Bioenergy for Sustainable Energy Access in Africa

PO 7420

Stakeholder Mapping and Literature Review Report

Submitted to DFID
by LTS International Limited, the University of Edinburgh and E4tech

17th February 2017

LTS International Limited
Pentlands Science Park, Bush Loan
Penicuik, EH26 0PL
United Kingdom

Tel. +44 (0)131 440 5500 | **Fax** +44 (0)131 440 5501 | **Email** mail@ltsi.co.uk

Web www.ltsi.co.uk | **Twitter** @LTS_Int

Registered in Scotland number 100833

Acronyms

ACTFCN	Africa Climate Technology and Finance Centre
AECF	African Enterprise Challenge Fund
AfDB	African Development Bank
AREF	Africa Renewable Energy Fund
BSEAA	Bioenergy for Sustainable Energy Access in Africa
C(C)HP	Combined (Cooling,) Heating and Power
CIF	Climate Investment Fund
CREEC	Centre for Research in Energy and Energy Conservation
CTF	Clean Technology Fund
DFID	Department for International Development
ECREE	ECOWAS Centre for Renewable Energy and Energy Efficiency
EEP	Energy and Environment Partnership programme for East & Southern Africa
EREF	ECOWAS Renewable Energy & Energy Efficiency Facility
ESMAP	Energy Sector Management. Assistance Program
EUEI-PDF	European Union Energy Initiative – Partnership Dialogue Facility
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
ORC	Organic Rankine Cycle
REACT	Renewable Energy & Adaptation to Climate Technologies
RECP	Africa-EU Renewable Energy Cooperation Programme
SCF	Strategic Climate Fund
SE4All	Sustainable Energy for All
SEFA	Sustainable Energy Fund for Africa

SREP	Scaling-Up Renewable Energy Program
SSA	Sub-Saharan Africa
SVO	Straight Vegetable Oil
TEA	Transforming Energy Access Programme (DFID)
TRL	Technology Readiness Level
TVC	Technology Value Chain
UNEP	United Nations Environment Programme
UNIDO	United Nations Industrial Development Organisation

Contents

Annexes

Executive Summary

Introduction

LTS International has teamed up with the University of Edinburgh and E4tech to implement Phase I of the Bioenergy for Sustainable Energy Access in Africa (BSEAA) study. BSEAA is investigating the challenges and opportunities affecting the adoption and roll-out of bioenergy technology in Sub-Saharan Africa (SSA) and supporting the development of innovative bioenergy solutions. The study began with a Literature Review and Stakeholder Mapping process to identify three to five promising technologies and 10 to 15 countries for more detailed research into innovation opportunities in the context of particular value chains.

Methodology

27 bioenergy technologies were identified at the defined Technology Readiness Level of 5 and above. Given that DFID's scale of interest lies above households but below large industry, an output ceiling of 5 MW_e or 10 Ml/yr was applied to pre-screen technologies, and several were eliminated on this basis. Others were screened out due to a global lack of operational examples, negligible prospects for piloting in SSA or an absence of necessary infrastructure. This left 15 technologies for investigation:

Primary conversion technology	Secondary conversion technology	End use					
		Heat	Power	C(C)HP*	Transport	Cooking	Other
Combustion	None	x					
	Steam turbine		x	x			
	Steam engine		x	x			
	Stirling engine		x	x			
	Organic Rankine cycle		x	x			
Gasification	Internal combustion engine		x	x			
Fast pyrolysis	Combustion	x	x	x			
Slow pyrolysis	Internal combustion engine		x	x		x	x
Oil pressing	Internal combustion engine		x	x	x		
	Transesterification				x		
Anaerobic digestion	None					x	
	Internal combustion engine		x	x			
Fermentation	Ethanol fermentation				x	x	x**
	Butanol fermentation				x		
Microalgae							Oils

* C(C)HP = Combined (cooling) heating and power

** Ethanol can be used indirectly for power and C(C)HP, via an internal combustion engine.

A review was undertaken of literature related to the shortlisted options. Published journal papers were analysed for volume, content, theme and geographic focus, while non-academic publications from commercial and publicly funded bioenergy initiatives were screened for relevance, content and implications for technology prioritisation. The landscape of actors in SSA's bioenergy technology sector was also mapped and key actors interviewed, to indicate levels of activity for technology prioritisation and generate contacts for further information and case study identification.

The literature review and stakeholder mapping together provided evidence for technology prioritisation through a 'high', 'medium' or 'low' score against five criteria:

1. Current level of deployment in Newly Industrialised Countries and SSA;
2. Appropriateness for SSA in terms of technological sophistication, infrastructure requirements and social workability;
3. Replication potential, based on adaptability to diverse contexts and feedstocks;
4. Competitiveness with other options for delivering the same energy; and
5. Opportunities for innovation, with potential for research to catalyse transformational change.

Geographic screening was also carried out and SSA countries were scored against 12 factors to identify those with closest synergy with DFID interests, most conducive commercial environments, highest indications of bioenergy demand, levels of sector interest and greatest potential for impact and reach.

Findings: Academic literature

Of 6,020 academic articles identified for the eight primary technologies, anaerobic digestion achieves the highest article count, followed by gasification, direct combustion and fast pyrolysis. Slow pyrolysis, though widely used in charcoal-making, features low in volume of literature. Of the bio-chemical pathways, microalgae and liquid biofuels from ethanol register fewer than a quarter of the number of articles of anaerobic digestion. Oil pressing and butanol register the lowest count. Africa features higher in articles about slow pyrolysis than any other technology, reflecting research interest linked to charcoal. A smaller percentage of articles with an SSA focus were found across the other technology types. Low rates of non-technical articles (indicating higher commercial development) were recorded for liquid biofuels. Analysis of feedstock mentions reveals that thermo-chemical technologies (such as direct combustion and slow pyrolysis) are skewed towards woody biomass, while liquid biofuel technologies (such as fermentation and oil pressing) rely on agro-fuels. The most feedstock-flexible technologies according to the literature are fast pyrolysis, gasification and anaerobic digestion, though each might need to be adapted for specific feedstocks.

In summary, gasification and anaerobic digestion emerge from the academic literature as the most promising technologies, followed by direct combustion and microalgae.

Findings: Non-academic literature

Combustion technology

Direct combustion for heat is the dominant biomass processing 'technology' worldwide. There are various SSA examples <5 MW in industries such as sugar, tea and forestry. Given that the technology is not sophisticated and can use multiple feedstocks, it is deemed appropriate, replicable and competitive for SSA, but with low potential for innovation and hence of limited value for further investigation.

Steam turbines can be used for electricity generation and industrial CHP above 100 kW. There is high potential in industries with lignocellulosic waste such as sugar, tea and pulp and paper. South African and Nigerian companies now manufacture suitable equipment. These systems take a relatively long time to start up, however, and can be costly to maintain, making the technology better suited to small industries than community installations. The technology has high replication potential and there is innovation potential in the development of off-the-shelf units from 250 kW to 5 MW.

Steam engines have existed since the industrial revolution but there are few manufacturers producing low power units. The sophistication level is lower than steam turbines and existing projects in SSA are at smaller capacities. Steam engines can be started up quickly and operate at lower load factors than turbines, with lower investment and maintenance costs (but still considerable compared to diesel gen sets). The technology has high replication potential as it can use numerous feedstocks. There is opportunity for innovation, potentially in manufacturing off-the-shelf units for community and small industrial applications.

Stirling engines are indirectly-fired gas engines and models for power and CHP exist from 1 kW_e to over 100 kW_e. The external heat may come from any source, though no biomass-fuelled examples are known in SSA. Given that the technology is not widely available, even in Europe and the US, appropriateness for SSA is low. Stirling engines are less competitive than other combustion-based systems due, for instance, to the need for special materials in the heat exchanger. With an absence of current SSA activity it is unrealistic to expect commercial penetration.

Organic Rankine cycle (ORC) systems use waste heat to produce electricity via turbines. Several European and US companies offer systems that can operate from biomass heat, although the ORC projects identified in SSA use geothermal sources or iron smelting. Opportunities exist to explore cost reduction and adaptation to SSA, but the absence of working models and high sophistication limit its potential.

Gasification technology

Syngas engine: Gasification entails heating a feedstock to produce gases that react to form syngas, which can co-fuel an internal combustion engine for electricity or meet heating and cooling needs. Efficiency should be higher than biomass combustion at small scale, and small gasification plants for power and heat are seen in India from 30-150 kW_e. Scattered demonstration projects exist in SSA. The technology is more sophisticated than combustion and requires skilled maintenance. Gas cleaning is crucial to avoid engine damage, but is expensive and produces carcinogenic waste. Gasification systems can be designed for a range of feedstocks, making them suitable for diverse applications to serve a mini-grid or industrial load. There is opportunity for innovation in gas cleaning, including reduction of water use and toxic effluents.

Pyrolysis technology

Pyrolysis is the thermal decomposition of biomass in an oxygen-free environment.

Fast pyrolysis produces bio-oil that can be used to generate heat or electricity, for example through a boiler and steam turbine or in a diesel engine. There are several companies in Europe and N. America with planned early commercial technologies in the range 20-40 Ml/yr, but fast pyrolysis is technically challenging and not yet deployed at scale due mainly to instability and high acidity of the bio-oil and technical difficulties associated with certain feedstocks.

Slow pyrolysis is widely used in SSA's charcoal industry but the capture of waste gases from centralised charcoal production for electricity or heat via an internal combustion engine has not been seen. There are companies in Brazil and France exploring this approach, but the dispersed nature of charcoal making in SSA limits transferability. The concept offers opportunities for technological innovation, but requires fundamental changes to the way the charcoal industry is configured, outside the scope of BSEAA.

Oil pressing technology

Oils and fats can be extracted from fruits, nuts and seeds via pressing and solvents.

Internal combustion engine: After filtering, the oil can be fed to diesel engines to power generators or pumps. Projects from a few kW to over 100 kW exist in SSA using jatropha, croton, castor or palm oil. Direct use of the oil may require regular cleaning of injectors. Evidence from pilots suggests that quality, availability and cost of feedstock in comparison with diesel is a major challenge. Although many jatropha oil projects sprung up in the early 2000s, most failed because yields were lower than anticipated. There is some innovation potential, especially in oil quality improvement to reduce engine damage. Competitiveness with other energy sources is questionable, however.

In the **transesterification** process, the oil reacts with methanol/ethanol in the presence of potassium or sodium hydroxide to form biodiesel. Palm, jatropha and croton have been used as feedstock in SSA, but projects tend to be >10 Ml/yr. Methanol is only produced in South Africa and its importation increases costs. The low price of fossil fuel means that the process is unlikely to be competitive within the BSEAAA time horizon.

Anaerobic digestion technology

Anaerobic digestion is the decomposition of biological feedstocks by micro-organisms in the absence of oxygen, producing a gas high in methane.

Direct use: Community biogas projects are technically understood and feedstock flexibility is high. The challenge is organisational, given the need for multiple families to cooperate in feedstock supply and gas sharing. Anaerobic digestion for community use would be highly challenging and no examples are known (except in institutions).

Internal Combustion Engine: Biogas can power engines to produce mechanical energy for direct use, to generate electricity or for heating or cooling. In SSA there is growing interest in using processing wastes from sisal, flowers, vegetables, tanneries and slaughterhouses, from 150 kW_e to 5 MW_e. The concept is appropriate given relatively low sophistication and feedstock flexibility. Biogas can provide electricity at lower cost than grid or generator electricity if feedstock is available *in situ*. There is scope for innovation on feedstocks, microbes and applications (e.g. for direct cooling).

Fermentation

Ethanol fermentation: Ethanol can be produced from starch- or sugar-rich crops in both hydrous form (usually for cooking) and anhydrous form (for blending with gasoline). Only three ethanol production projects could be found in SSA <10 Ml/yr, the most interesting being a micro-distillery initiative in Nigeria by a Brazilian company. Feedstocks such as cassava, sugarcane or sweet sorghum are available in a wide range of SSA countries. Micro-distilleries require secure feedstock supply, however, and this can be challenging. The lower energy content of ethanol and its higher price compared to other fuels also represent an economic challenge for ethanol cooking fuel projects. Innovation will lie in proving micro-distillery technology and the supply chain concept.

Butanol fermentation: Butanol is produced by fermentation from starch or sugars. It is in theory more appropriate for cooking than ethanol as its energy content is higher, but there are no pilots in SSA from which to draw experiences.

Microalgae

Microalgae are photosynthetic microorganisms that can produce lipid-rich biomass. Research on algal energy in SSA is dominated by South African universities, with a focus on project feasibility and identification of suitable strains. Algae-to-energy does not appear appropriate for SSA in the short- to medium-term as production systems are technically complex and require large scale operations.

Technology prioritisation

Of the eight primary conversion technologies compared in the academic literature review, direct combustion, gasification and anaerobic digestion achieved the highest combined scores. A more detailed comparison of the 15 *secondary* technologies based on non-academic literature produced the following composite scores for each option:

Secondary technology favourability scores

Primary conversion technology	Secondary Conversion technology	Level of activity	Appropriateness for SSA	Replication potential	Competitiveness	Opportunities for innovation	***Total***
Combustion	None	3	3	3	3	1	***13***
	Steam turbine	3	2	3	3	2	***13***
	Steam engine	1	2	3	2	2	***10***
	Stirling engine	1	1	3	2	3	***10***
	ORC	1	1	3	2	2	***9***
Gasification	Internal combustion engine	2	2	3	2	3	***12***
Fast pyrolysis	Combustion	1	1	2	1	2	***7***
Slow Pyrolysis	Internal combustion engine	1	1	3	1	1	***7***
Oil pressing	Internal combustion engine	2	2	2	1	2	***9***
	Transesterification	1	1	2	1	1	***6***
Anaerobic digestion	None	1	1	3	1	1	***7***
	Internal combustion engine	2	2	3	2	3	***12***
Fermentation	Ethanol fermentation	2	2	2	1	2	***9***
	Butanol fermentation	0	1	1	1	2	***5***
Microalgae		1	1	2	1	3	***8***

The highest scoring technologies are based on combustion, gasification and anaerobic digestion, reinforcing the findings of the academic literature review. Direct combustion-to-heat has been so widely employed for so long, however, that it lacks significant innovation potential. It is therefore recommended that the following three technologies are adopted for more in-depth investigation in the TVC Prioritisation stage:

a) Combustion-to-steam turbine
b) Gasification-to-internal combustion engine
c) Anaerobic digestion-to-internal combustion engine.

Country shortlisting

On the basis of cumulative scoring across the chosen enabling factors, the following ten focal countries are recommended for the remaining phases of the study:

East Africa		West Africa	Southern Africa
Ethiopia	Rwanda	Ghana	Mozambique
Kenya	Uganda	Nigeria	South Africa
Tanzania			Zambia

Those excluded are high risk investment destinations or countries of recent conflict (DR Congo, Liberia, Sierra Leone, Somalia, South Sudan, Sudan), along with Malawi and Zimbabwe, which rank low for rule of law, corruption and market potential.

Stakeholder mapping

In the public sector, the mapping exercise covered multilateral energy initiatives, UN agencies, technical, advisory and capacity-building projects, small grant funds, multilateral and bilateral bank projects, and specific UK-funded initiatives. Investment facilities in the private sector were also researched. It is notable that privately-funded examples of bioenergy technology in SSA at mid-scale are relatively few in number, reinforcing the need to investigate why this may be the case to unlock opportunities. The academic landscape around bioenergy technology in SSA is dominated by South African institutions, with hubs also in Kenya, Ghana, Tanzania, Nigeria and Malawi. Outside SSA, prominent European universities are conducting research on various facets of bioenergy, with some working directly in SSA. Brazil has strong research capacity in liquid biofuels and institutional expertise was also noted in India and the Philippines. Leading private sector project developers and technology providers active in SSA were also profiled for the prioritised technologies.

Next steps

The team will investigate feedstocks, end uses and enabling conditions in more depth through the Technology Value Chain (TVC) for the three proposed technologies and ten priority countries. From this will emerge the most promising TVC-country combinations. Case studies will be selected to provide examples from which to draw experiences and lessons. The Country Scoping Visits that were originally envisaged will now be merged with longer investigative missions to produce Case Study Reports covering more examples in more locations.

1. Introduction

LTS International has teamed up with The University of Edinburgh and E4tech to implement Phase I of the DFID-funded Bioenergy for Sustainable Energy Access in Africa (BSEAA) research assignment. BSEAA is investigating the challenges and opportunities affecting the adoption and roll-out of bioenergy across Sub-Saharan Africa (SSA) and supporting the development of innovative bioenergy solutions for developing countries. Phase I runs for 12 months from September 2016 and is intended to identify areas of potential innovation in bioenergy technology or related value chains in SSA for more targeted research in Phase II. Phase II will be part of the larger Transforming Energy Access (TEA) Programme, which seeks to test innovative technology applications and business models to accelerate the provision of affordable, clean energy-based services to poor households and enterprises.

A six-week Design Phase during September and October 2016 resulted in finalisation of the Phase I research methodology, results framework and work plan. The main research question was defined as "Which bioenergy technologies have the greatest potential for uptake at scale in Sub-Saharan Africa?".

The study got underway in November with background literature review and stakeholder mapping, which are described in this report. The expected outcome was the identification of three to five promising technologies and 10 to 15 countries for more detailed research in the next phase of the assignment, scheduled for February and March. This subsequent phase will investigate the shortlisted technologies in more detail in the context of particular 'Technology Value Chains' (TVCs), exploring opportunities for innovation that may exist around the technologies themselves or with feedstocks, supply modalities, end-use energy applications or business models.

To be clear, therefore, this phase was aimed at reducing the scope of the study to a shortlist of potentially suitable technologies, considered independently of geographic location, feedstock or business model. The next phase will begin the process of identifying particular value chains and locations in which those technologies offer the greatest potential for widespread uptake through support to research and innovation.

2. Methodology

2.1 Overview

The landscape of bioenergy technology is complex and evolving fast, with a growing variety of conversion pathways from raw biomass to final energy end-use. During the Design Phase, the study consortium identified nine primary technologies and 27 secondary technologies for processing biomass to bioenergy at the defined Technology Readiness Level (TRL) of 5 and above[1]. The list excluded technologies that simply convert biomass from one form to another, such as briquette presses or charcoal kilns. The area of potential research meanwhile covered all of SSA, theoretically including as many as 50 countries[2]. This wide scope of analysis clearly had to be reduced, both thematically and geographically, to facilitate more focussed investigation during the upcoming TVC Prioritisation phase.

2.2 Technology Pre-Screening

A systematic process of pre-screening was undertaken to eliminate technologies known from the outset to be inappropriate for further investigation because of intrinsic scale unsuitability or insurmountable commercial or infrastructural barriers.

On the issue of scale, DFID communicated an interest during the Design Phase in 'mid-scale' energy technologies suitable for large farms, agri-processing facilities, city neighbourhoods or communities of 30-50 households. Major industrial energy users (such as cement factories or sugar mills) were deemed to lie beyond the study scope as the investment considerations in such installations tend to be purely commercial.

It was therefore decided to set an upper output threshold for pre-screening the technology options. A ceiling of 5 MW_e was applied for power-oriented technologies, informed by the known operating scale of existing facilities in the desired range. For example, the Gorge Farm anaerobic digestion plant in Kenya delivers 2.4 MW_e from flower processing waste and is the largest of its size and type in East Africa[3]. Meanwhile liquid biofuel projects in the desired scale range generally produce less than 10 Ml/yr. Projects larger than this - such as the 80 Ml/yr Chisumbanje ethanol

---

[1] The TRL window was fine-tuned during a client consultation in November 2016 towards a technology-oriented analysis for TRL 5 to 7 and the exploration of more market-based solutions for TRL 7 and above, though this differentiation will only become relevant later in the assignment, once the technology options have been narrowed down.

[2] The full country list includes six small island states, so there are in practice 43 mainland countries plus Madagascar.

[3] www.tropicalpower.com/projects/gorge-farm-energy-park/

project in Zimbabwe[4] and the 85 Ml/yr Makeni project in Sierra Leone[5] - supply major industrial clients in the transport sector beyond the scope of BSEAA interest. Novozymes worked on a 2 Ml/yr ethanol venture in Mozambique to produce cooking fuel[6] and Nigeria has a 9 Ml/yr transport fuel project, both based on cassava grown by smallholder farmers at a scale deemed more appropriate for this study. An upper output limit of 10 Ml/yr was therefore set for liquid biofuel technologies

Some technologies with a single known developer (such as wet steam expansion and anaerobic fermentation of sugars) were also screened out at this stage, based on preliminary research confirming minimal commercial uptake and negligible prospects for piloting in SSA. The injection of upgraded bio-methane from anaerobic digestion into piped networks was also eliminated because the absence of gas distribution infrastructure in SSA[7] presents an insurmountable adoption barrier.

Table 1 summarises the results of the pre-screening and indicates the conversion technologies deemed unsuitable for further research (shaded rows). Technical descriptions of all the technologies listed are provided in the Glossary in Annex A.

Table 1. Pre-screening of technology options

Primary conversion technology	Secondary conversion technology	End use						Comments
		Heat	Power	C(C)HP*	Transport	Cooking	Other	
Combustion	None	x						
	Steam turbine		x	x				
	Steam engine		x	x				
	Wet steam expander		x	x				One developer[8] with proprietary technology; no interest in SSA
	Stirling engine		x	x				
	Organic Rankine cycle		x	x				
	Thermo-electric generator		x					Low DC output for household use
Gasification	Steam turbine		x	x				Direct combustion to steam turbine more efficient and economic

[4] dspace.africaportal.org/jspui/bitstream/123456789/35402/1/PLAAS_ADC%20Policy%20Brief_Zimbabwe_Web43.pdf?1
[5] www.sei-international.org/mediamanager/documents/Publications/Climate/SEI-PR-2015-09-Makeni-Project.pdf
[6] www.novozymes.com/en/news/news-archive/2012/05/cleanstar-mozambique-launches-worlds-first-sustainable-cooking-fuel-facility
[7] The only piped gas distribution systems in SSA are the West African Gas Pipeline (which supplies gas from Nigeria's Escravos region to Benin, Togo and Ghana) and a connector from the port of Durban to South Africa's Gauteng region, neither of which distribute gas to final consumers.
[8] www.heliexpower.com

Primary conversion technology	Secondary conversion technology	End use						Comments
		Heat	Power	C(C)HP*	Transport	Cooking	Other	
	Internal combustion engine		x	x				
	Syngas turbine		x	x				No gas turbines <5 MW
	Catalytic upgrading to methanol, DME, bioSNG, FT-diesel, hydrogen		x	x	x			Techno-economically unsuitable for small- to medium-scale
	Syngas fermentation to ethanol[9]				x			Not suitable for small- / medium-scale. Current first-of-a-kind commercial plants at larger scale.
Fast pyrolysis	Combustion	x	x	x				
	Catalytic upgrading				x			Requires large industrial plants
Slow pyrolysis	Internal combustion engine		x	x		x	x	
Oil pressing	Internal combustion engine		x	x	x			
	Transesterification				x			
	Hydro-treated vegetable oil				x			Not suitable for small- to medium-scale.
Anaerobic digestion	None					x		
	Internal combustion engine		x	x				
	Biomethane upgrading						Grid injection	No distribution grids in SSA
Fermentation	Ethanol fermentation				x	x	x**	Mostly >45 MW, but micro-distilleries exist
	Butanol fermentation				x			
	Aerobic fermentation of sugars						Farnesene	One developer with proprietary process[10]; would not deploy in SSA; economic only at large scale.
Lignocellulosic hydrolysis	Ethanol fermentation Butanol fermentation				x			Commercial at >50 Ml/y
Catalytic conversion of sugars					x			Few technology players; would not pilot in SSA; commercial plants likely to be large.
Microalgae							Oils	

* C(C)HP = Combined (cooling) heating and power

** Ethanol can be used indirectly for power and C(C)HP, via an internal combustion engine.

Based on the (unshaded) exclusions, 15 secondary technologies were selected for further investigation.

[9] Refers to the INEOS process www.ineos.com/businesses/ineos-bio/technology using fermentation initiated by naturally occurring anaerobic bacteria (the biocatalyst) to ethanol.

[10] www.amyris.com/products/fuels/

2.3 Literature Review

An in-depth review was undertaken of both academic and non-academic literature related to the shortlisted technology options. In the academic domain, published papers in peer-reviewed journals were analysed quantitatively for content, theme and geographic focus, while non-academic publications from commercial and donor-funded bioenergy initiatives were systematically identified and analysed for content and implications. The findings are presented in section 3: Literature Review.

Academic literature

Academic literature was accessed via *Scopus* and *Science Direct,* the leading databases of peer-reviewed journals, in accordance with the following steps:

1. Advanced search strings were developed to identify literature relevant to the eight pre-screened primary technologies. The following syntax was developed:
    - *Filter 1:* 'Technology X' Appearing in: 'Article Title'
    - *Filter 2:* (Potential OR Scope OR Innovation) AND (Scale OR capacity OR MW OR kW or community OR pilot OR demonstration OR commercial) Appearing in: 'All Fields'

    Incremental adjustments were made to the search terms to ensure that articles were being correctly selected and duplication avoided.
2. Once results had been generated by technology with confidence from both databases, header information (title, journal, year, author[s] and abstract) from the relevant articles was exported to the *Mendeley* reference management software, and from there re-exported to *Excel*. Duplicate entries were removed and articles were organised technology-wise in readiness for meta-analysis[11].
3. Meta-analysis was then carried out to identify the following patterns:
    a. *Volume of published literature*: The number of publications related to each technology gives a broad indication of relative levels of interest from academic researchers. A simple count by technology was generated.
    b. *Percentage of articles by geographic area:* Knowing the proportion of research taking place in different regions of the world gives an indication of the level of

[11] Meta-analysis is a statistical study approach that can systematically assess the results of previous research to derive conclusions about that body of research in an effort to increase power (over individual studies), improve estimates of the size of the effect and/or to resolve uncertainty when reports disagree.

academic interest around each technology globally, in Newly Industrialised Countries[12] and in SSA. The categories are particularly useful for indicating technologies attracting research interest in Africa or in environments not dissimilar with transferability potential. The percentages of articles by region were generated for each technology (reflecting the region addressed by the research, not the region of origin of the author[s])

c. *Feedstock flexibility:* The number of feedstocks mentioned in the articles was counted for each technology type, as feedstock flexibility is one determinant of replicability potential. Feedstocks were assigned to one of eight categories based on a system adapted from FAO (2004), which is explained in Annex B.

d. *Article theme:* By applying a carefully tested set of keywords (Annex C), the percentage of articles with the following themes could be determined:
   i. Review and/or comparison
   ii. Feasibility analysis
   iii. Environmental implications
   iv. Policy and regulations
   v. Barriers and opportunities

   A higher percentage of articles discussing operational matters like these - as opposed to pure technical issues - is likely to indicate technologies closer to commercial viability, hence of greater interest for catalytic research and innovation.

The outputs of the academic literature review were quantifiable and could therefore be illustrated graphically using charts and diagrams (see section 3.1). By ranking each primary processing technology against the four criteria and summing the ranks, a preliminary indication of the most promising technology areas for research support was generated. This set the scene for investigation of the *non-academic* literature at the more specific level of the *secondary* conversion technologies.

Non-academic literature

The aim of the **non-academic** literature review was to inform the main research question and to provide supporting evidence for the technology prioritisation, the

[12] Eight of the ten recognised Newly Industrialised Countries were included: Brazil, China, India, Indonesia, Malaysia, Mexico, the Philippines and Thailand. South Africa was omitted to avoid duplication with the SSA dataset and Turkey because the contextual similarities with SSA are less pronounced.

main output of this phase of the study. The focus of the review was the gathering of evidence for five prioritisation factors (which are outlined in section 2.4 below).

'Grey' literature is often unpublished and difficult to obtain, especially where it might be commercially sensitive, making it important to adopt a systematic and thorough approach. The identification of relevant literature was carried out simultaneously with the stakeholder mapping process to facilitate triangulation of organisations and individuals with the publications they have produced. The process consisted of (i) an in-depth search via relevant institutional websites and (ii) a snowballing approach.

Search via institutional websites: The team identified an initial 30 institutional websites known to be engaged in bioenergy projects or research beyond the household scale in SSA, India, Brazil or China. These included international organisations, development agencies and banks, NGOs, multilateral energy initiatives and Africa-based renewable energy centres (for full listings see Annex E).

E4tech performed a focused search of the institutional websites using either their internal search engines or Google (using the 'site' function), with the search term combinations "(Biomass OR Bioenergy OR Biofuel) (Africa OR Sub-Saharan Africa OR SSA OR India OR Brazil OR China)".

The search started with "Bioenergy Africa" (or similar) and subsequent searches were more specific if the number of results was too high (>=100) or if the first search did not produce results of sufficient relevance on bioenergy technologies. More specific searches included the following primary technology names (and synonyms):

- Biomass combustion (minus "- cook stoves" if needed)
- Biomass gasification
- Pyrolysis
- Oil pressing OR Biodiesel OR FAME OR Transesterification
- Anaerobic Digestion OR AD OR Biogas
- (Ethanol) fermentation
- Microalgae

Links to reports or further websites were followed up if their title, table of contents or summary showed sufficient relevance on the following scale of 1 to 3:

3: Very relevant: Likely to provide information on most technology prioritisation criteria, covering at least one of the primary conversion technologies and providing several project examples in SSA, Brazil, India or China.

