POLICY BRIEF

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BIOMASS GASIFICATION FOR DECENTRALISED ELECTRICITY GENERATION IN MALAWI

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EXECUTIVE SUMMARY

Inadequate access to energy poses a critical challenge to Malawi's economic development. Less than 13% of the population has access to electricity and those who face insufficient and unreliable supply. Yet to date, renewable energy –both on-grid and off-grid has played a small role in electrification.

The objective of this study was to design, develop and characterise rice husk gasification system as an alternative source of power for electricity generation. The biomass-based power project aimed to provide access to clean energy services, primarily focusing on productive load using locally available biomass feedstock.

The study was carried out by collecting data in the paddy plantation area, paddy production, and in the rice milling industry. It was decided based on the potential analysis of collected data to develop a rice husk gasifier power plant in Wowo Cluster Village, Nkhulambe Extension Planning Area (EPA), Phalombe District.

INTRODUCTION

Access to affordable and reliable electricity is a key challenge and policy priority in Malawi. Currently, 87% of the population still lacks access to electricity, with a disparity of 4% in rural areas compared to 58% in urban areas (NSO, 2018). With residential tariffs at \$0.14/kWh and connection costs of \$150, electricity is unaffordable for many even in the vicinity of the grid. Unsurprisingly, electricity consumption is low; in 2016, Malawi's per capita electric consumption stood at about 110 kWh, far lower than the African average of 153 kWh.

Against this backdrop, the government sees renewable energy (RE) as a potential solution to low levels of access. Moreover, renewable energy is also viewed as one way to reach rural populations who live beyond the national grid. The Government of Malawi has set an ambitious target to increase electricity access to 30% by 2040, primarily by increasing generation capacity and expanding the grid. They recently identified that off-grid technologies can be cost-effective in providing electricity to a dispersed rural population.

Malawi's rural communities, which constitutes 85% of the country's population, are dispersed and demand insufficient electricity (at existing prices) to justify the cost of extending the grid. Going forward, despite aggressive grid targets, off-grid technologies are likely to play an increasingly important role in bringing electricity to the rural poor. The overall goal of the project was to design, develop and characterise rice husk gasification system as an alternative source of power for electricity generation. The study intended to increase awareness on the benefits of utilising biomass (agricultural waste) for useful products with several social and environmental benefits.

APPROACHES AND RESULTS

This study consisted of desk studies, primary data collection in field visits (February and March 2019), laboratory analysis in Malawi, and the integrated feasibility study assessment of the Wowo Cluster Village Community.

The main tasks undertaken were:
a) Desk review and inception: feasibility analysis methodology adaptation (components, quantified criteria, protocols); and desk review of available information on gasifiers.

b) Field work: preparation of field work-materials, logistics; and field visits to over 50 rice mills spread across the eight agricultural development divisions (ADDs).

c) Study tour: tour of Makerere University gasification facilities and other gasification plants within Kampala, Uganda, study excursions at Kayak Refugee Camp-300km outside Kampala and powered by rice husk or maize cob-based gasification plant.

Figure 1: Gasifier

Figure 2: Reaction and ash chamber assembly

d) Feedstock characterisation: proximate and ultimate analysis.

e) Feasibility characterisation and community ranking

- Socio-economic component analysis (needs assessment, energy demand, income structures, prospects for business development, willingness to pay;
- Technical and technological component analysis (supply chains, biomass resources, distribution);
- Financial component analysis (cost-benefit analysis, cash flow projects, social NPV); and
- Ranking of communities potentials and selection for detailed implementation preparation.

f) System design: design theory, mathematical modeling, computational fluid dynamics; final design and manufacture of different parts and assembly.

The summary of the key findings are given below:

1. Crop residues contribute significantly to the biomass sector

in Malawi and can potentially be used as energy source for rural electrification. Rice straw, rice husks, maize straws[stalks], maize cobs are the major agricultural residues that can be used to meet the electricity needs of rural communities in the country.

