SUPERGEN Bioenergy Hub

A Bioenergy Research Prospectus for Southern Africa

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SUPERGEN Bioenergy Hub

The SUPERGEN Bioenergy Hub aims to bring together industry, academia and other stakeholders to focus on the research and knowledge challenges associated with increasing the contribution of UK bioenergy to meet strategic environmental targets in a coherent, sustainable and cost-effective manner.

The hub's partners include:

This report represents the views of the named authors and should not necessarily be taken as representing the views of the hub partners identified above.

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Executive Summary

Biomass is widely used across the Southern African Development Community, including in South Africa. A large proportion of the existing resource is used in relatively inefficient, small scale devices, including combustion of fuel wood for heating and cooking, although larger scale applications can be found in some regions.

The land base and agricultural patterns in southern Africa could yield large quantities of biomass for more strategic use, but the size of the biomass resource that may be available in the future has not been robustly tested or demonstrated. It is important that the potential resource is quantified with due regard to environmental, social and economic sustainability constraints. Many relevant feedstocks have also not been well characterized to date. The physical characteristics, diversity and dispersed nature of the resource mean that significant levels of feedstock processing will be required, integrated with appropriate supply chain logistics.

A variety of different conversion routes could be adopted, matching the different feedstocks to specific energy demands. In some cases there is already significant research capability that could be exploited, but, in general, there is a need to better understand the most appropriate conversion technologies for less thoroughly examined feedstocks and to characterize the behaviour of African-specific feedstocks in relevant conversion processes.

A key role of bioenergy development in southern Africa is to improve energy access to support livelihood and social development. It is therefore essential to appreciate the location, magnitude and nature of different energy demand vectors to understand whether the main requirements are for large or small scale electricity, liquid fuels, syngas, fertilizer, chemicals or heat. Knowledge about the demand sectors exists at national level, but has not previously been considered alongside bioenergy supply/resources in specific regions.

It is vital that development of new bioenergy capacity contributes to local and global environmental sustainability and that potential negative impacts of bioenergy systems are identified, managed and mitigated.

Calculating greenhouse gas balances is a key component of evaluating and understanding the environmental risks involved in bioenergy systems. Bioenergy has potential to reduce the carbon intensity of South Africa's fossil-fuel dominated energy supply if biomass sourcing and conversion is carried out in a way that reduces, not increases net global greenhouse gas emissions. Establishing this is non-trivial, as it requires careful consideration of the full scope of the bioenergy system, interfaces with other systems (particularly food) and detailed consideration of the land-use implications for soil and other carbon stocks.

It is equally important to evaluate other environmental impacts of bioenergy implementation. Emissions to air are often particularly important when dispersed biomass resources and energy demands lead to small scale conversion facilities. However, control of emissions from small scale conversion processes is challenging, as it requires adaptive control in response to feedstock variations, but small scale monitoring instrumentation is often uneconomic and unrepresentative because of edge effects, non-uniform flow and device dynamics.

Emissions to land need to be considered to ensure that there is adequate recycling of nutrients and organic carbon to maintain soil fertility. Integration of bioenergy strategies with waste management strategies can yield mutual benefits, but care is needed e.g. when land-spreading ash or digestate to avoid accumulation of heavy metals or bacteria. Emissions to water also need to be better understood, and in particular, water use compared to local availability. Finally, land use and land use change impacts need to be considered not only from an environmental perspective in order to avoid indirect greenhouse gas emissions and land degradation, but also from a socio-economic perspective.

There is potential for increased levels of bioenergy deployment in southern Africa to deliver socio-economic benefits including improving rural energy access, reducing costs of energy provision and providing economic and socially sustainable development by boosting rural agriculture and facilitating participation of rural communities in the agricultural value chain. Bioenergy can deliver energy access to rural communities to reduce energy poverty associated with poor social mobility. Schools benefit substantially from energy for light, cooking and computing facilities. Energy access can also allow small businesses to develop as goods can be transported to market and there may be particular synergies here with biomass transportation infrastructure being used for transport of other goods/services.

These objectives will only be attained if the knowledge gaps, technical and non-technical barriers listed above are addressed by researchers and collaborators. A summary of key contacts who are taking forward research in the relevant areas is given in Appendix A, who are available for contact by interested parties.

1. Background

This report is based around a workshop funded by the British Council and held in South Africa in September 2014. The workshop was organized by Dr Patricia Thornley of The University of Manchester and Prof. Emile van Zyl of the University of Stellenbosch. Expert mentors included Prof. Jim Lynch (emeritus Surrey), Prof. Johann Gorgens (Stellenbosch), Prof. Tim Benton (Leeds) and Mr Nico Stolz (TSB). A full list of participants is given in Appendix A.

Figure 1: Workshop participants.

The participants were split into groups and challenged to develop sustainable visions of integrated food-fuel futures in the Southern African Development Community (SADC) (Angola, Botswana, Democratic republic of Congo, Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, Seychelles, South Africa, Swaziland, United Republic of Tanzania, Zambia and Zimbabwe).

The SADC is committed to ensuring the well-being of the region by ensuring that low income residents have access to energy and increasing regional energy self-sufficiency. It has a co-operation strategy on energy which notes that wood fuel is and will continue to be the dominant fuel in the region and so sustainable, rational and environmentally benign use needs to be developed with local communities [1]. There is also explicit support in the SADC for new and renewable sources of energy including biogas [1].

The experience of and discussion between participants is mostly based on knowledge pertaining to South Africa. However, there appear to be many common issues with bioenergy development in the wider SADC region and so the report is likely to also be of relevance in that context.