2: Relevant. Likely to provide information on some technology prioritisation criteria, covering at least one of the primary conversion technologies and providing some project examples in SSA, Brazil, India or China.

1: Somewhat relevant: May provide information on a few of the prioritisation criteria for at least one primary conversion technology.

Studies or websites scoring 2 or 3 were targeted for more detailed investigation, while those scoring 1 were only investigated if there were insufficient results scoring 2 or 3 for a particular primary technology. For all recorded results, the technologies and countries were logged, with the reason for their relevance ranking and whether the study contained information relevant for TVC Prioritisation in the next phase.

In addition to screening studies and websites according to these relevance measures, the following generic criteria were also applied to eliminate non-relevant material:

- technologies operating at household level or large industrial scale (biofuel plants >10 Ml/yr or biomass co-generation plants >5 MW); and
- reports published before 1990.

Around 170 reports were identified and about 60% were ranked as 2 or 3, and were thus included in more detailed investigation to inform the five factors of the technology prioritisation. This screening process did not, however, lead to any results for four secondary technologies (Stirling engine, organic Rankine cycle, direct use of biogas and butanol), and very limited results for pyrolysis-based technologies. Specific searches were carried out for these technologies and experts were consulted as part of the snowballing approach.

Snowballing: Using the consortium partners' networks and searches via organisational websites, the team identified and interviewed knowledgeable individuals on bioenergy technologies in SSA at key institutions such as industry associations, think-tanks, international and development organisations, funding agencies and government bodies (as indicated in Annex E). The aim was to identify important bioenergy technology projects and relevant literature, and to discuss with interviewees the prioritisation criteria for the bioenergy conversion technologies. The information and contacts generated via the interviews served as a starting point for further snowballing, which fed usefully into the parallel stakeholder mapping process.

The combination of snowballing and detailed non-academic literature research served as a basis to inform the technology prioritisation.

2.4 Technology Prioritisation

The team set out to identify between three and five secondary processing technologies for further investigation in the next phase of the study. At this initial stage, technologies were considered largely in isolation, on their technical merits and potentials, whereas the TVC Prioritisation Phase will explore the value chains in which each technology is positioned - feedstocks and supply systems, energy applications and business models - in the specific operating context of a sub-set of SSA countries.

As explained, the academic literature review first provided a high level comparison of primary technologies based on four quantifiable factors: the volume of published research material, the percentage of those publications linked to NICs and SSA, the variety of feedstocks researched and the degree to which research themes were non-technical. The resulting rankings of each technology against each factor were summed, to provide a high level indication of comparative potential.

This process did not, however, distinguish between the 15 *secondary* processing technologies. For this comparison, the team drew also upon a combination of the non-academic literature review (as above), the stakeholder mapping process (described below) and diverse professional knowledge, to rate each secondary technology against a set of five factors.

The 15 secondary technologies were assigned a 'high', 'medium' or 'low' score (3, 2 or 1 points) against the following five criteria:

1. **Level of activity and deployment in NICs and SSA.** Higher numbers of successful pilots within SSA and in NICs with potentially similar environments are likely to indicate greater technological suitability and scale-up potential. Technologies with higher levels of existing activity in these regions were therefore given a higher rating.
2. **Appropriateness for SSA** in terms of technological sophistication, infrastructure requirements and social workability. Technologies that can be installed, operated and maintained relatively simply, within the means of most SSA countries, earned a higher rating. Lack of an equipment supply chain or a critical mass of trained technicians contributed to this rating as such limitations make a technology less appropriate, at least within the scope of DFID to make an impact through BSEAA.
3. **Replication potential,** based on the degree to which a technology is adaptable to diverse contexts and feedstocks. Technologies that can operate with a wide range of materials in different environments are likely to have

greatest replication potential and were rated higher. This was a functional judgement based on technical factors.

4. **Competitiveness** compared with other means of delivering the same form of energy. Technologies offering energy that would cost more than existing supply options or more than other renewable alternatives were rated lower. A low scoring example would be biodiesel from energy crops for transport fuel, which is technically proven but cannot currently offer a price-competitive alternative in most SSA countries.
5. **Opportunities for innovation,** technological or otherwise, lie at the heart of BSEAA. However widely deployed, appropriate, scaleable and competitive a particular technology might be, DFID's interest lies in identifying technologies where research and innovation has the potential to catalyse transformational change. To achieve a higher rating and be relevant for further study, opportunities for novel approaches should therefore exist around the technology itself or its value chain positioning in terms of feedstocks, application or operating model. Opportunities for innovation dependent on systemic change (e.g. in governance) are beyond the scope of BSEAA and resulted in a low score against this factor.

The sum of the scores against the five criteria (summarised in section 4) revealed the top-rated technologies for suggested TVC Prioritisation in the next study phase.

2.5 Country Shortlisting

Geographic screening was also carried out to develop a viable selection of countries for further research and potential inclusion in BSEAA Phase II. DFID's 18 countries of interest in SSA were compared against a set of 12 enabling criteria to identify those with closest synergy with DFID's existing interests, the most conducive commercial environments, highest indications of bioenergy demand, current levels of sector interest and greatest potential for impact and reach. The countries were ranked from 1 to 18 against each factor. They were then assigned a score of 2, 1 or 0 according to whether they fell into the top, middle or bottom six (of 18). The scores were summed to give a final figure for country comparison.

Table 2 lists the country shortlisting criteria and the rationale for their inclusion.

Table 2. Criteria for country shortlisting

Description	Rationale for inclusion	Data source
Inclusion in DFID Energy Africa programme	Supports synergy with existing DFID programmes, country office interests and climate/environment staffing	(Wray, 2016)
Inclusion in EEP[13] programme		(EEP Africa, 2016)
Number of DFID countries bordering	Blocks of contiguous countries enhance regional replication potential	Map of Africa
Gross Domestic Product (current US$ bill., 2016)	Wealthier countries are likely to have more investible resources	(World Bank, 2016)
Population (millions, 2015)	Larger populations indicate greater market potential	(World Bank, 2016)
Gross National Income per capita (Atlas method (current US$, 2016)	Individual income indicates energy purchasing power	(World Bank, 2016)
Unmet electricity demand (GW, 2030)	Higher demand gap indicates greater potential demand for new energy sources	See below
Agricultural value added/worker (constant 2010 US$)	Value-addition indicates agricultural intensification and greater potential for centralised residues	(World Bank, 2016)
Ease of Doing Business (2016)	These measures are all likely to indicate ease of project planning, financing and commissioning	(World Bank Doing Business, 2016)
Global Entrepreneurship Index (2017)		(GEDI, 2017)
Corruption Perception Index (2015)		(Transparency International, 2015)
Rule of Law (2015)		(World Bank, 2015)
Quality of national accounts data (2013)		(AfDB, 2013)
Number of active stakeholders	Presence of existing actors is likely to indicate viability and a critical mass of expertise	Own research

Note: *Unmet electricity demand in 2030 refers to the giga-watts (GW) required to satisfy an increase in demand due to population growth on top of existing unmet demand in 2015, assuming a load factor of 0.62 and 20% reserve capacity*[14] (Moss & Gleave, 2013)*:*

Unmet demand (GW, 2015) =

$$\frac{(2015\ pop.*\ \%\ without\ electr.access) * per\ capita\ consump.(kWh)}{(24\ hrs * 364\ days * 1000\ *\ 0.62)} * 1.2$$

Future demand (GW, 2030) =

$$Unmet\ demand\ (2015) + \frac{(2030\ pop. - 2015\ pop.) * per\ capita\ consump.(kWh)}{(24\ hrs * 364\ days * 1000 *\ 0.62)} * 1.2$$

---

[13] Energy and Environment Partnership (EEP) programme for East and Southern Africa.

[14] A different assumption load factor or reserve capacity would produce a different projection of unmet demand, but would not affect the ranking of countries relative to each other.

Population data were taken from UN DESA (2015), *electricity access data from IEA* (2014) *and electricity consumption data from World Bank* (2016). *Missing consumption figures*[15] *were interpolated from a best-fit line of consumption against GNI per capita* (World Bank, 2016).

2.6 Stakeholder Mapping

Finally, the landscape of actors in the bioenergy technology sector in SSA, or with close links or direct relevance to SSA, was mapped. This process of 'stakeholder mapping' was designed to:

- indicate relative levels of activity around different bioenergy technologies and in different countries, thus feeding into the aforementioned processes of prioritising technologies and countries for more thorough analysis;
- generate contacts for further information gathering during the follow-on TVC Prioritisation; and
- provide leads for identifying suitable case studies for the later stages of the assignment.

The stakeholder mapping entailed an exhaustive search and analysis of bioenergy-related projects, programmes and initiatives in SAA (or linked to SSA) in the public, private and academic sectors, identified as described above for the non-academic literature snowballing process. LTS mapped publicly funded multi- and bi-lateral bioenergy programmes, and financing initiatives in the public and private sectors. The University of Edinburgh focussed on the academic sector to identify the leading institutions engaged in bioenergy research on African bioenergy. E4tech's expertise from the commercial domain informed a similar process in the private sector to identify the leading bioenergy project developers and technology providers.

Initiatives of particular scale or relevance were researched in greater depth and individuals with key expertise were followed up in person, by Skype or via email as part of the 'snowballing' process already described to ensure full investigation of all significant activities. Over 100 academics were contacted with a personalised questionnaire, of which 38 responded.

The findings are summarised in section 6: *Stakeholder Mapping*. While the full database of organisations and individuals researched and consulted is too voluminous to include, summary information by organisational type is in Annex E and details are available on request.

[15] For Liberia, Malawi, Rwanda, Sierra Leone, Somalia and Uganda.

3. Findings of Literature Review

3.1 Academic literature

As described in the methodology, the academic literature review followed a systematic process of selecting and analysing relevant literature for each of the shortlisted primary technologies. 6,020 articles across the eight technology types were ranked against the selected criteria, thereby contributing to the final technology shortlisting process. Of the articles identified, over 91% were published in the last decade, reflecting the growing digitisation of academic research material.

3.1.1 Volume of literature

Figure 1 compares the volume of academic publications concerning each of the primary technology types. Articles also mentioning other technology types are differently shaded in the stacked columns.

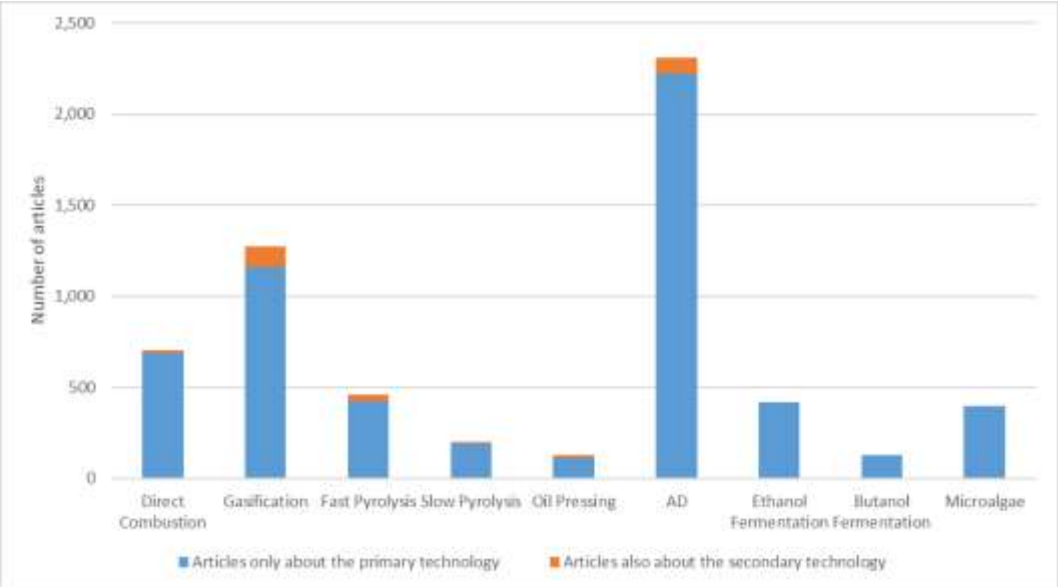


Figure 1: Number of articles per primary technology

Anaerobic digestion has clearly enjoyed the greatest interest from academic authors, followed by the thermo-chemical pathways of gasification, direct combustion and fast pyrolysis. Slow pyrolysis, though widely used in Africa's charcoal industry, features low in volume of literature, suggesting that there is limited academic research interest in this type of technology. Amongst the bio-chemical pathways, technologies such as microalgae and liquid biofuels from ethanol fermentation are gaining academic interest, but still register fewer than a quarter of the number of articles of anaerobic digestion. Oil pressing and butanol fermentation register the lowest article count, perhaps because these are relatively narrow technological areas with less room for novel research.

The technology ranks are summarised in the following table. A similar summary is included at the end each section below.

Summary scores: Volume of literature

Description	Direct combustion	Gasification	Fast pyrolysis	Slow pyrolysis	Oil pressing	Anaerobic digestion	Fermentation	Microalgae
No. of publications	704	1,274	457	201	128	2,312	546	398
Score (8-1)*	6	7	4	2	1	8	5	3

* - Highest numerical score (8) indicates most favourable option

3.1.2 Geographic spread

Figure 2 provides an indication of the geographic focus of the articles concerning each technology type. The aim was to identify technologies revealing a particularly high level of interest around subject matter from SSA or from the eight selected Newly Industrialised Countries, thus providing an indication of the level of academic interest in each technology within SSA and in locations with transferability potential.

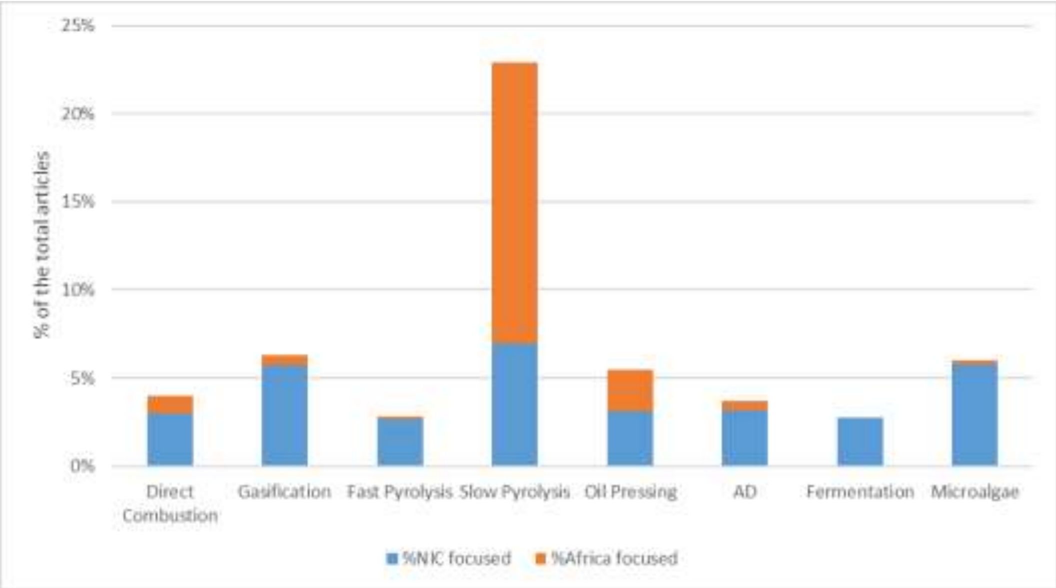


Figure 2: Percentage of articles for each primary technology concerning SSA or Newly Industrialised Countries

The data show that Africa features much higher in articles about slow pyrolysis than any other technology type, with 16% of such articles having an SSA focus. This indicates the huge research interest in understanding the charcoal industry and its impacts. A much smaller percentage of articles with an SSA focus were found across the other technologies. Articles on gasification and anaerobic digestion tend to analyse the applicability of the technology for certain operating contexts or the status and technology development in a particular country, so have a relatively strong geographic orientation. Articles relating to the other technologies are more likely to address experimentation with performance using certain types of feedstocks, rather than in particular countries, and show less country-specificity. Though accounting for a small number of mentions overall, the countries within SSA most highly represented in the literature are South Africa, Kenya and Tanzania, with a handful from elsewhere (e.g. Ghana, Malawi, Mozambique, Uganda and Zambia).

With respect to the Newly Industrialised Countries, the data shows a more even spread across the different technologies. Slow pyrolysis, gasification and microalgae record a slightly higher percentage of Newly Industrialised Country articles than the rest. Not surprisingly, over 83% of the these articles come from Brazil, China and India, given their population and historical experiences. An analysis of specific technology trends suggests that China features highest for anaerobic digestion articles whereas India is more highly represented in articles about gasification. Brazil scores highest in articles about fermentation and slow pyrolysis (this being no surprise as Brazil is the world's largest charcoal producer). These countries therefore seem to offer particularly rich learning grounds for the technologies in which they dominate the academic literature, and could be explored in more detail depending on the technologies shortlisted for the next phase.

Summary scores: Geographic spread of articles

Description	Direct combustion	Gasification	Fast pyrolysis	Slow pyrolysis	Oil pressing	Anaerobic digestion	Fermentation	Microalgae
NIC (%)	3.0%	5.7%	2.6%	7.0%	3.1%	3.2%	2.7%	5.8%
SSA (%)	1.0%	0.5%	0.2%	15.9%	2.3%	0.5%	0.0%	0.3%
Total (%)	*4.0%*	*6.3%*	*2.8%*	*22.9%*	*5.5%*	*3.7%*	*2.7%*	*6.0%*
Score (8-1)	4	7	2	8	5	3	1	6

3.1.3 Article theme

Figure 3 shows the percentage of published articles mentioning themes other than purely technical matters. These articles are then broken down by primary theme in Figure 4.

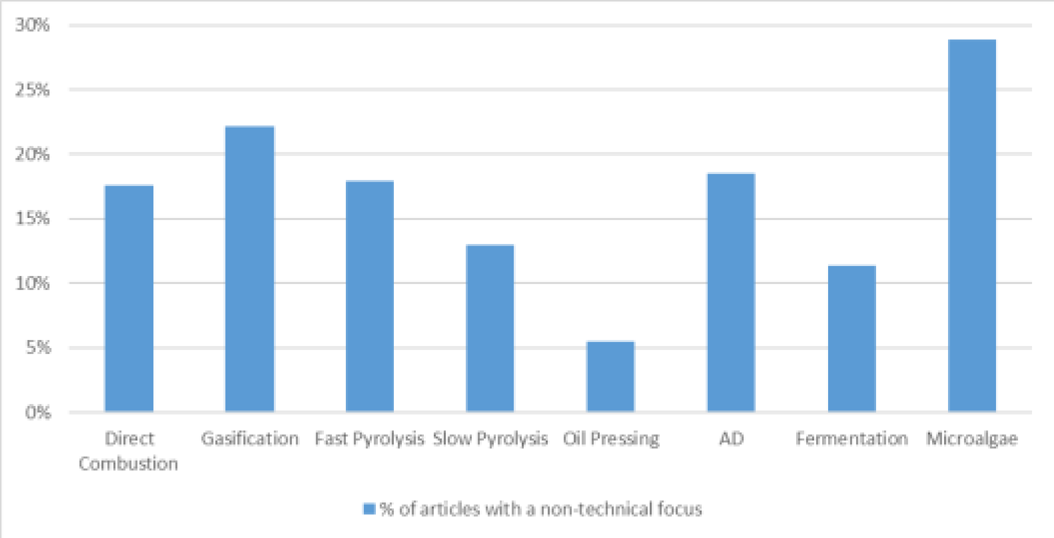


Figure 3: Percentage of academic articles with a non-technical focus

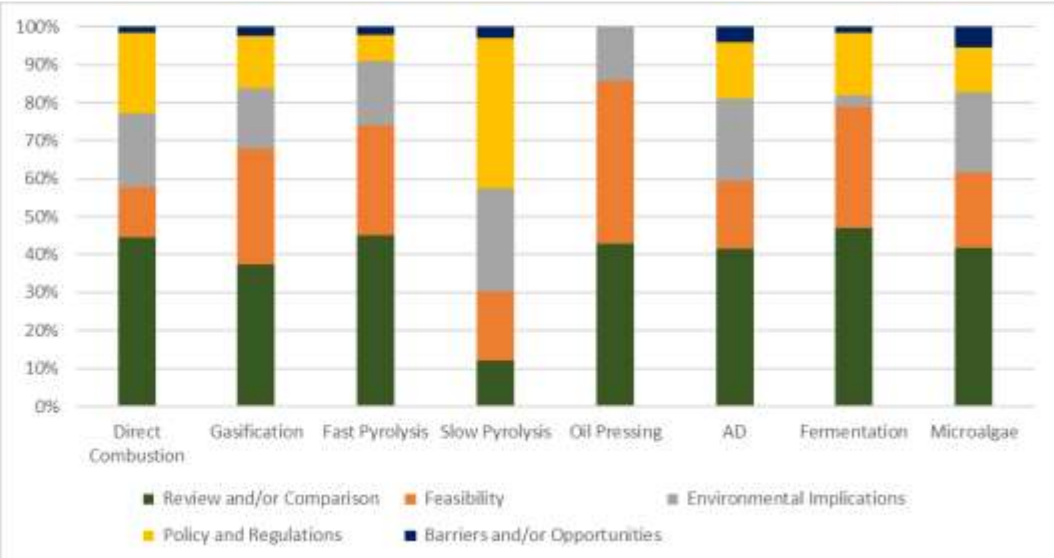


Figure 4: Comparison of non-technical articles by theme

The results in Figure 3 suggest relatively low rates of publication on non-technical themes for liquid biofuel production, as indicated by the lowest percentages for oil pressing and fermentation. There is also limited evidence of non-technical research on slow pyrolysis. In fact, Figure 4 shows that 67% of slow pyrolysis research concerns regulatory issues or environmental implications, which is unsurprising as it confirms that most 'technical' challenges in this area have been resolved and research tends to address life cycle assessment, forest degradation or policy options.

Of the other technologies, direct combustion, anaerobic digestion, gasification and fast pyrolysis all stand at around 18% for non-technical article themes. From Figure 4 it is evident that a majority of articles across all technology types address reviews or comparative analysis. Further analysis suggests that the most mature technologies - like anaerobic digestion and direct combustion - give a more uniform spread across article themes while newer technologies - such as fast pyrolysis and gasification - attract more research on techno-economic feasibility. Such feasibility studies tend to include case studies, sensitivity analysis or cost benefit analysis. Articles coming from India focus almost exclusively on decentralised, rural research.

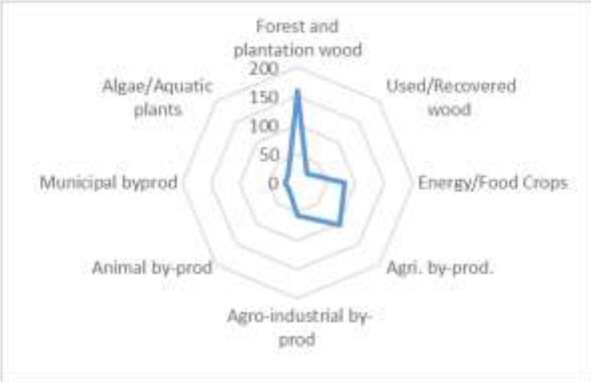
Interestingly, microalgae features highest in the proportion of 'non-technical' article themes, at close to 30%. This might seem counter-intuitive for a highly academic area of research. Closer analysis of article abstracts shows that researchers see algal technology at the forefront of future bioenergy production (owing to high rates of biomass accumulation, CO_2 capture and oil production) and many review studies are already looking beyond laboratory research towards impending implementation issues such as economic, environmental and policy considerations.

Summary scores: Article theme

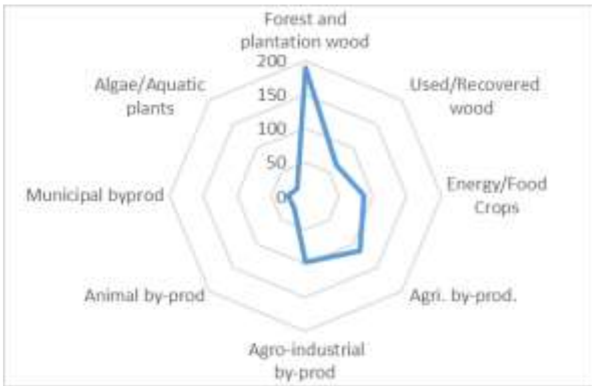
Description	Direct combustion	Gasification	Fast pyrolysis	Slow pyrolysis	Oil pressing	Anaerobic digestion	Fermentation	Microalgae
Non-technical focus (%)	17.6	22.1	17.9	12.9	5.5	18.6	11.4	28.9
Score (8-1)	4	7	5	3	1	6	2	8

3.1.4 Feedstock flexibility

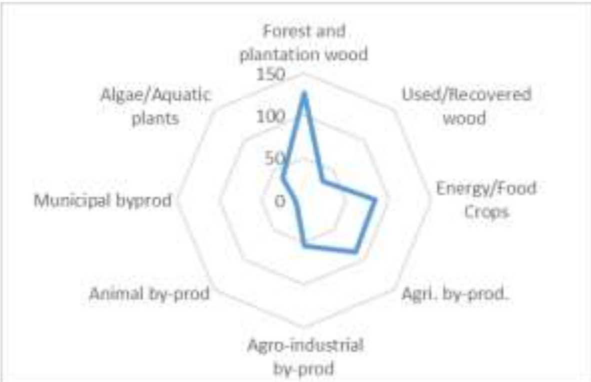
The radial graphs in Figure 5 provide a visual impression of feedstock flexibility for the different primary conversion technologies, according to the number of feedstocks mentioned in the published literature. This is one indication of potential suitability for replication under diverse geographic and climatic conditions.



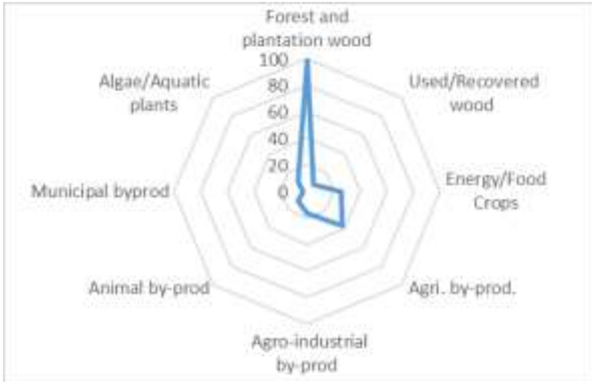
Direct combustion



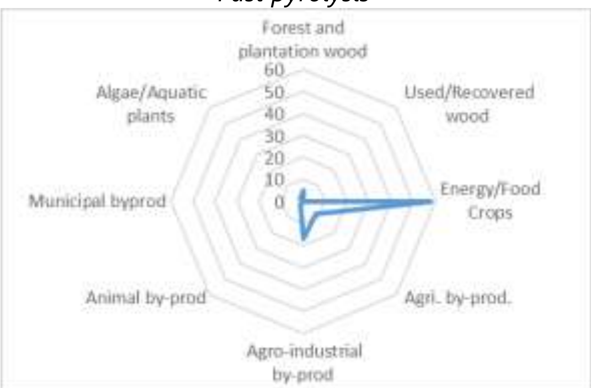
Gasification



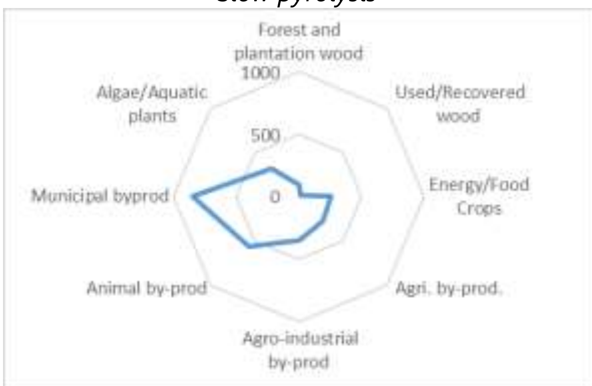
Fast pyrolysis



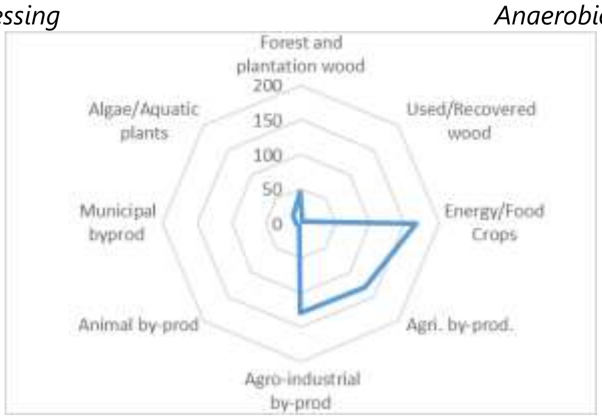
Slow pyrolysis



Oil pressing



Anaerobic digestion



Fermentation

Figure 5: Feedstock flexibility of different primary conversion technologies

The graphs give a clear visual indication that thermo-chemical technologies (such as direct combustion and slow pyrolysis) are skewed towards woody biomass feedstocks, while liquid biofuel technologies (such as fermentation and oil pressing) are heavily reliant on agro-fuels. The literature indicates that oil pressing is carried out almost exclusively using the food or energy crop itself, which inevitably means that only feedstocks that yield oil will be suitable, whereas fermentation is a more flexible technology with a broader range of feedstocks across other categories of agro-fuels, agricultural by-products (such as leaves, stalks, straw and stover) and industrial by-products (such as bagasse, rice husk and seedcakes). The most feedstock-flexible technologies according to the literature are fast pyrolysis, gasification and anaerobic digestion, with the latter demonstrating highest flexibility of all. Anaerobic digestion is also notable in being the only technology that can use municipal and animal wastes as the principal biomass source.

