizabeth Muchiri, Director, East Africa
25 years' experience in the gas sector. Served as the LPG Manager for the National Oil Corporation of Kenya. Advisor to East African LPG companies on management and distribution strategies. Served as the LPG Expert on Kenyan national clean cooking and energy sector planning committees. Senior roles in GLPGP national LPG planning work in Kenya and Rwanda. Served as the LPG Expert for the EU-sponsored Uganda LPG sector evaluation and recommendation.

Derek Saleeby, Senior Advisor, Blended and Investment Finance.
Partner in TOTAL Impact Capital, a global finance advisory and impact investment firm. His previous roles have included senior positions with global firms including Citibank and Deutsche Bank Asset Management/RLJ.

8.2 Independent consultants

Prof. Matthew Leach, Professor of Energy and Environmental Systems in the Centre for Environment and Sustainability at the University of Surrey.
More than thirty years research and consulting experience in systems analysis for sustainability appraisal of energy and waste systems and in energy policy analysis and advice. An expert in sustainable energy systems analysis and policy, with special interest in clean cooking. Led studies for the UK government on

renewable aviation fuels and on low carbon technologies, and a recent research project on biogas for cooking in Africa.

Dr Mairi Black, Research fellow at the University of Surrey and at University College London.
A Life Cycle Assessment and Sustainability expert with over 25 years of industrial and academic experience in global sourcing and the applications of plant, agricultural and forestry materials for non-food uses, including feedstocks for bioenergy and associated land use issues

Dr Onesmus Mwabonje, Research Fellow at Imperial College London's Centre for Environmental Policy (CEP).
Academic and industrial experience in analysis of supply chains for biochemicals and bioenergy in both EU and East Africa policy contexts. Consultant on production of biodiesel.

Dr Meron Tesfamichael, Research Fellow at the Department of Science, Engineering, Technology and Public Policy, UCL.
Her research and government and institutional advisory work focuses on combining technical, policy, institutional and behavioural elements to facilitate household access to clean, sustainable and affordable energy in Sub-Saharan Africa.

Jean-Claude Uwizeye, Consultant and Managing Partner at Regional Engineering Consult (RECONS Ltd.).
Over 20 years' experience on Rwandan energy sector projects, with a leading role in Rwandan biogas sector analysis and planning. Lead consultant on projects and reports for World Bank, UNDP, GIZ (Germany), SIDA (Sweden), Government of Rwanda, IFAD, SNV, UNHCR and others. Senior consultant on development agency-funded national biogas capacity building programs in Rwanda, Uganda, Burkina Faso and Senegal.

Jake Penrose, LACworks Ltd.
Consultant in life cycle assessment and sustainability.

Dr. Patrick Littlewood, Principal Scientist, GTI Energy
Expert on heterogenous catalysts and reforming of renewable feedstocks into biofuels. Co-head of GTI Energy Cool LPG development project work.

Dr Emmanuel Ngnikam, Civil Engineering Professor at the National Advanced School of Engineering in Cameroon.
A recognized expert on the Cameroon waste sector. He has published extensively on municipal waste and waste management.

Thomas Minter, Managing Director, Malaby Biogas Ltd., a specialist AD operator.
Developer of the Bore Hill Farm Biodigester In Wiltshire, England, taking it through the complete development life cycle. He advises existing and potential AD developers in Europe and Africa.

ACKNOWEDGEMENT: The Study Team thanks Dr. Elisa Puzzolo (Senior Research Fellow at the University of Liverpool / Co-Director of the CLEAN-Air (Africa) Global Health Research Unit and also GLPGP Senior Scientific Advisor to the Chairman) for her advice on certain household air pollution and clean cooking issues.

Appendices

A. KENYA

Appendix A1: Policies reviewed for enabling environment framework

1. Ministry of Energy and Petroleum (MoE&P)

The MoE&P is in-charge of all energy matters, including the petroleum sector. The Ministry is already working closely with other stakeholders in the clean cooking sector and has formed a team to develop the Kenya National Clean Cooking Strategy, as part of the Integrated National Energy Plan (INEP). The state agency relevant to bioLPG is REREC.

2. Ministry of Environment, Climate Change and Forestry (MoECC&F)

The MoECC&F seeks to promote and facilitate good governance in protection, restoration, conservation, development and management of environment and forest resources for equitable and sustained development. The ministry has six state agencies, including the National Environment Management Authority (NEMA), which regulates environmental matters.

Other ministries that have cross cutting functions include Ministry of Lands, Ministry of Trade and Industry, and Ministry of Finance and Treasury.

Relevant Policies

1. Vision 2030, the overarching policy for Kenya's development which aims to transform Kenya into a newly industrializing, middle-income country providing a high quality of life to all its citizens by 2030 in a clean and secure environment.
2. Kenya Constitution 2010

One of the key impacts of the 2010 Constitution is the creation of two levels of government; the national government and 47 county governments. The county governments are mandated to manage resources within their devolved units, while the national government coordinates the devolved functions through the relevant ministries, such as MoE, MoP&M, MoE&F, etc.

3. SE4All Action Agenda

SE4ALL Action Agenda aims at ensuring energy affordability, energy efficiency and energy access, with the stated objective of having 100% access of clean energy for all Kenyans by 2030.

International Commitments

Kenya is also a signatory to the SDG goals, and while SDG 7 targets access to clean cooking for all by the year 2030, Kenya has committed to have access to clean cooking for all by the year 2028. This was stated during the Clean Cooking Conference in Nairobi in 2019, and was recently reiterated during the COP 26 forum.

1. The Energy Policy 2018

The Kenya Energy Policy 2018[1] aims to ensure affordable, competitive, sustainable and reliable supply of energy at the least cost in order to achieve the national and county development needs, while protecting and conserving the environment for inter-generational benefits.

2. Kenya National Waste Management Policy 2021

This Policy aims to advance Kenya towards a more sustainable and circular economy and moving the country towards realization of the Zero Waste principle by minimizing waste generation, and ensuring that waste is collected, separated at the source, reused and recycled, and that the remaining waste stream is destined to a secure, sanitary landfill.

3. Kenya National Environment Policy 2013

The Kenya National Environment Policy 2013 aims to provide a framework for an integrated approach to sustainable management of Kenya's environment and natural resources.

Regulatory Framework

The specific acts that govern the sector are the Energy Act of 2019 and the Petroleum Act of 2019. Both acts were developed to close the previous gaps as well as align with the Kenya Constitution 2010.

1. The Energy Act 2019

The Energy Act 2019[2] replaced the previous Energy Act 2006, and was enacted in order to consolidate the laws relating to energy, to provide for National and County Government functions in relation to all forms of energy, excluding Petroleum, which is under the a separate Act (see following section). The Act also created four National Energy includes REREC

2. The Petroleum Act 2019

The Petroleum Act 2019[3] was created as a law specific to petroleum products, which is a major energy sector and a State department under the MOE&P. The specific regulations pertaining to LPG, are enacted under this Act.

3. Environment Management and Coordination Act (EMCA) 1999 (Revised 2012)

An Act of Parliament to provide for the establishment of an appropriate legal and institutional framework for the management of the environment and for matters connected therewith and incidental thereto [Act No. 6 of 2006, Act No. 17 of 2006, Act No. 5 of 2007, Act No. 6 of 2009.]

4. The Sustainable Waste Management Act, 2022

The Sustainable Waste Management Act 2022 became effective Thursday July 7, 2022. The Act establishes the legal and institutional framework for the sustainable management of waste; in line with the constitutional provision.

Part 9 of the Act provides the roles of County governments. County governments are responsible for the devolved function of waste management, and ensure county waste management legislation are in conformity with this Act within one year.

Regulatory Bodies

1. The Energy and Petroleum Regulatory Authority (EPRA)

EPRA was established under the Energy Act, 2019, replacing the former Energy Regulatory Commission (ERC), and with an expanded mandate to regulate upstream petroleum and coal.

2. Rural Electrification and Renewable Energy Corporation (REREC)

REREC was established under the Energy Act 2019, which expanded the mandate of the previous REA (Rural Electrification Authority), to include renewable energy, and spearhead Kenya's green energy drive. REREC continue to manage rural electrification projects both off-grid and on-grid in the rural areas.

3. Kenya Bureau of Standards

Kenya Bureau of Standards (KEBS) is the government agency for the provision of Standards development, Metrology, Conformity Assessment, Training and Certification services.

4. The National Environment Management Authority (NEMA)

The role of NEMA is to ensure management and protection of the environment, as per the Environmental Management and Coordination Act (EMCA) of 1999[4].

