
Photo credit: Matthew Owen/LTS. Anaerobic digester in Kenya.

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Bioenergy for Sustainable Local Energy Services and Energy Access in Africa (BSEAA 2)

Stage 2 Report- Top-Down Scoping

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Table of Acronyms

Abbreviation	Name
AD	Anaerobic Digestion
AFD	*Agence Française de Développement* (French Development Agency)
BEST	Biomass Energy Strategy
BNEF	Bloomberg New Energy Finance
BSEAA	Bioenergy for Sustainable Local Energy Services and Energy Access in Africa project (BSEAA2) (DFID-funded programme)
C(C)HP	Combined (Cooling) Heat and Power
CAADP	Comprehensive Africa Agriculture Development Programme
CAPEX	Capital Expenditure
CDC Group	Formerly Commonwealth Development Corporation (UK international investment finance group)
CHP	combined heat and power
COMESA	Common Market for Eastern and Southern Africa
DFID	Department for International Development
EAC	East African Community
EC/EU	European Commission to the European Union
ECOWAS	Economic Community of West African States
ECREEE	ECOWAS Centre for Renewable Energy and Energy Efficiency
EEP	Energy and Environment Partnership (multi-donor trust fund under management of Nordic Development Fund)
EPC	Engineering Procurement and Construction
ERB	Energy Regulation Board (Zambia)
EWURA	Electricity and Water Regulatory Authority (Tanzania)
FAO	Food and Agricultural Organisation (United Nations)
FiT	Feed-in Tariff
FMO	*Nederlandse Financierings-Maatschappij voor Ontwikkelingslanden* (Netherlands' Development Finance Company)
GET FiT	Global Energy Transfer Feed-in Tariff Programme (Uganda)
GHG	Greenhouse Gas
IEA	International Energy Agency
IFC	International Finance Corporation (World Bank Group),
IPP	Independent Power Producer
KfW	*Kreditanstalt für Wiederaufbau* (Germany's Development Finance Group)
LCC	Life Cycle Cost
LCOE	Levelized Cost of Electricity

LFG	Landfill gas
MW_e	Megawatt (electric)
NREEEP	National Renewable Energy and Energy Efficiency Policy (Nigeria)
O&M	Operation and Maintenance
OECD	Organisation of Economic Co-operation and Development
OPEX	Operating Expenditure
PPA	Power Purchase Agreement
PV	Photovoltaic
REA	Rural Energy Agency or Rural Electricity Agency
REDD+	Reduced Emissions from Deforestation and forest Degradation (plus other forest protection and enhancements)
REF	Rural Energy Fund or Rural Electricity Fund
REFiT	Renewable Energy Feed-in Tariff
REIPPPP	Renewable Energy Independent Power Producer Procurement Programme (South Africa)
RISE	Regulatory Indicators for Sustainable Energy (World Bank programme)
SADC	Southern Africa Development Community
SPP	Small Power Producer
SSA	Sub Saharan Africa
TEA	Transforming Energy Access (DFID-funded programme)
TRL	Technology Readiness Level
UNFCCC	United Nations Framework Convention on Climate Change
UNIDO	United Nations Industrial Development Organisation
WEF	World Economic Forum
WGI	Worldwide Governance Indicators

Executive Summary

Introduction

A team led by LTS International, in partnership with Aston University, E4tech and Aiguasol, is implementing Phase 2 of the DFID-funded Bioenergy for Sustainable Local Energy Services and Energy Access in Africa project (BSEAA2). This report documents the work undertaken from October 2019 to March 2020 during Stage 2 of the project: 'Top-down scoping of bioenergy pathways'.

Methodology

A longlist of bioenergy pathways in ten target countries in Sub-Saharan Africa (SSA)[1] was developed, screened and assessed, in order to shortlist the five most promising bioenergy pathways for further investigation during Stage 3. This entailed the following three steps:

- **Step 1: Development of a longlist of bioenergy pathways.** A longlist of pathways was developed for the two BSEAA2 project target technologies (anaerobic digestion [AD] and combustion), using conceptual frameworks defined by FAO (2004). Bioenergy projects in the target countries representative of these pathways were mapped, investigated and validated in the form of a comprehensive matrix, hereafter referred to as the 'Projects Grid'.
- **Step 2: Pre-screening and thematic assessment**. Projects were pre-screened to confirm operating status. Each pathway was then assessed in depth under the following themes:
    - Theme 1: Suitability of biomass resources for bioenergy (Aston University)
    - Theme 2: Status of technical development (LTS)
    - Theme 3: Supply chain archetype analysis (E4tech)
    - Theme 4: Economic viability and barrier analysis (Aiguasol)
    - Theme 5: Institutional, regulatory and market frameworks (LTS)
- **Step 3: A prioritisation process** to shortlist the five most promising pathways.

Task E, Biomass gasification technology, was addressed in parallel by LTS, to examine the current status of bioenergy gasification in SSA. A brief description of the findings is presented, and a report will be produced during Stage 3 on the current status of gasification, focusing on why this technology has not been successful in SSA and setting out recommendations with critical success factors.

Findings

Step 1: Development of longlist of bioenergy pathways

11 pathways were identified based on feedstock category and conversion technology:

5 AD pathways based on:	1. Agro-processing residues
	2. Crop harvesting residues
	3. Livestock wastes
	4. Municipal by-products
	5. Purpose grown or novel feedstocks
6 combustion pathways based on:	6. Forest and plantation wood
	7. Wood processing residues
	8. Wood harvesting residues
	9. Material wastes
	10. Herbaceous energy crops
	11. Agro-processing residues

Step 2: Pathway pre-screening and thematic assessment

South Africa dominates the **AD landscape**, followed by Tanzania, Kenya and Ghana. The highest level of commercial activity is across agro-processing and livestock waste-based pathways. No operational projects were identified using crop-harvesting residues or purpose grown or novel feedstocks. Projects using municipal-byproducts were found mainly in a South African context with poor replicability potential in other target countries. Projects are predominately for combined heat and power (CHP) or electricity only. The **combustion landscape** is also dominated by South Africa, followed by Tanzania, Kenya and Ghana. The highest level of activity is in the agro-processing based pathway (although most examples were in the sugar sector and lay outside the BSEAA2 target range

[1] Ethiopia, Ghana, Kenya, Mozambique, Nigeria, Rwanda, South Africa, Tanzania, Uganda and Zambia.

of 10 kW to 5 MW), with some activity in pathways using forest and plantation wood, and wood processing residues.

Theme 1: Biomass resources

Theme 1 provided a robust understanding of the bioenergy resource potential across the agriculture, livestock and forest sectors in the target countries. **Crop harvesting residues** were found to offer the highest potential biomass volume, but there is limited aggregation and strong competing uses so they are not the optimal feedstock category for bioenergy. **Agro-processing residues** are a smaller feedstock source but represent a stronger commercial opportunity, with better aggregation and fewer competing uses.

The most promising feedstocks include residues from the processing of fruits and vegetables, coffee/cocoa/tea, oil palm and fibre crops, particularly sisal. The use of sugar residues for bioenergy is already commercially successful and presents little additional scope within this project. Opportunities for commercial energy generation from **livestock wastes** lie in dairy farms or cattle feedlots.

Opportunities for **wood residues** lie in the wood processing industry, as wood sources directly from plantations or managed forests. Wood residues pose challenges for bioenergy use in terms of competing uses, sustainability and management.

Theme 2: Status of technical development

Theme 2 provided an overview of the technological landscape of AD and combustion, exploring innovation and adaptation opportunities for SSA based on deployment in SSA, adaptation potential, innovation potential, reliability and availability of technology support. It was found that in the **AD sector** there is proven commercial potential for several biodigester technologies within the desired scale range, with innovation and adaptation potential for specific feedstocks and conditions found in SSA. No AD technology type is ruled out for further investigation in Stage 3.

For **combustion based bioenergy**, incremental technology innovation for heat-only applications, and for steam turbines at large scale, falls outside the scope of interest for BSEAA2. However, there may be innovation potential with sub-3 MW turbines, which could fill a niche for small-scale CHP systems as global demand grows for decentralised heat and power from renewables. The promising sectors at this scale are those generating woody residues from agro-processing (e.g. oil palm, coffee and coconut residues), and wood and wood residues from plantations and forestry processing.

The uptake potential of dispersed, small-scale plants may be of interest to DFID. Looking beyond technology innovation, there is also potential for developing feedstock supply chains for combustion-based pathways that can bring wider development impacts than centralised, in-house feedstock sourcing operations. This offers particular promise in the tea industry.

Theme 3: Supply chain archetype analysis

Theme 3 sets out a bioenergy supply chain archetype framework to examine where commercially operational projects are clustered in terms of supply and demand. Six supply chain archetypes were defined according to the nature of feedstock supply (aggregated or disaggregated) and primary energy demand (centralised, grid export or export to local cluster). This provided insights into how the supply chain structure of a bioenergy pathway affects its likelihood of success.

The overwhelming majority of operational AD and combustion-based bioenergy projects in the target countries fit into archetype of aggregated feedstock supply and centralised energy demand. When a business produces or controls its own biomass production and supply, it is clearly in a strong position, with low (or negative) acquisition costs, no or low aggregation costs, and a long term, secure supply of feedstock.

AD and combustion projects based on agro-processing residues generating energy primarily for self-consumption account for 80% of the operational projects identified. Going beyond self-use to selling energy makes sense only when the enabling environment for exporting electricity to the grid or selling via wheeling agreements is supported by a political, regulatory and financial framework that makes it easy to capture the extra value from such sales. There are limited examples of this model but exploring them further during Stage 3 will provide insights into how barriers to replication could be overcome.

Theme 4: Economic viability and barrier analysis

Theme 4 used the archetype framework to understand the economic viability of deploying bioenergy in the target countries and the economic barriers and incentives available to commercial bioenergy developers and investors. In calculating the levelised cost of electricity from different bioenergy pathways, generic references suggest a breakdown of 31% feedstock, 50% CAPEX (capital expenditure) and 19% OPEX (operating expenditure) for combustion-based projects, and a range of 10% to 18% feedstock, 36% to 75% CAPEX and 20% to 45% OPEX for AD-based projects.

Supply chain archetypes that include the use of heat tend to be more successful than those producing only electricity . A key success factor in the existence of rural electrification projects (with potential subsidies) is the possibility of electricity sales to the national grid via Power Purchase Agreements (PPAs) under feed-in tariff (FiT) or renewable/bioenergy electricity procurement schemes. Such incentives could motivate producers of biomass electricity to increase electricity production to provide the additional electricity to their workers and/or to neighbouring commercial buyers.

The combined GHG emissions from generation of electricity have fallen enormously across the target countries over the past 15 years. If more attention were paid to bioenergy investment, the benefits for climate change, employment, income generation, health and other externalities would be substantial. The development of inclusive bioenergy pathways, particularly in the farming sector, can also generate local income and improve livelihoods in rural and peri-urban areas.

Theme 5: Institutional, market and regulatory framework

This theme provided an overview of the institutional, regulatory and market framework in the ten SSA countries according to governance, regulatory environment, government bioenergy support, degree of market openness, and finance. The following were the key takeaways:

- Bioenergy receives a fraction of the support that governments, donors and national and international investors in terms of US dollar equivalent both per kW installed and per kWh generated relative to solar PV and small-scale hydropower electricity in all ten SSA countries. Total installed capacity of bioenergy electricity is less than 5% of all renewable electricity in the target countries.[2] This is a major barrier to the development of bioenergy in SSA.
- Bioenergy, within the size range of the BSEAA2 Project (10 kW to 5 MW) is relatively new, particularly anaerobic digestion (AD), in all 10 SSA target countries with the exception of sugar bagasse (which is almost all combustion CHP greater than 5 MW), pulp and paper (again, all over 5 MW) and wood processing (e.g. sawmilling and use of residues for generating heat, particular for timber drying); almost all bioenergy projects shortlisted (operational and commercial) are relatively recent investments, in the six countries, including Kenya and South Africa, where the Project team prioritised bioenergy pathways during Stage 2.
- South Africa, followed by Kenya, are the 'sweet spots' for bioenergy development, demonstrating the most supportive enabling environments and private sector interest for bioenergy development.
- Ghana, Tanzania and Uganda follow next, but have all reduced their support for bioenergy and small-scale renewable electricity projects, due to oversupply of electricity (Uganda and Ghana), grid-extension in lieu of mini-grids (Tanzania) or achievement of renewables targets (Uganda).
- Nigeria, given its fossil fuel dominance, has not paid much attention to bioenergy. Nonetheless, given large agricultural, livestock and forestry sectors, and the government's ambitions for renewable energy and bioenergy (at least on paper), there is potential for bioenergy development if strong regulatory support and finance is provided.
- Rwanda, Ethiopia, Mozambique and Zambia have weak or absent supporting frameworks for bioenergy, with any support mainly targeted at household cooking and at non-bioenergy sources for electricity generation.

Despite many obstacles, commercially successful bioenergy projects can be found in all countries except Rwanda, Ethiopia, Zambia and Mozambique.

Step 3: Pathway prioritisation

The five bioenergy pathways identified as having replicable, operational projects during the pre-screening stage were analysed based on the operational projects identified, applying the lessons from the thematic assessments, to prioritise the following nine sub-pathways (in six countries) for further review and analysis in Stage 3:

Under AD:

1. Oil palm mill effluent for CHP in the oil processing industry (focus country: Ghana)

[2] See Table 10, Theme 4 and Theme 5, below for data and more extensive analyses.

2. Vegetable processing residues for CHP in the vegetable processing industry (focus country: Kenya)
3. Fruit processing residues for CHP in the fruit processing industry (focus country: Kenya)
4. Sisal waste for CHP in the fibre processing industry (focus country: Kenya)
5. Cattle manure for CHP in the dairy industry (focus country: South Africa)

Under Combustion:

6. Oil palm residues for CHP in the oil processing industry (focus country: Ghana)
7. Forest and plantation wood for heat-only in the tea industry (focus country: Kenya)
8. Wood processing residues for CHP in the wood processing industry (focus country: Tanzania)
9. Mixed agricultural and forest processing residues for heat-only in the cement industry (focus country: Nigeria)

Next steps

The work undertaken during Stage 2 has set the stage for Stage 3 ‘bottom-up evaluation of selected bioenergy pathways’ between April 2020 and March 2021. The thematic teams will undertake more in-depth assessments, develop toolkits and practical resources, and make recommendations on successful bioenergy project development in SSA. Task E – Gasification will proceed to complete the qualitative assessment of key factors hindering the uptake of gasification and set out enabling conditions to ensure its viability in SSA, including a screening checklist (a decision tree matrix) to assist potential gasification investors make an initial judgement of the investment opportunity.

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1 Introduction

1.1 Project overview

LTS International (LTS) has teamed up with Aston University, E4tech and Aiguasol to implement the UK Department for International Development (DFID)-funded Bioenergy for Sustainable Local Energy Services and Energy Access in Africa: Academic Research Project - Phase 2 (BSEAA2). BSEAA2 is part of the DFID-funded Transforming Energy Access (TEA) programme. The TEA programme aims to create innovative solutions to support scaling up of technologies and business models to support energy access in Sub-Saharan Africa (SSA). In doing so, it will accelerate access to affordable and clean energy for all, aligning with UN Sustainable Development Goal no. 7.[3]

BSEAA2 is a two-year project that follows a Phase 1 scoping study carried out during 2016 and 2017. The objective is to identify and support the development of innovative, commercial bioenergy pathways and technologies that will accelerate the successful production and use of bioenergy in SSA.[4] Building upon the Phase 1 results, this phase focuses on researching commercially viable opportunities for the development of anaerobic digestion (AD) and combustion technologies for electricity and/or heat generation in the output range 10 kWe to 5 MWe, with a Technology Readiness Level (TRL)[5] of 5+.[6]

The research team is investigating the challenges and opportunities affecting the adoption and commercial deployment of these technologies and their associated value chains, with a focus on ten countries in SSA: Ethiopia, Ghana, Kenya, Mozambique, Nigeria, Rwanda, South Africa, Tanzania, Uganda and Zambia.

BSEAA2 is targeted at bioenergy entrepreneurs (particularly technology and project developers), investors[7] and policymakers, to catalyse action for bioenergy development in SSA.[8] The project is working closely with participants and partners of the TEA Programme, Energy Catalyst, Innovate UK and others who are active in bioenergy in SSA, or interested in becoming engaged. The research has a practical focus; it is designed to lead to the development of resources and tools that will assist industry and investors to assess the feasibility, use and applications of bioenergy technologies.

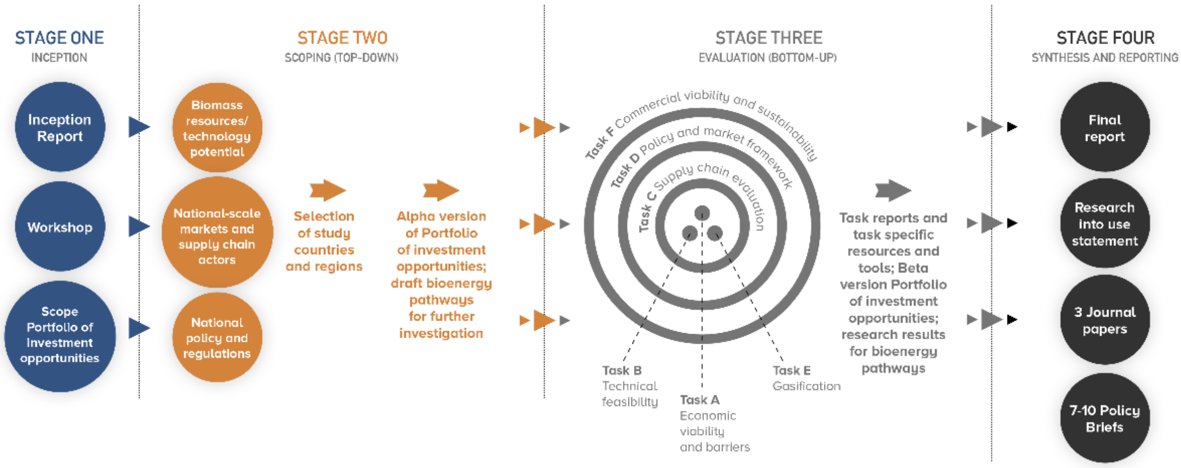
In accordance with the BSEAA2 Terms of Reference, specific research is also being undertaken into biomass gasification, a technology that has largely failed in the region so far, to investigate the barriers and critical success factors to help catalyse its successful adoption in SSA.

[3] BSEAA2 Invitation to Tender, 19 November 2018
[4] As per section 1.2.2 (Project Objectives) of the Terms of Reference
[5] For more information on TRLs see en.wikipedia.org/wiki/Technology_readiness_level
[6] As per section 2.1 (Scope of Work) of the Terms of Reference
[7] Particularly impact funds, private and public investment facilities, and development finance institutions.
[8] As per section 1.2.2 (Project Objectives) of the Terms of Reference

1.2 Approach

The project is structured in four stages as shown in Figure 1.

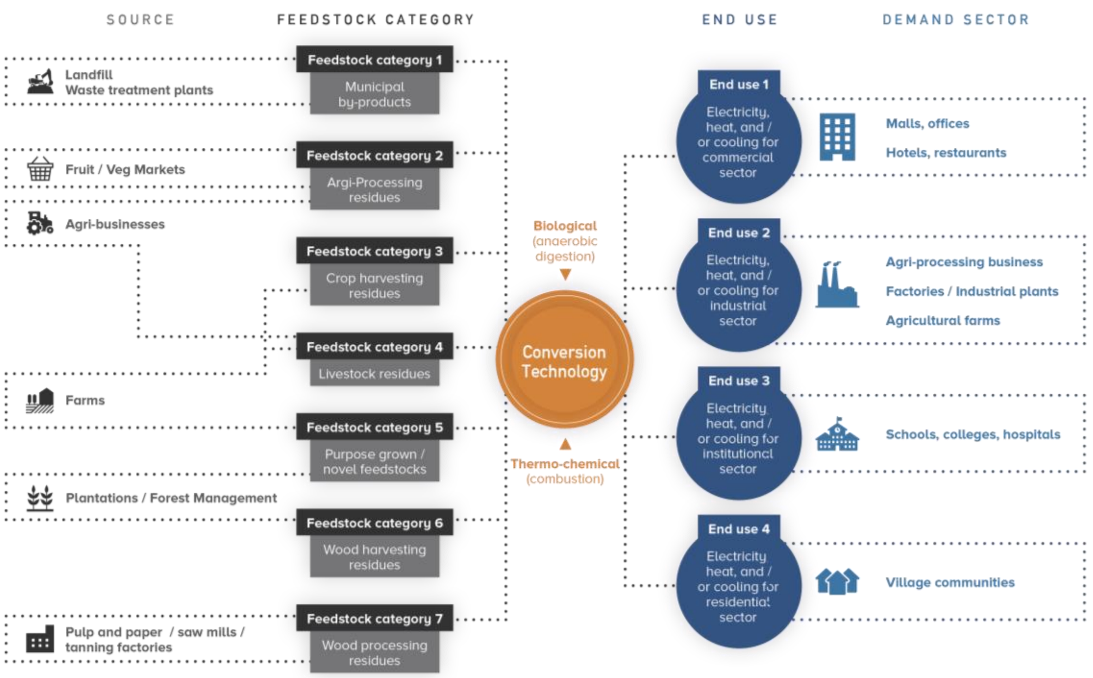
Figure 1: BSEAA2 project stages



Stage 1: Inception (June - August 2019) enabled the project team to elaborate the research methodology, workplan, quality processes, gender and inclusion plan and risk management plan.

Stage 2: Top-down bioenergy assessment (September 2019 - March 2020): Stage 2 comprised the development and top-down examination of a longlist of bioenergy ‘pathways’. A pathway comprises a specific feedstock, a feedstock category, a conversion technology, an end use and a demand sector. Figure 2 provides a representative set of examples of bioenergy pathways linked to AD and combustion. The feedstock categories have been adapted from FAO (FAO 2004), as described in the Inception Report.

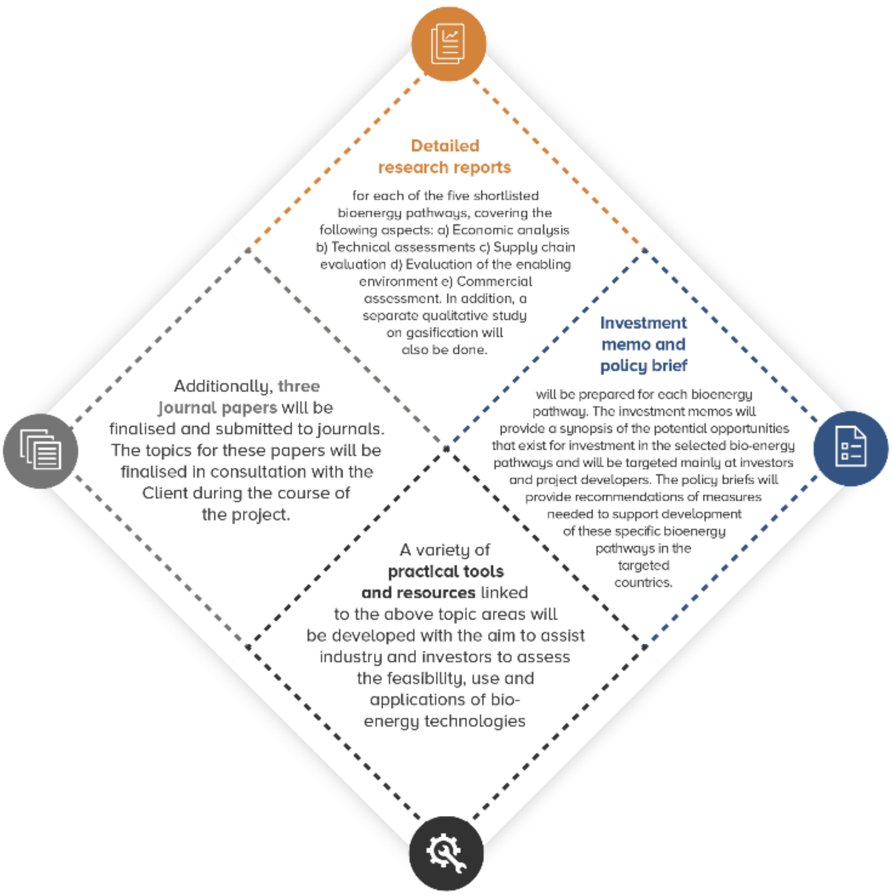
Figure 2: Schematic of potential bioenergy pathways



This schematic representation was further elaborated to finalise a longlist of pathways for more detailed investigation. This investigation involved an assessment of biomass resources, status of technological development, economic potential, applicable business models and institutional frameworks linked to the most promising bioenergy pathways in the ten target countries. The aim of this top-down scoping was to shortlist at least five promising bioenergy pathways in at least five countries for further investigation during Stage 3. The final shortlist is provided in section 6.3.

Stage 3: Bottom-up evaluation of promising bioenergy pathways (April 2020 - March 2021): During Stage 3, a bottom-up evaluation of the shortlisted bioenergy pathways will be undertaken. This will involve a deep-dive assessment into each pathway, developing solutions, designing tools and providing recommendations on technological, economic, commercial, policy and market-related aspects to support uptake and commercialisation. Stage 3 will have a practical focus. It is designed to lead to development of resources and tools that will assist industry and investors to assess the feasibility, use and applications of bioenergy technologies in the shortlisted countries and pathways. Figure 3 summarises the research outputs that will be developed.

Figure 3: BSEAA2 research deliverables



Stage 4: Reporting and dissemination (April – June 2021): During this final stage, the team will synthesise and disseminate the final reports, journal papers, policy briefs and other communication products to key stakeholder groups.

2 Methodology

2.1 Clarification of key terms

During the Inception phase, the boundaries of the research were clarified by defining key areas of focus from the Terms of Reference to ensure coherence between client expectations and the team's understanding of the client's expectations. A summary of those terms is repeated here.

Bioenergy pathways

A bioenergy pathway is 'a process that starts with the selection of a particular biomass source and, through the application of a conversion process, culminates in the generation of bioenergy in a form suitable to satisfy the energy demand profile of the end-use sector' (IEA/FAO, 2017). This definition was elaborated to include:

1. **Production** of biomass (including planting, harvesting and collecting, e.g. agri-residues, other 'wastes' such as sewerage, industrial and landfill that can be utilised for energy.
2. **Transformation** of that biomass (e.g. milling, pressing, chilling, canning, freezing, juicing) into a higher value product which can itself, or using residues from processing, be 'converted' into energy through any number of technologies and processes, e.g. generating biogas from AD to provide heat and/or electricity.
3. Supply to points of **demand and utilisation** such as industrial, commercial or community scale residential sectors.

Portfolio of investment opportunities

This refers to a selection of potential projects or pathways in a region or country for which external funding would provide a significant boost to prospects for replication or scale-up. This may encompass a range of projects and pathways from those that are commercially well-developed and close to bankability, through to others that have been validated in SSA but require pre-commercial support to move them towards commercial profitability.

Commercial and productive uses of energy

In the context of this project, this denotes non-household, non-subsistence energy produced in the 10 kW_e to 5 MW_e range with quantifiable value, either for direct sale (e.g. electricity for grid feed-in) or for the costs it displaces (e.g. reducing dependence on generators). Economic and commercial viability underpins the sustainability of each bioenergy pathway and is therefore central to the analysis.

Thermal-only applications

This refers to applications where heat is generated for direct use (i.e. process heat) for applications such as dairy production, manufacturing, food processing, drying, steaming and sterilisation.

Sweet spot regions/countries/locations

This refers to geographic areas (regions or countries) or specific locations where the conditions for successful bioenergy projects are very good. This requires access to the right biomass feedstocks, conversion technology (whether AD or combustion) with supportive technology providers and service back-up, an enabling regulatory environment to attract and access finance, skilled labour, and good demand for the bioenergy produced.

2.2 Methodology

The Stage 2 top-down scoping, involved a systematic process of identifying, analysing and screening potential bioenergy pathways (based on a systematic investigation of the current deployment pattern for AD and combustion in the defined scale range) to ascertain which combination of feedstock, technology, end use and demand sectors are worth exploring in more depth during Stage 3.

2.2.1 Step 1: Development of longlist of bioenergy pathways

Stage 2 began with the development of a longlist of bioenergy pathways based on the conceptual frameworks from FAO's Unified Bioenergy Terminology (FAO, 2004) and the FAO/IEA How2Guide for Bioenergy (IEA/FAO, 2017). As defined above, a bioenergy pathway comprises the five elements shown in Figure 4.

Figure 4: Elements of a bioenergy pathway

Given the significant diversity of feedstock options and demand sectors, segments 2, 3 and 4 were defined as the 'backbone' for developing a list of primary pathways. Numerous variants (or 'sub-pathways') exist for each primary pathway, depending on the feedstock (segment 1) and energy demand sector (segment 5).

Based on this conceptual framework, bioenergy pathways incorporating AD and combustion were developed, drawing upon the information in the FAO guides and the team's extensive experiences from SSA. These pathways were reviewed by the core team and the national experts to confirm their validity in the SSA context and compliance with the BSEAA2 criteria, i.e. operating scale 10 kW_e to 5 MW_e, TRL 5+, end-use focused on electricity and/or heat for commercial and productive applications.

Having defined the longlist of potential pathways, the team then mapped bioenergy projects in the target countries representative of these pathways. The mapping exercise provided a detailed snapshot of the current landscape of bioenergy development in each country. This took the form of a comprehensive matrix (hereafter referred to as the 'Projects Grid') for capturing relevant bioenergy projects representing the longlist of pathways. Diverse information regarding the type of feedstock, technology, end use, demand sector, location, operating status, financing entity and other relevant information was collected and recorded in this grid.

The development of the Projects Grid required significant inputs to identify, scrutinise and validate bioenergy projects, based on available information from BSEAA Phase 1, supplemented with extensive new internet research, additional references and contacts, and investigations by the core team and the national experts. A breakdown of the categories within the Projects Grid and the level of data disaggregation available is provided in Annex 1. The complete grid is available on request.

2.2.2 Step 2: Pathways assessment

The Projects Grid was a powerful tool for grounding the analysis. It not only facilitated a thematic investigation of the various pathways, but also provided an evidence base for gauging the current deployment status of each of the pathways in the target countries.

The pathway assessment was undertaken in two stages:

(a) Pre-screening of longlist of pathways

The level of commercial activity linked to each pathway was assessed. The lack of any operational project is a strong indication that a pathway is not currently viable in the SSA context. The grid was therefore an important first filter to determine whether a pathway was suitable for further thematic-based assessments.

Maps were developed to capture the distribution of this activity across the target countries in order to provide a high-level assessment of which pathways demonstrate a reliable level of actual uptake (and, therefore, potential for further replication); and to aid in the identification of the 'sweet-spot' countries and regions where these activities are occurring, to provide early insight into which countries demonstrate greater potential for replication and scalability.

This assessment was used to screen out pathways that showed little or no potential for commercial adoption. This was based on an investigation of operating status of the projects identified across the longlist of pathways. The non-existence of operational projects indicates that the pathways in which they occur have yet to be validated in an operational environment. This indicates a lack of basic level of commercial maturity, which is a key criterion set out in Section 2.1 of the Terms of Reference. This allowed the thematic investigations to focus mainly on pathways that have been tested and validated, indicating higher prospects of promoting commercial adoption.

(b) Thematic assessment of pathways

The pre-screened pathways were analysed based on five interlinked themes:

- **Theme 1** - Biomass resources.
- **Theme 2** - Status of technical development.
- **Theme 3** - Business model suitability assessment.
- **Theme 4** - Economic viability and barrier analysis; and
- **Theme 5** - Institutional, regulatory and market framework.

Under each theme, the team developed a set of criteria to assess the conditions, factors and opportunities for adoption in the SSA context, allowing the specific pathways and sub-pathways that demonstrate sufficient commercial and innovation potential to be identified for further exploration during Stage 3.

2.2.2.1. Theme 1: Biomass Resources

The objective of the Theme 1 assessment (by Aston University) was to identify biomass resource availability, type, location and bioenergy potential through a high-level assessment against four main criteria. This informed the selection of the biomass resources and locations of most relevance for Stage 3 analysis.

The team analysed land use categories, biomass resources, quantities and spatial distribution, following the categorisation principles of FAO's Global Agro-Ecological Zones[9] and the UN Economic Commission for Europe (UN ECE) framework for land use and agro-ecological zoning.[10] The agro-ecological zones were mapped across the target countries to identify the dominant land use types, main crops and potential biomass sourcing opportunities. This highlighted the types of biomass available, the feasibility of sourcing that biomass, the land suitability for producing it and the wider sustainability implications (environmental, economic, social) of using it.

The most promising feedstocks were then investigated in more detail using the following criteria:

a. **Sustainable resource potential:** Type, quantity and scale of feedstock availability and competing uses.
b. **Bioenergy generation potential:** Form, quality and characteristics of feedstocks suitable for AD and thermochemical conversion, consistency and scale of supply, infrastructure and aggregation potential, and socio-economic aspects such as ownership and access.
c. **Feedstock-technology interfaces:** Feedstock availability, choice of conversion technology, pre-treatment requirements, scale, consistency of supply, logistics, load factor and final application.
d. **Sustainability**: Environmental, economic and social implications of feedstock, potential bioenergy pathways and current competing uses and beneficiaries.

2.2.2.2. Theme 2: Status of technical development

The objective of the Theme 2 assessment (under LTS International) was to examine the innovation-led growth potential of AD and combustion technologies in SSA within the desired output range. The primary criteria applied were:

[9] For more information on FAO's global agro-ecological zones, see http://www.fao.org/nr/gaez/en/
[10] For more information on UN ECE, please see https://www.unece.org/

a) **Existing extent of deployment in SSA:** Higher deployment within SSA serves as a proxy for viability in the SSA context. It may also demonstrate seriousness and commitment on the part of technology developers (though noting that some technologies are a legacy of colonial economics and agri-sectors that were established historically, some of which are in decline, while others are on the rise);[11]
b) **Technological adaptation:** Technologies that have been adapted (or are adaptable) for the SSA context have better prospects for scalability, e.g. adapted for SSA climates, seasonality, feedstocks, water availability, power limitations or skill sets.
c) **Reliability:** Less complex technologies that are easier to operate, are robust and have low maintenance needs in proven real-world settings indicate greater prospects for SSA.
d) **Innovation potential:** Without overlooking the importance of using tried and tested technology, if a technology offers opportunities for innovation to suit SSA contexts, it could unlock significant scaling potential; and
e) **Availability of technology support:** A developer should have the confidence that the technology as well as support, servicing and spares are available to ensure that equipment can be reliably operated and maintained.

2.2.2.3. Supply chain archetype assessment

The objective of this theme (under E4tech) was to evaluate the relative attractiveness from a business and financing point of view of the five primary bioenergy pathways. In this context, the business potential must be evaluated as an end-to-end value chain, from the feedstock producer through to the end use customer. The title of Theme 4 was adapted to reflect this supply chain emphasis. Six variants of bioenergy supply chains (or 'archetypes') were assessed against the following five criteria:

a) **Supply chain archetype that is proven and can be replicated:** Supply chain archetypes that are (i) well proven and (ii) which have been replicated (both within the same sector and in others) are more likely to be economically attractive and investor friendly. To assess this, the team defined the conditions needed for a supply chain archetype to be 'proven' in the context of energy provision from biomass resources.
b) **Demand sector analysis:** It was assumed that demand sectors with high energy demand and a large, growing and diversified end-use customer base will be more attractive to investors and entrepreneurs than those whose customer base is stagnant or shrinking.
c) **Competitiveness of the supply chain archetype:** Supply chain archetypes that are less vulnerable to competition are more likely to succeed. In this context, competitors are other potential value chains in the energy sector providing the same end-use service, to the same market segment (e.g. solar PV and storage for commercial electricity). A high-level assessment of the barriers to entry to the market and an assessment of the competitive landscape was carried out to determine whether each supply chain model is likely to face strong competition.
d) **Scalability of the supply chain archetype:** Enablers and barriers associated with each archetype were assessed. This determines how easy it is to expand a supply chain model whilst maintaining or improving its margin per unit of service sold.
e) **Lowest cost source of finance available:** Lower risk projects will have lower financing costs and will likely be more attractive to target investor groups (e.g. development banks, impact investment funds, etc.) than others (e.g. venture capitalists and donor agencies who may have an appetite for higher risk). The expected cost of providing finance to a supply chain archetype was qualitatively assessed. This in turn reflects the risk and thus the expected return on investment associated with it.

2.2.2.4 Economic Viability and Barrier Analysis

The main objective of this theme (under Aiguasol) was to determine the most promising biomass conversion technologies and associated pathways based on their economic viability and potential or probable barriers for their implementation. This encompassed the pre-evaluation of the economic viability of different bioenergy supply chain models and countries to select the most promising options.

[11] Examples of successful transformation from colonial or international estate-based agri-sectors include tea, sugar, coffee, cocoa, palm oil, horticultural and floricultural crops, among others.

This closely coordinated with other thematic areas (particularly the supply chain archetype analysis and the assessment of institutional, regulatory and market frameworks).

The primary criteria used in the assessment of economic viability of the conversion pathways were:

a) **Accuracy and availability of cost estimation references and expected evolution:** Due to the long payback periods of energy investments (typically 5 to 10 years), the accuracy of cost references is crucial to minimise investment risk. If all other things are equal, those pathways for which relevant Life Cycle Cost (LCC) figures are readily available, accurate and reliable, therefore received a higher prioritisation.
b) **Cost reduction potential**: Assessing the cost reduction potential of each pathway was undertaken by determining the main LCC costs at each stage of the pathway and the influence of project scale. This was complemented by an assessment of the current energy costs (both heat and electricity) to provide a qualitative assessment of where cost reductions could potentially be achieved.
c) **Subsidy availability for Capital Expenditure (CAPEX) and/or Operating Expenditure (OPEX):** Subsidy availability was used to assess the potential cost reductions in CAPEX and / or OPEX to enhance the commercial prospects for replication. It is important to distinguish between CAPEX and OPEX subsidies because they address different financial and economic risks.[12]
d) **Intangible socio-economic benefits:** In addition to quantifiable costs and revenues, the implementation of biomass conversion pathways embodies several socio-economic benefits such as greenhouse gas (GHG) emission reduction potential, women's empowerment, improved land and forest management benefits, and other impacts of energy access. An assessment of such intangible benefits was carried out to determine the impact bioenergy can have on people and environment.
e) **Revenue stream stability/predictability or volatility:** This criterion refers to the stability and predictability (or volatility) of revenue streams, which is important due to the long payback periods of energy investments. Volatile revenue streams penalise projected LCC, whereas predictable and stable revenue streams improve the accuracy of projected cost estimations.

2.2.2.5. Institutional, Regulatory and Market Frameworks

The objective of this theme (under LTS) was to examine the institutional, regulatory and market framework in each of the ten SSA countries for gauging:

- How conducive the institutional, regulatory and market framework is to commercial agriculture and agri-business, which is the major source of feedstock supply for most bioenergy technology;[13]
- How supportive national laws, regulations and the market framework are to the production, and utilisation of biomass to generate energy that meets commercial and industrial demand.
- How supportive the national regulatory and market framework is for local and international finance, and local and international development assistance to finance the investment in supply, transformation, bioenergy generation, and end-use consumption and sales; and,
- Overall, how sustainable the regulatory and institutional framework and environment is for profitable bioenergy production and markets.

The five primary criteria used to assess the institutional, regulatory and market framework were:

a **Governance:** Is there rule of law? Is the legal structure transparent? If not, is this holding back investment in renewable energy (and bioenergy in particular)? Are laws enforced? Is there corruption? Does corruption hold back investment?

[12] Potential abandonment Expenditure is considered as part of OPEX. We assume these facilities have operational lifespans longer than the economic analysis period (with proper maintenance).
13 Livestock is considered to fall into the agricultural sector. Hence, animal waste as a feedstock would fit within agriculture. Forest residues (e.g. from sawmills and other wood industries) can be an important feedstock for bioenergy, as are municipal solid waste (MSW) and waste water (e.g. industrial, municipal, etc.).

b **Regulatory environment:** Are there regulatory frameworks for agriculture, waste management, water and soil management and energy? Is there a national energy regulator? If not, is there a national electricity regulator? Is the regulator effective? Does the regulator set out and enforce the 'rules of the road' on energy/electricity? Is the regulator supportive of bioenergy? Are licences for bioenergy projects easy to obtain? Are power purchase agreements (PPAs) easy to obtain? Is access to national and regional grids for electricity supply open and easy? Is regulation 'fair' and transparent to all players, big and small, national and international?

c **Level of government support for bioenergy and the agriculture sector:** Are there laws, decrees, etc. that put bioenergy front and centre with government support? Does government actively support investment in the agricultural sector, particularly the agri-business and agro-processing sectors? Is foreign investment in the agriculture, agro-processing and agri-business sectors welcome? Does government welcome investment from the private sector in renewable energy, bioenergy specifically?

d **Degree of market openness, liberalisation:** Is the energy market open and liberal, with ease of entry and exit? Is the energy market a monopoly, oligopoly or free and open for all? Does this only apply to electricity and petroleum products, or, is this also the case in renewable energy (bioenergy, solar, wind, hydropower, etc.)? These factors are of most relevance to enterprises seeking to sell their power into local or national grids.

e **Finance:** Is the banking sector open, with ease of entry and exit for national and international banks and International Financing Institutions? Are commercial banks active in renewable energy project financing, specifically for bioenergy projects? How easy is it to obtain international project finance for bioenergy projects? Is local access to international finance open? Are international finance flows relatively easy and unrestricted? How easy is it to remit profits abroad?

2.2.3 Step 3: Prioritisation of promising bioenergy pathways

The prioritisation followed a systematic process of screening the longlist of pathways to a shortlist of the most promising options. Owing to the fragmented nature of bioenergy development in the target countries and the limited number of operational projects identified, the team adapted its approach by analysing as a first pass the level of commercial activity linked to each pathway. The non-existence of any operational projects indicates that the pathways in which they occur have yet to demonstrate a reliable level of uptake. The team therefore adapted its scoring methodology to rank pathways based on the level of commercial activity. This allowed the team to focus its investigations on those pathways and projects that exist, are operational and have therefore been validated in an SSA context, thus demonstrating higher opportunity for commercial adoption and replicability.

In order to further screen this shortlist of pathways to identify promising sub-pathways, the findings and insights developed from the thematic assessments were used to develop a deeper understanding of the dynamics of commercial bioenergy 'success' in the target countries. These insights were systematically applied to the operational projects identified from the pre-screening process to identify specific sub-pathways deemed most suitable for taking into Stage 3.

3 Step 1: Development of longlist of pathways

As described in the methodology, elements 2 (feedstock category), 3 (conversion technology) and 4 (energy-vector) of the pathway model formed the backbone of the bioenergy pathways. A total of 11 pathways were identified, of which five were AD-based and six were combustion-based (Table 1 and Table 2). Annex 2 provides further description of the feedstock categories linked to each pathway.

Table 1: AD-based bioenergy pathways

Feedstock Category	Conversion technology	Energy vector
Agro-processing residues	**Primary[14]:** Anaerobic Digestion **Secondary[15]:** Reciprocating gas engine	**Primary:** Electricity, heat and/or cooling **Secondary:** value-added conversion by-products
Crop harvesting residues		
Livestock wastes		
Municipal by-products		
Purpose grown or novel feedstocks		

Table 2: Combustion based bioenergy pathways

Feedstock Category	Conversion technology	Energy vector
Forest and plantation wood	**Primary:** Combustion **Secondary:** Steam turbines	**Primary:** Electricity, heat and/or cooling **Secondary:** value-added conversion by-products
Wood processing residues		
Wood harvesting residues		
Material waste		
Herbaceous energy crops		
Agro-processing residues		

[14] Refers to the conversion technology that converts the biomass feedstock into a product (such as biogas, bio-ethanol or steam) that can be further processed for electricity and/or heat generation.
[15] Refers to the conversion technology that converts the product generated from the primary conversion process into electricity and/or heat.

4 Step 2(a): Pathway pre-screening

4.1 Key findings

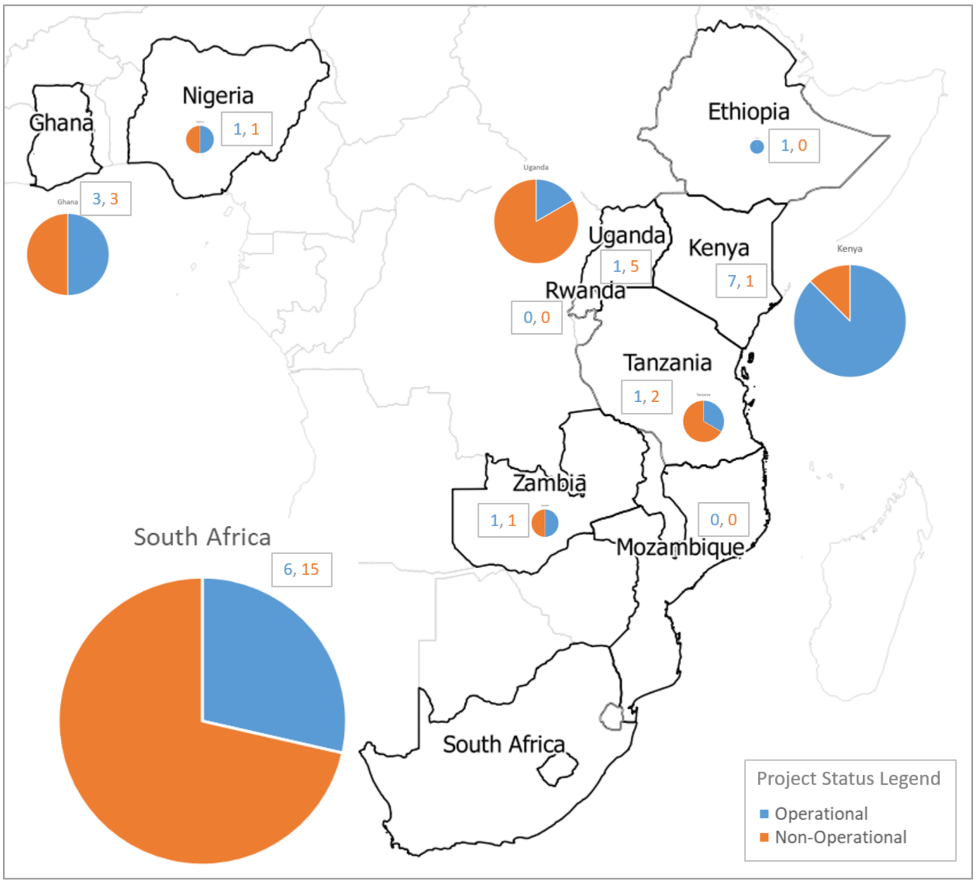
The development of the longlist of pathways was followed by a mapping exercise to deliver a snapshot of the current landscape of commercial bioenergy development in the 10 target countries, with a focus on AD and combustion-based technologies. While the database of AD projects developed is believed to be very comprehensive, the combustion-based projects provide a representative sample of commercially active projects. Given the time and resources available, not all combustion-based installations have been captured. The likely omissions are primarily small-scale heat-only systems, widely dispersed in forestry processing companies, tea factories, sugar mills and other agribusinesses that are not publicly promoted or were not accessible during Stage 2.

The following maps illustrate the distribution and operating status of AD and combustion-based projects across the 10 target countries. 'Non-operational' projects are those that are shut down, under construction, in the planning stages or of unclear operating status.

4.1.1 High-level assessment of AD landscape in Sub-Saharan Africa

The AD projects in the target countries are mapped in Figure 5.

Figure 5: Distribution and operating status of AD projects



Source: Projects Grid

A total of 49 commercially oriented AD ventures were identified. Of these, only 40% were found to be operational while 20% were non-operational, 16% with an unclear status, 18% under various stages of planning and 6% under construction.

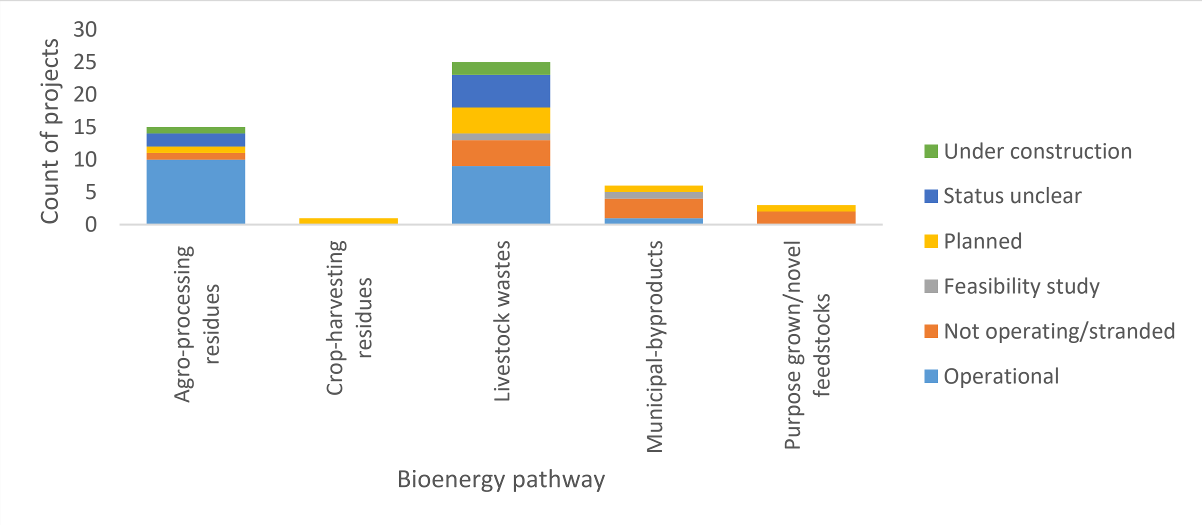
South Africa leads the development of AD in the SSA target countries with 43% of all projects, followed by Kenya (16%), Ghana (12%) and Uganda (12%). Of the remaining six countries, Tanzania (6%), Zambia (4%), Nigeria (4%) and Ethiopia (2%) have had little to no commercial AD uptake and success. Mozambique and Rwanda do not currently feature in the context of commercial biogas development in the target scale range and end use demand.