2. Introduction

Africa is the second largest and most populous continent in the world. It covers 20% of the available land area worldwide in 53 countries. More than half of Africa's 900+ million people do not have access to electricity, yet Africa has abundant resources, including sun, wind and biomass. Biomass is the main source of energy for most of southern Africa, mainly used for cooking and heating. Projections of future resources (such as by Smeets et al. [2], reproduced in figure 2) show that Africa has very significant future bioenergy potential, especially under high technology future food production systems (e.g. enclosed cattle housing and intensive feed production). The vast majority of feedstocks, however, are expected to take the form of dedicated woody crops.

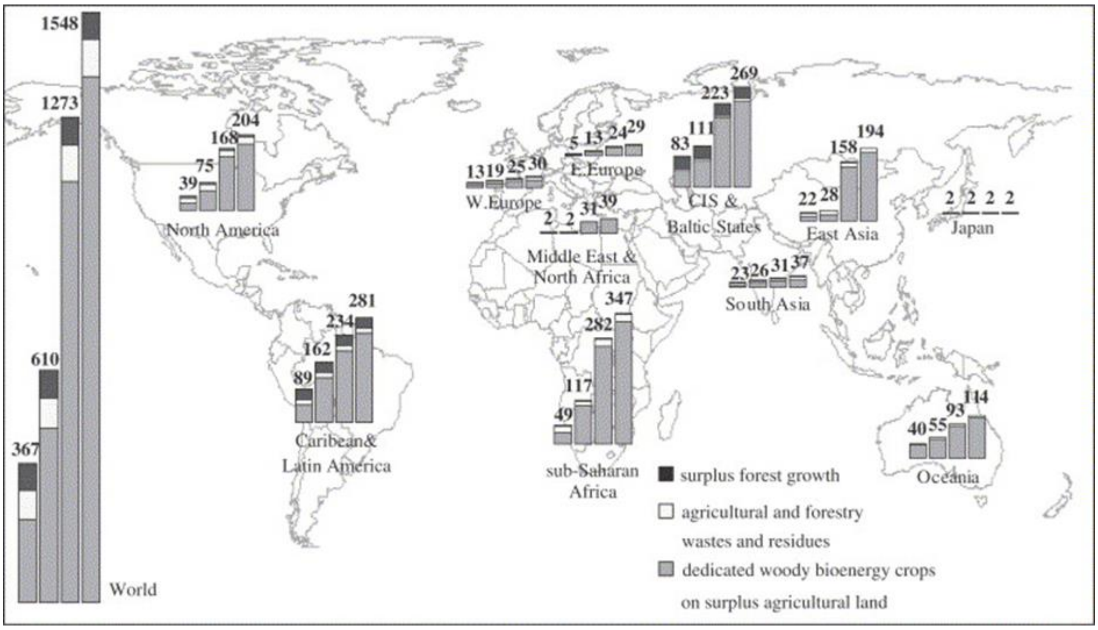

Figure 2: Projected global biomass supply [2].

Energy is recognised as playing a critical role in efforts to address poverty. The UN Secretary-General, Ban Ki-Moon, argued that energy is ‘the golden thread that connects economic growth, increased social equity, and an environment that allows the world to thrive’ [3]. The designation of 2014 – 2024 as the “International Decade of Sustainable Energy for All” further highlights the increased global emphasis on the provision of sustainable energy, particularly for the poorest.

South Africa has a population of 53 million, of whom 62% live in urban areas. Although efforts to tackle deprivation have led to reductions in the number of people living in poverty, it remains a critical issue: in 2011, 46% of the population of South Africa lived in poverty and, of these, 20% lived in extreme poverty [4]. Traditional biomass remains a key source of energy in South Africa, particularly for cooking and boiling water, although this varies according to province, with only 0.6% of the population relying on biomass in the Western Cape, but 41% in Limpopo [5].

Access to electricity has increased from 77% of the population in 2002 to 85% by 2012 [5]. However, for many households, access to electricity remains limited and restricted to lighting services. To transform lives, access should go beyond meeting basic needs to stimulate small businesses and provide energy for communities.

Figure 3: Significance of Africa in the context of global land area.

The situation in sub-Saharan Africa is even austere: over 40% of people in Sub-Saharan Africa live in absolute poverty and 620 million (two thirds of the population) live without electricity. Nearly 730 million people rely on dangerous, inefficient forms of cooking and the use of solid biomass outweighs that of all other fuels combined.

Bioenergy has potential to help unlock cycles of poverty by developing energy security, food security, job creation, income diversification and rural development. Care is needed because bioenergy could have both positive and negative impacts on local food security. For example, increased bioenergy production may lead to a reduction in land used to produce staple crops, meaning less food is grown locally and impacting food prices. But conversely, bioenergy systems could improve food security through improvements in agricultural productivity and the development of value added products. A key issue for future food/ fuel systems is therefore the need to take into account the social, economic and livelihood impacts. Integrated food-fuel futures can combine sustainable bioenergy with food production to promote social and economic development, but how local people are incorporated into future food/ fuel systems will be critical for determining whether modern bioenergy systems can deliver benefits to South Africa's poorest.

The world has resources, especially of land and fresh water. As the population grows, the amount of agricultural land per capita in the world shrinks proportionately; at the moment, each person's "current share" of land equates to about a football pitch in size, and this to produce food, fibre and fuel. The 7000 m^2 per person at the moment is likely to shrink to closer to 5000 m^2 by 2050, so even if our individual demand doesn't change, a piece of land will have to produce about a third more to maintain the status quo. But demand is changing, and land intensification may have to increase even more: such that if demand continues unabated for food, over the next 35 years the world will need to produce more food than it has done to date, throughout human history.