County governments

County governments provide annual business permits for any business within their county. Additionally, many governments functions, including Energy and Environment, are devolved functions. This means the functions are under the county governments but coordinated by the National government through the relevant Ministries (MoE&P and the MoECCF).

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[1] National Energy Policy,Kenya,2018

[2] The Energy Act, 2019

[3] The Petroleum Act, 2019

[4] Environmental Management and Coordination Act (EMCA),1999

Appendix A2: Kenya MSW-to-bioLPG Stakeholders

The stakeholders that impact this study include:

List	Stakeholder name	Expected role in the bioLPG project
1	Ministry of Energy and Petroleum (MoE&P)	Overall in charge of Energy policy
2	Rural Electrification and Renewable Energy Corporation (REREC)	State agency in charge of renewable energy
3	Energy & Petroleum Regulatory Authority (EPRA)	Licensing and permits
4	National Environment Management Authority (NEMA)	In charge of environment
5	Nairobi City County (NCC)	In charge of MSW in Nairobi
6	Energy Dealers' Association (EDA)	A group of local investors in domestic LPG
7	Kenya Bureau of Standards (KEBS)	Develops standards
8	Oil Marketing Companies (OMCs)	Market leaders in supply of domestic LPG
9	French Development Agency (AFD)	Supporting the LPG sector in KNCCS
10	Africa Gas and Oil Ltd (AGOL)	Owner of largest LPG storage
11	Strathmore University	Conducting field research on MSW
12	Clean Cooking Association of Kenya (CCAK)	Promoting clean cooking in Kenya
13	GIZ	Supporting renewable fuels in KNCCS
14	Kenya National Clean Cooking Strategy (KNCCS)	Currently working on Kenya's transition to clean cooking by 2028
15	Garbage Companies	Alternative uses of MSW
16	Kenya Revenue Authority (KRA)	Taxes and levies related to waste-processing
17	Kenya Industrial Research and Development Institute (KIRDI)	Conducts tests on new fuels and cooking
18	Kenya Petroleum Refineries Ltd (KPRL)	Processing biofuels from waste cooking oil
19	Africa BioEnergy Programme Kenya (ABPL)	Support in sharing experiences in biogas production in Kenya
20	MECS	Funding bioLPG project

Appendix A3: Sample questionnaire

Waste Collection Companies Questionnaire

1. What are the coordinates of your organization?
2. Where is the organization located?
3. How many days do you operate in a week?
4. Which days are you not in operation?
    a. Holidays
    b. Weekends
    c. Sundays
5. Total number of workers in the organization:
    a. 1-100
    b. 100 - 200
    c. 200 -300
    d. Other
6. How many hours do you work per day?
7. How do you ensure that you collect waste safely and efficiently?
    a. Personal Protective Equipment
    b. Vehicle Safety
    c. Training
    d. Segregation and Labeling
    e. Regular Maintenance
    f. Emergency Response Plan
    g. Environmental Regulations
8. Have you received any training related to waste collection and disposal?
    a. Yes
    b. No
9. If yes, in which institution/organization?
10. How many households or businesses do you typically collect waste from in a day?

11. What equipment do you use to collect waste?
    a. Garbage trucks’
    b. Dumpsters
    c. Compactors
    d. Recycling Bins
    e. Hazardous waste
    f. Street sweepers
    g. Handheld tools
12. What type of waste does your organization collect?
    a. Hazardous waste
    b. Construction and demolition
    c. Municipal Solid waste
    d. Electronic waste
    e. Industrial waste
    f. Bio-medical waste

    g. Agricultural waste
    h. Sewage and wastewater
13. Do you segregate the waste?
    a. Yes
    b. No
14.If yes, how do you segregate the waste?
    a. Source aggregation
    b. Collection
    c. Manual sorting
    d. Mechanical sorting
    e. Disposal
15. Which waste storage equipment do you distribute to your clients?
    a. Polythene bag
    b. Drum
    c. Skip
    d. Other
16. For the polythene bags:
    a. How much do you charge for the polythene bag?
    b. Maximum waste that the polythene bag can carry(kg)?
17. For the Drum:
    a. What is the size of the drum that you give to your clients?
    b. How much do you charge when waste is collected from clients using the drum?
18. For the skip, what is the size of the skip that you give to your clients?
    a. 4*4*4
    b. 6*4*4
    c. Other (specify)
19. For the 4*4*4 skip,how much is charged for it?
20. For the 6*4*4 skip, how much is charged for it?
21. Is there any offer given to the clients for the waste storage equipment?
    a. Yes
    b. No
22. If yes, what offer is given?
23. How much waste do you collect in a day?
    a. 10 - 20 tonnes
    b. 20 - 30 tonnes
    c. Other
24. What percentage of the waste you collect is organic?
25. How is organic waste disposed of?
26. Does waste include human waste?
    1. Yes
    2. No
27. If yes, what quantity is the collected human waste?
28. Do you recycle any of the waste collected?
    a. Yes
    b. No
29. If yes, what quantities are recycled?
30. Have you noticed any changes in the amount of waste being generated in your area over time?
31. How often is the waste collection done?

a. Everyday
b. Twice in a week
c. Thrice in a week
d. Weekly
e. Irregularly
f. Don't know

32. How much do you charge for waste collection?
33. How are the waste collection fees determined and billed to residents?
34. How is the collection of waste done?
    a. Door to door collection
    b. Collection point within 200 m of distance
    c. Collection point further than 200 m of distance
35. How many people have access to your waste collection services?
36. Where is the waste collected from?
    a. School
    b. Open markets
    c. Households
    d. Supermarkets
    e. Slaughterhouse
    f. Hospitals
    g. Hotels
    h. Malls
    i. Agro processing firm
    j. Other
37. Kindly quantify how much waste is collected from each category above:
38. How many staff are employed in waste collection?
39. How much are you paid per day/week/month?
40. After collection of waste, where is the waste transported to?
    a. Dumping site
    b. Recycling center
    c. Other place (kindly specify)
41. How is the waste transported?
42. How far is the distance from the point of collection to the dumping site in kilometers?
43. What is the cost incurred for transporting the waste to the dumping site?
44. Do you have/know of a dumping site?
    a. Yes
    b. No
45. If yes:
    a. How long has it been operational?
    b. How far is the dumping site?
46. Are there any restrictions on the size or weight of waste that can be disposed of?
    a. Yes
    b. No
47. If yes, which are these restrictions?
48. How can residents report missed collections or damaged bins?
49. What is the process of requesting special pickups or extra waste bags?
50. Are there any additional services offered,such as bulky waste collection or composting?
    a. Yes

b. No

51. If yes, kindly provide more details:
52. Are there any upcoming changes or improvements to the waste collection program?
    a. Yes
    b. No
53. If yes, kindly give more details:
54. Do you encounter any challenges during waste collection?
    a. Yes
    b. No
55. If yes,what challenges are these?
56. Are there any waste disposal regulations that you should adhere to?
    a. Yes
    b. No
57. If yes, what regulations are there?
58. Are there any gate fees paid at the dumpsite?
    a. Yes
    b. No
59. If yes, how much is the gate fee?
60. What improvements would you like to see in waste collection and disposal practices?

Waste Management Facility/Plant

1. What are the coordinates of your organization?
2. Where is the organization located?
3. How many days do you operate in a week?
4. Which days are you not in operation?
    a. Holidays
    b. Weekends
    c. Sundays
6. Total number of workers in the organization:
    a. 1-100
    b. 100 - 200
    c. 200 -300
    d. Other
7. What is the amount of waste brought to the plant(tons/day)?
    7. Do you segregate the waste?
    a. Yes
    b. No
8. If yes, how do you segregate the waste?
    a. Source aggregation
    b. Collection
    c. Manual sorting
    d. Mechanical sorting
    e. Disposal
9. How much of the waste brought is organic?
10. How is the waste disposed of?
    a. Internally used

b. Selling the waste.
c. Paying someone to collect.