2. With the total agro-crops production of 2.45 million tons, and considering the amount of fraction of different types of crops, the total contribution of biomass residue potential is about 5.5 million tons.
3. The baseline study found that rice husk is approximately 20% of rice production by weight, and rice straw is approximately 29%-130% of rice production by weight.
4. Considering a combustion efficiency of 95%, with calorific of 13.3 GJ/ton and 15.65 GJ/ton, for rice husks and maize cobs, respectively, and at power plant efficiency of 25%, the amount of power generated is in the range of 0.013 – 0.544 MW. For gasification of maize cobs, the amount of power generated is in the range 2.0 – 20 MW.
5. Results of the proximate and ultimate analyses showed that rice husks have high volatile matter contents (59.63 % dry basis) and low bulk density (120 kg/m3), consequently, it is easier to ignite and burn than coal because of the high volatile matter. The low density complicates its transportation, storage and processing. The ultimate analysis showed that carbon content is 38 to 50%, hydrogen is around 6%, oxygen is 30 to 43%, and nitrogen is around 2% and traces amount of Sulphur.
6. The study found that collection and transportation of agricultural residues especially rice husk, corn cobs and fuel wood are somehow established but it is purely in customary form in Malawi. Due to the nature of commodity, specialized storage and transport facilities are required.
7. The key lessons learned through the study tour were as follows:
   (i) Uganda has adequate capacity to undertake research and development (R&D) in renewable energy in general, and gasification of biomass for electricity generation in particular.
   (ii) Participants were equipped with professional skills and knowledge on layout, set up, operation, and management of gasification plant.
   (iii) The team also acquired sufficient skills and knowledge on theoretical design of gasifier and reaction kinetics to optimise gasification efficiency.
   (iv) The study tour provided a great opportunity to gain know-how and lessons learnt from established biomass gasification plants and to discuss different perspectives with representatives of the gasification plants. Relevant supporting factors, obstacles and pitfalls were presented and openly discussed with these representatives. Thus, the participants realised the complexity of the process to plan, initiate and manage a biomass gasification plant.
8. The economic analysis showed that the leveled electricity costs (LEC) ranged between 460–156.62 MWK/kWh to electrify communities between 200-400

Figure 3a&b: Gasifier hearth and nozzle arrangement

Table 1: Feasibility calculation results for the base case

PARAMETER	UNIT	VALUE
NPV	MWK	(34 331 806.54)
FIRR	%	6.72
Payback Period	Years	11.55
WACC	%	9.94

Table 2: Feasibility calculation results for the base case

PARAMETER	UNIT	VALUE
NPV	MWK	25, 883,268.66
FIRR	%	13.35
Payback Period	Years	7.37
WACC	%	9.94

Table 3: Estimated cost structure of biomass gasification plant

PARAMETER	UNIT	VALUE
Installed capacity of the biomass gasification plant	kWe	32
Annual hours of operation	h	5700
Life in years of plant	years	20
Biomass in tons dry mass/year	tons	467
Biomass gasification system capital investment	US$	154,000
Interest on value of the machinery and equipment	US$	27, 118
Depreciation	US$	3 176.01
Annual labour cost	US$	4266.67
Annual repair and maintenance cost	US$	2 280
Insurance and taxes	US$	2745
Total biomass cost/year	US$	10,741
Total cost	US$	201,581.67
Annual electricity production from the plant	kWh	182, 400
Cost of operating per hour	US$	
Benefit delivered annually	US$	
Net Present Value of the benefit	US$	3 589.41
Net Present Value of operation and maintenance	US$	
Accumulated Net Present Value of all the cost	US$	11 629.37
Net Present Value of the project	US$	
Benefit Cost Ratio	-	0.31
Payback Period	year	11.75
Internal Rate of Return	%	6.72
Levelized cost of kWh of gasification electricity generated	US $. kWh-1	0.143
Annual revenue from the sale of electricity	US$	26,083

households with the gasifier considered.