Interestingly, however, South Africa accounts for a lower percentage of projects that are currently operational (29%). This likely reflects the country's first-mover status. It has led many research and development efforts, including several 'first of their kind' bioenergy projects. This includes, for instance, the use of novel feedstocks (e.g. dedicated Napier Grass used by Sucropower),[16] novel technologies (e.g. an induced blanket reactor developed by Renen)[17] or novel business models (e.g. the commercially functioning 4.6 MW AD plant developed by Bio2Watt[18] at Bronkhorstspruit that sources wastes from a cattle feedlot together with industrial wastes, and supplies power to an industrial off-taker).

Kenya has shown a much higher AD project success rate. As section 5.5 (institutional, market and regulatory framework) will demonstrate, this is reflective of a strong enabling environment, including supportive government bioenergy policies and regulation, fairly open market economy and a high degree of international competitiveness.

Figure 6 provides an overview of the current landscape of projects across each pathway. This provides an early indication of which pathways demonstrate a higher level of commercial maturity.

Figure 6: AD - operating status by bioenergy pathway



Source: Projects Grid

It is evident from Figure 6 that certain bioenergy pathways have had a poor to no track record of operational projects in the 10 target countries.

For the bioenergy pathways based on **crop-harvesting residues** as the primary feedstock source, no operational projects were found. Crop harvesting residues refer to by-products from agricultural activities left in the field such as maize cobs and stalks, cotton stalks, sugar cane trash and rice straw. These by-products are often not suitable for direct use in biogas plants owing to the comparatively high lignocellulosic content, thus requiring considerable pre-treatment or plant design modifications. Given that these are residues left in the field, the logistical and economic considerations of

[16] http://www.ibert.co.za/reference/sucro-power-mandini/
[17] http://renen.co.za/
[18] https://www.bio2watt.com/bio2watt%E2%80%99s-bronkhorstspruit-biogas-plant-(pty)-ltd.html

aggregation also make them less attractive. Furthermore, leaving them in the fields contributes to the recycling of nutrients.

The other bioenergy pathway that has witnessed no operational success is the use of **purpose-grown/novel feedstocks**. This includes plant species such as elephant grass, napier grass and water hyacinth, which are either grown for energy generation (generally supplemented by another feedstock source) or are invasive, hence targeted for bioenergy production. However, the fact that two of the three projects in this category identified are abandoned and the other is still in the planning stages indicates that this bioenergy pathway demonstrates negligible commercial viability at present. Issues such as land ownership, food-versus-fuel, consistency and reliability of supply and lack of proven business models make this unattractive for potential investors and project developers.

The third AD pathway that has seen little commercial success in an SSA context is that based on the use of **municipal by-products**. This comprises both solid and liquid municipal biomass wastes from households and industry. This includes a) the organic fraction of Municipal Solid Waste (MSW); b) waste waters, i.e. sewage sludge, industrial waste waters; and c) landfill gas.

While waste-to-energy generation from MSW offers significant advantages over fossil fuel sources in terms of reduced carbon emissions, improved air and water quality and improved waste management (SEA, 2017), this sector has witnessed negligible commercial success. Successful examples are found only in South Africa within the framework of the ten target countries. This is because, compared to other bioenergy pathways, there are considerations of ownership and control of the feedstock as waste management sites are almost always under the ownership of municipal or district/county governments. Further, in most SSA countries, either no effective legislation exists on waste management, or such legislation is not enforced. This makes it unattractive to private capital owing to governance and/or control issues.

Amongst the six projects identified as using municipal by-products, three are currently non-operational. In one case this is due to corruption issues in the municipality and at two others reflects low economic viability due to high operating costs. The one operational project found in South Africa targets electricity production for self-use from biological treatment of municipal wastewater. However, the gas engines powering the facility are reportedly operating well below their design capacity.

There are also a number of land-fill gas (LFG) projects in South Africa with combined capacity of 30 MW, of which 8.5 MW are currently installed across three municipal landfills, 18.6 MW are under construction and a further 4 MW are being planned (SEA, 2017). LFG projects generating electricity for the grid attract a relatively high-power purchase price through the Renewable Energy Independent Power Producers Procurement Programme (REIPPPP) The REIPPP is delivered by the Independent Power Producers Procurement Programme (IPPPP) Office, operationalised by the DBSA Programmes Department. The IPPPP office was jointly established in 2010 by the then Department of Energy (DoE), National Treasury (NT) and the DBSA.

The sub-pathway involving LFG was not deemed suitable for shortlisting given that the only known operating examples are almost exclusively found in South Africa and the near-term potential for replication in other SSA countries is very low. [19] This reflects several known barriers to LFG projects such as:

- LFG projects are still relatively new in SSA and investment costs and returns are highly variable and uncertain. This is largely due to the difficulties encountered in the realisation of financial incentives from emissions mitigation owing to lengthy Clean Development Mechanism processes, poor policies (except in South Africa) and poor data on waste generation (Njoku, et al., 2018) (SEA, 2017);
- Inappropriate and poor management of landfill sites, posing serious risks for successful gas extraction and utilisation (SEA, 2017);

[19] The one non-South African landfill project registered under the UNFCCC's CDM is at the Mtoni landfill site in Dar es Salaam, Tanzania. The project was designed to extract LFG and combust it for electricity. However, the system for electricity generation was never installed due to problems of extraction and licensing. Thus, the site only flares gas, on occasion. See: CDM00604, No. 908, 'Landfill gas recovery and electricity generation at "Mtoni Dumpsite", Dar Es Salaam, Tanzania', UNFCCC.

- Lack of finance for municipalities and counties in the non-South African target countries, with lack of staff, handling infrastructure (vehicles, dozers, etc.) and separation facilities.
- Lack of lining at landfills and very little monitoring of the lining in the few sites that are lined;
- Lack of legislation enforcing gas extraction from landfill sites (SEA, 2017); and
- Onerous planning and development processes, with experience from South Africa indicating a project development time of 3-8 years. (SEA, 2017).

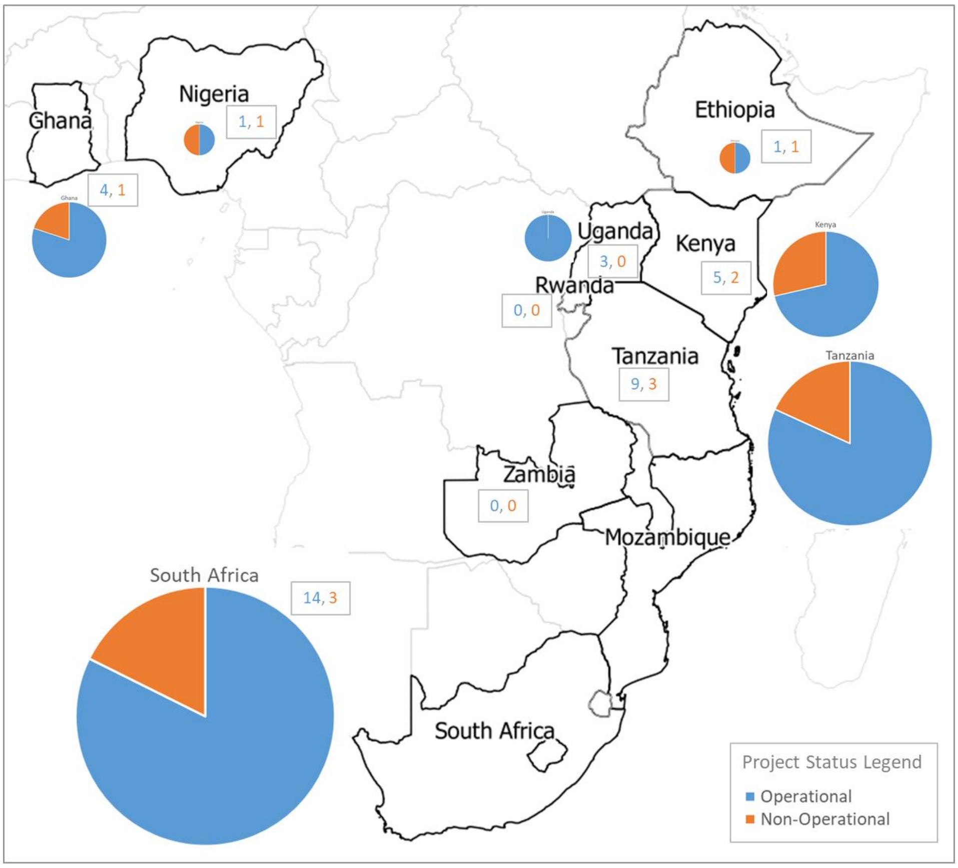
The barriers and challenges are too wide-ranging, given also that the necessary supporting frameworks, laws and regulations currently do not exist in other SSA countries.

The remaining two pathways, i.e. electricity and/or heat generation from **agro-processing residues** and **livestock wastes,** have seen much higher rates of adoption. There are currently ten operational examples under the agro-processing residues-based bioenergy pathway and nine using livestock wastes. Between these two, pathways using agro-processing residues have demonstrated a better level of success, with 66% of all projects identified still operating. Of those projects using livestock wastes, 36% are operational. Characteristics of the associated industry, the regions and countries in which they are prominent and the associated business models all play a role in determining the success of these pathways. This is explored in more detail in Section 5.

4.1.2 High-level assessment of combustion landscape in SSA

Combustion-based bioenergy projects are mapped in Figure 7. This includes both projects for heat-only applications and combustion-based steam turbine projects for CHP applications.

Figure 7: Distribution and operating status of combustion-based projects

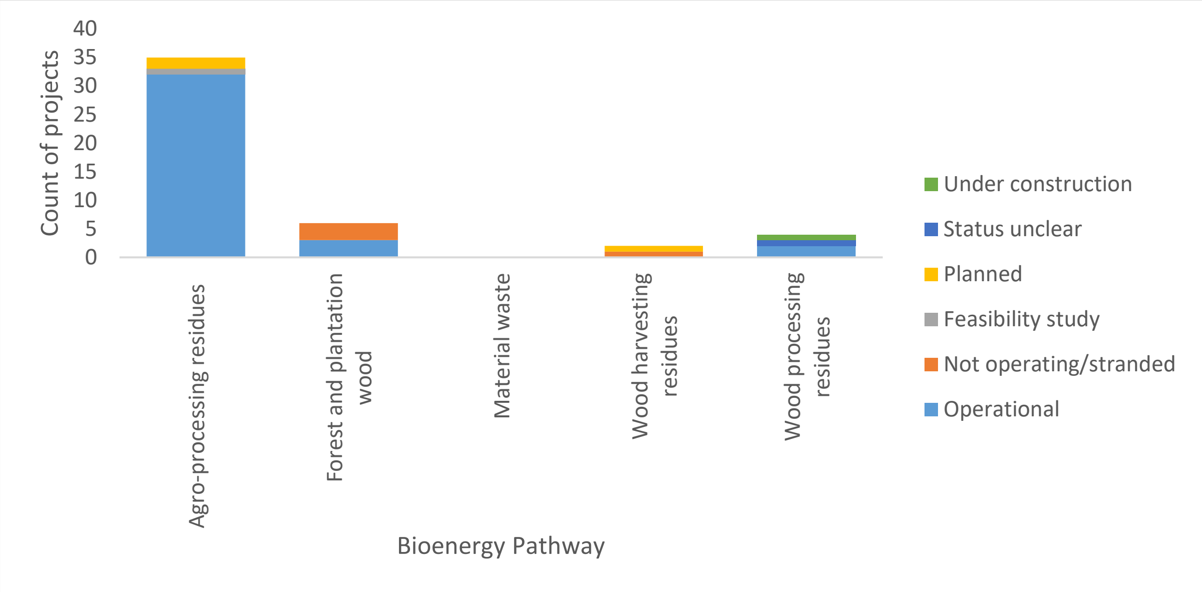


Source: Projects Grid

A much higher proportion of the combustion-based projects are operational (37 out of 48 identified) compared with AD (20 out of 49). South Africa again dominates the landscape, followed by Tanzania, Kenya and Ghana. While no projects are currently listed in Mozambique, Zambia and Rwanda, this is not indicative of the fact that these do not exist.[20]

An assessment of the combustion-based project landscape based on different bioenergy pathways is presented in Figure 8. As with AD, this provides an early indication of which pathways and associated countries demonstrate a higher likelihood of being viable for shortlisting.

Figure 8 Combustion - Operating status by bioenergy pathway



Source: Projects Grid

It is clear that the highest level of commercial activity and success has been in the agro-processing industry. A closer examination reveals that of the 37 operational projects identified, 24 are sugar mill projects using bagasse for CHP generation, while four are oil palm projects, together covering 76% of the projects under this category.

Sugar overwhelmingly dominates the combustion category in most of the target SSA countries, including South Africa, Kenya, Tanzania, Uganda and Nigeria, with fewer plants in Mozambique (three), and Rwanda and Zambia (one each). However, only three of the 24 operational projects fall within the BSEAA2's size range (10 kW_e to 5 MW_e), with the smallest sugar plant operating with a 750 kW boiler.

This suggests a highly commercialised industry operating at largely medium-to-large scale (i.e. outside the project scope). The team took the view that including the remaining three smaller operational sugar projects would shed little light on the key issues on bioenergy pathways that the project was designed to address. Essentially, these factories do not offer any innovative technical, commercial or business organisational insights that would benefit the project team's analyses. Therefore, they were not considered for further shortlisting. The oil palm projects, on the other hand, are within the size range and are found mainly in Ghana and possibly Nigeria.

Turning to the woody biomass sector, two feedstock categories also emerge as having potential for further exploration- **forest and plantation wood** and **wood processing residues**. There is potential

[20] It is estimated that there are over 90 tea factories in Kenya, nine in Ethiopia, 24 in Uganda, four in Rwanda, 18 in Tanzania and three in Mozambique. On the sugar side, while the analysis has captured all the South African sugar factories, and most in Kenya, Uganda and Tanzania, it does not include all the sugar factories in Ethiopia, and others in Mozambique, Zambia, Ghana and Nigeria. From the team's experience in Ethiopia, Zambia and Nigeria, the same (very large) size profile applies. However, there is a lack of publicly accessible information on these facilities. The same applies for many timber, lumber and other forest and plantation-supplied facilities. There are many of these which are very small and hard to find, though many would be larger than the size range prioritised for this project.

to use this type of biomass for heat-only or CHP applications, and this is explored further in the thematic chapters below.

On the other hand, **wood harvesting residues**-based pathways, using residues from felling or forest management practices (such as upper logs, branches and off-cuts left in the field) support no commercially active projects that could be identified. The low prevalence of sustainable forest management practices (as will be shown in section 5.1) reflects uncertainty of supply, owing to both quality (moisture content, contamination issues, particle size, etc.) and quantity (site access and recovery rate) of this feedstock. Further, it highlights the costs of collection and the lack of handling infrastructure. These factors that have hindered the uptake and use of this type of feedstock as a primary energy source (ICFR, 2013). Wood harvesting residues can nevertheless be a useful source of supplementary feedstock where sustainable forest management practices already exist. In such conditions, these residues can be harvested simultaneously with forest or plantation wood and can then be commercially (co-)transported to the processing site.

The last category is that of **material waste**. This refers to the bio-waste (i.e. wood or wood-derived materials) generated during construction activities, including surplus material and waste from the end of a building’s life. The lack of any projects in this pathway indicates a lack of such important factors as predictable resource availability (as it depends on level of construction activity), ownership and control dynamics, as well as potentially unattractive business models.

5 Step 2(b): Thematic assessments

5.1 Theme 1: Suitability of biomass resources for bioenergy

5.1.1 Aim

The objective under this theme was to identify the biomass resource availability, type and location in the ten target BSEAA2 countries. This was done through a high-level assessment considering biomass resource potential, bioenergy potential, feedstock-technology interface and sustainability.

5.1.2 Approach

This assessment was guided by considering the spatial distribution, following the categorisation principles of FAO's Global Agro-Ecological Zones and UN ECE framework for land use, and agro-ecological zoning relevant for the 10 target countries. Based upon this, the regions most appropriate for biomass sourcing and the current and potential land use were identified to understand the prospective types of biomass, the feasibility of biomass sourcing, land suitability and wider sustainability implications (i.e. environmental, economic, social). This provided a first understanding of the regional and in-country biomass potential for residues and wastes, technical and socio-economic challenges and opportunities of biomass availability, and sourcing.

This was followed by an in-depth assessment of specific feedstock categories to assess the most promising feedstocks for further consideration during Stage 3. The pre-screening assessment (described in chapter 4) helped to focus the feedstock assessments on the most promising biomass feedstock categories. These included:

- **Agricultural residues (**including both **agro-processing residues** and **crop harvesting residues)**;[21]
- **Wood residues** from plantations, managed forests and wood processing residues; and
- **Livestock wastes.**

Theme 1 considered land availability and suitability, as defined by FAO (FAO, 2020), and included biomass and yield production and potential in the ten target countries (Hugo, 2016, IRENA 2017, Stecher 2013, IEA/FAO 2017, FAO Stats 2019, Wicke 2011) as well as residue factors and residue removal rates, as described by (IRENA, 2017), (Smeets et al., 2004), (USDA, 2020), (Abiom, 2009) and (Thiffault et al., 2015). These were used to calculate the bioenergy feedstock potential of the produced crops. For the selection of the most feasible biomass feedstocks, the following factors were considered:

- volume, availability, access and ownership of biomass production and sourcing;
- economic relevance of product and related biomass feedstock;
- sustainability in terms of removal and other uses;
- consistency in terms of biomass supply and feedstock quality, and;
- technical feasibility for selected conversion pathways (biological and thermo-chemical).

The Projects Grid was also considered in the feedstock scoping, emphasising those feedstocks that have been used, or are currently used, to help determine the most promising for further consideration.

[21] Although the use of crop harvesting residues has seen limited to no commercial success in SSA, given its high biomass resource potential and potential to be coupled with other feedstocks, its potential was investigated under this theme.

5.1.3 Land use in the 10 target countries

Dominant land cover pattern

Figure 9 shows the land cover pattern in SSA. The dominant land cover is grassland and woodland, followed by barren land, forest land and land cover associations (land with mixed land cover and uses). The smallest share is cultivated land.

For the purposes of this assessment, grassland and woodlands are not considered as a land type for biomass production and sourcing, based on environmental and socio-economic sustainability constraints. Grassland and woodlands play an essential role in the sequestration of atmospheric CO_2 and are key soil carbon stocks in SSA (Milne et al., 2016; Suttie et al., 2005; Vågen et al., 2005). Intensive usage through livestock rearing or agricultural activities like tillage, fertilisation and crop cultivation can lead to permanent loss of soil carbon, while crop productivity will be low (Bombelli et al., 2009; Milne et al., 2016; Oba et al., 2000; Suttie et al., 2005; Vågen et al., 2005). Moreover, grassland and woodland are important pools of biodiversity with sensitive ecosystems at high risk of degradation in the case of disturbance (Maitima et al., 2009; Oba et al., 2000). Traditionally, grassland is used for livestock, often with ownership of the commons, non-defined land tenure and nomadic grazing. Hence any usage for bioenergy feedstock production could lead to environmental and social sustainability risks.

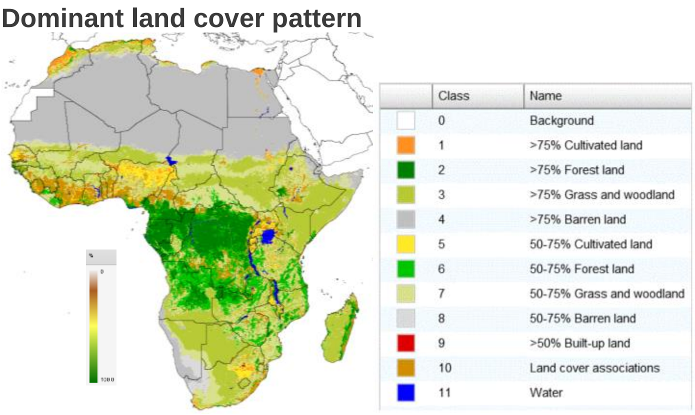
Land cover associations, for example agro-forestry, can offer some biomass potential depending on actual land use and economic scale and infrastructure. However, land cover associations are usually not further specified, and reliable assessment of feedstock supply potential would require local assessments of how such areas are used in their specific contexts, which is outside the scope of this project.

Natural forests, as well as protected land, were also excluded as sources for sustainable bioenergy feedstock. However, managed forests can provide residues and low-quality wood for sustainable bioenergy use. To ensure sustainability and carbon benefits from utilising biomass feedstock from managed forests, a full carbon balance assessment of the whole forest product basket would be necessary (Röder et al., 2019). To ensure a minimum level of sustainability, residues should only be sourced from internationally independent certified forests. Identifying the availability of certified forests in the project's target countries was outside the scope of the assessment.

Residues from wood processing (e.g. in sawmills, pulp and paper mills, tanning production, wood processing facilities for poles, timber, furniture, etc.) were considered as bioenergy feedstocks. As a large share of processed wood is traded, it is assumed that the wood is sourced from certified forests with low sustainability risks.

Cultivated land can provide agricultural and horticultural residues. Cultivated land can also potentially grow energy crops - where economically feasible and environmentally and socially sustainable. From an SSA perspective, this is the smallest area of the different land cover patterns. However, it is potentially the main source for bioenergy feedstock.

Figure 9: Land cover maps SSA (FAO, 2020)



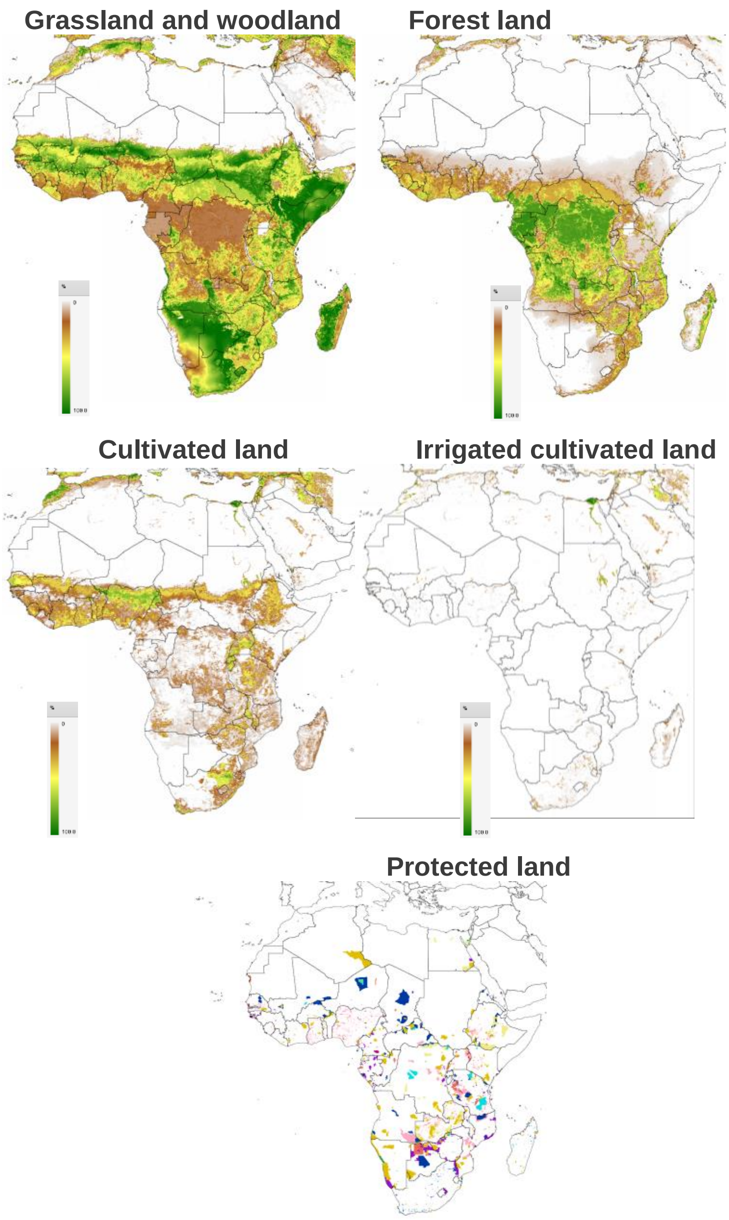
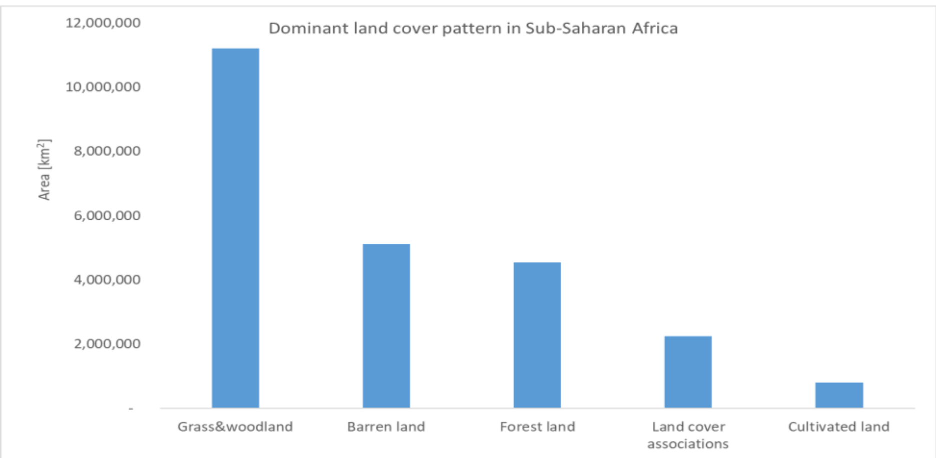


Figure 10: Dominant land cover pattern in Sub-Saharan Africa



Source: Adapted from FAO (2020)

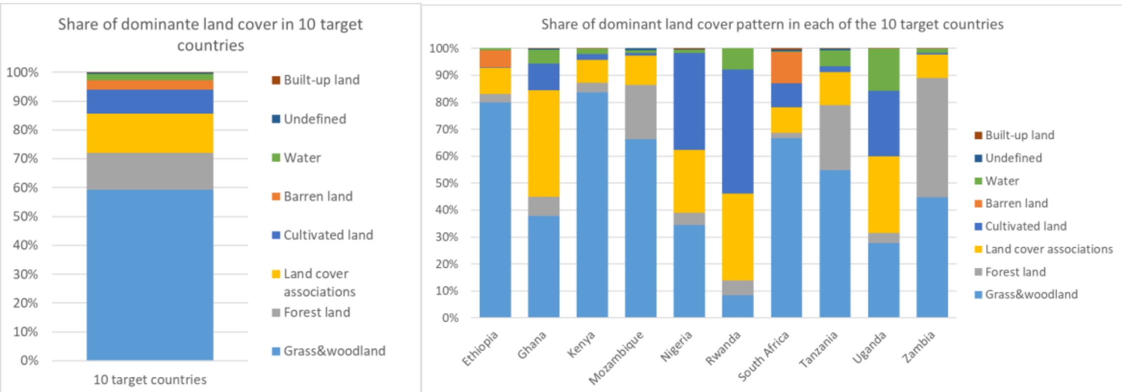
Land cover patterns in the ten target countries

As illustrated in Figure 10 above, the dominant land cover in Sub-Saharan Africa is grass and woodlands. The overall land cover pattern in the BSEAA2 target countries largely reflects the continent as a whole, with grassland and woodland accounting for almost 60% of land cover. This is followed by land cover associations and forest, which account for 14% and 13%, respectively. Cultivated land accounts for approximately 8% and barren land for 3%.

Land cover patterns vary significantly between the countries, however (Figure 11). Cultivated land is the most relevant type of land for this project as it can provide various feedstock categories from purpose-grown crops to harvest and processing residues and allows a better tracing of sustainability and land use implications. In Rwanda and Nigeria, around half and one third (respectively) of total land area is cultivated land, In Uganda, about one quarter of the land is cultivated land, and in the other seven countries, less than 10% of the land area is cultivated land. The share of the cultivated land area is particularly small in Ethiopia, Kenya, Mozambique, Tanzania and Zambia, where grassland and woodland dominate the land cover patterns. Zambia in has a particularly large share of forest, with forest, grassland and woodlands together making up 90% of its land area, while dedicated cultivated land covers only around 1%.

Depending on their use, land cover associations could also potentially be areas for sourcing bioenergy feedstock. Agroforestry systems with tea, coffee, cocoa, palm plantations, and fruit orchards fall into this category. In Ghana, Rwanda, Uganda and Nigeria, land cover associations account for about a quarter to a third of land area.

Figure 11: Dominant land cover pattern in BSEAA2 target countries



Source: Adapted from FAO (2020)

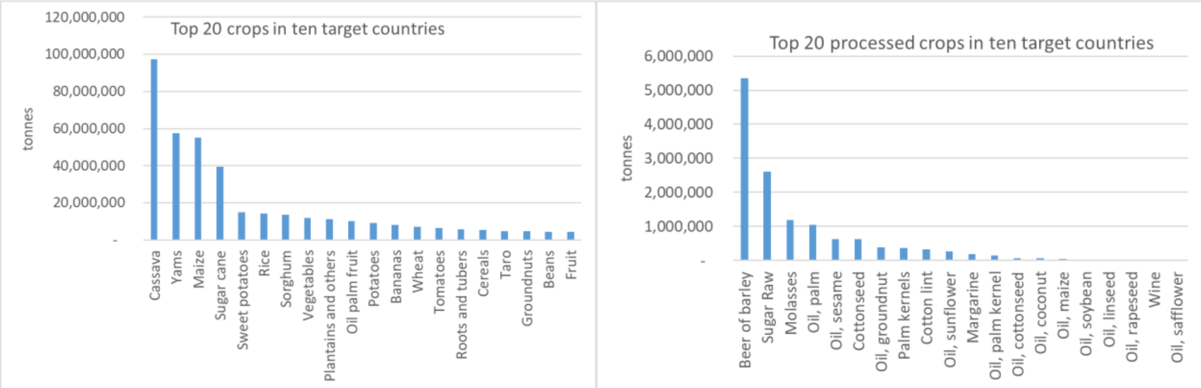
5.1.4 Key findings

Each of the feedstock categories presented below has been assessed according to biomass resource potential, bioenergy potential, feedstock-technology interface and sustainability.

1.2.3.1 Agricultural residues (from crop production and processed crops)

Figure 12 presents the 20 leading crops across the ten target countries, by tonnage harvested. Tubers and roots (e.g. cassava, yams, sweet potatoes, potatoes) are dominant, followed by maize, sugarcane, cereals (e.g. rice, sorghum and to some extent wheat), vegetables, fruits and oil fruits (palm oil, groundnuts). The dominant crops are mostly subsistence and staple crops grown in small-scale farming systems, often for direct consumption or non-commercial processing. Processed crops are dominated by the brewing, sugar and edible oil industries. Sugarcane and oil palm, and to some extent vegetables and fruits, are mostly grown as market crops, often in a commercial farm.

Figure 12: Top 20 agricultural and processed crops in BSEAA2 target countries



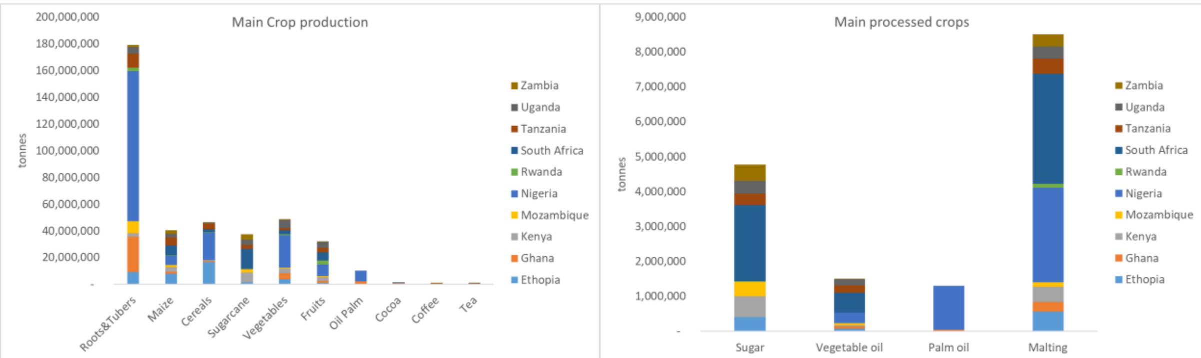
Source: Adapted from FAO (2019d)

Figure 13 presents crop outputs by category. In practice, feedstock properties for bioenergy purposes vary between crops and genotypes, and this will be assessed in more detail in Stage 3. Agricultural crops are categorised into roots and tubers, maize, cereals, sugar cane, vegetables, fruits, oil palm, cocoa, coffee, and tea. Processed crops are categorized as sugar, vegetable oil, palm oil and malting. Cocoa, coffee and tea are also included as they are commercially important in the target countries, although they are not among the top 20 crops and processed crops by harvest tonnage.

Fibre crops do not feature in the charts as output volumes are much smaller. However, the fibre industry, in particular, cotton and sisal, has grown significantly in the past 20 years as international demand has grown for 'green' packaging materials, carpets, personal accessories, etc. Given their high commercial and export value, fibre crops were included in the assessment. Although coconut coir is another prominent fibre industry, its production has dwindled considerably owing to yellow leaf blight disease that destroyed most of the industry, particularly in Mozambique and Tanzania.[22]

Edible oil production from various sources is a key crop processing industry. However, in terms of crop production and value of production, oil crops play a minor role compared to other categories. Apart from oil palm, other oil crops were excluded from the high-level assessment and will be revisited in Stage 3, if necessary and relevant to the research.

Figure 13: Main crop production and main processed crops in ten target countries



Source: Adapted and categorised from FAO (2019d)

[22] See: https://www.frontiersin.org/articles/10.3389/fpls.2016.01521/full ; Dollet, M., Macome, F., Vaz, A., and Fabre, S. (2011). Phytoplasmas identical to coconut lethal yellowing phytoplasmas from Zambesia (Mozambique) found in a pentatomide bug in Cabo Delgado province. Bull. Insectol. 64, S139–S140; Pushpakumara, Hon. Jagath, H.P.N Gunasena, Nyanie Aratchige, P.A.H. Nimal Appuhamy, Development of the Coconut Industry in Tanzania, November 2013.

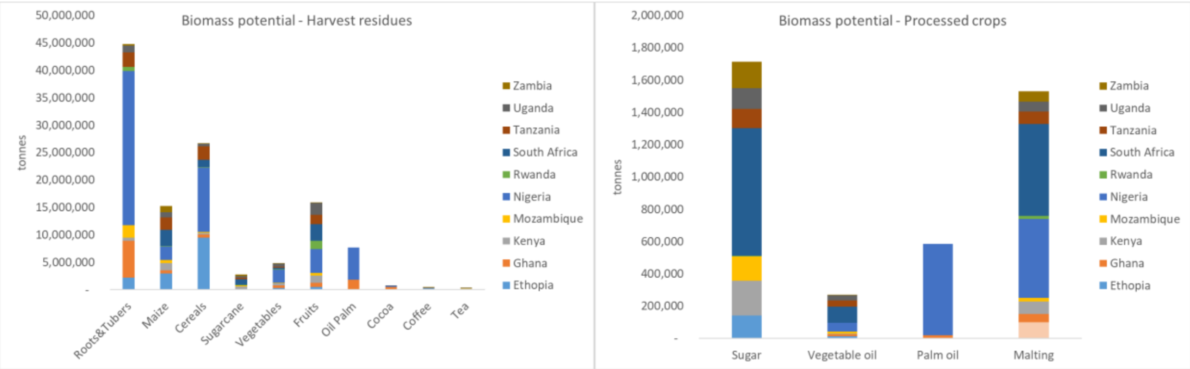
Biomass potential from crop production and processed crops

Two types of residue from crop production are considered; harvest residues (sourced from the field when harvesting crops) and agro-processing residues (sourced after crop processing). As examples, straw, leaves, stems and stalks are harvest residues, while bagasse, seed shells, kernels, peels, press cakes, husks and spent grain are agro-processing residues.

The biomass supply potential of harvest residues is based on the area available as cultivated land to grow crops (FAO, 2020), residue factors (how much of a crop is residues/waste) (IRENA, 2017; Smeets et al., 2004) and sustainable removal rates (IRENA, 2017; Smeets et al., 2004; Thiffault et al., 2015). Removal rates should allow enough return of nutrients and organic matter. It is assumed that for arable crops, at least 50% of residues must be returned to the soil for sustainable management and maintenance of soil organic matter and soil nutrients.[23]

Based on these factors, Figure 14 shows the biomass potential from harvest residues. The supply potential is shown for the main crop categories (roots and tubers, maize and cereals) in the form of straw, leaves and stalks. There is also biomass supply potential from fruits and oil palm (e.g. stalks, stems and branches). Vegetables and sugarcane can also provide harvest residues including leaves and stalks. Cocoa, coffee and tea can provide biomass from pruning residues.

Figure 14: Biomass potential from main crops and commercial processed crops based on residue factors and removal rates



Source: Adapted and categorised from FAO (2019d)

The biomass potential from processing residues (Figure 14) was calculated from residue factors and removal rates provided by Smeets et al. (Smeets et al., 2004). Removal rates for processing residues are much higher than for harvest residues as these residues accumulate at processing sites and can be more easily removed. Because processing residues relate to the already harvested main products, there should not be additional sustainability considerations in terms of returning organic matter and nutrients to the soil.

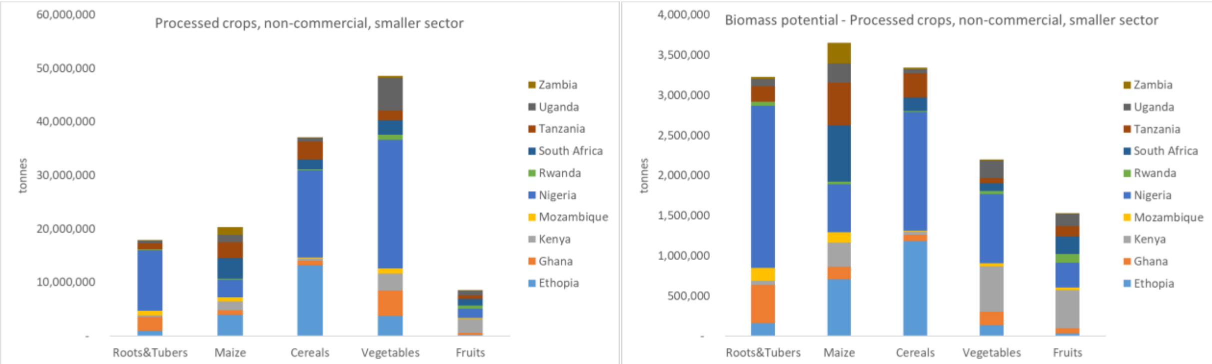
There is additional biomass potential from small-scale processing of staple crops and those with low commercial or export value, such as roots and tubers, maize and cereals. For instance, small-scale cassava processing can be found across the target countries but is not necessarily captured in statistics of the processing industry. While this is an important small-scale commercial activity in many rural areas, the quantities milled, and residues generated, are generally too small for commercial

[23] Digestate as a returned fertiliser has not been considered as this point for three main reasons. a) Digestate alone cannot replace the value of residue return in terms of organic matter; b) The assessment did not consider how much of the residues are used with AD/specific conversion technology versus thermal pathways under which there are no remaining residues. c) The use of AD doesn't automatically mean digestate can be returned to the fields due to logistical challenges. A more detailed analysis in Stage 3 can explore these issues.

bioenergy production. Moreover, in areas of severe wood fuel shortages, residues such as rice husks, coffee husks etc. are often directly used for cooking and heating purposes in poorer households.

In some of the target countries, commercial processing of vegetables, fruits and flowers can be found. The biomass potential for these processed crop categories has been estimated [24] and is presented in Figure 15.

Figure 15: Non-commercial and small sector processed crops and their biomass potential



Source: Adapted and categorised from FAO (2019d)

Bioenergy potential from crop production and processed crops

While the previous section highlights the biomass generation potential of leading crops, this cannot be taken to imply their suitability for use as bioenergy feedstocks. There are opportunities and challenges related to each of these feedstocks in relation to their use for bioenergy. These aspects can be of environmental, technical, economic or social nature. This section highlights the main constraints and opportunities for each of the main crop categories in the context of bioenergy applications.

Roots and tubers

- **Supply chain:**
  - Large quantities of biomass are produced on a small-scale basis and partly in inter-cropping systems (Bokanga, 1999; E-TIC, 2019c; Tewe, 2004);
  - Crops are grown in low-intensity systems with scattered production sites (Bokanga, 1999; FAO, 2015c);
  - Key subsistence crops having a very low level of industrial processing (Bokanga, 1999; E-TIC, 2019c; FAO, 2015c; Tewe, 2004). Important cash crop for local / farmer markets (FAO, 2015c);
  - Dedicated trade supply chains with intermediaries and traders are limited, due to challenges of storage in terms of scale and spoilage (Bokanga, 1999; E-TIC, 2019c; FAO, 2015c; Tewe, 2004).
- **Availability:** Stalks and leaves are currently left on the field. These harvest residues can potentially be used as bioenergy feedstocks. Peels and fibre are processing residues, where such processing industry is place, and can be used as bioenergy feedstock as they are usually dumped or composted. In most roots and tuber producing regions, these are harvested throughout the year.
- **Current/competing use:** A small share of cuttings is used for re-planting (E-TIC, 2019c; FAO, 2015c; Grace, 1977). Leaves of some varieties are used as a vegetable, left on the soil or composted. Stalks are often left to rot or are burned (Aso et al., 2018; Zhu et al., 2015).

[24] ‘Chapter 5, Agriculture and Agro-Industrial Residues’, AGS Divisional Project 214A1, ‘Small Farmer Livelihoods’ Energy from Agriculture & AgroIndustrial Residues: Income Generating Activities in Rural Communities, H. P. W. Jayasuriya, Peeyush Soni, Asian Institute of Technology, ed: Peter Steele, Agricultural & Food Engineering Service, FAO, Oct. 2003.

- **Access to biomass residues/processing residues:** Accessible potentially on village/community scale, with challenges of centralised collection and transport (Aso et al., 2019; Aso et al., 2018).
- **Bioenergy potential:** Harvest residues can potentially be used at village/community scale for AD. Commercial processing is currently very limited and mainly at small-scale (FAO, 2015c; Grace, 1977). However, at medium-large-scale, bioenergy potential could be high (e.g. peel, residues from starch processing) (Aso et al., 2019; Aso et al., 2018; Sivamani et al., 2018; Zhu et al., 2015). Depending on the specific crop characteristics, it can be used with biological or hydrothermal conversion processes to produce biogas.

Maize

- **Supply chain:**
  - Produced mainly at small-scale (FAO, 1992; Kornher, 2008; Mejía, 2003; VIB, 2017a). A key food crop in Africa, but also used for other purposes (animal feed, brewing).
  - A small proportion may be traded as marketable surplus in local and regional markets, with a few countries exporting (FAO, 1992; Kornher, 2008; Mejía, 2003; VIB, 2017a; Wilson et al., 2015);
  - Low levels of industrial processing to flour and fermented products (Kornher, 2008; Moeletsi, 2017; RIBEIRO et al., 2019; Wilson et al., 2015).
- **Availability:** Seasonal feedstock with maize stover the key harvest residue.
- **Current/competing use:** Maize stover used for animal feed and bedding, or returned to the soil, used as a building material or sometimes left to rot or burned (FAO, 1992; Kornher, 2008; Mejía, 2003; VIB, 2017a; Wilson et al., 2015).
- **Access to biomass residues/processing residues:** Potentially accessible at a village/ community scale. However, there are challenges around collection and infrastructure as maize is grown at a small scale and the feasibility of collection therefore depends on harvest practices, size and locations of fields. Use of processing residues is feasible where commercial infrastructure exists (markets, processing industry).
- **Bioenergy potential:** Surplus maize stover available at village/community scale can be used for AD or combustion. But the potential is limited by other current competing uses (soil amendment, livestock fodder and bedding). There is a higher potential for processing residues in the case of commercial processing from, e.g. milling and brewing industries that offer bioenergy production at scale through biological or thermochemical treatment. But again, competing uses are applicable, especially from use as animal feed.

Cereals

- **Supply chain:**
  - Produced mainly at small/medium-scale, being the key food crops in many regions (Chauvin et al., 2013; E-TIC, 2019a; Elbehri, 2013);
  - A smaller extent is traded as marketable surplus in local, regional markets and milling in local small-scale mills mainly for household consumption and local markets (E-TIC, 2019a; Elbehri, 2013).
- **Availability:** Grown seasonally, but availability also dependent on processing practices and storage. Straws left on the field are available as harvest residues, while husks and hulls are available as processing residues.
- **Current/competing use:** Common practice is to return straw to the soil or use it for animal feed and bedding, as well as building material. In other cases, harvest residues are left to rot or are burned (DFS, 1999; Kajuna, 2001; Lantin, 1999; Refera, 2001). Husks are used for animal bedding and (to a very limited extent) used in mills or dryers for heat and power generation. In other cases, they are often dumped or burned.
- **Access to biomass residues/processing residues**: Harvest residues (i.e. surplus straw) are potentially accessible on village/community scale. However, as with maize, challenges exist around collection and infrastructure as cereals are grown at small scale and feasibility of collection is likely to depend on harvest practices, size and locations of fields (DFS, 1999;

Kajuna, 2001; Lantin, 1999; Refera, 2001). Husks and milling residues only feasible in mills or where commercial infrastructure exist. But in Africa, this is mainly at a small, village-scale (DFS, 1999; Kajuna, 2001; Lantin, 1999; Refera, 2001).

- **Bioenergy potential:** Surplus straw available at village/community scale can be used for biological or thermochemical energy conversion. But this use is currently limited by other competing uses (soil amendment, livestock fodder and bedding) and barriers around logistics and cost of collection (Borromeo et al., 2016). On the other hand, the use of processing residues is most feasible where processing and commercial infrastructure exists.

Sugarcane

- **Supply chain:**
  - Important cash crop in producer countries, produced at all scales from small to large-scale commercial (Röder et al., 2017);
  - Although supply chains in major producing countries are well-developed, production and processing scales vary greatly in the target countries, e.g. Rwanda has one small sugar plant and South Africa has 18 large sugar factories.
  - In all target countries, the sugar sector is well-organised and commercial.
  - Small-scale out-growers are generally part of well-developed supply chains and infrastructures, with commercial supply chains.
- **Availability:** Sugarcane is grown seasonally, with trash and leaves available as harvest residues where the cane is harvested green (without pre-harvest burning). Bagasse is also available as a processing residue.
- **Access to biomass residues/processing residues:** Where the cane is harvested green, leaf material offers considerable potential as biomass feedstock at various scales and levels (village scale to industrial applications). Leaves are also available from green cane processing in sugar mills where leaves are utilised along with bagasse (Röder et al., 2017). Where commercial supply chains exist, there is a significant advantage to use existing supply chains and infrastructures to collect leaves for community or centralised energy production.
- **Current/competing use:** The trash is returned to the soil or used as soil cover to reduce soil water evaporation or burnt in situ. Bagasse is used at mills for co-generation of process heat and electricity, with surpluses exported to the grid where supporting mechanisms are in place.
- **Bioenergy potential:** There is potential to use the surplus trash at village/community scale for biological or thermochemical energy conversion, but this is currently limited by competing uses (soil amendment) and barriers around logistics to transport wastes. If trash is used in mills, existing supply chains can be used at the expense of additional transport cost. Processing residues (bagasse) are already used in mills for producing heat and electricity, with surplus electricity almost always fed into the grid. Improved boilers could increase energy output (Röder et al., 2017; VIB, 2017b).

Fruits/Vegetables

- **Supply chain:**
  - Most fruits and vegetables in the target countries are produced for local and export markets. However, export markets are growing rapidly in Ethiopia, Kenya, South Africa, Tanzania and Ghana.
  - Only a small share of fruit and vegetables (about 10%) is processed (Broek et al., 2016; Lin et al., 2018; Mithöfer et al., 2011; Ogwu et al., 2016);
  - Vegetable and fruit production ranges from small-scale to large-scale commercial production with small scale farmers often supplying the products to a trader (Ogwu et al., 2016; T et al., 2015).
- **Availability:** Production is usually seasonal, but this can vary depending upon the type of fruit or vegetable. Feedstock is available in the form of both harvest residues (leaves, stalks, prunings) and processing residues (peels, stones or fibre).
- **Access to biomass residues/processing residues:** The scale of production and the density of the production area determines if harvest residues can be collected centrally. At a small-

scale, the feedstock is likely to be scattered, with challenges to gather and collect. To utilise fruit and vegetable feedstocks, a more centralised production and collection/infrastructure for residues is required. Where a processing industry is in place, the potential for utilising processing residues at scale for bioenergy production can be considered.

- **Current/competing use:** Harvest residues in the form of leafy, wood material are normally returned to the soil, while wetter material (e.g. spoilt or rotten fruit or vegetable) are normally disposed of or burned, depending on the fruit. Processing residues, depending on the fruit, are either used as animal feed, composted or disposed.
- **Bioenergy potential:** Surplus harvest residues can be used at a village/community scale for biological (e.g. AD) or thermochemical (e.g. combustion or gasification) energy conversion. But barriers around logistics and cost of collection exist. Use of processing residues or wastes requires commercial processing and infrastructure. Some fruit residues might present challenges for AD (e.g. high acidity). High moisture content may meanwhile mean that gasification, pyrolysis or combustion cannot take place without pre-treatment.

Coffee/Cocoa/Tea

- **Supply chain:**
  - Composed of mainly small-scale producers, often organised in cooperatives, sometimes with processing facilities. Also, some large-scale/state-owned plantations.
  - Well-established commercial supply chains (Davis et al., 2017; Fairtrade, 2019; SOMO, 2008; USDA, 2019a).
- **Availability:** Seasonal feedstock with residues available from pruning and trimming trees and bushes.
- **Access to biomass residues/processing residues:** Mainly in the form of woody residues in plantations and pulp and husks in processing facilities.
- **Current/competing use:** Woody residues from pruning used for domestic heat or at a small level for drying but are also just disposed of. Pulp (berries) and husks composted or disposed of, but of limited use (e.g. coffee has a high-level of tannins which limits return of compost to the soil and is also challenging for AD) (Fairtrade, 2019; Mutua; R.M et al., 2005; SOMO, 2008, 2019)
- **Bioenergy potential:** Harvest residues can be used for heat and electricity generation for local households. Alternatively, the heat requirements for drying and processing tea or coffee can also be partly met through burning of these residues. Many tea farms have established plantations for fuelwood to provide processing heat (Mutua; R.M et al., 2005; SOMO, 2008).