11. If used internally:
  a. How is the waste used internally?
  b. What quantity is used internally?
12. If you sell the waste:
  a. How much do you sell it for
13. If you pay someone to collect your waste:
  a. Who collects the waste?
  b. If you pay for collection, how much do you pay?
    i. 250 ksh – 500 ksh
    ii. 500ksh – 1000ksh
    iii. Other (kindly specify other range)
14. How is the payment done?
  a. Weekly
  b. Monthly
  c. On collection
15. How often is the waste collection done?
  a. Everyday
  b. Twice in a week
  c. Thrice a week
  d. Weekly
  e. Irregularly
16. How is the waste transported
17. What is the average moisture content of MSW brought in?
18. Is there a seasonal variation in the moisture content of the waste?
  a. Yes
  b. No
19. If yes, kindly give more details on this:
20. Does the waste require any special treatment
  a. Yes
  b. No
21. If yes, what kind of treatment does it undergo?
22. Do you have a gas collection system in the dumping site?
  1. Yes
  2. No
23. If yes:
  a. What is its capacity?
  b. What is the methane concentration level in the dumping site gas?
  c. What type of equipment is used to store the methane gas?
24. Can the waste be recycled?
  1. Yes
  2. No
25. If yes:
  a. What percentage of MSW is recycled?
  b. What technologies are used to recycle waste?
  c. is recycled waste used?
26. Do you encounter any challenges during waste management/disposal?

1. Yes
2. No

27. If yes, what challenges are these?

<u>Open markets (Generalization of the other sectors)</u>

1. What are the coordinates of your organization?

2. Where is the organization located?

3. How many days do you operate in a week?

4. Which days are you not in operation?
   a. Holidays
   b. Weekends
   c. Sundays

5. Total number of workers in the organization:
   a. 1-100
   b. 100 - 200
   c. 200 -300
   d. Other (Kindly specify)

6. What type of waste does the market produce?
   a. Food residue
   b. Fruit waste
   c. Vegetable waste
   d. Polythene bags/ Paper.
   e. Other waste.

6. What container is used for the storage of waste?
   a. Buckets
   b. Drums
   c. Polythene bags
   d. Other (kindly specify)

6. How many waste storage bins do you have?
   a. 1-5
   b. 5-10
   c. 10-15
   d. Other (kindly specify)

7. What are the sizes of the waste storage bins?
   8. How often are the containers emptied?
   a. Everyday
   b. Twice in a week
   c. Weekly
   d. Irregularly

9. How is the waste disposed of in the market?
   a. Heaped at a corner
   b. Left by the roadside
   c. Left in the market
   d. Other (give details)

10. Generally, when do you dispose of your waste?
   a. Between 6am to 6pm

b. After 6pm
c. No definite time.

10. In a day, how much waste does the mark generate?
    a. 10 kg - 20 kg
    b. 21 kg - 30 kg
    c. Other
11. Do you segregate the waste?
    a. Yes
    b. No
12. If yes, how do you segregate it?
    a. Source Aggregation
    b. Collection.
    c. Manual Sorting.
13. In a week, how much organic waste is produced by the market (in kgs)??
    a. 500 - 1000 kg
    b. 1001 - 2000 kg
    c. Other
14. If you were to sell the organic waste to us, how much would you sell it at?
15. How is the waste disposed of?
    a. Internally used
    b. Selling the waste.
    c. Paying someone to collect.

15. If used internally:
    a. How is the waste used internally?
    b. What quantity is used internally?
    i. All
    ii. Half
    iii. Other

16. If you sell the waste:
    a. How much do you sell it for?

17. If you pay someone to collect your waste:

    a. Who collects the waste?

    b. If you pay for collection, how much do you pay?
    i. 250 ksh – 500 ksh
    ii. 500ksh – 1000ksh
    iii. Other(kindly specify other range)

18. How is the payment done?
    a. Weekly
    b. Monthly
    c. On collection
19. How often is the waste collection done?
    a. Everyday
    b. Twice in a week
    c. Thrice a week
    d. Weekly
    e. Irregularly

20. How is the waste transported?
21. How many staff are employed for waste management in total?
    a. 5
    b. - 10
    c. 10 – 15
19. Do you know of a dumping Site?
    a. Yes
    b. No
20. If yes:
    a. How long has it been operational?
    b. How far is the dumping site?
20. Do you encounter any challenges during waste management?
    a. Yes
    b. No
21. If yes, what challenges are these?

<u>County Waste Management Office</u>

1. What are the coordinates of your organization?
2. Where is the organization located?
3. How many days do you operate in a week?
4. Which days are you not in operation?
    a. Holidays
    b. Weekends
    c. Sundays
8. Total number of workers in the organization:
    a. 1-100
    b. 100 - 200
    c. 200 -300
    d. Other
6. What is your total area of jurisdiction(square kilometers)?
7. What is the total population you serve?
8. What type of waste does the County Office collect?
    a. Hazardous Waste
    b. Construction and Demolition
    c. Municipal Solid Waste
    d. Electronic waste
    e. Industrial waste
    f. Bio-Medical Waste
    g. Agricultural Waste
    h. Sewage and Wastewater
10. How many dustbins are in Nairobi county?
    a. 1-10
    b. 11- 20
    c. Other(Kindly specify)
11. How frequent are the dustbins emptied?
    a. Everyday.

b. Twice in a week
c. Once in a week
d. Thrice in a week
e. Other

12. What is the size of the dustbins(kg)?
13. How much waste is generated per day by the county (ton)?
    a. 1900 tons - 2100 tons
    b. 2200 tons - 2400 tons
    c. Other
14. Do you segregate the waste?
    a. Yes
    b. No
15. If yes, how do you segregate it?
    a. Manual Sorting
    b. Source Aggregation
    c. Collection
    d. Disposal
    e. Mechanical Sorting
16. In a week how much organic waste does the county produce(kg)?
    a. 500 kg - 1000 kg
    b. 1001 kg - 2000 kg
    c. Other
17. How is organic waste disposed of?
18. Where is the waste collected from?
    a. School
    b. Open markets
    c. Households
    d. Supermarkets
    e. Slaughterhouse
    f. Hospitals
    g. Hotels
    h. Malls
    i. Agro processing firm
    j. Other
19. Kindly give a breakdown on the number of places and quantities of waste collected from the places listed above?
20. What equipment do you use to collect waste?
    a. Garbage Trucks
    b. Dumpster
    c. Compactors
    d. Recycling Bins
    e. Hazardous Waste Containers
    f. Street sweepers
    g. Hand held tools
21. How do you ensure that you collect waste safely and efficiently?
    a. Segregation and labeling
    b. Personal Protective Equipment
    c. Training

d. Vehicle Safety
e. Segregation and Labeling
f. Regular Maintenance
g. Emergency Response Plan
h. Environmental regulations

22. How much do you charge for waste collection?
23. How are waste collection fees determined and billed to residents?
    a. Area of residence
    b. Quantity of waste
    c. Other
24. How is the collection of waste done?
    a. Door to door collection
    b. Collection point within 200m of distance
    c. Collection point further than 200m of distance
25. Do you recycle any of the waste collected?
    d. Yes
    e. No
26. If yes, what quantities are recycled?
27. Have you noticed any changes in the amount or type of waste being generated in your area over time?
28. How many staff are employed for waste management in total?
    a. 5
    b. 5-10
    c. 10 - 15
    d. Other(Kindly specify)
29. How do you transport the waste?
30. Do you use the waste for other purposes?
    a. Yes
    b. No
31. If yes, please state those uses
32. Do you have/ know of a dumping site in the city?
    a. Yes
    b. No
33. If yes:
    a. How long has it been operational?
    b. What is the distance between your location and the dumping site?
34. Are there gate fees charged at the dumping site where you dump waste?
    a. Yes
    b. No
35. If yes, how much is the fee?
36. Is there a budget for MSW?
    a. Yes
    b. No
37. If yes, how much is allocated?
38. Is there a government grant for MSW?
    a. Yes
    b. No
39. If yes, do you receive a percentage of the grant

a. Yes
b. No

40. If yes, how much do you receive?
41. How frequently do you receive funds?
42. Is there internal revenue spent for MSW?
    a. Yes
    b. No
43. If yes, what amount is spent?
44. Do you encounter any challenges during waste management/disposal?
45. If yes, what challenges are these?