9. The analyses in this study have shown that it is technically feasible and under certain circumstances economically viable to establish a power plant based on rice husks and maize cobs.
10. The net present value of the project is positive, the financial internal rate of return is 13.35%, and the payback period of the project is 7.37 years. These economic indicators established the economic viability of the project at the given cost. However, the selling price of US$0.08/kWh (MWK60.00/kWh) is on a rather high side, which the rural dwellers cannot afford.

    Since the biomass gasification technology represents the least-choice technology for rural electrification especially where there is no extension of electricity grid, the capital investment cost, operation and maintenance cost, the fuel cost should be reduced through development of the gasification system using local materials, purposeful and efficient plantation of biomass for electricity generation, giving out financial incentives by the Government to the investors, and locating the power plant very close to the source of feedstock generation.
11. Table 1 depicts the estimated cost structure of the gasification power plant project. Although investment in biomass gasification power plant will bring economic dividends to the Wowo Cluster Village, the results of the financial analysis reveal that investing in the gasification system for electricity generation in rural areas is not economically viable and profitable.

    The present negative net value of MWK 34,331,806.54 and the benefit cost ratio that is far less are financial indicators of a financial loss if the cost of the electricity is at US$0.14/kWh (MK107.72). This is almost double the tariff currently used for Bondo Microhydropower plant, which is the average willingness to pay for rural communities.
12. The estimated cost structure of the biomass gasification system with a planned selling price of US$0.08/kWh (MWK60.00/kWh) is shown in Table 2. In Table 2, the net present value of the project is positive, the financial internal rate of return is 13.35%, and the payback period of the project is 7.37 years.

    These economic indicators established the economic viability of the project at the given cost. However, the selling price of US$0.08/kWh (MWK60.00/kWh) is on the high side making it unaffordable to the rural dwellers.

    The capital investment cost, operation and maintenance cost, and the fuel cost should be reduced given that the biomass gasification technology represents the least-choice technology for rural electrification especially where there is no extension of electricity grid. This can be done by developing the gasification system using local materials, purposeful and efficient plantation of biomass for electricity generation. The government can also provide financial incentives to the investors, and locate the power plant close to the source of feedstock generation.

IMPLICATIONS AND RECOMMENDATIONS

Biomass continues to play an important role for energy sustainable development in Malawi, the potential of biomass is huge but its conversion to modern energy is still low. Biomass gasification can offer an attractive alternative renewable energy system especially in rural areas where biomass fuel is readily available.

These resources could provide community based small-scale independent power plants. Rice husks and straw as well as maize stalks and maize cobs can be ranked the two top available biomass types in Malawi.

This study has undertaken a baseline study and feedstock assessment. It has also conducted a detailed feasibility assessment; carried out system design, fabricated and assembled a gasification system.

To address the energy challenges facing rural areas in Malawi, by converting agricultural residues, the study proposes the following recommendations:

- Industrial Research Centre (IRC) through the Malawi University of Science should continue with one or more sites that have been analysed in this feasibility study. If the aim is to contribute to integrated rural development using small-scale technology, biomass gasification should be pursued. In this case, Wowo Cluster Village could offer a good starting site, albeit public-private partnerships should be pursued.
- Financial support will be necessary to get biomass gasification started in Malawi. It is the task of IRC to formulate concrete projects resulting from this feasibility study and to develop framework for further research on biomass gasification.
- Research and development institutions in Malawi should play an important role in accelerating biomass utilisation and conversion to modern energy
- Research and development collaboration among researchers in Malawi and the SADC region should be developed and realised.
- Community based, decentralised electricity production from agricultural residues should be supported, e.g. local

entrepreneurs could operate small-scale conversion systems (e.g. 50 kW) and the community could produce and provide the biomass feedstock and would receive energy services in return. This model-if successful-can be replicated in cooperation with micro-finance institutions, community extension organisations and energy producers.

CONCLUSIONS

Biomass is an emerging renewable resource for bioenergy production that can meet the future energy demands in developing countries. Malawi as a developing country also needs to put forth its efforts for potential production of bioenergy from biomass to tackle the energy crises. Biomass gasification can offer an attractive renewable energy system especially in rural areas where biomass fuel is readily available.