Oil palm

- **Supply chain:** Grown as a cash crop at various scales, from small-scale with traditional practices and processing for local use, to medium and large-scale for commercial production and processing (Poku, 2002).
- **Availability**: Seasonal feedstock with biomass available from trunks and stems from felled oil palms or from the residues from oil production.
- **Access to biomass residues/processing residues:** Main residues during processing are empty fruit bunches, palm fibre and palm kernel shells (Poku, 2002). Various possibilities to use residues for energy exist and are commercially deployed, particularly in Ghana.
- **Current/competing use:** At a medium and large-scale, residues are already used as compost (returned to plantation) or as fuel for processing. Shells are also used for road surfacing and in construction (Poku, 2002; Sridhar et al., 2009). Processing residues are already utilised to some extent for energy generation.
- **Bioenergy potential:** At commercial scale, various options to use different residues from palm oil processing exist with biological and thermochemical treatment. Also potential to use old trunks and stems for energy generation (Elbersen, 2013; Sridhar et al., 2009).

Oil crops

- **Supply chain:** The scale and level of mechanisation varies between crops and countries. At one end of the scale, there is small-scale production and processing with traditional practices and processing for local use. At the other end, are commercial plantations and large-scale processing. Larger processors also buy from smaller processors using a network of traders and intermediaries (Buruchara, 2018; SNV, 2010; USDA, 2019c; Vorley et al., 2015).
- **Availability:** Seasonal feedstock with biomass availability coming from harvest residues (straw, leaves, and stalks) and processing residues (shells and husks). Oil and oil meal is excluded from the assessment due to food-fuel/fodder-fuel concerns (OECD-FAO, 2019).
- **Access to biomass residues/processing residues:** Scale and level of commercialisation determines access and logistics of biomass feedstock.
- **Current/competing use:** Straw/harvest residues of crops often used as animal fodder as it is nutritious in many cases (E-TIC, 2019b). Also, oil meal is a high-value animal feed (OECD-FAO, 2019; USDA, 2019c). Some oilseed mills use shells and husk already for energy generation for oil processing.
- **Bioenergy potential**: Potential for the use of harvest residues and processing residues (shells and husks), which have been removed before milling and oil extraction. In particular, the processing residues can be a feedstock for providing processing energy. There is also the potential for using the oil for liquid biofuels, though with risks of food/fodder – fuel conflicts. Oil production for bio-diesel is not covered within the technological scope of this project.

Fibre producing crops (sisal/cotton)

- **Supply chain:** Scale and level of mechanisation varies between countries. Sisal is mainly grown as a plantation crop in Tanzania and Kenya, which are the second (30,000 tonnes per year - tpa) and the third (25,000 tpa) largest producers after Brazil, with growing production in South Africa and Mozambique (FAO, n.d.). Cotton is grown by small-farm holders in nine of the 10 target countries (excluding Rwanda), with Nigeria and Tanzania leading the production in Africa.
- **Availability:** In the case of sisal, the biomass left after the sisal fibres have been removed represents as much as 98% of the plant (pulpy material scraped off by mechanical decortication or hand stripping). (FAO, n.d.). Cotton residues, particularly cotton stocks contain, lignin and carbohydrates like cellulose and hemicelluloses, which can be converted into a variety of usable forms of energy (Afif, et al., 2019)
- **Access to biomass residues/processing residues:** Sisal is grown as a plantation crop, with minimum pre- and post-harvest residue losses, with yields in East Africa reaching up to 4 t/ha (FAO, n.d.), indicating good availability and centralised aggregation potential. In the case of cotton, scale and level of commercialisation determines access as a biomass feedstock.
- **Current/competing use:** The biomass waste produced from sisal during its processing is mainly flushed away as waste. The waste generated can be used to generate bioenergy, produce animal feed, fertiliser and ecological housing material land. (FAO, n.d.). In the case of cotton, cotton stalk plant residue left in the field following harvest must be buried or burned to prevent it from serving as a site for insects such as the pink bollworm (Afif, et al., 2019)
- **Bioenergy potential:** Good potential exists for using the processing waste from sisal for AD. To exploit this economic potential, the Common Fund for Commodities, UNIDO and the Tanzanian sisal industry funded the first commercial plant to use sisal residues to produce biogas, electricity process heat and fertilizer (FAO, n.d.). In the case of cotton, the stalks can be used for direct combustion to meet heating requirements of manufacturing industries . For example, a Coca-Cola bottling company in Mwanza, Tanzania uses cotton residues from nearby cotton gins to produce heat for sterilisation of glass bottles.[25]

1.2.3.2 Livestock wastes

From a bioenergy perspective, manure and slurry from livestock is a potentially valuable feedstock. However, most livestock in Africa are kept in traditional smallholder systems with a small number of

[25] More information available at: www.ewwconsultancy.com/project/cdm-verification-nyanza-bottling-company

animals per livestock-owning household. In most cases, livestock is seen as an opportunity to improve household income and is considered a sign of wealth (Herrero et al., 2014).

In the ten target countries, ruminates like cattle, goats and sheep are generally kept in traditional systems on extensive rangelands and pasture with flock sizes of less than 20 animals (FAO, 2014b, 2016, 2017a, 2019a, 2019c; MLFandILRI, 2018; MoFA, 2004; MvBZ, 2016a). In some instances, herds can contain 50 to over 1000 animal per flock (EastAfrica_DDP, 2008; FAO, 2017a, 2019a, 2019b, 2019c; MLF, 2015; MLFandILRI, 2018; MvBZ, 2016a; World_Bank, 2011, 2018). As long as livestock herds are kept on grazing land and pasture, even more intensive herding systems will not allow the collection of manure. This means that most of the meat-producing herds will not offer the opportunity for manure collection (Herrero et al., 2014).

In some cases, cattle (and dairy cows in particular) are kept in stalls. For most of the ten target countries, this practice is applied to only 1% to 6% of the total cattle population. South Africa has a larger share of intensive cattle (beef and dairy) sector (DAFF, 2020) as compared to other target countries.

Dairy production in Kenya is high and growing, with over 1 million smallholders organised into co-operatives, practising ‘zero-grazing’ (stall feeding) with between 1 and 20 cows. Increasing numbers are using dairy cow manure for biogas production, which has the potential to power for on-farm milk refrigeration for collection by their cooperatives (e.g. SimGas[26]). Where power is produced, these biogas systems for small-holder farmers generally have a system capacity of well below 10 kWe, which is out of the scope of BSEAA2. Biogas adoption by dairy farmers is also growing in neighbouring Uganda and Tanzania.

Like ruminates, in countries where pigs are reared, these animals are mainly kept in traditional small-scale systems. Even where a commercial pig industry exists, it is relatively small with a few modern piggeries (DAFF, 2017; FAO, 2016; Gilbert et al., 2018).

While most poultry are kept on a small-scale with a few chickens per household, there are increasingly industrial scale poultry farms housing 100 to several thousand chickens each. This is the case in each of the 10 target countries, with South Africa again leading the list, but Kenya, Nigeria, Ghana, Tanzania and Uganda also having dozens of these large businesses. (AgriProFocus, 2015; FAO, 2013, 2014a, 2018a, 2019e, 2019f; Mbuza et al., 2017; MvBZ, 2016b; Ringo et al., 2018; SAPA, 2017; USDA, 2019b; WATTAgNet, 2017; World_Bank, 2018).

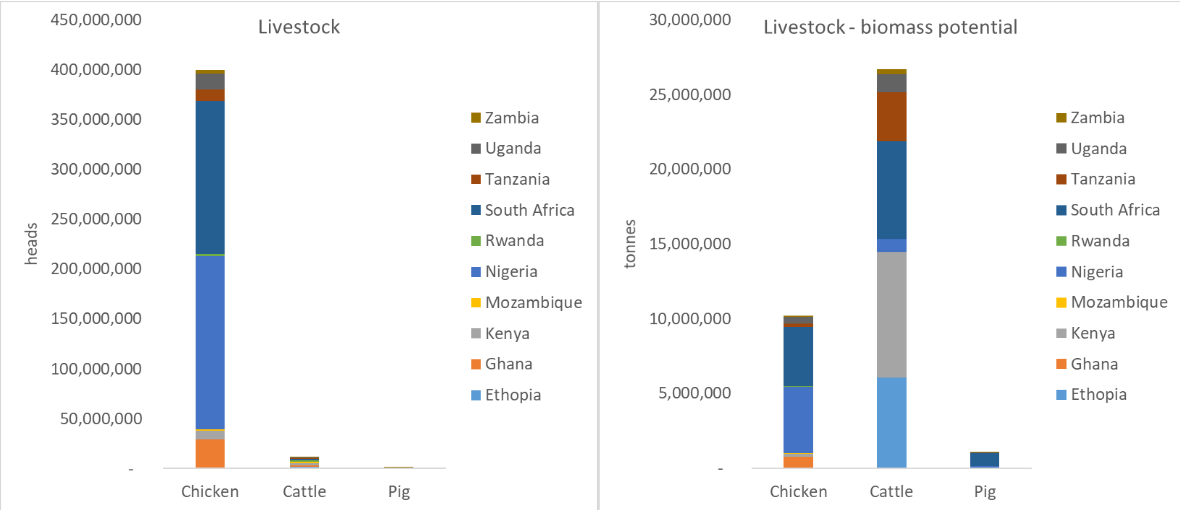
Figure 16 shows the livestock numbers and biomass potential for the three livestock groups (cattle, pigs and chicken) that can provide manure for bioenergy. For livestock manure, only housed livestock in intensive systems has been considered, because collection from small-scale and free-ranging systems will not be technically and financially feasible.

It is interesting to note that while the poultry industry is considerably larger than the cattle industry in terms of headcount, its biomass potential is much lower. The highest potential for bioenergy generation lies within the cattle industry, with South Africa presenting the greatest opportunity followed by Kenya and Uganda, although at a somewhat smaller scale.

It must be kept in mind that the manure, mainly from dairy cows, is widely used as crop fertiliser. Nevertheless, passing cattle or pig manure and slurry through an AD system before applying it to the field has agronomical and nutrient benefits. The use of chicken waste for bioenergy needs to be considered more carefully because of the properties of the mixture of manure and bedding. Energy generation from poultry litter can be achieved by AD, combustion, co-firing and gasification (P. Perera et al., 2010).

[26] www.simgas.org/projects/biogas-milk-chilling/

Figure 16: Numbers of chicken, cattle and pigs and related biomass potential from manure



Source: Adapted from FAO (2019d)

It is projected that the livestock industry will grow significantly in Africa until 2030. This will likely lead to an increase in the ongoing trend of intensive livestock rearing, which presents opportunities for the owners of dairy farms and cattle feedlots to utilise manure and slurry more efficiently and at a larger scale (Herrero et al., 2014).

1.2.3.3 Wood residues from plantations, managed forests and wood processing residues

In Africa, wood fuel accounts for about 90% of all roundwood removal (FAO, 2018b). Fuelwood and charcoal are the most common energy sources in most African households (FAO, 2017b). These types of traditional biomass are excluded from the assessment, as households would not process biomass at the scale of interest for this project. Deforestation of natural forests and woodland is continuing in Africa as a whole and within the ten target countries (Figure 17) while the area of planted forests has increased in many regions (FAO, 2015a, 2015b).

To support the sustainable use of woody and forest-based biomass feedstock, this assessment of biomass potential includes residues from wood processing, such as sawdust, chips and cut-offs. Even with the assessment of the wood processing industry only, there is still a risk of unsustainable practices in the forest sector as only about 4% of the managed forest area in Africa is under independently verified forest management certification schemes (FAO, 2015b).

Figure 17: Condition of forest and woodlands in SSA

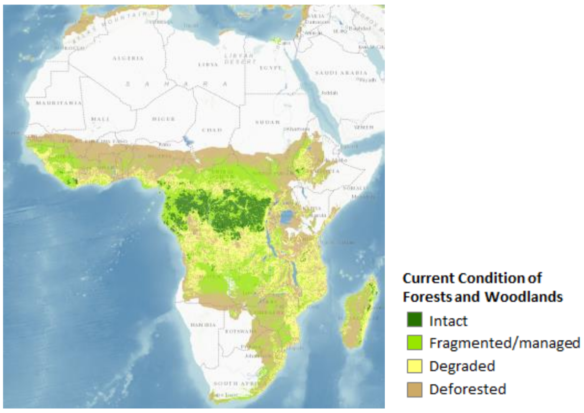
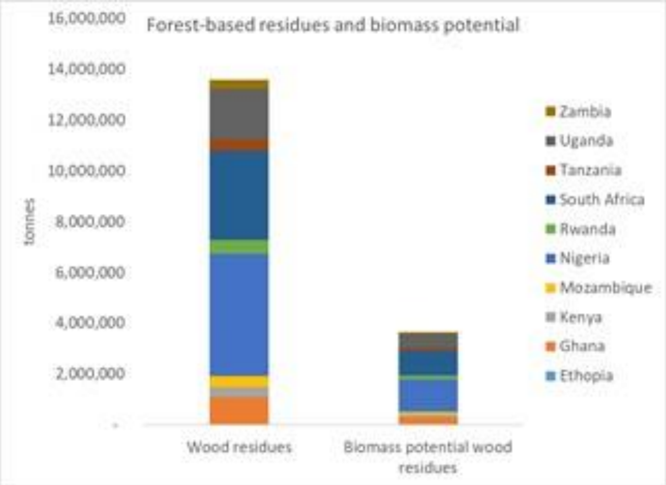


Figure 18 shows the biomass potential from forest-based residues. All ten target countries have a commercial forest sector. Utilising residues from timber processing appears to be feasible due to existing supply chains and infrastructure. It can be presumed that the managed forests are managed commercially under private or public ownership. Compared to the agricultural sector (especially crop production), small-scale producers will not take a direct part in forest product supply chains. The availability of feedstock depends on the specific forest management and harvest regimes.

Sawmills are often already using some of the residues (sawdust and cut-offs) for internal processes (e.g. kiln drying of wood), but there may be potential for other energy applications, which can avoid storage of residues and reduce the risk of auto-ignition of sawdust and wood chip piles. Considering the properties of these residues, thermochemical conversion is the best option. Sawdust residues are ideal feedstocks for combustion-based applications as they are already relatively dry and of a small particle size, reducing the requirements for expensive pre-treatment.

Figure 18: Forest-based residues and biomass potential

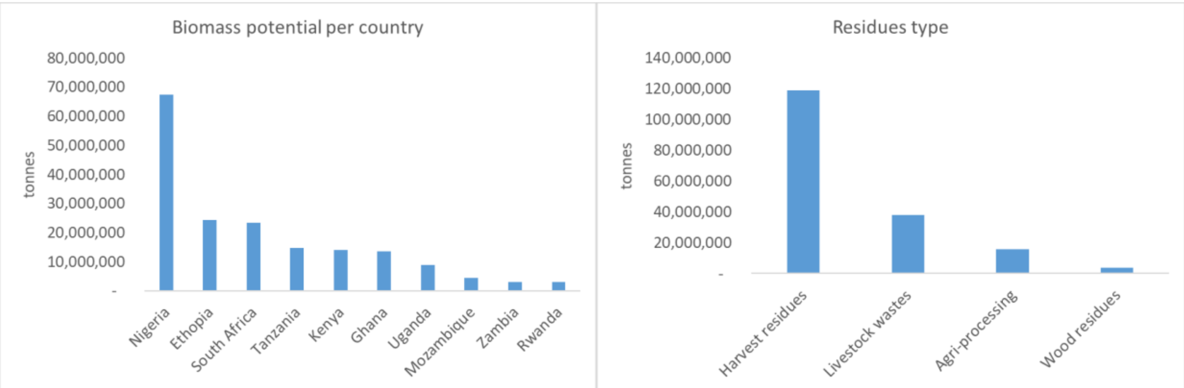


Source: Adapted and categorised from FAO (2019d)

5.1.5 Summary

The overall biomass residue supply potential of the ten target countries is presented in Figure 19 for the crop, forest and livestock feedstocks within the scope of the research.

Figure 19: Biomass residue potential of the assessed crop-, forest- and livestock-based feedstocks



Source: Adapted and categorised from FAO (2019d)

As is evident, although **crop harvesting residues** offer the highest biomass volume, evidence reveals limited aggregation and strong competing uses (mulching, composting, animal feed etc). Using many of these residues (from roots and tubers, maize and cereals) might also be economically unfeasible, as they require appropriate local governance and supply chain infrastructure to ensure that small-scale feedstock providers can benefit from potential bioenergy deployment.

On the other hand, **agro-processing residues**, although a smaller feedstock source, represent a stronger commercial opportunity for bioenergy generation, with fewer competing uses and other challenges. Based on the preceding assessments, the most promising feedstocks for further consideration include residues from the processing of fruits and vegetables, coffee/cocoa/tea, oil palm and fibre crops, particularly sisal. The use of sugar residues for bioenergy is already commercially successful and presents little additional scope as part of this project.

With respect to **livestock wastes**, opportunities for commercial bioenergy generation within the BSEAA2 scale range lie with dairy farms or feed-lots, where large numbers of cattle are centralised.

Opportunities for **wood residues** mainly seem to lie in the wood-processing industry, as wood from plantations or managed forests poses significant challenges in terms of competing uses, sustainability concerns and/or conducive forest management and harvesting regimes.

5.2 Theme 2: Status of technical development

5.2.1 Aim

The Stage 2 aims under this theme were to:

a) characterise the technology landscape for AD and combustion within the target countries; and

b) identify the AD and combustion technologies with greatest potential for 'innovation-led adoption' in SSA.[27]

This provides the basis for more detailed exploratory work in Stage 3, when technology supply chains within the shortlisted pathways will be further investigated to identify the prospects, frameworks and technical support networks that can facilitate the necessary innovations for scaling up.

It had been the intention under this theme to shortlist up to five technology variants for AD and combustion. As will be explained below, the Project Grid revealed only three primary AD variants in the target countries and only one basic combustion-based technology. While there are sub-variants of the technologies within each category, the nuanced differences and unrepresentative sample sizes (with just one plant per variant in the case of some AD technologies) made it inappropriate to use their experiences as a basis for ruling out any technology type for Stage 3 investigation.

National market maps had been envisaged showing linkages between technology suppliers and institutional gaps and bottlenecks. The scale of the AD industry proved too small to make such maps meaningful, with just three of the target counties having more than one functional AD plant (Figure 5) and no consistent technology design or sourcing model. AD suppliers were nevertheless categorised by type (see this section) and Stage 3 will include detailed investigation of supply chains at continental scale. The technology for combustion-based systems was meanwhile too standardised (as this section outlines) to draw instructive guidance from the composition of national supply chains.

5.2.2 Approach

The technology landscape was characterised by first working with other team members to develop and validate the Projects Grid to reflect the known AD and combustion-based commercial projects in the BSEAA2 target countries. Given the time and resources available during Stage 2, not every installation in all ten countries will have been captured. Most of those omitted will be small-scale heat-only systems, widely dispersed in forestry processing companies, tea factories, sugar mills and other agri-businesses. These are not publicly promoted and were not accessible during the Stage 2 period.

Classification of combustion-based projects

The **combustion-based projects** were categorised for analysis by country, by functionality status and (for the power or CHP installations) by size of associated steam turbine in MW_e or combined MW_e. The determinant for inclusion of a particular combustion-based pathway in Stage 3 was that either: a) the technology should offer innovation-led adoption potential (in the case of CHP); or, b) the pathway should have potential for supporting a 'development'-oriented business model (e.g. by involving local people in feedstock supply).

The dominant industrial-scale combustion technologies are moving grates and fluidised beds. They differ in the way the fuel is introduced, how the fuel and air are mixed, and how the fuel moves within the combustion chamber. These are mature technologies and their reliability is high (UK Dept. of Energy & Climate Change 2008). For heat-only applications, there is minimal potential for technology innovation within DFID's scope of interest for BSEAA2, and these applications were therefore not explored further during this stage from a technological point of view.[28]

[27] 'Innovation-led adoption' refers to the opportunity for significant acceleration in commercial deployment in SSA catalysed by technology R&D, e.g. unlocking technical barriers, overcoming operational bottlenecks, delivering performance improvements, facilitating cost savings, improving reliability or adapting for local conditions.

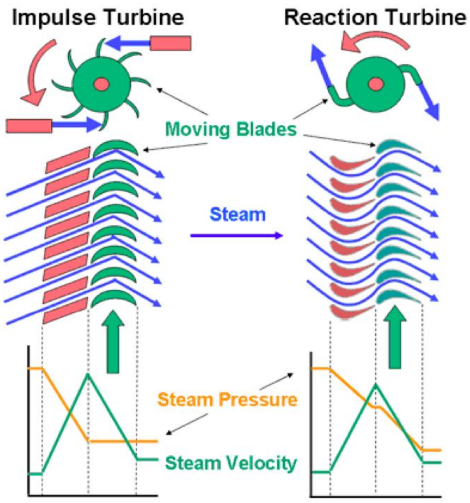
[28] While technology innovation potential may exist for some heat-only applications, this is likely to evolve in the private sector on a commercial basis. Cement production, for example, is a major heat-only industry in the

In power and CHP systems, the fuel is burned in a boiler, which is separate from the power generation equipment. The energy is transferred from the boiler to the generator by an intermediate medium, usually steam under pressure. The boilers used for steam generation within the BSEAA2 target range of 10 kWe to 5 MWe are usually manufactured to a standardised horizontal design, as this allows them to be factory-produced and shipped to the installation site by road or rail.

Both grates and boilers are highly standardised. They are relatively homogenous in design, are readily available on the open market and are not major determinants of project viability. Disaggregation of the combustion-based projects by type of grate or type of boiler would therefore not contribute to the process of pathway shortlisting during this stage of the analysis.

There are two main designs for steam turbines – impulse and reaction turbines (Figure 20). In an impulse turbine, steam is directed at high velocity against rotor buckets. In a reaction turbine, the moving blades of the turbine are shaped in such a way that the steam expands and drops in pressure as it passes through them. As a result of pressure decrease in the moving blade, a reaction force is produced. This force makes the blades rotate (Anon 2017).

Figure 20. Comparison of impulse and reaction turbine design



Source: (Woodbank Communications 2005)

The competitive merits of these designs are the subject of business competition, as both designs have been sold successfully for over 75 years (US EPA 2015). Both designs may also be seen in a single turbine, each helping to extract a little more energy from the steam before it is exhausted. Often the impulse stage comes first and extracts energy from the steam when it is at high pressure, followed by a reaction stage that removes additional energy as the steam is expanded to a larger volume and lower pressure using longer, wider blades (Woodford, 2019).

For **power-only applications**, a *condensing turbine* is usually used**.** These exhaust directly to water-cooled condensers that maintain vacuum conditions at the point of discharge. For **CHP applications**, steam turbines can be classified as *non-condensing* and *extraction*. A non-condensing (or back pressure) turbine exhausts some or all its steam to an industrial process or steam mains at conditions close to the process heat requirements. An extraction turbine meanwhile has one or more openings in its casing for extraction of a portion of the steam at some intermediate pressure. The extracted steam in this case may be used for process purposes in a CHP facility or for feedwater heating (e.g. in a power plant). The rest of the steam can be expanded to below atmospheric pressure to a condenser or delivered to a low-pressure steam application (US EPA 2015).

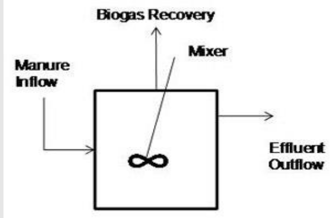
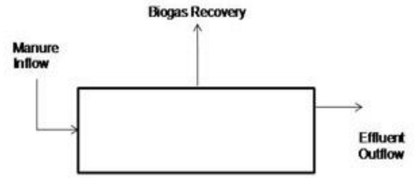
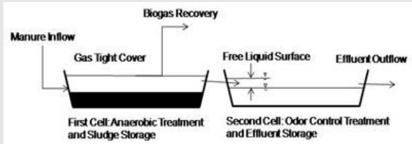
Models of steam turbine were researched, highlighting those suitable for small-scale operations within the BSEAA2 target output range, and the companies that supply them. Some of the leading manufacturers of small-scale steam turbines are listed in Annex 4.

Classification of AD projects

The identified **AD projects** were classified by country, by size of associated gas engine, by functionality status and by the type of technology provider (i.e. European, South African or local, with imported components). It was also possible through project-specific research to classify the AD projects into one of the three primary technology categories presented in Table 3. While there are isolated examples of more complex, high-rate AD systems, such as an induced blanket reactor developed in South Africa by Renen, almost all the projects for which technology details could be assessed fall into these three primary categories.

BSEAA2 target countries. Biomass is often used to co-fire cement kilns with coal, heavy fuel oil or residual oil. There are opportunities for heat recovery systems to be installed in cement kilns, potentially linked to CHP plants.

Table 3. Primary AD technology types

Digester type	Description	Photo	Schematic	Solids conc.	Solids size	Heated?	HRT* (days)
Complete mix	Usually aboveground insulated round tanks; sometimes heated. Wastes with 2-10% solids are pumped in and the contents are continuously or intermittently mixed to prevent separation using gas recirculation, mechanical propellers or circulation of liquid. These are the most flexible AD systems in terms of the variety of wastes that can be accommodated.			2-10%	Coarse	Sometimes	15+
Plug-flow	Unmixed tanks, often rectangular, that function by horizontally displacing old material with new material, which is usually pumped in. Used to digest thick wastes (11-13% solids), as these form a viscous material and limit solids separation. If the raw material is too dry, water or a liquid organic waste can be added.			11-13%	Coarse	Rarely	15+
Covered lagoon	Used for dilute wastes (<2% solids). Coarse solids (e.g. fibres in cow manure) must be separated through pre-treatment, otherwise they float and form a crust, reducing gas production and eventual filling the lagoon. Lacking any insulation or heating, covered lagoons are unsuitable for colder climates.			<2%	Fine	No	40+

Source: (Krich et al. 2005; U.S. Department of Agriculture 2019)
[*] HRT: Hydraulic Retention Time = digester volume/daily influent volume

AD installations can be further classified according to several processing variants, for example:

- whether mesophilic (30-38ºC) or thermophilic (50-60ºC)
- whether single-stage or two-stage
- whether based on a single feedstock or multiple feedstocks
- whether wet method (solids <15%) or dry method (solids >15%)
- according to feedstock pre-processing method: e.g. blending, screening, thermal conditioning
- according to digester capacity and processing rate.

Most commercial AD plants in SSA use single stage biodigesters with the wet method, operating in the mesophilic temperature band. A more detailed sub-analysis was neither feasible nor necessary at this stage.

For most of the AD projects it was possible to identify the main technology supplier. A database of 18 of these suppliers was built up with information on their location, size (measured by turnover or number of employees), main functions, technology focus, product specifications and scope of projects in Africa (see Annex 3). These suppliers were contacted to introduce the BSEAA2 project and to establish willingness to engage.

For the combustion-based systems, the same depth of site-specific analysis was not possible due to commercial confidentiality. A shortlist of specialist companies providing sub-5 MW steam turbines was nevertheless drawn up. These were profiled according to their main technological specialisations, potentially providing the basis for more detailed investigation in Stage 3 if steam turbines are retained (see Annex 4).

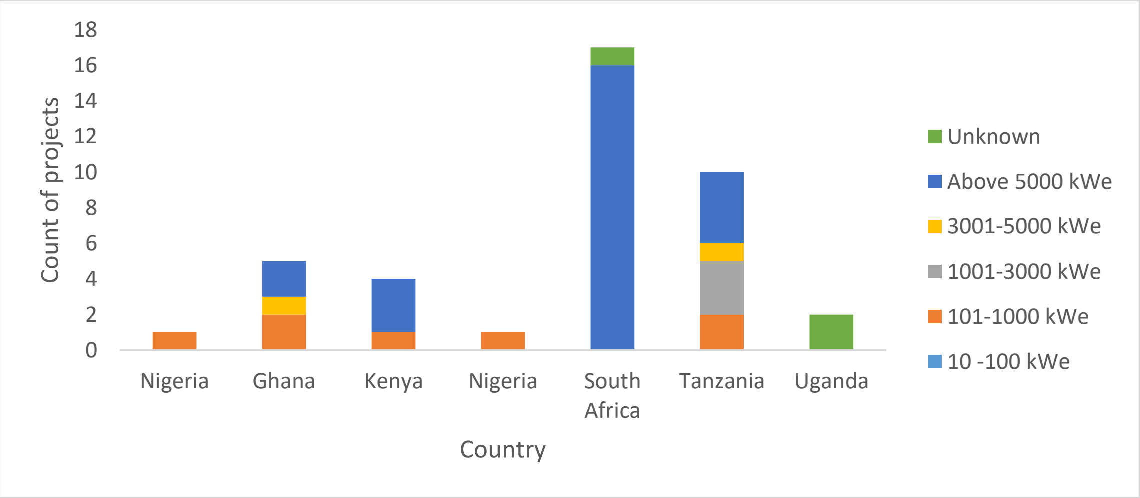
5.2.3 Key Findings

Combustion

Deployment in SSA

Of the 48 identified combustion projects, 40 are CHP projects (the rest being heat or power only). Turbine size details were available for 37 of these. Figure 21 illustrates the scale and distribution by country for these 37 projects.

Figure 21. Combustion-based projects in target countries by steam turbine size (MWe)



Source: Project grid.

Combustion systems powering steam turbines are widely distributed across the target countries, with prominence in South Africa and Tanzania. These investments are characterised by large (or very large) power outputs, some exceeding 25 MW_e. They are dominated by installations in sugar mills using bagasse as feedstock, with examples also found in forestry processing industries and agribusinesses where woody biomass residues are generated.

The number and size of these installations indicates high commercial maturity. These investments are made based on economic considerations, unconstrained by the availability of suitable furnace, boiler or turbine equipment, or the means to operate and maintain it.

There is an investment gap at the lower end of the steam turbine scale range, however. There are only a few projects found in the target countries in the 2-3 MW_e range, and virtually no commercial projects smaller than this. This likely reflects higher CAPEX and OPEX for smaller turbine sizes, as illustrated in Table 4 for back-pressure turbines for CHP applications.

Table 4. Back-pressure steam turbine cost and performance characteristics

Nominal electrical capacity (kW)	Total installed cost ($/kW)	Operation & maintenance cost ($/kW)	Turbine isentropic efficiency (%)	Total CHP efficiency[29]
500 kW	$1,136	$0.010	52.5%	79.6%
3 MW	$682	$0.009	61.2%	79.68%
15 MW	$666	$0.006	78.0%	79.7%

Source: (US EPA 2015)

The analysis shows that while isentropic efficiencies[30] of steam turbines decrease with size, total CHP efficiencies[31] are very similar. Thus, while smaller systems may be less efficient for generating electricity, there is benefit in valorising the heat for small-scale applications, subject to more detailed assessment of cost considerations of recovering and utilising the heat for productive uses.

Adaptation potential

A steam turbine relies on a separate heat source. This separation of functions enables steam turbines to be operated with an enormous variety of fuels from clean natural gas to solid wastes, including all types of coal, wood, wood waste, and agricultural by-products (such as bagasse, fruit pits and rice hulls) (US EPA 2015). Simplicity, durability and flexibility make this technology highly adaptable, thus suitable for a variety of conditions across SSA where ligno-cellulosic biomass is available. Replication potential is not constrained by technological limitations of grates and boilers, as there are versions adapted to almost any viable feedstock that can provide the heat or steam that is required.

Innovation potential

Large-scale combustion-based steam turbine systems use well-understood technology that is widely deployed, especially in the sugar and timber processing industries. While there is some ongoing commercial research and innovation potential with these systems - for example, to deliver incremental improvements in boiler efficiency, emissions reductions, cooling water requirements, turbine blade aerodynamics and boiler tube materials that can withstand higher operating pressures (US EPA 2015) - much of this research and development is already in the commercial domain and is likely to fall outside DFID’s scope of interest.

The adoption gap – and innovation potential within DFID’s potential scope – appears to lie at the smaller end of the turbine scale range. Of the 37 commercial combustion + steam turbine projects (for which turbine sizes were known), only 12 were sub-5 MW and only nine were sub-3 MW. Just four of these sub-3MW installations are thought to be operational.

Yet there is a growing global focus on renewable energy markets, such as waste heat recovery, biomass-fuelled power and CHP plants. Small and medium-sized steam turbines suitable for a wide range of applications in a distributed set-up represent an efficient, reliable, safe and flexible solution for these opportunities (US EPA 2015). Technology and product development for these markets should bring about future improvements in steam turbine efficiency, longevity and cost. This could be particularly true for systems below 500 kW that are used in small biomass systems (US EPA 2015).

[30] Isentropic efficiency is a comparison of the actual power output compared to the ideal output.
[31] Total CHP efficiency = (Net electricity generated + Net steam to process)/Total fuel into boiler.

Reliability

Combustion technology is relatively simple and well-understood. It is therefore well-suited to SSA environments where manufacturing capacity may be limited, and technical back-up is often remote. Relying on straightforward thermal processes, the proportion of these systems that are currently functional, based on the projects identified, is relatively high at around 75%.

Availability of technology support

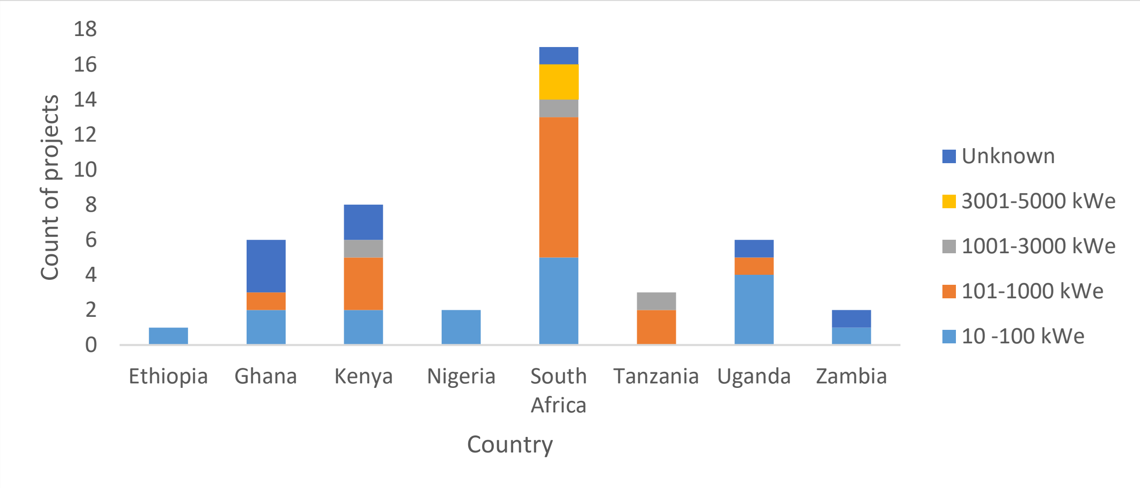
Large-scale combustion and boiler equipment are available from established manufacturers within Africa (mainly in South Africa) and from other developing countries (notably India).[32] Often originating in the tea industry dating back to the early 20th century, these manufacturers are well-positioned to provide support, servicing and spares for reliable operation and maintenance. The manufacture of steam turbines is more specialised, with the best-known suppliers in Germany, Japan and the USA.

Anaerobic Digestion

Scale of deployment in SSA

Figure 22 illustrates the size of the identified AD projects across the target countries. Of the 49 identified projects, plant size information was available for 40 of them.

Figure 22. AD projects in target countries by engine size (in kWe)



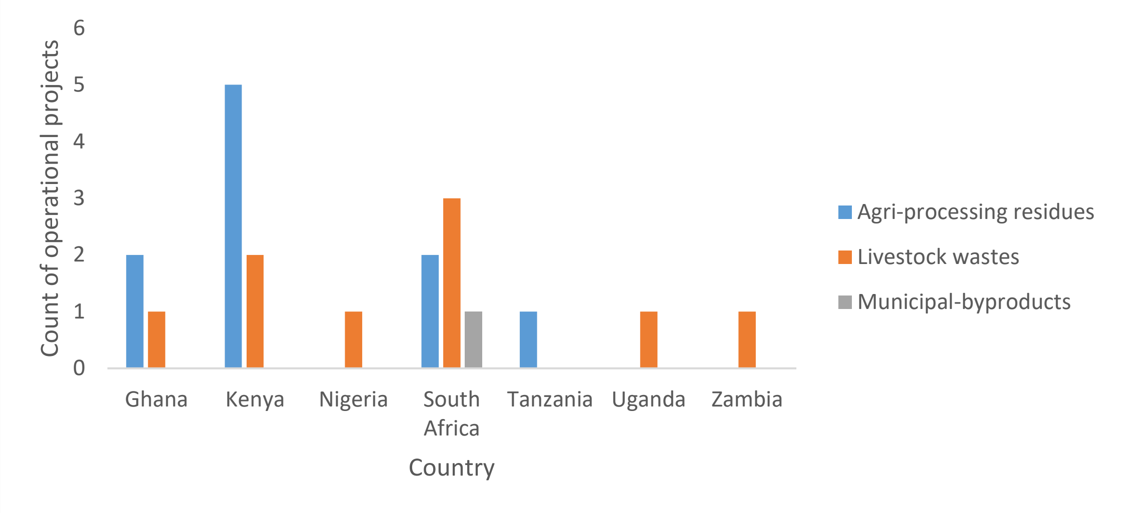
Source: Project grid

There are a relatively small number of operational investments outside South Africa and Kenya. These two countries dominate the sector with 29 (60%) of the 49 identified AD projects and with 13 (65%) of the 20 that are operational. The AD projects tend to be significantly smaller than the combustion-based installations, with an average power rating of 645 kW_e (compared with 12.4 MW_e for the operational combustion systems). If a 4.6 MW_e AD plant in South Africa and a 2.3 MW_e plant in Kenya are discounted, then the average power rating of the remaining operational AD plants comes down to 270 kW_e.

Figure 23 presents the operational AD projects by feedstock category. These plants are dominated by agri-residues (10) and livestock wastes (9), plus an example of municipal by-products at a wastewater treatment plant in South Africa. As pathways are shortlisted for Stage 3, it is unsurprising that successful AD plants are dominated by these two feedstock types, given that they are aggregated at agri-businesses, dairies and feedlots. They also have high moisture content and require minimal pre-processing for AD due to low ligno-cellulosic content.

[32] For example, John Thompson (South Africa) offer a 'SIMPAC' wood-fired boiler with a fixed grate in three sizes and a 'Torripac' hybrid biomass boiler for pellets, briquettes and loose biomass https://www.johnthompson.co.za ISGEC (India) have supplied 27 boilers to agri-businesses in Africa www.isgec.com/boilers/ba-boilers-overview.php There is growing competition from Chinese suppliers for heat-only and CHP application, such as Zhengzhou Boiler Group, which has supplied tea factories in Kenya www.zgboilers.com

Figure 23. Operational AD projects in target countries by feedstock category

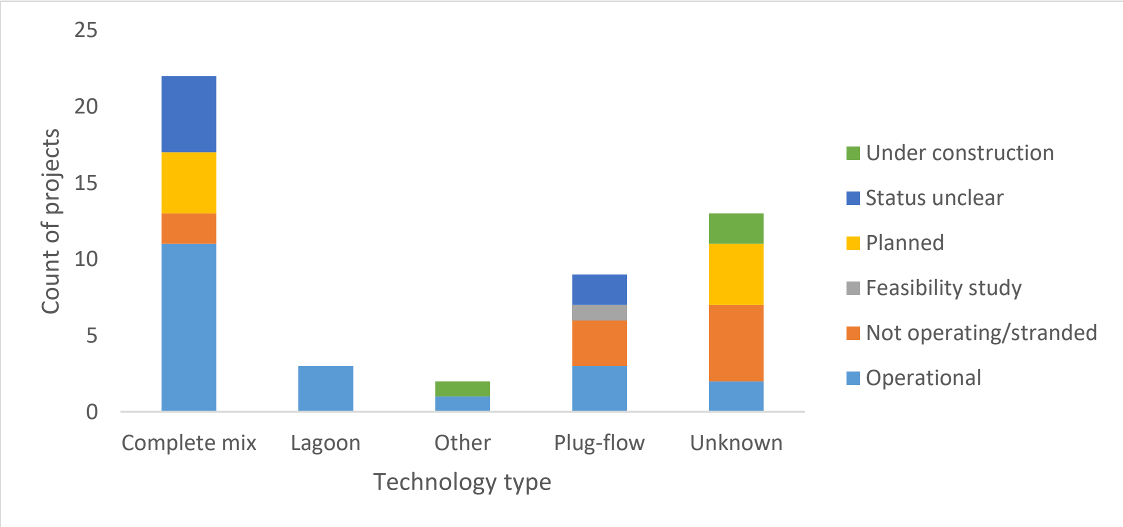


Source: Projects Grid

Adaptation potential

What further distinguishes the AD projects from their combustion counterparts is the variability in technology type. As Figure 24 illustrates, although complete mix digesters are the most widely adopted (55% of all operational projects) there is no standard AD technology. The commercial projects identified represent a blend of complete mix, plug-flow and lagoon-type digesters, with significant operational variation within these categories, especially among the complete mix digesters.

Figure 24. AD projects by technology type



Source: Projects Grid

With a variety of primary technologies and numerous sub-variants, there is an AD technology suited to every condition. This technology type has significant adaptation potential - thus, good prospects for replication and scalability. There is scope within each category for adaptation to Africa-specific feedstocks and operating conditions. At a vegetable processing facility deploying an AD plant developed by the project developer, Tropical Power, in Naivasha, Kenya, for example, the original German mixing system in the first hydrolysis tank was built to a specification for ensiled maize, based on the non-availability of fresh material during the European winter. The Kenyan plant is fed daily with fresh (non-ensiled) material, however, and its waxy coating makes the material hydrophobic, giving it a spongy consistency and a tendency to float. The German mixing system was therefore replaced with a local alternative that ensures stronger vertical mixing. Such differences in seasonality and a host of other operating parameters provide fertile ground for local adaptation of proven European AD technology.

Innovation potential

Modifying established international designs to suit African contexts is an example of technological adaption, as exemplified by the project developer Tropical Power mentioned above. There is also significant scope for innovation by using cheaper components and locally sourced materials, to complement a minimum set of mandatory high-grade components. An example of this innovation can be seen at an avocado processing facility in Kenya, which used in-house expertise to design its own AD system. The company hired a local construction firm for the civil works and sourced the individual components from Kenyan, Indian and Israeli suppliers for self-installation, while retaining state-of-the-art German gas engines for power generation. On the downside, only 37% of the locally built AD systems are thought to be operational. Designing and operating a locally adapted, low-cost version of European technology requires a high degree of technical AD expertise.

Reliability

There is a mixed picture of functionality in the AD projects (as shown in Figure 24 above). Only 20 (42%) of the projects are operational. Differences in operational performance are apparent between the digester types. Considering only the sub-set of projects constructed, 100% of the lagoon-type digesters are thought to be operational (out of a small sample of just three), while complete mix digesters have an 85% success rate and plug-flow digesters just 50%.

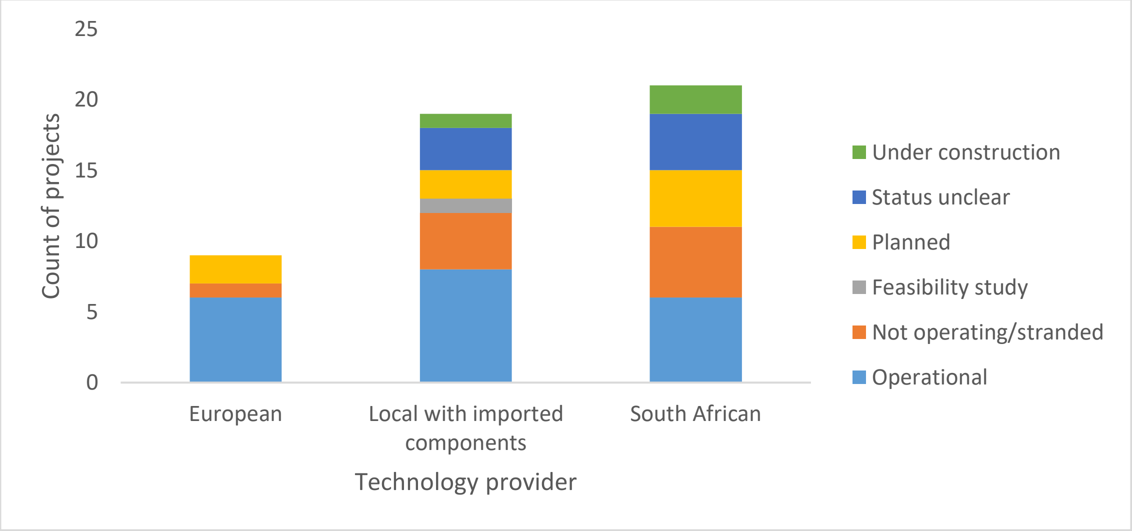
Even among the operational plants, many are performing sub-optimally. For example, the 2.3 MW_e Tropical Power plant in Kenya reportedly operates at less than 50% capacity due to feedstock shortage. The HPW Fresh & Dry plant in Ghana provides only heat, though was initially designed also to generate electricity. A further 15 plants identified during Stage 2 are non-functional or of indeterminate status (assumed to be defunct).

AD is a relatively complex technology, and has not always proven sufficiently robust, easy to operate and simple to maintain to ensure reliable adoption and operation in SSA. It is apparent that commercial AD in Africa is at a relatively immature stage of development. This is evidenced by sparse adoption rates, a concentration of successful investment in South Africa and Kenya, a diversity in technology type and a relatively high degree of failure or under-performance.

Availability of technology support

Unlike combustion, where there is a variety of technology providers located within the target countries, the picture for AD is rather different (Figure 25).

Figure 25. AD projects by type of technology provider



Source: Projects Grid

South African companies have provided the technology for 21 (43%) of the installations identified. Only six of these (27%) are operational and commercial, however. European firms (mostly German, also Danish and Dutch) have supplied just nine of the projects (18%), but their functionality rate is much higher at six projects (67%).

The balance of 19 projects have been installed by local providers or the project developers themselves, using a combination of domestically sourced and imported components (with functionality below 40%). These installations tend to be built using local contractors (largely the digesters) and bespoke equipment (largely the gas engines) procured from a variety of local and offshore suppliers. The avocado processing facility in Kenya (mentioned above) provides a prominent and scalable example. The company is an example of a project developer taking the lead, hiring its own expert consultant to design and install a bespoke system using components from multiple sources.

The only European AD company with a known presence in Africa is Anaergia, with an office in Cape Town. The other suppliers are all African, though some have European partnerships to give access to specialist technology (for example, IBERT in South Africa is linked to an Austrian technology developer). Such African technology providers can be sub-categorised according to their particular commercial niche as either: 1) suppliers of technology only (possibly with some O&M services); 2) suppliers of technology who also offer engineering, procurement and construction (EPC) services; and, 3) EPC-only providers.

There is a general lack of technology suppliers outside South Africa able to provide reliable support, regular servicing and rapid supply of spares. This, no doubt, explains why many developers in the other nine countries have chosen to design and install their own systems. However, these self-designed systems show a very high failure rate at over 60%. Within a broad picture of rather low functionality, it is the European-made systems that have fared best.

5.2.4 Summary

There is potential for incremental technology innovation in combustion for heat-only applications, and for steam turbines at large scale. This falls outside the scope of interest for the BSEAA2 project. Within this technology category, there may be innovation potential with sub-3 MW turbines, which are rarely seen at present. These could fill a niche for small-scale CHP systems as global demand grows for decentralised heat and power from renewable energy. The promising sectors at this scale are those generating woody residues from agro-processing (e.g. oil palm, coffee and coconut residues), and wood and wood residues from plantations and forestry processing (e.g. eucalyptus, wattle and pine). There are several such activities in most of the BSEAA2 target countries. The uptake potential of dispersed, small-scale plants may be of interest to DFID.

Looking beyond technology innovations, there is also potential for developing feedstock supply chains for combustion-based pathways that can bring wider development impacts than centralised, in-house feedstock sourcing operations. This offers promise in the tea industry, based on out-grower fuel production supplying farmer-owned factories, or premium tea producers keen to enhance community empowerment. Tea processing enterprises based on both estate and smallholder production are found in six of the ten target countries (Kenya, Uganda, Tanzania, Rwanda, Ethiopia and Mozambique, in order of their scale of production).

In the AD sector there is proven commercial deployment potential for all the best-known types of biodigester technology within the desired scale range in the BSEAA2 target countries. All designs offer innovation and adaptation potential for specific feedstocks and conditions found in SSA, and it is therefore recommended that no AD technology type is ruled out for further investigation in Stage 3 as the project concentrates on a shortlist of bioenergy pathways.

5.3 Theme 3: Supply chain archetype analysis

5.3.1 Aim

The main objective of Theme 3 is to understand how the supply chain structure of a bioenergy pathway affects its likelihood of success, which helps to narrow the list of pathways under consideration. The theme also aims to help the team to understand which end-use sectors should form part of the shortlisted pathways for Stage 3.