Whilst each of us clearly doesn't have a piece of land as our share, thinking about our personal share does highlight the implicit choices. If agricultural land can only expand via appropriating land that serves other purposes, such as habitat for wildlife in forests, which on a global basis is undesirable; then "our" share of land is essentially fixed and could be used for food, fuel or fibre or some combination of the three. Typically, at the moment, crops are grown for food or fuel or fibre, so more fuel means less fibre or food. This clearly need not be the case: crops could provide food and fuel (sugarcane does, after all), but crops could provide fruit (food) and their stems be digested into fuel. Whether this really becomes viable depends in part on biology (stems suitable for biofuel may reduce the investment in, and quality of, the food) and energy (it may not be viable energetically to digest at scale).

Whilst much can be done to make landuse more sustainable, in terms of matching production to the environment in a way to minimise environmental impacts, and research can also create biofuels from agricultural by-products, ultimately there does exist the potential for food vs fuel trade-offs. These can be mitigated by reducing waste (about a third of agricultural production for food is wasted) and also by changing diets (calories sufficient to feed the current population of Asia are currently fed to livestock). So reducing meat consumption and waste *could* free up sufficient land to allow production of food and fuel.

The key to sustainable development of bioenergy in southern Africa is ensuring the sustainability of cumulative biomass resource supply and translating that to provide identified local energy demands in practical small scale systems that deliver socio-economic benefits to local communities. So, consideration of environmental, social and economic impacts at multiple scales is important as well as adequate consideration of co-evolutionary interfaces with the food, land-use and energy systems.

3. Feedstocks and availability

When assessing the availability of biomass feedstocks in a region, it is important to take account of constraints which will reduce the theoretical and technical potentials to a practical potential [6]. Within that practical potential there will be a range of material that is sustainable and can be obtained at a price that is affordable. This results in the actual feedstock availability usually being much smaller than initial theoretical estimates might suggest, as illustrated in figure 4.

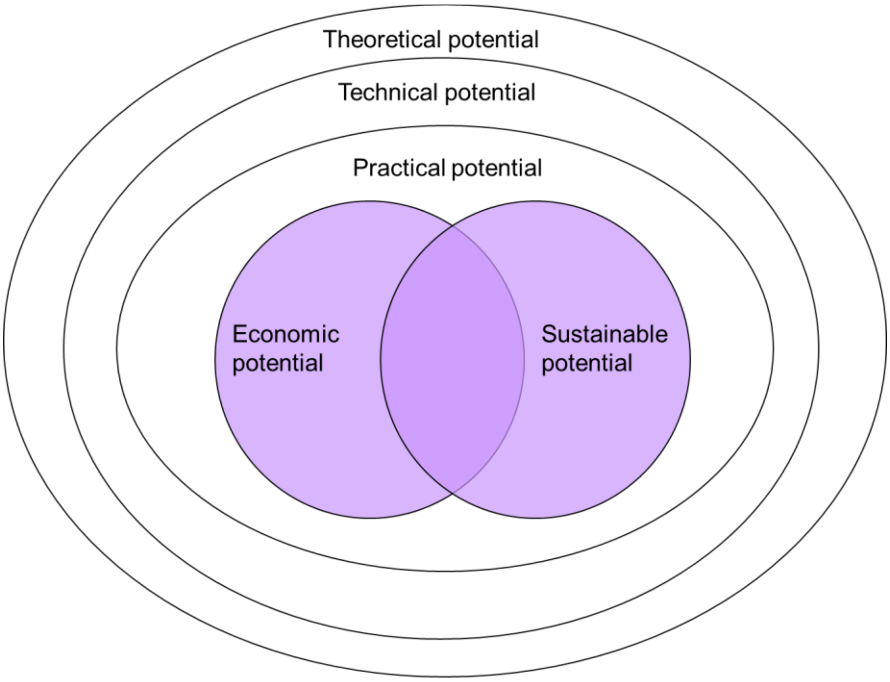

Figure 4: Constraints on biomass resource potential [6].

The 2014 British Council workshop focused particularly on food-fuel interfaces and it is particularly important that these interactions are considered carefully when assessing the sustainability of biomass resources.

The Global Bioenergy Partnership has worked to gather and assess evidence on the sustainability of integrated food energy systems [7] and have worked with the United Nation's Food and Agricultural Organization to develop a BEFS (Bioenergy and Food Security) Approach which consists of a multi-disciplinary and integrated set of tools and guidance that can support countries through the main steps of bioenergy policy development and implementation process [8]. Part of the first stage of the approach is to undertake a review of agriculture, energy and food security situation at country level and the UNFAO have published BEFS country briefs for every SADC country [9] which provide high level data that can be used to carry out the first step of a sustainable bioenergy assessment.

Figure 5: Bagasse from sugar plantations, TSB Maleane site, South Africa.

The UNFAO held a conference of SADC nations in 2014 and most countries are now embarking on action plans to facilitate BEFS development but there are many knowledge gaps in the existing published literature relating to the sustainable availability of biomass resources that may impede or misdirect this work. It is essential that the bioenergy strategies being developed are based on reliable and robust evidence of biomass resource availability.

Recommendation 1

The research community should improve knowledge of biomass resources by:

• Carrying out independent resource assessments, where appropriate, to evaluate the occurrence of sustainable biomass resources in the SADC regions.

• Reviewing and monitoring resource assessments or other bioenergy strategies produced by SADC countries and comparing these with international best practice.

• Building in-country capacity in this area among the bioenergy research community so that the profile of sustainable biomass resources is increased and bioenergy researchers are aware of the relevant issues. This could be supported by developing a database incorporating information on the characterisation (yields and compositional analysis) of the available biomass and waste (latrine, municipal solid waste etc.) and the relative collection and transport systems.

4. Supply Chain, Processing and Logistics – Building a Value Chain

The primary source of energy for many Sub-Saharan Africans in rural locations is traditional wood fuel. Many people burn solid fuels in the home, with little ventilation and inadequate flue systems. This has negative implications for health and efficient fuel use. The acquisition of traditional wood fuel also increases deforestation and has a negative impact on the lives of women and children who traditionally gather and carry large amounts of wood fuel.