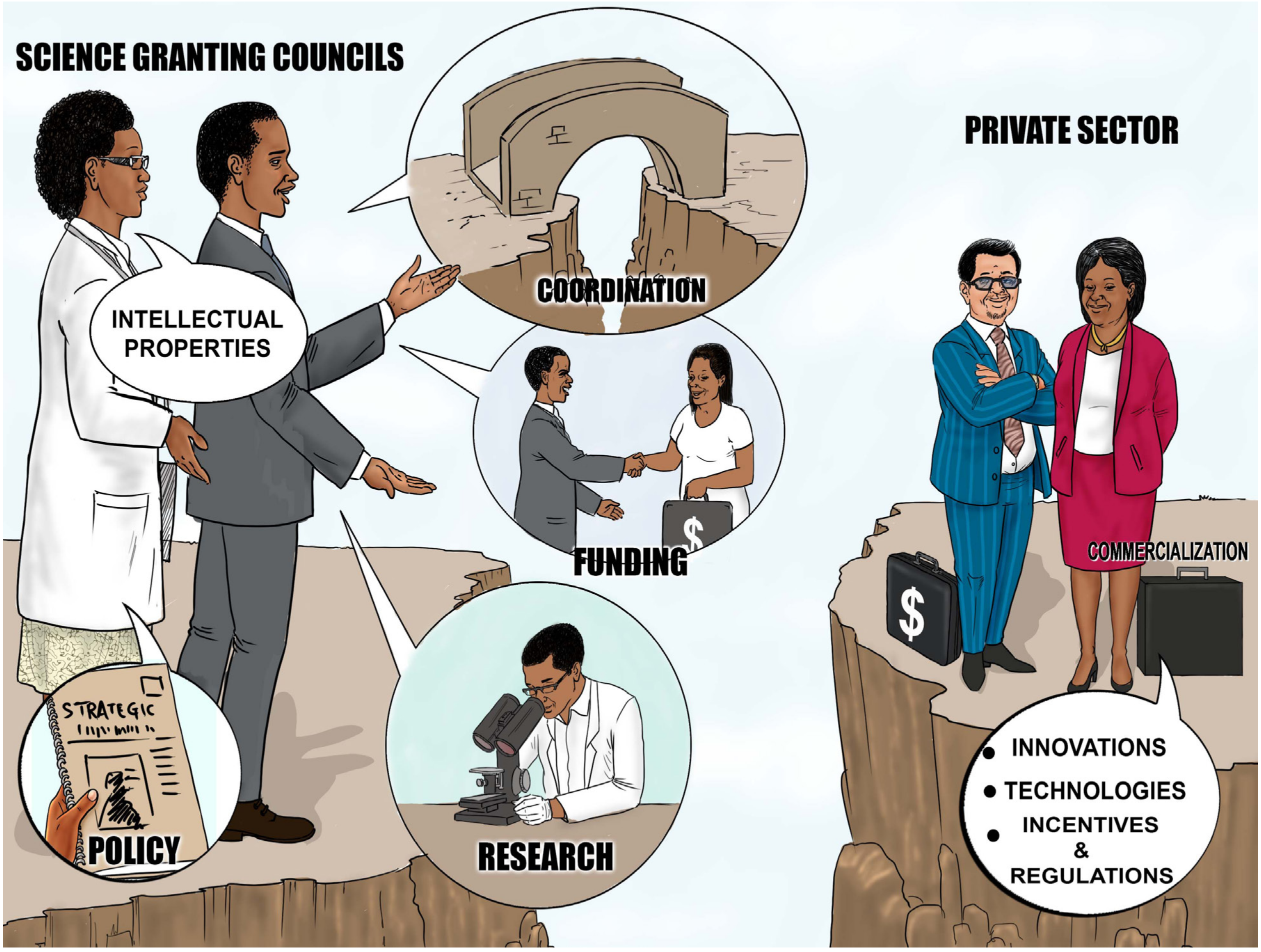
These resources could provide community based small-scale independent power plants. Rice husk and straw can be ranked at the top of the available biomass types in Malawi and have power generation potential of around 87 Mwe. The power plant could be installed near the larger rice mills 'cluster areas' in Karonga, Nkhata Bay, Nkhotakota, Salima, Zomba, and Phalombe with the surplus rice husk. However, establishment of rice husk based power plants in rice milling industry will lead to an enormous change in rice production and the surplus power can be supplied to the national grid and local communities. However, other types of biomass such as maize cobs, maize stalks and rice straw should also be considered for gasification.