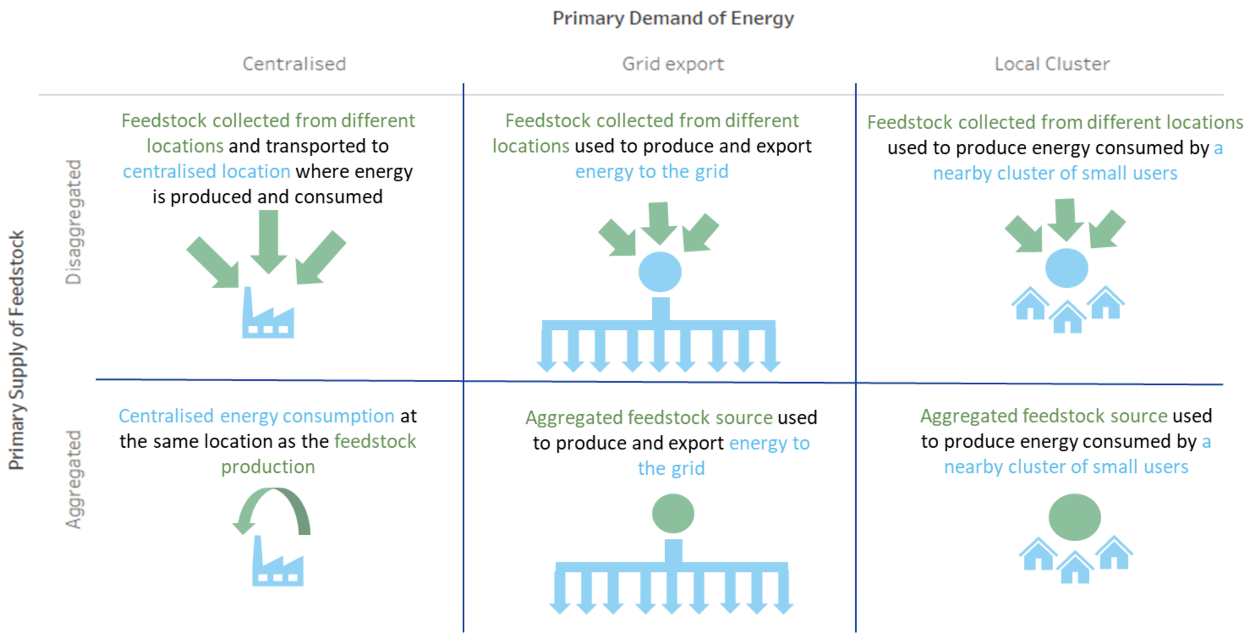
5.3.2 Approach

The following five assessment criteria were considered to assess the different supply chain models:

- Replicability
- Demand assessment
- Competitiveness
- Scalability
- Attractiveness of financing

A consistent framework for characterising these supply chain structures was created in order to understand how the supply chain structure impacts the likelihood of success of a bioenergy pathway. Supply chain structures were grouped according to six archetypes, as shown in Figure 26. A ‘supply chain archetype’, for the purposes of BSEAA2, is a specific combination of primary feedstock supply and primary energy demand, which together define how feedstock is obtained and how energy is produced, distributed and consumed.

Figure 26: Framework for bioenergy supply chain archetypes



The six archetypes are labelled Aggregated (A) from A1 to A3 and Disaggregated (D) from D1 to D3, as described in Table 5.

Table 5: Supply and demand features of bioenergy archetypes

To	Type	Definition	Example
Primary supply of feedstock	Aggregated - A	Feedstock primarily available on site, at the location where the bioenergy is produced	Vegetable wastes from a central processing facility
	Disaggregated - D	Feedstock primarily sourced from multiple locations and needs to be collected and transported, with the main purpose of supplying the bioenergy plant	Forest wood sourced from multiple plantations
Primary demand for energy	Centralised - 1	Bioenergy primarily consumed by a single user, usually a large processing facility	Electricity to power a fruit processing facility
	Grid export - 2	Bioenergy primarily consumed by users dispersed over a large geographical area via a grid network to transport the energy	Export of electricity to a national or regional grid
	Local cluster - 3	Bioenergy primarily consumed by nearby small-scale users	Mini-grids to supply electricity to nearby households or businesses

The distinction between the archetypes is not always clear-cut. For example, projects in the A1 archetype (aggregated feedstock supply, centralised energy consumption) may sell excess electricity to the grid, thus overlapping with the A2 archetype. Similarly, aggregated feedstock could be complemented by additional feedstock from disaggregated sources, overlapping with the D1 archetype. To maintain clarity and simplicity, the archetypes reflect *primary* supply and demand characteristics.

It is also important to note that the archetypes are based on the geography of the feedstock supply and energy demand. They do not necessarily reflect the ownership structure of the supply chain. For example, under archetype D1 (disaggregated feedstock supply, centralised energy consumption), the owner of the processing facility might own the land from which the feedstock is collected, but the feedstock could equally be supplied by contracted third parties (such as out-growers). Under a cooperative model, it is also possible for the processing facility to have multiple owners, who are simultaneously its suppliers. The key to an archetype is therefore not ownership, but how feedstock flows and how energy is consumed.

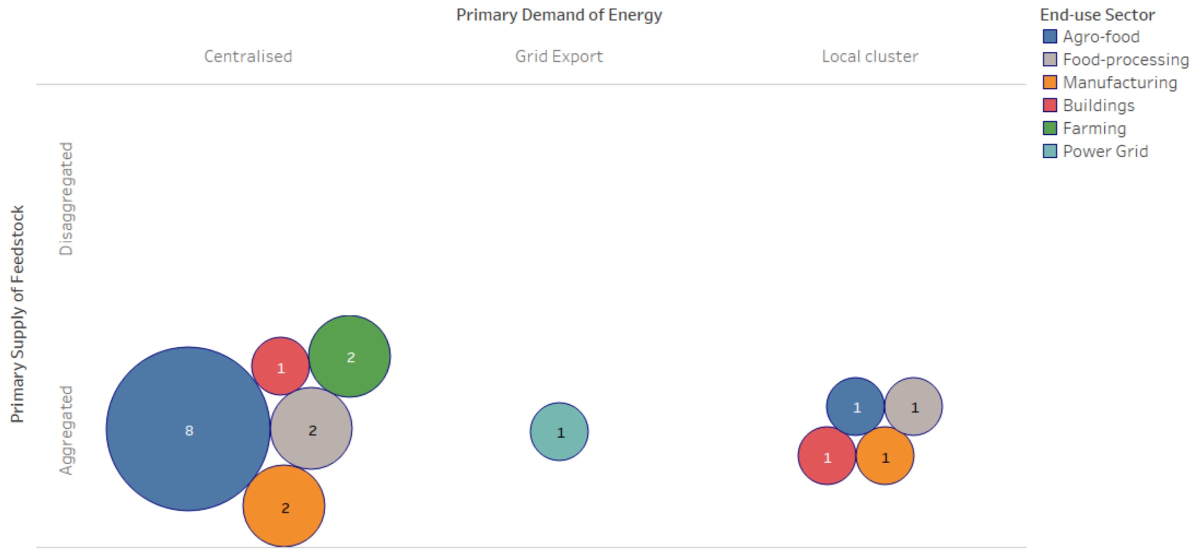
5.3.3 Key findings

Criterion 1: Replicability of supply chain archetypes

Since Stage 2 aims to identify bioenergy pathways that are not just at laboratory stage or characterised by one-off projects, replicability forms a key element of understanding representative supply chain models that have demonstrated commercial potential and can also be successfully rolled out in multiple locations.

In order to achieve this objective, the number of current operational projects in the Projects Grid was plotted within each supply chain archetype to determine where commercial interest and viability were highest, thus giving an indication of replication potential. The analysis is presented for AD in Figure 27 and for combustion in Figure 28.

Figure 27: Supply chain archetypes associated with anaerobic digestion



Source: Projects Grid

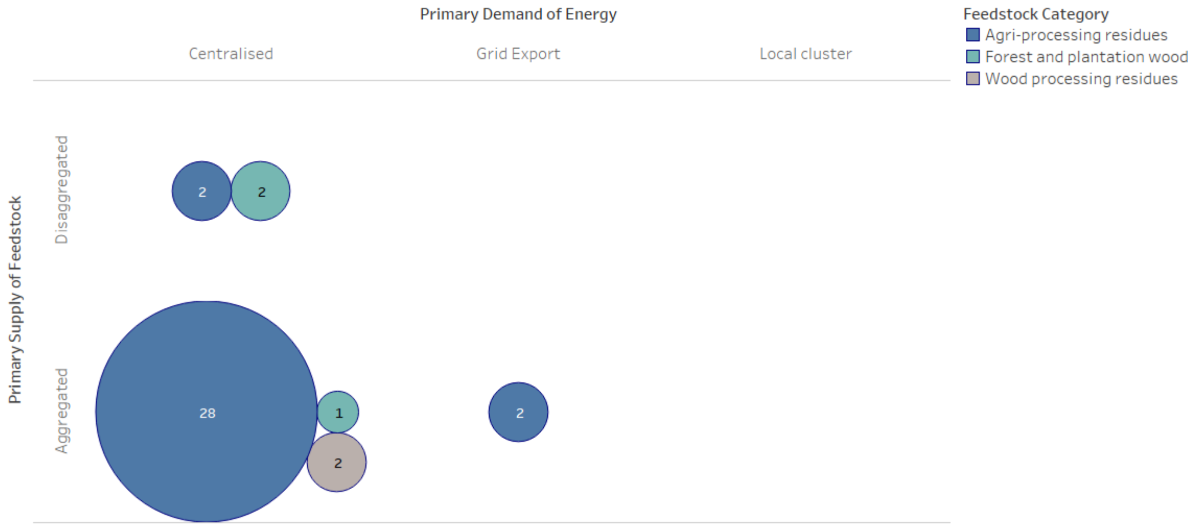
As illustrated, none of the operational AD projects appear to use disaggregated feedstocks as their primary supply source (i.e. they all fall within category ‘A’). One possible reason is that AD tends to use wet biomass,[33] which is generally difficult (and expensive) to transport. AD-based pathways based on aggregated feedstocks have had some degree of commercial success. This is **an important factor in shortlisting those AD pathways that demonstrate economically viable aggregation potential**.

The operational AD projects are dominated by centralised energy demand (A1), with limited successful cases of supply to a local cluster (A3). Where there have been operating examples of AD projects that serve local clusters (A3), donor funding has been needed to ensure viability. For example, the Waste-2-Watt AD project in Rije, Nigeria, which produces 20 kW of electricity to serve a rural off-grid community, was the recipient of a sizeable grant.

Just one project was found where the primary purpose was to supply electricity to the grid (A2). The agro-food industry is the most prominent end-use sector, followed by the farming and manufacturing (particularly wood processing) sectors. This is likely due to these industries having both feedstock and demand at the same location. One A1 example in the agro-food industry is a fruit derived cold-pressed oil processing facility in Kenya that uses fruit processing residues as feedstock for AD, which in turn provides power for the facility’s presses, cooling and pumping needs.

[33] Wet biomass refers to feedstock with moisture content above 0.8 kg/kg-wet.

Figure 28: Supply chain archetypes associated with combustion



Source: Projects Grid

No operational combustion projects supply their primary energy primarily to local clusters (archetype A3 or D3). This could reflect size flexibility considerations. This project focuses on combustion technology coupled with steam turbines for CHP generation. As discussed under Theme 2, steam turbines are better suited to larger scale applications, whereas local clusters generally have relatively low energy demand compared with centralised consumers (such as industries, commercial establishments or other bioenergy processing facilities) or the electricity grid. Additionally, if the policy, regulatory and finance frameworks are not in place to make generation and sale of electricity to clusters viable, this demand archetype will not be of interest to bioenergy investors.

There is no example of archetype D2 (disaggregated feedstock and electricity supply to the grid). This could reflect a lack of surplus electricity or, more probably, a policy or regulatory framework that is not supportive, either because there is no guaranteed feed-in tariff or the administrative and regulatory requirements for selling to the grid are too onerous to make it worth the facility's effort. The same could apply to archetype D3, where selling to local communities could also be too administratively complicated to warrant the effort.

Like AD, the A1 supply chain archetype dominates the combustion-based projects, with the agro-food industry being the most common end-use sector. This archetype is dominated by sugar factories and, to a lesser extent, palm oil processing facilities in Ghana and Nigeria. While these projects are categorised under A1, most are in fact hybrids, generating electricity for self-consumption and exporting any excess to the grid, if the regulatory regime is supportive and if electricity prices are high enough to make it financially attractive.[34]

At two large sugar factories (Mumias in Kenya and Mtibwa in Tanzania), electricity generation for sale to the grid (A2) is the primary commercial objective for much of the year and electricity sales generate significant additional revenues to supplement sugar sales (and ethanol production). This indicates the high commercial value that can be derived from bioenergy if the feedstock is plentiful and aggregated, and the electricity regulatory regime is supportive.[35]

[34] As noted under Theme 5, the price of grid electricity in Ghana has dropped so much the past four years, due to a major surplus of inexpensive natural gas-generated electricity, that palm oil producers find it cheaper to buy electricity from the grid than to generate it themselves

[35] In the case of Mumias, the Kenya Energy and Petroleum Regulatory Commission offers a high feed-in-tariff for biomass CHP-generated electricity. See Theme 5. In the case of Mtibwa, the Energy and Water Utilities

The manufacturing sector (mainly wood-processing industries) also uses combustion technology, based on industrial by-products (e.g. sawdust, wood chips) that can be used onsite in boilers for heat and/or electricity generation. As with sugar, selling surplus electricity to the grid makes sense if the regulatory regime is supportive (e.g. with feed-in tariffs or preferential PPAs). In some counties, the power can be sold directly to willing customers.[36]

There is also some activity under the D1 archetype, with examples including cement factories, such as WAPCO Cement in Nigeria and Hima Cement in Uganda. Fossil fuel sources that are expensive, insufficient or unreliable (primarily coal and heavy fuel oil) create an incentive for cement factories to source locally available bioenergy feedstocks for 'co-firing' (e.g. wood waste or agri-residues such as coffee husks, rice husks or cotton residues). Examples can be found in the cement sectors in Ethiopia, Kenya, Uganda, Tanzania, Nigeria and South Africa.

In summary, the most replicable supply chain archetypes for both AD and combustion use aggregated feedstocks, which produce energy for the same facility that generates the feedstock (i.e. A1). Examples are found in the agro-food, livestock and manufacturing (mainly wood processing) industries.

Criterion 2: Demand sector analysis

This criterion aims to assess the potential market size for electrical and thermal energy produced from biomass in the target countries, based on an assessment of current energy consumption in various energy end-uses compatible with bioenergy. The identification of the largest energy end-uses and most attractive countries helps to inform the selection of priority pathways, alongside other factors.

Energy demand was classified into four macro sectors: agro-food processing, livestock farming, manufacturing industry and buildings (see Appendix 6). Various sub-sectors were explored according to data availability. When market size data for a sub-sector was unavailable, proxies such as annual production quantity or economic value were used. A scoring exercise was carried out to identify the predominant industries across the different countries. In each macro sector, the sub-sectors and/or countries were ranked from 0 to 3, corresponding to an absent, low, medium or large energy end-use. An example of this scoring is provided in the Annex 5 for the farming sector.

The energy end-uses and respective countries that demonstrate the largest market potential for bioenergy projects are summarised in Table 6.

Table 6: Energy end-uses and countries with the largest demand potential

Top end-use markets	Agro-food processing	Livestock farming	Light/heavy Industry	Wood and paper	Buildings
By sectors	Vegetables Cotton Tree nuts Tobacco Beer	Meat Dairy Eggs	Light manufacturing Mining Cement Lime	Sawn wood & wood products Pulp & Paper	Residential (unmet) demand
By countries (listed from highest to lowest)	South Africa Kenya Nigeria Ethiopia Uganda	South Africa Nigeria Kenya Ethiopia	South Africa Nigeria Zambia Uganda Tanzania	South Africa Nigeria Mozambique Tanzania Uganda Kenya	Nigeria Ethiopia Tanzania

Regulatory Authority has a feed-in-tariff for biomass Small-Scale Power Producers up to 10 MW generation capacity.

[36] In some countries, e.g. Uganda and South Africa, electricity generated at an eligible facility (e.g. sugar factory) can be sold either 'over the fence' (i.e. to a neighbour willing to buy the electricity at an agreed price), or to a customer who could be connected to another part of the grid through a 'wheeling contract' that enables the seller to sell directly to a distant customer by paying the electricity transmission company a 'wheeling fee' for using the grid to transport the electricity.

Agro-food processing industry: Vegetable processing (e.g. in the horticulture industry) is the agro-food industry with by far the highest applicability potential in terms of scale and level of aggregation. Vegetable processing typically consists of processes that turn perishable vegetables into stable products that can be stored and transported. Examples include blanching, dehydrating, canning, refrigerating, freezing, fermenting and pickling. Vegetables are processed with a high-level of aggregation, especially in Kenya, South Africa, Ethiopia and Tanzania. The size of the vegetable processing industry and its presence in multiple countries strongly supports its selection as a prioritised energy end-use. The industrial processes typically employed in vegetable processing require both electricity and low-grade heat and can therefore be integrated with AD CHP technology. The fruit processing industry has similar characteristics, with significant applicability potential in Kenya and South Africa and, increasingly, Tanzania and Ethiopia.

Tea production is another agro-food industry requiring a considerable amount of energy, primarily in the form of low-grade heat for drying purposes. In Kenya, Tanzania, Uganda, Rwanda, Mozambique and Ethiopia, some of the production is centralised in large estates. In Kenya, Tanzania, Uganda and Rwanda, there is also significant supply from smallholders, either organised in cooperatives (particularly Kenya, and somewhat in Uganda and Tanzania) or as out-growers supplying small to medium tea estates (Uganda, Tanzania, Rwanda, Kenya and, increasingly, Ethiopia).[37]

The tea industry lends itself to the commercial use of bioenergy for heat and possibly electricity generation, given the high value of the processed crop and the attractive size of the industry. There is great potential for bioenergy to play a major role in further expansion, both in BSEAA2 target countries and other SSA countries, including Malawi (one of SSA's largest tea producers), Burundi (a relatively large tea producer), Zambia, the Democratic Republic of the Congo and South Africa (all with relatively small, but growing, tea sectors).

Tree nuts as a feedstock source are not suitable for use with either combustion or AD and are best suited to bio-diesel production. In the other two sectors (tobacco and beer), the potential for bioenergy generation is high, but these industries present ethical concerns in the donor context, so were not examined closely. While many beer breweries internationally use brewery waste for AD to generate energy, the team examined breweries in all the target SSA countries and found no use of waste for energy production. There is meanwhile very little tobacco waste produced during harvesting and curing, and no evidence of centralised conversion of any tobacco waste to energy in the target countries.

Livestock farming (meat, dairy, eggs) and the **wood and paper industry** (sawmills, timber producers, high-grade pole producers, pulp and paper producers) are highly attractive for bioenergy generation, as they often produce their own feedstocks or, in the case of wood and paper industries, contract the production of certified forest wood to out-growers and other forest estates.

Dairy production is of growing importance in the target countries, with South Africa having the largest dairy production for both domestic consumption and exports. Small-scale biogas from animal waste is of growing importance in Kenya,[38] Uganda and increasingly in Tanzania, providing energy for milk cooling for small dairy producers, often organised in cooperatives for supplying larger dairy concerns.

An analysis of operational projects suggests that AD could play an important role in the South African dairy and feedlot (meat) industries, based on energy derived from cattle manure. While in the case of wood-processing sector, CHP generation using sawmill and wood industries' own residues could meet the energy demands of the growing sawn wood industry in all ten target countries, and pulp and paper industries in Tanzania, South Africa and Nigeria.

[37] There are over 700,000 smallholder tea growers organised in co-operatives that own their processing factories (69) in Kenya, with over 40,000 smallholder growers in Uganda and 30,000 smallholder tea growers in Tanzania and Rwanda respectively.
[38] Over 1 million smallholders are organised into dairy cooperatives in Kenya. Dairy ranks as Kenya's third largest export. www.lrrd.org/lrrd29/7/atiw29139.html and ccafs.cgiar.org/nationally-appropriate-mitigation-actions-kenya%E2%80%99s-dairy-sector#.XmI2lqj7Q2y

Within **light/heavy industry**, there are several industries where heat from bioenergy can theoretically be used (such as textiles, mining, lime production and chemical production). But commercial consumption is dominated by the cement industry. Cement production is an energy-intensive process and one of the largest heavy industries in Nigeria, South Africa, Kenya, Tanzania, Uganda, Ghana and Ethiopia. The production and use of cement is expected to grow significantly in Sub-Saharan Africa, driven by increasing population, rising incomes and urbanisation. As a result, the energy demand from this sector (and associated sectors, such as lime production) is likely to grow. This would offer additional demand for bioenergy for co-firing to substitute for fossil fuels and could successfully compete in the provision of direct heat.

During Phase 3, biomass feedstock supply will be mapped against demand in different areas for the bioenergy pathways selected. This will include examining rural and urban areas where a large portion of local energy demand is currently being met by diesel generation, and where bioenergy resources are abundant and could serve as a source of electricity, given the right policy and regulatory frameworks. As discussed under Theme 5 below, unreliability of electricity supply is a major reason why many SSA countries are less attractive to investors.

Energy use in **buildings** is the largest demand sector for most SSA countries, with additional unmet demand due to lack of access to energy infrastructure. Despite this high potential, the building end-use sector does not lend itself to prioritisation within the scope of the BSEAA2 project for two reasons:

- Much of the energy demand from households comes from the small-scale combustion of solid biomass (primarily wood and charcoal) for cooking and, to a lesser extent, for water heating. The energy requirements are well below 10 kW and do not support economically productive operations.

- Experience from bioenergy projects in SSA shows that generating and supplying electricity to local clusters of households tends to be commercially uneconomical. This is often due to a lack of 'anchor' ('base load') customers who have substantial energy demands and are already paying for that energy (e.g., through diesel gensets, diesel-driven grinding mills, oil presses, welding machinery). It should be noted that this challenge is not unique to bioenergy. Solar PV and mini-hydro based mini-grids also face similar challenges. However, these technologies, particularly solar PV, have usually a cost advantage over bioenergy technologies and their modular nature allows them to be more easily scaled to match the size of the mini-grid load. Whilst bioenergy's advantage is that it is not an intermittent source, the fact that there is an absence of successful combustion and AD projects serving this particular sector, indicates that many commercially focused bioenergy project developers are currently not considering serving mini-grids as a viable option.

  This constraint is particularly important in rural and peri-urban areas, where the number of anchor consumers may be very small relative to the number of household consumers who would be able and willing to pay for electricity, but, whose demand is individually very low (for lighting, TV, radios, phone charging and other low-demand purposes) and cannot sustain the infrastructure and operational costs of distributing electricity. It is also difficult and expensive for an enterprise which is producing bioenergy to meet its own demands to accurately estimate the additional demand that might exist from nearby consumers, and to determine their willingness and ability to pay.[39]

[39] Innovative and commercially viable mini-grids are being developed in SSA using solar or mini-hydro. It is crucial to note that there is a fundamental difference in business model between using solar or mini-hydro for the sale of electricity to mini grids, and the use of biomass to produce electricity for self-consumption. The former requires licensing, regulatory and other elements that are not required for own/self-use. Generating electricity for sale is, thus far, in our experience, not part of the business model for the bioenergy projects the Project Team found. Adding electricity supply to third parties is a completely different business model, which has not been successfully demonstrated in any projects identified. The use of bioenergy has seen more limited uptake, with some examples using gasification technologies that have largely failed or are barely working. This topic is explored in more detail under Theme E.

Criterion 3: Competitiveness of Supply Chain Archetypes

The aim of this criterion is to identify the end-use markets in which the supply chain archetypes have a competitive advantage against other technologies that can provide the same service and level of service, and in doing so, which bioenergy pathways could be commercially attractive.

Combustion of biomass for heat-only purposes (e.g. direct use for drying in the tea sector) has a distinct advantage over other energy supply options because it is difficult to convert electricity into heat in a cost-effective manner at small scale. This is particularly relevant for high grade heat, such as that required for cement kilns. Also, there is an increasing trend of shifting from coal-fired boilers to wood-fired ones when lifetime costs are taken into consideration. This builds a commercially attractive case to use bioenergy in industries where there is a strong pull for process heat, such as in the tea, oil palm, food agro-processing, wood-processing and cement industries.

Both AD and combustion also have a distinct advantage over technologies such as diesel generators (when no fossil-favouring subsidies are present) in situations where the user of the energy is the same as the producer of the feedstock (the A1 archetype). Predominantly this is an economic advantage, as the feedstock can be considered to have no cost or even a negative cost (when there is a need to pay for its disposal). Industries within the agro-food, wood processing and livestock sectors are prime examples of such end-users. An example is an instant tea facility in Kenya, where an AD plant generating power for the tea factory also avoids the cost of disposing of spent tea waste.

Although current waste management laws, regulations and enforcements are weak in almost all target countries except South Africa, with increasing public awareness and climate action, this trend is likely to change with companies adopting mandatory or voluntary measures to dispose of ‘waste’ in an environmentally friendly manner, a service which both AD and combustion can provide.

On the other hand, AD and combustion have less competitive advantage for archetypes serving local cluster demand, for reasons cited above. To be commercially viable, most clusters will require an ‘anchor’ load such as an agro-processing facility, grinding mill or welding shop, with high energy demands typically met by diesel engines. Most rural or peri-urban clusters are comprised of low-income households with low energy demand. The regulatory framework for selling electricity and the technical requirements for doing so via local clusters is also often discouragingly complex.

Moreover, selling electricity or heat is not the core business of an agro-processing facility or a sawmill. Becoming an energy supplier requires very different skills, technology knowledge and regulatory familiarity that can distract an enterprise from its core business. These are the primary reasons for finding no working D2 or D3 archetypes. Theoretically, energy service companies (ESCOs) could help to overcome these barriers, however, most ESCOs tend to operate in urbanised environments with stable anchor loads. Since many of these bioenergy projects are found in rural settings, it is less likely that they would be attracted to operate in such areas, as energy demand tends to be more dispersed. Additionally, competing technologies such as solar PV and small-scale or micro hydro, which receive much more government support than bioenergy in most of the target countries, and have a cost advantage versus combustion and AD, further explains why these two archetypes are currently not operational or attractive.

Lastly, the hybridisation of archetypes could increase the competitiveness of a pathway, for example, through diversification into alternative markets such as fertilizer production, gas bottling, electricity supply to local clusters or export to the grid. For example, AD produces by-products with additional economic and environmental value, such as digestate, which can be used to replace high-cost fertilisers. A good example is the same AD project using organic tea waste for producing instant tea (Kenya), where the production of chemical-free digestate has reduced the need for the tea company to purchase expensive fertiliser, thus providing additional economic returns from the AD investment.

Criterion 4: Scalability of supply chain archetypes

The scalability of a supply chain in this context is defined as the feasibility to increase the amount of feedstock used and energy delivered, whilst maintaining financial viability. Scalability depends on key enablers and barriers right along the bioenergy pathway related to feedstock, technology, environment, business model, licensing, economics, regulations and country-specific factors. The aim is therefore to understand how such enablers and barriers affect the scalability of the supply chain archetypes, and thus the selection of promising bioenergy pathways.

The 57 operational projects were reviewed from a thematic point of view (feedstock supply, technical and technological, economic, business model and commercial, institutional, financial and regulatory), with weekly meetings and team updates. The objective of this four-month exercise was to extract the key enablers and barriers for each supply chain archetype. The following were the key observations:

A1: Aggregated feedstock supply, centralised energy demand
For this supply chain archetype, the cost of feedstock is often very low (when there is no alternative use for the feedstock), or negative (when costs are incurred for disposal), giving projects an inherent economic advantage compared with those which require feedstocks to be grown purposely for energy. In cases where the feedstock is considered a 'waste' and where its disposal is mandated by law, there is an additional incentive to build bioenergy conversion plants utilising such waste. Another key enabler is the cost of feedstock transport, which is much lower for this archetype than those with disaggregated feedstock supply and does not require a supply chain to be established.

Demand for the energy under this archetype often comes from a large, stable anchor loads (i.e. own demand), which provides investors and project developers with certainty. Such sources of demand are likely to be able to fulfil their financial obligations (e.g., loan repayments, operating costs). If the energy generated was instead sold to local clusters of residential users, revenues and their reliability might not be enough to make the investment profitable or the extra effort commercially attractive.

For these reasons, a significant majority of the identified projects represent the A1 archetype.

A3: Aggregated feedstock supply, local cluster energy demand
Projects of this archetype benefit from the same supply-side enablers as the A1 category. On the demand side, the key difference is that it is often difficult to accurately estimate the demand from local clusters, which might be rural communities where the bulk of demand is from households. As noted above, household demand is rarely enough to cover the bioenergy investment costs.

The risk can be mitigated if the local cluster has sufficient anchor load from commercial, large institutional and small industrial customers, not only because these can ensure that there will be sufficient local energy demand, but also because businesses are more likely to be able to pay for their energy than residential customers. Furthermore, particularly in non-grid-connected areas, non-household consumers are likely to be using expensive diesel generators. Therefore, they are not only more willing, but, more able to pay higher prices for electricity supplied from these A3 suppliers than households. A good working model, seen in many places in rural SSA, is for electricity suppliers to charge a higher industrial/commercial tariff to these large consumers to help cross-subsidise smaller household, school, rural clinic and other low-demand consumers.

A good proxy for 'ability to pay' is to determine how many diesel and petrol generators will be displaced by the bioenergy supply (only if the cost of the energy, especially electricity is less than the cost of owning and operating fossil fuel generators).

Given that these consumers usually have no stake in the bioenergy project, there is always the risk of non-payment. Government support in the form of subsidies, favourable regulation (light touch and easy to comply with) and technical support (e.g. support in developing and operating mini-grids) can go a long way, particularly for larger A1 industries, to support a move into supplying electricity to clusters. Such support is common in most of the target countries for other renewable energy technologies, particularly solar PV and hydropower, but it should be understood that solar PV and hydropower suppliers to rural clusters/mini-grids tend to be in the business primarily to supply electricity, not to process biomass with electricity as a side-business.

These barriers may explain why fewer projects are developed in this archetype. The drive for improved local amenities such as water, sanitation, health and education could play a significant role in determining whether more projects under this archetype will be seen in the future.

Only a few operational projects are currently seen in this archetype. One example is a rural community mini-grid (including biogas for clean cooking) powered by a 20 kW AD unit in Nigeria, with cow dung as the primary feedstock, together with communal waste from the local village. It is desirable to understand the key enablers and barriers in more detail during Stage 3.

A2: Aggregated feedstock supply, grid connected energy demand
In situations where there are no (or few) local competing sources of demand for energy, and where electricity markets and regulations permit (or actively support) electricity supply for grid export, this can be an attractive option. This archetype also requires proximity to the grid and a relatively low connection cost.

Whilst these barriers are not insurmountable, it is evident that technologies such as solar PV, small- or mini-hydropower face fewer barriers to electricity production, which may explain why only a few operational bioenergy projects were seen for this archetype. As will be described in more detail in section 5.5, support for the export of electricity from bioenergy to the grid in the 10 kW to 5 MW range is presently lacking, or very difficult to obtain, in all countries except South Africa, Kenya and Tanzania. This is not the case for electricity from solar PV and small hydro.

While this archetype is rarely seen in its pure form, projects are often hybrids of the A1 and A2 archetypes, where the primary energy is for self-consumption (A1), but opportunistically expands to exporting the electricity (A2) *if the right incentives and enabling environment are present.*

> The lifting of tariffs and other international trading barriers, e.g., through ‘preferential trading areas’ and ‘common markets’ such as the South African Development Community (SADC), Common Market for Eastern and Southern Africa (COMESA) and Economic Community of West African States (ECOWAS), has had a marked effect on scaling up electricity generation from larger bioenergy industries, particularly sugar. The removal of trade barriers, coupled with liberalised electricity markets and preferential tariffs or feed-in-tariffs for bioenergy electricity, has stimulated significant investment in Kenya, Uganda, South Africa and Tanzania in grid-exporting electric capacity. Very few sugar factories in the target countries have not scaled up their generating capacity to sell electricity into the grid and diversify their revenue sources. Similarly, support programmes and increased demand for liquid biofuels have stimulated investment in many sugar factories for bio-ethanol production.[40]

D1: Disaggregated feedstock supply, centralised energy demand
Given the cost of securing and transporting feedstock from locations which are not close together, as well as the time needed to set up the physical supply chain to mobilise the feedstock, it is not surprising that fewer projects are seen which use geographically disaggregated feedstocks. However, when a large user has a need to diversify its energy provision in order to give it a more secure and stable supply of energy, there exists a strong driver to procure feedstocks from a wider range of locations, with the WAPCO cement factory in Nigeria being an example of this.

D2: Disaggregated feedstock supply, grid connected energy demand; and
D3: Disaggregated feedstock supply, local cluster energy demand
The supply side and demand side barriers have been discussed in earlier archetypes (A1, A2 and D1, in particular). These barriers help to explain why no operational bioenergy projects are observed for the D2 and D3 archetypes.

How this analysis will be used in pathway selection
Based on this analysis, the A1 archetype is, by far, the most replicable under the conditions found in the ten target countries. It faces the fewest barriers and has the greatest number of key enablers in a cross-section of industries. If feedstock supply can be locked in, then D1 is the second most replicable

[40] Liquid bio-fuels were ruled out of the project as most industrial scale production is to supply to the transport sector or as a cooking fuel for distribution to residential customers (both of which are out of BSEAA scope). Those examples within the scale range suffer from issues of feedstock supply security, food-versus-fuel or competitiveness concerns.

archetype. The third is A2 (essentially A1, but selling electricity to the grid). A3 (aggregated feedstock, selling energy to a local cluster) shows some promise, and includes four AD projects.

This analysis also shows that hybridisation of the core archetypes could increase scalability (for example, A3, exporting surplus electricity to a local clusters) if those clusters fit the description above (strong commercial anchor load alongside supportive government policy and regulatory support).

Criterion 5: Attractiveness of financing the supply chain archetypes
Since one of the aims of the research is to gain an understanding of which bioenergy pathways are likely to be attractive to investors, this criterion informs the shortlisting of pathways from a financing perspective. This was examined (above) in terms of the framework and incentives of selling surplus electricity to the grid or clusters (e.g., mini-grids, or cluster of other industries or other potentially large consumers). This was carried out by examining critical aspects of each supply chain archetype and different end-use sectors, alongside the number of operational projects within each archetype, to determine the key reasons why certain archetypes are more likely to obtain finance than others.

A key factor attracting investment is the certainty of demand revenue. As previously discussed, the archetypes that with centralised demand and/or grid export tend to have stable and predictable demand for energy. The end use sectors tend to be medium- or large-scale companies, which are likely to be reliable in meeting their payment obligations. On the other hand, archetypes reliant on local cluster demand tend to have customers whose demand for energy is less predictable, and whose ability to meet payment obligations is less reliable, particularly in rural areas.

Another factor in attracting investment is the security of feedstock supply. The aggregated supply archetypes are more likely to have secure feedstock supply, particularly when the energy is produced at the same location. Disaggregated projects will often depend upon multiple sources of supply, spread across a large geographical area. Locking in feedstock supply through long term agreements is key for those relying on disaggregated sources of feedstock.

The cost-competitiveness of the A1 archetype, due to low feedstock and transportation costs, helps to explain why most operational commercial projects fall under this archetype.

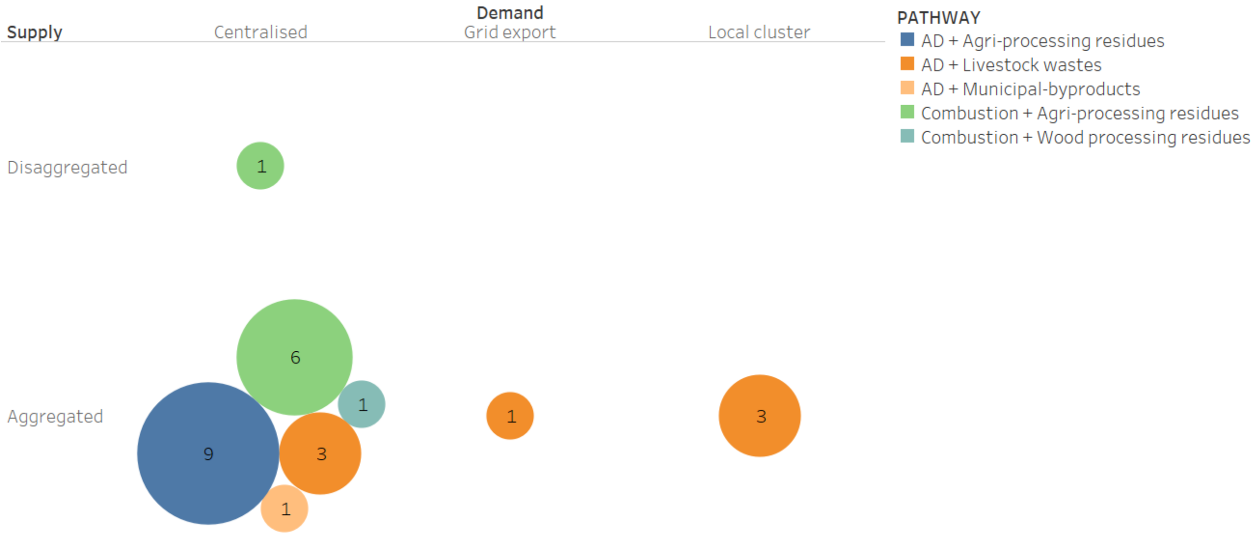
It is also worth mentioning the relative attractiveness for commercial businesses and investors of heat-based applications versus those whose customers demand electricity. In the countries considered (indeed in most countries), no licence is required to produce heat, as it is for electricity, and there is no set price for heat, even when sold to another entity. In most of the BSEAA2 target countries, the lack of incentives (e.g. subsidies, government finance, feed-in-tariffs), plus the number of entities engaged in the generation and sale of electricity (ministries, regulators, local governments, etc.) does not encourage investors whose core business is not the generation of bioenergy, to invest in bio-electricity. The lack of regulation and licensing for heat-only applications of bioenergy shows why so many investors in bioenergy stick with this option and are discouraged from engaging in power or CHP supply.

Having said this, some investment has gone into other archetypes, such as the D1 and the A3 models. This suggests that hybridisation of archetypes could potentially increase the likelihood of obtaining finance. The suggestion for Stage 3 is therefore to shortlist pathways that are largely based on the A1 archetype, while looking also at what may attract investors to these other archetypes.

5.3.4 Summary

The categorisation of the known bioenergy projects into supply chain archetypes helps to focus on the issues that affect investment in different business structures. As Figure 29 shows, of all the projects identified for bioenergy generation by AD or combustion, the overwhelming majority fit into archetype A1. This is for good reason. As discussed in this section, when a business produces or controls its own biomass production and supply, it is in a very strong position, with low (or negative) acquisition costs, and no or low aggregation costs, and a long term, secure supply of feedstock.

Figure 29 Status of identified operational projects by bioenergy supply chain archetype



Sum of Number of Records broken down by Demand vs. Supply. Colour shows details about PATHWAY. Size shows sum of Number of Records. The marks are labelled by sum of Number of Records. The data is filtered on PATHWAY #, Total power rating and Status. The PATHWAY # filter has multiple members selected. The Total power rating filter has multiple members selected. The Status filter keeps Operational.

AD and combustion projects based on agro-processing residues, generating energy primarily for self-consumption, account for 80% of all operational projects identified. Over 60% of all agriculture processing projects (AD and combustion-based) fit within the A1 archetype. Again, having control of feedstock supply and generating the energy necessary to process that feedstock has been the most successful business approach.

Going beyond bioenergy self-use to selling energy is a powerful economic incentive for a business. However, it makes sense only when the enabling environment for exporting electricity to the grid (or the sale of electricity via wheeling agreements) is supported by a political, regulatory and financial framework that makes it easy to capture the extra value from such sales. There are limited examples of this model but exploring these examples during Stage 3 will provide insights into how barriers to replication could be overcome.

5.4 Theme 4: Economic viability and barrier analysis

5.4.1 Aim

The objective of this theme is to determine the most promising biomass conversion technologies and associated pathways based on their economic viability,

5.4.2 Approach

Economic viability was considered against five criteria:

1. **Accuracy and availability of cost estimations:** A cost benchmark 'language' was developed to establish a set of terms for bioenergy pathway comparison. This included defining the main contributors to Life Cycle Cost (LCC), i.e. CAPEX (capital expenditure), OPEX (operational expenditure) and revenue streams. Taking advantage of the Projects Grid, non-operational projects were filtered out, on the basis that operational projects will provide more reliable and accurate data.
2. **Cost reduction potential:**
   a) **Pre-evaluation of energy costs by pathway:** A qualitative assessment of energy costs was conducted to identify the key cost categories in each pathway, and to characterise the economic incentives and barriers within each supply chain archetype.
   b) **Confirmation of current energy costs:** Electricity tariffs and heat supply costs were established for each target country, to estimate the economic incentives that would be necessary to stimulate investment in self-generated[41] supply of energy from biomass. Data was gathered jointly with the Theme 5 team, complemented by references from national energy statistics (e.g. annual reports from national energy agencies, energy suppliers or energy regulators), multilateral development projects and local rural energy/electricity agencies.
   c) **Estimation of cost reduction potential**: Project data was not uniformly available across the pathways in sufficient detail to inform a quantified discussion of specific costs and cost-reduction opportunities for bioenergy projects during this stage. The cost categorisation will form the basis for modelling and quantifying the LCC and LCOE (Levelized Cost of Energy) for the specific pathways during Stage 3.
3. **Subsidy availability:** The availability of national subsidies, as an incentive to enable or improve project economic performance, was determined for each of the target countries. Subsides to CAPEX and subsidies from regulated support schemes (e.g. negotiated PPAs with set floor prices for 5-20 years, as in South Africa's REIPPPP) were also examined. Regional and international grant schemes that support bioenergy projects were assessed. The functionality of subsidy schemes was also assessed, given that several are not operational (e.g. in Nigeria, Ghana and Uganda). The potential impact of subsidy and support schemes and their potential impact on the various bioenergy pathways was evaluated.
4. **Intangible socio-economic benefits:** The following intangible socio-economic costs and benefits (i.e. externalities) on bioenergy pathways were assessed at macro level:
   a) GHG emission reduction.
   b) Improved land and forest management; and
   c) Income inequality reduction potential.

   National benefits tend to be higher from bioenergy activities than from other renewable energy sources. These benefits accrue especially from biomass feedstock supply and transformation. Both tend to take place in rural areas, where they bring a range of socio-economic benefits including adding providing new employment for farmers and plant workers, diversifying economies and incomes, promoting sustainable agriculture practices, bringing infrastructure improvements (e.g. roads, electricity supply, improved water supplies) and stimulating spin-off investments in commercial and social enterprises, among others.

[41] 'Self-generation' is defined as heat or power generated on-site by an energy user.

Bioenergy is a natural spin-off of certain key agricultural sectors in each of the ten target countries, from cocoa and palm oil in Ghana; to horticulture, sugar, livestock, fruits, wood industries (including pulp and paper) in South Africa; to tea, coffee, horticulture, floriculture and fruits in Kenya; to tea and coffee in Rwanda; to sugar and (increasingly) tea in Mozambique; to coffee, horticulture and floriculture in Ethiopia; to tea, sisal, wood, coffee and cashews in Tanzania; to palm oil and cotton in Nigeria; to coffee, tea and wood in Uganda; to wood and sugar in Zambia. Each of these feedstocks have spawned bioenergy investments in these countries.

Bioenergy helps support those pathways and supply chains, thereby stimulating rural agriculture, livestock and sustainable forestry economies, with positive effects on primary production and employment and income in the industries themselves. This will be explored further in Stage 3.

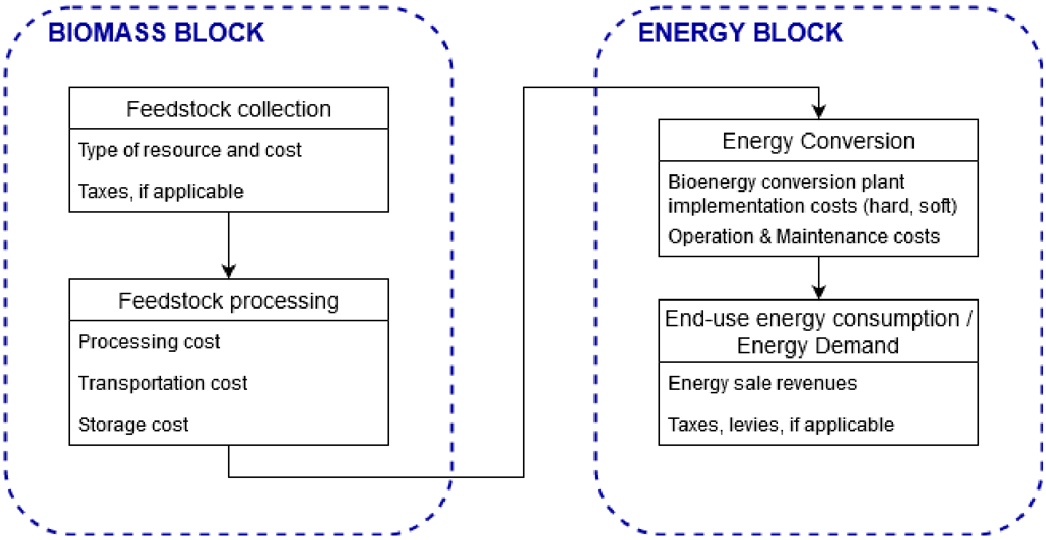
5. **Revenue stream predictability:** Revenue streams are critical to the economic performance of bioenergy pathways. Revenue stream guarantees were investigated as they can incentivise investment and guarantee early stage revenues. These may include feed-in-tariffs (FITs)[42] and PPAs with medium- to long-term guaranteed purchase price agreements, among others. Country risk assessments were carried out, closely linked to areas covered by Theme 5 such as institutional capacity and risk, access to public and private finance, ability to utilise PPAs (e.g. for bank guarantees), ability to access foreign exchange and repatriate earnings, transparency of granting licences, and accessibility of subsidies, among others.

5.4.3 Key findings

Criterion 1: Accuracy and availability of cost estimations

Development of a cost benchmark language for bioenergy projects analysis
The identification of the costs in a bioenergy project is structured according to the typical steps in a bioenergy pathway. A generic pathway has been broken down into a 'biomass block' and an 'energy block', with two steps under each block: Feedstock Collection plus Feedstock Processing under the Biomass Block, and Energy Conversion plus End-use Energy Demand under the Energy Block, as shown in Figure 30. CAPEX and OPEX are found in each step. These costs might be, in turn, broken down into **"Hard" costs** and **"Soft" costs**, as detailed in Annex 6.

Figure 30 Bioenergy pathway generic steps for costing language definition



The overall goal of the cost analysis is to model the headline economic metrics - LCC and LCOE - for the bioenergy pathways. LCC of a venture is derived from CAPEX and OPEX as follows:

[42] Feed-in-Tariffs are special electricity tariffs paid to suppliers who feed in electricity (usually renewable electricity) to a grid/network. They are paid ex post facto on the actual amount (kWh) of electricity covered by the FiT that is generated and supplied to the grid. FiTs are designed to stimulate investment and generation by renewable electricity suppliers.

$$LCC\ [\$] = CAPEX\left[\frac{\$}{kW}\right]\cdot P_n\ [kW] + \sum_i \frac{\left(OPEX\left[\frac{\$}{kWh}\right]\cdot E_{prod}\left[\frac{kWh}{year}\right] + OPEX\left[\frac{\$}{year}\right]\right)\cdot years}{(1+DR)^i} \quad (1)$$

Figure 31 illustrates a simplified framework for determining bioenergy pathway costs. The Inputs and Outputs of this model are laid out in Figure 32. Details on the cost categories and reference units are provided in Annex 6.

Figure 31 Relevant pathway costs

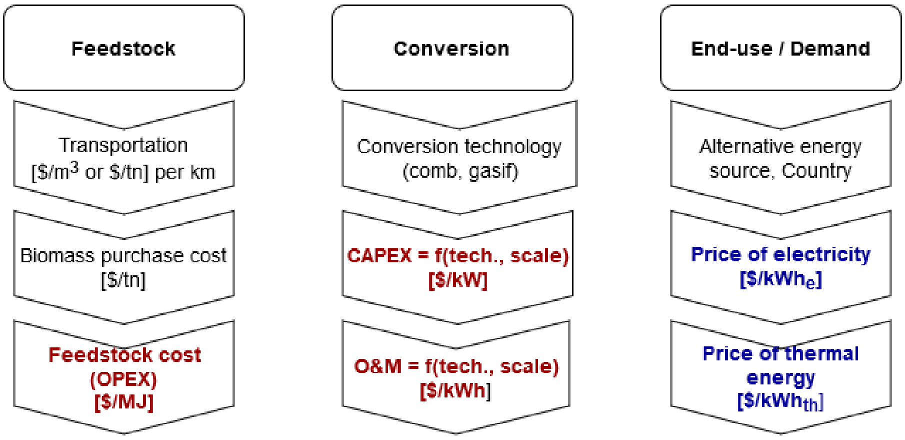
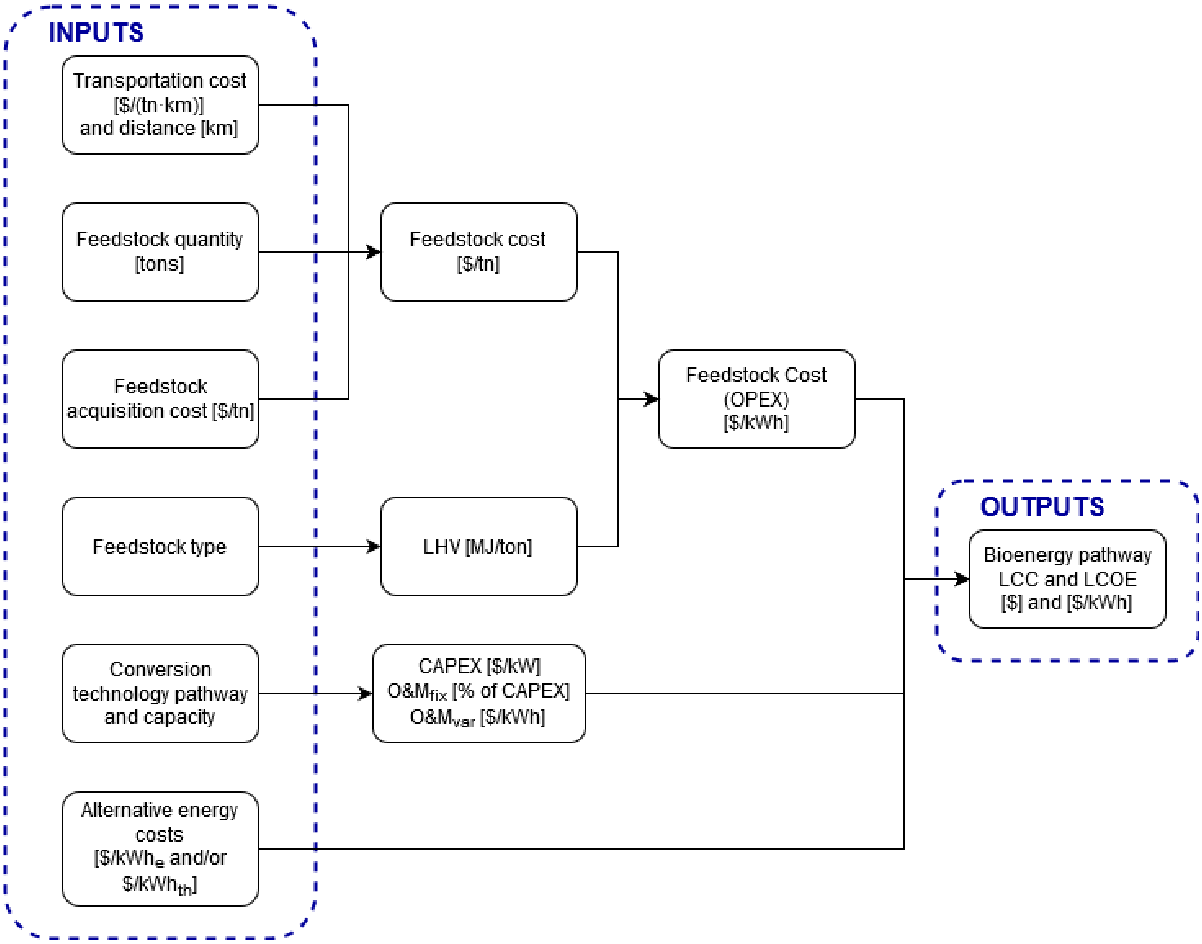


Figure 32 Summary of bioenergy pathway cost modelling



Availability of cost references
The larger the sample of operational projects, the higher the accuracy of data that can be gathered for pathway analysis and the more reliable is any analysis of 'success factors' for commercial viability. As highlighted in pre-screening, bioenergy pathways based on agro-processing residues (AD and combustion), livestock wastes (AD), forest and plantation wood (combustion) and wood processing residues (combustion) contain projects that are commercial and operational and lie within the BSEAA2 scale and scope range. These will form the basis for sourcing economic and financial data.