By contrast, in countries where bioenergy is well established significant infrastructure has developed around the main biomass feedstocks e.g. wood fuel in Sweden and straw in Denmark. However, the feedstocks that constitute the main resources in SADC have very different physio-chemical properties and different interactions with other relevant systems (e.g. food, waste etc). Consequently, it is necessary to investigate the most efficient, cost-effective and appropriate mechanisms for processing, handling and transporting these feedstocks, within the context of the pre-existing infrastructure in the relevant countries.

Figure 6: Example of an African agricultural supply chain.

Research work is needed to understand the current limitations and capacities of existing transportation systems as well as understanding the logistical needs of different biomass types and biomass applications. Consideration of scale and its impact on biomass logistics from dispersed systems to centralised production would also be useful. This analysis would identify areas where novel production, handling, processing and storage methods are needed to deal with specific feedstocks and locational issues.

Such an analysis would also include consideration of: transportation infrastructure, management and technology; types of transport requirements (bulk, field to factory, dispersed, centralised); road, rail and system connectivity; management and control systems; biomass production and storage;

annual and continuous cropping; annual variability of biomass and handling issues. These issues could be assessed by modelling of the logistical supply chain to evaluate costs, life-cycle and energy balances and identifying infrastructure needs at different scales. This would involve flow and supply chain modelling, combined with understanding of biomass production, handling and use requirements as well as local cultural and operational knowledge.

It is very important that adequate account is taken of the distinctive nature of relevant African feedstocks, including the relationship between biomass composition (elemental and structural) and biomass conversion route options.

Inclusive bioenergy requires consideration at different scales in different regions and these chains are likely to be very different from those developed in other global regions, possibly requiring new technologies to maximize efficiency and minimize cost and environmental impacts of these feedstocks/chains. Small to medium scale bioenergy schemes that target rural communities in Sub Saharan Africa have particular potential to deliver much-needed socio-economic benefits. It is extremely important that supply chains are developed in a way that is attractive to participants, delivers added value for stakeholders and communities and that the resultant energy is delivered in a form that is suitable for community needs.

Recommendation 2

The research community should carry out strategic analysis of the potential to build biomass value chains in the SADC region to support policy and industrial development by:

• Characterizing the physical and chemical properties, availability and location of the most relevant feedstocks.

• Assessing biomass production and storage e.g. annual v. continuous cropping, annual variability of biomass, handling issues.

• Cataloguing the existing relevant transport infrastructure.

• Carrying out systems level analysis to match resources to end-user demands.

5. Conversion

5.1 Conversion Technologies

Significant knowledge and experience exists of the conversion technology performance of the most common biomass resources in north and south America and Europe. However, there is much less published information on the conversion performance of the feedstocks most relevant to the SADC region. This impedes assessments of bioenergy potential, commercial development and engineering design. It is critical that the performance of the most relevant feedstock- technology combinations is characterized to determine the most appropriate bioenergy solutions in different contexts. In some cases it may be possible to extrapolate from existing knowledge with other similar feedstocks, but validation of this performance in test or pilot facilities will be required to reduce investment risk and accelerate deployment.

5.2 Conversion Options

Performance data on individual feedstock-conversion system combinations can then be used in a systems level model to identify technologically viable biorefinery routes that contribute to social welfare, economic development and environmentally sustainable utilization of local biomass/resources. An example of the sort of framework that might be developed is shown in figure 8. This outlines a multi-objective optimization model for the optimal strategic design of biorefinery processing routes from food and non-food biomass resources (including biowaste) in South Africa. The model could be configured to account for environmental and techno-economic perspectives of bioenergy/biofuel/bioproducts from a range of feedstocks and for potential high-value biopolymers/biochemicals extraction via emerging technologies.

An appropriate model would evaluate economic performance as well as parameterizing a range of environmental indicators, including global warming potential (GWP). The model could be validated by application to case studies. For example, sugarcane and fruit biorefineries are two particularly relevant case studies for integrating food-fuel systems in South Africa. This would identify opportunities that are technically viable while avoiding socio-economically constraining or environmentally-damaging options.

Figure 7: TSB Mill, Maleane – A food production facility that could be adapted to include bioenergy.

5.3 Conversion resilience and flexibility

While this modelling may identify optimal pathways for optimal feedstocks the reality of bioenergy implementation is that the feedstock is inherently variable in terms of availability and quality. This means that overall project viability is vulnerable to adverse weather and changing prices for global commodities such as sugar and oil. In many areas of Africa the dependence of feedstock production on small-scale rain-fed agriculture also makes it extremely sensitive to climate change and longer term variability. Many resource assessments suggest that biomass should be limited to marginal land, but this restriction tends to increase costs as yields will be lower, and transport distances will most likely be higher. Strategies to overcome these challenges include increasing feedstock flexibility, down scaling production facilities, increasing integration with existing infrastructure, product diversification and the ability to switch production between products. Yet these options present their own challenges. Developing a process that can accept a wide variety of feedstocks may come at the cost of reduced impaired process performance as well as requiring additional capital. Downscaling can mean that economies of scale are lost. Increasing integration can reduce the flexibility of the combined system, potentially impeding process innovation and causing sub-optimal choices to become locked in, while switching between products may be associated with additional downtime. From a business perspective it may also be undesirable to try and grow multiple product markets in parallel.