Of the technologies that favour the use of woody biomass, direct combustion shows the most even spread across feedstocks, with highest species mentions for pine, poplar, willow and olive. For fast and slow pyrolysis, the highest count is for pine (including pine sawdust), with eucalyptus and poplar also featuring for fast pyrolysis. The majority of the woody feedstocks mentioned for gasification are from pine wood and olive (including stones and kernels). Amongst all types of woody biomass, pine wood is the most frequently mentioned while eucalyptus, oak, olive, willow and poplar are also mentioned to different degrees depending on the technology.

Amongst the by-products from processing industries, sawdust is the prominently mentioned woodfuel (contributing to 64% of the total) with much lower counts for other options such as waste wood, paper, black liquor and demolition wood.

The use of agro-fuels, including raw and industrial by-products, shows interesting diversity (except for slow pyrolysis, which is heavily dominated by woody feedstocks). Amongst the thermo-chemical pathways (direct combustion, fast pyrolysis and gasification), the dominant agro-fuel feedstocks are second generation energy crops such as switchgrass and miscanthus, and by-products of first generation food crops such as maize, sugarcane and wheat. Among direct agricultural by-products, straw/stover is the most used feedstock (and to a lesser extent shells, leaves, root, peels and stalks). This is common across the bio-chemical pathways as well. Agro-industrial by-products most commonly cited are bagasse, bran and husk.

Amongst the liquid biofuel production technologies, jatropha features highest as feedstock for oil pressing, followed by other oil crops such as rapeseed, sunflower, pumpkin seed, oil palm and sesame. The most common feedstocks for fermentation are maize and sorghum (including sweet sorghum), and to a lesser extent sugarcane, cassava and wheat. Industrial by-products for fermentation, on the other hand, are dominated by bran and bagasse, and to a lesser extent pulp, whey and molasses.

The dominant feedstock category for anaerobic digestion is municipal by-products, including sewage sludge, organic fraction of municipal solid waste and food/kitchen waste. Animal by-products used are mainly manure, including poultry litter and cattle dung, and to a much smaller extent slaughterhouse waste. Food crops associated most commonly with anaerobic digestion are maize, sugar beet and wheat, while the main industrial by-products are pulp, bran and silage.

Finally, where microalgae is the biomass source (either using anaerobic digestion or growing), the most prominent species are chlorella followed by nannochloropsis and scenedesmus, and - to a much smaller extent - spirulina, dunaliella and gracilaria.

Summary scores: Feedstock flexibility

Description	Direct combustion	Gasification	Fast pyrolysis	Slow pyrolysis	Oil pressing	Anaerobic digestion	Fermentation	Microalgae
Score (8-1)	6	7	5	3	2	8	4	1

3.1.5 Summary

Based on the systematic analysis of the academic literature described in this section, the scores assigned to each technology against the four criteria are consolidated in Table 3. This provides a preliminary indication of the most promising areas of primary processing technology for research and innovation support.

Table 3. Ranking summary from academic literature review

Criteria:	Volume of literature	Deployment pattern	Article theme	Feedstock flexibility	***Total score***
Direct combustion	6	4	4	6	***20***
Gasification	7	7	7	7	***28***
Fast pyrolysis	4	2	5	5	***16***
Slow pyrolysis	2	8	3	3	***16***
Oil pressing	1	5	1	2	***9***
Anaerobic digestion	8	3	6	8	***25***
Fermentation	5	1	2	4	***12***
Microalgae	3	6	8	1	***18***

Gasification and anaerobic digestion come out as particular promising technologies from this analysis, followed by direct combustion and then microalgae. Technologies involving pyrolysis show a lower potential, with fermentation and oil pressing (aimed mainly at the production of liquid biofuels) scoring lowest of all.

3.2 Non-academic literature

3.2.1 Combustion-based technology

Direct combustion

Direct combustion for heat is the oldest and most prevalent energy biomass processing 'technology' worldwide. Appliances used at household level include basic open fires and traditional hearths, manufactured cookstoves and fuel-efficient chip burners and pellet boilers. On a small to medium industrial scale (200 kW - 20 MW), grate boilers and underfeed stokers provide both heat and steam (IEA, 2009). These well-established technologies are at TRL 9.

At household scale, there is significant activity in this domain in SSA, given that dependency on 'traditional' biomass energy for cooking, lighting and heating is high compared to other regions (Stecher, et al., 2013). At small to medium industrial scale, there are also various examples of direct combustion in the sugar, tea and forestry sectors (under the 5 MW ceiling) and there may be many more unreported cases of direct combustion for heat boilers (Pasquiou, et al., 2012). Companies such as John Thompson in South Africa produce boilers within the region (John Thompson, 2017).

Given that the technology is of low sophistication, has been in use for a long time and is able to use multiple feedstocks that are cheap and readily available, direct biomass combustion for heat can be deemed highly appropriate, replicable and competitive in the SSA context. There is very low potential for innovation, however, besides some improvement in efficiencies, making this technology of low overall interest for further investigation under BSEAA.

The following table summarises the ratings for this technology option against the five prioritisation criteria. A similar table is repeated at the end of each sub-section and the combined scores are summed in the next chapter to reveal the most promising opportunities overall.

Summary evaluation

Level of activity	Appropriateness for SSA	Replication potential	Competitiveness	Opportunities for innovation
High	High	High	High	Low

Steam turbine

Steam turbines can be used for electricity generation as well as industrial CHP. While the former are usually large scale projects outside the scope of this study, steam turbines for CHP using back-pressure or extraction-condensing systems operate from below 100 kW_e to over 1000 MW_e (E4tech, 2016; Siemens, n.d.) and thus fall within the desired scale range. The technology is at TRL 9 and there is a high level of activity globally.

Low pressure boilers feeding back-pressure steam turbine CHP systems have been economically viable where there is demand for electricity as well as steam (Anon., 2006). Such boilers operate at very low efficiency, however, and since the early 2000s, sugar factories have instead started to use high pressure boilers with extraction-condensing steam turbines for electricity export to the grid (Kartha, et al., 2005). In SSA, there is high potential for CHP in industries with a lignocellulosic waste stream. CHP has thus become widely used in the sugar industry, where there are at least ten combustion-based steam turbine projects in SSA (<5 MW) and others in the pulp and paper, tea and palm oil sectors. These projects are mostly in Cameroon, Kenya, Tanzania and South Africa (Pasquiou, et al., 2012).

Steam turbine generators are technically more complex than simple combustion-to-heat boilers, and most steam turbines in SSA have historically been manufactured in Brazil, India and South Africa (mainly >5 MW) (Karekezi, 2017). However, companies such as Quintas Renewable Energy in Nigeria now produce steam turbines outside South Africa in the range 100 kW to 1 MW (Quintas, 2017). Such local manufacture requires the establishment of durable supply chains for spare parts and a network of trained technicians.

Theoretically it is possible to operate steam turbine technology at large community scale, though research did not identify any working examples in SSA. The smallest project identified was at 0.5 MW (Pasquiou, et al., 2012). There are also technical impediments to use by communities or small businesses, as their demand for heat and power tends to fluctuate significantly and frequently not together; small businesses in rural areas using heat and electricity for applications such as fruit drying or water pumping will only require energy for parts of the day. CHP systems based on steam turbine technology meanwhile take a relatively long time to start up (to reduce thermal shock to the turbine blades) and can be costly to maintain when not in use (Muller, 2005). They are also less efficient when used intermittently (Thomas, 2017). These considerations probably make the technology better suited to small to medium scale industries, rather than community installations.

Given that industries with suitable feedstock, like sugar factories and sawmills, are present in large numbers across Africa (although sugar factories with a potential of <5 MW are concentrated in East Africa) and need both electricity and heat, this technology has high potential for replication in SSA. Water is needed for the steam cycle and for cooling, should air cooling not be available, and could reduce replication potential in some regions. Using steam turbines for co-generation could be competitive in small to medium scale industries compared to diesel, where a low cost or no-cost (waste) feedstock is available. Capital costs of boilers and steam turbines are very scale-sensitive, however, and steam turbines below a few MW are significantly more expensive per unit of output than larger units (Kartha, et al., 2005).

There is potential for innovation with this technology, mainly in the development of off-the-shelf boiler, steam turbine + generator combi units in the range 250 kW to 5 MW. Smaller units currently come from India (with others from Brazil and South Africa above 5 MW), but at a scale of <5 MW they have to be custom-built and are not available ready-made.

Summary evaluation

Level of activity	Appropriateness for SSA	Replication potential	Competitiveness	Opportunities for innovation
High	Medium	High	High	Medium

Steam engine

Steam engines (which produce mechanical work through pistons using steam as a working fluid) have existed since the industrial revolution and are at TRL 9, but there are surprisingly few manufacturers producing steam engines that generate electricity. In Germany, Spilling Technologies fabricate units with a capacity of 100-1200 kW (Spilling, n.d.). In the context of SSA, very few steam engine projects at a scale of <5 MW were found. One example, Sao Hill Sawmills in Tanzania, has a 1 MW co-generation plant (with steam engine) that uses sawmill waste as fuel to generate power for internal use (Brew-Hammond & Kemausuor, 2008). At the nut processor SICAJU in Guinea Bissau, there is a 60 kW_e steam engine that runs on cashew shells (Fredericks, 2015). Village Power Industries, a US social enterprise, has manufactured a 10 kW steam engine which it claims is simple to maintain and repair, and can despatch power at any time. There is no requirement for lubricants as the sliding surfaces of the piston and piston seals are made of carbon graphite material (Goudarzi, 2016).

Steam engine technology is deemed appropriate for SSA as its sophistication level is lower than steam turbines and existing projects are at smaller capacities (in kW) than those using steam turbines (Goudarzi, 2016). Village Industrial Power claim an electrical efficiency of 10% for their steam engine (higher for steam turbines but they operate at a larger scale) and a thermal efficiency of 60%. Steam engines are also more suitable for a community setting as they can be started up quicker and can operate at lower load factors than steam turbines (Muller, 2005). They have lower investment and maintenance costs, making them a more affordable option. But investment costs for a community scale 7 kW unit can still be double the price of a diesel generator set, as the example of Village Industrial Power shows (Goudarzi, 2016). The technology has high replication potential as it is capable of using a variety of feedstocks and can be used at small to medium scales. However, water is required for the open steam cycle (water is not reused), which might reduce replication potential in water-scarce regions. Finally, there is opportunity for innovation with this technology, potentially in manufacturing steam engines as an 'off-the-shelf' unit.

Summary evaluation

Level of activity	Appropriateness for SSA	Replication potential	Competitiveness	Opportunities for innovation
Low	Medium	High	Medium	Medium

Stirling engine

Stirling engines are best described as indirectly-fired gas engines. The working fluid is a gas (normally air, helium, nitrogen or hydrogen), which is used in a closed cycle (E4tech, 2016). The heat is transferred to the working fluid from an external source through a heat exchanger, hence the description 'indirectly-fired'. The working fluid is compressed and expanded in a cycle. During the expansion, force is transmitted to a crankshaft and can be used for electricity generation. Stirling engines for power and CHP exist in a scale range from 1 kW_e to slightly over 100 kW_e and are currently at TRL 7 (van Loo et al., 2008).

The external heat may come from any source, such as waste heat or concentrated solar power (E4tech, 2016). For biomass-fuelled set-ups, the heat could potentially come from a combustion chamber fuelled by solid biomass, or a burner running on pyrolysis oil, or gases from gasification or anaerobic digestion.

European companies such as Cleanergy, Stirling DK, Wudag and Bios Bioenergiesysteme have developed Stirling engines for different contexts. Stirling DK filed for bankruptcy in 2013, however, and the Bios Bioenergiesysteme engine has only been tested at demonstration scale (E4tech, 2016; Ingenioren, 2013; Bios Bioenergiesysteme GmbH, n.d.). However, Qnergy, a US-Israeli outfit and Cleanergy, a Swedish company using German Stirling technology, appear to be more successful.

Qnergy has a reported production capacity of 18,000 Stirling engines per year and Cleanergy has 10-15 CHP Stirling units installed, mainly in Europe and the US (Qnergy, n.d.; Cleanergy, 2017). Cleanergy advocate their 9 kW CHP unit for use at landfills, biogas plants and sewage treatment plants. Qnergy units can theoretically use biomass as a heat source, but it is unclear whether any such installations actually exist.

In SSA it was not possible to identify any Stirling engines running on heat produced from a biomass feedstock. No supply chain or trained technicians therefore exist. Given that the technology is not yet commercially widely available even in Europe or the US, the appropriateness for SSA under current conditions is judged as low.

The fact that any external solid, liquid or gaseous biomass heat source can be used to run a Stirling engine nevertheless means that theoretical replication potential is high. Stirling engines can be used in conjunction with anaerobic digestion plants, gasification units or biomass combustion units, making them very context-flexible. Attention needs to be paid to fouling of the heat exchangers due to contaminants in the combustion gases. Commercial roll-out is held back by high production costs. The heat exchanger in the engine may need to be made of special materials to ensure high efficiency and these materials are costly and difficult to replace. This makes Stirling engines less competitive than internal combustion engines or solar PV devices, which are currently more affordable and effective (Gadré & Maiorana, 2014).

The efficiency and cost of Stirling engines has further improvement potential (given that it has not reached TRL 9) so testing and adaptation to the SSA context could offer considerable opportunities for innovation. The set-up of a viable supply chain, a workable business model at smaller community scale and medium industrial scale that could work with a variety of gaseous, liquid or solid biomass heat sources and training of local technicians also hold potential for innovation, but with an absence of current SSA activity around this technology it would be a mammoth task to achieve any significant commercial penetration.

Summary evaluation

Level of activity	Appropriateness for SSA	Replication Potential	Competitiveness	Opportunities for innovation
Low	Low	High	Medium	High

Organic Rankine cycle

Organic Rankine cycle (ORC) systems normally use waste heat (at temperatures below those of a steam cycle) from a range of processes to produce electricity through a turbine system, using an organic fluid as the working medium. ORC heat sources can be solid, gaseous and liquid biomass, exhaust gas from gas turbines, waste heat from industrial processes or process steam (Rowshandzadeh, 2011).

Several companies in Europe and the US (such as Siemens, Turboden, Infinity, Exergy ORC and Electratherm) offer ORC systems from a few kW_e to 15 MW_e and Turboden alone has installed around 300 ORC systems globally (ElectraTherm, n.d.; Siemens, n.d.; Turboden, n.d.). Around half of all ORC systems are integrated in biomass plants using waste heat, and two thirds of ORC heat recovery projects use the waste heat from diesel engines or gas turbines (Tartiere, 2015). The only three ORC projects identified in SSA are, however, using heat from either geothermal sources (in Ethiopia and Kenya) or iron smelting (in South Africa), rather than from biomass feedstocks (Tartiere, 2015). This suggests a possible lack of competitiveness with other renewable energy options.

Given that no biomass ORC systems seem to be operational in SSA, only very limited supply chains and technical capacity exist (based on the three non-biomass projects) and the technology is very costly in comparison to steam turbines, current appropriateness for SSA can be judged as low (Karekezi, 2017). The fact that any external solid, liquid or gaseous biomass heat source can be used to run an ORC system nevertheless makes its theoretical replication potential high. ORC systems as tertiary conversion technologies come at an additional investment cost to increase the overall efficiency of a system. Competitiveness will depend on the investment costs, increased electricity production and its price, and has to be evaluated for each investment case.

Opportunities to explore cost reduction, testing and adaptation to the SSA context offer moderate opportunities for innovation with ORC. The development of a viable supply chain, cadres of technical professions and competitive business models for smaller community scale and medium industrial scale that can work with a variety of gaseous, liquid or solid biomass heat sources and training also hold potential for innovation. The absence of working models in SSA and high technical sophistication still make for only moderate overall potential.

Summary evaluation

Level of activity	Appropriateness for SSA	Replication potential	Competitiveness	Opportunities for innovation
Low	Low	High	Medium	Medium

3.2.2 Gasification-based technology

Syngas engine

Gasification is a thermo-chemical process in which the feedstock is heated to high temperatures to produce gases that react to form syngas, which comprises mainly hydrogen and carbon monoxide (plus nitrogen, carbon dioxide, methane, other hydrocarbons and tars, organic compounds and metallic contaminants). Once the syngas is cleaned it can be used to operate a gasoline or diesel engine for electricity production (UNIDO, 2014). A small proportion of diesel (10-15%) is often co-injected to ensure proper ignition (UNIDO, 2014). Gasification can achieve an efficiency of 19% compared to 15% for a dedicated biomass combustion CHP plant[16] (E4tech, 2016), though basic gasifiers made by the Indian company Husk Power Systems (HPS) have an efficiency of 7-14% (IRENA, 2014; UNIDO, 2014). Heat recovery at the engine for biomass drying or outside endothermic processes can significantly increase the overall efficiency of biomass use.

Fixed bed gasifiers in the capacity range of less than 100 kW_{th} to a few MW_{th} were developed from the late 1980s for heat generation (now commercially established) or power generation using diesel or gas engines (UNIDO, 2014). For power generation, fixed bed gasification works well at the scale of several kW_e up to 3 MW_e and can be well suited to rural electrification if sustainable biomass is locally available (UNIDO, 2014). Small to medium scale gasification for power and heat generation (a few kW_e to over 100 kW_e) is applied at many locations in India, including at community scale (30-150 kW_e), and includes applications such as cardamom-drying and silk processing (TERI, 2017). The main manufacturers are HPS, Decentralised Energy Systems India, Saran Renewable Energy and The Energy Resources Institute, who have together installed at least 400[17] projects (IRENA, 2014; Kennedy, 2012; Husk Power Systems, 2017; DESI Power, 2017). In SSA several small-scale gasification projects exists, such as the Mukono gasification plant in Uganda at 10 kW_e, but - in contrast to India - projects are scattered and at demonstration scale. The International Finance Corporation has a partnership with HPS to increase the uptake of gasifiers in Kenya and Tanzania (IRENA, 2014). At larger scale, bankable projects using municipal solid waste for gasification have proven almost impossible to develop because of low tipping fees at landfills or uncontrolled landfills (Williams,

[16] Efficiency = MWh of electrical energy out/MWh of feedstock energy in. 1 MW gasifier operates at 62% efficiency and internal combustion engine at 31%. 2-10 MW bio-dedicated CHP steam turbine plant has 15% electrical and 45% thermal efficiency.
[17] The Energy Resources Institute around 300, HPS 84, Decentralised Energy Systems India 15 and SRE a few.

2017). Such initiatives would require wider governance interventions to regulate municipal solid waste and enforce penalties for dumping.

The modular set-up of gasification plants, their availability at small scale and their labour-intensive nature makes them well suited to SSA, if suitable training and spare parts were available (UNIDO, 2014). Gasification can be carried out in batch mode to meet fluctuating electricity demand and potentially supplement a solar mini-grid (Thomas, 2017). Gasification is a more sophisticated technology than combustion and requires more experienced personnel for maintenance and cleaning (in particular for tar cleaning) (Karekezi, 2017; UNIDO, 2014). Even though skills and expertise to operate certain renewable energy systems are partly available in East Africa, local manufacturing capacity for gasification does not currently exist (Kennedy, 2012). Cleaning of the syngas to achieve high purity for internal combustion engines is crucial to avoid reduced lifetime and higher maintenance intervals, but these removal processes come at considerable cost (UNIDO, 2014; Kennedy, 2012). The required gas filters can produce carcinogenic waste (in the case of wet stripping). For small-scale gasifiers, it is important to achieve maximum turn-down ratios of 50% of load for efficiency and low tar production (UNIDO, 2014). A main by-product, inert organic material, has value as fertilizer or building material (Kartha, et al., 2005).

Gasification systems can be designed for a particular feedstock and across the full-scale range for this study. This makes them suitable for a wide range of areas in SSA. HPS even operates multi-fuel gasifiers that can be fed with rice husk, wheat husk, mustard stems, wood chips or corn cobs (Husk Power Systems, 2013). The systems can operate at community scale (even in batch operation) to serve a mini-grid or small industrial load, for electricity, heating or cooling. Replication will depend, however, on the establishment of a local or regional cluster of gasification projects, a supply chain for spares and competent maintenance personnel.

Relatively high efficiencies and the potential for small operating scales can make gasification an attractive choice compared with combustion. Competitiveness with available commercial fuel (such as diesel) to produce heat or power will depend on local availability and cost of the biomass feedstock. HPS can reportedly provide electricity in India more cheaply than power from kerosene or diesel, while gasification for water pumping can be one third of the cost of using diesel-powered engines (GIZ, 2015; Kennedy, 2012), in both cases using rice processing by-products.

Improved gas clean-up to avoid tars and ensure reliable engine operation will be an important factor for ensuring the robustness of gasification systems in rural SSA. The reduction of water use and carcinogenic waste through different gas cleaning systems represent attractive innovation opportunities, as water can be scarce and toxic waste treatment systems are often not in place (Thomas, 2017). The Energy Resources Institute (India) is researching a closed water loop for syngas clean-up with significantly reduced water use (Thomas, 2017). A well-designed business model providing appropriate incentives to farmers, community members, entrepreneurs and technicians, as well as the development of an innovative regional value chain, represent potential non-technical innovation opportunities (Kennedy, 2012).

Summary evaluation

Level of activity	Appropriateness for SSA	Replication potential	Competitiveness	Opportunities for innovation
Medium	Medium	High	Medium	High

3.2.3 Pyrolysis technology

Pyrolysis is the controlled thermal decomposition of biomass in an oxygen-free environment to produce a mixture of solid bio-char (charcoal), liquid bio-oil and gases. The terms fast and slow pyrolysis reflect different residence times in the reactor. The higher temperature and shorter residence time of fast pyrolysis favours the production of 'bio-oil' (see below), which can be used for power, heat or upgrading to transport fuel. Fast pyrolysis produces around 12% char, 75% liquid and 13% gaseous products (Czernik, 2008). The lower temperature and longer residence time of slow pyrolysis maximise the production of solid bio-char, producing around 35% char, 30% liquid and 35% gaseous products (Czernik, 2008).

Fast pyrolysis

Fast pyrolysis produces a dark brown, viscous liquid called bio-oil. This can be used for the generation of heat or electricity, for example through a boiler and steam turbine or in a diesel engine. It can also be co-fired with fossil oil in an existing power plant. The bio-oil has a higher volumetric energy density (MJ/l) than the biomass feedstock from which it was produced, hence may be more economical to transport.

Globally, there are several companies with early commercial fast pyrolysis technologies (TRL 7-8), with current and planned commercial scale plants in the range of 20 to 40 Ml/yr (LBNet, 2016). These plants are all located in Europe or North America, however. Some companies focus on pyrolysis as a waste treatment technology, such as Beston, who have deployed such a plant in Nigeria (Beston, 2017), and GrahamTek, who are planning a plant in South Africa (Williams, 2017). The use of fast pyrolysis to produce bio-oil in SSA remains extremely limited, however.

Fast pyrolysis is a technically challenging process which is not yet deployed at wide scale, mainly due to the instability and high-acidity of the bio-oil and technical difficulties associated with certain feedstocks (e.g. ash content) (IRENA, 2016). This makes it a difficult technology to deploy in SSA. Skilled personnel are required to operate plants and optimise the process for feedstocks that may be available in different regions. Expertise in the supply chain and corrosion resistant boilers or engines are also required, to ensure safe handling and use of the corrosive bio-oil.

A wide range of feedstocks can be used for fast pyrolysis, as long as they are pre-treated to the required moisture content and particle size. So, in theory this technology could be widely replicated across SSA. The composition of the feedstock (e.g. ash content) can impact the yield of bio-oil, however (E4tech internal, 2015).

It has been noted that fast pyrolysis bio-oil has a higher energy density than the biomass feedstock, allowing easier transport of the fuel. If the bio-oil is simply combusted *in situ* to produce electricity in a steam turbine or engine, it may be economically more competitive (and technologically much simpler) simply to combust the biomass directly rather than convert it to bio-oil.

Even companies in Europe and North America specialising in fast pyrolysis are not producing plants yet at full TRL 9, so there is still scope for technological innovation. In addition, given that pyrolysis technology has not been trialled with the sorts of biomass feedstocks that might be available in SSA, further innovation will likely be required. There is also opportunity for innovation around value chains, as biomass pyrolysis value chains have not yet been established in Africa.

Summary evaluation

Level of activity	Appropriateness for SSA	Replication potential	Competitiveness	Opportunities for innovation
Low	Low	Medium	Low	Medium

Slow pyrolysis

Slow pyrolysis has a long history of use in charcoal production across SSA and throughout the world. Charcoal is still used extensively for household cooking and heating, and much charcoal production occurs at small scale in the informal sector. Charcoal production is excluded from this review because it is a process that changes biomass from one form to another rather, than into useful energy. Instead, we focus on the more innovative capture of waste gases from advanced charcoal production processes for electricity or heat production in an internal combustion engine.

There are companies in Brazil and France exploring the cogeneration of electricity using pyrolysis gases from charcoal production, as well as scattered examples of other companies in Denmark and Australia (de Miranda, 2012). The large-scale, mechanised nature of charcoal production in these regions means that their activity has limited transferability to SSA, however, and there are currently no charcoal-gas cogeneration plants operating or under development in SSA (de Miranda, 2012).

Many SSA governments are unwilling to intervene or support the charcoal sector as it is seen as an outdated energy source associated with environmental and health problems (Neufeldt, 2015). Capturing waste gases from more advanced charcoal production methods to generate electricity is not deemed appropriate for SSA within the scope of the current study, due to the extensive change that it would require in the informal charcoal production industry across the whole continent. Production is currently carried out by small-scale artisanal operators, but waste gas capture would require a larger processing scale to be economical (de Miranda, 2012). The unregulated nature of the sector is unlikely to attract formal sector investors, as long as the current punitive regulatory regimes against charcoal are in place.

The potential replicability of this technology across SSA is theoretically high, as charcoal production takes place extensively across the continent and can use a variety of biomass feedstocks, in principle offering a huge opportunity to use more advanced charcoal production methods capable to capture the currently wasted gases from this process. The technology could in theory be implemented wherever charcoal production takes place.

Given, however, the small scale of charcoal production in SSA, the required investment and the social and political changes that would be required to implement new technology in this sector, it is considered that electricity generated from waste gases of advanced charcoal production is not a straightforward or suitable conversion technology for providing electricity or heat, compared to alternative technologies evaluated. In addition, this process might not be cost-competitive with electricity produced from combustion of biomass.

Generation of electricity from the waste gases of new charcoal production plants would offer opportunities for technological innovation, but more problematically would require fundamental changes to the way the charcoal industry is configured and regulated across the continent. As these non-technical barriers are so significant and would limit the opportunity to achieve technological or value chain innovation, a low score has been given in this category.

Summary evaluation

Level of activity	Appropriateness for SSA	Replication potential	Competitiveness	Opportunities for innovation
Low	Low	High	Low	Low

3.2.4 Oil pressing technology

A wide variety of fruits, seeds and nuts contain oils and fats that can be extracted through oil pressing. The process of extracting straight vegetable oil (SVO) at small scale first requires the raw material to be prepared by cleaning and, in some cases, drying, de-hulling, husking and flaking. The material is then pressed, resulting in crude pressed oil (which is often filtered) and cake (E4tech, 2016). The crude oil contains moisture, fibre and resins that are removed by clarification, either by letting the oil stand undisturbed for a few days and then separating the upper layer, or by using a clarifier. Larger scale operations (beyond the scope of this study) use solvent oil extraction systems. Mechanical pressing systems come at half the investment cost per unit of capacity and are more suitable for the smaller scale SSA context (Binns, 2009). Clarified or filtered SVO can be used directly in diesel engines or converted into biodiesel through transesterification. Oil pressing and subsequent conversion of pressed oil to biodiesel is an established process and the technology is at TRL 9.

Internal combustion engine

SVO can be fed directly to diesel engines to power generators or pumps. The engines normally require a second fuel tank for the plant oil as diesel is still needed for start-up and shutdown (Binns, 2009). Pre-heating the engine allows the free flow of the plant oil, despite its higher viscosity and flash point (Binns, 2009).