Criterion 2: Pathway cost reduction potential

Pre-evaluation of energy costs
Having developed a costing language to identify the necessary inputs to the LCC modelling, the team explored the available energy cost references to be used for these inputs. Benchmark costs were gathered where possible as reference values, to be fine-tuned during Stage 3. These are presented in more detail in Annex 7.

Generic cost references were applied for conversion technologies (IRENA, 2012) (Table 7).[43] As indicated, combustion-based plants have CAPEX values the range 1,800 to 4,200 US dollars ($) per kW for power generation only, and from $3,800 to 7,000 per kW in case of heat use (CHP), which are similar to those of AD-based plants, which are in the range $2,700 - 6,400 /kW.

Table 7 Conversion technology costs

Conversion technology	CAPEX ($/kW)	O&M variable cost ($/MWh)	O&M fixed cost (% of CAPEX)
Combustion + CHP	3,800 – 7,000	3.8 – 4.7	3.2 – 4.2
Combustion + steam turbine	1,800 – 4,200	3.8 – 4.7	3.2 – 4.2
AD + reciprocating engine	2,700 – 6,400	4.2	2.1 – 3.2

Source: (IRENA 2012)

In estimating the remaining contributors to OPEX, the following rules were applied:

- For the disaggregated supply chain archetypes (D1, D2 and D3), the cost of the Biomass Block is the cost of feedstock purchase and transportation, expressed in $/t or $/m^3 per distance (km).
- For the on-site bioenergy feedstock supply chain archetypes (A1, A2 and A3), the cost of biomass acquisition and transportation is assumed to be negligible.

$$Feedstock\ cost\ \left[\frac{\$}{MJ}\right] = \left(Resource\ cost\ \left[\frac{\$}{ton}\right] + Transport\ cost\ \left[\frac{\$}{ton}\right]\right) / LHV\ \left[\frac{MJ}{ton}\right] \qquad (2)$$

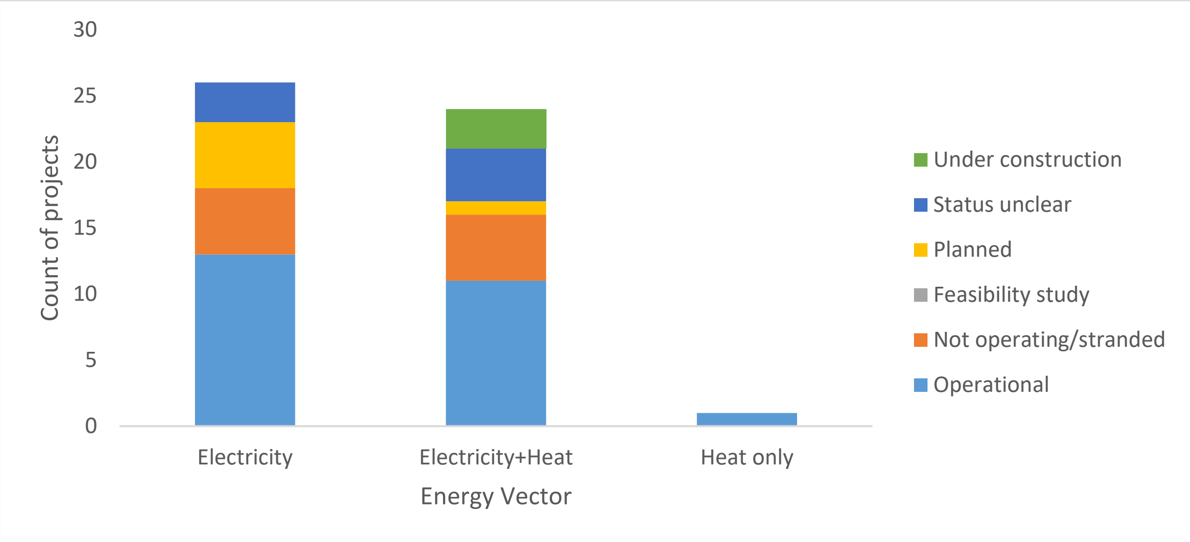
Current energy costs in target countries
Baseline electricity prices (consumer tariffs) were sourced from national electricity companies and energy/electricity regulators (see Annex 8 for details). Some have very inexpensive electricity, such as Ethiopia, Zambia, Mozambique and Nigeria (with tariffs between 2 and 8 US cents (¢) per kWh), and there is minimal financial incentive for switching from grid supply to bioenergy-based power self-supply, at least where grid electricity is available (which it may not be in many bioenergy production areas). On the other hand, in countries with relatively high grid electricity prices, such as Ghana, Kenya, Rwanda and Tanzania (ranging from 11 to 13 ¢/kWh), electricity from bioenergy is more likely to be a viable alternative.

The provision of heating or cooling services is an interesting case for economic viability, since neither is licensed or regulated in the target countries. Knowing that one of the key factors for economic viability of a bioenergy project is the exploitation of heat energy, it is worth analysing the success or

[43] Finance for fixed and variable costs originates from different sources, as discussed in Theme 3, Finance. However, where possible, the team obtained data on CAPEX for each project. These included own capital, local finance from commercial, and in most part, government funds (for the energy components of projects) from Renewable Energy Funds, local and international development finance (local agriculture and other development finance banks), African Development Bank, IFC, World Bank and other development partner or donor funds.

failure of projects in the Projects Grid against this criterion. The results from this analysis of operational status of projects (within the scale range of 10 kW_e to 5 MW_e) for each primary energy vector are illustrated in Figure 33.

Figure 33 Projects classified by status and primary energy vector



The data show that around half of the non-operational projects (6 out of 13) were set up to produce electricity only.[44] Among the operational projects, 42% (15 out of 37) produce both electricity and heat, rising to 64% (23 out of 37) if heat-only projects are added. Projects supplying only electricity represent one third of the identified operational projects.

These data show a prevalence of heat use within the operational projects. This is probably because biomass conversion efficiency more than doubles when using the heat output, as compared with electricity-only generation.[45] Furthermore, and perhaps more compelling from an economic and financial analytical point of view, heat is essential to most of these projects' core production processes. Furthermore, electricity generation for self-consumption is not licensed or regulated, nor is the production and consumption of heat.

It is thus not surprising that most CHP projects do not export electricity. This stems not only from the administrative and licensing requirements for electricity sales, but, also because the prices that companies can obtain in most of the target SSA countries are too low to make it worth the investment in the necessary electricity grid export infrastructure, or, administratively, taking on additional regulatory, reporting and licensing tasks that are above and beyond those required for own consumption. Even in Ghana, where grid electricity prices are higher than several the other target countries, the purchase price offered for electricity to the grid does not warrant such investments.[46]

While the benefits of CHP are evident, recovering the process heat usually adds significant cost and a robust cost-benefit analysis will be necessary to determine its commercial viability and replicability potential within the targeted pathways for Stage 3.

Estimation of cost reduction potential

A qualitative assessment LCOE references was undertaken, in order to breakdown LCOE categories and identify cost categories with higher impact in terms of cost reduction. LCOE ranges for biomass-fired power generation technologies are summarised in Table 8.

[44] This does not mean that generating electricity was the only or primary purpose of the projects highlighted. Electricity was cited in the information obtained, but there could have been other intended outputs or benefits (e.g. agro-processing).
[45] This assumes that the load factor is high enough to drive the investment in CHP.
[46] See section 5.5.4, below. Note also that Ghana does not currently offer any subsidies or FiTs for bioenergy.

Table 8 LCOE ranges for biomass-fired power generation technologies

Technology	LCOE range ($/kWh)	Cost structure ($/kWh)
Stoker CHP (5 MW)	$0.12 including heat revenue	$0.08 CAPEX $0.03 OPEX $0.05 feedstock -$0.04 heat revenue
Landfill gas (5 MW)	$0.11	$0.04 CAPEX $0.05 OPEX $0.02 feedstock cost
Digestor (1 MW)	$0.08 – 0.17	$0.06 – 0.11 CAPEX $0.02 – 0.03 OPEX $0.01 – 0.05 feedstock cost

Source: (Biomass for Power Generation, 2012). Values are well aligned with other academic literature findings (Lamidi et al., 2019, Amirante et al., 2019, Dhital, 2018, Borineth, 2019). Details in Annex 7.

The data support the following conclusions:

- For combustion-based pathways, CAPEX represents about 50% of LCOE, OPEX accounts for 18.75% and feedstock represents 31.25%.
- For AD pathways, CAPEX represents 36 to 75% of LCOE, OPEX accounts for 20% to 45% and feedstock represents 10% to 18%.

Summing up, **Biomass Block costs** (feedstock acquisition, transportation and pre-treatment) account for around one third of LCOE for combustion-based pathways and range from 10 to 20% for AD pathways %. **Energy Block costs** (conversion technology CAPEX and OPEX) account for the remaining two thirds of LCOE for combustion-based pathways and up to 80% for AD pathways. For both combustion and AD, conversion technology CAPEX constitutes more than 50% of LCOE.

However, Biomass Block costs might be negligible for business model archetypes A1, A2, A3, i.e. those relying on aggregated feedstock supply. In these cases, conversion technology CAPEX may account for around 70% of LCOE in combustion pathways, rising to 80% for AD-based pathways.

Available literature indicates that conversion technology CAPEX is the cost category with highest impact on overall LCOE because (for example):

- Conversion technologies are usually imported, as their manufacturers are transnational companies from Europe, Asia and North America;
- Project development and engineering sometimes require international consultancy and advice, which add to investment costs; and,
- Power generation plants often require significant civil works plus, in case of electricity export to the distribution grid, power electronics and transformer substation equipment.

For disaggregated supply (‘D’-type) business models, feedstock costs represent significant costs to an enterprise. This involves feedstock aggregation and transport costs, which the centralised feedstock archetypes are not exposed to. Additionally, feedstock pre-treatment costs are generally higher in the companies supplied from decentralised sources, often requiring densification (e.g. chipping or pelleting) to reduce handling and haulage costs. Cost reduction opportunities exist when feedstock supplies can be centralised and when supply chains are simplified by either own-production, or by tying in feedstock suppliers to long-term contracts.

While an in-depth quantitative assessment of cost reduction potential was not possible owing to restriction and reliability of quantitative data that could be gathered at this stage, an assessment of some of the key economic incentives and barriers that can influence the success of bioenergy deployment is presented in Table 9. The pathway selection stemming from Stage 2 will direct further investigation into project-specific costs to inform LCOE and LCC analysis in Stage 3.

Table 9 Summary of economic enabling and limiting factors by supply chain archetype

		Primary energy demand					
		Centralised		Grid export		Local cluster	
Primary feedstock supply	Disaggregated	**D1: Enabling** - High grid electricity tariffs and/or high fuel prices - Unreliability of grid supply - Avoidance of contracts for energy sale	**D1: Limiting** - Greater complexity of supply chain - Costs of feedstock acquisition and transportation - Possible energy surpluses without economic return	**D2: Enabling** - Possibility of stable revenue streams through PPA - Possibility of higher revenue streams with FIT - Easy to combine with self-consumption (centralised demand)	**D2: Limiting** - See D1 - Difficulty in enforcing PPAs or FITs in some countries - Costs of grid export, transformers, MV/HV protection and safety equipment	**D3: Enabling** Eligibility for rural energy funds / grants / subsidies	**D3: Limiting** - See D1 - Potential costs related to off-grid distribution infrastructure (mini-grid) construction and operation - Potential costs related to off-grid electricity service provision: administration/ management, operation and maintenance
	Aggregated	**A1: Enabling** - Low (near-zero) feedstock aggregation costs - High electricity tariffs and/or high fuel prices	**A1: Limiting** - Possible energy surpluses without economic return	**A2: Enabling** - See A1 - feedstock - Possibility of stable revenue streams through PPA - Possibility of higher revenue streams with FITs - Easy to combine with self-consumption (centralised demand)	**A2: Limiting** - Difficulty in enforcing PPAs or FITs in some countries - Costs of grid export, transformers, MV/HV protection and safety equipment	**A3: Enabling** - See A1 - Possible eligibility for rural energy funds / grants / subsidies	**A3: Limiting** - Potential costs related to off-grid distribution infrastructure (mini-grid) construction and operation - Potential costs related to off-grid electricity service provision: administration/ management, operation and maintenance

From an economic standpoint, those supply chain models with heat use and electricity export have performed best. Whether they will continue to do so in the future will depend upon factors such as government energy, agriculture and other economic policies, and international markets (given the high proportion of projects that are in export-oriented sectors). There are additional success factors to be considered, such as having an on-site feedstock supply, that dramatically reduces the OPEX.

Criterion 3: Subsidy availability assessment

The investigation of country subsidy programmes revealed that most **subsidies to CAPEX** come from Rural Energy or Rural Electrification Funds (REFs) managed by Rural Energy/Electrification Agencies (REAs) or similar. Such funds are, or have been, active in Ghana, Zambia, Mozambique, Tanzania, Rwanda, Uganda and Kenya.[47]

Bioenergy was supported, until recently, by these REFs (finance) and REAs (technical assistance) in Uganda and Ghana (see Theme 5 below). However, both countries have ceased almost all financial support to renewable energy, and to bioenergy. Today, Kenya, Tanzania, Rwanda and Zambia support renewables through their REAs and REFs. However, Zambia does not support bioenergy at the required scale for BSEAA2 and Rwanda has only a small facility for such support.

Nigeria's REF has never been operationalised, while Mozambique's FUNAE (equivalent to a REA/REF) does not include bioenergy electricity in its framework. Ethiopia's REF equivalent has never been operationalised. South Africa supports renewable electricity through the REIPPPP, although bioenergy electricity procurement is focused almost entirely on wind and solar. Only a fraction (less than 5%) of electricity contracted through the REIPPPP from bioenergy projects (almost all from bagasse-generated electricity at a production scale outside this project's framework). As noted elsewhere in this report, bioenergy has therefore received very little assistance from the REAs or their REFs, or indeed from any other government programmes, and very little from international development partners.

Most bioenergy self-consumption projects (i.e., not supplying electricity to communities, mini-grids or national grids) have been excluded from receiving equity funding for CAPEX from REFs (or equivalent) because most REAs/REFs are focused on rural electrification. In those countries with high rural electrification rates (e.g. Ghana), subsidies to CAPEX are difficult for bioenergy project developers to access.

In countries with lower rates of rural electrification (e.g. Zambia, Ethiopia, Nigeria and Mozambique), these subsidy schemes receive almost no support, with the overwhelming majority of funds going to solar PV, small hydropower (including micro- and mini-hydropower), wind and geothermal, at a scale larger than 10 kW. Below that, household biogas, cooking fuels (e.g., briquettes and pellets) and improved cookstoves (ICS) receive the bulk of any bioenergy financial and technical support, both national and international (donors, development banks and finance projects, NGOs and investors).

Some countries have already achieved their renewable electricity targets (e.g. over 90% of Uganda's grid electricity is now renewable) so their REFs are no longer allocating funds for investment in renewable energy for electricity. In Tanzania, Zambia and Rwanda, governments and development partners are focusing on grid extension rural electrification, rather than stand-alone, off-grid or mini-grid renewable projects, whether bioenergy or not. Bioenergy is not included in grid electrification in Zambia and Rwanda and has been scaled down considerably in Tanzania. Only South Africa and Kenya are supporting bioenergy grid electrification, while Tanzania is not. In fact, in Tanzania and Zambia grid extension is making existing renewable electricity projects, mini-hydropower, small solar PV mini-grid and bioenergy projects, uneconomical. Effectively, when the grid arrives' most mini-grid generation, and oftentimes the actual mini-grid infrastructure itself, becomes a stranded asset.[48]

Dozens of projects funded by Tanzania's REF have stopped operations because the grid has reached the locations they serve, essentially putting them out of business (given that grid electricity is invariably cheaper than stand-alone renewable electricity). Further, in many cases, particularly when stand-alone rural renewable electricity projects are operational when the grid 'arrives', regulators insist

[47] Nigeria's REF was set up in 2009 but has never been capitalised. A separate fund for rural solar PV mini-grids is operational, but bioenergy projects do not qualify.
[48] "What happens when the main grid arrives is a major concern for mini-grid developers. Investors face two risks: The first is that their assets will be stranded. This can occur when the main grid builds over the mini-grid, pulling customers to the cheaper or better service that the main grid offers. The second risk is expropriation of assets, which occurs if the utility or the government takes over the mini-grid assets without adequate compensation." See: World Bank, LiveWire, "Investing in Mini Grids Now, Integrating with the Main Grid Later: A Menu of Good Policy and Regulatory Options" – 2019/97. http://documents.worldbank.org/curated/en/732841558714625815/pdf/Investing-in-Mini-Grids-Now-Integrating-with-the-Main-Grid-Later-A-Menu-of-Good-Policy-and-Regulatory-Option.pdf

they cease independent operations, either by being absorbed by the grid, getting compensation for ceasing operations, or simply having their licences rescinded.

The only **subsidies to revenue streams** are the electricity feed-in tariffs sometimes complemented with PPAs (as in Tanzania and Kenya). Both FITs and PPAs are under the framework of the national electricity regulators. These incentives are therefore often only available for projects with electricity export to national, regional or local grids (as in South Africa, Tanzania, Kenya and Zambia).

Subsidy availability by country and by supply chain archetype is summarised in Figure 34. Details are in Annex 9.

Figure 34 Subsidy schemes by country and supply chain archetype

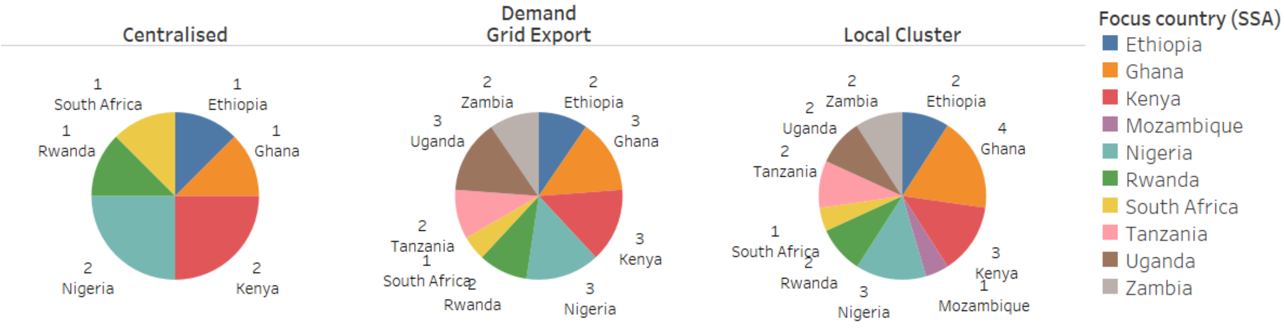


Figure 34 shows that business models based on centralised energy demand or self-consumption can benefit from fewer subsidy schemes than those involving grid export or export to a local cluster. There are several donor-funded projects for non-electricity renewable energy, but they are almost exclusively focused on small-scale, household-level, small-institutional level support. Most additional CAPEX subsidies centre on extending rural electricity access.

An assessment of the Projects Grid and consultations with national experts in the study team, indicates that in countries with conducive regulatory environments (such as Kenya, Tanzania and South Africa), some self-supply project operators are considering scaling up to export power to the national grid. In such cases, the identified subsidies could act as an enabling instrument to complement the core business model, deliver additional revenues and bankability.

While rarely eligible for subsidy, generating electricity for own use falls under little regulation (and heat generation falls under almost no regulation), while selling electricity to the public or to a grid immediately brings the company into an entirely new regulatory framework that can involve multiple agencies and require multiple strands of compliance. Final pathway prioritisation will aim to identify pathways and sub-pathways that demonstrate such a potential, while cognisant of the bureaucratic and commercial risks.

Criterion 4: Intangible socio-economic benefits (externalities)

Successful bioenergy projects provide various socio-economic benefits that should be examined as part of an economic analysis as important ‘externalities. They include GHG emissions reduction, sustainability improvements in agriculture and forest management, and benefits for socio-economic equality.

GHG emissions reductions

Climate change is a major global concern and its effects on national and global economics are enormous. As set out in every United Nations Inter-Governmental Panel on Climate Change (UNIPCC) assessment report, energy is the largest source of global GHG emissions. Within the energy sector, electricity generation is the largest contributor. One of the many positive external benefits of bioenergy is its contribution to GHG emissions reduction.

Table 10 summarises the electricity supply mix by country to indicate the degree of reliance on fossil fuel sources.

Table 10 **Fossil fuel dependency of national power sectors in the ten SSA target countries**

Country	Main electricity source	Grid power production mix (IRENA 2018)	GHG intensity of national electricity mix (1=lowest)	% pon. with access to electricity[49]	Ranking of % pop. with access to electricity (1=highest)
Ethiopia	Hydro	86% hydro, 7% wind, <7% fossil fuels	1	44.3%	5
Ghana	Natural gas	50% NG, 43% hydro,7% oil	7	79%	2
Kenya	Geothermal	49% geothermal, 39% hydro, 2% biomass, <10% fossil fuels	3	63.8%	3
Mozambique	Hydro	83% hydro, 17% NG	5	27.4%	9
Nigeria	Natural gas	81% NG ,19% hydro	9	54.4%	4
Rwanda	Hydro	57% hydro, 3% solar, 40% fossil fuels	6	34.1%	7
South Africa	Coal	90% coal, 5% nuclear. 2% wind, 2% hydro, 1% other RE	10	84.4%	1
Tanzania	Natural gas	55% NG, 35% hydro, 2% biomass. 8% other fossil fuels	8	32.8%	8
Uganda	Hydro	81% hydro, 6% biomass, 13% other RE	2	22.0%	10
Zambia	Hydro	94% hydro, 5% oil, 1% coal	4	40.3%	6

Source: *IRENA, 2016*

Ethiopia generates more than 93% of its electricity from renewable energy, mainly large-scale hydropower. It has the lowest GHG intensity for electricity generation of the ten target countries. When considering access to electricity, however, it falls to fifth place. Similarly, Uganda ranks second in GHG intensity owing to a high contribution of renewables, but it has the lowest access to electricity. Kenya, which has the largest geothermal electricity capacity in Africa, a large hydropower sector and growing supplies of bioenergy electricity, ranks third.

South Africa, on the other hand, has the highest GHG emissions intensity for electricity but comes first in access to electricity, making enormous strides in increasing the absolute quantity of renewable electricity in its national mix. Nigeria, Africa's largest producer of petroleum and its second largest producer of natural gas, ranks second highest in GHG intensity in its electricity supply.

As discussed in more detail under Theme 5, the mix of electricity sources is not static. In fact, the past 20 years have seen more changes in the technology and mix of electricity generation than any other period since electrification began in SSA. Policy changes, with economic and technical support for new investment in renewable energy, have made a significant difference in each country's GHG emissions from electricity generation. In 2005, nearly 60% of Uganda's electricity was generated from petroleum fuels. In 2010, nearly 40% of Kenya's electricity was generated from fossil fuels.

South Africa now generates more renewable electricity than any of the ten target countries. In fact, it generates more renewable electricity than Kenya, Uganda, Rwanda, Tanzania and Ghana combined. It has gone from less than 300 MW of electricity from renewables in 2005 to over 4,600 MW today, out of a total of 51,500 MW of installed capacity.

Sustainable agriculture and improved forest management

[49] World Bank, "Access to electricity (% of population): 2017", data.worldbank.org/indicator/EG.ELC.ACCS.ZS

In and of itself, increased bioenergy production does not necessarily have a positive effect on land or land use quality. However, good practices in bioenergy production can have positive external effects on reducing land degradation, improving water quality and enhancing soil and water conservation. Experience with Payment for Environmental Services mechanisms has been mixed in forestry, land management and soil and water conservation in water catchment areas, improved land use practices in agricultural production, and improved livestock management, and can have 'unintended consequences. It can work, but there are some notable failures.

There is a clear role for government (local government, national regulators, forest departments and environmental agencies, among others) in establishing the necessary framework for improving agricultural and forest management practices, to reduce land degradation. Furthermore, businesses have their own interests in putting in place incentives to improve soil and water conservation, land and forest management to reduce degradation. This has been demonstrated through a number of Reduced Emissions from Deforestation and Degradation (REDD+) and other forestry (including agroforestry, community-based forestry, and similar approaches). All these approaches, if designed and implemented well, can result in improved soil and water quality, and reduced degradation. [50]

Improved forestry management, as set out under the UN Framework Convention on Climate Change's (UNFCCC) REDD+, has positive environmental, social and economic benefits. REDD+, including reduced soil and water degradation, focuses on fostering and increasing forest and land use conservation. REDD+ programmes are growing rapidly in Ethiopia, Ghana, Kenya, Nigeria, Uganda, Tanzania and Zambia, supporting increased sustainable management of forests, with enhancement of forest carbon stocks, and improvements in water and land management. Community-Based Forestry, which involves agro-forestry and improved agricultural production and forest management, is one of the key REDD+ approaches in SSA.

Based on the above discussions, Table 11 provides a qualitative assessment of the land-degradation mitigation potential associated with each of the identified bioenergy pathways.

Table 11 REDD+ as a land degradation mitigation action in bioenergy pathways

Technology	Bioenergy pathway	Land degradation mitigation	Ranking notes
AD	Agro-processing residues	Medium	Reduced land degradation should increase crop yields. Organic compost from AD increases soil fertility
	Crop harvesting residues	High	If crop harvesting residues for energy are collected in best practice manner, can reduce degradation. Organic compost from AD increases soil fertility
	Livestock wastes	Medium	Organic compost from AD increases soil fertility
	Municipal by-products	Medium	Stringent measures on waste management practices, open dumping etc can avoid damage to land, water and other natural ecosystems
	Purpose grown/novel feedstocks	Low - Medium	Degree to which reduces erosion and improves soil & water quality depends on type of feedstock. Organic compost from AD can increase soil fertility
Combustion	Forest and plantation wood	High	Sustainably grown forest can improve soil quality & reduced degradation
	Wood processing residues	High	If forests are managed properly, can help improve soil moisture & fertility
	Wood harvesting residues	High	If wood is harvested according to best practice, will reduce land degradation
	Material waste	None	
	Energy crops	Low-Medium	As with purpose-grown feedstocks, if energy crops are grown in a way to reduce erosion & improve soil & water quality

[50] Payments for Ecosystem Services and the Water-Energy-Food Nexus, Jean Carlo Rodríguez de Francisco, Nexus Brief no. 4/2016, *Deutsches Institute fuer Entwicklungspolitik*, www.die-gdi.de/uploads/media/Two-Pager_4.2016.pdf

	Agro-processing residues	Medium	Reduced land degradation should increase crop yields

Bioenergy and socio-economic inequality
Land distribution and ownership, access to income, availability of credit, access to education, access to roads and other infrastructure, access to electricity, access to health services, among others, affect socio-economic equality. The development of inclusive bioenergy pathways, particularly in the farming sector, can generate local income and improve livelihoods in rural or peri-urban areas. Pathways focused on the use of agri-residues lend themselves well to this objective. If this is done in a focused, systematic way, bioenergy development can contribute to alleviate inequality in each country.

Criterion 5: Revenue stream predictability
The main revenue stream guarantee measure is the PPA, in cases where electricity is generated for external purposes (such as grid export or wheeling to nearby consumers). PPAs that provide bioenergy projects with a premium power purchase price - such as under the South African REIPPPP - are particularly attractive to investors and have a major effect on stimulating investment. Bioenergy FITs are also strong stimulants for investment, particularly when they are provided on a long-term basis. The countries with existing PPA schemes to which bioenergy projects can apply are:

- Ghana, 10 years extendable on bi-annual basis. Associated with FIT.
- Kenya, 20 years. Associated with FIT.
- Nigeria, 20 years. Associated with FIT.
- South Africa, 20 years, guaranteed power purchase price as part of PPA (only if part of the REIPPP process).
- Tanzania, 20 years. Associated with FIT.
- Uganda, 15 years. Associated with FIT.
- Zambia, 3 years, extendable under revision of associated FIT.

In practice, however, Ghana's programme has not awarded any bioenergy PPAs or FITs for over five years. Nigeria has never set the money aside to pay for preferential PPAs or any FITs (except a special programme for off-grid solar PV electrification). Uganda achieved its renewable energy target in 2018 and has ceased awarding renewable electricity PPAs with FITs. Zambia does not include bioenergy in its FIT programme. From a financial incentive point of view, only South Africa, Kenya and Tanzania therefore provide financial incentives on revenue streams for bioenergy projects. Enabling regulation instruments are great policy assets, but from an economic point of view they can be a practical impediment if they are not effectively supported by financial and financing instruments and are relatively easy to access and to operate without significant transaction costs.[51]

It is then no surprise that a significant number of operational projects are aimed at generating heat, primarily for on-site self-consumption, and the largest number of grid-supply/export projects using CHP occur in South Africa, Kenya and Tanzania (although 'legacy projects' funded before these financial incentives were introduced can be found in Ghana and Uganda as well). The possibility of 'exporting' surplus heat to nearby consumption points could be an attractive economic prospect, if local industrial, institutional, commercial demand is close by (e.g. in an industrial park, export processing zone or cluster of industries).

In terms of country risk analysis, the following parameters are considered relevant to address the reliability of the economic and financial status of the ten SSA countries targeted by this project:

- **Per capita Gross Domestic Product, Purchasing Power Parity (GDP PPP)**: a metric to compare countries from an economic standpoint, adjusting GDP based on the cost of a standard basket of consumed goods.

- **Annual inflation rate** helps measure economy volatility.

[51] See Section 5.5, Theme 5, Key Findings, South Africa on the Renewable Electricity Power Independent Power Purchase Programme (REIPPPP) on small-scale bioenergy projects that qualify for a long-term guarantees power purchase price.

- **Paying taxes score:** a combined index from the World Bank's Ease of Doing Business (EoDB) classification that measures the ease of paying taxes from an administrative standpoint. A higher score therefore indicates higher EoDB.
- **Enforcing contracts score:** another combined index from the Ease of Doing Business classification that expresses the ease of enforcing a contract once signed and approved. A higher score therefore indicates higher EoDB.
- **Gini index:** a measure of inequality based primarily upon the distribution of national income. Higher values mean higher inequalities, tending to indicate greater risk of instability and security, which can affect investors' perceptions of the economic viability of projects.

These measures of national economic and financial reliability are summarised in Table 12.

Table 12 National economic and financial reliability (or stability) for selected metrics

Country	GDP PPP ($), 2018	Annual inflation rate (%), 2016-2018 average	Paying taxes score (DB* 2017-20)	Control over corruption[52] (10 = highest)	Enforcing contracts score (DB 2017-20)	Gini index (highest = greatest inequality)
Ethiopia	$2,022	8.6%	62.9	6	60.0	35.0
Ghana	$4,746	13.2%	66.5	8	54.0	43.5
Kenya	$3,467	6.3%	67.5	3	58.3	40.8
Mozambique	$1,459	N/A	61.8	4	39.8	54.0
Nigeria	$5,990	14.8%	53.0	1	57.6	43.0
Rwanda	$2,251	5.0%	84.2	**10**	**65.1**	43.7
South Africa	**$13,686**	5.4%	81.2	9	54.1	**63.0**
Tanzania	$3,227	4.7%	73.1	7	60.6	37.8
Uganda	$2,038	**4.5%**	**88.9**	2	51.7	42.8
Zambia	$4,223	10.6%	50.8	5	61.7	57.1

** DB = World Bank's 'Ease of Doing Business', whereby the higher the number, the easier it is to do business.*

The countries display varying levels of attractiveness for investors across the different indices. For instance, while South Africa has the highest GDP PPP and a relatively low inflation rate, it scores poorly on metrics such as the Gini Index. This warrants a qualitative discussion of each country, exploring the diverse market, institutional, financial and regulatory systems that are in place. This is explored in more detail in Theme 5.

5.4.4 Summary

Conclusions on economic viability can be drawn at three levels:

- From a **cost category perspective**, conversion technology CAPEX is the category with highest impact on overall LCOE; for disaggregated supply business models, feedstock costs are also important and represent a necessary target for cost reduction. Available references on LCOE show a breakdown of 31.3% feedstock, 50% CAPEX and 18.8% OPEX for combustion-based projects, and a range of 10-18% feedstock, 36-75% CAPEX and 20-45% OPEX for AD projects.
- From a **supply chain perspective**, results of data gathering from national experts and developers, reviews of policies, regulations and ease of doing business indexes show that the supply chain archetypes that include the use of heat – usually process heat – are more commercially viable. Supply chain archetypes are sensitive to subsidy availability and revenue stream predictability. In this regard, the key success factor is the existence of rural electrification projects (linked to subsidies from Rural Energy Funds) and / or the existence of electricity sales,

[52] World Governance Indicators (2009 to 2018), 2019, https://info.worldbank.org/governance/wgi/

usually linked to the existence of PPAs (particularly with guaranteed tariffs) or FIT schemes. The aggregated or 'on-site' supply of feedstock is another commercial success factor as it implies reduced or near-zero cost of feedstock aggregation and transport (and risks). Conversely, disaggregated supply requires the purchase and transportation of feedstock, increasing the cost of aggregation and the risk of volatility of feedstock price, without increasing energy production.

- From a **country perspective**, South Africa, Ghana and Kenya offer better economic prospects for commercial bioenergy project development than the other countries, mainly due to fewer regulatory impediments, better policy enabling and support schemes, higher conventional energy costs and higher bankability. Tanzania has relevant incentives in place and a relatively large number of operational bioenergy projects, but the regulatory and permitting environment has experienced numerous changes, which discourages project development in practice. A similar situation is found in Uganda. Zambia, despite having high GDP PPP, has higher inflation rates and low scoring in selected Ease of Doing Business categories, and its REF does not offer support for bioenergy, either on subsidies or on PPAs or FITs. The same applies to Nigeria, but in this case the GDP is significantly higher. Ethiopia and Mozambique have the least favourable economic viability prospects for bioenergy, mainly due to regulatory impediments for private sector led investments, low level of government support and low degree of market openness.

- As noted in the Externalities Sub-section (see Table 10), the combined GHG emissions from the generation of electricity have fallen significantly across the target countries over the past 15 years, due in great part to the rapid growth or renewable electricity generation. While bioenergy substitution for fossil fuels has contributed relatively little compared to other renewable energy resources, it has still made a significant contribution in Uganda, Tanzania and Kenya.

  This is one of the biggest and most positive externalities that bioenergy, though small in the mix, has helped improve. If more investment was made in bioenergy for electricity generation, this would not only reduce GHG emissions. Given the target SSA countries' significant agriculture and forest resources, the effect on employment and income generation, improved health, and other externalities would also be substantial.

  In terms of land-degradation mitigation, the identified bioenergy pathways can have medium to high impacts. Finally, the development of inclusive bioenergy pathways, particularly in the farming sector, can generate local income and improve livelihoods in rural and peri-urban areas, a key contribution to alleviating inequality in each country.

5.5 Theme 5: Institutional, Regulatory and Market Framework

5.5.1 Aim

The aim of Theme 5 is to provide up-to-date information on the institutional, regulatory and market framework for bioenergy[53] in the ten target BSEAA2 countries.

5.5.2 Approach

As set out in the Inception Report, ten country profiles were produced covering the following five criteria that are key to promoting investment in commercially viable bioenergy ventures:

- governance,
- regulatory environment,
- government bioenergy support,
- degree of market openness; and
- finance.

Theme 5 was designed to support the other themes. It has relevance for Theme 3 (Economics) and Theme 4 (Business Models), which require information on institutional frameworks, policies that affect bioenergy development, deployment and pricing, and the availability of, and access to, different forms of finance. The country profiles were therefore made accessible to the whole team and updated regularly through a detailed spreadsheet. Team members were encouraged to use the information therein for their own analyses, and to add new material where appropriate.

5.5.3 Key Findings

Criterion 1: Governance

Good governance is a critical factor for successful bioenergy project development. A key resource for gauging governance is the Worldwide Governance Indicators (WGI) Project (Kaufmann and Kraay 2019), which draws upon numerous data sources[54] to report aggregate and individual governance indicators for over 200 countries and territories, covering the following six measures of governance:

- Voice and accountability.
- Political stability and absence of violence.
- Government effectiveness.
- Regulatory quality.
- Rule of law; and
- Control of corruption.

Table 13 summarises the weighted aggregate WGI scores across these six criteria for the BSEAA2 countries for the 10-year period from 2009 to 2018. Descriptions show the trends on each topical area (i.e. Voice & accountability, etc.) from the beginning to the end of the ten consecutive years covered.

[53] In accordance with the definition in the BSEAA2 project Terms of Reference, as clarified in the Inception Report, 'bioenergy' in this context refers to projects between 10 kWe and 5 MWe in scale. Liquid biofuels are not considered, because the Terms of Reference and the Inception report specify technology categories to which liquid fuels do not apply. Bioenergy technologies must be at TRL5+ to be shortlisted for consideration for Stage 3 'bottom-up' evaluation. For priority bioenergy pathways and sub-pathways, projects should also use biomass feedstocks that fit the FAO/IEA definitions of bioenergy from the 2017 'How2Guide for Bioenergy: Roadmap Development and Implementation'. Finally, projects considered for Stage 3 must be operational and commercial.
[54] Including the Afrobarometer surveys, Gallup World Poll, Global Competitiveness Report survey, The Economist Intelligence Unit, Global Insight, Political Risk Services, Global Integrity, Freedom House, Reporters Without Borders, CPIA assessments of World Bank, African Development Bank (AfDB), and regional development banks, including the East African Development Bank, West African Development Bank, the EBRD Transition Report, French Ministry of Finance Institutional Profiles database. The full listing of WGI sources can be found here: (https://info.worldbank.org/governance/wgi/Home/Documents)

Table 13 - Governance scores using World Governance Indicators (2009 to 2018)

Governance indicator	Ethiopia	Ghana	Kenya	Mozambique	Nigeria	Rwanda	South Africa	Tanzania	Uganda	Zambia
Voice & accountability	16%	68%	35%	33%	34%	17%	70%	34%	29%	36%
Political stability & absence of violence/ terrorism	10%	47%	12%	19%	4%	53%	36%	26%	21%	53%
Government effectiveness	29%	46%	39%	18%	15%	62%	66%	21%	30%	33%
Regulatory quality	14%	50%	44%	24%	17%	59%	62%	29%	42%	35%
Rule of law	37%	57%	38%	14%	18%	58%	51%	31%	43%	41%
Control of corruption	38%	53%	19%	24%	13%	71%	57%	39%	14%	28%
Average governance score (%)	***24%***	***53%***	***31%***	***22%***	***17%***	***53%***	***57%***	***30%***	***30%***	***38%***
Index score*	2	3	2	2	1	3	3	2	2	2

Source: (Kaufmann and Kraay 2019)
** - Index Score: 1 to 4, 1 being worst governance and 4 being best governance*

Ghana, Rwanda and South Africa rank highest in overall governance among the ten target countries, while Nigeria ranks lowest. Governance is not the only factor that determines how an investor chooses where to invest, although it is an important consideration.

Between 2009 and 2018, the WGI data reveal the following trends in governance indicators:

- **Ethiopia:** Voice and accountability were very low and stayed about the same from 2009 to 2018. The same applies to stability. Rule of law has improved, as has control of corruption. Regulatory quality has declined over the ten years covered.
- **Ghana:** Voice and accountability are high. All indicators remained relatively constant.
- **Kenya:** Voice and accountability remained relatively high, though political stability stayed very low. Rule of law and regulatory quality improved substantially, while control of corruption changed little.
- **Mozambique:** Voice and accountability started relatively high and dropped during the period covered, as did political stability. Violence declined. Government effectiveness deteriorated, as did regulatory quality. Rule of law and control of corruption fell sharply.
- **Nigeria:** Voice and accountability slowly increased, while political stability and absence of violence remained low. Government effectiveness remained low, as did regulatory quality. Rule of law improved slightly, while control of corruption stayed at the same low level.
- **Rwanda:** Voice and accountability remained much the same (low), while political stability improved significantly over the period. Government effectiveness increased steadily, as did regulatory quality, rule of law and - most of all - control of corruption.
- **South Africa:** Voice and accountability remained relatively high, while political stability improved slightly over the period. Government effectiveness and regulatory quality stayed at high levels, as did rule of law, while control of corruption stayed the same.
- **Tanzania:** Voice and accountability fell over the period, while political stability dropped. Government effectiveness and regulatory quality remained relatively low, as did rule of law and control of corruption.
- **Uganda:** Voice and accountability stayed relatively low, as did government effectiveness. Regulatory quality improved, while rule of law was stable. Control of corruption stayed low.
- **Zambia:** Voice and accountability remained high, while political stability stayed at a medium level. Government effectiveness and rule of law were relatively low. Control of corruption was moderate.

Criterion 2: Regulatory environment

Energy regulations: It is clear from a review of the regulatory environment that most of the target country governments, as well as development finance agencies, multilateral and bilateral donors, and NGOs, do not view bioenergy as an important area of focus, certainly compared to other renewable energy options. Household bioenergy (especially improved cookstoves and small-scale biogas) and transport biofuels receive far more regulatory attention, policy support and finance than the type and scale of bioenergy opportunities on which the BSEAA2 project is focussed.

Even though most bioenergy projects in the target countries are for heat-only applications, there are very few heat-only bioenergy regulations in place, other than some covering health and safety. If there is CHP, regulators focus on the electricity side of energy generation, not the heat. When a commercial firm generates and sells electricity, it comes under regulation by at least one, and sometimes a number, of ministries, agencies, licensing bodies and other authorities.

Table 14 sets out the primary energy regulators in each country using the World Bank's aggregated Regulatory Indicators for Sustainable Energy (RISE), together with information from the regulatory authorities and line agencies themselves.[55] Annex 10 summarises the regulatory frameworks in each of the target countries for forest waste, forestry, water and waste management, land use and soil and water conservation, and Annex 11 summarises the main agricultural support groups and associations that exist in each of the target countries

Other relevant non-energy regulatory regimes: Overall, agricultural waste, forestry waste and residues, MSW, sewage waste, animal waste and animal industry wastes, industrial wastes, water management, and soil and water conservation and management are poorly regulated in most of the target countries. South Africa, Africa's most industrialised and most developed economy, has far more extensive laws, regulations and government organisations (including strong provincial and municipal governments) that manage wastes, residues, water and land use very stringently. Waste separation is not mandated at a national level in South Africa. However, there are national guidelines (e.g., 'Guidelines on Separating Waste at Source', 2019; National Environmental Management Waste Act, 2008; National Waste Management Strategy Goal 1: 'Promote waste minimization') as well as provincial guidelines. Ghana and Rwanda have some of the strongest frameworks in these areas, with Rwanda enforcing the legal framework better than any other target country except South Africa.

It should be noted that MSW, liquid organic waste (e.g., sewage waste, animal waste from meat and dairy industries), and associated energy activities, particularly landfill gas, were not included in the shortlisted bioenergy pathways. In the case of MSW, it is very difficult to find operational systems that practice wide-scale, mandated waste separation of organic content in all the countries except South Africa. Ghana is moving towards a more regulated and industrialised urban waste management system, but, the other eight countries still are a long way from having waste management systems that lend themselves to true bioenergy projects. This is discussed in more detail in Annex 10. Urban waste incineration is not considered a bioenergy pathway by the FAO/IEA. Therefore, Ethiopia's Addis Ababa Reppie 50 MW urban waste incineration plant was not considered for pathway short-listing.

[55] Ethiopian Energy Authority (www.eea.gov.et), Ghana Energy Commission (www.energycom.gov.gh), Kenya Energy and Petroleum Regulatory Authority (www.epra.go.ke/); Nigeria Energy Regulatory Commission (nerc.gov.ng/); Rwanda Utilities and Regulatory Authority (irembo.gov.rw/rolportal/en/web/rura); National Energy Regulator of South Africa (http://nersa.org.za); Tanzania Energy and Water Utilities Regulatory Authority (www.ewura.go.tz); Uganda Electricity Regulatory Authority (www.era.or.ug); and Zambia Energy Regulation Board (www.erb.org.zm)

Table 14 - Energy regulatory effectiveness ranking

Country	Energy/electricity regulator	Licensing IPPs[56]	Approving allocation of FiTs[57]	Does regulator monitor other govt. bioenergy support (e.g. subsidies)	RISE scores* Financial & regulatory support for renewable energy	RISE scores* Financial & regulatory incentives	Index Score:** Degree of regulatory effectiveness in support of bioenergy (1=low)
Ethiopia	Ethiopian Energy Authority	Yes	No	No	0%	25%	1
Ghana	Ghana Energy Commission	Yes	No	No	70%	92%	3
Kenya	Energy & Petroleum Regulatory Commission	Yes	Yes	Yes	60%	67%	4
Mozambique	Autoridade Reguladora de Energia/ARENE	No	No	No	23%	0%	1
Nigeria	Nigerian Electricity Regulatory Commission	Yes	No	No	44%	17%	2
Rwanda	Rwanda Utilities Regulatory Agency	No	Yes	Yes	50%	33%	3
South Africa	National Energy Regulator of South Africa	Yes	Yes	Yes	76%	25%	4
Tanzania	Energy & Water Utilities Regulatory Authority	Yes	Yes	Yes	24%	58%	3
Uganda	Energy Regulatory Agency	Yes	Yes	Yes	56%	50%	4
Zambia	Energy Regulatory Board	Yes	Yes	Yes	45%	83%	4

Sources: Regulators' own websites; World Bank/RISE (Anon n.d.), Climatescope (Bloomberg n.d.) published directives in each country.
**RISE scores: (Ranking Index for Sustainable Energy - World Bank) - Scores (0% to 100%) **Index Score: 1 to 4, 1 being worst regulatory effectiveness and 4 being best*

[56] An IPP is an Independent Power Producer, 'independent' in so far as they are not owned by the national electricity company, or the primary national electricity provider.
[57] Feed-in-Tariffs (FiTs) are special electricity tariffs paid to suppliers who feed in electricity (usually renewable electricity) to a grid/network. They are paid ex post facto on the actual amount (kilowatt hours) of electricity covered by the FiT that is generated and supplied to the grid. FiTs are designed to stimulate investment and generation by renewable electricity suppliers.

- **Ethiopia:** The Ethiopia Energy Authority was originally established to cover what was intended to be a liberalised electricity sector, issuing licences for IPPs and overseeing PPAs. Liberalisation in stalled in the early 2000s and the Authority currently has responsibility for supporting energy efficiency, setting electrical and thermal cooking equipment standards and carrying out public education on energy conservation. It can license Small-Scale Independent Power Producers (SSIPP) for rural electrification, but no bioenergy electricity projects have yet been licensed. The Ministry of Water, Irrigation and Electricity, through its Electricity Division, has licensing authority for large-scale power projects. Bioenergy of the BSEAA2 scale is not supported.

- **Ghana:** On the bioenergy side, the Ghana Energy Commission focuses on promoting waste-to-energy, domestic and institutional biogas, improved charcoal production, biomass briquetting and liquid biofuels, in its capacity as the lead agency for Ghana's Renewable Energy Management Programme (REMP). The Energy Commission has set out feed-in-tariffs (FiTs) for bioenergy sources in the past. But no bioenergy FiTs are currently offered. In fact, the Energy Commission recognises that the low price for grid electricity discourages electricity generation from biomass.

- **Kenya:** Originally established as the Kenya Electricity Regulatory Commission, the current Kenya Energy and Petroleum Regulatory Authority (EPRA) has responsibility for regulating the wholesale and retail electricity sectors, as well as issuing licenses and offering FiTs for bioenergy projects between 500 kW and 10 MW. Bioenergy FiTs are lower than those for solar and wind, but higher than for geothermal and fossil-fuel electricity generation.

- **Mozambique:** The new *Autoridade Reguladora de Energia* (the Mozambique Energy Regulatory Authority) is taking control of the energy sector from the *Conselho Nacional de Electricidade* (National Electricity Council). It has been in the process of becoming a fully operational energy regulator for three years. There are currently no policies for bioenergy IPPs, FiTs or subsidies.