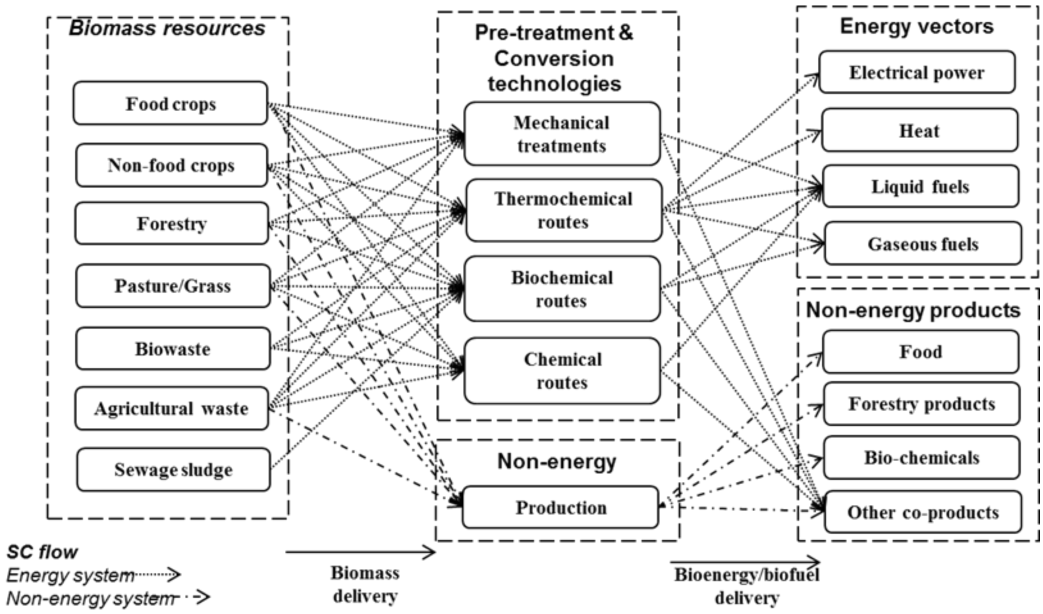

Figure 8: Framework for multi-objective optimisation model for the optimal strategy design of biorefinery processing routes.

It is therefore important that researchers consider the technical, environmental, economic and social performance of bioenergy systems across the full range of potential conditions and that bioenergy options are identified that are technologically robust and resilient to rapidly changing conditions.

Recommendation 3

The research community should practically validate the performance of the most important feedstocks in the SADC region with key conversion technologies.

Recommendation 4

The research community should provide a technical evidence base to support bioenergy development strategies by:

- Evaluating the environmental, economic and social performance of different bioenergy conversion systems, including the implications of utilising digestate, biochar and water.
- Quantifying the impact of feedstock and other variations on system performance.
- Evaluating the associated infrastructure needs of dispersed and centralized bioenergy options to generate comprehensive data of the impact of entire bioenergy systems.
- Identifying preferred solutions that achieve environmental, economic and social sustainability benchmarks but are resilient to anticipated variations.

6. Energy Demand

One key advantage of bioenergy systems over other renewable energy forms is that they can service a wide variety of energy demands with a range of intermediate energy vectors. It is therefore critically important to understand the nature of the existing and projected future energy demands when designing implementation schemes.

A growing population and continued economic growth mean that demand for energy is set to increase across Africa; it is therefore vital that any vision for bioenergy takes changing energy demands into account. At the household and community level, energy provision will need to go beyond meeting basic needs to consider how interventions may be tailored to local contexts and to meet household needs, productive uses and community services. At the local level, this will require an understanding of the communities and their energy needs. This may involve the use of models to assess future energy demand at different scales, and/ or household surveys to explore peoples' aspirations and the role of energy within these. A key question is therefore to what extent bioenergy can meet future demand given the local context. While the energy demand may exist, the form in which the bioenergy is presented may not be appropriate.

Figure 9: Example of African transport fuel demand.

When evaluating energy demand it is extremely important to account for economic development potential. Energy access should not just be limited to the provision of energy at the household level, but should also incorporate productive uses (e.g. smallholder agriculture, small-scale manufacturing, service sector activities and transport) and community services (e.g. health centres, schools, street lighting etc).

Recommendation 5

The research community should provide evidence of existing and future energy demands relevant to bioenergy systems by:

• Engaging with stakeholders and assimilating data to establish existing energy demand patterns.

• Evaluating projected energy demand types and levels via numerical modelling and engagement with key stakeholders, including consideration of how bioenergy could enhance or promote micro-enterprises.

7. Environmental Sustainability

Bioenergy systems are designed primarily to produce renewable energy which is low carbon and minimises environmental impacts. When implemented appropriately, bioenergy can enhance food production by using wastes and residues, recycling nutrients and generating energy. Potential issues may arise where land for biomass competes with food, biodiversity is compromised, feedstocks are intensively produced, greenhouse gas (GHG) savings are negligible, or other environmental impacts arise. It is therefore critical that bioenergy systems are assessed to understand the energy and GHG balances, in addition to other impacts such as resource depletion, damages to ecosystem services or effects on human health.

7.1 Greenhouse Gas Balances

Life cycle assessment (LCA) is widely acknowledged as the most suitable methodology for quantifying potential environmental effects of agricultural and bioenergy systems [10]. LCA is an established technique for evaluating the natural resource requirements and environmental impacts from the whole life cycle [10]. In practice LCA often focuses on land use, primary energy and GHG emissions, however it is also important to consider water use, local air quality, acidification, and eutrophication.

Figure 10: Example of agronomic steps underpinning LCA calculations.

Research is required to produce LCA results of current agricultural and forestry production in Southern Africa. A large number of LCA studies have been completed for European systems, but there is less published in the African context. The resource requirements of both current and future food-bioenergy systems need to be characterised and inventory databases produced so positive impacts such as energy production and nutrient recycling are maximised, whilst reducing GHG emissions, resource depletion, and other emissions. It is proposed that LCAs are conducted of common production systems in Africa to allow a comprehensive assessment of future crops and bioenergy technologies that may be implemented.