The use of SVO in diesel engines is taking place in countries such as India (one example being an 11-kW diesel engine fuelled with jatropha oil to run a rice de-husking facility and provide electricity to a village in Chhattisgarh) (Winrock International India, 2011). Projects with low technology sophistication at scales from a few kW to over 100 kW, are also known to exist within SSA, for example in Mali, Kenya and Tanzania (Karekezi, 2017; Practical Action Consulting, 2009; UNDP, 2009; EcoFuels Kenya, n.d.).

Depending on the sophistication of the engine, using SVO directly after filtering might require regular cleaning of injectors to maintain performance. The feedstocks typically used are jatropha, croton nuts, castor seeds, and oil palm, but other locally available oil seeds can be used if the oil can be produced to sufficient quality. The use of croton nuts to produce SVO for diesel engines, organic fertiliser and pesticides is being more widely discussed based on the activity of EcoFuels Kenya (Ibelle, 2016). The thrust has been on rural processing in order to contribute to rural development as well as becoming a potential off-grid power supply.

Other SVO diesel engine projects in SSA include several installed for Multi-functional Platforms. This involves combining oil/biodiesel production with other economic activities like soap production, seed cake supply for feed or fertilizer and milling of cereals. The Tanzania Traditional Energy Development Organisation (TaTEDO), has established multi-functional platforms at three sites and installed a village mini-grid to 50 households and 12 businesses. Availability of quality feedstock has been a major challenge, however, and more readily available diesel is likely to be used instead of SVO (UNDP, 2009).

Although jatropha oil projects sprung up rapidly in the early 2000s in many African countries, most failed because crop yield was lower than anticipated and land ownership and potential conflict with production of food or more established cash crops became a thorny issue. Farmers who transferred land to project developers risked losing ownership and not earning anything if the project shut down[18]. Locals are now not easily swayed to engage in jatropha-based projects, unless land tenure and earnings are guaranteed (Sulle & Nelson, 2013; Souza, et al., 2015). A project developer in Mali and Burkina Faso opted to collect jatropha seeds from smallholder farmers who were encouraged to inter-crop with food or other cash crops to increase income security, rather than risk dedicating entire fields to the crop (Langkeek, 2007; Netherlands Enterprise Agency, 2014; Mali Biocarburant, n.d.). Two jatropha projects believed to still be operating are the BERL project in Malawi and a large-scale plantation project in Nigel, Mozambique, but the focus lies on using SVO as transport fuel rather than powering static diesel engines (von Maltitz, et al., 2016).

Given that oil expellers and internal combustion engines are well established and readily available technologies, small-scale oil extraction for use in engines is deemed appropriate to the SSA context. The operation by an entrepreneur (selected by the locals) who operates the multi-functional platform, collects connection/service fees and performs/contracts maintenance appears feasible (UNDP, 2009).

[18] Bioshape Tanzania (part of Netherlands-based Bioshape Holdings) acquired 34,000 ha of land in 2008 to farm jatropha for biofuel. 'Village land', over which villagers had customary rights, was transferred to 'general land' (with compensation set by the investor), bringing it under the control of the Tanzania Investment Centre for lease to Bioshape. Leaseholds to the land would be used as collateral. So if the project failed, it could be sold off.

Simple oil pressing in combination with diesel engines to power generators or water pumps is also replicable across SSA, as long as there is a dependable supply of cheap feedstock. As mentioned above, however, it is labour intensive and people might be easily swayed to use diesel instead, should it be cheaper and if more attractive markets for the oil crop exist (e.g. for soap making).

There is some degree of innovation potential in this sector, especially in oil quality improvement so that engines can run for longer before requiring major maintenance. For example, TaTEDO have fabricated a 100 l bag filter that can improve the purity of jatropha oil to make it suitable for diesel engine use (Binns, 2009). The technology is highly dependent on global oil prices to remain competitive, however, and faces major issues around potential land, food and energy conflict, and thus represents a low opportunity overall for further investigation in this study.

Summary evaluation

Level of activity	Appropriateness for SSA	Replication potential	Competitiveness	Opportunities for innovation
Medium	Medium	Medium	Low	Medium

Transesterification

In the transesterification process, SVO reacts with methanol/ethanol in the presence of potassium or sodium hydroxide to form biodiesel. Biodiesel production via transesterification at a scale of under 10 Ml/yr is taking place in India (e.g. through CTxGreEn, a Canadian not-for-profit organisation, and Gram Vikas, an Orissa-based NGO with a biodiesel-based water pumping project) and China (waste cooking oil-based) (Binns, 2009; Kang, 2014). In SSA there are a few examples of such projects in Ghana, Kenya, Tanzania and South Africa, where palm, jatropha and croton seeds have been used as feedstock.

Biodiesel production via transesterification is theoretically possible anywhere where there is reliable access to an oil crop and the processing chemicals. In practice, however, the African countries that have experimented with biodiesel production have indicated that the absence of local methanol/ethanol production facilities makes production expensive and risky. At present, methanol is produced only in South Africa by Sasol (Williams, 2017). Importing methanol increases the overall biodiesel cost. Feedstock availability and cost also have a significant impact on the economic viability of biodiesel production.

Small scale transesterification to produce biodiesel for transport fuel does have some replication potential in SSA if the challenges mentioned can be overcome. Given the current low prices of fossil fuels, however, it is unlikely to be cost-competitive within the BSEAA research horizon.

The process and technology used to extract the oil from the seeds and to convert it to biodiesel (at a small scale) via transesterification are basic and established. There is therefore low innovation potential for this process.

Summary evaluation

Level of activity	Appropriateness for SSA	Replication potential	Competitiveness	Opportunities for innovation
Low	Low	Medium	Low	Low

3.2.5 Anaerobic digestion technology

Anaerobic digestion is the decomposition of biological feedstocks by micro-organisms in the absence of oxygen, to produce a gas comprising mostly methane and carbon dioxide. The biogas composition (and thus energy content) depends on the volatile organic compounds of the feedstock. The digestion process can take place under wet or dry conditions at a range of temperatures. Three basic designs of small-scale digester are in use today: flexible balloon, floating drum and fixed dome. Industrial scale digesters can be differentiated by batch and continuous flow versions. Anaerobic digestion is a mature technology at TRL 9. The biogas can be channelled directly to households for cooking or can be converted into electricity, heat or cooling.

Direct use

There is much activity around household biogas for cooking in developing countries, including in SSA, as evidenced by the work of the African Biogas Partnership Programme and equipment suppliers such as Flexi-Biogas Solutions in Kenya (Flexi Biogas Solutions, n.d.). They operate well below the BSEAA scale of interest, however. There are working institutional applications, such as a plant set up in a school in Uganda supplying biogas for cooking (Binns, 2009), but such non-commercial settings offer little scope for replication without continuous external funding.

Community-scale biogas projects are technically well understood, involving construction of a digester and laying down of a pipe network. Feedstock flexibility is high as the process can run on a variety of wastes and residues, though for maximum efficiency each plant needs to be optimised to digest a particular type of waste, with appropriate microbes. The challenge in community installations is not so much technical as it is organisational, given the difficulty in finding a business model that is socially workable. It would require 30-50 households to cooperate closely to ensure a steady supply of feedstock, with inevitable discrepancies in the quantities supplied by participating families. It would further need a mechanism to ensure regular biogas supply for every participating household, instead of a first come first served basis (Srinivas & Prabhu, 2013). The difficulty in monitoring and charging for biogas use compounds the low level of social appropriateness in SSA.

From a technology and feedstock flexibility perspective, the replication potential of anaerobic digestion at community level in SSA is theoretically high, but its low appropriateness due to workability limitations makes replication highly challenging in practice. Further, biogas as a cooking fuel faces stiff competition from cheaper alternatives such as biomass, charcoal or kerosene that local populations can often access with relative ease, i.e. there are established alternatives for providing the same energy services.

Finally, there is little opportunity for innovation in community or institutional biogas plants for cooking, given that the technology is well established and the organisational set-up at institutional level does not require further innovation. It is unlikely that an innovation in the organisational arrangements at community scale could overcome the barriers described.

Summary evaluation

Level of activity	Appropriateness for SSA	Replication potential	Competitiveness	Opportunities for innovation
Low	Low	High	Low	Low

Internal combustion engine

Biogas may be used in internal combustion engines to produce mechanical energy for direct use (e.g. water pumping) or in generators to produce electricity. There are successful examples of community- to large-scale biogas-based electricity projects in India and China. China has around 3,500 medium to large scale digester units and more than 20,000 biogas digesters are installed at urban sewage treatment plants (IEA, 2009; Kartha, et al., 2005). India has more digesters at household level, but community scale biogas-to-electricity units have been developed and installed in local councils and fish markets, as seen in projects undertaken by BIOTECH (a Kerala-based NGO) (GoI, et al., n.d.). In China, there are around 500 large scale biogas digesters in pig farms, as well as smaller units such as a 1 MW biogas power system at Xingtai pig farm that can supply 3 GWh of electricity annually to the grid (World Bank, 2012).

In SSA there is growing interest in the development of biogas power in the industrial and agricultural sectors using wastes from sisal, flower and vegetable processing, and from tanneries and slaughterhouses (UNIDO & REN21, 2016). There are also a few landfill bioenergy projects in operation. Examples of biogas power projects have been noted in Uganda, Kenya, Ethiopia, Ghana, and South Africa, at scales from 150 kW_e to 4.6 MW_e (Bio-Innovate Africa, 2015; allAfrica, 2015; Khennas, 2015). In Kenya, Tropical Power Energy Group has built a 2.2 MW_e anaerobic digestion plant at a horticulture business and in South Africa, Bio2Watt has established a 3.3 MW_e biogas plant (allAfrica, 2015a; Bio2Watt, 2016). UNIDO are facilitating several biogas projects from 200 kW to 2 MW, but these still need to be financially closed. UNIDO can facilitate compensation to companies for every kW installed, thereby providing an incentive to install renewable energy technologies (Thomas, 2017). In 2010/12 they conducted a pilot project at Dagoretti slaughter house in Nairobi for power generation at a scale of 15 kW. The plant was still in operation in 2016.

The biogas-to-power concept is appropriate for SSA given the low technological sophistication, feedstock flexibility and uptake potential by the public sector, small farms and industries. Anaerobic digestion plant construction is a civil engineering issue and gas engines and generators for digestion plants are widely used in SSA, but are generally imported or repurposed from other applications (which might reduce their efficiency).

The waste resources of a wide range of small to medium scale agro-industries across SSA offer high replication potential for such projects and microbes are likely available for a diverse range of feedstocks. The existing operational projects provide useful experiences to inform further replication. Biogas plants using waste resources from dairy farms, for instance, are likely to provide electricity at lower cost than grid-based electricity or electricity from diesel engines. For off-grid cooling needs, biogas can be an attractive option - as two innovator projects financed by the Powering Agriculture initiative show (Powering Agriculture, 2013; Powering Agriculture, 2015).

The major barrier for biogas-to-power generation is the reliable availability of feedstock. The examples mentioned above, however, seem to be addressing this issue by using their own feedstock on site. Other potential barriers are poor construction or design of digester hardware and lack of maintenance, compounded by a lack of technical support personnel. Barriers that are not technology-related are evident in the Bio2Watt project in South Africa using animal waste. It was conceptualised in 2007 but reached financial closure only in 2014 and started supplying power in 2015. The delay was attributed to complicated licensing processes, a requirement for a full EIA, a lack of understanding of biogas among local officials, and lengthy negotiations with a legal team for transactions (Bio2Watt, 2016).

There seems to be good scope for innovation in this sector on feedstocks and the microbes that can be used to digest them. Other innovation opportunities relate to feedstock supply chains and the application of the biogas, which can (for example) be used for milk cooling to reduce waste and maximise farmer profits (Powering Agriculture, 2013) and a number of other emerging opportunities.

Summary evaluation

Level of activity	Appropriateness for SSA	Replication potential	Competitiveness	Opportunities for innovation
Medium	Medium	High	Medium	High

3.2.6 Fermentation

Ethanol fermentation

Ethanol can be produced from crops such as corn, wheat, sugar beet and sugarcane. Ethanol produced from these crops is termed 'first generation' as the feedstocks are conventional sugar and starch crops. The process can be categorised as wet and dry mill, the latter being more common due to lower capital and operational costs. Hydrous ethanol (around 96% ethanol) is the output of the distillation process and can be used for cooking in liquid or gel form. Anhydrous ethanol (without water content) can be obtained through the dehydration process and may be blended with gasoline as transport fuel.

At the sub-10 Ml/yr scale considered in this research, not many projects exist globally or in SSA. Ethanol production plants using wheat or sugarcane for transport fuel usually operate in the much higher range of 50 to 250 Ml/yr (E4tech, 2016). Even projects that aim (or have aimed) to introduce hydrous ethanol or ethanol gel for cooking (seen in Kenya or Ethiopia) often use ethanol from large scale production at sugar mills (128 Ml/yr in the case of Ethiopia and 22 Ml/yr in Kenya) or initially plan to import the ethanol (Thomas, 2017; Practical Action Consulting, 2009; Mumias Sugar, n.d.). Only three ethanol production projects could be found in SSA <10 Ml/yr. The first is a 9 Ml/yr distillery in Nigeria using cassava; the second is a 0.4 Ml/yr micro-distillery from Brazilian company Green Social Bioethanol, also in Nigeria; and the third is a South African company Taurus Distillation offering 0.8 to 8 Ml/yr plants, with one project running in Mauritius (Olawale, 2014; Taurus Distillation, 2016; Green Social Bioethanol , 2015a).

Micro-distilleries at scales <10 Ml/yr are still relatively new and have few technology providers and no supply chain or technical support in most parts of SSA. Brazil has experimented with very small mini-distilleries (see Green Social Bioethanol above) up to 1 Ml/yr. The infrastructure for the supply of feedstock to a small-scale distillery run by smallholders may prove challenging (Biello, 2014). On the other hand, the existence of Green Social Bioethanol micro-distilleries in Nigeria shows that the technology could be evolving to be more appropriate for SSA. The indirect impacts of using food crops for ethanol production for cookstoves to replace solid biomass have to be evaluated carefully, however, to avoid unintended impacts (such as the clearing of greater areas of land for planting energy crops than the land potentially under threat from woodfuel harvesting).

Feedstocks such as cassava, sugarcane or sweet sorghum that can be used for ethanol production are available in a wide range of countries in SSA. Micro-distilleries require secure feedstock supply, however and this can be challenging for smallholder farmers - as the failed CleanStar project in Mozambique has shown (Biello, 2014). A wider feedstock flexibility - as targeted by the Green Social Bioethanol plant - can somewhat reduce this challenge. Making ethanol production successful and competitive with other cooking fuels requires a country with very highly priced charcoal or kerosene, and this has not yet come about.

The lower energy content of ethanol and its higher price compared to kerosene (or charcoal) represent considerable challenges for ethanol cooking fuel projects. Even though excise duty has been removed for denatured alcohol in Kenya, for example, ethanol still retails at more than twice the price per unit of delivered energy than kerosene (Government of Kenya, 2015; Kariuki, 2016). This price disadvantage does not overcome the higher efficiency of the stoves or the convenience compared to a charcoal fire of immediate heat and the option to turn the stove on/off (Biello, 2014).

Looking beyond the economically successful large-scale plantations for feedstock supply to ethanol plants, options for smallholder feedstock supply models remain unproven, so opportunities for innovation exist. The main micro-distillery technology and project developer (Green Social Bioethanol) claims to have achieved several innovations by developing a micro-distillery in the range 0.5-2 Ml/yr, allowing several feedstocks to be used, the option to produce hydrous and anhydrous ethanol, using an innovative set of enzymes and yeast, and the combination with an ethanol engine and power generator (Green Social Bioethanol, 2015). Further innovation will lie in proving such technology and the novel supply chain concept in a wider range of countries in SSA. As ethanol fermentation is a well-known process, however, the overall innovation opportunity has been judged only as moderate.

Summary evaluation

Level of activity	Appropriateness for SSA	Replication potential	Competitiveness	Opportunities for innovation
Medium	Medium	Medium	Low	Medium

Butanol fermentation

Butanol is produced from starch or sugars through the 'ABE' fermentation process, named after the three main products: acetone, butanol and ethanol. In common with ethanol, products from the fermentation process are recovered through distillation (E4tech, 2016). Butanol projects exist mainly in the US and consist of retrofitting existing ethanol plants. In contrast with ethanol, no butanol projects exist at micro-distillery scale below 10 Ml/yr in India, China, Brazil or SSA.

Butanol is in theory more appropriate for cooking than ethanol as its energy content is higher. Replication potential is lower as butanol micro-distilleries do not yet exist so there are no pilots from which to draw lessons, but this may make the innovation opportunities around the technology slightly higher than for ethanol.

Summary evaluation

Level of activity	Appropriateness for SSA	Replication potential	Competitiveness	Opportunities or innovation
None	Low	Low	Low	Medium

3.2.7 Microalgae

Microalgae are photosynthetic microorganisms that can produce lipid-rich biomass more rapidly than terrestrial plants. Cultivation can be carried out in open raceway ponds or in closed photo-bioreactors. Raceway ponds have lower capital cost but require a large land area and there is a risk of algae being attacked by pests or grazers. Photo-bioreactors provide a more controlled growth environment.

Options for converting the algae to fuel include (Darzins, et al., 2010; E4tech, 2014):

- transesterification or hydro-treatment via solvent-based extraction;
- methane via anaerobic digestion, catalytic hydrothermal gasification; or
- drop-in fuel via hydrothermal liquefaction and fractionation,

The technology is at TRL 6-7, with many activities at lower TRL levels.

There are a large number of algal biofuel research projects being undertaken around the world, mainly in the US, Europe, S.E. Asia and Australia. Some research is also underway in the Middle East, India and China (E4tech, 2014). Commercially produced algal biomass is so far mainly used for production of high value food supplements, neutraceuticals, aquaculture feed and pigments (Darzins, et al., 2010).

In SSA there are research projects on algal energy taking place, especially in South African universities, but the focus is mainly on project feasibility and identification of suitable microalgae strains, rather than on operational projects. For example, five regions of Ethiopia were identified as potential sites for algal biomass cultivation using open ponds in a study undertaken by Addis Ababa Institute of Technology (Asmare, et al., 2013). A survey of microalgae biodiversity in three Rift Valley lakes in Kenya identified high oil-yielding species occurring abundantly and their bio-fuel production potential was analysed (Abubakar, et al., 2012). South African universities have lab-based research projects on algal fuels ranging from bioprospecting to biofuel production. Nelson Mandela Metropolitan University is researching 'coalgae', involving the recovery, beneficiation, and agglomeration of discarded coal using microalgae to convert it into usable feedstock (GIZ & SANEDI-RECORD, 2013; Algae Industry Magazine, 2014). In Zimbabwe, Harare Polytechnic has been successful in producing algal-based biodiesel at lab-scale in photo-bioreactors. Oil is extracted using solvents and converted to biodiesel via transesterification (Sapp, 2016; Nzira & Mundondwa, 2016). A news article points out that algal feedstock cultivation is much faster than jatropha as a potential oil source (one month versus 3-4 years), making it a potentially better option (Sapp, 2016). Installation and maintenance of photo-bioreactors is expensive, however, and the oil-to-biodiesel route via transesterification is the same as the route for jatropha and brings the same challenge in accessing a regular supply of the necessary chemicals (like methanol and sodium hydroxide).

Algae-to-energy does not appear to be appropriate for SSA in the short- to medium-term as production systems are complex and energy production will need large scale operations. It further requires a level of technical knowledge for operation and improvement not available in most of the continent. Existing projects are lab-based, have high capital and operational costs, and - due to complexity and expertise required - do not currently appear appropriate to the SSA context (Winston, 2013).

Climatic conditions are suitable for cultivation of algae in open ponds in Africa and waste water or saline water can be used, which makes them theoretically widely replicable. Production requires a source of CO_2, however, and this could be challenging in many areas. There are also more competitive alternatives to the applications addressed by microalgae. The application of algae may be interesting at small to medium scale as raceway ponds used in wastewater treatment could serve as potential source of nutrients (Darzins, et al., 2010).

There is immense scope for innovation in algal-based energy, both globally and in SSA. The main areas where innovation is required are productivity, reliability and cost reduction for ponds and photo-bioreactors. Areas of potential research include finding algae strains that have high lipid content or increasing the lipid content while maintaining productivity (for biodiesel production), reducing losses from grazers in open pond systems and finding ways to prevent algae from sticking to the inner walls of photo-bioreactors (as this reduces light entry and affects growth rates) (E4tech, 2014).

Summary evaluation

Level of activity	Appropriateness for SSA	Replication potential	Competitiveness	Opportunities for innovation
Low	Low	Medium	Low	High

4. Technology Prioritisation

The academic literature review (section 3.1) generated four quantitative measures against which the eight primary conversion technologies were compared. **Direct combustion, gasification and anaerobic digestion** achieved the highest combined scores.

A more detailed comparison of the 15 secondary technologies (section 3.2) was informed by the review of non-academic literature, stakeholder research and individual consultations. Ratings of high, medium or low were assigned to each of the technologies against five enabling factors, in accordance with the methodology in 2.4. These ratings were summarised at the end of each sub-section in the previous chapter. A composite score was then generated for each technology and the consolidated results are in Table 4.

Table 4. Secondary technology favourability scores

Primary conversion technology	Secondary Conversion technology	Level of activity	Appropriateness for SSA	Replication potential	Competitiveness	Opportunities for innovation	***Total***
Combustion	None	3	3	3	3	1	***13***
	Steam turbine	3	2	3	3	2	***13***
	Steam engine	1	2	3	2	2	***10***
	Stirling engine	1	1	3	2	3	***10***
	ORC	1	1	3	2	2	***9***
Gasification	Internal combustion engine	2	2	3	2	3	***12***
Fast pyrolysis	Combustion	1	1	2	1	2	***7***
Slow Pyrolysis	Internal combustion engine	1	1	3	1	1	***7***
Oil pressing	Internal combustion engine	2	2	2	1	2	***9***
	Transesterification	1	1	2	1	1	***6***
Anaerobic digestion	None	1	1	3	1	1	***7***
	Internal combustion engine	2	2	3	2	3	***12***
Fermentation	Ethanol fermentation	2	2	2	1	2	***9***
	Butanol fermentation	0*	1	1	1	2	***5***
Microalgae		1	1	2	1	3	***8***

* - a score of zero for butanol fermentation indicates no known example in SSA or Newly Industrialised Countries in the desired scale range

The results indicate that four technologies achieve combined scores of 12 or 13: direct combustion, combustion-to-steam turbine, gasification-to-internal combustion engine; and anaerobic digestion-to-internal combustion engine. The remainder score between 5 and 10. This pattern of ratings reinforces the high-level findings of the academic literature review, in which combustion, gasification and anaerobic digestion scored highest of the eight primary technologies.

Of the top four secondary technologies, direct combustion rated highly across four of the five measures, being a simple and widely used technology across Africa – in tea drying, lime burning, brick firing and cement production, for example. Crucially, however, the combustion of biomass for direct heating has been so widely employed for so many decades that it merits only a 'low' (1 point) score for *Opportunities for Innovation*. As explained in the Methodology, for the purposes of BSEAA this is a crucial limitation as technologies lacking innovation potential offer few areas where research could lead to transformational change.

Figure 6 charts the secondary technologies by combined score, with combustion for direct heating cross-hatched to indicate unsuitability on the grounds that it lacks significant innovation potential.

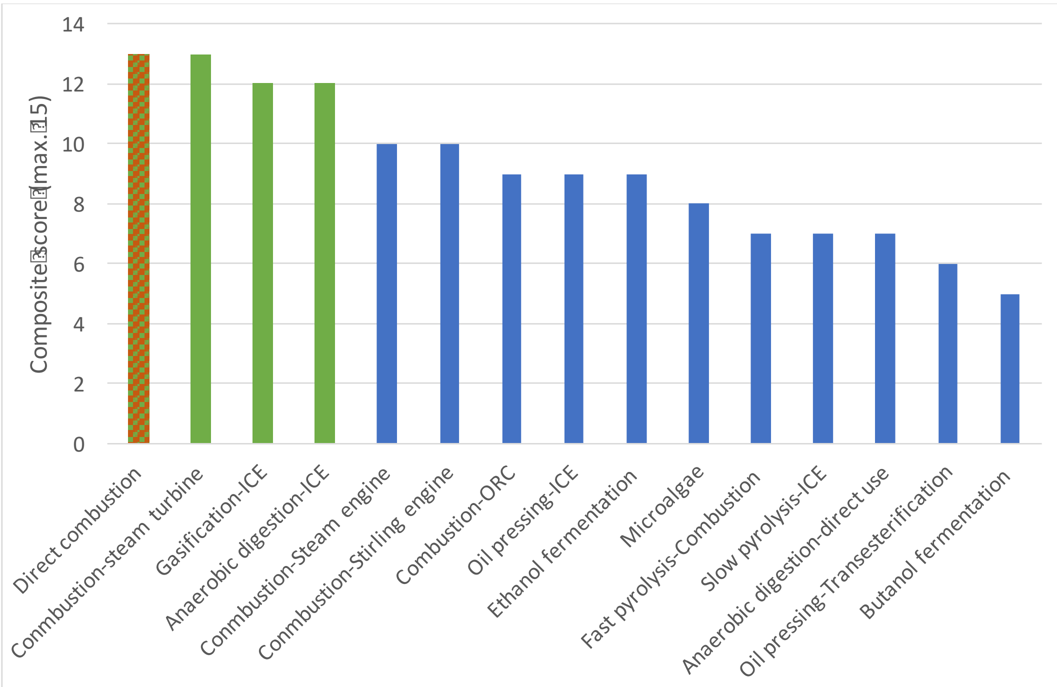


Figure 6. Technologies ranked by composite score

On the basis of these findings, the study team recommends that the following three technologies are taken forward for more in-depth investigation in the TVC Prioritisation stage:

a) **Combustion-to-steam turbine;**
b) **Gasification-to-internal combustion engine;** and
c) **Anaerobic digestion-to-internal combustion engine.**

The broad conclusions are clear that fermentation or oil pressing to produce liquid biofuels, as well as pyrolysis and microalgae, offer significantly lower potential for research-led replication in SSA across the range of factors considered than the technologies based on direct combustion, gasification and anaerobic digestion. The latter appear to offer the optimal combination of ongoing activity, technological appropriateness, replication potential, competitiveness and - above all - innovation opportunities in the value chain. As these three technology pathways are explored further in the upcoming TVC Prioritisation phase, the door nevertheless remains open to other combustion-based technologies such as steam engines, Stirling engines and ORC, should the analysis reveal any opportunities linked to these options that may have been overlooked.

5. Country Shortlisting

The team set out to shortlist 10 to 15 countries for TVC research, applying the methodology in 2.5. Table 5 presents the scores for DFID's 18 countries of interest.

Table 5. Scoring matrix for country shortlisting

Description	Notes	DR Congo	Ethiopia	Ghana	Kenya	Liberia	Malawi	Mozambique	Nigeria	Rwanda	S. Africa	S. Sudan	S. Leone	Somalia	Sudan	Tanzania	Uganda	Zambia	Zimbabwe
In Energy Africa?	2 for Yes,	0	2	2	2	0	2	2	2	2	0	0	2	2	0	2	2	2	2
In EEP?	0 for No	0	0	0	2	0	0	2	0	2	2	0	0	0	0	2	2	2	0
Geographic contiguity	Countries bordering	5	4	0	5	1	3	5	0	3	2	5	1	2	2	7	5	5	3
	Rank	2	8	17	2	15	9	2	17	9	12	2	15	12	12	1	2	2	9
	Score	2	1	0	2	0	1	2	0	1	1	2	0	1	1	2	2	2	1
GDP	Current	32.4	61.3	36.7	63.0	1.8	6.3	14.5	466	7.9	305	8.0	4.4	5.5	82.3	44.1	25.7	20.1	13.1
	Rank	8	5	7	4	18	15	11	1	14	2	13	17	16	3	6	9	10	12
	Score	1	2	1	2	0	0	1	2	0	2	0	0	0	2	2	1	1	1
Population	Millions	77.3	99.4	27.4	46.1	4.5	17.2	28.0	182.2	11.6	55.0	12.3	6.5	10.8	40.2	53.5	39.0	16.2	15.6
	Rank	3	2	10	6	18	11	9	1	15	4	14	17	16	7	5	8	12	13
	Score	2	2	1	2	0	1	1	2	0	2	0	0	0	1	2	1	1	0
GNI per capita	Current	410	590	1480	1340	380	350	580	2820	700	6050	790	630	349	1840	910	670	1500	850
	Rank	15	13	5	6	16	17	14	2	10	1	9	12	18	3	7	11	4	8
	Score	0	0	2	2	0	0	0	2	1	2	1	1	0	2	1	1	2	1
Unmet elec. demand (2030)	GW	2.8	1.7	1.5	2.1	0.3	1.0	2.9	5.7	1.1	13.1	0.2	0.6	0.5	1.5	1.0	5.8	3.4	1.8
	Rank	6	9	11	7	17	14	5	3	12	1	18	15	16	10	13	2	4	8
	Score	2	1	1	1	0	0	2	2	1	2	0	0	0	1	0	2	2	1
Agric. value added/ worker	2010 US$	350	483	1530	821	593	411	340	8579	471	8739	339	1144	339	2,465	570	473	574	422
	Rank	15	10	4	6	7	14	16	2	12	1	17	5	17	3	9	11	8	13
	Score	0	1	2	2	1	0	0	2	1	2	0	2	0	2	1	1	1	0
Ease of Doing Business	Global	44	31	9	5	40	15	16	36	2	3	46	23	47	35	14	12	7	28
	Rank	16	12	5	3	15	8	9	14	1	2	17	10	18	13	7	6	4	11
	Score	0	1	2	2	0	1	1	0	2	2	0	1	0	0	1	2	2	1
Global Entrepreneurship Index	Africa rank	25	12	5	11	18	24	19	8	10	2	25	27	25	25	16	22	7	25
	Rank	13	7	2	6	9	12	10	4	5	1	13	18	13	13	8	11	3	13
	Score	0	1	2	2	1	1	1	2	2	2	0	0	0	0	1	1	2	0
Corruption Perception Index	Global	39	20	7	34	15	23	25	32	4	10	45	27	46	45	26	35	13	41
	Rank	14	6	2	12	5	7	8	11	1	3	16	10	18	16	9	13	4	15
	Score	0	2	2	1	2	1	1	1	2	2	0	1	0	0	1	0	2	0
Rule of Law	Percentile	0.03	0.38	0.61	0.37	0.19	0.44	0.20	0.13	0.60	0.59	0.01	0.18	0.00	0.08	0.39	0.43	0.47	0.06
	Rank	16	8	1	9	11	5	10	13	2	3	17	12	18	14	7	6	4	15
	Score	0	1	2	1	1	2	1	0	2	2	0	1	0	0	1	2	2	0
Quality of national accounts data	Africa rank	38	6	17	13	40	21	8	39	28	3	32	40	40	32	16	31	15	1
	Rank	14	3	8	5	16	9	4	15	10	2	12	16	16	12	7	11	6	1
	Score	0	2	1	2	0	1	2	0	1	2	1	0	0	1	1	1	2	2
No. of active stakeholders	Count	4	9	12	17	5	5	10	10	6	26	1	5	1	0	13	12	10	4
	Rank	14	9	4	2	11	11	6	6	10	1	16	11	16	18	3	4	6	14
	Score	0	1	2	2	1	1	2	2	1	2	0	1	0	0	2	2	2	0
	Total score:	***7***	***17***	***20***	***25***	***6***	***11***	***18***	***17***	***18***	***25***	***4***	***9***	***3***	***10***	***19***	***20***	***25***	***9***

Note: In a small number of cases where data were missing, low end values were estimated (in red).