- **Nigeria:** The Nigerian Electricity Regulatory Commission (NERC) is responsible for regulating Nigeria's extensive petroleum, natural gas and electricity sectors. As Nigeria is Africa's largest oil producer, and a major natural gas producer (with liquefied petroleum gas [LPG], oil refining facilities, and an almost fully privatised electricity sector). Little support has been given by NERC to renewable electricity, except for off-grid PV electrification. While there are approved FiT rates in place for bio-electricity, no FiTs have been provided to any supplier.

- **Rwanda:** The Rwanda Utilities Regulatory Agency (RURA) was established in 2001 to regulate the electricity, telecommunications, water, gas, transport and waste sectors. It has responsibility for licensing electricity facilities and for supporting Rwanda's ambitious rural electrification programme, including a large off-grid electricity component. Rwanda's bioenergy focus is on household cooking and heating. There is a relatively small special renewable electricity open tender which has funded one bio-electricity project under the Utilities Regulatory Agency.

- **South Africa:** South Africa has a dynamic energy regulator, the National Energy Regulator of South Africa (NERSA). It has been promoting electricity sector liberalisation and diversification from primarily coal, coal gas, natural gas and nuclear-generated electricity to renewables since the mid-2000s. Initially, FiTs for different renewable electricity sources were put in place by NERSA. However, renewable energy FiTs were never operationalised. Instead of FiTs, an innovative market-based mechanism, the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP), was created to promote investment in renewable electricity generation capacity, including bioenergy electricity. The REIPPPP is operated jointly by the Department of Mineral Resources and Energy's' IPP Office, in conjunction with South Africa's National Treasury and the Development Bank of Southern Africa. The REIPPPP uses PPA auctions for promoting investment in renewable electricity, including bioenergy electricity. Winning bidders negotiate power purchase prices for a given generation capacity over an agreed power purchase contract period. Qualifying bioenergy sources include electricity from sugar bagasse, wood residues, animal waste and other biomass residues. However, out of a total of 6,329 MW of renewable electricity contracted to date under the REIPPPP, less than 1% (59 MW) comes from bioenergy generation, primarily from the sugar and wood industries, with some agricultural/livestock biogas, and some municipal and industrial landfill gas projects.

There is a Small Projects IPP category, which includes bioenergy, whereby an additional 400 MW has been allocated. Each project must have a contracted generation capacity of between 1 and 5 MW.[58] However, thus far, no 'preferred bidders' have been identified under this mechanism.

Additionally, most medium- to-large South African municipalities have their own electricity companies. These companies primarily distribute and sell electricity within their constituencies. Larger municipalities have significant generation capacity and have often been in the forefront of investing in and developing renewable energy. Landfill gas has been an important area of municipal investment over the past 14 years in South Africa.

- **Tanzania:** Tanzania's Electricity and Water Regulatory Authority (EWURA) is a dynamic national utilities regulator, which has received considerable support from the World Bank, the UK, Norway and Sweden. Tanzania's electricity sector liberalisation stalled in the mid-2000s. The Tanzania Electricity Supply Company was due to be privatised by 2007, but the government halted the process and put in place a large Renewable Energy Agency which manages a well-funded Renewable Energy Fund. EWURA has set up a simplified small-scale IPP licensing programme for electricity projects between 250 kW and 5 MW. Over 20 small-scale IPPs have been awarded special FiTs for small hydropower, some solar PV farms and four bioenergy projects (using forest residues). Under EWURA, very small power producers with an installed capacity of less than 15 kW at a single site selling power to at least 30 retail customers, or with a capacity between 15 and 100 kW, do not require an IPP licence. They simply register with EWURA with a letter of support from the Ministry of Energy and Minerals.

- **Uganda:** Uganda established one of the first electricity regulatory authorities in Africa, the Electricity Regulatory Agency. The Agency was established as part of a long process of liberalising the former Uganda Electricity Board, a monopoly which owned all grid-connected generation, as well as the transmission and distribution systems. These were privatised in the early-to-mid-2000s, with the Electricity Regulatory Agency taking a major lead in the privatisation process and electricity market liberalisation, with assistance from Norway, the World Bank and the UK. The Regulatory Agency oversaw licensing of three bioenergy IPPs in the sugar sector under the 'bagasse FiT', each of which has more than 5 MW capacity. Uganda had an extensive renewable electricity support programme from 2010. The KfW, and other development finance institutions, funded the GET-FiT (Global Energy Transformation-FiT) programme from 2014-2015. It 'topped-up' the ERA's existing FiTs with a premium and supported investments in 17 renewable electricity projects (14 hydro, two solar PV and one sugar bagasse) with installed capacity of 158MW. Both the GET-FiT and the ERA have stopped any new FiT projects since 2018. However, the one bioenergy project (bagasse at Kinyara Sugar Company) is larger than 5 MW.

- **Zambia:** The Zambia Energy Regulation Board (ERB) was established with Swedish assistance in 1997 as part of Zambia's electricity sector liberalisation. Two electricity entities had existed since colonial times, the Zambia Electricity Supply Corporation (ZESCO) and the Copperbelt Energy Corporation. The latter was privatised as an independent electricity company in 1997 as the power company of the Zambia Consolidated Copper Mines. The ERB has regulatory powers over the operations of both the electricity and petroleum fuels sectors. It works closely with ZESCO and the Rural Electrification Agency and its Rural Electrification Fund. As in Uganda, the Rural Electrification Fund primarily funds extension of the national grid into rural areas. The Rural Electrification Agency is responsible for supporting Zambia's ambitious Rural Electrification Master Plan, in tandem with the ERB and ZESCO. The ERB has supported licensing of bioenergy projects in the past, but, has not done so for the past five years as there is no FiT or subsidy support for bioenergy electricity investment.

Of the ten electricity and energy regulators in the BSEAA2 target countries, Uganda, South Africa, Tanzania and Kenya rate highest in terms of overall regulatory performance, with special attention paid to bioenergy electricity.

[58] "Sustainable energy solutions for South African local government A practical guide", Sustainable Energy Africa, Cape Town 2017. EThekwini LFG Project has a capacity of 1 MW generation. There are now 8 municipal LFG projects in South Africa, with capacities from 1-4 MW.

Criterion 3: Government bioenergy support

The level of government financial support to bioenergy investment is summarised against several relevant indicators in Table 15.

Table 15 - Level of government bioenergy support

Country	Bioenergy primary legislation	Non-Bioenergy RE FiT?	Bio-electricity FiT?	Bioenergy Auctions & tenders?	Debt finance?	Equity finance?	Tax relief?	One-off subsidies (e.g. for capital investment)?	Performance-based subsidies?	Other subsidies?	***Index score: Overall level of bioenergy support (4=high)***
Ethiopia	Yes	No	No	No	No	No	Yes	No	No	No	***1***
Ghana	Renewable Energy Act 2011	Yes	Yes	Yes	No	Yes	No	No	No	Yes	***3***
Kenya	FiT revised 2016	Yes	Yes	No	No	Yes	Yes	Yes	No		***4***
Mozambique	New & Renewable Energy Strategy 2009; Renewable Energy Atlas	No	No	No	No	No	No	No	No	No	***1***
Nigeria	National Renewable Energy & Energy Efficiency Policy 2015	Yes	No	No	Yes	No	Yes	No	No	No	***2***
Rwanda	Simplified licensing for off-grid renewable electricity mini-grids (<1 MW) & small generation (<5 MW)	No	No	No	No	No		No			***2***
South Africa	National Energy Act 2008; REIPPPP; national renewable energy targets 2010-30	No	No	Yes (Round 4 REIPPPP)	No	Yes	Yes	No	No	Yes	***4***
Tanzania	Power System Master Plan 2012-2030; SIPP 2nd Generation 2016; Rural Energy (and Fund) Act, 2007; 2nd 5 Year Dev't. Plan 2016/17-2020/21	Tariffs negotiated with Regulator (EWURA) for PPA	Tariffs negotiated with Regulator (EWURA) on SIPP licensing	No	No	Yes	Yes	Yes	No	No	***3***
Uganda	Renewable Energy Policy 2008; Renewable Energy Agency/Fund Act 2003	No	No	No	Yes	No	No	Yes	No		***3***
Zambia	Rural Electrification Agency/Fund Act 2003; Rural Electrification Master Plan	No	No	No	Yes	No	No	Yes	No	No	***2***

- **Ethiopia:** Ethiopia's second Growth and Transformation Plan sets an ambitious target of adding 420 MW of electricity from biomass to the national grid and off-grid between 2016 and 2020. A negligible part of this target has been achieved. The second phase of the National Biogas Programme supports the government's efforts to develop extensive small-scale, household biogas in rural areas. Under the Universal Energy Access Plan, the Ethiopia Rural Electrification Fund should provide funding for this programme. However, the programme virtually came to a halt in December 2015 after the withdrawal of Norwegian support. The government offers 100% import duty exemption on all capital goods, including those related to energy, heat sector included. The National Energy Policy 2013 does not have specific provisions for bioenergy. The EU-funded Biomass Energy Strategy (BEST) 2013, sets out targets and actions for biomass energy, although BEST has not been adopted by the government. Ethiopia participates in the Scaling Up Renewable Energy Program in Low Income Countries programme. Although bioenergy is one of the specified technologies, the country program in Ethiopia focuses on hydro, solar and geothermal energy.

- **Ghana:** Ghana's Renewable Energy Act 2011 set a target for 10% renewable energy in the electricity sector by 2020. As of now, that target has not been achieved. Government has backed away from promoting renewable energy, including biomass energy, due to a major surplus of electricity and low grid prices. Many potential bioenergy suppliers find it less expensive to use electricity from the grid than to generate it themselves. They have even less incentive to sell it to the grid. Import duty for new electricity equipment is zero. While bioenergy policies have been in place since 2015, with a major surplus of natural gas-fuelled electricity supply, no tenders or new FiTs have been awarded for any renewable energy project.

- **Kenya:** Kenya introduced its renewable energy FiT Policy in 2008. Revisions in 2010 and 2012 included the addition of FiTs for biogas and other biomass-supplied electricity. The Policy requires the national electricity company, Kenya Power, to sign PPAs with eligible bioenergy suppliers licensed by the Energy and Petroleum Regulatory Commission as IPPs. The biomass (including bioenergy) FiT is for plants with installed capacity between 0.5 MW and 10 MW. The tariffs apply to grid-connected plants and are valid for 20 years. Under the VAT Act 2013 and VAT (Amendment) Act 2014, Kenya offers exemptions from VAT and import duties on equipment for constructing power plants (including those using bioenergy) that will supply electricity to the national grid. The Kenya Rural Electrification Programme does not include bioenergy, only wind, solar and hydropower.

- **Mozambique:** The New and Renewable Energy Strategy 2009 and the Renewable Energy Atlas 2013 published by the Mozambique National Energy Fund, targets the installation of 128MW of electricity generation from biomass, prioritising 'residues from forestry operations, agro-processing, pulp and paper industry and municipal solid wastes'. However, there are no government incentives for commercial generation from biomass, with the result that no bioenergy electricity generation has so far been supported. Mozambique's Biomass Energy Policy focuses on biofuels for transport and on household biomass (mainly improved cookstoves, charcoal production and small-scale biogas). Companies investing in electricity generation and CHP are eligible for certain 'infrastructure concessions' that could support bioenergy investments. In practice, with substantial investment in major hydropower (83% of electricity), coal and some natural gas, there are practically no incentives for supporting bioenergy generation. Were bioenergy investment encouraged, projects could benefit from (i) 80% corporate tax reduction for the first 5 years, 60% for years 6-10 and 25% for years 11-15; (ii) up to 50% accelerated depreciation; (iii) up to 15% tax deduction for modernisation and introduction of new technology; and (iv) VAT exemption.

- **Nigeria:** Nigeria's Vision 2020 development plan envisages an increase in installed electricity generating capacity to 35 GW by 2020, using a range of technologies that include bioenergy and other renewables. In response, the National Renewable Energy and Energy Efficiency Policy (NREEEP) 2015 targets installation of 57MW of biomass electricity by 2020 and 293MW by 2030. The Nigerian Electricity Regulatory Commission approved the FiT regulations for this biomass electricity in 2015. Solar, wind, small hydro and biomass are also included in the NREEEP. FiTs are to be awarded for eligible IPPs for 20 years and the tariff rate for biomass is $154.71/MWh.

The regulations apply to projects over 1 MW at sites either connected to the transmission grid or for off-main grid distribution networks. For biomass, the project can be of maximum size of 10 MW. However, as noted in the regulatory criteria section, above, no PPA has been signed or any FiT paid under the NREEEP, as the government has not allocated any funds to fulfil its commitments.

- **Rwanda:** The Rwanda Renewable Energy Feed in Tariff (REFiT) was introduced in 2012 for attracting private investment in the renewable energy sector, including bioenergy. REFiT applied to small plants with generating capacity between 50 kW and 10 MW located within 10 km of the national grid. Under the Simplified Licensing Procedure for Off-grid Renewable Energy Projects, developers can apply for licences to develop mini-grids of up to 1 MW and small generation projects of up to 5 MW. The full mini-grid licences award exclusive rights for transport and retail of energy for 5 to 25 years in a geographically-determined area. Rwanda's EU-financed BEST 2009 focuses on efficient biomass combustion technologies for households and small enterprises. It does not cover commercial heat or power generation, and no bioenergy electricity projects have been funded under this policy framework. The national Domestic Biogas Programme is well-funded and focuses on efficient household energy production for cooking and lighting. Improving household energy efficiency is a cornerstone of Rwanda's drive to reduce deforestation and improve household well-being.

- **South Africa:** The National Energy Act 2008 emphasises the contribution of renewable sources (including biomass) to national energy supply. The Carbon Tax Act 2019 provides financial incentivises (notably tax exemptions and allowances) for heat and electricity generation from wood, as well as bio-based wastes from pulp, paper, printing, food processing, beverages, tobacco and wood product industries. The Integrated Resource Plan, the primary driver of all electricity policies in the country, specifies that biomass from waste, paper and pulp and sugar industries should also be utilized in co-generation plants and deliver electricity at a price-competitive level, with minimal transmission and distribution infrastructure requirements. The REIPPPP, introduced in 2011, enables IPPs from the private sector to generate electricity from both large (>10 MW) and small (<10 MW) projects to supply the national grid. REIPPPP replaced the former Renewable Energy Feed-in Tariff programme and was designed to respond to the call to increase electricity capacity by the National Development Plan 2030 and the Integrated Resource Plan, using renewable energy sources such as solar PV, wind, concentrated solar power, small hydro, biomass and landfill gas. As of June 2018, a total of 112 projects had been procured from IPPs in four bidding windows over seven rounds, including five bioenergy projects, which together represent just under 1% of electricity capacity procured under REIPPPP. The Programme provides cash grants (15-30% of investment costs) for local manufacturers and foreign investors looking to expand or construct new production facilities for generating clean energy. A Foreign Investment Grant is also available for foreign companies importing new machinery and equipment to South Africa, up to a maximum of ZAR 3 million (approximately US$170,000) and the cost of relocating, or 15% of the value of new machinery and equipment relocated from overseas.

- **Tanzania**: The Power System Master Plan 2012-2030, a long-term plan for driving investments in the power sector, foresees more than 9 GW of additional electricity generating capacity installed by 2030, out of which just 2.7% will come from biomass, solar and wind combined. Among the renewables, the plan gives highest priority to large hydro projects. The National Energy Policy 1992 (revised in 2003), stresses the application of market mechanisms and improved private sector participation for improving efficiency in the energy sector. Subsequently, the Public Private Partnership Act 2010 and the Private Partnership Regulations 2011 were enacted to support private sector investments in the energy sector. Tanzania established a Small Power Producer (SPP) program and introduced a FiT program for renewables in 2008, which was revised in 2015. SPP projects are defined to have an electricity generation capacity of 10 kW to 100 MW. SPP projects based on hydro and biomass qualify for the FiT. Under the second-round of SPP, biomass projects receive a fixed FiT decided by the Rural Energy Agency in conjunction with the regulator, EWURA. Biomass energy projects can receive debt financing from the Rural Energy Fund, but no grants towards operating or debt-service costs of any project or developer. Tanzania's BEST 2014 focuses on enhancing the efficiency of producing and utilising biomass energy and promoting access to alternative energy sources such as bioenergy. It was, however, not adopted by the Tanzania government.

- **Uganda:** The Renewable Energy Policy 2007 provides a framework for increasing the contribution of renewables beyond large hydropower in the energy mix. It particularly promotes power generation from municipal and industrial wastes, mini-hydro, biomass, co-generation, wind, solar, geothermal, peat and nuclear. The Electricity Act 1999 disbanded the Uganda Electricity Board into three entities, Umeme (distribution), UETCL (transmission) and UGEN (Owens Fall Hydropower). Under the Rural Electrification Strategy and Plan 2013-22, the Uganda Rural Electrification Fund provides funding for the construction of mini-grids involving bioenergy and a range of other technologies, but not for the costs of generation. The REFiT programme introduced in 2007 (revised in 2013 and 2016) applies to power plants with maximum generation capacity of 20 MW. Under this program, IPPs may enter PPAs at a fixed tariff rate with the Uganda Electricity Transmission Company. The premium set under the GETFiT Programme in 2014 for biomass and bagasse projects was 1 US cent per kWh. Biogas and landfill gas projects were not eligible. A range of fiscal incentives, including investment capital allowances (i.e., tax deductible expenditure) and exemption for duties and taxes is available for imports of plant and machinery for biogas, heat and CHP projects.

- **Zambia:** Zambia's Renewable Energy Feed-in-Tariff (REFiT) and GET FiT programme (which complements REFiT), do not include biomass. There is finance available from the Rural Energy Fund for eligible biomass electricity projects, although this has so far been targeted mainly at solar PV.

Criterion 4: Degree of market openness

A critical element for successful development and investment in bioenergy technology is the degree to which a country's market is open to domestic and foreign investment, the amount of domestic and international participation in the bioenergy sector and the degree to which the bioenergy sector is organised (to be able to articulate needs and to lobby for policies and support that stimulate the sector and enable it to grow). Table 16 summarises several indicators of market openness.

Table 16 - Market openness Indicators from international indices and presence of biomass-bioenergy associations

Country	Market openness (lowest=most open) ICC*	Market openness (lowest=most open) OECD**	Global Competitiveness Index (lowest=most competitive internationally)***	Bioenergy trade & promotion associations	Comments, other trade organisations	**Index Score: Country openness ranking (lowest=least competitive)**
Ethiopia	73		108	No trade or other association of renewable energy businesses or organisations	There is no Ethiopian renewable energy or bioenergy member or trade organisation. The East African Centre for Renewable Energy and Energy Efficiency (www.eacreee.org), funded by UNIDO and based in Kampala was formed in 2014 with a remit to support renewable energy trade groups in each of the seven East African countries, including Ethiopia.	2
Ghana			111	Renewable Energy Association of Ghana (website not operational); ECOWAS Centre for Renewable Energy & Energy Efficiency (ECREEE) - Ghana	ECREEE is very active in Ghana. Bioenergy is a focal area.	3
Kenya	66		91	Kenya Renewable Energy Association web.kerea.org	Has some 30 corporate members who cover bioenergy, as well as solar PV, wind, small-hydropower and other clean energy companies.	3
Mozambique			136	Associação Lusófona de Energias Renováveis em Moçambique (ALER) www.aler-renovaveis.org/en/ Mozambican Renewable Energy Association (AMER) amer.org.mz/?lang=en	Associated with other renewable energy associations in Angola, Cape Verde, Brazil, Portugal and other Portuguese-speaking countries. It is very active in promoting bioenergy, as well as solar PV, wind, small-hydropower and energy efficiency. Its members are mostly large corporations, including *Electricidade de Moçambique* and *Energias de Portugal*.	1
Nigeria		71	125	Renewable Energy Access Network	Operating as the Renewable Energy Association of Nigeria. Operated by GOGLA, the Netherlands-based global association for the off-grid solar energy industry.	2
Rwanda			100	Rwanda Energy Private Developers; https://www.epdrwanda.com/	The Energy Private Developers (EPD) association is a registered professional association in Rwanda, bringing together private companies operating in energy sector. It is one of the 5 associations	3

Country	Market openness (lowest=most open) ICC*	Market openness (lowest=most open) OECD**	Global Competitiveness Index (lowest=most competitive internationally)***	Bioenergy trade & promotion associations	Comments, other trade organisations	**Index Score: Country openness ranking (lowest=least competitive)**
					composing the Chamber of Industry under the Private Sector Federation of Rwanda. EPD focuses on advocacy, encouraging collaboration and partnership for development of energy sector in Rwanda.	
South Africa	49	33	60	Southern Africa Biogas Industry Association,; ; South African Sugar Association sasa.org.za	The **Southern African Biogas Industry Association** (SABIA) is a non-profit organisation with a mission to promote the benefits of **biogas in South Africa** . The South Africa Sugar Association's members own 15 sugar factories and estates and include the continent's two largest pulp and paper facilities.	4
Tanzania			117	Tanzania Renewable Energy Association (TAREA) www.tarea-tz.org; Tanzania Private Sector Foundation (TPSF) www.tpsftz.org	TAREA is an active renewable energy association with 12 corporate (business and NGO) members who work in bioenergy, including some of the most active bioenergy companies in Tanzania. TPSF has nearly 100 corporate members, including several of the largest bioenergy producing companies in Tanzania. TPSF is a strong supporter of sustainable biomass energy.	2
Uganda	65		115	Uganda National Renewable Energy and Energy Efficiency Alliance www.unreeea.org	An alliance comprised of the Uganda National Biogas Alliance, Biomass Energy Efficient Technologies Association, as well as solar, wind, hydropower and energy efficiency association members.	3
Zambia			120	Zambia Renewable Energy Agency www.zarena.org	A private sector association of renewable energy companies and organisations that promotes bioenergy, solar PV, small-hydropower, wind and energy efficiency.	2

Sources: International Chamber of Commerce New Market Openness Index;[59] OECD 'Open Markets Matter';[60] World Economic Forum, Global Competitiveness Index[61]
** ICC (International Chamber of Commerce) only to 75 countries in the 'Market Openness Scale'*
*** OECD focuses on DFI (direct foreign investment) & employment in those sectors relative to other non-DFI sectors*

[59] www.iccwbo.org/media-wall/news-speeches/icc-open-markets-index-effort-required-open-economies-global-trade/ https://www.chamber-commerce.net/
[60] www.oecd.org/trade/understanding-the-global-trading-system/why-open-markets-matter/ (Anon n.d.)
[61] reports.weforum.org/global-competitiveness-index-2017-2018/competitiveness-rankings and World Bank's TCdata360

*** *Global Competitiveness Index, 4.0, 2019, World Economic Forum, reports.weforum.org/global-competitiveness-index-2017-2018/*

The table highlights the target SSA countries' lack of commercial attractiveness for foreign investment. Only four of the countries rank in the International Chamber of Commerce's top 100 countries for 'degree of economic openness', with South Africa in the top 50 and Uganda, Kenya and Ethiopia close in the third quartile. In the Organisation of Economic Cooperation and Development's top 100 most open economies, only South Africa and Nigeria rate.

There are several international organisations that represent the business community, including the agricultural sector, in each of the target countries. An indicative list of these organisations provides some indication of how open and interactive with the African and international business community the target countries are:

- **Pan African Chamber of Commerce and Industry (PACCI)**[62]**:** All ten target countries are members of PACCI, an organisation which promotes inter-African and international trade, development and investment.

- **Union of African Chambers of Commerce, Industry, Agriculture and Professions**[63]**:** This Pan-African association includes eight of the ten target countries, with only South Africa and Zambia not being members.

- **Chambers of Commerce and Industry**[64]**:** All target countries have national chambers of commerce under the umbrella of the International Chambers of Commerce. All promote investment and development in agriculture in their respective countries.

Criterion 5: Finance

Bioenergy finance is critical to the success of bioenergy technology development and investment. There are several different sources for bioenergy finance, both international and domestic. International financial flows are often easier to track, as financing from the World Bank, International Finance Corporation (IFC), African Development Bank, KfW, *Agence Française de Développement* (AFD), FMO[65], CDC Group, etc. is publicly disclosed. Table 17 provides information on international flows to renewable energy investment to the target countries for the period 2009 to 2018.

Table 17 - International finance flows for renewable energy investments in biomass or waste (million USD, 2009 to 2018)

Country	Ethiopia	Ghana	Kenya	Mozambique	Nigeria	Rwanda	South Africa	Tanzania	Uganda	Zambia	Total (million USD)
Commercial bank finance			360	10			110		10		**490**
Development bank finance	120	30	1,990	20	20	160	3,330	10	140	70	**5,890**
Export credit finance	850		12							13	**875**
Industrial user investment		20					100	10			**130**
International utility			130				510		30	20	**690**
Manufacturer credit/equity	40		30				340			10	**420**
Private equity			17	30			22	10	20		**99**

[62] https://www.pacci.org/
[63] http://uacciap.org/
[64] https://www.chamber-commerce.net/
[65] *Nederlandse Financierings-Maatschappij voor Ontwikkelingslanden* (Netherlands Development Finance Company)

Project developer finance	100		410	10	20		820	10	70	10	**1,450**
Sovereign investment	110		580		10		40		70		**810**
Other investment		10					10		10		**30**
Undisclosed investment		50	120	20	530		510	40	250	20	**1,540**
Total	**1,220**	**110**	**3,649**	**90**	**580**	**160**	**5,792**	**80**	**600**	**143**	**12,424**
Index Score: Level of financial flows for renewable energy (1 = low, 4 = high)	3	2	4	1	3	2	4	1	3	2	

Sources: BNEF (BNEF, 2019)*, World Bank and national sources*

As the data show, development bank finance accounted for nearly half of all international flows to the target countries. This was followed (after 'undisclosed', meaning no source information was provided) by international project developer finance.

Export credit finance followed, with almost all of that directed to Ethiopia with China as the major source. International utility finance (e.g. EDF/France, ENEL/Italy, Iberdrola/Spain) accounted for a large portion of investment finance in renewable energy, with most going to South Africa, followed by Kenya. Commercial bank finance was not insignificant, with the bulk of that going to Kenya and South Africa.

Overall, South Africa and Kenya account for over 75% of the international finance flows to the SSA target countries. Ethiopia has attracted considerable international finance, primarily from China, and primarily for two major hydropower plants on the Blue Nile. South Africa's finance comes from many sources, though almost 60% is from development banks. These include the Development Bank of South Africa, the African Development Bank, KfW (Germany), FMO (Netherlands) and the CDC Group (UK). Kenya's sources are more evenly distributed, although international development banks figure prominently with most funds coming from the World Bank, the UK (the UK's Greening Africa Power Project), the EU (European Investment Bank and other EU funds) and the African Development Bank.

Operational Rural Energy Funds or Rural Electricity Funds (REFs) are found in Ghana, Uganda, Tanzania, Zambia, Kenya and Rwanda. The World Bank has been the largest financier for these REFs, followed by Sweden, Norway, the UK and the USA. Non-performing REFs are found in Ethiopia and Nigeria.[66]. Operational REFs are funded primarily by international development partners, with the World Bank being the largest, followed by Sweden, Norway and the UK. These REFs provide the biggest proportion of bioenergy finance in the six countries with operational REFs. They are also an important source of equity financing, as well as technical assistance to help design and finance renewable energy projects.

Bilateral development finance is provided in the ten target countries by KfW (South Africa, Uganda, Tanzania and Kenya), CDC Group[67] (through one of its investment funds, Frontier Ltd is established to fund renewable energy projects, including bioenergy, in Kenya, Tanzania, Uganda and Rwanda), AFD[68] (bioenergy in Kenya),the Energy and Environment Partnership/EEP, funded by the Nordic Development Fund/NDF with funding from Austria, Finland and the NDF (formerly the Finnish Government) rebranded as EEP Africa, the European Commission/EU and FMO[69], primarily through

[66] The Rural Energy Funds in Uganda, Tanzania, Zambia, Ethiopia and Nigeria were core-funded, initially, by the World Bank under the 'African Rural and Renewable Energy Initiative' which commenced in 1999 with the participation of Norway, Sweden, the UK, The Netherlands and, later, the African Development Fund. AFRREI evolved by the mid-2000s into 'Energy for Rural Transformation', and its legacy World Bank projects supporting these active Rural Energy Funds, continue in Uganda, Tanzania and Zambia.
[67] https://www.cdcgroup.com/en/our-investments
[68] https://www.sunref.org/en/projet/?secteur=renouvelable
[69] https://www.fmo.nl/partner-with-us/energy

Frontier Energy. Multilateral development finance for bioenergy projects has been provided in the target countries by the IFC, the African Development Bank and the European Investment Bank.

However, there is little information on how much international finance went to SSA for bioenergy investment, as there are almost no statistics covering biomass or bioenergy, as the bulk of the financial flows during the ten year period covered by Table 17 went to hydropower, geothermal (Kenya), solar PV and Concentrated Solar Power/CSP (almost all in South Africa).

Table 18 summarises the state of development of the financial markets in each of the target countries.

Table 18 - Financial market development - world ranking (lowest number = best performance)

Country	Ethiopia	Ghana	Kenya	Mozambique	Nigeria	Rwanda	South Africa	Tanzania	Uganda	Zambia
Global Competitiveness Index	108	111	91	136	125	58	61	113	114	118
Financial market development	109	84	55	131	91	34	44	103	89	94
Availability of financial services	103	94	58	125	102	72	32	99	93	108
Affordability of financial services	79	110	96	126	129	84	48	108	126	109
Financing through local equity markets	78	59	32	122	48	70	25	66	82	76
Ease of access to loans	95	113	58	122	130	55	62	105	71	115
Total tax rate	74	47	70	66	54	49	31	94	53	10
Legal rights index	95	30	30	127	30	4	69	69	49	30

Source: World Economic Forum, Global Competitiveness Rankings (Finance), reports.weforum.org/global-competitiveness-index-2017-2018/competitiveness-rankings/

Using the World Economic Forum Global Competitiveness Rankings, Rwanda scores highest on financial market development, ease of access to loans and legal rights protection for investment. South Africa has the best scores for availability and affordability of financial services and financing through local equity markets. Kenya ranks next highest with financial market development, with relatively strong financing through local equity markets and good legal rights for investors.

5.5.4 Summary

The table below summarises the index scores (from 1 to 4 with one being lowest and 4 being highest) for each of the 10 target countries based on their overall performance on each of the six criteria i.e. Governance, Regulatory Environment, Government Support for Bioenergy, Market Openness, Bioenergy Financial Environment, and International Competitiveness.

Table 19: Overall summary of country ranking against the five assessment criteria[70]

Country	Ethiopia	Ghana	Kenya	Mozambique	Nigeria	Rwanda	South Africa	Tanzania	Uganda	Zambia
Governance	2	3	2	2	1	3	3	2	2	2

[70] International Competitiveness is a set of indices and policies that the World Economic Forum have put together into a web-based tools. The finance part covers local commercial finance, banking sector policies, foreign exchange access, and other aspects that are cross-cutting beyond finance to the other Theme 5 criteria. See: http://reports.weforum.org/global-competitiveness-index-2017-2018.

Regulatory Environment	1	3	4	1	2	3	4	3	4	4
Government Bioenergy Support	1	3	4	1	2	2	4	3	3	2
Market Openness	2	3	3	1	2	3	4	2	3	2
Finance (International)	2	1	3	1	2	1	4	1	2	1
International Competitiveness	2	2	3	1	1	4	4	2	2	2
Total Index Score	**10**	**15**	**19**	**7**	**10**	**16**	**23**	**13**	**16**	**13**
Average Index Ranking	**1.7**	**2.5**	**3.2**	**1.2**	**1.7**	**2.7**	**3.8**	**2.2**	**2.7**	**2.2**

South Africa is, by far, the strongest investor in, and producer of, bioenergy. Although, of all the target countries, it has the smallest proportion of its working population engaged in forestry, livestock and agriculture (around 6%), it is, by far, the leader in SSA in almost all institutional, regulatory and market areas affecting bioenergy investment and commercial operations. It falls short on governance, but, excels at all others. Its installed capacity for electricity generation from bioenergy has risen from less than 100 MW in 2005 to 4,100 MW today due primarily to Government's institutional, regulatory and market framework.

Kenya is next among the target countries. Where it excels is in government bioenergy policies and regulation. Its markets are relatively open, and it has an open economy with a high degree of international competitiveness. These factors show in the number of commercially operational bioenergy projects, second only to South Africa.

Rwanda stands out among the ten. It ranks just below Kenya and on a par with Uganda in third place using the Theme 3 institutional, regulatory and market framework indices. It is the smallest country of the 10 both in geographic size and in population. It has made enormous strides since the mid-1990s' genocide, ranking close to the top in governance, regulation, political stability and international competitiveness (the only one of the ten to get this top ranking by the World Economic Forum/WEF). The major factor that restricts Rwanda's bioenergy development and attractiveness for the BSEAA2 bioenergy focal areas, is that it explicitly focuses on household and small-scale bioenergy with a strong, and successful, target of reducing deforestation and increasing afforestation. Further, its drive to achieve very ambitious national electrification targets and limited land resources lead it to focus on its abundant hydropower and solar resources, rather than bioenergy. Thus, lack of explicit policy or regulatory support in the areas the BSEAA2 project focuses on leads to its relatively low ranking.

Uganda ties for third using the aggregate Theme 5 index. In 2005, most of Uganda's electricity was generated from thermal (fossil fuel) sources. Today, over 95% of its electricity comes from renewable energy resources. It was an early starter in setting up the policy, regulatory and financial framework to promote renewable energy through its dynamic Electricity Regulatory Agency and its Rural Energy Agency and Fund. It exceeded its targets on both the proportion of renewable electricity and its absolute amount of electricity generated, leading Government to pull back almost all financial supports for renewable electricity in 2018. However, other than its FiT for electricity from sugar bagasse, Government has never been strong on the bioenergy, primarily due to Uganda's abundant hydropower resources.

Ghana is next in the ranking index. This is attributable in large part to Government's lack of ambition on renewable energy, and even less on bioenergy. It has most of the frameworks for bioenergy investment to thrive but, does not use any incentives or other fiscal tools to promote it. Further, with the discovery in the late-2000s of considerable oil and natural gas reserves, its electricity mix has shifted to natural gas with such a surplus of new generation that it is cheaper for potential bioenergy producers (e.g., in the cocoa and oil palm sectors) to buy cheap grid electricity than to generate it themselves. The fact that its electricity grid reaches more of its population than any other of the target countries except South Africa further reduces incentives to generate bioenergy electricity when few biomass producers are so close to the grid.

Tanzania and Zambia rank next with relatively low average indices. Tanzania was, like Uganda, an early starter in the renewable electricity area, setting up a very strong Rural Energy Agency with its Rural Energy Fund. It has set very ambitious renewable electricity targets, but, has significantly slowed down achieving those targets by its highly ambitious national grid extension programme. This has thwarted both early-starter bioenergy projects and potentially new ones. Its rural bioenergy policies have been strong – Government intentionally named the Rural Energy Agency/Fund to focus not only on electricity, but, on energy. Unfortunately, the institutional, regulatory and market incentives for bioenergy, as opposed to rural electrification, are not in line with Government's stated objectives.

Zambia was another early-starter in the renewable energy area. However, owing to its circumstances, namely, heavy investment in mining and mineral processing industries, Zambia's governments have never paid as much attention to agriculture, forestry and livestock as most of the other ten target countries. Moreover, like Rwanda, it explicitly targets the bioenergy focus on household energy, and on rural electrification. Like Tanzania, Government has thwarted investment and incentives for investment in bioenergy, and other renewable sources other than hydropower, by going for an ambitious, and increasingly successful, rural electrification and electricity access programme through grid extension. Its Rural Electricity Agency/Fund is the lead government agency for Zambia's Rural Electrification Management Programme – thus, its efforts and targets are more on grid connections than bioenergy promotion.

Ethiopia and Nigeria rank the same (low) in the Theme 5 indices. While very different economically, politically and socially, they have similarities to one another. Nigeria has SSA's (indeed, Africa's) largest population. Ethiopia has SSA's second-largest population. Both are large countries with poor national infrastructure (road, transport, federal institutional, banking, among others).

Nigeria is Africa's largest oil producer and second largest natural gas producer. At one stage during the colonial era, it was Africa's second largest coal producer, after South Africa. Fossil fuels have skewed Nigeria's political economy since before independence from the UK. Its institutional, regulatory and market framework are highly skewed in the energy sector towards petroleum and natural gas, and large-scale electricity. Its agricultural sector has suffered significantly over the years due to large-scale imports financed by foreign exchange generated by fossil fuels.

Nonetheless, there is much going on in Nigeria in the agricultural, livestock and forestry sectors. However, data are difficult to come by on these sectors. It is one of Africa's largest palm oil producers and one of its largest cotton producers. A weak central government makes good data and information on bioenergy hard to obtain. Its strong federal system, with it 36 states, further makes centralised information difficult to obtain. Governance is a major issue, as is international finance. On paper, federal ambitions on renewable energy and bioenergy are strong. But there has been no finance, no strong regulatory support, to meet those ambitions.

Ethiopia's ambitions in bioenergy have never been strong, nor have its rural electrification policies, or, policy enforcement. It has ambitious targets in other renewable energy additional to large hydropower, including geothermal, solar and wind. Government never liberalised the electricity sector. It has focused instead on some of the largest hydropower projects in Africa, with the future intent of extending the grid to its overwhelmingly rural and large agrarian population. Its REA/REF never actually came into being, although it received assistance for establishing and operationalising both from the World Bank, the Swedes and the UK back in the early-2000s when Uganda, Tanzania, Zambia and Nigeria were receiving similar support under the same World Bank programme (AFRREI, see Criterion 1, Finance, above). Even as Africa's largest vegetable exporter, its production is highly centralised provided with cheap electricity near the capital, Addis Ababa, and focused entirely on exports. It does not have a regulatory or incentive framework to encourage bioenergy. There are no foreign banks in Ethiopia, and it is one of the most difficult countries in SSA to obtain foreign exchange. As with Rwanda, its bioenergy attention is more on reducing deforestation and improving household biomass energy efficiency.

Mozambique is a country that was at war, first for colonial independence until 1975, then in civil war until 1994, with sporadic flare ups until 2019. It is a country rich in coal, natural gas and large hydropower resources, all of which have been, or are being, exploited to meet Mozambique's growing needs. The war of independence and the civil war had major negative effects upon Mozambique until very recently. The catastrophic spread of the coconut yellowing disease (lethal yellowing) has decimated the country's once extensive coconut economy which, until ten years ago, was the largest cash crop and largest agricultural export earner in the country. Mozambique's sugar, tea and timber industries are slowly recovering from the war of independence and the subsequent long civil war, but bioenergy is not a priority, either for Government or for investors. Government's rural and renewable energy efforts are focused, as are Rwanda's and Ethiopia's, on household woody biomass energy efficiency and substitution. Mozambique is a very large country, and one of Africa's poorest countries with many pressing priorities. Bioenergy is not one of them. It carries the lowest ranking index.

Overall, these rankings match closely to what one finds in bioenergy investment and development in the rest of the report. As Rwanda shows, focus on bioenergy and a relatively ambitious programme of support are essential to encouraging investment and production. While other factors can hinder bioenergy, lack of an articulated strategy with policies to back it are impediments too high for potential investors to ignore. None of the 10 countries has a strongly articulated bioenergy strategy, but, some, such as South Africa and Kenya are still stronger than the others. South Africa offers long term PPAs with fixed power purchase prices (PPPs) for bioenergy projects, and Kenya has included bioenergy in its renewable energy electricity FiTs for many years, and currently specifically targets bioenergy projects for electricity generation in the 500 kW to 10 MW range. This is reflected in the fact that both countries have the greatest number of commercially operational bioenergy projects covering the widest range of bioenergy pathways.

Uganda and Tanzania rank next in number of operational bioenergy projects that, in Uganda's case, stem from both the ambitious GET-FiT programme and inclusion of bioenergy under its FiT programme, when it was operational. Tanzania's SIPP licensing and PPA programme continues to be open to bioenergy projects for electricity generation that have brought several operational bioenergy projects. Ghana has a relatively large number of palm-oil bioenergy projects due to legacy polices that are no longer applies to new investments.

5.6 Task E update: Biomass gasification technology in Sub-Saharan Africa

5.6.1 Aims and approach

This section provides a short update on Task E - Biomass gasification. During Stage 2, the focus has been to begin profiling the key success factors for gasification in SSA and the most viable markets for gasifier technology. This profiling of success factors and market opportunities was informed by a thorough investigation of gasification projects in SSA. A secondary aim during this phase was to determine if commercially viable opportunities exist, that could be opportunistically included as part of the Stage 2 prioritisation process.

The database from BSEAA1 has been extensively updated and expanded, and project status has been determined for as many ventures as possible. Thirty-seven projects have now been identified in the target countries with biomass gasification coupled to a gas engine. Almost all are based on downdraft, fixed-bed gasification technology, with just three using bubbling, fluid-bed technology. A summary of these projects, including location, owner, manufacturer, developer, financier and operational status is included in Annex 12

5.6.2 Success factors for gasification

Small scale gasification is one of the most efficient means of extracting energy from biomass. It also offers the prospect of using biomass instead of petroleum products to power internal combustion engines. In principle, gasification therefore represents an attractive option for countries that lack fossil fuel resources, or have an abundance of biomass resources, or simply wish to shift towards renewable energy.

Gasification should be particularly attractive in tropical countries with high biomass productivity, where residues from crops and other forms of biomass can be used for electricity generation. It is for this reason that the technology has attracted significant interest in SSA, but with varying and rather limited success.

To develop a successful gasification venture, evidence from the projects identified during Stage 2 suggests that the following critical success factors need to be clearly understood:

1. Feedstock supply
2. Energy demand
3. Economic viability
4. Mature gasification technology
5. Realistic business plan
6. Technology supplier commitment
7. Operator skills.

These success factors will be explored in more depth during Stage 3

5.6.3 Main gasifier markets in SSA

Evidence from the projects developed to date suggests that there are two main markets for small-scale gasification in SSA:

- **Captive power plants for small-scale industries** that otherwise depend on diesel generators, either due to lack of grid connection or unreliability of grid supply; and
- **Electrification of villages and semi-urban areas** as Independent Rural Power Producers.

The first market has tended to be more successful, as it generally involves private sector financing based on a sound business plan. The host industry tends to be both the investor and the customer, and makes its decision based on a favourable economic case. The industry often develops the project internally and organises the necessary finance, permitting, contracting, installation and O&M.

In contrast, rural electrification projects are frequently developed by non-profit institutions such as government agencies, parastatals, cooperatives or NGOs. They may secure project funding and then hand over to the final owner, which is often a community-based organisation or a cooperative. When a technical or financial problem arises, the local organisation often lacks the necessary resources and expertise to resolve the problem and has weak technical back-up.

5.6.4 Status of biomass gasification in SSA

Research into the individual plants reveals that most have been non-operational or were never constructed after a feasibility study or investment plan. Some plants still act as isolated pilots or demonstrations, meaning that they are technically ‘operational’ on request, but are not commercially functional. There is some evidence of potential operation at just five of the 33 identified units. Of these, one is waiting for equipment to clear customs so is not yet fully commissioned. Information tends to come from technology suppliers, and the plant owners will be able to provide definitive status updates via the national experts. All project data will be further updated during Stage 3.

Based on the unpromising assessment of gasification projects in the target countries, which reinforces the findings of the BSEAA1 research, there are no commercially viable opportunities that could be opportunistically included as part of the Stage 3 pathway prioritisation process.

6 Step 3: Pathway prioritisation

6.1 Development of longlist of projects and pathways

As described in Section 2.1, significant effort was expended during Stage 2 on the development and elaboration of a longlist of projects in the Projects Grid. Information in the grid was iteratively improved through internet research, review of secondary literature, investigations either with select project developers or through the network of national consultants. An initial database of over 200 bioenergy projects was screened to remove those in non-target countries, those at very early stages of planning and those outside the BSEAA2 technology and pathway scope. Certain projects outside the technology scale range (i.e. >5 MWe) were retained to provide a sense of the level of commercial interest and activity at this scale and in which sectors this was occurring. Bioenergy for (or from) the tobacco and beer industries was excluded on the basis that these sectors present ethical issues. As a result of this process, the longlist was reduced to 97 projects (49 AD, 48 combustion).

6.2 Pathway pre-screening

The 97 identified projects were analysed to assess the level of commercial activity across the 11 bioenergy pathways to determine those most suitable for further investigation. Pathways with operational projects demonstrate validation in an SSA context and thus provide higher confidence of suitability for replicability and scalability.

Table 20 categorises the operational projects by pathway. Of the 97 projects, 18 AD projects and 12 combustion projects were found to be operational within the BSEAA2 scope of 10 kWe - 5 MWe and TRL 5+. Although the number of operational combustion projects was much higher (37), 25 were ruled out as they were large-scale sugar plants (and one wood-processing facility) not suitable for further consideration (see section 4.1.2).

Table 20: List of operational projects in the BSEAA2 target countries, by bioenergy pathway

	Anaerobic Digestion			Combustion		
Pathway no.	1	3	4	6	7	11
Primary feedstock category	Agro-processing residues	Livestock wastes	Municipal by-products	Forest & plantation wood	Wood processing residues	Agro processing residues
No. of operational projects	9	8	1	3	1	8
Locations of operational projects	Ghana Kenya S. Africa Tanzania	Ghana Kenya Nigeria S. Africa Uganda Zambia	South Africa	Kenya Nigeria Tanzania	Tanzania	Ghana Kenya S. Africa Tanzania Uganda

6 of the 11 bioenergy pathways have operational projects within the BSEAA2 target range. Of these, pathway no. 4 (AD using municipal by-products) was screened out, as this sector has witnessed no commercial success outside South Africa due to the lack of effective legislation or enforcement on waste management, which makes such projects unattractive to investors owing to uncertainty over feedstock supply and ownership, and economic competitiveness. With increasing urbanisation, more awareness of modern waste management practices and adoption of climate charge targets, clearer policies governing waste management are likely to develop, together with better enforcement of waste management standards. Conversion of municipal wastes to energy could then become more attractive to investors, as it already is in South Africa and some OECD countries. This is particularly the case where policies exist to support the generation of electricity (and, in some cases, gas for feeding into natural gas networks) from municipal waste, particularly landfill gas.

6.3 Final pathway selection

The remaining five pathways for which operational projects exist (17 AD and 12 combustion) within the scale range of 10 kW_e to 5 MW_e were analysed in more detail, through the thematic assessments, to inform the final shortlisting of the most promising sub-pathways. The bioenergy pathways for the operational projects are presented in Figure 35 (for AD) and Figure 36 (for combustion).

Figure 35: Operational bioenergy pathways (projects) using anaerobic digestion

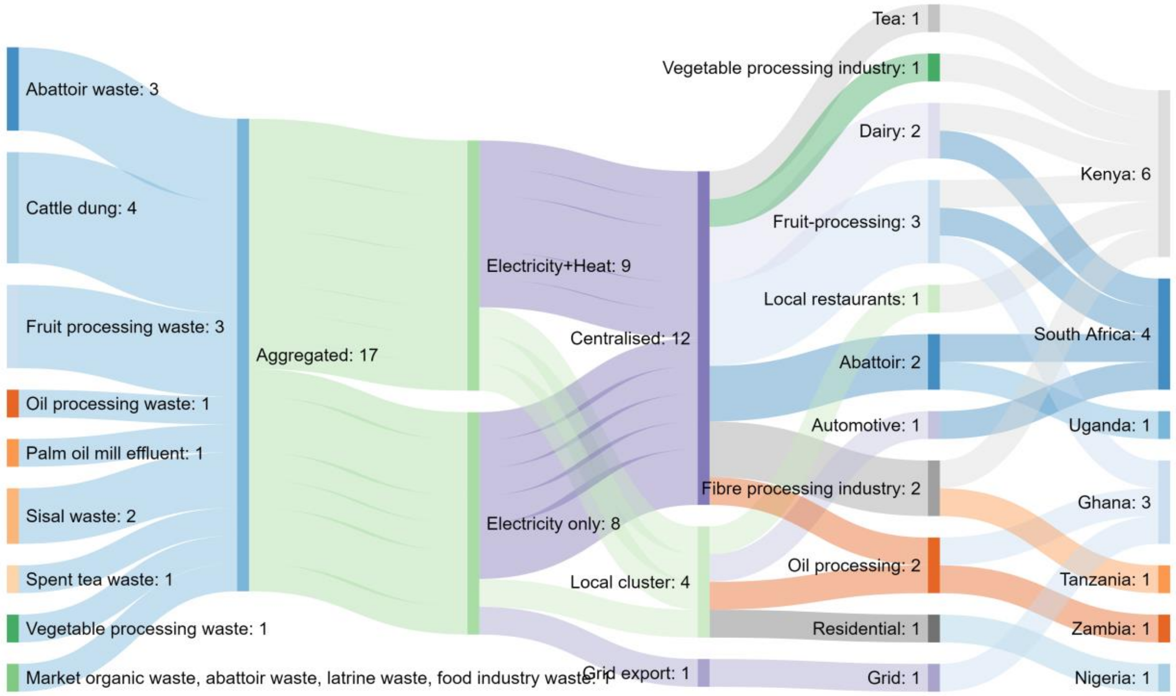
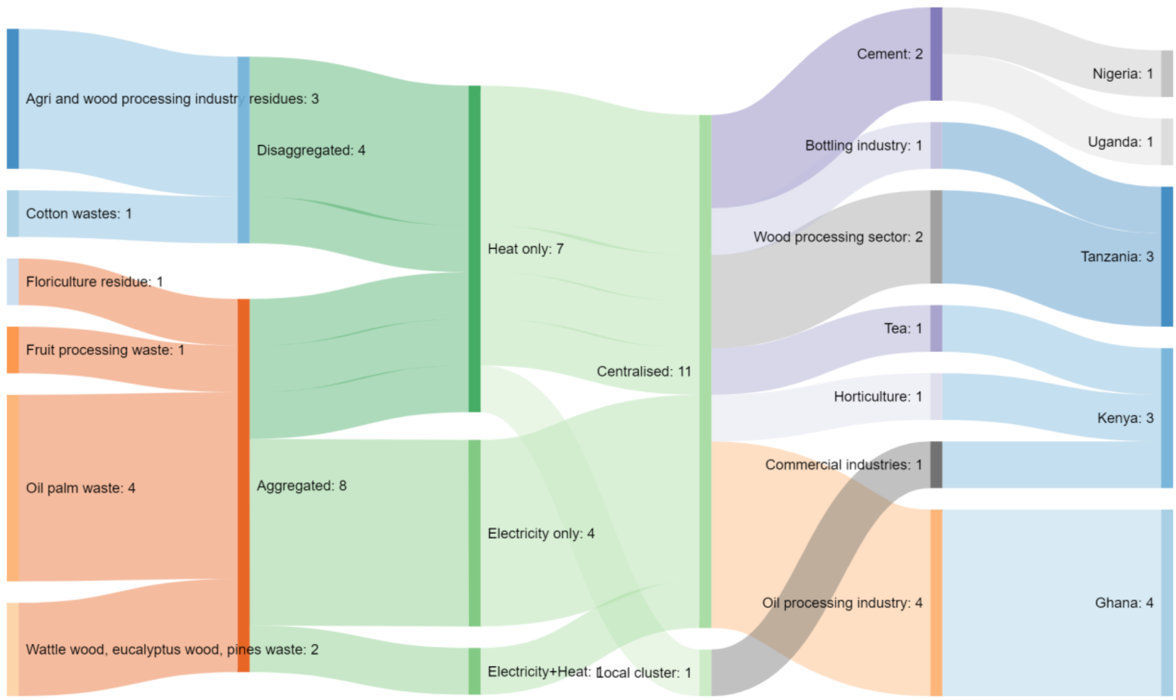


Figure 36: Operational bioenergy pathways (projects) using combustion



The thematic analyses enabled the team to explore the different elements of these pathways from feedstock source through to final end-use, in the context of the specific ventures in the Projects Grid, as well as the institutional, regulatory and market frameworks for bioenergy in the target countries. This provided a deeper understanding of the dynamics of commercial bioenergy success, and the factors that contribute to that success, thus guiding the selection of sub-pathways worth retaining for more detailed investigation during the Stage 3 bottom-up evaluation.