Recommendation 6

The research community should provide independent evidence of the quantitative impact of SADC bioenergy on global GHG emissions by:

- Carrying out life cycle assessment of potentially key bioenergy systems in southern Africa (to be scoped and defined taking into account interfaces with food and land systems).
- Evaluating the cumulative (macro-level) consequences of bioenergy implementation in the SADC region. (It may be appropriate to use a consequential LCA approach to evaluate the strategic impacts of bioenergy implementation for policymakers).

7.2 Emissions to air

An acknowledged disadvantage of bioenergy systems in western Europe is that they may increase airborne emission of key pollutants compared to natural gas or other alternative energy sources. This could lead to unacceptably high levels of environmental pollution, with associated risks to human health and eco-toxicity. This depends critically on what fuel source is being displaced by the bioenergy system and so in an African context, this may not be the case, particularly where previously inefficient cookstoves are being replaced by cleaner versions.

Figure 11: Emissions from uncontrolled biomass combustion.

It is important that comparisons are consistent and therefore that measurements are made of existing stoves in the most typical usage patterns (not idealized conditions used for certification and standards). These then need to be compared to the emissions achievable with modern cookstoves to identify the true benefit of replacement. This should be translated into life cycle impact to identify the actual impacts on key receptors including human eco-toxicity evaluations. It is also important to consider forward projections regarding scale-up e.g. it is pointless to establish "advanced" bioenergy technologies if demand trajectories indicate that these will lead to unacceptable levels of air quality within the medium term. It is important therefore to establish the potential future impacts of bioenergy implementation scenarios on air quality. In an African deployment context cookstoves are particularly relevant (as reflected in recommendation 7), but the airborne emission impact of development of other small scale conversion systems will also need to be taken into account.

Recommendation 7

The research community should establish baseline figures for existing cookstove emissions and compare these to available advanced stoves under typical operational conditions. These should be used to evaluate direct local impacts and potential future impacts on air quality as biomass use changes.

7.3 Emissions to land

The application of ash, biochar or digestate to land may be an important feature of bioenergy system design. A new installation may also cause changes in current practices for the incorporation of crops or residues into land. Either of these may modify the levels of soil nutrients, contaminants and organic carbon, with consequent impacts on soil fertility and agricultural productivity. It is therefore extremely important that the impact of new bioenergy systems on land and soil is taken into account.

Recommendation 8

The research community should carry out basic research to provide underpinning data to facilitate assessments of the potential impact of individual bioenergy systems on land by:

- Analyzing the ash composition of key feedstocks.
- Analyzing the composition of digestate from key feedstocks.
- Analyzing the composition of and evaluating the impacts on soils of biochar.

7.4 Water interfaces

All bioenergy systems use water during crop growth. The hydrological requirement of different crops is one of the factors that determines their suitability in different agro-ecological zones and specific locations. In addition some bioenergy systems involve emissions to water at different production stages e.g. water washing as a pre-treatment before conversion or discharge of liquor from anaerobic digestion. It is important that these are taken into account in life cycle assessments of individual systems. The environmental consequences of water consumption are inherently site specific and depend to a large extent on competing uses and the local level of water scarcity or abundance.

Figure 12: Irrigation channel (L) and Automated sprinkler (R).

<u>Recommendation 9</u>

The research community should provide underpinning data on water interfaces to facilitate project assessment by:

• Quantifying the water requirements of key bioenergy crops in the SADC region alongside corresponding yield and other agronomic data.

• Characterizing the effluent from relevant bioenergy system processes.

• Identifying how water footprinting methodologies can be adapted to guide bioenergy value chain design and implementation.

8. Economic sustainability

In the long term it is desirable that bioenergy systems become self-sustaining in the SADC region. This requires projects to be commercially viable and risk-resilient. The prospects of this are maximized if bioenergy development builds on previous experience, operates with robust business models and builds capacity and resilience.

8.1 Building on previous experience

To maximize chances of success it is important to have an idea of what bioenergy and other energy projects have been implemented within South Africa and southern Africa more generally. This should include both successful and unsuccessful projects so that we may learn from previous experiences, avoiding mistakes and learning from best practice. In particular numerous projects were undertaken across Africa to generate biodiesel from jatropha; the vast majority of which have failed. Examination of the causes of failure and how local communities were affected could help future projects succeed.

8.2 Robust business models

Research has shown that when local communities have invested in renewable energy projects, they can become not only consumers but active participants in those projects. Contributions do not have to be financial – communities may donate time, land and/or other resources. It is important to investigate models for community ownership of bioenergy systems, including how these vary across different feedstocks, regions and scales in order to fit with local contexts in southern Africa. For example, if a programme seeks to incorporate many thousands of smallholders into sugarcane cultivation, what contractual arrangements would enable smallholders to benefit and how might such initiatives be financed?

8.3 Building capacity and resilience

South Africa is a relatively high-tech country; however, there may be a skills gap in the implementation and management of bioenergy plants, particularly at the community level. Key research questions are: what specific skills gaps are they and how might capacity development be incorporated into the design of bioenergy projects? Is there a role for 'energy villages' to showcase (distributed) renewable energy in South Africa? Could bioenergy models that pair large and small-scale producers be a solution, and how could such a model be designed so as to provide mutual benefits?

Many African countries are vulnerable to economic and environmental shocks that can have catastrophic effects on rural communities. These communities are vulnerable for reasons including: water scarcity, limited infrastructure, weak governments and institutions, high reliance on agriculture and low levels of financial reserves. It is expected that climate change will exacerbate these insecurities. Counter-measures to increase resilience can take many forms including:

- Institutional – land use zoning
- Economic – insurance, microcredit, income diversification
- Environmental – mangrove shelterbelts, buffer zones

- Education – skills development

Bioenergy in Africa has the potential to increase resilience and contribute to social development goals, alternatively it might exacerbate existing demand for land and water. It is important that case studies of bioenergy development in SADC are explored to better understand coping mechanisms and how bioenergy could play a role within these.