The same total scores are presented graphically in Figure 7.

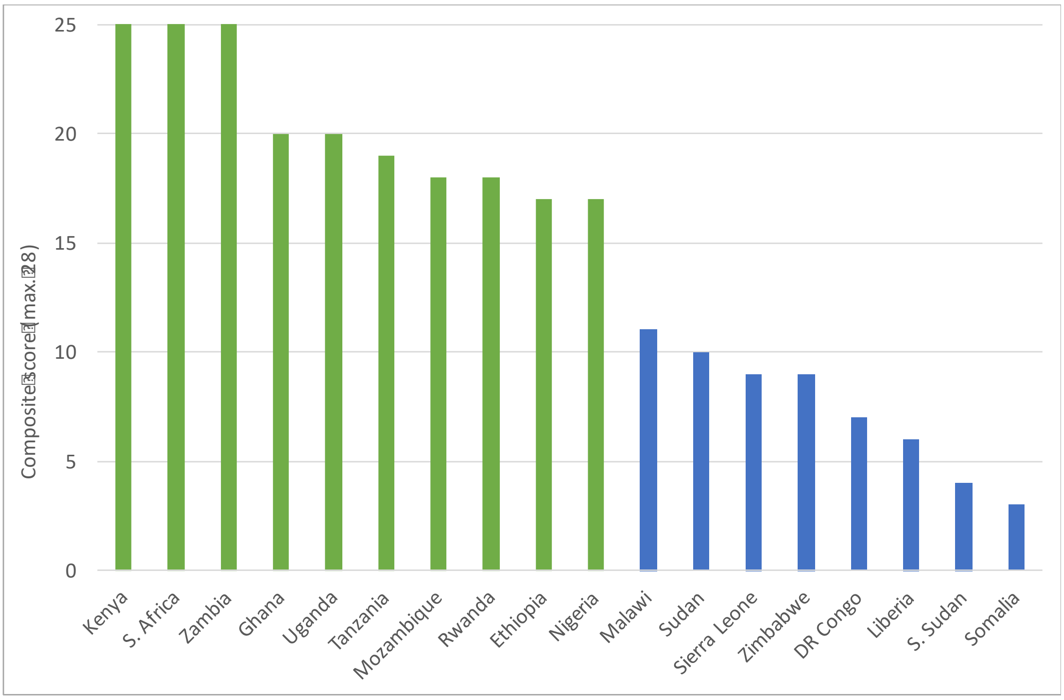


Figure 7. Countries ranked by composite score

The outcome of the shortlisting process is that ten countries score between 17 and 25 (from a maximum of 28) across the diverse range of factors that were considered. There is then a gap to the other eight countries, which score between 3 and 11.

On this basis, the following ten countries will become the focus for the remaining phases of the study:

East Africa	**West Africa**	**Southern Africa**
Ethiopia	Ghana	Mozambique
Kenya	Nigeria	South Africa
Tanzania		Zambia
Rwanda		
Uganda		

Those excluded are high risk investment destinations or countries of recent conflict (DR Congo, Liberia, Sierra Leone, Somalia, South Sudan, Sudan), along with Malawi and Zimbabwe, which rank low for rule of law, corruption and market potential.

6. Stakeholder Mapping

The research and individual consultations that took place during the stakeholder mapping (by email, Skype and in-person) indirectly informed the technology shortlisting, by supplementing the team's existing knowledge of the bioenergy technology landscape. The process had additional value in its own right by providing an overall picture of the bioenergy landscape in SSA. This section summarises the main institutions and initiatives of relevance in the public, commercial and academic spheres.

6.1 Multilateral energy initiatives

6.1.1 Data providers

Reliable data on energy supply and demand in SSA is generated primarily by the **International Energy Agency** (IEA) and the **International Renewable Energy Agency** (IRENA).

The IEA is an autonomous organisation whose Bioenergy Division aims to achieve a substantial bioenergy contribution to future global energy demands by accelerating the production and use of environmentally sound, socially accepted and cost-competitive bioenergy on a sustainable basis. The IEA produced the widely-quoted *Africa Energy Outlook* (IEA, 2014), a special report that gives a comprehensive analytical overview of energy in SSA. The report noted that the region's energy resources are more than sufficient to meet overall needs, but that they are unevenly distributed and under-developed.

IRENA is an Inter-governmental organisation that supports countries in their transition to a sustainable energy future, and serves as the principal platform for international cooperation, a centre of excellence and a repository of policy, technology, resource and financial knowledge on renewable energy. As an advocate for renewables, IRENA has a positive and proactive stance on bioenergy possibilities.

6.1.2 UN agencies

Several United Nations (UN) agencies are supporting the development of modern bioenergy in SSA. For example, the UN Food and Agriculture Organisation in Rome hosts the **Global Bioenergy Partnership**, which provides a mechanism for partners to organize, coordinate and implement research, development, demonstration and commercial activities around biomass for energy, with a focus on developing countries. It supports high-level policy dialogue on bioenergy globally, regionally and nationally, while fostering exchange of information, skills and technologies through bilateral and multilateral collaboration, and facilitating bioenergy integration into energy markets by tackling barriers in the supply chain.

Other UN agencies active in bioenergy are the **UN Environment Programme** (UNEP) and the **UN Industrial Development Organisation** (UNIDO). UNEP works in partnership with governments, the private sector, NGOs and civil society on a number of activities to help bioenergy reach its sustainable potential. This is mainly in scientific assessment, decision-making tools and creative financing, rather than direct implementation. UNIDO is engaged more directly and works on bioenergy in Africa by supporting regional centres for renewable energy and energy efficiency (with Austrian funds). The centre for West Africa is located in Cape Verde and a counterpart centre for East Africa has recently been opened in Uganda at the Centre for Research in Energy and Energy Conservation (CREEC). UNIDO also supports small energy pilots with a focus on agro-industries, such as biogas at the 0.2-2 MW scale as well as gasification and cogeneration.

6.1.3 Other technical, advisory and capacity-building initiatives

Among the multilateral development banks, The **World Bank**'s leading initiative supporting renewable energy is the **Energy Sector Management. Assistance Program** (ESMAP). ESMAP is a global knowledge and technical assistance programme with 14 bilateral donors. Across a wide remit covering capacity building, institutional and technical solution-finding, and mobilising financial resources, it provides governments with analytical and advisory services to increase their know-how and institutional capacity to achieve environmentally sustainable energy solutions. A particular success has been reaching 7 M people in SSA with clean and improved lighting through the Lighting Africa programme. ESMAP also manages the SE4ALL Technical Assistance Programme and a Renewable Energy Resource Mapping initiative.

One of ESMAP's funding windows, the **Africa Renewable Energy Access Programme**, aims to meet energy needs and widen access to energy services in an environmentally responsible way. It focuses on mainstreaming successful innovations by leveraging public and private investment resources for renewable energy and other low carbon energy sources. It has a business orientation so aims to create an enabling environment for private sector participation in energy generation, transmission and distribution.

Within the **African Development Bank** (AfDB) there are also a number of multilateral energy initiatives underway. Notable among these is the **Sustainable Energy for All** (SE4All) programme, hosted by the AfDB in partnership with the African Union, NEPAD and UN Development Programme (UNDP). SE4All is a multi-stakeholder partnership between governments, the private sector and civil society. Launched in 2011, it has three interlinked objectives to be achieved by 2030:

1. Ensure universal access to modern energy services;
2. Double the global rate of improvement in energy efficiency; and
3. Double the share of renewable energy in the global energy mix.

SE4All hosts the **Africa Climate Technology and Finance Centre** (ACTFCN), which seeks to enhance and share knowledge on the barriers constraining market dissemination of climate-friendly technologies in SSA. ACTFCN is financed by the Global Environment Facility to support scaling-up of low-carbon and climate resilient technologies for climate change mitigation and adaptation in SSA by:

1. enhancing networking and knowledge dissemination on climate technology transfer and financing;
2. enabling the scaling-up of technology transfer through policy, institutional and organisational reforms of national and regional enabling environments; and
3. integrating climate change technologies into investment programmes and projects.

Since its inception in 2014, ACTFCN has been financing technical assistance activities related to SE4All implementation in ten SSA countries. ACTFCN has also finalised a framework contract facility with six consulting consortia to assist SSA governments with policy, institutional and organisational reforms. The facility allows the Centre to respond quickly to specific requests for technical assistance, including on early stage activities that will generate opportunities for bringing in complementary financing from AfDB's own instruments, such as SEFA (see next section).

Working outside the multilateral development banks, a notable European initiative in the energy sector is the **European Union Energy Initiative Partnership Dialogue Facility** (EUEI-PDF). Managed from Eschborn by Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), EUEI-PDF has several service lines that have achieved a high profile in the policy and investment environment:

1. The **Africa-EU Energy Partnership** is a framework for strategic dialogue between Africa and the EU aimed at sharing knowledge, setting political

priorities and developing joint programmes on the key energy issues and challenges, with a special focus on increasing investment in energy infrastructure. Among other targets, it aims to triple Africa's production of bioenergy by 2020. It supports high level policy dialogue, stakeholder events and information exchange for both government and non-state actors (private sector, civil society and academia).

2. The **Africa-EU Renewable Energy Cooperation Programme** (RECP) stimulates develop of the renewable energy market in Africa through private investments. RECP develops markets for small/meso-scale renewable energy in Africa by supporting attractive policy & regulatory frameworks, Africa-EU private sector exchange and business development, project bankability and financing, as well as building technical and doing-business capacity. RECP maintains a useful online database of funding sources for African energy projects.
3. The **Strategic Energy Advisory and Dialogue Services** (SEADS) supports the development and improvement of energy policies, strategies and regulations to create an enabling environment for sustainable energy investments. SEADS has supported the development of Biomass Energy Strategies for several SSA countries, though in many cases implementation of these strategies has proven challenging due to government resistance towards solid biomass fuels.

GIZ has various energy programmes of its own, such as Energising Development (EnDev) and Poverty-Oriented Basic Energy Services (HERA), but direct consultations confirm that these work exclusively at household scale.

6.2 Public financing facilities

The relatively risky nature of commercial investment in SSA's renewable energy sector, particularly in bioenergy, means that publicly-funded institutions and development banks dominate the investment landscape, with relatively few projects fully funded from commercial sources.

6.2.1 Small-scale grant funds

At the smaller and more innovative end of the project spectrum are numerous providers of grant financing for start-ups, of which two prominent examples are co-funded by DFID:

- The **Energy and Environment Partnership Programme** (EEP) for East and Southern Africa is a £52M collaboration (of which DFID has provided £32M) with the governments of Finland and Austria, managed from South Africa by KPMG Finland. EEP has funded over 200 renewable energy projects in 13 SSA countries since 2008 from pilot to feasibility, demonstration and scale-up, of which 23 have involved bioenergy. Examples include conversion of invader bush to boiler fuel (Namibia); bioenergy crop production on degraded mine sites (Zambia); a 3.5 MW biogas unit to produce electricity at Bronkhorstspruit (South Africa); and biodiesel production from waste vegetable oil in Lobatse (Botswana). Phase 3 (beginning in 2018) is currently being designed and is likely to extend EEP to additional countries (probably Malawi and Zimbabwe).

- DFID also co-funds **Renewable Energy & Adaptation to Climate Technologies** (REACT) through the African Enterprise Challenge Fund (AECF) office in Kenya, also currently managed by KPMG (but moving to direct AECF management from April 2017). REACT is a competitive fund open to business ideas based on low cost clean energy solutions that help smallholder farmers adapt to climate change. Up to 50% grant financing is offered to businesses at the scale EUR 0.5-1 M. REACT blends funds from DFID's Africa Regional Department, DFID Tanzania and DFID Kenya (via StARK+ - Strengthening Adaptation and Resilience to Climate Change in Kenya). A separate REACT fund for Mozambique is believed to be funded by Denmark.

REACT overlaps geographically with EEP, but has a narrower funding range (usually in agricultural value chains) and funds larger projects with a lower grant percentage. It is designed for projects at a more advanced stage of commercial development.

Other challenge funds in the renewable energy sector that potentially cover bioenergy include **Demo Environment**, a Swedish fund for financing innovative technology that includes a window for 'energy & urban development'. This is a new fund covering four of DFID's countries of interest (Kenya, Mozambique, Tanzania and Zambia) but is yet to make its first awards. In Uganda, the Nordic Climate Facility supports the **Renewable Energy Business Incubator**, which offers technical assistance for product development, business planning and competence sharing. Innovative clean energy start-ups have been supported in bio-waste electricity generation and liquid biofuel production (as well as micro-hydro and solar PV).

DFID funds the Shell Foundation's **Transforming Inclusive Energy Markets** project and this support continues under the TEA programme (see below), with practical links to two bioenergy companies of potential interest for BSEAA - Sistema Biobolsa (installing mid-scale flex-biogas systems in Mexico) and Village Industrial Power (a start-up demonstrating stand-alone biomass-based power production in SSA using steam engine technology).

The ECOWAS **Renewable Energy & Energy Efficiency Facility** (EREF), hosted from Cape Verde by the afore-mentioned **ECOWAS Centre for Renewable Energy and Energy Efficiency** (ECREE), provides small grants for renewable energy projects including the following bioenergy initiatives:

- Village electrification using biogas, Benin (EUR 20,000)
- Jatropha for village biodiesel, Burkina Faso (EUR 15,000)
- Biogas in schools, Burkina Faso (EUR 25,000) and Guinea (EUR 20,000)
- Small-scale gasification for electricity via Multifunctional Platforms, Ghana (EUR 30,000)
- Biogas for isolated electricity supply, Liberia (EUR 25,000)
- Bio-ethanol production from sweet sorghum, Mali (EUR 25,000)

It would be instructive to know more about what has happened to past award recipients under programmes such as EEP, REACT, REBI and EREF, as these potentially provide useful case study examples through which to investigate barriers and opportunities in later phases of the study.

6.2.2 Large-scale multilateral bank programmes

The multilateral development banks meanwhile manage significant funds earmarked for energy, including renewables.

Most significant among these are the USD 8.1 billion **Climate Investment Funds**, channelled through five multilateral development banks to scale up deployment of renewable energy solutions in poor countries to increase energy access and economic opportunities. The Climate Investment Funds comprise the **Clean Technology Fund** (CTF) and the **Strategic Climate Fund** (SCF).

The USD 5.8 billion CTF is managed by the World Bank and promotes scaled-up financing for demonstration, deployment and transfer of low carbon technologies with significant potential for long-term greenhouse gas emissions savings. Research did not yield any projects of relevant scale in the bioenergy sector.

The SCF is managed in Africa jointly by the World Bank and AfDB, and has a number of sub-funds to finance new approaches to promoting climate resilience and address deforestation. These include:

a) the **Pilot Programme for Climate Resilience** explores practical ways to mainstream climate resilience into core development planning and budgeting and funds National Adaptation Programmes of Action and other national strategies in 11 pilot countries and regions.

b) the **Scaling-Up Renewable Energy Programme** (SREP) in Low Income Countries demonstrates the economic, social and environmental viability of low carbon development pathways in the energy sector by creating new economic opportunities and increasing energy access through the use of renewable energy; and

c) the **Forest Investment Programme** supports developing countries' efforts to reduce emissions from deforestation and forest degradation by financing readiness reforms and practical measures to address the underlying causes of deforestation and forest degradation.

SREP is the most relevant of the Climate Investment Funds for bioenergy development and has already co-financed 44 projects and programs with USD 501 M to support the installation of 840 MW in renewable energy capacity and improve energy access for 14 M people in 27 countries. Although bioenergy is included among the renewable energy technologies that qualify for support, information provided by AfDB's Senior Climate Finance Officer suggests that no bioenergy projects have in fact been financed by SREP to date.

The AfDB also manages the USD 95 M **Sustainable Energy Fund for Africa** (SEFA), a multi-donor facility (funded by Denmark, UK, USA and AfDB) launched in 2012 to support the sustainable energy agenda in Africa through grants for project preparation, equity investments and support to government to improve the enabling environment for private investments in sustainable energy. Equity investments were deployed jointly with the **Africa Renewable Energy Fund** (AREF), now closed, in the range USD 10-30M for small hydro, wind, geothermal, solar, stranded gas and biomass energy, including one investment in a 60 MW wood-fired power plant. In late 2016, SEFA awarded a USD 993,000 grant to Earth Energy in Uganda to prepare the country's first-ever biomass gasification project, expected to add 20 MW of baseload power to the national grid. The grant will facilitate a feasibility study, environmental and social impact assessment, engineering design and project management activities.

6.2.3 Bilateral investment programmes

Individual donor countries also support publicly-funded investment institutions, such as the Dutch-funded EUR 362M **FMO Infrastructure Development Fund**. This invests EUR 5-50M (debt or equity) in projects that enable new access to energy, with a preference for sustainable solutions, and also offers technical assistance, capacity development and assistance for early-stage project developers to secure capital. The most notable FMO investment has been in the former Addax (now SunBird Energy) ethanol project that covers 14,000 ha in Sierra Leone with sugarcane plantations, an ethanol refinery and a biomass-fuelled power plant. It was the first large-scale bioenergy project to be brought to financial close in Africa.

Norway is a prominent supporter of renewable energy investments, including bioenergy. The **Norwegian Investment Fund for Developing Countries**, has invested heavily in hydro and solar in eastern and southern Africa, as well as one bioenergy project via the company Bio2Watt in South Africa, which built and owns the 4.7 MW_e Bronkhorstspruit biogas plant near Johannesburg. Norway also supports the five year, NOK 60M **Capacity Building for Managing Climate Change in Malawi** project to strengthen training, research and outreach in climate change adaptation and mitigation by the Lilongwe University of Agriculture and Natural Resources. The project supports six action-research projects, one of which concerns ethanol for fuel blending from smallholder cassava wastes.

Norway is a co-funder (with the UK, Germany and the EU) of the **GET FiT Uganda Program**, which assists East African nations in pursuing a climate resilient low-carbon development path. As well as supporting the development of up to 15 small hydro projects and two solar PV projects in Uganda, it has granted USD 7.1 M (from total investment of USD 61 M) for a 20 MW bagasse-to-power plant at Kakira Sugar in Jinja District, which signed a power purchase agreement in mid-2015.

Norway also launched the **Clean Energy for Development Initiative** in 2007, but no bioenergy projects have yet been funded.

The Sweden-funded **Guarantee Portfolio: Bioenergy Zambia** aims to increase lending to SMEs in the bioenergy and agriculture sectors to increase employment opportunities and promote productive businesses (locally via Madison Finance), but has yet to lend to bioenergy.

DFID's **Transforming Energy Access (TEA) Programme** is just getting underway, and Phase II of BSEAA will be an integral part of this GBP 65M initiative. TEA aims to support early stage testing and scale up of innovative technologies and business models that will accelerate access to affordable, clean energy services for poor households and enterprises. The programme will include: i) partnership with the Shell Foundation, enabling support to another 30+ early stage private sector innovations. ii) Innovate UK's Energy Catalyst to stimulate technology innovation by UK enterprises; iii) build other strategic clean energy innovation partnerships (e.g. testing a new solar power crowdfunding platform; and scoping a potential new partnership with Gates Foundation); and iv) skills and expertise development.

The US (with other donors including the UK, Sweden and Norway) finances the **Power Africa Off-Grid Challenge**, which is part of the larger **Power Africa** programme. Relevant projects funded between 2012 and 2014 include:

- Bio-digesters to produce electricity and biogas for small urban businesses in Kenya (Afrisol Energy Ltd.);
- Bio-diesel production from cottonseed in Kitui, Kenya;
- 500 kW biomass plant using agricultural waste and forestry residue in Nigeria (Quintas Renewable Energy Solutions);
- 20 kW biomass gasifier to produce electricity for palm kernel cracker, oil expeller and oil squeezer in Ghana (KITA); and
- a biogas venture in Amhara, Ethiopia (ORDA).

The US also co-funds (with Germany and Sweden) the **Powering Agriculture** initiative, described as an Energy 'Grand Challenge' that supports the development and deployment of clean energy innovations that increase agriculture productivity and stimulate low carbon economic growth in the agriculture sector. Through funding calls in 2013 and 2015, Powering Agriculture has supported a handful of potentially interesting innovations in biogas and biomass-fuelled projects for electricity, industrial heat and direct cooling in Ghana, Nigeria, Ethiopia and Tanzania

6.2.4 UK-funded initiatives yet to invest in bioenergy

Finally, a number of DFID-funded projects support the full range of renewable energy options in theory, including bioenergy at the desired scale, but in practice have not yet supported or invested in bioenergy projects on the ground. Examples include:

- **Green Africa Power:** Developed jointly by the Department of Energy and Climate Change (GBP 25 M) and DFID (GBP 53 M) to capitalise GAP, a new company established under the Private Infrastructure Development Group Trust to invest in renewable energy projects to demonstrate viability and attract private developers and investors. As far as could be ascertained, no bioenergy investments have yet been made by GAP.
- **Energy Africa** initiative: This funds various country-specific projects in the renewable energy sector, though very few have supported bioenergy initiatives at the non-household scale. For example, BRILHO Mozambique (2016-2022) aims to increase energy access for business and households

through private sector innovation and investment, and government support, through supply of off-grid energy solutions and improved cooking solutions, but is not believed to have invested in bioenergy beyond support for domestic stoves.

- **Renewable Energy Performance Platform**: Managed from South Africa by Camco Clean Energy and Greenstream, this GBP 48 M programme (co-financed by UNEP and the European Investment Bank) seeks to mobilise private sector investment in renewable energy projects up to 25 MW in SSA. It supports developers throughout the project development life cycle with technical assistance, risk mitigation instruments, lending and assistance with financial structuring, and results-based finance. No bioenergy initiatives appear to have been supported thus far.
- **Improving Energy Access in Tanzania**. This £30M project supports green mini-grids. A call for Expressions of Interest is not believed to have generated any bioenergy ideas for full proposal development (subject to confirmation once screening is complete).
- TEA will extend DFID's partnership with **Innovate UK**, an executive non-departmental public body sponsored by the Department for Business, Energy & Industrial Strategy. It has committed over GBP 1.8 M to innovation since 2007, matched by a similar amount in partner and business funding, helping more than 7,600 organisations with projects estimated to add more than GBP 11.5 billion to the UK economy. There have so far been no investments thus far in projects linked to bioenergy in Africa.

6.2.5 Renewable energy initiatives beyond desired scale or theme

Various other high profile renewable energy projects were investigated but found not to cover bioenergy, or not to do so at the desired scale. For example, the DFID-funded £65M **Africa Clean Energy** Business programme catalyses a market-based approach for private sector delivery of solar home system products and services; the Dutch-funded **Africa Biogas Partnership Programme** works through NGO partners (e.g. SNV and Hivos-Novib) to disseminate domestic bio-digesters; the previously-mentioned GIZ-run **EnDev** programme also works only at household level, incorporating DFID finance for cookstove promotional projects based on **results-based financing**; as do the variety of other cookstove programmes operating under the umbrella of the **Global Alliance for Clean Cookstoves** (which also has DFID co-financing to achieve its goals of 100 M households adopting clean cooking by 2020).

6.3 Private investment facilities

A useful database of equity, loan and grant facilities for private renewable energy projects in Africa is maintained by RECP[19] and lists 35 institutional investors with interests in bioenergy. The majority finance equity and/or debt across a wide range from USD 0.1 to 50 M, though the database also includes publicly-funded grant-making organisations already mentioned such as EEP, SREP, SEFA and the Nordic Climate Facility, as well as funding windows of the German Investment Corporation to support feasibility studies and upscaling.

Research into the financing facilities reveals that the majority of the renewable energy projects that have attracted commercial investment (and have provided publicly accessible information) are in renewables other than bioenergy. For example:

- Vantage GreenX fund has loaned to a 30 MW solar PV plant in Mpumalanga, South Africa;
- the responsAbility Energy Access Fund has taken a stake in three 8 MW hydropower plants in Kirinyaga, Kenya;
- Inspired Evolution Investment's Evolution One Fund has invested in hot water heat pumps in South Africa;
- GuarantCo has guaranteed a 1.6 MW hybrid solar generation, transmission and distribution systems on Bugala Island, Uganda;
- AREF has invested in tackling market barriers to the development of solar PV systems in Tanzania;
- German Investment Corporation has invested in the off-grid solar energy start-up company Mobisol;
- the Danish Climate Investment Fund has taken a stake in the 300 MW Lake Turkana Wind Power project in Kenya (the largest in SSA);
- DI Frontier Investment has financed a 40 MW geothermal power project in Kenya;
- SEFA has funded a technical feasibility study for an 8 MW hybrid solar/hydro off-grid project in Madagascar; and

[19] www.africa-eu-renewables.org/funding-database-2/

- the InfraCo Africa Sub Sahara Infrastructure Fund has invested in the first commercial scale, privately financed PPP wind farm in SSA in Cape Verde.

The limited examples from the database of (quasi-)commercial investment in bioenergy are:

- the FMO Infrastructure Development Fund investment in the Addax Bioenergy project in Sierra Leone (the same project received co-financing from the Emerging Africa Infrastructure Fund);
- investment from AREF in Berkeley Energy's 60 MW power plant linked to a eucalyptus plantation (confidential country and technology); and
- Factor[E] venture capital investment in three bioenergy start-ups: Sistema Biobolsa, Village Industrial Power and Pivot.

Meanwhile DP Cleantech (waste-to-power in Addis Ababa), BWSC from Denmark (project confidential) and InfraCo (supporting EleQtra in a 20 MW bamboo combustion-to-power venture in Ghana) have supported large projects outside the BSEAA scale of interest.

Smaller investment examples can be found through country-level research. For example, in Kenya (Tropical Power joint biogas-to-power venture with VegPro in Naivasha; Cummins Co-Gen wood chip to power project at Marigat) and in Tanzania (Tanganyika Wattle power plant fuelled with waste wood from a tannin operation in Mufindi). It is notable that these privately-funded examples at mid-scale are few in number and quite well-known. Investigations soon close the loop and bring research back to the same relatively small collection of practical case studies. While very large ventures have been gaining traction and attracting private investment, the options for mid-scale bioenergy investment opportunities seem to be limited - which is of course why BSEAA is interested in providing further support to investigate the reasons this may be the case, and to unlock opportunities at this scale.

6.4 Universities and research institutions

This section describes the academic landscape of universities and research institutions (including both technical/technology-oriented research and policy/socio-economic research) working on bioenergy research and projects in or related to SSA. Such a mapping exercise has provided a more focused sense of where the research thrust lies, both in terms of technology and region, the scale at which it is taking place and the centres of excellence that can be further pursued for the next phase.

6.4.1 Universities and research institutions within SSA

South Africa

The academic bioenergy landscape of SSA is dominated by South Africa. Prominent are academics from Stellenbosch University, the University of Pretoria, University of Johannesburg, Durban University of Technology and the University of Cape Town, among others.