The highlights from each thematic assessment that guide this final selection are presented below.

Theme 1: Biomass resources

- **Agro-processing residues:** This feedstock category offers the most promising commercial opportunities for bioenergy generation from both AD and combustion, having fewer competing uses and utilisation challenges than other pathways. The processing residues from the following agricultural sectors show the highest bioenergy generation potential for the target countries:

  - Fruits;
  - Vegetables;
  - Coffee, cocoa and tea;
  - Oil palm (mill effluent being suitable for AD, empty fruit bunches, trunks and shells being more suitable for combustion); and
  - Fibre crops (particularly sisal and cotton)

  This list reflects the importance of high value agricultural sectors such as fruit production, horticulture, floriculture, palm oil, tea, coffee and organic fibres in six of the target countries (Ethiopia, Ghana, Kenya, South Africa, Tanzania and Uganda). Kenya, South Africa and Ethiopia export fresher horticultural, floricultural and fruit produce than any other countries in SSA.

- **Livestock wastes:** Of the three main livestock waste sources (poultry, cattle and pigs), manure from zero-grazing dairy cattle and from cattle feedlots (the latter predominantly found in South Africa, but, increasingly around the target countries' main cities) present the highest potential for bioenergy generation from AD. Zero-grazing dairy cattle in the five East African countries, particularly Kenya, is providing animal waste for small-scale biogas milk cooling. Pilot investments in larger dairy cattle waste biogas chillers(>10 kW) for milk collection centres are in the works in Uganda and Kenya.[71] [72]

- **Wood residues:** The opportunities in this category are linked mainly to the use of wood processing residues (sawdust) or sustainably sourced residues from (agro-)forestry in the form of briquettes or pellets for direct combustion.

Theme 2: Status of technical development

- **Combustion:** From a technological perspective, there is possible commercial growth potential with sub-3 MW turbines to fill a niche in small-scale CHP systems. The promising sectors at this scale are those generating woody residues from agro-processing (e.g. oil palm, coffee and coconut residues), and from forest plantations and forestry processing (e.g. eucalyptus, wattle and pine).

- **Anaerobic digestion:** Evidence of modification and localisation of European AD technology to suit local contexts in the target countries indicates potential for further innovation and improvement to suit feedstocks, climatic conditions, seasonality and other operating conditions specific to SSA. There is a proven commercial deployment and innovation potential for all the best-known types of bio-digester (complete mix, lagoon and plug flow), so it is recommended that no AD technology type is ruled out for further investigation during Stage 3.

[71] https://simgas.org/projects/biogas-milk-chilling/ Kenya.
[72] https://nl.paulmueller.com/klantcase/melkveebedrijf/making-an-impact-with-milk-in-africa

Theme 4: Supply chain archetypes

- The thematic assessment demonstrates that the most successful and replicable archetype is the 'A1' type, where centrally aggregated feedstocks produce energy for the same facility which produces the feedstock. When a business produces or controls its own biomass production and supply, it has low acquisition costs and low (nor no) aggregation costs. End-use sectors that produce suitable feedstocks include agro-food, livestock and manufacturing (mainly wood processing) industries.

- There is also some activity under the 'D1' archetype, particularly in the tea and cement industries, where expensive, insufficient or unreliable fossil-based energy sources have created demand for locally available bioenergy feedstock for heat-based applications (e.g. drying). This offers promise in the tea industry, based on out-grower fuel production supplying farmer-owned factories, or premium tea producers enhancing their community engagement credentials (which is also of growing importance for other high-value crops such as coffee and cocoa).

- Several successful projects are hybrids of two or more archetypes, with examples in the agro-processing and wood-processing industries. The potential of mixed models is worth exploring in pathways that have already demonstrated, or can demonstrate, this potential.

Theme 4: Economic viability and barrier analysis

- Pathways with a higher number of operational projects provide higher confidence of obtaining realistic cost data. After assessing the operational projects in the Projects Grid, these include:

  a) **AD:** Agro-processing residues (dominated by fruit and vegetable waste, palm oil mill effluent and sisal waste) and livestock wastes (mainly cattle manure and abattoir wastes);

  b) **Combustion:** Agro-processing residues (cotton wastes, oil palm residues, floriculture residue) and wood residues (sawmill and other wood residues from wood processing industries)

- Archetypes that include the use of heat, usually process heat, have been more successful than electricity-only applications. While this does not suggest direct causality, this is worth exploring in sectors with dominant heat demand, such as wood processing and agro-processing industries.

- Archetypes are sensitive to subsidy availability and revenue stream predictability. Countries offering economic incentives and/or bankable PPAs offer higher potential for commercial interest. From an economic perspective, South Africa, Kenya and Ghana (although decreasingly so) offer relatively better economic and regulatory incentives for bioenergy production. Such incentives can motivate producers of the biomass energy to consider expanding its production and extending the additional electricity generated to their workers and/or neighbouring communities.

Theme 5: Institutional, market and regulatory framework

- Bioenergy receives a fraction of the support that governments, donors and national and international investors provide to other renewable energy resources, particularly solar PV and small-scale hydropower. This is a major barrier to the development of bioenergy in SSA.

- South Africa, followed by Kenya, are the 'sweet spots' for bioenergy development, demonstrating the most supportive enabling environment and private sector interest for bioenergy development.

- Ghana, Tanzania and Uganda follow next, but have all reduced their support for bioenergy and small-scale renewable electricity projects, due to oversupply of electricity (Uganda and Ghana), grid-extension in lieu of mini-grids (Tanzania) or achievement of renewables targets (Uganda).

- Nigeria, given its fossil fuel dominance, has not paid much attention to bioenergy. Nonetheless, given large agricultural, livestock and forestry sectors, and the federal government's ambitions for renewable energy and bioenergy (at least on paper), there is potential for bioenergy development if strong regulatory support and finance is provided.

- Rwanda, Ethiopia, Mozambique and Zambia have weak or absent supporting frameworks for bioenergy, with any support mainly targeted at household cooking and other renewable and non-renewable energy sources for electricity generation.

   a) In **Rwanda**, the absence of commercially operational bioenergy projects stems from a strong, consistent focus on small-scale, primarily household bioenergy (improved cookstoves, small-scale biogas and PV rural electrification for off-grid applications), alongside support for hydropower and solar PV for off grid and grid-based electrification.

   b) In **Ethiopia** there has been no bioenergy policy or focus on bioenergy within the scope of the BSEAA2 Project. Although commercial activity and opportunities do exist in Ethiopia's cement and sugar industries, these lie outside the project's scope and scale range. At present, bioenergy is focused primarily on improved cookstoves and small-scale biogas. These technologies, as well as grid extension to rural areas, are the focus of government for addressing Ethiopia's rural and urban household energy situation, with emphasis on reducing deforestation. For the longer-term, however, there are ambitions for large-scale bioenergy projects for grid electrification.

   c) **Mozambique** is also focused on improving charcoal production, raising efficiency in household and support biomass briquettes and other options for household use. Enormous large-scale hydropower resources, and extensive coal and natural gas resources, divert policy attention from bioenergy; indeed, from most renewable energy other than hydropower.

   d) In **Zambia** there has been no focus on bioenergy other than household cooking with biomass and biogas. The ambitious Rural Electrification Master Plan focuses entirely on grid extension, hydropower and solar PV.

The team met in early February to deliberate upon these thematic findings. Each of the five bioenergy pathways, and the list of identified operational projects (as shown in Figure 35 and Figure 36), were analysed in detail, applying the lessons and recommendations from the thematic assessments to collectively assess and agree upon the specific sub-pathways for further analysis in Stage 3.

Nine sub-pathways covering the five primary pathways were chosen that offer the highest potential for commercial adoption and replication across the target countries, whilst also providing sufficient information and insights to support Stage 3 research. This final list of sub-pathways is presented in Table 21.

It should be noted that although South Africa scores highly with respect to its enabling environment and in terms of number of projects, its operating context is very different from the rest of the SSA countries. Several bioenergy sub-pathways in SA context do not appear replicable in other SSA countries (e.g. landfill gas, shopping mall wastes), due to different legislative and enforcement regulatory framework (landfill and solid waste separation requirements) among others. Furthermore, the team decided to prioritise focus countries that despite the lack of strong regulatory and enabling environment, have existing operational projects in those respective pathways. This is because if these projects have managed to succeed in a more difficult enabling environment as compared to South Africa, it potential for replication in other SSA countries will be comparatively higher.

Table 21: Final list of proposed sub-pathways for Stage 3

Feedstock	Feedstock category	Technology	End-use	Primary demand sector	Country[73]	Supply chain archetype
Oil palm mill effluent	Agro-processing residues	AD + gas engine	CHP	Oil processing industry	Ghana (Nigeria)	A1, with potential for grid export
Oil palm shells, fibres & fruit bunches	Agro-processing residues	Combustion + steam turbine	CHP	Oil processing industry	Ghana (Nigeria)	A1, with potential for grid export
Wattle, pine, eucalyptus	Forest & plantation wood (for energy production)	Combustion only	Heat only	Tea (agro) industry	Kenya (Tanzania)	D1
Wattle, pine and eucalyptus waste; sawdust	Wood processing residues	Combustion + steam turbine	CHP	Wood processing industry	Tanzania (Ghana, Nigeria, South Africa)	D1, with potential for local cluster or grid export
Fruit processing residues	Agro-processing residues	AD + gas engine	CHP	Fruit processing industry	Kenya (Ghana, South Africa)	A1, with potential for grid export
Vegetable processing residues	Agro-processing residues	AD + gas engine	CHP	Vegetable processing (agro) industry	Kenya	A1, with potential for grid export
Sisal waste	Agro-processing residues	AD + gas engine	CHP	Fibre processing industry	Kenya (Tanzania)	A1, with potential for grid export
Cattle manure	Livestock wastes	AD + gas engine	CHP	Dairy industry	South Africa	A1, with potential for local cluster or grid export
Coffee husk, coconut husk, wood waste	Mix of agro + wood processing residues	Combustion only	Heat only	Cement industry	Nigeria (Uganda)	D1

[73] Countries in regular font refer to those where concrete operational projects exist for that sub-pathway and reliable data can be obtained. Countries in brackets indicate those where additional projects exist or likely to exist (given the presence of that industry) thus offering potential for additional country missions subject to budget considerations and if suitable contacts can be established.

7 Summary and conclusions

Stage 2 enabled the team to focus on a broad range of themes and projects that have not only set the stage for more in-depth analysis of the shortlisted pathways during Stage 3, but have also provided valuable insights for those looking to invest in bioenergy in the range and scope considered by this project.

- **Theme 1** provided a robust understanding of the **bioenergy resource potential** across the agriculture, livestock and forest sectors in the target countries. **Crop harvesting residues** were found to offer the highest potential biomass volume, but there is limited aggregation and strong competing uses so they are not the optimal feedstock category for bioenergy. **Agro-processing residues** are a smaller feedstock source but represent a stronger commercial opportunity, with better aggregation and fewer competing uses. The most promising feedstocks include residues from the processing of fruits and vegetables, coffee/cocoa/tea, oil palm and fibre crops, particularly sisal. The use of sugar residues for bioenergy is already commercially successful and presents little additional scope within this project. Opportunities for commercial energy generation from **livestock wastes** range lie with dairy farms or cattle feedlots. Opportunities for **wood residues** lie in the wood processing industry, as wood sources directly from plantations or managed forests poses challenges in terms of competing uses, sustainability and management.

- **Theme 2** provided an overview of the **technological landscape** of AD and combustion, exploring innovation and adaptation opportunities for SSA. It was found that in the **AD sector** there is proven commercial potential for several biodigester technologies within the desired scale range, with innovation and adaptation potential for specific feedstocks and conditions found in SSA. No AD technology type is ruled out for further investigation in Stage 3. For **combustion-based bioenergy**, incremental technology innovation for heat-only applications, and for steam turbines at large scale, falls outside the scope of interest for BSEAA2. However, there may be innovation potential with sub-3 MW turbines, which could fill a niche for small-scale CHP systems as global demand grows for decentralised heat and power from renewables. The promising sectors at this scale are those generating woody residues from agro-processing (e.g. oil palm, coffee and coconut residues), and wood and wood residues from plantations and forestry processing. The uptake potential of dispersed, small-scale plants may be of interest to DFID. Looking beyond technology innovation, there is also potential for developing feedstock supply chains for combustion-based pathways that can bring wider development impacts than centralised, in-house feedstock sourcing operations. This offers promise in the tea industry.

- **Theme 3** set out a bioenergy supply chain archetype framework to examine where commercially operational projects are clustered in terms of supply and demand, providing a clearer picture of the **business dynamics** of each pathway. The overwhelming majority of operational AD and combustion-based bioenergy projects in the target countries fit into archetype ‘A1’, meaning aggregated feedstock supply and centralised energy demand. When a business produces or controls its own biomass production and supply, it is clearly in a strong position, with low (or negative) acquisition costs, no or low aggregation costs, and a long term, secure supply of feedstock. AD and combustion projects based on agro-processing residues generating energy primarily for self-consumption account for 80% of the operational projects identified. Going beyond self-use to selling energy makes sense only when the enabling environment for exporting electricity to the grid or selling via wheeling agreements is supported by a political, regulatory and financial framework that makes it easy to capture the extra value from such sales. There are limited examples of this model but exploring them further during Stage 3 will provide insights into how barriers to replication could be overcome.

- **Theme 4** used the archetype framework to understand the **economic viability** of deploying bioenergy in the target countries, and the economic barriers and incentives available to commercial bioenergy developers and investors. In calculating the levelized cost of electricity from different bioenergy pathways, generic references suggest a breakdown of 31% feedstock, 50% CAPEX and 19% OPEX for combustion-based projects, and a range of 10 to 18% feedstock, 36 to 75% CAPEX and 20 to 45% OPEX for AD-based projects. Supply chain archetypes that include the use of heat tend to be more successful than those producing only electricity. A key success factor is the existence of rural electrification projects (with potential subsidies) and the possibility of electricity sales via Power Purchase Agreements under FIT schemes. The aggregated supply of feedstock is another important success factor as it implies reduced or near-zero feedstock aggregation and transport costs. The combined GHG emissions from generation of electricity have fallen enormously across the target countries over the past 15 years. If more attention were paid to bioenergy investment, the benefits for climate change, employment, income generation, health and other externalities would be substantial. The development of inclusive bioenergy pathways, particularly in the farming sector, can also generate local income and improve livelihoods in rural or peri-urban areas.

- **Theme 5** profiled the **institutional, regulatory and market frameworks** for supporting bioenergy in each target country, giving an in-depth view of the realities facing developers and investors. It was found that South Africa is the leader in SSA in almost all institutional, regulatory and market areas affecting bioenergy investment and commercial operations. Kenya is next among the target countries. It is in bioenergy policies and regulation, its markets are relatively open, and it has an open economy with a high degree of international competitiveness. Rwanda ranks just below Kenya and using various institutional, regulatory and market framework indices, but it focuses on household and small-scale bioenergy rather than commercial bioenergy. Uganda ties for third using the aggregate Theme 5 index. It was an early starter in setting up the policy, regulatory and financial framework to promote renewable energy and has exceeded its targets on both the proportion of renewable electricity and its absolute amount of electricity generated, leading Government to pull back almost all financial support for renewable electricity in 2018. Ghana ranks next, largely due to the government's lack of ambition on renewable energy, and even less on bioenergy. With the discovery of considerable oil and gas reserves, its electricity mix has shifted to natural gas with such a surplus of new generation that it is cheaper for potential bioenergy producers to buy cheap grid electricity than to generate it themselves. Tanzania and Zambia rank next with relatively low average indices, followed by Ethiopia and Nigeria. Mozambique ranks lowest.

Despite many obstacles, commercially successful bioenergy projects can be found in all countries except Rwanda, Ethiopia, Zambia and Mozambique. Nine commercially viable bioenergy sub-pathways have been identified, with representative projects spread over the remaining six countries, providing a solid basis for bottom-up evaluation of bioenergy pathways in Stage 3.

8 Next steps: Stage 3 bottom-up evaluation

8.1 Stage 3 summary

Stage 3 is intended to commence in April 2020 and run to the end of March 2021. The five bioenergy pathways prioritised at the end of Stage 2 together cover at least five countries. The team's work on each pathway will focus on the sub-pathways (each with at least one project from the Projects Grid) proposed at the end of Stage 2, to investigate the replication potential of these bioenergy pathways in other SSA countries. Task E, gasification, will run in parallel.

The Stage 3 methodology will be build upon the five themes explored during Stage 2.. Each thematic team will carry out in-depth research and evaluation of the pathways using the identified operational projects as primary data sources. An in-depth assessment will be made on how these bioenergy pathways, using the bioenergy sub-pathways as examples, could be operationalised in other target countries. This will be based upon the findings, lessons and recommendations generated from the in-depth ('deep dive') research carried out during Stage 3, based on operational projects in selected target countries). The team will propose how the lessons learnt and critical success factors from these operational bioenergy pathways and sub-pathways could be applied to the same bioenergy pathways in other target SSA countries.

8.2 Stage 3 approach

As set out in the Inception Report, the following tasks will be addressed using the five shortlisted bioenergy pathways from Stage 2, with the corresponding sub-pathways (projects) providing context, information and insights for recommendation on ways to improve the success of bioenergy in SSA. These tasks comprise:

Theme 1: Technical Assessment: The thematic team will carry out and prepare an assessment of the technical feasibility of the five prioritised bioenergy pathways and the sub-pathways (projects) covered in their respective countries. A Technical Assessment Report will be prepared covering:

- An overview at region/country level of availability and properties of the shortlisted feedstocks and infrastructure for bioenergy distribution.
- A suite of feedstock-technology combinations with information on energy-mass balance, energy output and potential for performance improvement.
- A multi-criteria analysis of wider sustainability impacts and risks; and,
- In case enough open-access high quality and verified data is available, a set of multi-layer geo-spatial maps of potential hot-spots for bioenergy development in the ten target countries.

Theme 2: Technology Supply Chain Evaluation: The team will carry out a study covering an evaluation of the capacity of technology value chain and support network for five selected bioenergy pathways-covering at least five countries. A Supply Chain Evaluation Report will be prepared along with tools/practical resources covering:

- Market maps of identified bioenergy technological value chains
- Database of current technology and support providers both within SSA and offshore (where a significant African interest is evident).

Theme 3: Commercial Assessment: The team will provide an assessment of suitable financial models, risk mitigation instruments and commercial pathways for shortlisted bioenergy pathways and business models in various contexts, covering at least five countries. The theme outputs will include:

- Handbook/guidelines on attractive business models and financing methods.
- Spreadsheet model to rank most attractive business models and financing methods
- Financial tool to evaluate business model viability (e.g. Internal Rate of Return, Net Present Value)

Theme 4: Economic Analysis: The thematic team will provide an investment appraisal of selected bioenergy technologies, covering five project-specific economic assessments of the Stage 2-selected bioenergy pathways in the countries (sub-pathways) selected. An Economic Analysis Report will be prepared and a Life Cycle Cost (LCC) analysis toolkit will be developed.

Theme 5: **Evaluation of enabling environment**: The team will provide an evaluation of policy, regulatory and market factors influencing the development, deployment and expansion of investigated bioenergy pathways, in the context of the countries in which the priority pathways exist. An Enabling Environment Evaluation Report will be prepared.

Gasification synthesis: A synthesis study, which commenced during Stage 2, will provide a qualitative assessment of key project related factors hindering gasification and an outline of key enabling conditions required to ensure viability in SSA. A Report on Gasification in SSA will be prepared with tool/practical resource covering**:**

- A Screening Checklist and Decision Tree to inform potential investors regarding the key elements and preconditions needed for successful investment in gasification in SSA.

Annex 1: Projects Grid categories

The column titles show the different parameters against which projects are recorded in the Projects Grid.

Feedstock	Feedstock category (FAO)	Technology	Type of AD system
	Agro-processing residues	Combustion + steam turbine	Complete mix
	Crop harvesting residues	Combustion + other secondary conversion tech	Lagoon
	Livestock wastes	AD + reciprocating engine	Plug-flow
	Municipal by-products	AD + other secondary conversion technology	Other
	Purpose grown/novel feedstocks	AD only	Unknown
	Forest and plantation wood	Gasification + gas engine	
	Wood processing residues	Combustion only	
	Wood harvesting residues		
	Energy crops		
	Material Waste		

Primary Energy Vector	Supply	Demand	Target demand sector		
			Level 1	Level 2	Level 3
Electricity	Aggregated	Centralised	Buildings	Agro-food	
Electricity + heat	Disaggregated	Grid-export	Energy conversion	Buildings	
Trigeneration (electricity + heat + cooling)		Local cluster	Farming	Farming	
Heat only			Industry	Food processing	
				Grid	
				Manufacturing	

Location	Focus country	Region	Project developer / owner/entity	Technology provider	Technology provider type (AD)
	Ethiopia	East Africa			European
	Ghana	Southern Africa			South African
	Kenya	West Africa			Local with imported components
	Mozambique				
	Nigeria				
	Rwanda				
	South Africa				
	Tanzania				
	Uganda				
	Zambia				

Capacity	Status	Project description	Financed by
	Not operating/stranded		
	Feasibility study		
	Operational		
	Planned		
	Status unclear		
	Under construction		

Annex 2: Feedstock category definitions

Feedstock categories linked to Anaerobic Digestion (adapted from (IEA/FAO, 2017))

Feedstock category	Description
Agro-processing	Biomass produced in food, fibre and oil processing industries: bagasse, palm oil mill effluent, sisal waste; fruit pulp; unprocessed liquids, flower wastes, nut shells, etc.
Crop harvesting residues	By-products from agricultural activities left in the field: maize cobs & stalks, cotton stalks, sugar cane trash, rice straw, etc
Livestock wastes	Manure, litter, slaughterhouse effluent & other waste from cattle, pigs, poultry, etc
Municipal by-products	Solid and liquid municipal biomass materials from households and industry. Includes: a) organic fraction of Municipal Solid Waste (MSW) i.e. kitchen waste, waste from vegetable markets, etc.; b) waste waters, i.e. sewage sludge, industrial waste waters; and, c) landfill gas
Purpose-grown/ novel feedstocks	Feedstocks either grown specifically for energy purposes, or wild crops harvested specifically for energy production. Includes CAM plants for instance

Feedstock categories linked to Combustion (adapted from (IEA/FAO, 2017))

Feedstock category	Description
Forest and plantation wood	Wood from forests, shrubs and other trees purpose grown for direct use as fuel or with minimal processing (wattle, eucalyptus, acacia etc)
Wood processing residues	Solid biofuels produced from wood processing activities (e.g., sawmills, furniture production, other wooden construction materials; etc.
Wood harvesting residues	Residues from felling or forest management practices (such as upper logs, branches and different off- cuts) which are not removed from the forested area.
Material waste	Waste generated during construction activities; surplus material and waste from the end of building life.
Herbaceous energy crops	Purpose-grown crops (such as miscanthus, Prosopis juliflora, elephant grass, etc.) used specifically for energy production.
Agro-processing residues	Lignocellulosic residues from agro-processing that are fibrous and mostly dry, e.g., bagasse, coffee husks, cocoa pods, macadamia shells, cashew nut shells, and other crop residues.

Annex 3: AD technology providers and developers in target countries

Name	Head office	System size	Technology specifications	Services offered	Size	Projects in SSA	Presence in Africa?
Agri Komp	Germany	75 kW to 2.5 MW	1) Indi-plant flex: 100 kW – 2.5 MW, individually planned and constructed. 2) Agriselect: 75-250 kW for slurry or slurry/ manure; 3) Gullewerk Flex: up to 250 kW. Ready to run small-scale biogas plant.	EPC and O&M services, techno-economic assessment, lab services	Approx. 500 employees internationally. >950 plants (over 50% in Germany).	Biogas Power Holdings (East Africa), Kilifi, Kenya	No
AKUT	Germany	NA	1) Industrial size 'Nawaro' plants >300 kW. 2) Small fixed dome agricultural plants (16-124 m^3) for developing countries for cooking and lighting. 3) Agricultural plants 30-100 kW for developing countries.	Design, financing, contracting, concepts, feasibility studies, building applications, planning, technical design, tendering, construction; management, engineering, support	Unknown	James Finlay tea, Kericho, Kenya.	No
Albers Alligator	Netherlands	Not specified	1) Double-membrane gas storage system up to 5,000 m^3 / 60 mbar. 2) Single-layer gas storage system up to 50 mbar. 3) Double-layered gas storage system for covering fermenters up to 15 mbar on silos made from concrete, steel or wood.	Specialise in plastic films and coated fabrics. Produce flexible storage systems up to 10,000 m^3 for water, slurry, biogas and industrial liquids.	50 employees (across all services). Operate in over 35 countries.	12 kW project developed by Fact Foundation and GRS Commodities in Ssese Islands, Uganda	No
Anaergia	South Africa	Not specified	Helios digester for easily biodegradable organic waste. Triton digester for materials needing primary and secondary fermentation	Equipment design, process engineering, manufacturing, project integration, financing and project execution to	13 office locations (incl. 4 manufacturing facilities). Over	1. Operation of AD plant at Bronkhorstspruit, S. Africa for Bio2Watt 2. Supplied tech to	Yes

Name	Head office	System size	Technology specifications	Services offered	Size	Projects in SSA	Presence in Africa?
			such as energy crops. Additional solutions incl. effective solids feeding, efficient pre-treatment, High Solids PSM SMART Mixing, digestate and nutrient management. Pumps, mixers and separators supplied by a subsidiary, UTS Products	efficiently deliver effective solutions for MWS, wastewater, and agro-food resource recovery facilities. Wide range of delivery options from the sale of equipment and services, to design-build-own-operate approaches.	1,600 installations on 4 continents.	large scale waste-to-energy plant in Cape Town using MSW.	
Avenam Links	Nigeria	Small to large scale (upper limit not known)	1. Plants comprising greenhouse made with hollow sunlight sheet on metal frame, combo membrane digester + gas storage bag, stainless-steel sink and outlet, biogas filter and gas pump. Options to add feeding pump, circulating pump, shredder, electric heater. 2. Anaerobic baffle reactor for sewage treatment. Settling chamber for larger solids followed by 3 up-flow chambers.	Turnkey EPC provider feasibility studies, engineering designs, construction, operations and maintenance	4 in management team	McNichols poultry farm, Ogun State, Nigeria	Yes
Bio2Watt	South Africa	Large plants (1-5 MW)	Two known projects are conventional continuous stirred tank reactors, known for reliability and efficiency.	A project developer taking early development risks from feasibility stage, and retain full ownership up to financial closure	Unable to verify.	1. Bronkhorstspruit Biogas Plant; 2. Cape Dairy Biogas Plant.	Yes
Bioenergy Berlin	Germany	Not specified	None provided.	Planning, design and construction supervision of biogas facilities, mainly for agricultural waste treatment.	Set up in 2004. Germany and China offices. Small specialist firm.	1. Hale sisal plant, Tanzania. 2. Feasibility study in Tanzania for additional sisal estates. 3.	No

Name	Head office	System size	Technology specifications	Services offered	Size	Projects in SSA	Presence in Africa?
						Feasibility study in Benin for AD plant using faecal sludge.	
Biogas SA (now defunct)	South Africa	Small, agricultural and commercial scale	Agency agreement with Sauter Biogas (Germany) to use their 'sprinkled, not stirred' technology.	1) Commercial turnkey projects; 2) Feasibility studies; 3) Agent for Schumann Tank & Stahlbau (digester panel tanks), Wiefferink (flexible foil covers and storage solutions) and Progeco Biogas (flares and biogas conditioning equipment).	Was a one-man show (Mark Tiepelt), founded in 2009. Tiepelt now working as an AD consultant.	0.4 MW plant at Morgan Abattoir, Springs, S. Africa	Yes
Cape Advanced Engineering	South Africa	Seems to be sub-1 MW focused	No details available. Interview with CEO suggests digestor based on German tech, locally adapted, with gas engines procured locally.	Research, design, development, prototyping and testing services to automotive, marine and energy production industries.	Started in 1993 at Stellenbosch University. Set up independently in 2008.	Darling Dairy Farm, South Africa	Yes
CombiGas	Denmark	Not specified	Thermophilic process, 52°C; feedstock intake flexibility; GasMix system; fully automated with low OPEX	1. Feasibility assessment; 2. Project design incl. technical solutions, equipment, construction work; 3. Construction advisory and supervision; 4. Commissioning (including staff training); 5. Support and optimisation.	Relaunched in 2017 by Frank Wennerberg, Kent Skaanning and Chinese investor. Focus on development, design and support.	Bronkhorstspruit Biogas Plant, South Africa	No

Name	Head office	System size	Technology specifications	Services offered	Size	Projects in SSA	Presence in Africa?
iBERT (liquidated early 2020)	South Africa	NA	Biogas Express Reactor Technology developed by Innsbruck University. Uses natural forces for mixing, saving on costs. Offer DIY systems with assembly and construction plans.	Technology, bio-audit, lab services	8-11 staff	6 projects in Africa from 18 to 210 kW	Yes
Mattla Engineering Solutions	South Africa	Not specified	NA	Substation design, control plant design, technical audits, distributed generation design, technical advice on grid code compliance, interpretation of industry standards, SCADA and metering solutions.	Size unclear. Offices in Pretoria and Johannesburg	1. Bio2Watt Bronkhorstspruit plant. 2. Bio2Watt Cape Diary (grid code compliance and technical advisory.	Yes
Nijhuis Industries	Netherlands	Not specified	1. AECOMIX-TAURUS: Complete mix reactor suitable for all types of waste, manure, sludge and RE crops. 2) AECOMIX-AnMBBR: Simple system that fits into any tank. 3) AECOMIX-DGF: For food and beverage plants to treat raw wastewaters with high TSS and FOG.	Variety of services related to sustainable water use and resource recovery. In-house solutions and services such as oil-water separators, dissolved air flotation and dissolved gas flotation units, biological treatment systems, recycling, disinfection and sludge dewatering systems.	Work in over 110 countries and employ 240 water specialists.	Complete mix digester for Safi Sana International, Ghana.	No
Renen	South Africa	Not specified	Induced blanket reactor prototype, based on US design.	Project management, power auditing, research, green consulting.	2-10 employees Founded in 2010.	Midlands Biogas Project, KwaZulu-Natal, S. Africa	Yes

Name	Head office	System size	Technology specifications	Services offered	Size	Projects in SSA	Presence in Africa?
Sauter Biogas	Germany	75 kW to >1 MW	1) SM Mini LEA: Compact, suitable for all biomass types, <75 kW. 2) SB Midi: Mid-range, compact, 150 - 800 kW. 3) SB Maxi: 0.5 - 1.5 MW. 4) SB Mega: >1 MW. Patented sprinkler system requires no agitators.	Consultancy, planning, construction, commissioning, remote support	6 staff. 50 installations, of which 42 in Germany.	James Finlay tea, Kericho, Kenya	No
Snow Leopard	Germany	10 kW - 4 MW	High Performance Temperature Controlled biogas plant. Small modular unit. Front-end batch hydrolysis treatment to prepare fibrous biomass makes it possible to digest nearly every biomass.	Consultancy, construction and training services for biogas-based waste management and energy generation.	Founded by Walter Danner, UN biogas consultant, and Katharina Danner, RE engineer. 2-10 employees. 360 kW plant in Bavaria; 499 kW plant in UK.	2 MW biogas plant, Gorge Farm, Kenya.	No
Southern BioPower	Zambia	Not specified	Underground fixed-dome digesters made from local materials, without need for heating and stirring.	Consultancy, construction, training.	Not known	Agro-industrial waste-to-energy project in Zambia (for BORDA). No firm evidence of implementation.	Yes
Tropical Power	Kenya	Not specified	Technology supplied by Snow Leopard.	Based in Oxford with subsidiaries in Ghana and Kenya. EPC company developing power plants that use AD, biomass boiler systems and solar PV. Associate companies Biojoule and Solarjoule contract Tropical Power to build utility-scale power plants.	4 management staff	2.2 MW plant at Gorge Farm, Kenya. 5 MW plant at Kpong Farm, Ghana (planned). 0.5 MW biomass boiler system at Liki River Farm, Kenya.	Yes

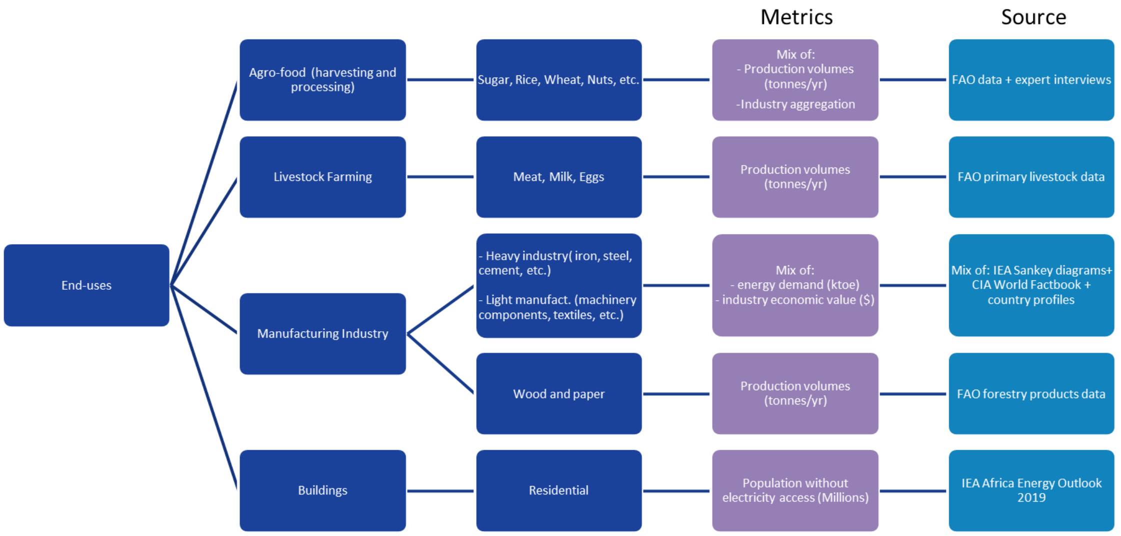
Annex 4: Manufacturers of small-scale steam turbines

Name	Head office	System size	Technology specifications/details
MAN Diesel & Turbo	Germany	0.5-180 MW	MAN is one of the leading suppliers of industrial steam turbines worldwide with a comprehensive range of products and services. The first industrial steam turbine was supplied in 1904. MAN, steam turbines can be used for both power generation and mechanical drive applications and cover a 1-180 MW range. Possible applications include waste to energy, biomass/pulp and paper, geothermal, CSP, combined cycle, waste heat recovery and refineries. Design features: • Various turbine models and sizes are available, including condensing type turbines, backpressure turbines, admission/extraction turbines and saturated steam turbines • Adaptable, space-saving arrangement • International design and manufacturing standards (e.g. API 612) • Modular arrangement for fast installation and service • Different turbine types available from MST 10 to MST 120 (8 in total)
Dresser Rand-Siemens	Germany	10 kW-25 MW	With the Dresser-Rand steam turbine portfolio, Siemens has the most comprehensive range of API turbines available on the market, including: • Standard single stage turbines for pump, fan & small compressor drives according to API 611 General Purpose (GP) standard; • Standard and engineered single stage turbines as generator drives for waste heat recovery applications; • Engineered single stage turbines for applications according to API 611 (General Purpose — GP) or API 612 (Special Purpose— SP) standards; • Standard multistage turbines for larger pumps, fans & compressors to API 611 or API 612 standards, or for power generation; • Turbines for geothermal plants; and • Turbines for expansion of ORC and process fluids
Elliot Steam Turbines		15 kW-100 MW	Elliott steam turbines are rated for inlet steam conditions up to 2000 psi/1,005°F and speeds up to 20,000 rpm. They come in a variety of sizes ranging from small, 20 HP (15 kW) single-stage units, to large 135,000 HP (100,000 kW) multi-valve, multi-stage extraction condensing units. These units can be built to API standards and customized to meet customer specifications.
Mitsubishi Hitachi Power Systems	Japan	Up to 40 MW	Amongst the available steam turbines, **Geared turbines** relate best to the scale/characteristics of the project’s scope. Geared turbines are used for power plants up to approximately 40 MW. A speed reduction gear is installed between the generator and turbine, allowing the turbine to be designed smaller while operating at high speeds. Due to its small frame and high operating speed, geared turbines offer the following advantages over direct-coupled turbines, higher efficiency, smaller initial investment, easier maintenance, shorter delivery lead time, and smaller space requirements. Steam conditions: Up to 12.5 MPa / Up to 541°C
G-Team AS	Czech Republic	80 kW - 5 MW	Six models from 80 kW (TR HI 150) to 5 MW (TRM)

Annex 5: Demand sector analysis

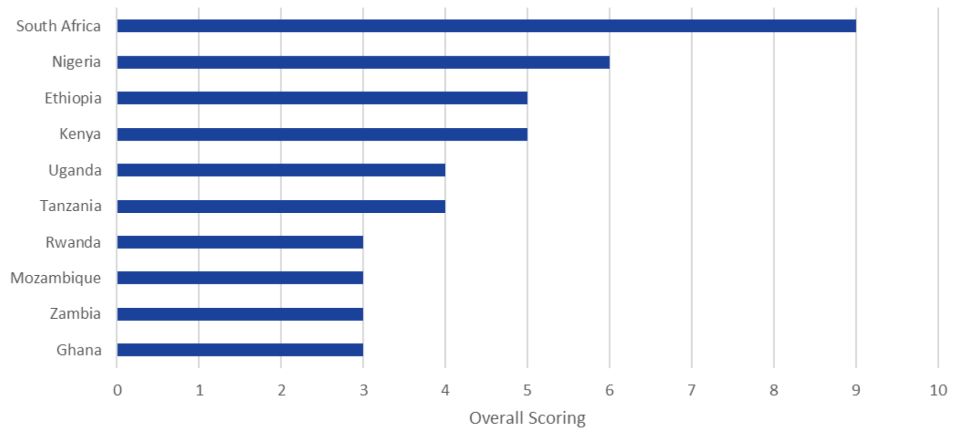
The figure below provides an expanded overview of the key end-use sectors linked to the different bioenergy pathways. This data was compiled based on an assessment of different up-to-date secondary data sources, information in the Project Grid and consultations with the national experts.

Segmentation of end-use sectors



Sources: Agro-food industry (FAO, 2017), Farming Industry (FAO 2017), Manufacturing Industry (IEA World Energy Balances), Wood and paper (FAO, 2018), Buildings (IEA, 2019)

Scoring results for the farming sector. The overall score of each country is the sum of the score for meat, dairy and eggs



Source: E4tech analysis based on FAO primary livestock production data (FAO, 2017)

Rank	Overall	Meat	Dairy	Eggs
#1	South Africa	South Africa	Kenya	Nigeria
#2	Nigeria	Nigeria	Ethiopia	South Africa
#3	Kenya	Kenya	South Africa	Tanzania

Annex 6: Economic terminology and cost categorisation

Under Theme 4 (economic viability assessment and barrier analysis) is it necessary to define a common cost benchmarking language.

General cost benchmark language

Three main cost terms are typically found in a bioenergy project. These are the upfront capital investment, the operational costs (including the O&M costs) and the revenue stream.

These can be defined as follows:[74]

- **CAPEX** (Capital Expenditures): money that a company spends on land, buildings, and equipment that it uses to produce products and provide services.
- **OPEX** (Operating Expenditures): all the costs relating to producing a company's goods and services.
- **Revenue streams**: the money coming into a company from a particular activity over a period of time, or the activity itself. In an LCC grants can be incorporated as (CAPEX) cost-reduction factors, while sales income (either regulated - e.g. PPA, feed-in tariff – or non-regulated – heat sales) can be incorporated as OPEX cost-reduction factors.

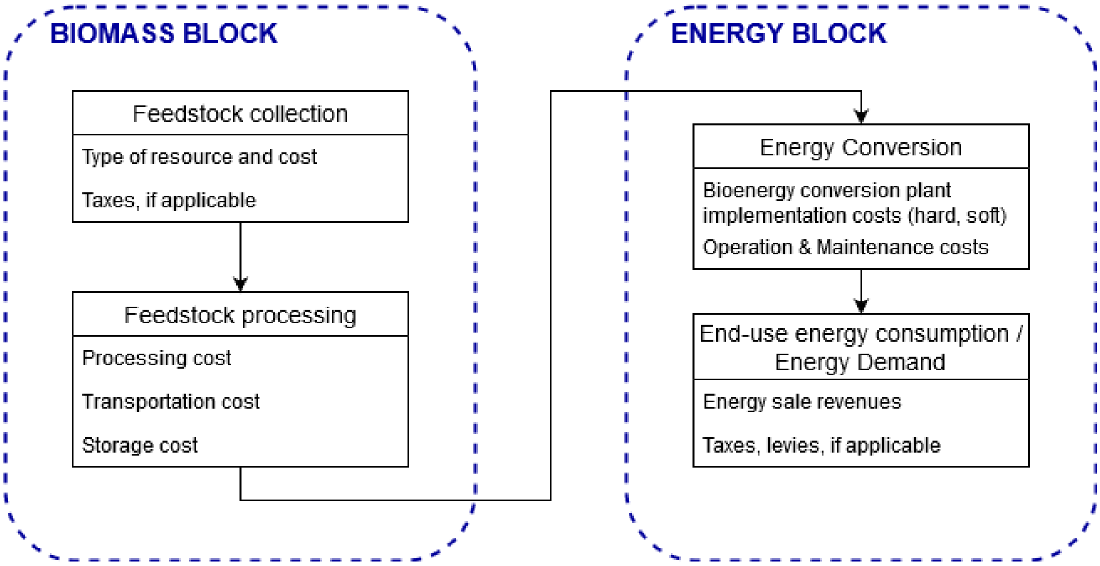
These are typically found at the initial stage of the project, in the case of the CAPEX; and repeated on annual basis, in the case of the OPEX and the Revenue streams.

However, with bioenergy projects, it is a common approach to see this process in four stages from the point of view of bioenergy conversion to energy.

The following graph shows the typical steps in a bioenergy pathway with the identification of relevant items for cost characterisation; the pathway has been broken down in two main “blocks”: the **biomass block** and the **energy block** (see figure below)

[74] https://dictionary.cambridge.org/dictionary/english/

Bioenergy pathway generic steps



CAPEX and OPEX terms might be found in each block. These CAPEX and OPEX costs might be, in turn, broken down in two categories: **"Hard" costs** and **"Soft" costs**.

Hard Costs

This category refers to goods – including equipment – and services, i.e. the products and services that are bought and sold in an economy according with the Cambridge Business English Dictionary. Also according with the same source, "Hard" costs might be defined as the money paid for building supplies and the work involved in building[75].

The different cost terms or parameters instrumental to define a sound cost benchmark that have been identified in each bioenergy conversion process step are listed below, together with their benchmark.

1. **BIOMASS BLOCK**:
    a. Feedstock collection:
        i. Feedstock purchase cost: [$/ton].
        ii. Feedstock Heating Value, usually the Lower Heating Value (LHV): [MJ/ton].
    b. Feedstock processing:
        i. Required feedstock processing cost: [$/tons].
        ii. Processed feedstock Heating Value (typically LHV): [MJ/ton].
        iii. Feedstock storage cost: [$/tons]
        iv. Transportation cost, if required: [$/(ton·km)].
2. **ENERGY BLOCK**:
    a. Conversion:
        i. Conversion plant upfront investment cost, i.e. the CAPEX: [$/kWth] or [$/kWe] (thermal, electrical).
        ii. Conversion efficiency η_e η_{th}: [%] according with wattage.
        iii. Conversion technology service life.
    b. End-use energy consumption or energy demand:
        i. Energy use costs: [$/kWh$_{th}$] [$/kWh$_e$] (thermal, electrical).
        ii. Taxes, fees: [$/kWh] as % of sold kWh.

[75] https://dictionary.cambridge.org/dictionary/english/hard-cost

Soft Costs

This category refers to the money that is spent on labour, services, transport, etc. rather than on physical equipment[76].

Some general soft costs include:

1. Use cost: Maintenance (goods and labour), other operational costs: variable costs [$/kWh$_{th}$] or [$/kWh$_{e}$] (thermal, electrical) and fixed costs [% of CAPEX].
2. General labour cost: [$/person month] depending on skills level.
3. Project development: [$/kW] or [%] of overall hard costs.
4. Logistics (international shipping costs, including customs; insurance, local (road) transport): [$/kW] or [%] of overall hard costs.
5. Storage, if needed, of the conversion technology: [$/kW] or [%] of overall costs.
6. Industrial benefit: [%] of overall costs.
7. Avoided costs of new infrastructure (e.g. grid extension): [$/kW].

Overall cost benchmarks for a comparative analysis

Hard costs, specifying if they belong to CAPEX (i.e. one-off costs) or OPEX (recurrent costs of operation), and other informative parameters relevant for biomass pathway cost characterisation are summarised below:

Biomass pathway characterisation hard costs (CAPEX and OPEX) and informative parameters

Cost category OR informative parameter	Cost category	Reference unit
Feedstock collection		$ / t and $ / MJ
Feedstock acquisition cost	OPEX	$ / t
Feedstock type and quality: type of biomass feedstock and heating value - Heating value of the feedstock - Density	N/A	% MJ / t kg / m3
Taxes, if applicable	OPEX	$ / t
Feedstock processing		$ / t and $ / MJ
Processed feedstock cost	OPEX	$ / t
Processed feedstock type and quality: - Lower Heating Value - Density	N/A	MJ / t kg / m3
Feedstock storage cost	OPEX	$ / t or $ / m3
Transportation cost	OPEX	$ / (t·km)
Taxes, if applicable	OPEX	$ / t
Conversion		
Bioenergy conversion technology upfront cost	CAPEX	$ / kW
Biomass electrical and/or thermal conversion efficiency η_e, η_{th}	N/A	%
Conversion technology service life	N/A	Years
End-use energy consumption or Energy demand		$/kWh$_e$,$ /kWh$_{th}$
Energy consumption price	OPEX	$/kWh$_e$, $/kWh$_{th}$
Taxes, if applicable	OPEX	%

[76] https://dictionary.cambridge.org/dictionary/english/soft-cost

Additionally, the "soft" costs, specifying if they belong to CAPEX (i.e. one-off costs) or OPEX (recurrent costs of operation), as well as related informative parameters are shown below:

Biomass pathway characterisation soft costs (CAPEX and OPEX) and informative parameters

Cost category OR informative parameter	Cost category	Reference unit
Feedstock collection		$
Productivity of feedstock collection	N/A	t / hour
Labour costs	OPEX	$ / person-month
Feedstock processing		$ / ton and $ / MJ
Productivity of feedstock processing	N/A	t / hour
Labour costs	OPEX	$ / person-month
Conversion		
O&M costs	OPEX	$ / kWh and / or $ / year
Labour costs	OPEX	$ / person-month
Project development	CAPEX	$ / kW
Shipping costs, including customs, insurance and transportation and installation costs	CAPEX	$ / kW
Storage, if needed, of the conversion technology	CAPEX	$/kW or % tech. acquisition cost
Industrial benefit of the project developer / installer	CAPEX	% of overall costs
End-use energy consumption or energy demand		
Administrative and management costs of energy export	OPEX	$ / person-month

Annex 7: Bioenergy pathway cost benchmarking

Feedstock Cost

At the current stage of the project, feedstock cost is closely dependent on the supply chain archetype. In particular, the supply side of the pre-defined supply chain archetypes will determine whether the feedstock cost can be zero or almost zero or significant costs shall be expected. Therefore, for the three **supply chain archetypes with aggregated supply, the feedstock cost is assumed to be negligible** whereas for the three **supply chain archetypes with disaggregated supply, acquisition and transportation costs** will be considered.

It is noteworthy to mention that at the current stage of the project, this rule of thumb is being applied in order to provide relevant input on Projects shortlisting. However, during Stage 3 of the project, detailed study on the **market value and opportunity cost of feedstock and acquisition costs** – if any – shall be included into the analysis whenever necessary.

The **transportation costs** show a wide variability depending on several factors, including the geography (directly affecting the type of road or path), the costs of transportation fuels of the country, the regulatory regime or market structure.

Figures provided in a report from the World Bank (Teravaninthorn and Raballand 2009) have been taken as initial reference values for the transport prices for some of the regions included in this study.

International Transportation costs in SSA regions.