Africa not only has huge potential in terms of untapped biomass resources, but also biodiversity (insects and microorganisms) that could provide unique technologies to extract value from biomass suited to African needs.

Bioenergy technologies should be developed for Africa, taking into account African conditions and indigenous knowledge systems. Local communities should be included in the development process to aid in adoption of the technology and knowledge transfer.

Recommendation 10

The research community should work with other stakeholders to provide an independent evidence base to guide economic development efforts by:

- Gathering information on previous bioenergy project successes and failures, examining underlying causes and common factors.
- Examining potentially viable business models in different SADC regions.
- Identifying skills and other gaps that could impede economic resilience and development.

9. Social Sustainability

As outlined in the introduction, energy is recognised as playing a critical role in efforts to address poverty [3]. The designation of 2014 – 2024 as the International Decade of Sustainable Energy for All further highlights the increased global emphasis on the provision of sustainable energy, particularly for the poorest [ibid].

South Africa has a population of 53 million, of whom 64% live in urban areas [11]. Although efforts to tackle deprivation have led to reductions in the number of people living in poverty, it remains a critical issue: in 2011, 46% of the population of South Africa lived in poverty and, of these, 20% lived in extreme poverty [4]. In terms of electricity access, electrification has increased from 77% of the population in 2002 to 85% by 2012 [5]. However, for many households, access to electricity remains limited and restricted to lighting services. To transform lives, access should go beyond meeting basic needs to stimulate small businesses and provide energy for communities. With regard to other energy sources, traditional biomass remains a key source of energy in South Africa, particularly for cooking and boiling water, although this varies according to province. For example, in the Western Cape 0.6% of the population rely on biomass, which increases to 41% in Limpopo [5]. These statistics highlight the diversity of energy needs across South Africa.

Figure 13: Agricultural labour.

Bioenergy has the potential to have both positive and negative impacts on local food security. For example, increased bioenergy production may lead to a reduction in land used to produce staple crops, meaning less food is grown locally and impacting food prices. Conversely, bioenergy systems could improve food security through improvements in agricultural productivity and the development of value added products. A key issue for future food/ fuel systems is therefore the need to take into account the social, economic and livelihood impacts. Whether and how local people are incorporated into future food/ fuel systems will be critical for determining whether modern bioenergy systems can deliver benefits to South Africa's poorest.

Most of the 250 million citizens of the SADC live in rural areas and use a variety of inefficient and low-intensity energy sources, with biomass playing a dominant role in energy supply. To harness this resource more efficiently, sustainable biomass production needs to increase and the use of inexpensive biomass energy technologies needs to be improved. Sugarcane is a highly productive feedstock and underpins the SADC sugar industry, providing employment and making a significant contribution to GDP. A wide range of materials and energy products can be produced from sugarcane, including ethanol for use as fuel and as gels for kerosene replacement, electricity and chemicals. Many options exist to increase process efficiency, including mechanical harvesting, installing efficient combined heat and power (CHP) to make better use of bagasse, and adopting precision farming techniques for water and nutrient monitoring. However many of these options are stalled by policy uncertainty, which limits investments. While many SADC countries have adopted policies and legal frameworks to promote sugarcane use for energy, these frameworks do not always address the needs of stakeholders in the private sector and local communities.

A number of countries have attempted to provide development aid focused on building capacity, which is essential for any improvement in policy to take place. Brazil is one example, as it has adopted a considerable range of foreign policy instruments to incorporate several SADC countries into its policies for biofuels expansion. While useful lessons could be learnt from these external initiatives, empirical evidence of how policy can foster the development of a viable sugarcane-based ethanol industry that contributes to energy, food, and welfare provision across SADC is largely lacking.

While some SADC countries have been willing to engage with Brazil in fostering bioenergy, others have lagged behind. It would be instructive to focus on case study countries in the SADC region to analyse the factors that allowed some countries to be proactive, while others were not. This would identify the barriers that have hampered the successful engagement of other countries, leading to policy recommendations on how to promote sugarcane-derived bioenergy across SADC and engage successfully with external actors.

Recommendation 11

The research community should work with government departments, private sector, international organisations and civil society to provide adequate data on social context and policy impacts to guide sustainable bioenergy development that delivers against social development goals by:

• Mapping the key stakeholders (state, private, academic and civil society actors) who are involved with the promotion, production, distribution, trade and use of bioenergy, including their respective roles and the factors that affect their interaction.

• Examining the existing policies, laws and regulations pertaining to bioenergy and how these affect the decisions made by the stakeholders, technological development and trade.

• Identifying replicable best practices at regional and international levels to guide the advancement of bioenergy policy and projects.

• Identifying "winners" and "losers" in different bioenergy development contexts to identify optimal smallholder models that maximise energy and food production.

10. Research Priorities

This work has identified a number of key research priorities which should be addressed in order to encourage expansion of sustainable bioenergy systems in the SADC region and maximize environmental, economic and social benefits from appropriate development. These have been presented as a set of research recommendations (summarized below with relevant page references).