An overwhelming number are engaged in research related to microalgae, exploring aspects such as algal cultivation methods, lipid production, yield optimisation and impacts of CO_2 sequestration. Prof. Johan Grobbelaar from the University of The Free State has been involved in spirulina production at Musina, a beta-carotene facility at Upington and aviation fuel research (in Germany). He believes that microalgal biotechnology failures to date reflect inadequate support, training and availability of experimental facilities at laboratory and pilot plant scales. He therefore pushed South Africa's Technology Innovation Agency to transform the Upington facility into a development and demonstration centre.

Among the other South Africa-based academics, Prof. Annie Chimpango (Stellenbosch) and Anthony Williams (Cape Town) are engaged in waste-to-energy projects, particularly using biomass from sewage and wastewater treatment plants. Dr. Williams notes that these sources are also environmental hazards if not managed correctly and his company, Citius Energy, is exploring opportunities to convert these feedstocks into useable power.

Other academics such as Prof. Charles Mbohwa (Johannesburg), Prof. Elsa du Toit (Pretoria), Prof. Harald Winkler (Cape Town) and Prof. Wikus van Niekerk (Stellenbosch) have focused their research on liquid biofuel production such as biodiesel and bioethanol. Another category of academics and research institutions such as Annie Chimphango (Stellenbosch), Dr. Bothwell Batidzirai (Cape Town), Helen Watson (Kwazulu-Natal) and the South African-German Energy Programme run by GIZ, are researching the broader implications of bioenergy use, such as environmental impacts, bio-based economic development, the current and future potential for bioenergy and its impacts on local populations. Gorgens and Van Zyl (Stellenbosch) for instance, who are working with several African and non-African research partners, cite 'affordability' as one of the important criteria for shortlisting the right technology. They note that the final bioenergy product must be cheaper than fossil fuel alternatives to promote widespread uptake (potentially opening up opportunities for ethanol as transport fuel in landlocked countries that are also forex constrained).

Kenya

Kenya is a second hub of academic research in bioenergy, with prominent institutions including Jaramogi Oginga Odinga University of Science & Technology (via Ben Muok, also Vice-President for Africa of the World-Bioenergy Association), the Technical University of Kenya (Bilha Eshton Gitonga), Strathmore University (Thomas Buchholz) and the Kenya Forestry Research Institute (Jesse Owino). Ben Muok, working in collaboration with the Kenya Forestry Research Institute and Environment Liaison Central International, is piloting a briquetting project from sugarcane bagasse and believes that agricultural and forest residues and invasive species hold immense potential and that their use for briquetting is gaining traction in SSA. Thomas Buchholz is focusing on Kenyan industrial process heat applications, channelled through the Strathmore Energy Research Centre and the Kenya Climate Innovation Centre that Strathmore hosts, and believes that future opportunities lie with Energy Service Companies that specialise in woodfuel supply chains, sourcing sustainable feedstock, ensuring long-term availability and owning and operating steam-generating equipment.

Ghana

The main centre of academic excellence identified in Ghana is the Kwame Nkrumah University of Science & Technology, with noted academics such as Dr. Francis Kemausuor, Dr. Gabriel Takyi and Dr. Moses Mensah. Both Drs. Takyi and Mensah work on the production of second generation biofuels, with noted interests also in as gasification and seaweed bio-refining, respectively. Dr. Kemausour has been conducting research in heat and power generation from biomass with a focus on feedstock assessment and value chains, though has now shifted focus to thermochemical technologies. He believes that gasification and combustion (particularly ORC engines) hold great potential in agro-processing and timber-processing industries. His work is carried out in collaboration with Universitat Politècnica de Catalunya and Trama TecnoAmbiental in Spain. Relevant Ghanaian research institutes are the Forestry Research Institute of Ghana (Beatrice Obiri) and the Council for Scientific & Industrial Research (Ben Ason), where the individuals contacted both advocated the use of lesser explored and sustainable woody biomass (such as bamboo) for heat and power production.

Tanzania

Several Tanzanian research institutions seem to have an interest in anaerobic digestion for different contexts. The Centre for Agricultural Mechanisation and Rural Technology in Arusha is working on non-commercial applications of biogas systems and the nearby Nelson Mandela African Institution of Science & Technology (Prof.

Karoli Njau) with agro-industry. Njau points to a company called Simgas, previously a manufacturer of water tanks and now manufacturing modular biogas systems which he believes could be a game changer, but states that the delivery model should be service- and not product-based. Prof. Jamidu Katima (University of Dar es Salaam) feels that biogas technology can be applied at both rural and urban level.

Nigeria

Nigerian academics were found to be working in different areas of bio-energy research, most without any external collaboration. Dr. Augustine Ayeni (Covenant University) is involved in the development of pre-treatment technologies for bioethanol production, development of viable catalysts for biodiesel production and production of pellets or briquettes from forestry and other agricultural wastes. Andrew Amenaghowon (University of Benin) is working on bioethanol production, particularly on feedstock pre-treatment research, citing huge availability of biomass feedstock in Nigeria such as cassava (largest producer), maize, sorghum, millet etc. as an important pull factor. Justus Nwaoga (University of Nigeria) is working on innovative solar technology for generating energy using mimosa weed, although the research is lab-based with no external collaborations. Prof. Joseph Odigure (Federal University of Technology) is working on building sustainable value chains for production processing and marketing of agricultural produce, citing that the major cause of poverty in the SSA farming communities is frustration arising for poor understanding at all levels of agriculture, starting from planting to storage, processing and marketing techniques.

Malawi

Of the researchers working in Malawi, Edgar Bayani (Community Energy Malawi), is working on biogas at a small scale, but believes that there is good potential for bioethanol production via fermentation with a push by the government to increase ethanol fuel blending from 10% to 30%. Robert Mkandawire's related work at the Malawi University of Science and Technology focuses on the decentralised production of ethanol from cassava wastes, under the above-mentioned Capacity Building for Managing Climate Change in Malawi project with Norwegian support. Wellam Kamthunzi (Lilongwe University of Agriculture & Natural Resources) is working on biogas technology and believes in the business case for large-scale generation from municipal solid waste, with a small pilot plant under construction at the university's Bunda campus supported by the same Norwegian-funded project.

Other regions of SSA

Our research also revealed useful information and suggestions coming from other regions in SSA:

- Mary Suzan Abbo at CREEC in **Uganda** highlighted several bioenergy initiatives under her centre's management, notably in the areas of cookstoves, biogas and gasification technologies. A new 5-year DFID-funded project is looking at the solar treatment of biomass for power generation using carbon slurries in hybrid renewable energy systems.
- Dr. Jerekias Gandure from the University of **Botswana** is working on transesterification for biodiesel production while his colleague Richie Moalosi is researching social innovation and sustainable design of energy technologies.
- In **Ethiopia**, Dr. Abubeker Yimama (Centre of Energy Technology, Addis Ababa University) has worked on different technologies such as anaerobic digestion of tannery waste, biodiesel production from jatropha and gasifier stoves, while Dr Ancha Ramayya (Institute of Technology, Jimma University) has worked on biomass gasification and pyrolysis, particularly using coffee husk as feedstock.
- Researchers from the School of Agriculture at the University of **Zambia** are engaged in bioethanol production from sweet sorghum.
- In **Zimbabwe**, Dr. Mercy Manyuchi (Harare Institute of Technology), is working on valorisation of waste biomass to produce bioenergy, citing the huge availability of waste agricultural biomass.
- Dinesh Surroop from the University of **Mauritius** has been working in selected African countries on research aimed at generating electricity through direct combustion and on biofuel production through the use of energy crops through the 'L3EAP' project.

6.4.2 Universities and research institutions outside SSA

Based on the snowballing approach, questionnaire responses and the team's own knowledge of the research landscape, the most prominent institutions and individuals outside Africa working on SSA bioenergy were identified. The focus was mostly on the technologies proposed for shortlisting for the next phase of the study.

United Kingdom

A range of academics from prominent universities in the UK (Oxford, Imperial College, South Wales, Nottingham, Manchester, Leeds, Liverpool and Aston) are conducting research on various facets of bioenergy, of which a couple were directly researched with respect to projects ongoing in SSA.:

- Prof. Jacob Mulugetta (University College London) is part of 5-year research programme (Agro-Industries & Clean Energy in Africa) investigating the willingness of agro-industry players in SSA to play a role in widening rural energy access and to identify the barriers that prevent this from happening on a larger scale.
- Prof. Jon Lovett (University of Leeds) heads a research project funded by the UK Royal Society and DFID, in collaboration with the Université Marien Ngouabi (Republic of Congo), Dar es Salaam Institute of Technology (Tanzania), Makerere University (Uganda) and Kwame Nkrumah University of Science and Technology (Ghana), which aims to create a new network for clean energy technologies, with biomass-based energy being one of the focal areas.

France

Several French institutions are carrying out innovative research in the context of decentralised energy production. Notable among these are:

- BioWooEB (a research unit of CIRAD, the French institute for agronomic research) focuses on decentralised energy with a wide range of technologies (torrefaction, carbonisation, gasification, combustion in engines, steam turbines);
- *Groupe Energies Renouvelables, Environnement et Solidarites* is carrying out worldwide R&D, including in West African countries such as Benin, Mali, Niger, Burkina Faso. This include biomass energy development from jatropha and other fuels recycled from biomass waste

Germany

Among the German centres, relevant research in the field was found to be carried out by:

- Fraunhofer Institute for Environmental, Safety & Energy Technology, which researches technologies that allow for mobile and decentralised implementation from lignocellulosic and/or wet biomass feedstock and related residues which may be stored and transported economically.

- German Biomass Research Centre, with dedicated working groups on bioenergy systems, biochemical conversion, thermo-chemical conversion and bio-refineries.

Elsewhere in Europe

- In **Sweden**, Prof. Mohammad Taherzadeh (Swedish Centre for Resource Recovery, University of Borås) is researching different technologies such as biogas production, ethanol from wastes, pyrolysis and combustion of wastes, of which he believes that biogas technology has the greatest potential for uptake in SSA.
- In **Italy**, Prof. David Chiaramonti (University of Florence) is an expert on the production and use of biomass and has been the coordinator of several projects and studies supported by the European Commission, the World Bank, Asian Development Bank and various national bodies.
- In **The Netherlands**, Prof. Martin Junginger (Utrecht University) is working on technological development and cost reductions of (renewable) energy supply and energy demand technologies, while Jaap Kiel's main focus as Programme Development Manager of the European Energy Research Alliance is on biomass upgrading, gasification, gas cleaning and downstream processing.

Brazil

Of the research centres identified in Brazil, the São Paulo Research Foundation Bioenergy Programme (FAPESP) and the National Reference Centre on Biomass and *Grupo de Pesquisa em Bioenergia* (University of São Paulo) were found to be carrying out research on a range of bioenergy technologies such as bio-ethanol, biogas, gasification, bio-diesel, microbiological energy and oil pressing. FAPESP has a large bioenergy programme with strong connections with SSA. Amongst other centres in Brazil, the Biofuels Centre of Excellence at the GE Global Research Technology Centre and the Bioethanol Science and Technology National Laboratory are important centres of liquid biofuel energy research. Researchers from the State University of Rio de Janeiro focus on biogas production from pig-wastes and *Centro Internacional de Energias Renováveis*, a centre formed by 16 academic institutions, is researching biogas produced from different types of biomass.

USA

Two prominent institutions carrying out relevant research are the National Renewable Energy Laboratory (NREL) and Biomass Conversion Research Laboratory (BCRL). The bioenergy program at NREL has a dedicated working group on Thermochemical Processes. BCRL's mission is to develop cost-effective and environmentally attractive means of generating fuels, chemicals, materials, foods and feeds from renewable plant biomass.

India

Although several organisations are working on bioenergy, consultations identified two leading research institutions, the Centre for Alternative Energy Research and the Indian branch of the World Agroforestry Centre (ICRAF), both working on a range of bioenergy research projects.

Philippines

Craig Jamieson from the International Rice Research Institute is involved in the planning and implementation of bioenergy projects with a specialisation in rice straw combustion.

6.5 Project developers and technology providers

This section describes the main project developers and technology providers active or based in SSA, identified as part of the non-academic literature research, the snowballing approach and from existing knowledge within the project team. Project developers and technology providers have been combined, as their activities often closely overlap. The profiles are based on the three primary technologies that have been prioritised for the next phase of the project: combustion, gasification and anaerobic digestion.

6.5.1 Combustion

As section 3.2 on combustion outlines, the existence of project and technology developers operating in (or based in) SSA strongly depends on the secondary conversion technology. Developers of both ORC and Stirling engines using biomass feedstocks are based entirely outside SSA. Combustion boilers for heat production as well as steam engines can often be re-purposed from other applications in SSA or globally. Companies such as John Thompson, based in South Africa manufacture biomass boilers to produce heat in the range up to 20 MW_{th} (John Thompson, 2017). Besides Spilling Technologies (Germany) and Village Industrial Power (USA, operating in SSA), steam engine technology providers at the desired scale could not be identified.

For biomass combustion with steam turbines for co-generation (<5 MW), equipment generally comes from Indian or US/European companies operating in the same sectors, with the exception of the Nigerian company Quintas. At the scale above 5 MW, South African and Brazilian technology providers supply steam turbines to SSA.

For example, the Tanganyika Wattle (2.5 MW_e co-generation plant in Tanzania uses a condensing steam turbine from Dresser Rands (USA), a generator from AVK (Germany) and the plant was manufactured by Mech Mar (Malaysia) (HEDON, 2004).

Steam turbine

- Quintas Renewable Energy Solutions: Since 2009 this Nigerian company has offered single- and multi-stage pressure and velocity-compounded pressure steam turbines at a scale of 100 kW_e to 1 MW_e as well as boilers in the range of 150 kW to 1.5 MW (Quintas, 2017). The company receives support from the Power Africa project.

Steam engine

- Spilling Technologies: A German engineering company offering steam engines in the range 0.1 to 5 MW_e. Spilling operates one steam engine at 0.5 MW_e used for timber drying at a sawmill in Africa. This seems to be the only project example in SSA (Spilling, n.d.).
- Village Industrial Power: A US-based social enterprise, financed by USAID and impact investors FACTOR[e], offers 10 kW engines for thermal, electrical and mechanical energy, mainly for rural farmers and communities. The system can use agricultural waste and woody biomass. The steam engine unit is currently in the demonstration phase in East Africa (Village Industrial Power, n.d.).

Companies such as Camco Clean Energy, a sustainable energy project developer with offices across Africa, develops rural electrification projects through solar, biomass, small hydro and biofuel technologies, addressing also traditional charcoal production and consumption. Camco Clean Energy works together with Village Industrial Power. Other SSA-based project developers include Kwamoka Energy (Ghana) who are developing a 6 MW biomass steam boiler plant in cooperation with GIZ (Kwamoka Energy, n.d.)

6.5.2 Gasification

As explained in the gasification section (3.2.2), few gasification projects currently exist in SSA and these are widely scattered. This explains the very limited number of project and technology developers involved in gasification projects (<5 MW) in SSA. The following were identified:

- Husk Power Systems from India has installed almost 100 gasification plants at a community scale of 30-50 kW in India, has an active interest in SSA and has installed a few pilot plants in the region with donor co-financing. HPS has a cooperation with the International Finance Corporation to increase the rollout of gasification systems in SSA (Husk Power Systems, 2017).

- German-based technology developer Entrade International offers a gasification CHP systems with 50 kW_e and 120 kW_{th} output installed in a shipping container, and has a specific interest in Africa (Entrade International, n.d.). Entrade cooperates with the Swedish project developer Pamoja Cleantech AB.
- Cummins Power Generation, through its Indian subsidiary, supplied equipment to a 12 MW_e gasification plant in Kenya, a project outside the scale range of BSEAA. Chipped *Prosopis juliflora* is powering a grid feed-in installation that was to start operating in October 2016 (Herbeling, 2016). The project was developed through a cooperation with British firm Gentec Energy.
- Ageco Energy, a Tanzanian EPC contractor, has installed a 32 kW_e biomass gasification system using rice husk in Magungumka village. The project was supported by Power Africa's Off-Grid Energy Grants (Power Africa, 2016). A similar project was installed by SESECOM in Tanzania and supported by Power Africa, however no further information was available on the company.
- CREEC in Uganda has active interest in developing biomass gasification projects in SSA using an Indian gasifier in cooperation with UNIDO (CREEC, n.d.).
- Mandulis Energy, a Ugandan renewable energy project developer, has contributed to the development of a 20 MW_e gasification project (outside the scale of BSEAA). Mandulis received a grant through SEFA and KfW, the German Development Bank (AfDB, 2013; Crunchbase, 2016; Mandulis Energy, n.d.).

6.5.3 Anaerobic digestion

There are a significant number of anaerobic digestion projects in Africa, especially at small to medium industrial scale, hence a larger set of Africa-oriented technology and project developers. African project developers and technology providers include:

- Biogas International, a Kenyan company marketing 'Flexi Biogas Solutions' based on a flexible biodigester design. Established in 2011, the company has been supplying digesters to households, small farms and institutions such as schools (Flexi Biogas Solutions, n.d.).

- Bio2Watt is a waste-to-energy company based in South Africa that focuses on industrial scale biogas projects. Its first project is a 4.6 MW plant situated in a cattle feed yard that uses around 20,000 t of organic waste per year and started supplying electricity to the grid in 2015. The company is developing a second biogas project (4.8 MW) at a dairy farm (Bio2Watt, n.d.).
- Tropical Power is an Oxford-based EPC company with subsidiaries in Ghana and Kenya that has built an anaerobic digestion plant at Gorge Farm, Kenya, with an installed capacity of 2.8 MW (output: 2.4 MW) (Tropical Power, n.d.).
- New Horizons Energy is developing a large waste-to energy anaerobic digestion plant in Cape Town. Under construction from 2015, the plant is expected to be commissioned in 2017 (New Horizons Energy, n.d.)
- Cape Advanced Engineering (Pyt.) Ltd. is a South African company that designs and installs biodigesters. One is currently in operation in a dairy farm in Darling, Western Cape. Electricity is being generated but not yet supplied to the grid (Cape Advanced Engineering, n.d.).
- Selectra, another South African company, designs, develops and implements biogas projects for agriculture, industry, mining and infrastructure-based clients in Africa. Its 'Dairy Power Box' is a containerised waste-to-power option for dairies that can generate around 1 kW_e and 2 kW_{th} per 36 cows (Selectra, 2014; Africa-EU Energy partnership, 2015).
- Biogas Power Holdings (East Africa) Ltd. is a Kenyan sister company of the German biogas developer and technology provider agriKomp GmbH. The company has an anaerobic digestion installation at Kilifi Plantations on the Kenyan coast. Using agricultural and dairy waste, the plant generates electricity and heat (Biogas Power Holdings, n.d.).
- Green Heat Uganda is a social enterprise that focuses on biogas and briquette production (Green Heat Uganda, 2014).
- Afrisol Energy Ltd. is a Kenyan social enterprise that designs and manufactures biodigesters. It has installed over 120 units catering to households and institutions such as schools and commercial operations like dairies. 15 commercial plants are reportedly at a capacity of around 124 m^3 (Afrisol Energy, n.d.).
- Avenam Links International is a Nigerian company that is working in the area of affordable biogas digesters and generator technology, among other renewable energy technologies. The company features four installations in

Nigeria that range from household to poultry farm scale. The biogas plants generally have a capacity of 10 m^3 along with a 5-kW generator.

The following international project developers and technology providers are known to have an interest in Africa:

- BioEnergy Berlin GmbH (BEB), which has installed a 2200 m^3 sisal biogas plant in Tanzania producing 150 kW of electricity (BioEnergy Berlin, 2011).
- Sistema Biobolsa: A Mexican social enterprise and manufacturer of mid-scale flexi-bag biogas units for farms, slaughterhouses and municipalities. There is transferability potential to SSA, especially if linked to promoters of similar technology, such as, Biogas International Ltd. (promoting 'Flexi Biogas Solutions') in Kenya (Sistema Biobolsa, n.d.). Sistema Biobolsa received funding from Impact Investor Futura[e].
- Bioeco is a French company that has implemented methanation (humid and liquid biomass) and combustion (dry biomass) projects in France as well as several African countries (Benin, DR Congo, Cote d'Ivoire, Gabon, Madagascar, Togo, Mali, Senegal, Niger) (Bioeco, n.d.), at capacities ranging from 1 to 5000 kW_e. They are looking for new partnerships.
- AKUT is a German biogas company that was involved in setting up a 160 kW_e CHP unit at the Finlays Tea factory in Kenya (AKUT, n.d.).
- Snow Leopard is a German developer of biogas plants that installed the Gorge Farm plant in Kenya in cooperation with Tropical Power and have installed biogas plants in 13 countries (Snow Leopard, n.d.). The gas boiler for Gorge Farm was supplied by GE, switchgear and transformers came from IET Siemens, instrumentation and control systems from SAR GmbH, material handling from BioG and agitators and stirring equipment from Paulmichel. In fact, all the technology was supplied from companies outside SSA.
- PlanET is a German company that builds biogas plants in the range 500-5,000 kW_e. It has completed over 400 projects worldwide, including the installation of a mini biogas plant in Busunu, Ghana in 200 and is looking for opportunities to build more biogas plants in the country.

7. Next Steps

7.1 Summary

Subject to DFID's approval of the three proposed technologies and ten short-listed countries, the team will now investigate in more depth the issues around feedstocks, end uses and enabling conditions through the medium of the Technology Value Chain. From this will emerge a list of the most promising TVC-country combinations.

Countries will be categorised for ease of collective analysis, probably according to agro-ecology as this has a major influence on feedstock availability. Each TVC will be assessed by country against a set of commercial, economic, policy, institutional, infrastructural and feedstock factors. These will be given a weighting and fed into an evaluation grid. The output will be a reduced list of potentially viable TVCs, each linked to a sub-set of the country list.

Representative case studies will then be selected to provide working examples from which to draw experiences and synthesise lessons, ideally from eastern, western and southern Africa, provided that the TVC selections make this appropriate. The case studies will use field data and local insights to highlight practical barriers and challenges to deployment of the prioritised TVCs in high opportunity situations.

7.2 Proposed merging of deliverables

It was initially proposed that one case study should be chosen for each TVC, meaning three case studies in total. It is now felt that this would yield insufficient insight into the diverse barriers and opportunities that may face the deployment of particular TVCs. It would also be risky to rely on so few case studies, in case a venture is no longer operational or if those involved cannot provide sufficient information to build up a comprehensive profile. It is now proposed that additional TVC examples are selected for the case studies, through longer missions to more countries. This proposal affects the study deliverables. 3-4 day scoping visits had been planned to three countries to verify the feasibility and appropriateness of the suggested case studies, resulting in short Country Scoping Reports. Given the proposal to cover more case studies and countries, pre-planning will now be conducted remotely within the same budget and timeframe. With DFID approval, the consortium will still produce the Case Study Reports as planned by 28th July, but with pared-down 'Country Scoping Reports' annexed as brief mission summaries of meetings held.

Annex A Glossary of energy conversion technologies

Though not mentioned against each technology, any heat-producing technology may also be used for direct cooling.

Primary technology	Description	Secondary technology	Description
Combustion	Direct combustion is the most common form of bioenergy conversion and involves the burning of solid biomass feedstock, most often some type of woody waste, in the presence of excess oxygen in a boiler.	None	Heat from combustion can be used in direct thermal applications, such as tea drying, lime burning or brick-making
		Steam turbine	The heat may be used to generate steam, which turns a rotating shaft that (usually) drives an electrical generator.
		Steam engine	The steam may be used to power a piston that can turn a crankshaft and power an electrical generator. Operating temperatures are generally lower than steam turbines, but some efficiency is sacrificed.
		Wet steam expander	If wet steam is expanded (e.g. with screw compressors) it releases energy, which can be captured by proprietary turbine technology to generate electricity.
		Stirling engine	A heat engine that operates by cyclic compression and expansion of air or other gas at different temperatures, such that there is a net conversion of heat energy to mechanical work that can be applied for generation of heat and/or power.
		Organic Rankine cycle	An organic fluid of high molecular mass is pumped to a boiler where it is evaporated, passed through an expansion device (turbine or other expander) and then through a condenser heat exchanger where it is re-condensed. The process allows heat recovery from relatively low temperature sources such as biomass combustion.
		Thermo-electric generator	A solid-state device that converts temperature difference directly into electrical energy through a phenomenon called the Seebeck effect (a form of thermoelectric effect).
Gasification	Solid biomass is heated to a high temperature (above 700 C) with limited oxygen. This converts the feedstock into a flammable synthesis gas known as syngas, which consists of CO, H_2, CO_2,CH_4 and smaller quantities of higher hydrocarbons. Syngas is either fed	Steam turbine	Heat from gasification is used to generate steam, which turns a rotating shaft that (usually) drives an electrical generator.
		Internal combustion engine	Syngas can be used in internal combustion engines, both spark ignited and compression ignited. It can also be dual-fed

Primary technology	Description	Secondary technology	Description
	back to the process to enhance combustion or may be used to power secondary technologies.		alongside fossil fuel.
		Syngas turbine	Untreated syngas can be run in hybrid turbines that allow for greater efficiency because of their lower operating temperatures, and extended part lifetime.
		Catalytic upgrading to • Methanol or DME • bioSNG • FT-Diesel • Hydrogen	Syngas can be upgraded to hydrogen or hydrocarbon fuels via a secondary catalytic reactor.
		Syngas fermentation to ethanol	Refers to the INEOS process[20] using fermentation initiated by naturally occurring anaerobic bacteria (the biocatalyst) to ethanol.
Fast pyrolysis	Pyrolysis uses high temperatures and pressure in the absence of oxygen to decompose organic matter, which results in gas, pyrolysis oil (bio-oil), or charcoal (bio-char). Bio-oil is the most common product as it has the most end-uses (such as for thermal energy that can be used for heat or power generation). The temperature of the reaction determines the end-product.	Combustion	Pyrolysis oil can be combusted directly.
		Catalytic upgrading	Pyrolysis oil can be upgraded to hydrocarbon fuels via a secondary catalytic reactor.
Slow pyrolysis		Internal combustion engine	Pyrolysis oil can be used to power internal combustion engines to generate heat or power.
Oil pressing	Oil-bearing seeds (e.g. jatropha, pongamia, castor) may simply be pressed and the oil extracted and filtered.	Internal combustion engine	Pressed oil may be fed directly to an internal combustion engine, though with detrimental effects on performance and engine lifetime depending on the sophistication of the engine.
		Transesterification	Transesterification converts oils or fats into biodiesel by removing water and contaminants, and mixing with alcohol (typically methanol), and a catalyst (such as sodium hydroxide). Fatty acid methyl esters and glycerin are produced. The esters are considered biodiesel and can be used in vehicles or other

[20] www.ineos.com/businesses/ineos-bio/technology

Primary technology	Description	Secondary technology	Description
			engines.
		Hydro-treated Vegetable Oil	Hydro-treating of vegetable oils is an alternative to esterification for producing bio-based diesel fuels. Such fuels do not have the detrimental effects of ester-type fuels (e.g. increased NOx emission, deposit formation, storage stability problems, rapid engine aging or poor cold properties).
Anaerobic digestion	Anaerobic digestion involves the decomposition of organic or biological waste by microorganisms in the absence of oxygen. The process produces a gas composed largely of methane and carbon dioxide.	None	Biogas may be used directly in adapted cookstoves or mantle lamps.
		Internal combustion engine	Biogas can be used to power an internal combustion engine and generate power and heat
		Bio-methane upgrading	Biogas can be upgraded for injection into piped networks that supply domestic or commercial customers.
Fermentation	Starchy plants (e.g. corn or sugar cane) may be used in the biochemical fermentation process to convert sugars into alcohol.	Ethanol or butanol fermentation	The sugars can be fermented with or without oxygen to produce different alcohols, including ethanol and butanol.
		Aerobic fermentation of sugars	
Lignocellulosic hydrolysis	Plants capture and store solar energy chemically in cellulose. Cellulose hydrolysis breaks down the molecules into sugars and separates them from the residual materials, notably lignin.	Ethanol or butanol fermentation	The sugar solution undergoes microbial fermentation and is then distilled to produce ca. 95% pure alcohol. Dehydration by molecular sieves brings the ethanol (or butanol) concentration to over 99.5%.
Catalytic conversion of sugars	Starchy or woody plants are subjected to biomass fractionation, hydrogenation, aqueous phase reforming and finally acid-catalysed dehydrations or condensations.		
Microalgae	Microalgae are small aquatic organisms that convert sunlight into energy. Some algae store energy in the form of natural oils that can be extracted using solvents or sound waves and upgraded to replace fossil fuels.		

Annex B Classification of feedstocks

Biomass feedstocks were assigned to one of eight categories in order to assess technology feedstock flexibility as part of the academic literature review. The team adapted a feedstock classification system from FAO (2004), as summarised in Table 6.