Table 4.2 International Transport Prices, Costs, and Profit Margins (from Gateway to Destination)

	Route gateway–destination[a]	*Price*[f] *(US$ per km)*	*Variable cost (US$ per km)*	*Fixed cost (US$ per km)*	*Profit margin*[f,h,c] *(percent)*
West Africa (Burkina and Ghana)	Tema/Accra–Ouagadougou (Ghana)	**3.53**[g] (2.01)	**1.54** (0.59)	**0.66** (0.64)	80
	Tema/Accra–Bamako (Mali)	**3.93** (1.53)	**1.67** (0.23)	**0.62** (0.36)	80
Central Africa (Cameroon and Chad)	Douala–N'Djaména (Chad)	**3.19** (1.10)	**1.31** (0.32)	**0.57** (0.30)	73
	Douala–Bangui (Central African Republic)	**3.78** (1.30)	**1.21** (0.35)	**1.08** (0.81)	83
	Ngaoundéré–N'Djaména (Chad)	**5.37** (1.44)	**1.83** (0.25)	**0.73** (0.44)	118
	Ngaoundéré–Moundou (Chad)	**9.71** (2.58)	**2.49** (0.64)	**1.55** (0.43)	163
East Africa (Kenya and Uganda)	Mombasa–Kampala[b] (Uganda)	**2.22** (1.08)	**0.98**[h] (0.47)	**0.35** (0.14)	86
	Mombasa–Nairobi[c] (Kenya)	**2.26** (1.36)	**0.83** (0.17)	**0.53** (0.19)	66
Southern Africa (Zambia)	Lusaka–Johannesburg[d] (South Africa)	**2.32** (1.59)	**1.54** (0.41)	**0.34** (0.40)	18
	Lusaka–Dar-es-Salaam[e] (Tanzania)	**2.55** (0.08)	**1.34** (0.52)	**0.44** (0.51)	62

Source: Trucking survey data and own calculations. Exchange rates come from International Monetary Fund-International Financial Statistics.

Note: Prices are in US$ per kilometer because most companies have the same truck capacity and similar (over)loading practices on a corridor. Moreover, because of questions in reporting overloading, prices in US$ per kilometer are probably much more reliable than prices per ton-kilometer. Prices and costs were obtained from reported truckload (approximately 30 metric tons). Values include trucking services (three or more trucks) and truckers (one or two trucks). Standard deviation is in parentheses.

a. Destination country is in parentheses.
b. First segment of the northern corridor
c. Second segment of the northern corridor
d. First segment of the north-south corridor
e. Second segment of the north-south corridor
f. Some indicative prices are set by ministries of transportation in Africa but are not used. Prices set by freight allocation bureaus in Central Africa may be more respected.
g. Prices from the trucking survey are similar to the ones given by the Conseil Burkinabe des Chargeurs (see table below). Depending on the tonnage (official or real), prices per ton-kilometers may be more or less higher.
h. Data should be taken cautiously since some companies may omit some costs or, conversely, double count some costs.

Source: (Teravaninthorn and Raballand 2009)

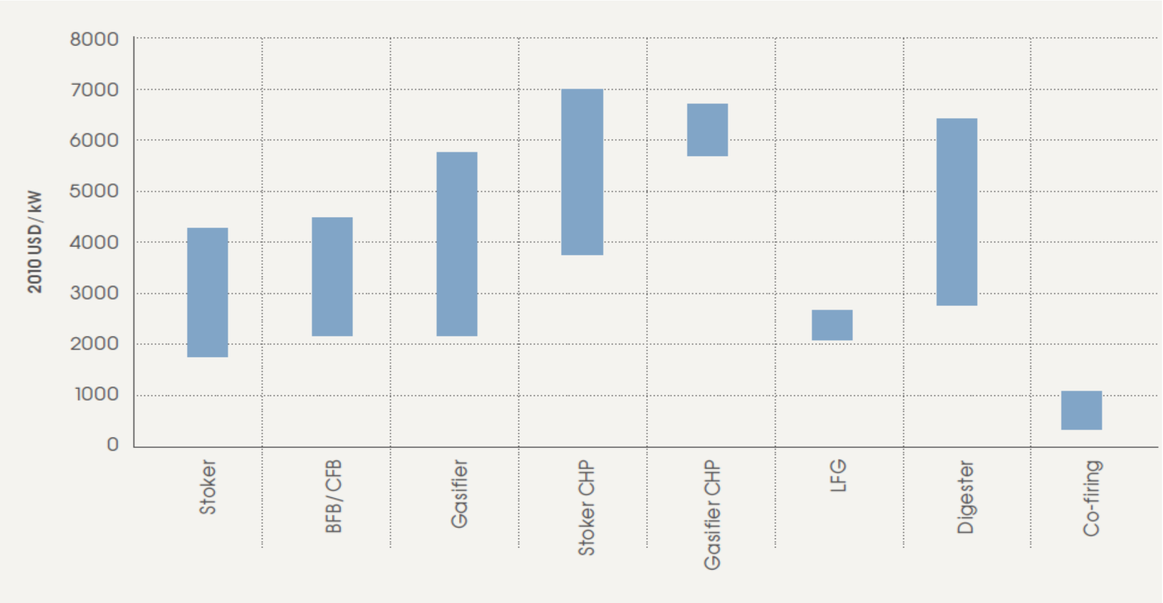
It must be noted that, since the project assumes that it will subcontract feedstock transportation services, the figure under "Price" category correspond to transportation costs assumed by the project. As first approach, feedstock transport costs might be assumed in the following manner:

- Ghana and Nigeria → West Africa costs: 3.53 $/km.
- Kenya, Tanzania, Uganda, Rwanda and Ethiopia → East Africa costs: 2.26 $/km.
- Zambia, Mozambique and South Africa → Southern Africa costs: 2.55 $/km.

Conversion technology costs

According to IRENA (2012), the following installed capital costs for biomass power generation technologies are observed:

Installed capital cost ranges by biomass power generation technologies.



Source: IRENA (2012)

The Operation and Maintenance (O&M) costs, are fixed costs proportional to installed capital costs [% of CAPEX] and variable costs, directly proportional to unit of energy produced [$/kWh], dependent on the type of conversion technology.

Fixed and Variable O&M costs for different biomass power generation technologies

Technology	Fixed O&M (% of installed cost)	Variable O&M (USD/MWh)
Stokers / BFB / CFC boilers	3.2 – 4.2 3 – 6	3.8 – 4.7
Gasifier	3 6	3.7
AD systems	2.1 – 3.2 2.3 – 7	4.2
LFG	11 – 20	n.a.
	SOURCES: US DOA, 2007; US EPA, 2009; AND MOTT MACDONALD, 2011.	

Source: IRENA (2012)

Levelised Costs of Energy (LCOE)

According to IRENA (2012), LCOE ranges for biomass-fired power generation technologies were, in 2010 USD/kWh, the following:

LCOE ranges for biomass-fired power generation technologies

Technology	LCOE range
Stoker boiler	0.06 – 0.21 USD/kWh
BFB/CFB	0.07 – 0.22 USD/kWh
Stoker CHP	0.08 – 0.29 USD/kWh
Landfill Gas	0.09 – 0.12 USD/kWh
Digestor	0.06 – 0.17 USD/kWh

Source: Biomass for Power Generation IRENA (2012)

These ranges are obtained by combining maximum and minimum investment and feedstock costs over a lifetime of 20 years. However, these figures are obtained from a range of different plant sizes and feedstocks. Narrowing down the analysis to the scales considered in the project, i.e. plant sizes up to 5 MW, the following values are obtained:

LCOE ranges for biomass-fired power generation technologies

Technology	LCOE range	Cost structure
Stoker CHP (5 MW)	0.12 USD/kWh, including heat revenue	0.08 USD/kWh CAPEX 0.03 USD/kWh OPEX 0.05 USD/kWh feedstock -0.04 USD/kWh heat revenue
Landfill Gas (5 MW)	0.11 USD/kWh	0.04 USD/kWh CAPEX 0.05 USD/kWh OPEX 0.02 USD/kWh feedstock
Digestor (1 MW)	0.08 – 0.17 USD/kWh	0.06 – 0.11 USD/kWh CAPEX 0.02 – 0.03 USD/kWh OPEX 0.01 – 0.05 USD/kWh feedstock

Source: (Biomass for Power Generation, 2012)

These values are aligned with other academic literature findings. For instance, (Lamidi et al., 2019) report LCOE of AD – ICE system of 72 kW between 0.08 and 0.14 USD/kWh depending on the financing conditions and plant's capacity factor. (Amirante et al., 2019) report 0.115 USD/kWh for a small-scale combustion – steam turbine system. (Dhital, 2018) found that AD for bioenergy production has LCOE of 0.07-0.09 USD/kWh. Also, according with (Borineth, 2019), combustion pathways would have 0.06-0.07 USD/kWh (0.031 USD/kWh CAPEX, 0.012 USD/kWh OPEX and 0.021-0.025 USD/kWh feedstock) whereas AD are at 0.07 USD/kWh (0.035 USD/kWh CAPEX, 0.013 OPEX and 0.021-0.025 USD/kWh feedstock) in Cambodia.

With the provided cost structures, it can be concluded that:

- For combustion pathways, CAPEX represents about 50% of LCOE, OPEX accounts for 18.75% and feedstock represents 31.25%.
- For AD pathways, CAPEX represents between 36 and 75% of LCOE, OPEX accounts for 20% to 45% and feedstock represents around 10% - 18%.

IRENA 2012 claims that fuel costs share, i.e. feedstock costs, in the LCOE of bioenergy power generation are between 20 to 50% for combustion in boilers, increasing to 30 to 55% for CHP, whereas for AD it is as low as 10-20%.

Annex 8: Baseline energy prices

The following table summarises the electricity sale prices at small commercial scale for all ten SSA countries of the project

Electricity sale prices – small industrial customers – per country

Country	Electricity price per kWh	Electricity Standing Charge	Source	Link
Ethiopia	0.6943 ETB ($0.021)	13.652 ETB /month	Energy4Sustainable Future	(IRENA 2012)
Ghana	58.6 GHC ($0.11)	4221.1 GHp /month	National Energy Statistics 2019	http://www.energycom.gov.gh/files/ENERGY_STATISTICS_2019_Updated.pdf
Kenya	12 KES peak 6 KES off-peak ($0.12 and 0.06)	520 KES/kVA	RegulusWeb	https://stima.regulusweb.com/
Mozambique	4.70 Mt ($0.072)	361.19 Mt/kW	EDM (Electricity de Mozambique)	https://www.edm.co.mz/en/website/page/electricity-tariffs
Nigeria	29.03 N ($0.08)		MYTO	https://nerc.gov.ng/index.php/library/documents/NERC-Orders/2016---2018-Minor-Review--and--Minimum-Remittance-Orders-for-the-11-DisCos/2016---2018-Minor-Review-of-MYTO-2015--and--Minimum-Remittance-Order-for-Port-Harcourt-DisCo/
Rwanda	222 (non-resid) FRW; 110 (com) FRW ($0.23 and 0.12)	10000 FRW /month	Rwanda Energy Group	http://www.reg.rw/customer-service/tariffs/
South Africa	70 to 143 Rand ($0.038 to 0.078)		South Africa Energy Prices Statistics	Price ranges are included in the reference below: http://www.energy.gov.za/files/media/explained/2018-South-African-Energy-Prices-Statistics.pdf However, it must be noted that municipalities can set their different prices, upon approval of the regulator
Tanzania	292 TZS ($0.13)	5520 TS/kWh	EWURA	https://www.ewura.go.tz/wp-content/uploads/2019/03/TANESCO-Tariff-Adjustment-Order-2016-GN.-119-2016.pdf
Uganda	165.6 – 272.3 – 354 UGX ($0.045 to 0.096)		ERA	https://www.era.or.ug/index.php
Zambia	0.54 TZS (0.035 USD)	96.41 TZS /month	ERB	http://www.erb.org.zm/downloads/eregulation/zescotariffs/erbApprovedTariffScheduleMay2017.pdf

Annex 9: Subsidy availability

The availability of subsidies to investment or to operational costs, as well as the stability and predictability of such economic inputs is of great importance when selecting the most relevant bioenergy pathways from an economic point of view.
In this sense, three different categories (and respective key aspects) are addressed:

1. Subsidies to CAPEX:
    - Available programmes.
    - Funding sources.
    - Funds management entities.
2. Subsidies to Revenue streams:
    - Existence of Feed-in tariffs (FIT).
    - Existence of Power Purchase Agreements (PPA).
    - Regulatory body or entity that assigns them.
    - Endorsement or guarantee schemes for subsidy collection along service life or contract duration.
3. Whenever available, information regarding their effective operationalisation / application to bioenergy projects in the past five years, including information to understand if there are some subsidy measures that – although theoretically available – are currently not being implemented in bioenergy projects.

This assessment directly draws from Theme 5 research on regulatory environment and finance aspects of the ten BSEAA2 countries, complemented with desktop-based search and information coming from databases such as Bloomberg's New Energy Finance (BNEF) "Climatescope"[77]. The main outcomes of the research undertaken are summarised in the table below. All data presented correspond to currently available measures. Previously available subsidy measures that have been abandoned, replaced or have become outdated are excluded from the analysis.

Assessment of subsidy availability to CAPEX per country

Country	Subsidising programs	Subsidy founding sources	Subsidy funds manager	Have they been applied to bioenergy projects in the past 5 years?
Ethiopia	Scaling up Renewable Energy Program (SREP)	Strategic Climate Fund from Climate Investment Funds: World Bank, African Development Bank (AfDB)	SCF committee, Ministry of Water and Energy	No, from the available data
	Rural Electrification Fund	Governmental budget and external loans	Ministry of Water and Energy	No, from the available data
Ghana	National Electrification Scheme	Fixed levy of $0.06/litre of gasoline	Renewable Energy Fund	No
	Self-Help Electrification Project	ECREEE, World Bank	Government of Ghana	Some electrification cases
	Ghana Energy Development and Access Project	ECREEE, World Bank	Ministry of Power	Not certain, based on available data
	Sustainable Energy Fund for Africa (SEFA) supporting SREP	AfDB and other international donors	AfDB Power, Energy, Climate and Green Growth Dept.	Not certain, based on available data

[77] http://global-climatescope.org/

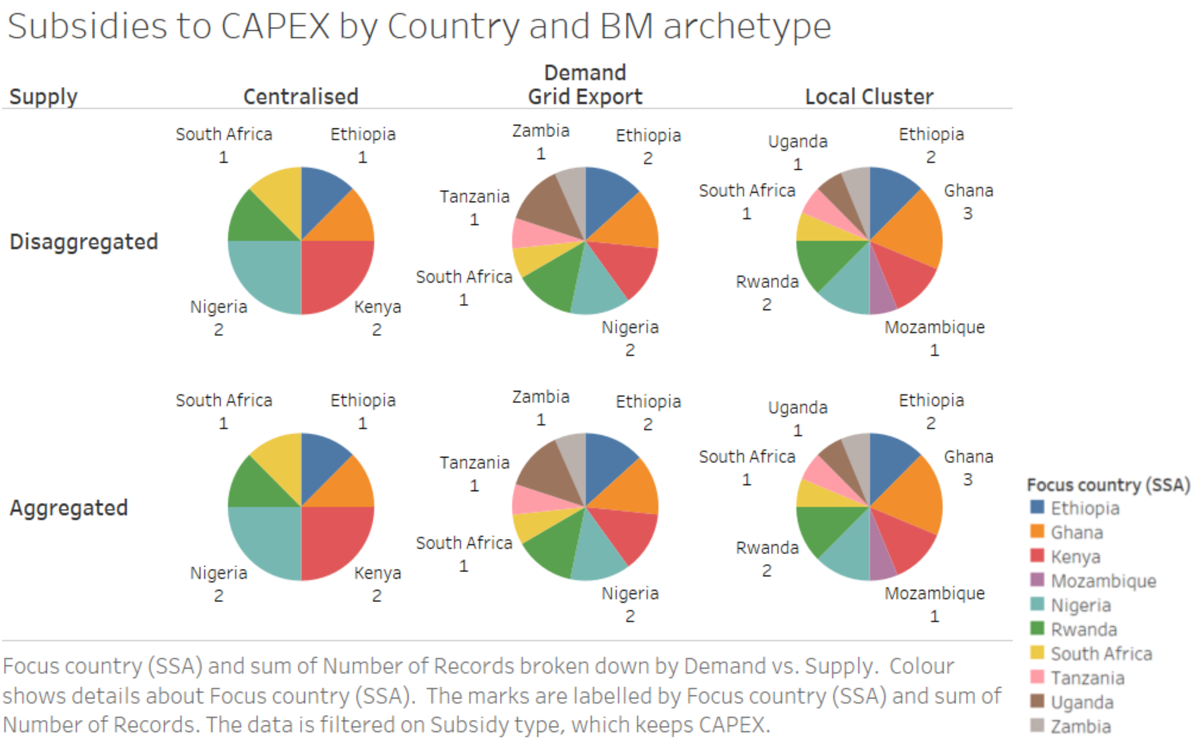
Country	Subsidising programs	Subsidy founding sources	Subsidy funds manager	Have they been applied to bioenergy projects in the past 5 years?
Kenya	SREP	Strategic Climate Fund from Climate Investment Funds: World Bank, AfDB	SCF committee	No, from the available data
	Other international funds (Frontier Investment Mgmt., EIB, GIZ, EUEI, Africa Inv. Bank…)	International funding sources	International founding sources	Some electrification cases
Mozambique	Scaling up Pro-poor Renewable Energy	Global Green Growth Institute (GGGI)	GGGI	Not certain, based on available data
Nigeria	CTF investment plan	Strategic Climate Fund from Climate Investment Funds: World Bank, AfDB	SCF committee	Not certain, based on available data
	Sustainable Energy Fund for Africa (SEFA) supporting Nigeria Energy Access Fund (NEAF)	AfDB and other Intl donors (SEFA) and Shell (NEAF)	Power, Energy, Climate and Green Growth Dept. of the African Develop. Bank	Not certain, based on available data
Rwanda	Rwanda Energy Development Plan	Government of Rwanda	Fund Management Team / Secretariat	The fund is available for Mini-grid projects since 2018. Actual implementation should be checked
	Rwanda National Fund for Environment and Climate Change	International funding sources (UK, Germany, UN etc)		Calls for projects twice a year. Some gasification projects have been funded
South Africa	Carbon Tax Act (2019): - Tax exemptions - Allowances - Subsidies	Tax on the CO_2 equivalent of GHG emissions	National Treasury of South Africa	Yes
Tanzania	Rural Energy Fund	Taxes levied on the sale of electricity and petroleum products	Rural Energy Agency	Not certain, based on available data
Uganda	Rural Electrification Fund	A levy of 5% on the cost of bulk electricity purchases; Money appropriated by Parliament; Intl. donors	Rural Electrification Agency	Not certain, based on available data
	Uganda Energy Credit Capitalisation Company	Government and development partners	Government of Uganda	Yes
Zambia	Green Climate Fund Zambia Renewable Energy Financing Framework	AfDB, NAPSA / commercial banks Intl. donors	Ministry of National Development Planning	Only solar PV projects have been funded

Revenue stream subsidies by country

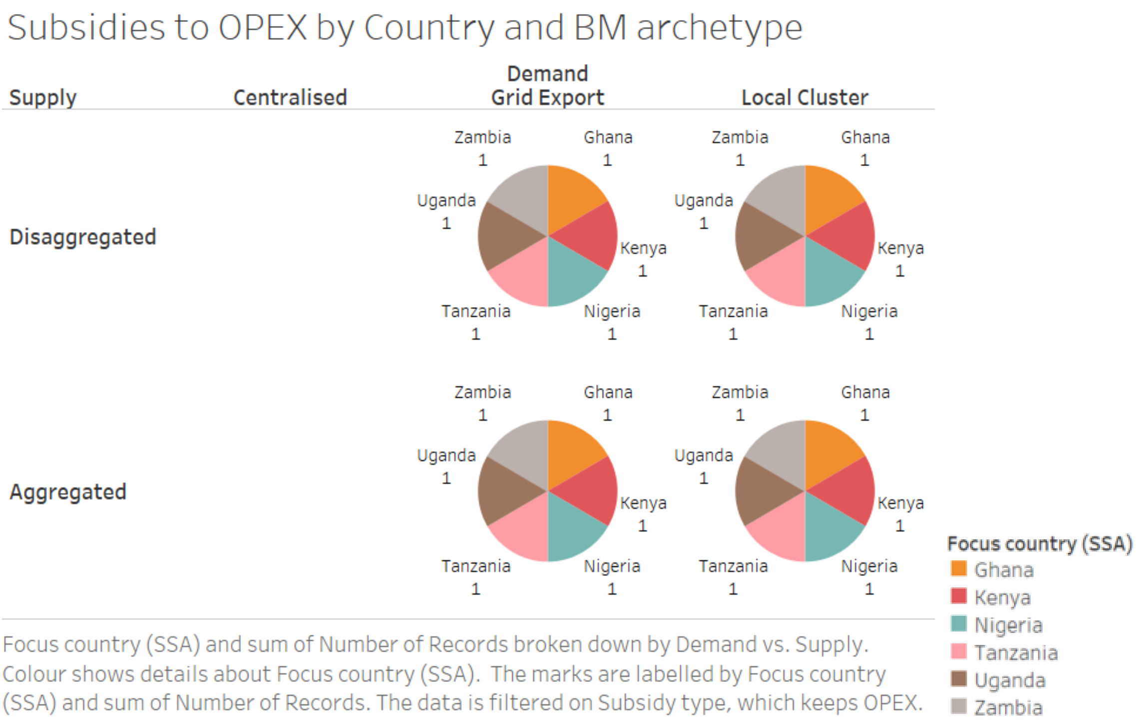
Country	Subsidy to revenue streams	Regulatory body	OPEX guarantee measures	Have they been applied to bioenergy projects in the past 5 years?
Ethiopia	None	Ethiopian Energy Authority (EEA)		The subsidised cost of electricity does not make the FiT attractive, so it has not been massively deployed
Ghana	FIT: $0.10-0.11/kWh PPA: 10 years, extendable in two-years basis	Renewable Energy Act (2014)	FIT: $0.10 to 0.11/kWh depending on the feedstock, paid by utilities. 10-year guarantee with bi-annual revisions afterwards, under PURC (Public Utilities Regulatory Commission) approval. PPA undertake or pay obligation	According to national expert, it is difficult to obtain FIT due to over-capacity and it is difficult to obtain regular payments from distribution company
Kenya	FIT: 10 c$/kWh PPA: 20 years	Ministry of Energy	FIT comes with 20 years of PPA.	TBC
Mozambique	No	N/A	N/A	N/A
Nigeria	FIT: NGN 30,941.62/MWh $154.71/MWh PPA: 20 years	Nigerian Bulk Electricity Trading	FIT apply to projects over 1MW and is associated with 20-years PPA	Low fossil fuel prices and high natural gas electricity generation makes FIT unattractive
Rwanda	N/A			Rwanda's feed-in tariff has been replaced by renewable energy tenders
South Africa	PPA: 20 years	NERSA as regulator, Dept. of Mineral Resources IPP Office as administrator	PPAs are enabled by the REIPPPP (auctions of fixed amount of MW) PPA guarantees a negotiated tariff by ESKOM (public utility) under 'take or pay' obligation	FIT was abandoned PPA auctions are ongoing, PV prevails, but some bioenergy projects have applied According to local experts, PPA signature process is bureaucratic and time consuming
Tanzania	FIT: 20% return on equity PPA	EWURA	FIT and PPA are bound to Small Power Producers (100 kW to 10 MW) program. FIT payable in USD. PPA undertake or pay obligation	Yes, although they are a minority
Uganda	FIT: 7.93 c$/kWh (Bagasse) 11.5 c$/kWh or lower (Biogas) PPA 15 years	Electricity Regulatory Authority (ERA)	For biogas, maximum of 13.5% return on equity or 11.5 c$/kWh. For bagasse, 7.93 c$/kWh	Anecdotal number of projects (e.g. Bagasse project in 2018) commissioned under GET FiT program (Norway gvt support)
Zambia	Renewable Energy Feed-in-Tariff (REFiT) with standardized PPA	Zambian regulator, ERB	ERB website not available REFiTs entitled to 3-year PPA and subsequent revisions	No, REFiT is mainly for small hydropower

The figure below shows the availability of subsidies by country, by CAPEX and OPEX using the supply chain archetype framework. A combined figure incorporating both CAPEX and OPEX based on the below is presented in the main report under section 5.4, Criterion 3.

Subsidies to CAPEX formally available by country and supply chain archetype



Subsidies to OPEX formally available by country and supply chain archetype



Annex 10: Agriculture, water, land use and other regulatory frameworks

As set out in the Inception Report – and in addition to the five primary criteria discussed in the main report above - Theme 5 also examined bioenergy regulation and support from the perspective of agriculture, waste management, water and water regulation, with a particular focus on soil and water conservation (SCW) and management. These all affect bioenergy investment and operations. These areas of research are described briefly here. They will be important in Stage 3 as the theme teams develop their bottom-up assessments.

As table below shows, except for South Africa, the percentage of the target SSA countries' population engaged in agriculture and forestry ranges from 37-38% (Nigeria and Kenya) to over 60% (Ethiopia, Mozambique, Rwanda, Tanzania and Uganda).

Statistic	Ethiopia	Ghana	Kenya	Mozambique	Nigeria	Rwanda	S. Africa	Tanzania	Uganda	Zambia
% working population in agriculture	68%	41%	38%	68%	37%	66%	6%	67%	69%	53%
Agriculture as % of GDP	46%	54%	26%	25%	21%	33%	2%	27%	24%	3%
Agriculture as % of total exports	84%	40%	70%	1%	1%	48%	10%	32%	80%	10%

Source: (Roser, 2013).

In 2003, the African Union (AU) met in Mozambique to adopt the Comprehensive Africa Agriculture Development Programme (CAADP), the AU's policy framework for agricultural transformation. In 2014, meeting in Equatorial Guinea, the AU adopted the 'Malobo Declaration' to promote improved agriculture throughout Africa (OSAA, n.d.). The Malobo summit declared 2014 as Africa's 'Year of Agriculture'. A key element of the CAADP and the two declarations are for AU member countries to allocate a minimum of 10% of their annual budgetary expenditures to agriculture. Thus far, only Kenya, Uganda and Ghana have met this target. This is further evidence of the overall lack of SSA country focus on bioenergy, given that six of the target countries have most of their populations engaged in biomass production (agriculture, livestock and forestry).

Agriculture-focused regional associations

In addition to pan-Africa programmes and initiatives, there are specific agriculture-oriented associations promoting horticulture, floriculture, dairy, livestock, tea, sugar, coffee, palm oil and a variety of specialised agriculture feedstock operations.

Five of the ten target countries (Ethiopia, Kenya, Uganda, Rwanda and Zambia) are members of the Common Market for Eastern and Southern Africa (COMESA), a free trade zone for 21 African countries. Four of the other target countries (Mozambique, Tanzania, South Africa and Zambia)78 are members of the Southern Africa Development Community (SADC) a free trade zone for 16 SSA countries. SADC and COMESA are now linked as one of the world's largest free trade zones, moving rapidly towards a customs union.

The effects of this on the region's agricultural sectors have been profound. From a point of view of agriculture, this liberalised trade has been very positive. Trade in agricultural products and inputs has

[78] Note that Tanzania is part of the East African Community (EAC) which preceded COMESA. Thus, while it is not a member of COMESA, as an EAC member it is in a free trade customs union with Kenya, Uganda, Rwanda and Burundi. Zambia is both a member of SADC and COMESA.

increased. Some areas of bioenergy have also benefited. There has been a dramatic increase in electricity generation from sugar bagasse as a means of maximising value from the production of sugar by creating or increasing revenues from sale of electricity.[79]

This has been made possible by liberalisation in every electricity sector in the ten target countries, making it possible for bioenergy companies (including certified wood processing plants such as sawmills, pulp and paper companies, building material companies, among others) to use wood waste and residues not only to generate heat, but also to cogenerate electricity to sell to the grid or to other customers.

Agricultural market outlook in target BSEAA countries

The agriculture, forestry and energy sectors in many SSA countries have undergone major changes from the mid-1990s to the present. On the agricultural side, increasingly 'liberalised' trade has opened markets in other African countries and in Europe and North America that were previously 'protected' from many agricultural imports from the target SSA countries. Additionally, as noted above, increasing numbers of SSA country governments have liberalised their agriculture and forestry sectors to attract new finance, innovation and investment.

The FAO has undertaken monitoring and analysis of food and agricultural policies (Pernechele et al., 2018) in eight of the ten target countries (Ghana, Nigeria, Mozambique, Tanzania, Rwanda, Kenya, Uganda and Ethiopia).80 It has examined process, handling and storage fees from farmgate to domestic markets (including clearinghouses for farm produce and agricultural products for export), and handling and storage fees for international exports. (Pernechele et al., 2018).

Government policies that are most relevant to agriculture, based upon review of successful bioenergy projects in the ten target countries, are in high-value crops, particularly those destined for export or for large urban areas. In several of the countries, a focus on rapidly growing urban cash markets and on rapidly growing international markets for high value products, have been two of the factors that have aided diversification and have attracted finance for investment and innovation.

Although, the degree of diversification of production and expansion of agriculture into the cash economy has been mixed in the ten target countries, overall, there has been an explosion of exports from SSA's agricultural sector in tea, palm oil, cocoa, coffee, fruits, nuts, horticulture (vegetables) and floriculture, as well as several niche areas such as sisal and organic produce of all types.

Today, Ghana is one of the world's largest producers of sustainable, high-quality palm oil and cocoa, which is grown primarily by smallholder farmers. Kenya is now the world's largest exporter of high-value black tea, with over 65% of that grown from nearly 700,000 smallholder families who co-operatively own 69 smallholder tea factories that consistently fetch the highest tea auction prices in the world. These factories are fuelled by certified, sustainably grown trees, as well as agri-residue briquettes and forest residues, often grown by the smallholders and their families themselves.

Rwandan smallholder tea fetches the highest prices in the world, and tea production has become one of the fastest-growing sectors in Ethiopia, Uganda, Tanzania, as well as in Rwanda and Kenya. Ethiopia is now Africa's largest exporter of high-value vegetables. Kenya and South Africa are neck-to-neck on export of high-value fruits and vegetables. Kenya is Africa's largest exporter of cut flowers, followed closely by Ethiopia, Tanzania and South Africa.

Coffee is both Ethiopia's and Uganda's largest export in terms of foreign exchange earnings. Cotton and coffee are Uganda's second and third largest exports in terms of value. Dairy production is a major source of rural smallholder income in Kenya and Ghana and is of growing importance supplying

[79] M. Bess personal communications with sugar companies and associations in BSEAA2 target countries (Kenya, Uganda, Tanzania, Zambia and South Africa), and in Mauritius, Swaziland, Zimbabwe and Malawi.

[80] Ethiopian Development Research Institute. Ghana Ministry of Food and Agriculture. Kenya Agricultural and Livestock Research Organization, Mozambique Ministério da Agricultura e Segurança Alimentar; Centro de Estudos de Políticas e Programas Agroalimentares, Nigeria Federal Ministry of Agriculture/National Bureau of Statistics, Rwanda Ministry of Agriculture and Animal Resources, Tanzania Ministry of Agriculture Food Security and Cooperatives, Uganda Ministry of Agriculture, Animal Industry and Fisheries; and Uganda National Agriculture Research Organization (Pernechele et al., 2018, p. 10)

the fastest growing cities in the world. Likewise, livestock, from feedlots to abattoirs, account for increasing cash income for farmers.

Solid and Liquid Waste Management
Apart from South Africa, the other nine target SSA countries either lack the legal or regulatory frameworks for municipal solid waste (MSW) or sewage waste management and/or lack the enforcement capabilities to consider extracting landfill or sewage gas for energy purposes. Ghana of the other 9 countries has the most promising legislation on MSW management, with several municipal facilities extracting organic matter for fertilizers.

Addis Ababa, Ethiopia, has Africa's largest (50 MW) waste incinerator Africa, but there is no separation of organic or inorganic matter. The Mtoni landfill site in Dar es Salaam in Tanzania was intended to extract landfill gas from the Mtoni municipal waste site as a UNFCCC-registered CDM project, but, after 13 years' operation only flares the LFG. Overall, except for South Africa and Ghana, very little is on the short- to-medium term on MSW or sewage gas extraction for energy

Further, for purposes of this project MSW, LFG and sewage gas were not considered suitable bioenergy pathways due to the lack of mandated, enforced and measured waste separation of the organic (biomass) composition of the waste.

Agricultural Waste Management
Again, South Africa has the most stringent and well-regulated agricultural waste management policies of the ten SSAs. There are municipal bylaws and other local (e.g., county) regulations on waste disposition of agriculture and livestock wastes in the other nine target countries, but, in none of them are these rigorously enforced.

It is very common in the larger cities of the other nine SSA countries for abattoir waste, for example, to be either discharged into municipal sewage systems, or dumped into pits or discharged into free running streams and rivers. While the national environmental agencies in all ten target countries[81], lack of full legislation, enforcement capacity, trained personnel and political will, often stifles waste management. Things are changing in these countries, but, except for South Africa, they are all still developing countries with limited resources to allocate to waste management.

The table below provides an overview of the key bioenergy regulations, policies and support programmes from the perspective of agriculture, waste management, water and water regulation, soil and water conservation and management.

[81] Environment Protection Agency, Ethiopia; Environment Protection Agency, Ghana; National Environmental Management Authority, Kenya; Divisão Gestão Ambiental/Department of Environmental Management, Mozambique; National Environmental Standards and Regulations Enforcement Agency, Nigeria; Rwanda Environmental Management Authority, Rwanda; Department of Environmental Affairs, South Africa; National Environment Management Authority, Uganda; National Environment Management Council, Tanzania; National Environment Management Authority, Tanzania; and, Zambia Environmental Management Agency, Zambia.

Country	Ag-residues/waste	Forest residues/waste	Waste management (e.g. MSW)	Water management	Soil & water conservation
Ethiopia	Ethiopia Environmental Protection Agency	National Biogas Programme and Ethiopian National Energy Policy 2013	Urban Green Infrastructure Development and Beautification Improvement Program under GTPII (2015/16-2019/20) to increase urban solid waste collection and disposal coverage to 90%.	Ministry of Water, Irrigation and Electricity (MoWIE)	Agricultural Transformation Agency (ATA), Ethiopia Soil Information System (EthioSIS), Ministry of Agriculture, Livestock & Fisheries (MoALF). The government has pledged to restore 15 million hectares of degraded lands by 2020 through investments in a range of SWC and land management practices
Ghana	Ghana Environmental Protection Authority	Ghana Forestry Commission is responsible for regulating forest use	Ghana Environmental Assessment Regulations implemented by district assemblies; Bioenergy Policy for Ghana (draft); National Energy Policy (2010)	Riparian Buffer Zone Policy (2013) and Water Use Regulation (2001) implemented by the Water Resources Commission; National Water Policy (2007) implemented by the Water Resources Commission and Water Directorate of the Ministry of Water Resources, Works and Housing (MWRWH)	National Water Policy (2007)
Kenya	National Environment Management Authority (NEMA), Ministry of Environment	Kenya Forest Act (2005) Kenya Forest Service (KFS)	NEMA's MSW/landfill rules are not enforced. Large municipalities (60+) responsible for implementing MSW & Sewage Management, but all are very poor and lack financial or other resources.	Water Resources Management Authority (WRMA) established under the Water Act (2002)	Ministry of Agriculture and Rural Development (MOA), National Soil and Water Conservation Programme (NSWCP),Kenya Forest Service (KFS), NEMA. WRMA
Mozambique	Divisão Gestão Ambiental/Department of Environmental Management	National Energy Policy 2015-2025, Renewable Energy Atlas (2013), New and Renewable Energy Strategy (2011) and Policy (2009)	MSW responsibility of each urban council (must have decrees on solid & liquid waste management)	Regulation on Noise, Soils & Water & Air (Decree 18 / 2004 of June 2), Water Sector Strategy 2006, The National Water Resources Management Strategy (ENGRH) 2007, Law on Water Affairs Ministry for Co-ordination of Environmental Affairs and the Ministry of	Regulation on Noise, Soils & Water & Air (Decree 18 / 2004 of June 2), Water Sector Strategy 2006, The National Water Resources Management Strategy (ENGRH) 2007, Law on Water Affairs

Country	Ag-residues/waste	Forest residues/waste	Waste management (e.g. MSW)	Water management	Soil & water conservation
				Agriculture and Rural Development	
Nigeria	National Environmental Standards and Regulations Enforcement Agency/NERSEA	Federal Ministry of Environment (FME), Federal Department of Forestry (FDF), 36 State Forest Departments.	Federal Environmental Protection Agency (FEPA) deals with the waste management issues; Feed-in-Tariff for renewable energy (approved in 2014), National Policy on Renewable Energy and Energy Efficiency 2015, Roadmap for Power Sector Reform 2013, National Renewable Energy Master Plan, National Power Sector Reform Act (EPSRA) 2005, Renewable Electricity Policy Guidelines 2006 have provisions for waste to energy generation	Environmental Impact Assessment Act 1992, Federal Ministry of Environment & NERSEA, Water Resources Act 1993, National Water Policy 2004, Federal Ministry of Water Resources, State Water Boards	Environmental Impact Assessment Act 1992, State Water Acts, Water Resources Act 1993, National Water Policy 2004; National Environmental Standards Regulations and Enforcement Agency (NESREA) Act 2007 established the National Environmental Standards Regulations and Enforcement Agency
Rwanda	National Biomass Strategy 2019 -2030, National Domestic Biogas Program, Rwanda Utilities Regulatory Authority (RURA)	Ministry of Lands & Forestry, Forest Investment Program, 2017, National Biomass Strategy 2019 -2030, National Forestry Policy 2018, National Strategy and Action Plan for Non-Timber Forest Products Sector in Rwanda, Forest Sector Strategic Plan 2018-2020 implemented by the Land, Water and Forest Directorate of the Ministry of Environment	National Biomass Strategy 2019 - 2030, National Domestic Biogas Program, National Waste Strategy, National Environmental Policy and Law, National Environmental and Climate Change Policy, Environment and Climate Change Directorate, Ministry of Environment;	Law determining the use and management of water resources in Rwanda, Rwanda Water Resources Master Plan, Rwanda Water Strategy, Water and Sanitation Policy, Revised Land Policy 2019 implemented by the Land, Water and Forest Directorate of the Ministry of Environment	Law determining the use and management of water resources in Rwanda, Rwanda Water Resources Master Plan, Rwanda Water Strategy, Water and Sanitation Policy, Revised Land Policy 2019, National Environmental Policy and Law, National Environmental and Climate Change Policy

Country	Ag-residues/waste	Forest residues/waste	Waste management (e.g. MSW)	Water management	Soil & water conservation
South Africa	Department of Environmental Affairs/DEA; Integrated Resource Plan (IRP);	Department of Agriculture, Forestry and Fisheries (DAFF); National Forests Act, 1998 (Act 84 of 1998), and the Forestry Laws Amendment Act, 2005 (Act 35 of 2005); Provincial Forest Acts and Bye-Laws,	Guidelines for the Development of the Integrated Waste Management Plans, provincial, municipal and other authorities. White Paper on Environmental Management Policy, Environment Conservation Act 1989, National Environmental Management Act 1998, Waste Amendment Act 2014 implemented by the Department of the Environmental Affairs, Waste Management website: http://sawic.environment.gov.za/?menu=13	National Water Act, 1999; Integrated Coastal Management Act 2008, Environment Conservation Act 1989, National Environmental Management Act 1998, Waste Amendment Act 2014	National Water Act, 1999, Integrated Coastal Management Act 2008; National Veld and Forest Fire Act (NVFFA), 1998 (Act 101 of 1998), and the National Veld and Forest Fire Laws Amendment, 2001 (Act 12 of 2001), are the primary legislation regulating wildfire management in the country. The National Wild and Forest Fire Amendment Bill, 2013.
Tanzania	National Environment Management Council/NEMC	Forest Act 2002, Tanzania Forest Service (TFS).	Solid Waste Management Proclamation (2007), Federal & Regional Environment Protection Agencies (EPAs) manage liquid, solid, chemical & industrial wastes; the Environmental Management Act 2018, National Environmental Policy 1997	EWURA (Electricity & Water Utilities Regulatory Authority); Water Utilisation Regulations 1997, National Water Policy 2002 implemented by the Ministry of Water and Irrigation	Water Resources Management Act, National Water Policy 2002; National Land Policy 1997 implemented by the Lands, Housing and Human Settlements Developments
Uganda	National Environment Management Authority (NEMA), Ministry of Water & Environment	National Forest Authority (NFA); Forest Sector Support Department (FSSD), Ministry of Water and Environment, FSSD under Directorate of Environmental Affairs working with NFA & District Forestry Services,	NEMA, National Environmental Act. Ministry of Water and Environment;	Environment and Social Safeguards Policy, the National Environment Management Policy 1994, Environment Management Act 1994, Water Policy 1997, Water Act 1997, National Irrigation Policy 2017 implemented by the Ministry of Water and Environment	Water Policy 1997; Land Policy 2013 implemented by the Ministry Lands, Housing and Urban Development
Zambia	Zambia Environmental Management Agency/ZEMA	Forestry Department, Ministry of Lands, with Provincial Forestry Offices,	Department of Water Resources Development (DWRD), Ministry of Energy and Water Development	The Water Supply and Sanitation Act 1997, Water Act implemented by Ministry of Energy and Water Development	Conservation Farming Unit (CFU), Ministry of Agriculture, Water Supply and Sanitation Act 1997, Water Act

Annex 11: Country agricultural trade associations

The table below summarises the main agricultural support groups and associations that exist in each of the target countries.

Target country agricultural support groups and associations *(Source: Trade association websites*)

Country	% of pop. in agric.	Agric. as % of GDP	Agric. as % of national exports	Country agriculture associations	Web addresses
Ethiopia	68%	46%	84%	• Ethiopia Horticulture Producer Exporter Assoc.	www.ehpea.org
				• Ethiopia Coffee Exporters Assoc.	www.ecea.org.et www.afca.coffee/portfolio-item/the-ethiopian-coffee-exporters-associa%C2%ADtion-ecea
				• Ethiopia Coffee & Tea Authority	www.ethiocta.gov.et
				• Ethiopian Pulses Oilseeds & Spices Processors Exporters Assoc.	www.epospeaeth.org
				• Ethiopian Sugar Corporation	www.ethiopiansugar.com/about
Ghana	41%	54%	40%	• Ghana Assoc. of Vegetable Exporters	www.virtualmarket.fruitlogistica.de/en/Ghana-Association-of-Vegetables-Exporter-GAVEX,c44840 www.gepaghana.org/import/cta/chili-pepper-ghana-2
				• Ghana Cocoa Board	www.cocobod.gh
				• Ghana Small-Scale Oil Palm Producers Assoc.	www.facebook.com/goppaonlineGH
				• Vegetable Producers & Exporters Assoc. of Ghana	www.vepeag.org
				• Oil Palm Dev't Assoc. of Ghana	
Kenya	38%	26%	70%	• Fresh Produce Exporters Assoc. of Kenya	www.fpeak.org/about-us
				• East Africa Tea Trade Assoc.	www.eatta.com
				• Kenya Coffee Traders Assoc.	www.kenyacoffee.co.ke
				• Kenya Flower Council	www.kenyaflowercouncil.org
				• Fresh Produce Consortium of Kenya	
Mozambique	68%	25%	1%	• Cotton Assoc. of Mozambique (Associação Algodoeira de Moçambique)	cta.org.mz/sobre-a-cta/membros/987/aam
Nigeria	37%	21%	1%	• Assoc. of Hibiscus Flower Exporters of Nigeria	

Country	% of pop. in agric.	Agric. as % of GDP	Agric. as % of national exports	Country agriculture associations	Web addresses
				• Agricultural Fresh Produce Growers & Exporters Assoc. of Nigeria	www.afgean.org
				• Nigeria Sugar Dev't. Council	www.nsdcnigeria.org
				• National Cotton Assoc. of Nigeria	nacotan.org.ng/portal
				• Nigeria Cotton Producers and Merchant Assoc.	
Rwanda	66%	33%	48%	• Rwanda Flowers Producers & Exporters Federation	www.rwanda-flowers.org
				• Rwanda Horticulture Exporters Assoc.	
South Africa	6%	2%	10%	• Agricultural Produce Agents Council	www.apacweb.org.za
				• Fresh Produce Exporters Forum /Fruit South Africa	www.fpef.co.za
				• SA Fruit & Vegetable Canners Export Council	
				• Wines of South Africa	www.wosa.co.za
				• South Africa Sugar Assoc.	sasa.org.za
				• South African Farmers Dev't. Assoc.	sa-fda.org.za
				• South Africa Honeybush Tea Assoc.	www.sahta.co.za sarooibos.co.za
Tanzania	67%	27%	32%	• Tanzania Horticultural Assoc.	www.taha.or.tz
				• Tea Association of Tanzania	www.inttea.com/tea-trade-directory/2073/tea-association-of-tanzania
				• Tanzania Sugar Producers' Assoc.	
				• Tanganyika Coffee Growers Assoc.	
Uganda	69%	24%	80%	• Uganda Coffee Federation	www.ugandacoffeefederation.org
				• Uganda Flower Exporters Assoc.	www.ufea.co.ug
				• Uganda Ginners & Cotton Exporters Assoc.	
				• Uganda Sugar Manufacturers Assoc.	
				• Uganda Tea Assoc.	www.utasso.co.ug
Zambia	53%	3%	10%	• Zambia Export Growers Assoc.	www.zambiaexportgrowers.com/code-of-conduct1.htm cotton.org.zm
				• Organic Producers & Processors Assoc. of Zambia	
				• Cotton Assoc. of Zambia	

Annex 12 List of gasification projects in SSA

Country	Location	Name of Gasifier Owner	Gasifier Supplier manufacturer	Project Developer	Financed by	Operational (Yes/ No)
Uganda	Magala village, Ssekanyonyi, Mityana District	Sawmill	Husk Power	Pamoja Cleantech	Nordic Climate Facility	No
Uganda	Unknown forestry plantation	Unknown	Entrade	Entrade	USPDA	No
Tanzania	Magungumka, Singida	Ageco	Husk Power	Ageco	Power Africa	?
Ethiopia	Unknown	Solar Trading	Unknown	Solar Trading	Climate Innovation Centre	No
Tanzania	Mbeya Region	Space Engineering Comp.	Ankur	Space Engineering	Day Ouwens Fund	No
Tanzania	Zombo community, Malalo, Kilosa District, Morogoro	Ruaha Energy	Husk Power	Ruaha Energy	EEP	No
Tanzania	Biro village, Kilombero District, Morogoro Region	TaTEDO	Husk Power	ONGAWA Engineering	EEP	No
Tanzania	Nyakagomba village, Geita district	Unknown	Husk Power	Nishati Associates Ltd	EEP	No
Uganda	Tiribogo, Mpigi District	50% REBi, 50% Pamoja Energy Ltd	Husk Power	Pamoja Cleantech	Nordic Climate Facility	No
Uganda	Opit Youth Training Centre, Gulu District	CREEC, Makerere university.	All Power Labs replaced by Ankur dual fuel gasifier	Pamoja Cleantech	World Bank, UNIDO	No
Ghana	Papasi, Offinso North District	Unknown	All Power Labs	Kumasi Institute	Power Africa Challenge	No
Nigeria	Ohaukwu, Ebonyi State	cooperative	IISc Bangalore	UNIDO	UNIDO	No
Mozambique	Titimane, Cumba District, Niassa Province	SAN-JFS	All Power Labs	SAN-JFS	EEP	No
Zambia	Kaputa	Unknown	Unknown	UNIDO	GEF, UNIDO, UNEP	No
Kenya	Turkwel, Turkana County	Turkana Basin Institute	All Power Labs	Turkana Basin Institute	Unknown	No

Ethiopia	Addis Ababa	MOWIE	Unknown	Unknown	Norwegian funds	No
Kenya	Marigat, Baringo County	Cummins Cogeneration Ltd	Biogen	Cummins Kenya	AECF REACT	No
S-Africa	Greater Tzaneen Municipality, Limpopo	Agatha Sawmill	Carbo Consult	Marawasi Consulting Services	Sawmill	No
Kenya	Elburgon	Timsales	Fengyu	Unknown	Industry	?
Uganda	Muzizi, Kibale District	James Finlay	Ankur	James Finlay	Estate	No
Uganda	Mukono	Farm	Ankur	Kaesenge Electricity Power	DED (Germany)	No
Uganda	Masindi	Forestry College	Husk Power	Nyabyeya Forestry College	Unknown	No
S-Africa	Melani Village, Eastern Cape	Eskom	Carbo Consult	University of Fort Hare	Eskom	?
S-Africa	Nampo Village	Sawmill	Recor	recor	Industry	?
Tanzania	Mngeta, Kilombero District	Kilombero Plantations Ltd	Fengyu	Kilombero Plantations Ltd	Plantation	?
S-Africa	Graskop, Mpumulanga	Sawmill	Fengyu	Unknown	South Africa Sherpa Trade and Invest 76	?
Tanzania	cashew producing area	SIDO	TERI	Unknown	UNIDO	No
Tanzania	Kibindu, Coast Region	TaTEDO	Husk Power	TaTEDO/Sescom	Power Africa	No
Ghana	Asueyi, Techniman Municipality, Brong Ahafo Region	Zoomilion Ghana Ltd	Ankur	Root and Tuber Improvement Project	IFAD	No
Tanzania	Mtwango village, Iringa Region	Unknown	Unknown	Redcot	UNIDO	No
Tanzania	Mbaha and Lituhi villages, Nyasa, Ruvuma Region	Unknown	Husk Power	Wananchi Power Providers	UNIDO GEF	Yes
S-Africa	Johannesburg, Gauteng	Unknown	Powermax	Unknown	Unknown	No
Uganda	Kayinja landing, Lake George, Kamwenge District	Unknown	Infinite Energy Pvt Ltd	Pamoja Cleantech	EEP	Yes
Kenya	Vipingo	Rea Vipingo	Unknown	Unknown	Unknown	No
S-Africa	Limpopo	Sawmill	Recor	recor	Industry	Yes
S-Africa	18 sites	Innov8 Africa and Black Swan Group	Carbo Consult	industry	Unknown	No

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