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A Study on the Market Potential of Biomass-Based Micro Gas Turbines in Sub-Saharan Africa

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ABSTRACT

Biomass can be used as an alternative fuel in micro gas turbines to produce electricity, heat and/ or cooling. This is an affordable carbon-neutral renewable energy source which is widely available in most African countries. In this project the main aim is to gather information and data to evaluate the feasibility and the market potential of this technology in three sub-Saharan African countries. This includes data about the energy market, information on feedstock availability in different regions, statistics on the electricity grid, the demand profiles of different consumers, as well as insight on the national policies and regulation. The information is used to help understand the needs of the energy market in the partner countries and the potential of the proposed technology.

Keywords: biomass, micro gas turbines, combined heat and power, market potential, Africa

NONMENCLATURE

Abbreviations	
CHP	Combined Heat and Power
MGT	Micro Gas Turbine

1. INTRODUCTION

Combined Heat and Power (CHP) is the simultaneous production of useful electricity and heat from different energy sources. This combined production doubles the utilisation of energy with respect to producing electricity and heat independently, halving the emissions of CO_2 and rendering a much more sustainable solution for the future.

The global market size for Combined Heat and Power applications was estimated at US$ 25 – 30 bn in 2019 and is anticipated to grow at an annual rate of 6 – 7% until 2026, particularly within the 0.5 to 5 MW_e power range [1, 2]. Regarding energy sources, biomass is foreseen to have a dominant role in the near future, with a high overall market share compared to other renewable sources. However, current state of the art CHP plants fuelled with biomass adopt steam Rankine cycles to convert thermal energy into electricity with inherently low efficiencies (< 40%) [3]. Therefore, more efficient, and cheaper CHP systems are necessary to increase the installed capacity of heat and power generation through renewable energy technologies

CHP plants based on biomass external firing are currently commercial at small scale, employing micro gas turbines (MGTs) [4]. MGTs represent an efficient (overall efficiency > 80%), small-scale power and heat generation solution able to significantly reduce greenhouses gas emissions in the short and long terms; MGTs are intrinsically cost competitive, environmentally friendly, fuel efficient and flexible [5]. In addition, they possess many other functional characteristics that make them a robust solution: compact size, light weight, low maintenance, low noise, low emissions, and multi-fuel capabilities.

According to the type of feedstock available, MGTs burn biomass with an external combustor. Externally fired MGTs have two main advantages: (1) the utilisation of the waste heat from the turbine in a recuperative

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process and, (2) the possibility to operate with direct combustion of exotic fuels.

The African continent has an enormous renewable energy potential which is only partially exploited, meaning that the existing innovative solutions and technologies generated for developed markets need to be tailored to the African context. It is estimated that biomass covers over 50% of the total primary energy in Africa making it the major energy vector [6]. A major issue is that at the current stage, the technologies that efficiently utilise biomass resources are not many and so, this energy vector becomes a source of health problems and deforestation, therefore, a sustainable regulation is necessary. In addition to that, equal access to energy is still far from reach considering that the electrification rate in Sub-Saharan Africa is around 30% [7].

These numbers represent the challenge of today, and thus technology innovation is a key for African countries to be part of the green energy transition. Africa's strong economic growth in the last decades has been related to the production and sale of natural resources (oil, copper, iron). The immediate subsequent step is related to the improvement of the productivity of those sectors, moving higher on the value chain. Such shifting requires investing in the creation of new technologies, certainly, but also in the adaptation of existing technologies to the local context for improving these processes. It is evident that there is a strong desire for the continent to grow and to adopt a bottom-up approach, with the emergence of more than 600 tech hubs in various Sub-Saharan countries (2019) [8].

The suggested biomass MGT CHP technology, schematically displayed in Fig. 1, will provide the Sub-Saharan energy system with flexibility thanks to its adaptability to a wide range of bio-feedstock — including low-grade opportunity fuels such as biowaste — and its fast-response capability enabled by the utilisation of a gas turbine as the core prime mover in the system. The integration of such a technology will also enable the exploitation of circular economy concepts that will yield negative carbon footprint. The facility can be fuelled by a wide range of solid and liquid industrial by-products and residues. Biomass-based CHP plants can be operated with solid feedstock including wood, forestry and forest industry residues, agricultural and agro-industrial residues, and the biological fraction of wastes. Liquid feedstock includes biodiesel and liquid industrial wastes such as molasses and black liquors. Solid feedstock can be gasified to produce biogas or syngas. Both feedstock types can be directly fired in an external-combustion system (furnace), producing thermal power which is then used in a thermal power cycle to produce electrical power and heat.