Table 6. System used for classifying biomass feedstocks

Primary category	Secondary category	Brief definition	Examples
Woodfuels	Energy forest trees and energy plantation trees	Wood from forests, shrubs and other trees either used directly or processed/ densified as fuel	Oak, elder, eucalyptus, Douglas Fir, birch, willow
	Wood processing-industry by-products or used/ recovered woodfuels	Wood used directly or indirectly as fuel, derived from wood processing or socio-economic activities outside the forest sector	Demolition wood, construction wood, used paper shavings, sawdust, viscose
Agrofuels	Herbaceous biomass and biomass from fruits and seeds	Plants or crops grown explicitly or available naturally for the production of biofuels	Energy crops including oilseed crops, grasses, starch crops, food crops, sugar crops
	Agricultural by-products	Mainly by-products from crop harvesting and other agricultural activities left in the field	Straw, stover, leaves, stalk, shell
	Argo-industrial by-products (indirect)	Biomass materials produced chiefly in food and fibre processing industries	Bagasse, husk, seed cake, empty fruit bunch, bio-sludge, vegetable oil
Others	Animal by-products	Primarily waste/by-products from cattle, horses, pigs and poultry	Dung, manure, poultry litter, hide, fish oil, tallow
	Other by-products	Several kinds of solid and liquid waste biomass materials produced in urban societies	Kitchen waste, MSW, refuse, horticultural by-products, sewage sludge
	Micro/macro-algae and aquatic plants		Water hyacinth, spirulina, chlorella

The words and phrases used to identify and categorise feedstocks are listed below:

Forest & plantation wood
poplar
willow
eucalyptus
logs
bole chip
silver fir
arolla pine
douglas fir
scots pine
black pine
cypress
stone pine
larch
maritime pine
yew
aleppo pine
alder
chestnut
cherry
elm
elder
birch
hazel
maple
plane tree
walnut
hackberry
common ash
manna ash
laburnum
beech
oak
black locust
peduncolate oak
hornbeam
hophornbeam
olive
cornel
pine
coniferous wood
deciduous wood
spruce
sycamore
hemlock
acacia
Calliandra calothyrsus
Casuarina equisetifolia
Derris indica
Gliricidia sepium
Gmelina arborea
Guazuma ulmifolia
Leucaena leucocephala
Mangroves
Mimosa scabrella
Muntingia calabura
Sesbania bispinosa
Sesbania grandiflora
Syzygium cumini
Terminalia catappa
Trema spp
Ailanthus altissima
Alnus acuminata
Alnus nepalensis
Alnus rubra
Grevillea robusta
Inga vera
Acacia decurrens
Albizia falcataria
Bursera simaruba
Coccoloba uvifera
Hibiscus tiliaceus
Maesopsis eminii
Pinus caribaea
Psidium guajava
Gleditsia triacanthos
Melaleuca quinquenervia
Melia azedarach
Robinia pseudoacacia
Sapium sebiferum
Adhatoda vasica
Albizia lebbek
Anogeissus latifolia
Azadirachta indica
Cajanus cajan
Cassia siamea
Colophospermum mopane
Emblica officinalis
Haloxylon aphyllum
Haloxylon persicum
Parkinsonia aculeata
Pinus halepensis
Pithecellobium dulce
Tamarix aphylla
Zizyphus mauritiana
Zizyphus spina-christi
Ailanthus excelsa
Balanites aegyptiaca
Combretum micranthum
Conocarpus lancifolius
Dalbergia sissoo
Populus euphratica
Sesbania sesban
Tarchonanthus camphoratus
cedar
bark
hardwood
softwood
honey locust
cabbage gum
douglas-fir
nypa palm
tung oil tree
chinese tallow
paulownia
mesquite
Copaifera langsdorffii
Millettia pinnata
argan tree
ironwood
Babassu palm
prosopis
shea tree
wood chip
woodchip
fuelwood
firewood
fuel wood
wood fuel

Used/recovered wood
demolition wood
construction wood
wooden beam
waste wood
used paper
waste paper
plywood
shaving
grinding dust
sawdust
fibre sludge
black liquor
fibre board
cork
viscose
saw dust
bark chip
thinning
chip fine

Energy/food crops
sweet sorghum
sugar beet
sugarcane
sorghum
milo
sweet potato
sugar palm
cassava
pennycress
karanj
linseed
maize
mustard
oil palm
peanut
safflower
sesame
wheat
corn
triticale
canola
rye
milkweed
coffee bean
palm kernel
cotton seed
saltwort
cardoon
castor bean
copra
cashew nut
oat
lupine
kenaf
calendula
cotton
hemp
soybean
coffee
hazelnut
euphorbia
coriander
camelina
sunflower
cocoa
rapeseed
castor bean
pecan
jojoba
jatropha
brazil nut
avocado
coconut
oil palm
agave
waxweed
persimmon
primrose
barley
pequi
oiticia
bacuri
gopher
crambe
rubber seed
alfalfa
flax shives
miscanthus
switchgrass
prairie grass
bluestem
bladderpod
indiangrass
cordgrass
bamboo
fodder beet
clover grass
sudan grass
carib grass
rye grass
cuphea
knotweed

kallar grass
kudzu
tamarind
pigeonpea
rocket
rosin weed
safou
sorrel
timothy
croton

Agric. by-products
straw
stover
leaves
shell
peel
cob
piassava
stalk
root
tuber

Agro-industrial by-products
bagasse
DDGS
pulp
glycerine
seed cake
whey
bio sludge
bio-sludge
soapstock
seed residue
presscake
vegetable oil
empty fruit bunch
cottonseed cake
groundnut cake
molasses
soybean cake
bran
husk
chaff
seedcake
silage
vinasse

Animal by-products
dung
manure
poultry litter
poultry waste
colostrum
milk
urine
animal fibre
hide
chicken litter
fish oil
tallow
offal
animal waste
slaughterhouse waste

Municipal by-products
kitchen waste
sewage sludge
bone meal
food waste
refuse
solid waste (including MSW)
garbage
OFMSW
organic fraction of municipal solid waste
wastewater treatment sludge
disaster debris
horticultural plants
fruit waste
vegetable waste
human waste
mill effluent

Micro/macro-algae
duckweed
seaweed
algae
microalgae
spirulina
chlorella
Gracilaria
Pleurochrysis carterae
Sargassum
CCMP647
Ankistrodesmus
Botryococcus braunii
Chlorella
Chlorella protothecoides
Crypthecodinium cohnii
Cyclotella
Dunaliella tertiolecta
Hantzschia
Nannochloris
Nannochloropsis
Neochloris oleoabundans
Nitzschia
Schizochytrium
Stichococcus
Tetraselmis suecica
Thalassiosira pseudonana
Phaeodactylum tricornutum
Tisochrysis lutea
Chlamydomonas reinhardtii
Saccharina latissima
Himanthalia elongate
Laminaria digitata
Fucus serratus
Ascophylum nodosum
Undaria pinnatifida
Saccorhiza polyschides
Sargassum muticum
Gracilaria verrucosa
Palmaria palmate
Asparagopsis armata
Codium tomentosum
Ulva lactuca
Scenedesmus
Dunaliella
Haematococcus
macroalgae
water hyacinth
azolla
water lettuce
hydrilla
water milfoil
coontail
water fern
alligatorweed
pennywort
cat tail

Annex C Classification of academic article themes

Academic articles were classified by theme using the search terms listed below:

Review and/or comparison
review
summarize
advancement
overview
summary
Comparative
study
Comparative
Analysis

Feasibility
sensitivity analysis
sensitivity test
internal rate of return
net present value
techno-economic
business model
feasibility stud
feasibility analysis
economic profitability
economic return
uncertainty analysis
economic viability
economic feasibility
payback period
life-cycle cost
life cycle cost
feasibility assessment
technoeconomic
case stud
cost benefit
techno economic

Environmental implications
environmental impact
environmental analysis
environmental Assessment
impact assessment
environmental effect
environmental sustainability
environmental consideration
carbon emission
life-cycle assessment
life cycle assessment
life-cycle analysis
life cycle analysis

Policy and regulations
policy
policy target
policy mechanism
energy target
policy recommendation
policy measure
policy scenario
regulation
regulatory
energy strategy
tariff
policies
market deployment
market trend
market stud

Barriers and/or opportunities
challenge
barrier
flip-flop
benefit
gap
advantage
disadvantage
opportunity
trend
limitation

Annex D Organisations researched – Non-academic literature review

Organisation	Acronym	Website
Africa Biogas Partnership Programme	ABPP	www.africabiogas.org
Africa-EU Renewable Energy Cooperation Programme	RECP	www.africa-eu-renewables.org
African Climate Technology Centre	ACTC	www.african-ctc.net
African Development Bank	AfDB	www.afdb.org/en
Austrian Development Agency	ADA	www.entwicklung.at
Centre for International Forestry Research	CIFOR	www.cifor.org
Danish International Development Agency	DANIDA	www.um.dk/en/danida-en
Deutsche Gesellschaft für Internationale Zusammenarbeit Gmbh	GIZ	www.giz.de
ECOWAS Centre for renewable energy and energy efficiency	ECREEE	www.ecreee.org
Finland Ministry of Foreign Affairs, Department for International Development Cooperation	MFA	formin.finland.fi/Public/default.aspx?nodeid=49273&contentlan=2
Food and Agriculture Organisation of the United Nations	FAO	www.fao.org/home/en
French Development Agency	AFD	www.afd.fr/lang/en/home
Global Bioenergy Partnership	GBEP	www.globalbioenergy.org
Global Environment Facility	GEF	www.thegef.org
International Energy Agency (IEA) Bioenergy		www.ieabioenergy.com
International Renewable Energy Agency	IRENA	www.irena.org/home/index.aspx?PriMenuID=12&mnu=Pri
Kreditanstalt für Wiederaufbau	KfW	www.kfw.de
New Partnership for Africa's Development	NEPAD	www.nepad.org
Norwegian Agency for Development Cooperation	Norad	www.norad.no/en/front
Oxfam		www.oxfam.org.uk
Practical Action		www.practicalaction.org
Swedish International Development Cooperation Agency	Sida	www.sida.se/English
Swiss Agency for Development and Cooperation	SDC	www.eda.admin.ch/sdc#1
US Agency for International Development	USAID	www.usaid.gov
UK Department for International Development	DFID	www.gov.uk/government/organisations/department-for-international-development
United Nations Development Programme	UNDP	www.undp.org
United Nations Environment Programme	UNEP	www.unep.org
World Agroforestry Centre	ICRAF	www.worldagroforestry.org
World Bank	WB	www.worldbank.org

Annex E Organisations researched – stakeholder mapping

Bi/multi-lateral energy initiatives, private investment facilities, public financing facilities and research institutions and universities

Organisation	Acronym	Location	Name	Position Held	Consultation
Bi/Multi-lateral energy initiatives					
Africa Renewable Energy Access Program	AFREA	Washington, DC			Website research
Africa-EU Energy Partnership	AEEP	Eschborn			Email exchange
Africa-EU Renewable Energy Cooperation	RECP	Eschborn			Email exchange
African Renewable Energy Access Program	AFREA	Washington, DC			Website research
Energising Development Program	EnDev	Eschborn	Christoph Messinger	Component Lead	Email exchange
Energy Sector Mgmt. Assistance Program	ESMAP	Washington, DC			Website research
Energy, Environment & Dev't. Network for Africa	AFREPREN	Nairobi	Stephen Karekezi		Phone/Skype
EU Energy Initiative – P'ship Dialogue Facility	EUEI-PDF	Eschborn	Michael Franz	Team Leader	Email exchange
Global Bioenergy Partnership	GBEP				Website research
Int'l. Renewable Energy Agency	IRENA	Abu Dhabi	Jeff Skeer	Technology Officer	Website research
International Energy Agency	IEA	Paris			Website research
SE4All Africa Hub	SE4All	Abidjan	Daniel-Alexander Schroth Giorgio Gualberti	Coordinator Consultant	Phone/Skype
Sustainable Energy For All Initiative	SE4All		Gerad Ostheimer	Global Lead for Sustainable Bioenergy	Website research
UNEP Bioenergy programme		Paris			Website research
United Nations Industrial Dev't. Orgn.	UNIDO	Vienna	Jossy Thomas	Ind. Dev't. Officer, Renewable & Rural Energy Unit	Phone/Skype
Private investment facilities					
Africa Renewable Energy Fund - Berkeley Energy	AREF	Berkeley, CA	Luka Buljan		Email exchange
Emerging Africa Infrastructure Fund	EAIF				Website research
Factor[E]		USA, India, Kenya			Website research
Green Angel Syndicate			Andre Aldrige		In person
InfraCo Africa			Alex Katon		Website research
Private Infrastructure Dev't. Group	PIDG				Website research
Public financing facilities					

Organisation	Acronym	Location	Name	Position Held	Consultation
AECF Renewable Energy & Adaptation to Climate Technologies	REACT	Dar es Salaam	Leanne Jones	Climate & Envt. Adviser, DFID Tanzania	Phone/Skype
Africa Biogas Partnership Programme	ABPP	The Hague			Website research
Africa Clean Energy Business programme	ACE	London			Website research
Brazil's Economic Engagement with Africa		Brazil			Website research
BRILHO - Energy Africa Mozambique		Maputo			Website research
Capacity Building for Managing Climate Change in Malawi	CABMACC	Malawi	David Mkwambisi	Programme Coordinator	Website research
Clean Energy for Development Initiative		Oslo			Website research
Clean Technology Fund	CTF	Washington, DC			Website research
Demo Environment					Website research
ECOWAS Renewable Energy & Energy Efficiency Facility	EREF	Praia, Cape Verde			Website research
Energy & Environment Partnership	EEP	Pretoria	Tim McNeill	Private Sector Dev't. Advisor, DFID SA	Phone/Skype
FMO Infrastructure Dev't. Fund		The Hague	Rob in 't Zand	Fund Portfolio Analyst, Energy Dept.	Website research
GET FiT Uganda Program	GET FiT	Kampala			Website research
Green Africa Power	GAP				Website research
Guarantee Portfolio: Bioenergy Zambia		Lusaka			Website research
Improving Energy Access in Tanzania		Dar es Salaam	Leanne Jones	Climate & Envt. Adviser, DFID Tanzania	Phone/Skype
Innovate UK Energy Catalyst		Swindon	Michael Priestnall	Lead Technologist	Email exchange
Norwegian Investment Fund for Developing Countries	Norfund	Oslo			Website research
Power Africa Off-Grid Challenge		Washington, DC			Website research
Powering Agriculture			Maria Weitz		Website research
Renewable Energy Business Incubator	REBI	Kampala	Shira Mukiibi	Incubator Manager	Website research
Renewable Energy Performance Platform	REPP	Johannesburg	William Lohrmann	Manager (Camco Clean Energy)	Website research
Results-Based Financing for Low Carbon Energy Access					Website research
Scaling Up Renewable Energy in Low Income Countries Program	SREP	Abidjan	Leandro Azevedo	Snr. Climate Finance Officer, AfDB Energy & Envt. Division	Email exchange
Shell Foundation - Transforming Inclusive	TIME	London	Gareth Zahir-Bil		Website research

Organisation	Acronym	Location	Name	Position Held	Consultation
Energy Markets					
Strengthening Adaptation and Resilience to Climate Change in Kenya Plus	StARCK+	Nairobi, Kenya			Website research
Sustainable Energy Fund for Africa	SEFA	Abidjan	João Duarte Cunha	Energy, Envt. & Climate Change Dept.	Website research
Transforming Energy Access	TEA		Alistair Wray	Snr. Responsible Officer	In person
World Bank			Klas Sander		Email exchange
Universities and research institutions					
Agro-Industries & Clean Energy in Africa	AGRICEN	London	Prof. Jacob Mulugetta	Principal Investigator	Website research
Bioethanol Science & Technology Nat'l. Lab.	CTBE	São Paulo	Dr. Luis Augusto Barbosa Cortez	Directorship Advisor	Website research
Biomass Conversion Research Laboratory	BCRL	Michigan, USA	Dr. Bruce Dale	Professor of Chem. Eng.	Website research
Biomass energy and biofuels	LBEB	Ouagadougou	Dr. Sayon Sidibe	Head of Lab.	Website research
Biomass, Wood, Energy, Bioproducts	BioWooEB	Montpellier	Rémy Marchal	Head	Website research
Bunda College of Agric.	BCA	Bunda, Malawi	Wellam Kamthunzi	Lecturer in Agric. Eng.	Emailed q'naire
Centre for Agric. Mechanisation & Rural Tech.	CAMARTEC	Arusha	Elda Kaaya	Extension Officer	Website research
Centre For Energy, Environment & Engineering Zambia	CEEEZ	Lusaka	Prof. Francis Yamba	Director	Website research
Centre for Research in Energy & Energy Conversion	CREEC	Kampala	Mary Suzan Abbo	Director	Emailed q'naire
Centro Internacional de Energias Renováveis–Biogás	CIBiogas	Foz do Iguaçu, Brazil			Website research
Clean Energy Consortium	CEC	Dschang	Dr. Julius Twir Tangka	CEO	Website research
Community Energy Malawi	CEM	Lilongwe	Edgar Bayani	National Coordinator	Emailed q'naire
Council for Scientific & Industrial Research	CSIR	Kumasi, Ghana	Ben Ason	Research Associate	Emailed q'naire
Covenant Univ.		Ota, Nigeria	Dr. Augustine Ayeni	Snr. Researcher, Sustainable Energy & Bioprocess Research Gp.	Emailed q'naire
ECOWAS Centre for Renewable Energy & Energy Efficiency	ECREEE	Praia, Cape Verde	Mahama Kappiah	ExeC. Director, Dept. of Sciences & Biomass Tech.	Website research
EnergieAgentur.NRW		Germany	Heike Wübbeler	Head Biomass Network	Website research
EPSRC Centre for Doctoral Training in Bioenergy	ECDT	Leeds	James McKay		Website research
European Energy Research Alliance	EERA	France	Benoit Gabrielle	Sub-prog. Coordinator, Sust. Biomass	Website research

Organisation	Acronym	Location	Name	Position Held	Consultation
European Energy Research Alliance	EERA	Netherlands	Dr. Maria Barbosa	Sub-prog. Coordinator, Biofuels from Algae	Website research
European Energy Research Alliance	EERA	Netherlands	Jaap Kiel	Sub-prog. Coordinator, Thermochemical Processing	Website research
Forestry Research Institute of Ghana		Kumasi, Ghana	Beatrice Obiri	Researcher	Emailed q'naire
Fraunhofer Institute for Environmental, Safety & Energy Technology		Oberhausen	Prof. Görge Deerberg	Institute Leader	Website research
GE Global Research Technology Centre		Rio de Janeiro	Clayton Zabeu	Leader, Biofuels Centre of Excellence	Website research
German Biomass Research Centre	DBFZ	Germany	Prof. Ing Daniela Thrän	Head of Bioenergy Systems Dept.	Website research
Groningen Univ.		Groningen	Dr. André Faaij	Distinguished Prof., Energy System Analysis	Website research
Groupe Energies Renouvelables, Environnement et Solidarites	GERES	France	Thierry Cabirol	President	Website research
Halmstad Univ.		Sweden	Prof. Sven Werner	Professor of Energy Technology	Website research
Harare Inst. of Technology		Harare	Dr. Mercy Manyuchi	Head of Dept., Chem. & Process Systems	Emailed q'naire
IFP Energies Nouvelles		France	Raymond Szymanski	Director	Website research
Imperial College London	ICL	London	Rocio Diaz-Chavez	Research Fellow	Website research
Institute Afrique Energies Nouvelles	IAEN	Yaounde			Website research
International Rice Research Institute	IRRI	Philippines	Craig Jamieson	Development Practitioner	In person
Jaramogi Oginga Odinga Univ. of Science & Technology	JOOUST	Bondo, Kenya	Ben Muok	Director, Centre for Research, Innovation & Tech.	Emailed q'naire
Jimma Univ.		Jimma, Ethiopia	Dr. Ancha Ramayya	Snr. Researcher, Institute of Tech.	Website research
Kenya Forestry Research Institute		Lodwar, Kenya	Jesse Owino	Lodwar Area Manager	Emailed q'naire
King Abdulaziz Univ.		Turkey	Prof. Ayhan Demirbas	Professor of Chem. Eng.	Website research
KTH Royal Institute of Technology		Sweden	Prof. Wlodzimierz Blasiak	Energy & Furnace Tech. Research Gp.	Website research
Kwame Nkrumah Univ. of Science & Tech.	KNUST	Kumasi, Ghana	Dr. Francis Kemausuor	Senior Lecturer, Dept. of Agric. Eng.	Emailed q'naire
Malawi U of S&T			Robert Mkandawire		Emailed q'naire
Mali Folkecenter	MFC	Bamako	Ibrahim Togola	Chair	Website research
Ministry of Energy		Nairobi	Isaiah Okuthe	Principal Renewable Energy Officer	Emailed q'naire
National Reference Centre on Biomass	CENBIO	Brazil	Suani Teixeira Coelho	Coordinator	Website research
National Renewable Energy Laboratory	NREL	USA	Adam Bratis	Biofuels Program Manager	Website research

Organisation	Acronym	Location	Name	Position Held	Consultation
Nelson Mandela African Institution of Science & Technology	NM-AIST	Arusha	Prof. Karoli Njau	Acting VC	Emailed q'naire
Nigeria Federal Univ. of Technology		Minna, Nigeria	Prof. Joseph Faihem	Snr. Researcher, Chem. Eng. Dept.	Website research
Núcleo Interdisciplinar de Planejamento Energético	NIPE	Brazil			Website research
Regional Centre for Renewable Energy and Energy Efficiency	ECREEE	Praia, Cape Verde	Bah Saho		Website research
Ruhr-Universität Bochum		Germany	Prof. Ing. V. Scherer	Head of Dept., Energy Plant Tech.	Website research
São Paulo Research Foundation Bioenergy Program	BIOEN - FAPESP	São Paulo	Glaucia Mendes Souza		Website research
South African National Energy Dev't Institute	SANEDI - RECORD	Johannesburg	Dr. Karen Surridge-Talbot	Manager, Renewable Energy Centre of Research & Dev't	Emailed q'naire
South African National Energy Dev't. Institute	SANEDI	Johannesburg	Renate Roux-v d Merwe	Centre Manager	Emailed q'naire
South African-German Energy Programme	SAGEN	Johannesburg	Marlett Balmer	Senior Energy Advisor	Website research
Stellenbosch Univ.	SU	Stellenbosch	Annie Chimphango		Website research
Stockholm Environment Institute	SEI	Nairobi	Francis Johnson	Senior Research Fellow	Email exchange
Strathmore Univ.		Nairobi	Buchholz	Manager of SERC	Emailed q'naire
SUPERGEN Bioenergy Hub		Manchester	Prof. Patricia Thornley	Director	In person
Unidersidade do Estado do Rio de Janeiro		Rio de Janeiro	Dr. Dongala	Researcher	Website research
Univ. of Benin		Benin City, Nigeria	Dr. Amenaghawon Andrew	Snr. Researcher, Dept. of Chem. Eng.	Emailed q'naire
Univ. of Bern		Bern	Dr. Albrecht Ehrensperger	Head of Innovations, Centre for Dev't. & Envt.	Website research
Univ. of Borås		Borås	Prof. Mohammad Taherzadeh	Researcher, Swedish Centre for Resource Recovery	Emailed q'naire
Univ. of Botswana		Gaborone	Olefile B Molwane	Head of Dept.	Website research
Univ. of Botswana		Gaborone	Richie Moalosi	Assoc. Professor	Website research
Univ. of Cape Town / Citius Energy	UCT	Cape Town	Anthony Williams	Dept. of Chemical Eng.	Phone/Skype
Univ. of Dar es Salaam		Dar es Salaam	Prof. Jamidu Katima	Consultant	Emailed q'naire
Univ. of Florence		Florence	Prof. David Chiaramonti		Website research
Univ. of Kwazulu-Natal	UKZN	Durban	Helen Watson	Lecturer	Emailed q'naire
Univ. of Lagos		Lagos	Dr. Ojolo Joshua	Snr. Lecturer, Dept. of Mech. Eng.	Emailed q'naire
Univ. of Leeds		Leeds	Prof. Jon Lovett	Lead, African Clean Energy Research	Email exchange

Organisation	Acronym	Location	Name	Position Held	Consultation
				Alliance	
Univ. of Lisbon		Lisbon	Dr. Doutora Mendes	President	Website research
Univ. of Manchester		Manchester	Dr. Mirjam Roeder	Research Fellow	In person
Univ. of Mauritius	UoM	Reduit, Mauritius	Dinesh Surroop	Academic	Emailed q'naire
Univ. of Nigeria		Nsukka, Nigeria	Prof. Justus Nwaoga	Chief Technologist, Dept. of Pharmaceutical & Medicinal Chem.	Emailed q'naire
Univ. of Nottingham		Nottingham	Dr. Alison Mohr	Lecturer in Science & Tech. Studies	In person
Univ. of Oxford		Oxford	Prof. Andrew Smith	Oxford (Bio)Energy, under Oxford Networks for the Environment	Website research
Univ. of South Wales		Cardiff	Prof. Alan Guwy	Head, Sust. Energy Research Centre	Website research
Univ. of the Free State	UFS	Bloemfontein	Prof. Johan Grobbelaar	Researcher, Dept. of Plant Sciences	Emailed q'naire
Univ. of Tsukuba		Japan	Prof. Makoto Watanabe	Head of Algae Biomass Energy System Dev't. Research Centre	Website research
Univ. of Washington	UW	Seattle, USA	Prof. John Kramlich	Professor, College of Engineering	Website research
Univ. of Washington	UW	Seattle, USA	Prof. Richard Gustafson	Denman Professor, Forest Resources	Website research
Universidade de Sao Paulo	GBIO	São Paulo	Suani Teixeira Coelho	Grupo de Pesquisa em Bioenergia	Website research
Utrecht Univ.		Utrecht	Prof. Martin Junginger	Copernicus Institute of Sust. Dev't.	Website research
World Agroforestry Centre	ICRAF	New Delhi	Navin Sharma	Biofuels Program Manager	Website research

Project developers and technology providers

Organisation	Technology	Activity	Location	Name	Position Held	Consultation
Afrisol Energy Ltd.	Anaerobic digestion	Social enterprise. Installed over 120 biogas units. Catering to households, schools, dairies	Kenya			Website research
Ageco Energy	Gasification	EPC contractor. Installed a 32 kW_e biomass gasification system using rice husk in Magungumka village	Tanzania			Website research
AgriKomp	Anaerobic digestion	Developed waste-to-energy biogas project in Kenya.	Germany			Website research
AKUT Umwelt	Anaerobic digestion	Built 160 kW biogas plant in Kenya	Berlin			Website research
Artaxerkes	Fast pyrolysis	Pyrolysis equipment provider (biomass/ organic waste to electricity/heat)	France	Olivier Kerfant	Africa representative	Website research
Avenam Links International	Anaerobic digestion	Four installations in Nigeria that range from household to poultry farm scale. (10 m^3 with a 5 kW generator)	Nigeria			Website research
BEB BioEnergy Berlin GmbH	Anaerobic digestion	Developed sisal biogas plant (Tanzania, 150 kW_e)	Berlin	Guy Kebengele		Website research
Bio2Watt	Anaerobic digestion	Industrial biogas plant developer (one 4.6 MW plant installed)	Johannesburg	Sean Thomas	CEO	Website research
Biocom	Fermentation, Steam turbine	Project developer-ethanol fermentation with bagasse cogeneration	Cacuso, Angola			Website research
Bio-e-co	Anaerobic digestion, combustion	Technology developer with experience in 10 African countries (1-5000 kW_e)	Maves, France	Angeli Nicolas	CEO	Website research
Bioenergiesysteme	ORC	Developed project on industrial waste heat recovery for electricity/heat in South Africa	Austria	Dr. Ingwald Obernberger	Chair, European Biomass Conference	Website research
Biogas International (Flexi Biogas Solutions)	Anaerobic digestion	Project developer cum technology provider focusing on flexible balloon digesters for household, small farms and commercial use	Nairobi	Andrew Amadi; Dominic Wanjihia	Business consultant; Director	Emailed q'naire; Website research
Biogas Power Holdings (East Africa) Ltd.	Anaerobic digestion	Anaerobic digestion installation at Kilifi Plantations on the Kenyan coast	Germany, Kenya			Website research
BIOTECH	Anaerobic digestion	Developed community-scale biogas to	India			Website research