1. **Improve knowledge of biomass resources (pg. 6)**
2. **Carry out strategic analysis of the potential to build biomass value chains in the SADC region to support policy and industrial development (pg. 8)**
3. **Validate the performance of the most important feedstocks in the SADC region with key conversion technologies (pg. 11)**
4. **Calculate the environmental, economic and social performance of bioenergy systems, considering feedstock and other variations and supporting infrastructure needs (pg. 11)**
5. **Evaluate existing and future energy demands relevant to bioenergy systems (pg. 13)**
6. **Quantify the impact of SADC bioenergy on global GHG emissions (pg. 15)**
7. **Establish baseline figures for cookstove emissions and compare to alternatives (pg. 16)**
8. **Analyze relevant ash, digestate and biochar compositions and evaluate their impacts (pg. 16)**
9. **Quantify the water impacts of bioenergy systems (pg. 17)**
10. **Provide independent data on project failures, business models and skills gaps (pg. 19)**
11. **Map key stakeholders and work with them to identify solutions, policies and best practices in appropriate social contexts (pg. 22).**

However, it is important to realize that many of these issues are interlinked. In the same way that feedstock composition can affect plant performance, contextual setting will impact on system performance and engineering design can affect socio-economic impacts; so too the progression of these research challenges and recommendations will yield most benefits with close collaboration between different disciplinary backgrounds and combining local knowledge with specialist expertise. A programme that integrates these components alongside engagement with key stakeholders, including government departments, private sector, international organisations and civil society is required in order to support sustainable bioenergy development in the SADC region.

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[11] Urban Population. The World Bank; 2015.

Figure

Figure 1: Photograph by Miao Guo (2014)
Figure 2: Smeets et al (2007) A bottom-up assessment and review of global bio-energy potentials to 2050. Progress in Energy and Combustion Science.
Figure 3:Krause (2010)
Figure 4: Photograph by Patricia Thornley (2014)
Figure 5: Photograph by Patricia Thornley (2014)
Figure 6: Photograph by Paul Adams (2014)
Figure 7: Photograph from tsb.co.za (website visited 6th March 2015)
Figure 8 Framework adapted from M. Guo, N. Shah 2015 Bringing Non-energy Systems into a Bioenergy Value Chain Optimization Framework, 12th Symposium on Process Systems Engineering (PSE 2015)/25th European Symposium on Computer Aided Process Engineering (ESCAPE-25)).
Figure 9: Photograph by The Climate and Development Knowledge Network.
Figure 10: Photograph by The Climate and Development Knowledge Network.
Figure 11: Photography by Paul Adams (2014)
Figure 12: Photograph by The Climate and Development Knowledge Network and Patricia Thornley (2014)
Figure 13: Photograph by The Climate and Development Knowledge Network

Appendix A: List of participants, contact details and research interests

Name	Institute	Email	Research interest keywords
Patricia Thornley	University of Manchester	p.thornley@manchester.ac.uk	Process analysis; Sustainability; Environmental impacts.
Emile van Zyl	Stellenbosch University	whvz@sun.ac.za	
Nico Stolz	TSB	stolzn@TSB.co.za	
Johann Gorgens	Stellenbosch University	jgorgens@sun.ac.za	Bioprocess Engineering; Biorefineries; Techno-economic Assessments.
Jim Lynch	University of Surrey	j.lynch@surrey.ac.uk	
Tim Benton	UK Global Food Security Programme and University of Leeds	t.g.benton@leeds.ac.uk	Landuse; Ecosystem services, Sustainability; Multi-functional landscapes.
Sagaran Abboo	Rhodes University	s.abboo@ru.ac.za	Fruit waste; enzyme synergy; Bioreactor.
Paul Adams	University of Bath	p.w.r.adams@bath.ac.uk	Greenhouse Gas; Life Cycle Assessment: Biogas
Priviledge Cheteni	University of Fort Hare	200909553@ufh.ac.za	Economical Impacts; Social Impacts ; Sustainability.
Annie Chimphango	Stellenbosch University	achimpha@sun.ac.za	Integrated food and bioenergy systems; Sustainability analysis; Biomass characterisation and fractionation; Biorefinery development.
James Colwill	Loughborough University	j.a.colwill@lboro.ac.uk	Sustainable Manufacturing; Resource Efficiency; Renewable Materials.
John Corton	IBERS, Aberystwyth University	jcc@aber.ac.uk	Sustainable system development; process optimisation; experience with low sugar feedstock processing; combining conversion routes into unified systems.
Nicola Favaretto	United Nations University	nicola.favretto@unu.edu	Policy & stakeholder analysis; Participatory research; Livelihood analysis.

Beatriz Fidalgo	Cranfield University	b.fidalgo@cranfield.ac.uk	Thermochemical and thermocatalytic conversion; Characterisation of biofuels; Integrated biorefinery.
Roshini Govinden	University of KwaZula Natal	Govindenr@ukzn.ac.za	Enzyme cocktails; Bagasse; Maize stover; Fermentation.
Miao Guo	Imperial College	miao.guo06@imperial.ac.uk	Bioenergy system modelling and optimization; Environmental assessment; Biogeochemical modelling.
Danie la Grange	University of Limpopo	Danie.LaGrange@ul.ac.za	Bioprospecting; Bioethanol; Cellulases.
Trudy Jansen	Stellenbosch University	trudy@sun.ac.za	S. cerevisiae physiology towards stress tolerance and general strain robustness.
Jon McCalmont	Aberystwyth University	jpm8@aber.ac.uk	Energy crop ecophysiology (Miscanthus); Environmental impact; Greenhouse gas research; Soil carbon dynamics.
Jon McKechnie	University of Nottingham	jon.mckechnie@nottingham.ac.uk	Bioenergy systems optimisation; Techno-economic and life cycle environmental analysis; Sustainable biomass supply chains.
Evodia Setati	Stellenbosch University	setati@sun.ac.za	Microbial ecology; Fermentation Biotechnology; Enzymology.
Raphael Slade	Imperial College	Raphael.slade@imperial.ac.uk	Sustainability; Energy systems; techno-economic analysis.
Julia Tomei	University College, London	j.tomei@ucl.ac.uk	Livelihoods; Social sustainability; Energy access.