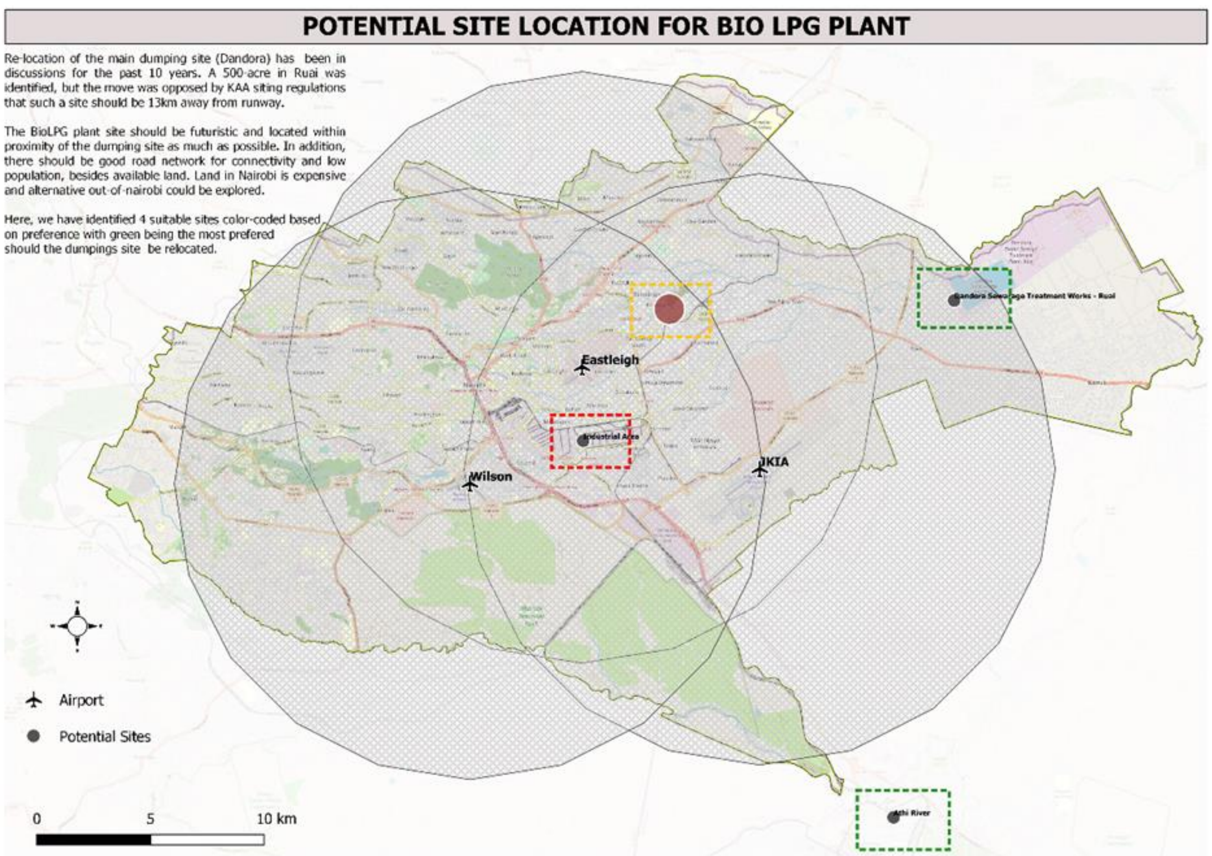
Appendix A4: Ground-truthing survey - Segregation of waste

The stakeholders surveyed who segregate their waste pre-collection and shown in Table A1 along with the method of segregation.

Table A1: Respondents and the type of segregation.

Company	Type of Segregation
Thiani Slaughterhouse	Source aggregation and Manual sorting
Dagoretti Slaughterhouses Co. Ltd	Source aggregation and Manual sorting
Lenana School	Source aggregation
Sarova Stanley	Source aggregation and Manual Sorting
Sankara	Source aggregation and collection
Village Market	Source aggregation and Manual Sorting

Appendix A5: Map of potential sites for AD-Cool LPG plant



Appendix A6: Contractor Fees for waste management in Nairobi

Table A2. Service charges and factors influencing the fee.

Company	Factors Influencing Fee	Amount Charged (Ksh)
Bins Nairobi Ltd	Location of client, quantity of waste	150 – 10,000
Pearl Ltd	Frequency of collection, type of client, quantity of waste and type of waste	10,000

Table A3. Fees dictated by waste storage type and size.

Company	Waste Storage Equipment	Fee Charged (KSH)
Bins Nairobi Ltd	Polythene Bags (5-10 kgs)	150/= per collection
	Drums (200 l)	500/= per collection
	Skip (4 by 4 by 4 ft)	2,000/= per collection
	Skip (6 by 4 by 4 ft)	3,000/= per collection
Pearl Ltd	Drum (200 l)	Residential= 400 -500 Corporates = 30,000-150,000
	Skip (4 by 4 by 4 ft)	2,000/= per collection
	Skip (6 by 4 by 4 ft)	3,000/= per collection

B. CAMEROON

Appendix B1: Policies reviewed for enabling environment framework

Key laws for the waste sector and the generation of energy from waste in Cameroon include:

1. Article 5 of Law 2011/022 of December 14, 2011 (regarding the electricity sector) contains texts on biomass energies and renewable energies. Subject IV is devoted to rural electrification, renewable energies and energy management. Chapter 2 lists the typologies of the energies; included in Article 63 is biomass energy. Articles 64, 65, 66 and 67 state the importance of renewable energies assigned to the state and the obligation to ensure their promotion, including incentives.

2. Law 96/12 of August 5, 1996, the framework law on environmental management, targets renewable energies and incentive measures for their promotion (Articles 75 and 76).

3. Article 14 of law number 2013/004 of April 18, 2013 encourages private investment in Cameroon. This text states that, in addition to general incentives, specific incentives may be granted to companies that make investments to achieve priority objectives, including in the fight against pollution.

4. Law number 2019/024 of December 24, 2019 (regarding decentralization of power) specifies among the powers transferred to local authorities the local pre-collection and management of household waste (Article 157).

5. Law number 2012/006 of 19 April 2012 (the gas code) is generally limited to natural gas (Article 1), but it also aims at the development of generic gaseous resources (Article 2).

Appendix B2: Household and market waste composition in Douala, Cameroon

The following tables presents the composition and recoverability of household waste and the composition of market waste in Douala, Cameroon.

Table B1. Douala household MSW composition

Constituents	Rainy season				Dry season			
	Wet mass (kg)	Dry mass (kg)	Gross (as %)	Dry (as %)	Wet mass (kg)	Dry mass (kg)	Wet (as %)	Dry (as %)
Drink	6.7	6.7	0.3%	0.7%	11.1	11.1	0.5%	1.1%
Paper/Cardboard	87.2	38.0	3.9%	4.2%	66.8	33.3	3.2%	3.4%
Textiles	124.1	55.5	5.6%	6.1%	102.8	71.6	5.0%	7.3%
Hygienic Textiles	189.6	84.8	8.5%	9.4%	113.2	75.7	5.5%	7.8%
Leftover Food	42.0	9.26	1.9%	1.0%	102.2	31.5	4.9%	3.2%
Various Plants	1377.7	389.1	62.0%	43.0%	1309.1	473.3	63.2%	48.5%
Metals	18.2	18.20	0.8%	2.0%	14	14	0.7%	1.4%
Dangerous Waste	6.4	6.40	0.3%	0.7%	10.5	10.5	0.5%	1.1%
Soft Plastics	150.4	129.73	6.8%	14.4%	102.1	59.4	4.9%	6.1%
Hard Plastics	40.4	40.40	1.8%	4.5%	46.3	46.3	2.2%	4.7%
Composites	51.8	51.80	2.3%	5.7%	40.1	40.1	1.9%	4.1%
Glasses and Ceramics	20.6	20.60	0.9%	2.3%	33.9	33.9	1.6%	3.5%

Constituents	Rainy season				Dry season			
	Wet mass (kg)	Dry mass (kg)	Gross (as %)	Dry (as %)	Wet mass (kg)	Dry mass (kg)	Wet (as %)	Dry (as %)
D3E	7.7	7.70	0.3%	0.9%	6.6	6.6	0.3%	0.7%
Rubber	6.3	6.30	0.3%	0.7%	5.6	5.6	0.3%	0.6%
Rubble	2.8	2.80	0.1%	0.3%	6.6	6.6	0.3%	0.7%
Thin (<20mm)	88.8	36.67	4.0%	4.1%	102	56.2	4.9%	5.8%
Total	**2220.7**	**904.0**	**100.0%**	**100.0%**	**2072.5**	**975.4**	**100.0%**	**100.0%**

Table B2. Douala household MSW recoverability

Component	Rainy season		Dry season		Combined	
	Bully	Dried	Bully	Dried	Bully	Dried
Fermentable (for biogas production)	63.9%	44.1%	68.1%	51.7%	66.0%	47.9%
Valorization of materials sciences	14.5%	28.0%	12.9%	19.7%	13.7%	23.8%
Inert	4.1%	4.4%	5.2%	6.5%	4.7%	5.5%
Hazardous waste and D3E	0.6%	1.6%	0.8%	1.8%	0.7%	1.7%
Other fuels	16.8%	22.0%	12.9%	20.3%	14.8%	21.1%
Total	**100.0%**	**100.0%**	**99.9%**	**100.0%**	**100.0%**	**100.0%**