Organisation	Technology	Activity	Location	Name	Position Held	Consultation
		electricity units in Kerala				
Brazilian Sugarcane Industry Association	Fermentation	Largest organisation in Brazil representing sugar, ethanol and bioelectricity producers	Brazil	Elizabeth Farina	CEO	Website research
Camco Clean Energy	Steam engine	Sustainable energy project developer working with Village Industrial Power in Africa	Johannesburg			Website research
Cape Advanced Engineering (Pyt.) Ltd.	Anaerobic digestion	Biodigester designed and installed in a dairy farm in Darling, Western Cape	South Africa			Website research
Cleanergy	Stirling engine	10-15 CHP Stirling units installed, mainly in Europe and the US. Use German Stirling technology	Sweden			Website research
Cogebio	ORC, gasification	Technology provider with expertise in biomass gasification and cogeneration (500 kW – 10 MW)	Irigny, France			Website research
Centre for Research in Energy and Energy Conservation (CREEC)	Gasification	Interested in developing projects in SSA using an Indian gasifier in cooperation with UNIDO	Uganda			Website research
Cummins Power Generation	Gasification	Supplied equipment to a 12 MW_e gasification plant in Kenya	USA			Website research
Decentralised Energy Systems India (DESI)	Gasification	Installed 15 gasification units	India			Website research
EcoFuels Kenya	Oil pressing	Producers of organic biofuel, animal feed, and fertiliser from Croton nuts	Nanyuki, Kenya	Alan Paul	Director	Website research
Electratherma	ORC	Focus on small-scale waste heat recovery	USA			Website research
Energias Renováveis Ltda	Anaerobic digestion, fast pyrolysis, gasification	Pyrolysis, methanation and gasification project developer (600-6000 kW)	Brazil			Website research
EnerTime	ORC	Technology provider focusing on ORC turbomachines	France	Gilles David	Co-founder & CEO	Website research
Entrade	Gasification	Technology provider working with Pajoma Cleantech to install gasification		Julien Uhlig	Director	Email exchange

Organisation	Technology	Activity	Location	Name	Position Held	Consultation
		units in Uganda (50 kW_e and 120 kW_e)				
Exergy ORC	ORC	Manufacturers of 'Radial Outflow Turbine' that uses lower quality heat sources and converts it into energy	Italy			Website research
Green Heat Uganda	Anaerobic digestion	Social enterprise that focuses on biogas and briquette production	Uganda			Website research
Green Social Bioethanol	Fermentation	Developed a 0.4 Ml/yr micro-distillery in Nigeria	Brazil			Website research
Heliex Power	Wet steam expander	UK manufacturer with no current projects in SSA	East Kilbride	Dan Wright	MD	Email exchange
Husk Power Systems	Gasification	Installed ~100 gasification plants at community scale of 30-50 kW in India. Has installed a few pilot plants in SSA with donor co-financing.	India			Website research
Infinity	ORC	Design and produce the radial outflow turbine for making power from waste heat	USA			Website research
John Thompson	Boilers	Offer boilers for direct combustion (<5 MW)	South Africa			Website research
Lean Energy Solutions	Combustion	Technology provider offering package of boiler conversion with fuel briquettes. Work in Kenya and Tanzania.	Nairobi	Dinesh Tembhekar	Managing Director	Website research
Mandulis Energy	Gasification	Contributed to the development of a 20 MW_e gasification project in SSA	Uganda			Website research
New Horizons Energy	Anaerobic digestion	Developing a large waste-to energy anaerobic digestion plant in Cape Town	South Africa			Website research
Novozymes	Fermentation	Developed cassava to ethanol for clean cookstove project in Mozambique in 2012.	Denmark	Stefan Maard	Head of sustainability innovation	Phone/Skype
Pajoma Cleantech	Gasification	Biomass gasification project developer in Uganda (use Entrade technology)	Sweden	Peik Stenlund		Website research
PlanET	Anaerobic digestion	Develop biogas projects in the range of 500-5,000 kWe. Installed mini biogas in	France	Timothée Bellet	Contact person	Website research

Organisation	Technology	Activity	Location	Name	Position Held	Consultation
		Ghana in 2009.				
Qnergy	Stirling engine	Production capacity of 18,000 Stirling engines per year. Engines can use biomass as a heat source (unconfirmed)	US-Israel			Website research
Quintas Renewable Energy Solutions	Steam turbine	Offer steam turbines (100 kW_e to 1 MW_e) as well as boilers (150 kW to 1.5 MW)	Nigeria			Website research
Saran Renewable Energy	Gasification	Installed a few units	India			Website research
Selectra	Anaerobic digestion	develops and implements biogas projects for agriculture, industry, mining and infrastructure-based clients in Africa	South Africa			Website research
Siemens	ORC	The Siemens ORC module can generate power from industrial waste heat without any additional fuels	Germany			Website research
Sistema Biobolsa	Anaerobic digestion	Manufacturers of mid-scale flexi-bag biogas units for farms, slaughterhouses and municipalities	Mexico City	Alex Eaton	CEO/Co-founder	Website research
Snow Leopard	Anaerobic digestion	Developed 2 MW biogas plant in Kenya and other anaerobic digestion projects in SSA	Germany			Website research
Spilling Technologies	Steam engine	Operates one steam engine at 0.5 MW_e used for timber drying at a sawmill in Africa. Offer steam engines in the range of 0.1 to 5 MW_e.	Germany			
Sunbird Bioenergy	Fermentation, combustion	Ethanol developer with projects in Sierra Leone, Zimbabwe and Zambia	Mauritius	Richard Bennett	CEO	Website research
Tanzania Traditional Energy Development and Environmental Organisation (TaTEDO)	Oil pressing	NGO that has established MFPs (jatropha-based) at three sites and installed a village mini-grid to 50 households and 12 businesses	Tanzania			Website research
Taurus Distillation	Fermentation	Offer 0.8 to 8 Ml/yr plants, with one project running in Mauritius	South Africa			Website research

Organisation	Technology	Activity	Location	Name	Position Held	Consultation
The Energy Resources Institute	Gasification	Installed around 300 units. Developing a sustainable prototype for SSA in association with UNIDO	India			Website research
Thecogas	Anaerobic digestion	Biogas market developer using agri, industrial and MSW (30 kW to several MW) (Dutch main HQ)	Dakar	Mouhamadou Ndiaye	CEO	Website research
Touba Energie Solutions	Oil pressing	Project developer focusing on Jatropha. Sell seeds + produce biofuel	Dakar			Website research
Trama TecnoAmbiental	Bioenergy (anaerobic digestion, boilers), solar, wind, hydro	Specialises in distributed generation through renewable energy sources, rural electrification, self-generation and integration of renewables in buildings	Barcelona			Website research
Tropical Power	Anaerobic digestion	Oxford-based EPC with subsidiaries in Ghana and Kenya. Built an anaerobic digestion plant in Kenya (2.8 MW)	UK			Website research
Turboden	ORC	Installed around 300 ORC systems globally	Italy			Website research
Village Industrial Power	Steam engine	Tech-cum-project developer focusing on small scale steam engines (10 kW)	USA & Tanzania			Website research
WIP Renewables	Bioenergy, solar, wind		Munich	Dominik Rutz	Snr. Project Manager	Website research

Annex F Bibliography

Abubakar, L., Mutie, A., Kenya, E. & Muhoho, A., 2012. Characterization of algae oil (oilgae) and its potential as biofuel in Kenya. *Journal of Applied Phytotechnology in Environmental Sanitation*, May, 1(4).

AfDB, 2013. *Situational Analysis of the Reliability of Economic Statistics in Africa: Special Focus on GDP Measurement,* Abidjan: African Development Bank.

AFDB, 2016. *SEFA Funds preparation of first-ever Biomass Gasification Project in Uganda.* [Online]
Available at: https://www.afdb.org/en/news-and-events/article/sefa-funds-preparation-of-first-ever-biomass-gasification-project-in-uganda-16582/
[Accessed 17 01 2017].

Africa-EU Energy partnership, 2015. *BEST PRACTICES for CLEAN ENERGY ACCESS in AFRICA,* s.l.: http://africa-eu-partnership.org/sites/default/files/documents/are_best_practices_africa_2014.pdf.

Afrisol Energy, n.d.. *Afrisol Energy.* [Online]
Available at: http://www.afrisolenergy.com/
[Accessed 24 January 2017].

AKUT, n.d.. *Finley biogas plant.* [Online]
Available at: http://www.akut-umwelt.de/referenzen/
[Accessed 24 January 2017].

Algae Industry Magazine, 2014. *Coalgae introduced in South Africa.* [Online]
Available at: http://www.algaeindustrymagazine.com/coalgae-introduced-in-south-africa/
[Accessed 10 January 2017].

allAfrica, 2015a. *Kenya: Naivasha Biogas Plant to add 2.2MW to the national grid.* [Online]
Available at: http://allafrica.com/stories/201502050085.html
[Accessed 15 January 2017].

allAfrica, 2015. *Uganda turns beasts to biogas.* [Online]
Available at: http://allafrica.com/stories/201502031202.html
[Accessed 10 January 2017].

Anon., 2006. *Steam Turbines.* [Online]
Available at: http://www.localpower.org/deb_tech_st.html
[Accessed 23 January 2017].

Asmare, A. M., Demessie, B. A. & Murthy, G. S., 2013. Theoretical estimation of the potential of algal biomass for biofuel production and carbon sequestration in Ethiopia. *International Journal of Science and Research*, June, 2(6).

Beston, 2017. *Beston.* [Online]
Available at: http://www.bestongroup.com/waste-pyrolysis-plant/waste-plastic-pyrolysis-oil-plant/
[Accessed 24 January 2017].

Biello, D., 2014. *Ethanol Scheme to Clean Air in Billions of Kitchens Goes Up in Smoke.* [Online]
Available at: https://www.scientificamerican.com/article/ethanol-scheme-to-clean-air-in-billions-of-kitchens-goes-up-in-smoke/
[Accessed 09 01 2017].

Binns, P., 2009. *Sowing the Seeds of Prosperity: Developing Bioenergy Technology to Alleviate Smallholder Farmer Poverty,* s.l.: Bill & Melinda Gates Foundation.

Bio2Watt, 2016. *Bio2Watt-A commercial path to generation of the South African Biogas market,* s.l.: http://suedafrika.ahk.de/fileadmin/ahk_suedafrika/Competence_Centres/Opportunities_for_Biogas_in_SA_2016/11_Bio2Watt.pdf.

Bio2Watt, n.d.. *Bio2Watt.* [Online]
Available at: http://www.bio2watt.com/bio2watt%E2%80%99s-bronkhorstspruit-biogas-plant-(pty)-ltd.html
[Accessed 10 January 2017].

Bioeco, n.d.. *Bioeco.* [Online]
Available at: www.bio-e-co.fr
[Accessed 24 January 2017].

BioEnergy Berlin, 2011. *BioEnergy Berlin.* [Online]
Available at: http://www.bebgmbh.de/
[Accessed 20 January 2017].

Biogas Power Holdings, n.d.. *Biogas Power Holdings.* [Online]
Available at: http://www.biopower.co.ke/About-us.html
[Accessed 25 January 2017].

Bio-Innovate Africa, 2015. *Turning noxious tannery waste into biogas and reusable water,* s.l.: http://www.bioinnovate-africa.org/turning-noxious-tannery-waste-into-biogas-and-reusable-wate/.

Bios Bioenergiesysteme GmbH, n.d. *Description of the biomass CHP technology based on Stirling engines.* [Online]
Available at: http://www.bios-bioenergy.at/en/electricity-from-biomass/stirling-engine.html
[Accessed 11 01 2017].

Brew-Hammond, A. & Kemausuor, F., 2008. *Guidebook on modern bioenergy conversion technologies in Africa,* http://s3.amazonaws.com/zanran_storage/energycenter.knust.edu.gh/ContentPages/106866899.pdf: UNIDO.

Cape Advanced Engineering, n.d.. *Cape Advanced Engineering.* [Online]
Available at: http://www.cae.co.za/Projects/
[Accessed 24 January 2017].

Cleanergy, 2017. *Worldwide installations.* [Online]
Available at: http://cleanergy.com/solutions/#installations
[Accessed 11 01 2017].

CREEC, n.d. *Gasification.* [Online]
Available at: http://creec.or.ug/our-departments/bioenergy/gasification/
[Accessed 17 01 2017].

Crunchbase, 2016. *Mandulis Energy.* [Online]
Available at: https://www.crunchbase.com/organization/mandulis-energy#/entity
[Accessed 17 01 2017].

Czernik, S., 2008. *Fundamentals of charcoal production.* Newcastle, s.n.

Darzins, A., Pienkos, P. & Edye, L., 2010. *Current Status and Potential for Algal Biofuels Production,* http://www.globalbioenergy.org/uploads/media/1008_IEA_Bioenergy_Task_39_-_Current_status_and_potential_for_algal_biofuels_production.pdf: NREL.

de Miranda, R., 2012. *Power cogeneration and charcoal production: technological status and commercial prospects,* s.l.: s.n.

DESI Power, 2017. *Recent activities and projects.* [Online]
Available at: http://www.desipower.com/Activities.aspx
[Accessed 19 01 2017].

E4tech internal, 2015. *TEAP project - D1,* s.l.: s.n.

E4tech, 2014. *Internal information,* s.l.: s.n.

E4tech, 2016. *Internal information.* London: s.n.

E4tech, 2016. *Internal information,* s.l.: s.n.

EcoFuels Kenya, n.d. *Biofuel in a nutshell: The energy and cash potential in croton trees.* [Online]
Available at: http://www.ecofuelskenya.com/biofuel-in-a-nutshell-the-energy-and-cash-potential-in-croton-trees/
[Accessed 16 January 2017].

EEP Africa, 2016. *Energy and Envronment Programme for East and Southern Africa.* [Online]
Available at: www.eepafrica.org
[Accessed 05 12 2016].

ElectraTherm, n.d.. *ElectraTherm Products.* [Online]
Available at: https://electratherm.com/products/
[Accessed 25 January 2017].

Entrade International, n.d. *Africa.* [Online]
Available at: http://www.entrade.co/africa.html
[Accessed 17 01 2017].

European Biofuels Technology Platform, n.d. *Waste oils and fats as feedstocks for biofuels production.* [Online]
Available at: http://www.biofuelstp.eu/waste-oils.html
[Accessed 23 January 2017].

FAO, 2004. *Unified Bioenergy Terminology,* Rome: United Nations Food and Agriculture Organisation.

Flexi Biogas Solutions, n.d.. *Flexi Biogas Solutions.* [Online]
Available at: http://biogas.co.ke/en/
[Accessed 16 01 2017].

Flexi Biogas Solutions, n.d.. *Flexi Biogas Solutions.* [Online]
Available at: Flexi Biogas Solutions
[Accessed 10 January 2017].

Fredericks, D. D. B., 2015. *ECOWAS Bioenergy Policy and implementation plan,* http://www.ecreee.org/sites/default/files/event-att/bioenergy_policy.pdf: ECREEE.

Gadré, I. & Maiorana, J., 2014. *Price model of the stirling engine,* Bachelor of Science Thesis EGI-2014: KTH Industrial Engineering and Management.

GEDI, 2017. *The Global Economic and Development Institute.* [Online]
Available at: www.thegedi.org/downloads/
[Accessed 05 01 2017].

GIZ, 2015. *Moving innovation forward,* Eschborn, Germany: Gesellschaft fuer Internationale Zusammenarbeit (GIZ).

GIZ & SANEDI-RECORD, 2013. *State of Algal Energy Research: Specific to Bio-energy Application in South Africa,* s.l.: http://www.record.org.za/resources/downloads/item/review-of-the-state-of-algal-energy-research-specific-to-biofuel-applications-in-south-africa.

GoI, UNDP & SDC, n.d.. *Access to clean energy: A glimpse of off grid projects in India,* s.l.: http://www.undp.org/content/dam/india/docs/access_to_clean_energy.pdf.

Goudarzi, S., 2016. *Reinventing the Steam Engine.* [Online]
Available at: https://poweringag.org/news-events/news/reinventing-steam-engine
[Accessed 17 January 2017].

Government of Kenya, 2015. *Kenya Gazette Supplement no. 181,* s.l.: s.n.

Green Heat Uganda, 2014. *Green Heat Uganda.* [Online]
Available at: https://greenheatug.wordpress.com/
[Accessed 24 January 2017].

Green Social Bioethanol , 2015a. *Ogbomosho.* [Online]
Available at: http://green-social.com/projects/ogbomosho/3#openedProject#openedProject
[Accessed 24 01 2017].

Green Social Bioethanol, 2015. *Technology.* [Online]
Available at: http://green-social.com/technology/
[Accessed 24 01 2017].

HEDON, 2004. *Biomass Based Electricity Production: TANWAT Case Study, Tanzania.* [Online]
Available at: http://www.hedon.info/TANWATBiomassElectricityTanzania
[Accessed 16 01 2017].

Herbeling, D., 2016. *US firm Cummins starts 12MW Baringo power production in October.* [Online]
Available at: http://www.businessdailyafrica.com/Corporate-News/US-firm-Cummins-starts-12MW-Baringo-power-production/539550-3356662-8a0etk/
[Accessed 17 01 2017].

Husk Power Systems, 2013. *Husk Power Systems.* [Online]
Available at: http://www.cseindia.org/userfiles/Gaurav%20Kumar_Design%20to%20Scale.pdf
[Accessed 12 01 2017].

Husk Power Systems, 2017. *Community Impact.* [Online]
Available at:
http://www.huskpowersystems.com/innerPage.php?pageT=Community%20Impact&page_id=81
[Accessed 19 01 2017].

Ibelle, B., 2016. *Seeds of Hope.* [Online]
Available at: https://www.northeastern.edu/magazine/seeds-of-hope/
[Accessed January 2017].

IEA, 2009. *Bioenergy - a Sustainable and Reliable Energy Source,* Paris: International Energy Agency.

IEA, 2014. *Africa Energy Outlook,* Paris: International Energy Agency.

IEA, 2014. *Africa Energy Outlook,* Paris: International Energy Agency.

Ingenioren, 2013. *Firmaet bag lovende, dansk stirlingmotor er gaet konkurs.* [Online]
Available at: https://ing.dk/artikel/firmaet-bag-lovende-dansk-stirlingmotor-er-gaaet-konkurs-157598
[Accessed 11 01 2017].

IRENA, 2014. *Prospects for the African Power Sector,* s.l.: IRENA.

IRENA, 2016. *Innovation outlook Advanced Liquid Biofuels,* Abu Dhabi: International Renewable Energy Agency.

John Thompson, 2017. [Online]
Available at: http://www.johnthompson.co.za/home.html
[Accessed 12 01 2017].

Kang, L., 2014. *Biofuel Experiences in China: Governance and Market Development Updates.* http://www.biofuelstp.eu/spm6/docs/liping-kang.pdf, Innovation Center For Energy And Transportation (iCET).

Karekezi, S., 2017. *Director of AFREPREN* [Interview] (13 1 2017).

Kariuki, J., 2016. *Personal communication* [Interview] (17 08 2016).

Kartha, S., Leach, G. & Chella Rajan, S., 2005. *Advancing Bioenergy for Sustainable Development. Guidline for Policymakers and Investors.,* Washington, D.C. : Energy Sector Management Assistance Program (ESMAP).

Kennedy, M., 2012. *Biomass Gasification - The East African Study,* s.l.: Practical Action.

Khennas, S., 2015. *Bioelectricity production and prospects for Africa,* s.l.: http://www.ecreee.org/sites/default/files/event-att/bioelectricity.pdf.

Kwamoka Energy, n.d. *The Kumasi Waste To Power Project.* [Online]
Available at: http://kwamokaenergy.com/projects/the-kumasi-waste-to-power-project/
[Accessed 17 01 2017].

Langkeek, A., 2007. *The Jatropha curcas agroforestry strategy of mali Biocarburant SA,* s.l.: s.n.

LBNet, 2016. *An assessment of the potential for the establishment of lignocellulosic biorefineries in the UK,* s.l.: s.n.

Mali Biocarburant, n.d. *Sustainable Production of Biodiesel in West Africa.* [Online]
Available at: http://www.malibiocarburant.com/website%20example%20-%20copie/Mali_Biocarburant_SA/Sustainable_production.html
[Accessed 23 01 2017].

Mandulis Energy, n.d. *Mandulis Energy.* [Online]
Available at: http://www.mandulisenergy.com/
[Accessed 17 01 2017].

Moss, T. & Gleave, M., 2013. *How much power does Africa really need?.* [Online]
Available at: http://www.cgdev.org/blog/how-much-power-does-power-africa-really-need
[Accessed 19 01 2017].

Muller, M. R., 2005. *The return of the steam engine,* http://quasiturbine.promci.qc.ca/Presse/SteamMuller050721.pdf: s.n.

Mumias Sugar, n.d. *Ethanol.* [Online]
Available at: http://www.mumias-sugar.com/index.php?page=ethanol
[Accessed 24 01 2017].

Netherlands Enterprise Agency, 2014. *Mali Biocarburant: jatropha press cake fuels local economy,* s.l.: s.n.

Neufeldt, H. L. K. F. J. L. M. D. P., 2015. *From transition fuel to viable energy source: improving sustainability in the sub-Saharan charcoal sector,* Nairobi: World Agroforestry Centre.

New Horizons Energy, n.d.. *New Horizons Energy.* [Online]
Available at: www.nhenergy.co.za
[Accessed 24 January 2017].

Nzira, V. & Mundondwa, C., 2016. *Harare Poly discovers biodiesel from algae.* [Online]
Available at: http://www.chronicle.co.zw/harare-poly-discovers-biodiesel-from-algae/
[Accessed 24 January 2017].

Olawale, O., 2014. *Africa's biggest maker of ethanol from cassava says IITA technologies are helping farmers to double yields.* [Online]
Available at: https://olawaleojo.wordpress.com/tag/allied-atlantic-distilleries-limited-aadl/
[Accessed 24 01 2017].

Pasquiou, V., Randimbivololona, P., Dunod , A. & Lepage, A., 2012. *Etude sur la valorisation des déchets agroindustriels pour la production de chaleur et d'électricité en Afrique subsaharienne,* http://www.afd.fr/webdav/site/afd/shared/PORTAILS/SECTEURS/ENERGIE/pdf/RECP-synthese-bioelectricite-2012.pdf: enertime, ecosur afrique.

Power Africa, 2016. *Off-Grid Energy Grants Portfolio,* s.l.: s.n.

Powering Agriculture, 2013. *Biogas-Powered Evaporative Cooling for the Dairy Industry.* [Online]
Available at: https://poweringag.org/innovators/biogas-powered-evaporative-cooling-dairy-industry
[Accessed 19 01 2017].

Powering Agriculture, 2015. *Biogas Milk Chilling to Increase Productivity and Incomes of Dairy Farmers.* [Online]
Available at: https://poweringag.org/innovators/biogas-milk-chilling-increase-productivity-incomes-dairy-farmers
[Accessed 19 01 2017].

PoweringAgriculture, 2013. *Biogas-Powered Evaporative Cooling for the Dairy Industry.* [Online]
Available at: https://poweringag.org/innovators/biogas-powered-evaporative-cooling-dairy-

industry
[Accessed 19 01 2017].

Practical Action Consulting, 2009. *Small-Scale Bioenergy Initiatives: Brief description and preliminary lessons on livelihood impacts from case studies in Asia, Latin America and Africa,* https://assets.publishing.service.gov.uk/media/57a08b8340f0b64974000bd2/FAO-PISCES-Casestudies.pdf: FAO & PISCES.

Practical Action Consulting, 2009. *Small-Scale Bioenergy Initiatives: Brief description and preliminary lessons on livelihood impacts from case studies in Asia, Latin America and Africa.,* s.l.: Prepared for PISCES and FAO by Practical Action Consulting.

Qnergy, n.d. *Production capabilities.* [Online]
Available at: http://www.qnergy.com/production-capabilities
[Accessed 11 01 2017].

Quintas, 2017. *Turbine technology.* [Online]
Available at: http://www.quintasenergies.com.ng/turbine-technology/
[Accessed 23 01 2017].

Rowshandzadeh, R., 2011. *Performance and cost evaluation of Organic Rankine Cycle at different technologies,* Stockholm: KTH.

Sapp, M., 2016. *Algae biofuel technology transferred to Zimbabwe.* [Online]
Available at: http://www.biofuelsdigest.com/bdigest/2016/06/30/algae-biofuel-technology-transferred-to-zimbabwe/
[Accessed 24 January 2017].

Selectra, 2014. *Selectra.* [Online]
Available at: http://www.selectra.co.za/index.html
[Accessed 24 January 2017].

Siemens, n.d.. *Siemens Product Overview.* [Online]
Available at: http://www.siemens.com/press/en/feature/2014/energy/2014-04-orc.php
[Accessed 25 January 2017].

Sistema Biobolsa, n.d.. *Sistema Biobolsa.* [Online]
Available at: http://sistemabiobolsa.com/?lang=en
[Accessed 15 January 2017].

Snow Leopard, n.d. *Biogas plants with batch hydrolysis.* [Online]
Available at: http://en.snow-leopard-projects.com/index.php/ad-plants
[Accessed 24 01 2017].

Souza, G. M., Victoria, R. L., Joly, C. A. & Verdade, L. M., 2015. *Bioenergy & Sustainability: bridging the gaps,* http://bioenfapesp.org/scopebioenergy/images/chapters/bioenergy_sustainability_scope.pdf: SCOPE.

Spilling, n.d.. *Steam Engines.* [Online]
Available at: http://www.spilling.info/products/steam-engines.html
[Accessed 23 January 2017].

Srinivas, S. & Prabhu, G., 2013. *Bioenergy for Rural India,* http://www.moef.nic.in/sites/default/files/bioenergy-for-rural-india---demonstration-of-decentralized-sub-m.pdf: UNDP.

Stecher, K., Brosowski, A. & Thrän, D., 2013. *Biomass potential in Africa,* https://www.irena.org/DocumentDownloads/Publications/IRENA-DBFZ_Biomass%20Potential%20in%20Africa.pdf: IRENA.

Sulle, E. & Nelson, F., 2013. *Biofuels Investment and Community Land Tenure in Tanzania: The Case of Bioshape, Kilwa District,* https://assets.publishing.service.gov.uk/media/57a08a2940f0b64974000464/FAC_Working_Paper_073.pdf: Future Agricultures.

Tartiere, T., 2015. *ORC World Map.* [Online]
Available at: http://orc-world-map.org/analysis.html
[Accessed 11 01 2017].

Taurus Distillation, 2016. *Bioethanol - fuel for the future.* [Online]
Available at: http://www.taurusdistillation.co.za/
[Accessed 24 01 2017].

TERI, 2017. *Biomass Gasifier for Thermal and Power applications.* [Online]
Available at: http://www.teriin.org/technology/biomass-gasifier
[Accessed 19 01 2017].

Thomas, J., 2017. *Renewable and rural energy unit. UNIDO.* [Interview] (17 01 2017).

Transparency International, 2015. *Corruption Perceptions Index.* [Online]
Available at: www.transparency.org/cpi2015
[Accessed 05 12 2016].

Tropical Power, n.d.. *Tropical Power.* [Online]
Available at: http://www.tropicalpower.com/projects/gorge-farm-energy-park/
[Accessed 24 January 2017].

Turboden, n.d.. *Turboden Case Studies.* [Online]
Available at:
http://www.turboden.eu/en/references/references.php?country=all&application=0&power=all
[Accessed 25 January 2017].

UN DESA, 2015. *2015 Revision of World Population Prospects,* New York: United Nations Department of Economic and Social Affairs.

UNDP, 2009. *Bio-carbon Opportunities in Eastern & Southern Africa,* s.l.: http://bit.ly/2gdIB77.

UNIDO, 2014. *Renewable Energy for Inclusive and Sustainable Industrial Development,* Vienna: United Nations Industrial Development Organisation (UNIDO).

UNIDO & REN21, 2016. *East African Community Renewable Energy And Energy Efficiency: Regional Status Report,* s.l.: http://www.ren21.net/wp-content/uploads/2016/10/REN21-EAC-web-EN.pdf.pdf.

van Loo et al., 2008. *Handbook of biomass combustion and co-firing.* s.l.:s.n.

Village Industrial Power, n.d. *Village Industrial Power.* [Online]
Available at: http://villageindustrialpower.com/
[Accessed 24 01 2017].

von Maltitz, G. P. et al., 2016. Jatropha cultivation in Malawi and Mozambique: impact on ecosystem services, local human well-being, and poverty alleviation. *Ecology and Society,* 21(3), p. 3.

Williams, A., 2017. [Interview] (12 January 2017).

Winrock International India, 2011. *Acess to Clean Energy - a glimpse of off grid projects in India,* New Dehli: Government of India, Ministry of New & Renewable Energy.

Winston, J., 2013. *Algae biofuels deemed unsuitable for developing nations.* [Online]
Available at: http://www.scidev.net/global/biofuels/news/algae-biofuels-unsuitable-developing-nations.html
[Accessed 24 January 2017].

World Bank Doing Business, 2016. *Doing Businesss rankings.* [Online]
Available at: http://www.doingbusiness.org/rankings
[Accessed 05 12 2016].

World Bank, 2012. *Implementation completion and results report: The First Phase of the Renewable Energy Scale-Up Programme and the Follow-up Project to the First Phase of the China Renewable Energy Sale-up Program,* s.l.: https://www.thegef.org/sites/default/files/project_documents/943_WB_TE_-P067625-ICR_China_0.pdf.

World Bank, 2015. *World Governance Indicators.* [Online]
Available at: info.worldbank.org/governance/wgi/index.aspx#reports
[Accessed 05 12 2016].

World Bank, 2016. *World Development Indicators.* [Online]
Available at: databank.worldbank.org/data
[Accessed 05 12 2016].

Wray, A., 2016. *Senior Responsible Officer, DFID TEA Programme* [Interview] (13 11 2016).

Zhang, L., Liu, R., Yin, R. & Mei, Y., 2013. Upgrading of bio-oil from biomass fast pyrolysis in China: A review. *RenewableandSustainableEnergyReviews,* Volume 24, pp. 66-72.