The research concludes that Malawi has a significant potential form of power generation from biomass gasification and has estimated around 87 MWe. Provision of government subsidies need to overcome the barriers for the installation of such gasification power plants. The Government of Malawi can seek funds from different foreign aids while carbon trade can be an option. Installation of biomass based power plants in rural areas will lead to an enormous change in the lifestyle of the local community by increasing the business hours in the market area, improving health conditions, and encouraging new business developments.

Additionally, biomass gasification for village electrification can be an option at those sites that do not have access to national electricity grid. The biomass can come from agricultural waste products. A relatively expensive grid that will have to be financed using donor money has to be established. The most important variables are the demand for electricity and the investment costs. The analysis shows that gasification is not viable given the current low demand and the high investment costs. However, a public-private funded village electrification project with a holistic approach to provide electricity and concerted effort to build capacity and encourage productive usage of electricity is a strategy worth pursuing.

Additionally, sites for residential and commercial applications can be explored whenever the electricity demand is high enough and when biomass is available at a low price. Especially when diesel consumption can be replaced, a biomass gasifier has a relatively short payback rate. Unfortunately, bigger mills and factories that are not connected to the national grid are not abundant in the country. However, even when a factory already has access to grid electricity, biomass gasification could still be an option.

This feasibility study has explored several options to implement biomass gasification in Malawi. The analysis shows that biomass gasification is not in all cases commercially viable, given the data collected for this study. However, taking into account the high potential for biomass resources and the lack of adequate energy provision in the country, the potential is unequivocally available. Some options mentioned in this study, such as village electrification, need clever social engineering and the concerted effort of private and public organisations. Other options, like commercial application can safely be selected for a demonstration project in the near future. Yet another range of options, such as, small scale gasifiers and irrigation projects deserve more attention, but have fallen outside the scope of this research.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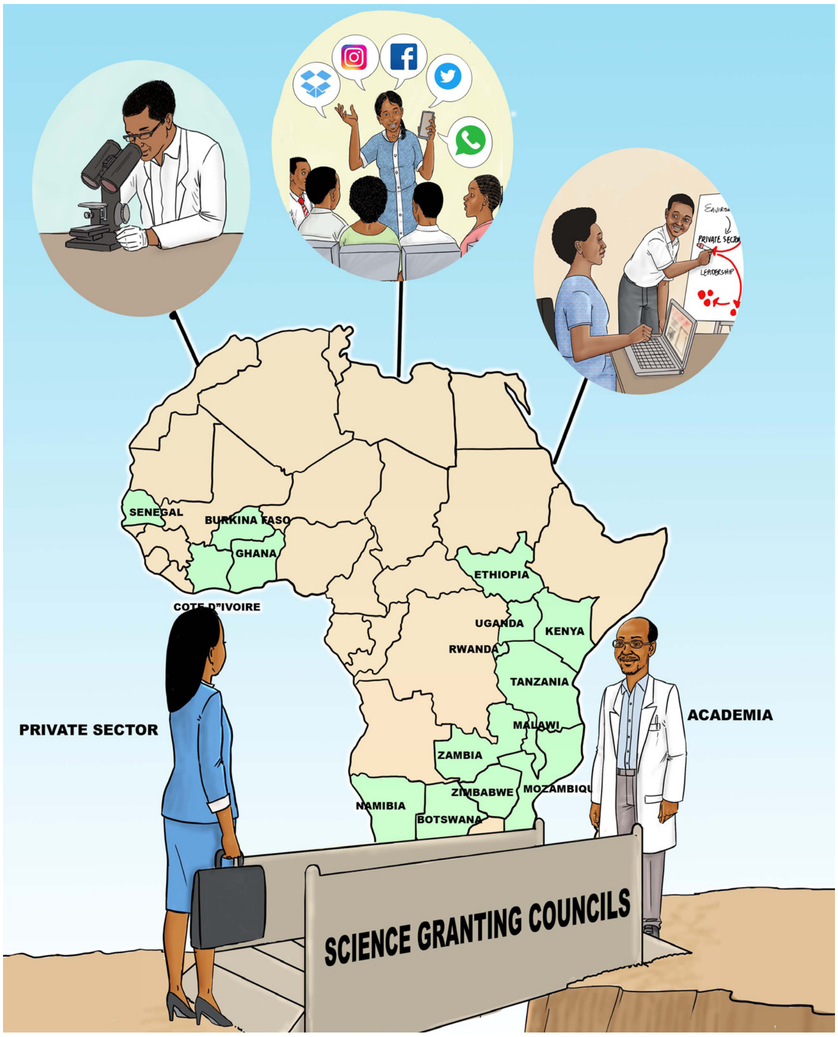
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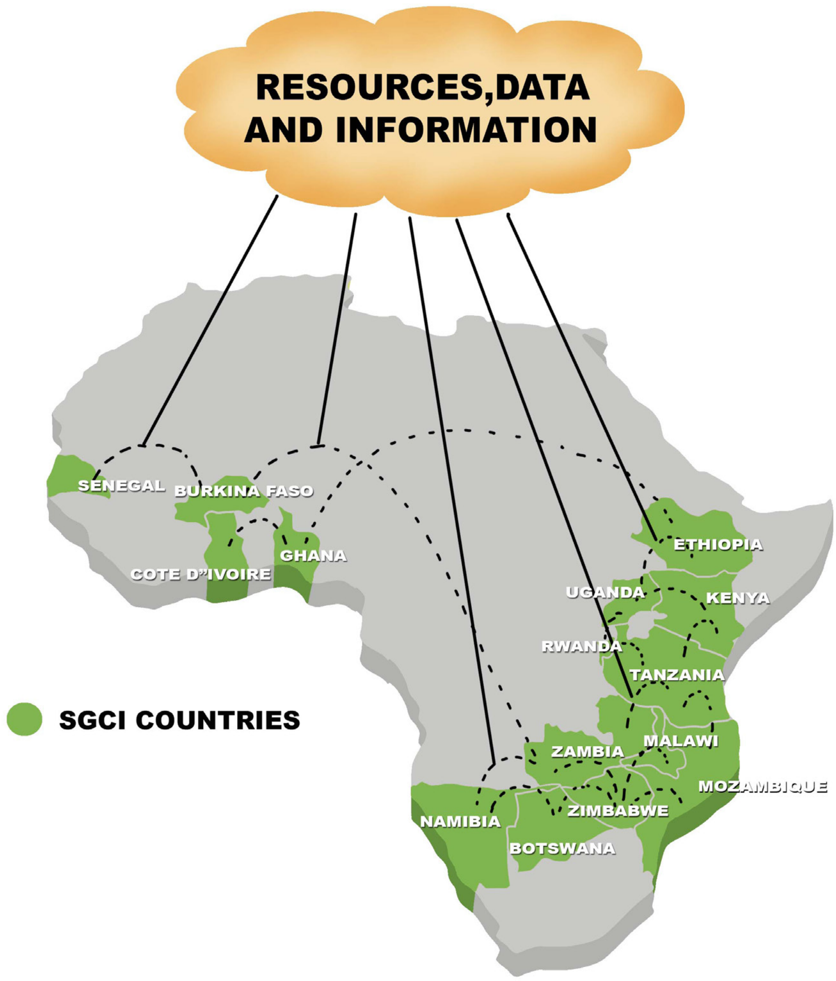

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