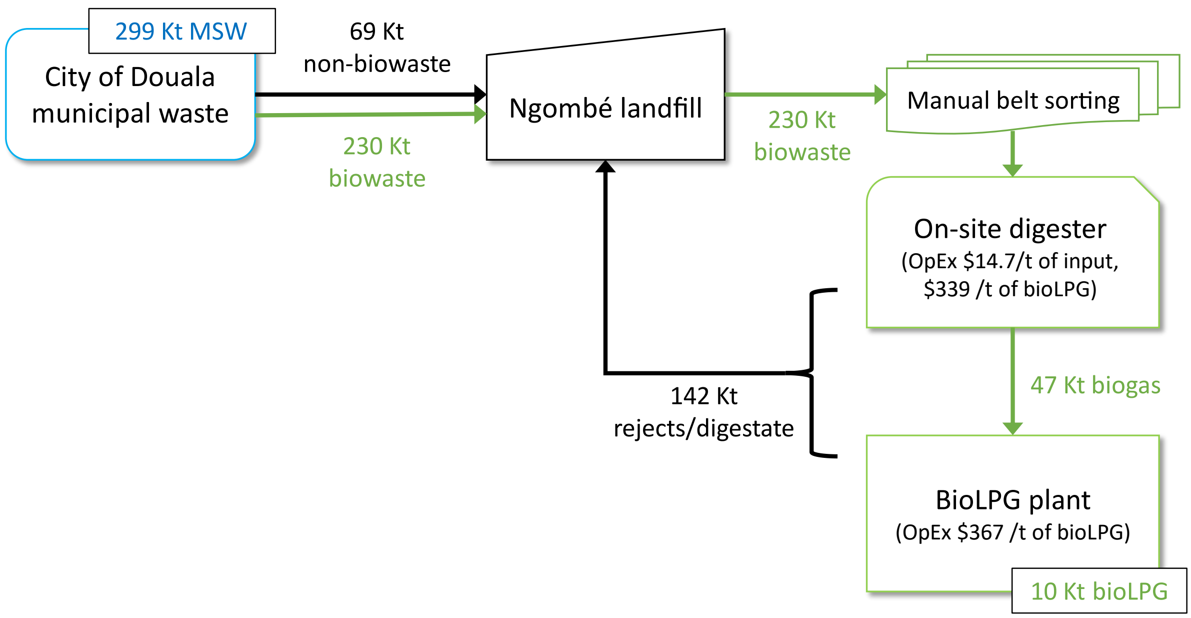
Table B3. Douala market MSW composition

Category	**Dry season**		**Rainy season**		**Combined**	
	Gross (as %)	**Dry (as %)**	**Gross (as %)**	**Dry (as %)**	**Gross (as %)**	**Dry (as %)**
Drink	0.49%	1.38%	0.34%	0.82%	0.4%	1.1%
Paper/Cardboard	6.85%	6.14%	5.20%	5.81%	6.0%	6.0%
Textiles	6.86%	5.70%	4.00%	4.58%	5.4%	5.1%
Hygienic Textiles	0.96%	0.79%	3.35%	3.83%	2.2%	2.3%
Rest Food	0.88%	0.63%	0.89%	0.63%	0.9%	0.6%
Various Plants	71.94%	66.54%	69.67%	54.25%	70.8%	60.4%
Metals	0.43%	1.21%	0.31%	0.74%	0.4%	1.0%
Dangerous Waste	0.03%	0.09%	0.29%	0.69%	0.2%	0.4%
Soft Plastics	4.93%	6.00%	4.40%	6.66%	4.7%	6.3%
Hard Plastics	1.18%	3.34%	2.32%	5.55%	1.8%	4.4%
Composites	0.75%	1.74%	1.79%	4.29%	1.3%	3.0%
Glasses and Ceramics	0.20%	0.58%	0.71%	1.69%	0.5%	1.1%
D3E	0.11%	0.32%	0.47%	1.13%	0.3%	0.7%
Rubber	0.09%	0.26%	0.05%	0.13%	0.1%	0.2%
Rubble	0.29%	0.81%	0.47%	1.13%	0.4%	1.0%
Thin (<20mm)	4.01%	4.47%	5.73%	8.06%	4.9%	6.3%
Total	**100%**	**100%**	**100%**	**100%**	**100.0%**	**100.0%**
Mass of sorted waste (kg)	982.1		1066.2		2048.3	

Appendix B3: bioLPG supply chain for Douala, Cameroon

The following diagram shows the recommended bioLPG feedstock supply chain for an initial demonstration plant of up to 10 Kpta of bioLPG output in Douala, Cameroon.

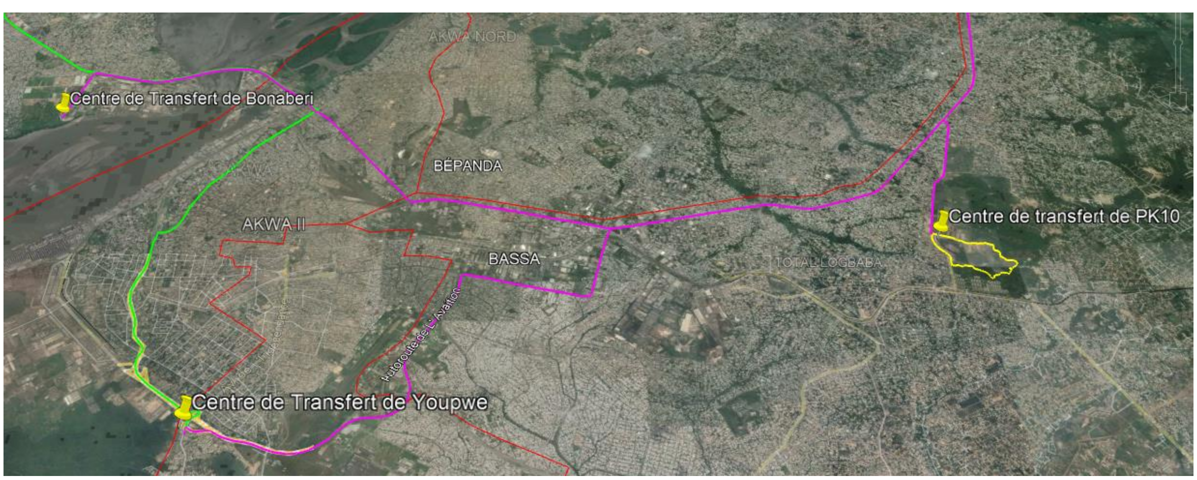
Figure B1. Recommended bioLPG feedstock supply chain diagram



The anticipated composition of the 158 MT of Douala market-sourced biogas is 43 t of methane (26%) and 126 t of CO_2 (74%).

To optimize waste transport, three transfer centers (CT) in the city of Douala, Cameroon are recommended for evaluation, at Youpwe, Bonabéri, and site PK10. The following map provides a general overview of their locations.

Figure B2. Map of recommended waste transfer locations for Douala, Cameroon



- The Youpwe transfer centre would receive waste from the districts of Douala I, II and half of III.
- The Bonabéri transfer center would receive waste from the Douala IV district.

- The PK10 transfer center would receive waste from the districts of Douala V and half of III.
- The range of transport distances is 6-24 km.

Appendix B4: Climate and co-benefits of bioLPG production

The following table summarizes the expected climate benefits and co-benefits of bioLPG production in Cameroon at a scale of 62,000 tonnes per year. These values scale the projected impacts from implementation of the Cameroon National LPG Master Plan (GLPGP, 2016 and GLPGP, 2019) proportionally to the level of bioLPG production shown in the table. For CO_2-eq, the calculations include additional avoidance from waste-sourced biogas (methane and CO_2) used as feedstock that would otherwise be released as methane and CO_2 into the atmosphere offset, in part, by waste CO_2 generated by the Cool LPG process.

Table B4 Potential Impact and Co-Benefits of BioLPG at Scale in Cameroon

Annual impacts of 62,000 tpa from bioLPG plants	**Low Case 2030**	**High Case 2030**
tCO2eq residential emissions averted [a]	3.13 mio	3.29 mio
Potential price per tCO2eq in 2030 [b]	€ 9	€ 13
tCO2eq economic value [a,b]	€ 29 mio	€ 43 mio
BCeq emissions averted [a]	3.44 mio	3.76 mio
Trees saved [a]	21.9 mio	25.4 mio
Averted premature deaths [a]	1,055	1,407
Avoided Disability Adjusted Life Years (DALYs) [a]	51,476	68,634
Consumer net energy spending savings [a] *	€ 488 mio	€ 564 mio
Value of labor time saved [a]	€ 24 mio	€ 32 mio
Trade balance benefit, vs importing all LPG as fossil LPG [a]	54,485 mio CFA	54,955 mio CFA
tCO2eq emissions averted from MSW repurposing to bioLPG [c]	1,748,782	1,748,782
CO2 waste emissions from Cool LPG process [d]	140,730	140,730
Total tCO2eq emissions averted (cooking + MSW - CoolLPG)	4.74 mio	4.90 mio
Total tCO2eq economic value (cooking + MSW- CoolLPG)	€ 44 mio	€ 63 mio

**Assuming end-user fuel cost is the same for bioLPG as fossil-sourced LPG including governmental LPG subsidy.*

References:

[a] GLPGP (2019). National Feasibility Assessment: LPG for Clean Cooking in Cameroon. New York: The Global LPG Partnership. http://glpgp.org/s/GLPGP-Clean-Cooking-for-Africa-Cameroon-National-Assessment-2019.pdf. At the time of this report, the exchange rate was 1 Euro = 656 CFA.

[b] EY (2022). Essential, expensive and evolving: The outlook for carbon credits and offsets. Australia: Ernst & Young. https://assets.ey.com/content/dam/ey-sites/ey-com/en_au/topics/sustainability/ey-net-zero-centre-carbon-offset-publication-20220530.pdf

(c] GLPGP (2020). Assessing Potential for BioLPG Production and Use within the Cooking Energy Sector in Africa, p. 56. New York: The Global LPG Partnership.

[d] GTI Energy (2022) pers. comm. Assumes no injection of H2 to neutralize waste CO2.

C. RWANDA

Appendix C1: Regulations and Policies reviewed for enabling environment framework

1. Law No. 47/2018 provides a comprehensive legal framework for environmental protection in Rwanda.

It addresses various environmental issues, including solid waste management. The law establishes principles for waste management, pollution prevention, and environmental impact assessment. It emphasizes the importance of waste reduction, recycling, and sustainable waste management practices.

2. Law No. 16/2018: Handling Hazardous Waste

Law No. 16/2018 plays a vital role in ensuring the safe handling of hazardous waste. It establishes guidelines for waste generators, transporters, and disposal facilities to minimize risks to human health and the environment. This law promotes the responsible management of hazardous waste and encourages waste reduction and recycling.

3. Law No. 47/2018: Relating to Environment

Law No. 47/2018 provides a comprehensive legal framework for environmental protection in Rwanda. It addresses various environmental issues, including solid waste management. The law establishes principles for waste management, pollution prevention, and environmental impact assessment. It emphasizes the importance of waste reduction, recycling, and sustainable waste management practices.

<u>Policies</u>

1. Rwanda National Sanitation Policy Implementation Strategy, 2016:

The Ministry of Infrastructure has developed the National Sanitation Implementation Strategy to ensure the proper implementation of key strategic actions in the sanitation sub-sector. The Policy and Strategy outlines initiatives to overcome challenges and exploit opportunities in an integrated manner and will effectively contribute towards achieving the goals of the National Development Agenda. National Sanitation Policy Implementation Strategy - MININFRA

2. Standards on the Management of Waste Disposal Site (Landfill) - RURA

These guidelines provide instructions on the proper management and operation of landfill sites in Rwanda. Standards On The Management Of Waste Disposal Site (Landfill)

3. National Environment and Climate Change Policy, 2019:

This policy sets out Rwanda's strategic approach to environmental protection and climate change mitigation and adaptation. It aims to promote sustainable development, strengthen environmental governance, conserve biodiversity, and build resilience to climate change. The policy emphasizes the integration of environmental considerations into development planning and decision-making processes.

4. Industrial Policy 2011

Industrial development in Rwanda with respect to the two pillars of export competitiveness and domestic production while considering environmental sustainability. Encourage industries to locate in industrial parks and special economic zones to benefit from centralized industrial waste management systems. All

Special Economic Zones should be set up with proper wastewater treatment facilities and garbage collection systems as per the Special Economic Zone policy of 2018. Industrial_Policy-2.pdf (minicom.gov.rw)

5. The National Land Policy, June 2019:

This policy provides a comprehensive framework for land governance and management in Rwanda. It emphasizes sustainable land use, equitable access to land, and the protection of land rights. The policy aims to promote efficient land administration, land-based investments, and environmental sustainability. Revised_National_Land_Policy-Final_Version_2019.pdf (environment.gov.rw)

6. National Guideline on Healthcare Waste Management 2016:

These guidelines provide guidance on the proper management and disposal of healthcare waste in Rwanda. They outline procedures for waste segregation, handling, transportation, treatment, and final disposal in healthcare facilities. The guidelines aim to minimize the risks associated with healthcare waste and promote safe and environmentally friendly practices. SPRP MWMP November 21 2017 - Final (rbc.gov.rw)

7. National Sanitation Master Plan:

The National Sanitation Master Plan provides a comprehensive framework for improving sanitation services in Rwanda. It outlines strategies and targets for improved access to sanitation facilities, behavior change, and sustainable sanitation solutions.

Waste-to-Energy Initiatives: Rwanda has also explored waste-to-energy initiatives, such as converting organic waste into biogas for cooking and electricity generation. These initiatives contribute to waste reduction, energy diversification, and climate change mitigation. Energy Policy 2015

The main policy objective for the biomass energy sub-sector in Rwanda is to promote fuel-switching from traditional biomass to modern and cleaner alternatives. This includes facilitating the adoption of sustainable biomass technologies such as biogas, LPG, and peat briquettes. The aim is to achieve a more sustainable wood fuel balance, reduce the consumption of non-renewable biomass, and deliver social, health, and environmental benefits.

8. Energy Sector Strategic Plan (ESSP)

One of the high-level target objective (HLTO) of ESSP in Sustainable biomass solutions is to halve the number of HH using traditional cooking technologies to achieve a sustainable balance between supply and demand of biomass through promotion of most energy efficient technologies. The strategy will deliver policy interventions and strategies to unlock barriers to the uptake of alternative fuel sources, such as LPG and biogas.

9. The National Waste Management Strategy (2019-2024)

The National Waste Management Strategy outlines Rwanda's vision and objectives for waste management. It sets specific targets for waste reduction, collection, recycling, and composting. The strategy emphasizes the importance of public participation, stakeholder engagement, and capacity development. It provides a roadmap for the sustainable management of solid waste in Rwanda.

10. Ministerial Order on Technical Requirements for Waste Management Facilities, 2019

Ministerial Order No. 001/MoE/2019 establishes technical standards for waste management facilities in Rwanda. It defines the requirements for landfill design, construction, and operation. The order also covers waste collection, transportation, and treatment processes. These technical standards ensure that waste management facilities comply with environmental and health regulations.

11. Rwanda Sanitation Master Plan, 2021

The National Integrated Water Supply and Sanitation Master Plans for Rwanda 2021 recommend the use of sanitary landfills as the most cost-effective method for solid waste disposal in urban areas. The plans consider both economic and technical factors in reaching this conclusion. Solid waste collection will be conducted using waste haul or container haul trucks, with options for door-to-door or skip/container-based collection methods. These approaches aim to efficiently gather and transport the waste to the landfill for proper disposal.

12. Revised Green Growth and Climate Resilience, National Strategy for Climate Change and Low Carbon Development Sept 2022

Rwanda recognizes solid waste as an untapped opportunity rather than a problem and aims to leverage it to achieve green growth and climate resilience. The country envisions a national mindset change that views solid waste as a valuable resource, implementing circular economy innovations, recycling initiatives, waste-to-energy systems, and efficient separation processes, including the promotion of sustainable waste management practices and the transition to a low-carbon economy.

13. Feasibility Study for Municipal Solid Waste Management in Kigali 2021

Feasibility Study for Municipal Solid Waste Management in Kigali: This study was conducted to assess the feasibility of implementing a comprehensive municipal solid waste management system in Kigali, Rwanda. It includes a detailed design for the construction of a sanitary landfill and proposes strategies for waste collection, recycling, and disposal.

14. The National Waste Management Strategy (2019-2024)

The National Waste Management Strategy outlines Rwanda's vision and objectives for waste management. It sets specific targets for waste reduction, collection, recycling, and composting. The strategy emphasizes the importance of public participation, stakeholder engagement, and capacity development. It provides a roadmap for the sustainable management of solid waste in Rwanda.

15. Ministerial Order No. 001/MoE/2019: Technical Requirements for Waste Management Facilities

Ministerial Order No. 001/MoE/2019 establishes technical standards for waste management facilities in Rwanda. It defines the requirements for landfill design, construction, and operation. The order also covers waste collection, transportation, and treatment processes. These technical standards ensure that waste management facilities comply with environmental and health regulations.

16. Rwanda Sanitation Master Plan

National Integrated Water Supply and Sanitation Master Plans for Rwanda, Phase 3: Master Plan, Volume 2: Sanitation Master Plan." Draft Version, December 2021. Prepared by JV Studi International/IDEA Consult/Landmark on behalf of Water and Sanitation Corporation, WASAC.

Appendix C2: Economic characteristics of potential waste handling investment

The total investments required for the entire projection period (years 2021-2027) amount to approximately 396 million EUR. This investment covers the construction of waste handling facilities, including a landfill, and the procurement of collection equipment such as trucks and containers.

Table C1. Rwanda project investment requirements

EUR X 1000	2023-2025	2031	2035	2041	2045	2050	TOTAL
Landfill works	31.112	4.752	35.972	1.467	6.422	10.338	90.062
Collection trucks	5.842	2.419	13.021	8.073	26.865	0	56.220
Facility	24.158	33.537	40.920	0	69.583	0	168.198
Transfer station	10.236	522	12.492	7.904	23.998	913	56.064
Collection point and containers	4.594	2.709	7.475	1.193	9.635	0	25.606
TOTAL	75.941	43.939	109.88	18.638	136.502	11.251	396.150

The financial analysis indicates that the investment package over the entire implementation period is financially viable. Several financial metrics are provided to support this claim:

Calculated Discount Rate: The calculated discount rate is 0.7%.

Financial Internal Rate of Return (FIRR): The FIRR is 5.3%, which is greater than the calculated discount rate of 0.7%. A positive FIRR indicates that the project's returns exceed the cost of capital, making it financially attractive.

Financial Net Present Value (FNPV): The FNPV stands at EUR 339 million. A positive FNPV suggests that the project is expected to generate a net cash inflow over its lifetime, after accounting for the initial investments and discounted future cash flows.

Debt Service Coverage Ratio (DSCR): The DSCR is always above 1, which means that the project's cash flow will be sufficient to cover its debt service obligations. This is a positive indicator of financial health, as it indicates that the project can meet its debt payments without difficulty.

The analysis concludes that the investment plan for waste management and infrastructure development is financially viable and should be able to generate positive returns over the projection period.

D. SUSTAINABLE DEVELOPMENT GOALS BENCHMARKS

	Provision of bioLPG as a clean cooking fuel (for home cooking via LPG distribution routes)			Influence of implementation of bioLPG on waste management (as a route to feed gas provision)			Enabling Environment
SDG Goal	**General**	**Metric**	**Existing schemes with associated methodologies for impact assessment**	**Unsorted waste (BAU) to landfill with collection of landfill biogas**	**Development of AD resulting in improved waste management through centralised collection or separation at source**	**Existing schemes with associated methodologies for impact assessment Guidance for Indicators to develop Metrics**	**Policies and regulatory frameworks (policies relating to energy and waste management reviewed as part of this study)**
Goal 1. End poverty in all its forms everywhere	Clean cooking is part of basic services necessary to lead a healthy and productive life and saves households time and money.	1. Cost ($) of LPG, bioLPG vs. traditional fuels or alternative clean cooking options. 2. reduction in time spent collecting or growing firewood.	1. Gold Standard SDG Impact Assessment tool.	Landfill biogas collection and management service job creation.	Waste management service job creation.	1. Gold Standard SDG Impact Assessment tool.	1. Kenya Vision 2030 2. Cameroon Vision 2035 3. Rwanda Vision 2050
Goal 2. End hunger, achieve food security and improved nutrition, and promote sustainable agriculture	Efficient cookstoves fuelled by cleaner energy sources reduce the amount of traditional fuels needed to cook, thus reducing the burden on families who would otherwise have	Cost ($) of LPG, BioLPG vs. Traditional fuels or alternative clean cooking options.	1. Gold Standard SDG Impact Assessment tool. 2. Benefits of Action to Reduce Household Air Pollution (BAR-HAP) tool.				1. Kenya National Clean Cooking Strategy (in development) 2. Cameroon National Development Strategy; NDC, 2021 promotes biogas projects; bioLPG is being promoted under multi-ministerial working group; National LPG Master Plan, 2016.

	to collect it, grow it, buy it, or trade food for it.						
Goal 3. Ensure healthy lives and promote well-being for all at all ages	Use of clean cooking options including LPG (bioLPG) reduces smoke emissions from cooking, decreasing the burden of disease associated with household air pollution, improving well-being, especially for women and children. Reduced drudgery of collecting and/or growing traditional fuels.	Adjusted Daily Life Years (aDALYS)	1. ESMAP (2020) Quantifying and Measuring Climate, Health, and Gender Co-Benefits from Clean Cooking Interventions: Methodologies Review. 2. Gold Standard SDG Impact Assessment tool. 3. Benefits of Action to Reduce Household Air Pollution (BAR-HAP) tool.	Development of waste management. Uncollected waste, dumped waste and open air burning of waste cause air, water and soil pollution. Waste clogs waterways and drains, exacerbating flooding, causing stagnant water contributing to water-borne diseases and malaria.	Development of waste management. Uncollected waste, dumped waste and open air burning of waste cause air, water and soil pollution. Waste clogs waterways and drains, exacerbating flooding, causing stagnant water contributing to water-borne diseases and malaria.	2. Gold Standard SDG Impact Assessment tool.	1. Kenya National Clean Cooking Strategy (in development); Kenya National Waste Management Policy. 2021 2. Cameroon National Development Strategy, 2021; NDC, 2021 promotes biogas projects; bioLPG is being promoted under multi-ministerial working group. 3. Cameroon Energy Policy, 2015 addresses fuel switching from traditional biomass to modern cleaner alternative, including biogas and LPG; Energy Sector Strategic Plan.
Goal 4. Ensure inclusive and equitable quality education and promote life-long learning	Children, particularly girls, are often kept out of school to contribute to household	Quality time saved; in hours/month and perhaps monetised using estimates of value of productive time	1. ESMAP (2020) Quantifying and Measuring Climate, Health, and Gender Co-Benefits from				

opportunities for all	tasks, like cooking and collecting and/or growing traditional fuels.		Clean Cooking Interventions: Methodologies Review. 2. Gold Standard SDG Impact Assessment tool.				
Goal 5. Achieve gender equality and empower all women and girls	Unpaid work, including collecting fuel and cooking, remain a major cause of gender equality.	Quality time saved; in hours/month and perhaps monetised using estimates of value of productive time.	1. ESMAP (2020) Quantifying and Measuring Climate, Health, and Gender Co-Benefits from Clean Cooking Interventions: Methodologies Review.				
Goal 6. Ensure availability and sustainable management of water and sanitation for all				Development of waste management. Uncollected waste, dumped waste and open air burning of waste cause water and soil pollution. Waste clogs waterways and drains, exacerbating flooding, causing stagnant water	Development of waste management. Uncollected waste, dumped waste and open air burning of waste cause air, water and soil pollution. Waste clogs waterways and drains, exacerbating flooding, causing stagnant water	1. UNEP Waste Management Outlook: Proportion of municipal solid waste collected and managed in controlled facilities out of total municipal solid waste generated by cities.	1. Kenya National Waste Management Policy, 2021; Sustainable Waste Management Act, 2022. 2. Cameroon Law number 2019/024 of December 24, 2019 specifies among the powers transferred to local authorities the local pre-collection and management of household waste (Article 157). 3: Rwanda: NDC addresses MSW and promotes sustainable waste

				and water-borne disease.	and water-borne disease.	2. Gold Standard SDG Impact Assessment tool.	management and waste as a resource; Law No. 47/2018 legal framework for the environment including solid waste management; National Waste Management Strategy, 2019-2024, sets targets for waste reduction, collection, recycling and composting; Revised Green Growth and Climate Resilience, National Strategy for Climate Change and Low Carbon Development, 2022, waste as a resource including waste-to-energy systems.
Goal 7. Ensure access to affordable, reliable, sustainable and modern energy for all	Clean cooking is essential to addressing energy poverty and ensuring sustainable energy security for billions of people.	Per capita consumption - traditional cooking fuel replaced by LPG (bioLPG potential). Cost ($) of LPG, BioLPG vs. Traditional fuels or alternative clean cooking options.	1. ESMAP (2020) Quantifying and Measuring Climate, Health, and Gender Co-Benefits from Clean Cooking Interventions: Methodologies Review. 2. Gold Standard SDG Impact Assessment tool. 3. Benefits of Action to Reduce Household Air Pollution (BAR-HAP) tool.	Implementation of waste-to-energy strategies targeted to include biogas/bioLPG production gives energy access opportunities. Considered in line with most affordable, practical application of biogas as an energy carrier.	Implementation of waste-to-energy strategies targeted to include biogas/bioLPG production gives energy access opportunities. Considered in line with most affordable, practical application of biogas as an energy carrier.	1. UNEP Waste Management Outlook: Proportion of municipal solid waste collected and managed in controlled facilities out of total municipal solid waste generated by cities. 2. Gold Standard SDG Impact Assessment tool.	1. Kenya: SE4All Action Agenda; The Energy Policy 2018 and Energy Act, 2019; Petroleum Act, 2019 (covers LPG). Developing Clean Cooking Strategy considering the role of bioLPG. 2. Cameroon National Development Strategy, 2021; NDC, 2021 promotes biogas projects; bioLPG is being promoted under multi-ministerial working group; Article 5 Law 2011/022 on biomass and renewable energies; Law 96/12 law on environmental management, targets renewables. 3. Cameroon Energy Policy, 2015 addresses fuel switching from traditional biomass to modern cleaner alternative,

							including biogas and LPG; Energy Sector Strategic Plan.
Goal 8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all	Energy access enables enhanced productivity and inclusive economic growth. The clean cooking sector offers many job opportunities and will impact on SDG8..2; SDG8.3; SDG8.4;	Number of people employed in MSW-to-bioLPG supply chains; qualifications; wages ($); Quality time saved in reduced efforts collecting and cooking with traditional fuels; in hours/month and perhaps monetised using estimates of value of productive time.	1. ESMAP (2020) Quantifying and Measuring Climate, Health, and Gender Co-Benefits from Clean Cooking Interventions: Methodologies Review. 2. Gold Standard SDG Impact Assessment tool.	Landfill biogas collection and management service job creation.	Waste management service job creation.	1. UNEP Waste Management Outlook 2. Gold Standard SDG Impact Assessment tool.	
Goal 9. Build resilient infrastructure, promote inclusive and sustainable industrialisation and foster innovation	Development of infrastructure for LPG/bioLPG under access to clean cooking	Based on existing/developing LPG routes	2. Gold Standard SDG Impact Assessment tool.				
Goal 10. Reduce inequality within and among countries	With reference to SDG 7: Clean cooking is essential to addressing energy poverty and ensuring	(Per capita consumption - traditional cooking fuel replaced by LPG (bioLPG potential).	1. ESMAP (2020) Quantifying and Measuring Climate, Health, and Gender Co-Benefits from				

	sustainable energy security for billions of people.	Cost ($) of LPG, BioLPG vs. Traditional fuels or alternative clean cooking options).	Clean Cooking Interventions: Methodologies Review. 2. Gold Standard SDG Impact Assessment tool.				
Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable	Clean cooking addresses household and ambient air pollution, resource efficiency, and climate vulnerability		ESMAP (2020) Quantifying and Measuring Climate, Health, and Gender Co-Benefits from Clean Cooking Interventions: Methodologies Review. 2. Gold Standard SDG Impact Assessment tool.	Development of waste management systems ensures access to adequate, safe, affordable basic services reduces adverse impact of unmanaged waste.	Development of waste management systems ensures access to adequate, safe, affordable basic services reduces adverse impact of unmanaged waste.	1. UNEP Waste Management Outlook: Proportion of municipal solid waste collected and managed in controlled facilities out of total municipal solid waste generated by cities	1. Kenya: National Waste Management Policy, 2021 – targets waste collection and separation at source; no indication of direction for use of OFMSW. 2. Cameroon: Local waste management plan considered for Douala, the Douala Solid Waste Sanitation Master Plan (2020). 3: Rwanda: NDC addresses MSW and promotes sustainable waste management and waste as a resource; Law No. 47/2018 legal framework for the environment including solid waste management; National Waste Management Strategy, 2019-2024, sets targets for waste reduction, collection, recycling and composting; Revised Green Growth and Climate Resilience, National Strategy for Climate Change and Low Carbon

							Development, 2022, waste as a resource including waste-to-energy systems.
Goal 12. Ensure sustainable consumption and production patterns				Waste management follows waste management hierarchy 'reduce; re-use; recycle; recover. Where biogas energy recovery at landfill is considered as part of the waste hierarchy, it may or may not follow the priority 3 'R's currently in the countries under consideration.	Waste management follows the waste management hierarchy 'reduce; re-use; recycle, recover' to avoid as much as possible any material entering landfill.	1. UNEP Waste Management Outlook: Proportion of municipal solid waste collected and managed in controlled facilities out of total municipal solid waste generated by cities. 2. Gold Standard SDG Impact Assessment tool.	1. Kenya: National Waste Management Policy, 2021 – targets waste collection and separation at source. 3: Rwanda: NDC addresses MSW and promotes sustainable waste management and waste as a resource; Law No. 47/2018 legal framework for the environment including solid waste management; National Waste Management Strategy, 2019-2024, sets targets for waste reduction, collection, recycling and composting; Revised Green Growth and Climate Resilience, National Strategy for Climate Change and Low Carbon Development, 2022, waste as a resource including waste-to-energy systems.
Goal 13. Target urgent action to combat climate change and its impacts	Generally clean cooking options are more efficient in energy use and reduce GHG emissions compared to traditional fuels. Use of bioLPG may further benefit GHG emission	1. CO_2eq of alternative cooking options e.g. bioLPG vs. fossil LPG vs. Traditional fuels (supply chain LCA). 2. black carbon as PM2.5. Measured as direct emissions from stoves using traditional fuel or LPG/bioLPG.	ESMAP (2020) Quantifying and Measuring Climate, Health, and Gender Co-Benefits from Clean Cooking Interventions: Methodologies Review. 2. Gold Standard SDG	Improved waste management and landfill gas collection can prevent ghg emission resulting from the decomposition of organic waste in unmanaged land fill (i.e. avoided emissions).	Improved waste management and landfill gas collection can prevent ghg emission resulting from the decomposition of organic waste in unmanaged land fill (i.e. avoided emissions).	1. UNEP Waste Management Outlook: Proportion of municipal solid waste collected and managed in controlled facilities out of total municipal solid waste	1. Kenya: National Climate Change Action Plan 2018 – identifies clean cooking as a target to reduce GHG emissions. 2. Cameroon National Climate Change Action Plan, 2015. 3. Rwanda National Environment and Climate Change Policy, 2019; National Strategy for the Reduction of

	reduction compared to fossil LPG. Further reductions in black carbon emissions from solid fuels used in households		Impact Assessment tool.			generated by cities. 2. Gold Standard SDG Impact Assessment tool.	Emissions due to Deforestation and Degradation of forests, 2019.
Goal 14. Conserve and sustainability use the oceans, seas and marine resources for sustainable development				Extend development of waste management to all sectors. Uncollected waste, dumped waste and open air burning of waste cause water and soil pollution. Better management of waste generated on land prevents waste ending up in oceans.	Extend development of waste management to all sectors. Uncollected waste, dumped waste and open air burning of waste cause water and soil pollution. Better management of waste generated on land prevents waste ending up in oceans.	1. UNEP Waste Management Outlook: Proportion of municipal solid waste collected and managed in controlled facilities out of total municipal solid waste generated by cities. 2. Gold Standard SDG Impact Assessment tool	
Goal 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and	Natural forest and woodland harvested for fuel use in coking is unsustainable, contributing to forest degradation, deforestation, and climate change.	potential tonnes wood/charcoal replaced by bioLPG		Uncollected waste, dumped waste and open air burning of waste cause water and soil pollution. Better management of waste prevents land contamination.	Uncollected waste, dumped waste and open air burning of waste cause water and soil pollution. Better management of waste prevents land contamination.	1. UNEP Waste Management Outlook: Proportion of municipal solid waste collected and managed in controlled facilities out of total municipal solid waste generated by cities.	1. Kenya National Environment Policy, 2013 includes management of forestry linked to extraction of wood for cooking and charcoal production.

halt biodiversity loss						2. Gold Standard SDG Impact Assessment tool	
Goal 16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels							
Goal 17. Strengthen the means of implementation and revitalize the global partnership for sustainable development.							

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