High-pressure air is delivered by the compressor and is then heated using a heat exchanger by the flue gases of a bio-feedstock combustion system. The compressed stream is expanded in the turbine, producing power to drive the compressor and the electric generator, as well as low-pressure air which is used in the primary combustion zone of the combustor to reduce the consumption of primary air to achieve the target temperature of flue gases in comparison with a standard bio-feedstock burner. The resulting flue gases from the combustor are finally used in the primary heater of the gas turbine to heat the high-pressure air delivered by the compressor, before being used to produce process heat downstream.

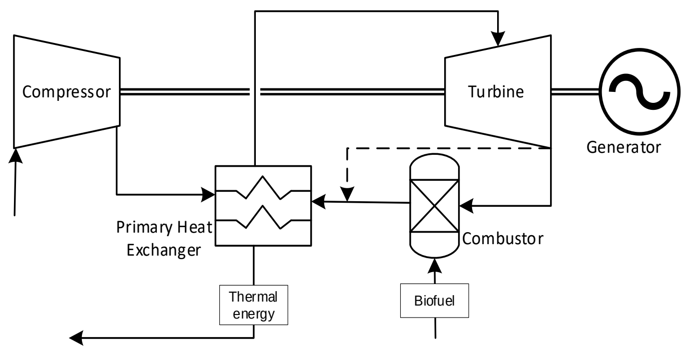

Fig. 1. Schematic diagram of biomass MGT

The selection and design of any biomass combustion system is determined mostly by the fuel characteristics, local environmental legislation, costs, and performance of the equipment, plus heat and electricity demands [9]. For the thermochemical paths, direct combustion is the best established and most commonly used technology to convert biomass into heat. Biomass combustion systems, using a range of furnace designs, can be very efficient at producing hot gases, hot air, hot water, or steam, typically recovering 65 – 90% of the energy contained in the fuel [10]. In order to select the most suitable combustion technology, and MGT plant design case, an analysis of the requirements specific to the targeted markets is necessary.

The aim of this study is to assess the potential of the suggested technology in penetrating the Sub-Saharan African energy markets across three representative countries by considering the following elements:

- Finding use cases for heat and electricity

- Considering the economic and demographic landscapes
- Exploring the barriers and opportunities from a regulatory point of view
- Gathering information on the type and availability of biomass waste/ feedstock

Section 1 of this paper defines the considered problem and provides an overview of the market, and the proposed solution. The following section (2) presents the methods used to fulfil the aim of the work. The collected data is summarized and discussed in Section 3 where the recommendations for the adoption of the technology for each market are given. The final section draws the conclusion of the paper and gives insights on additional future work based on findings.

2. MATERIALS AND METHODS

This work is part of a project which involves partners from three Sub-Saharan African countries, namely Kenya, Ghana, and South Africa. Given the geographical location of the partners which spans over different regions of the continent, the results of the study can be used to obtain a representative view of the markets in east, west and south Sub-Sharan Africa.

The study utilised a mix of primary and secondary data collection performed by each partner in their respective countries. Primary data comprises interviews and surveys with various players in the energy sector and the biomass industry; the aim being to assess user perception and attitudes towards deploying biomass energy and distributed power generation technologies. Secondary data is drawn from a thorough literature/ market review, along with the partners' compendium of knowledge in the targeted sectors through research and collaboration efforts. The gathered information is divided into four main categories:

1. Electricity and heat markets: Electricity consumption and demand, as well as the characteristics of the power grid, dictate the requirements for production units and their scales. Sizing of the MGT systems is done via identifying the heat applications and requirements. The share of renewables in the energy mix is also a key indicator to the employability of the proposed technology.
2. Economy and demographics: The size of the market is also dependent on the population, area, and density of the given country. Economic growth/ strength and financial risk also affect the likelihood of investment and uptake.
3. Regulatory framework: Current and future related energy policies and regulations effect the commercialisation of distributed power generation through MGTs using biomass resources.
4. Biomass feedstock: Availability of the biomass feedstock controls how likely the technology is going to be feasible. The type of the resource influences the combustor selection.

The data is then analysed simultaneously to either completely disregard the biomass-MGT-CHP system or to discuss the requirements/ recommendations to enable a successful technology adoption.

3. RESULTS AND DISCUSSION

The results are based on the market potential for each country; the discussion links the multi-disciplinary analysis of the conducted work.

3.1 Market Potential

3.2.1 Ghana

Ghana records high rates of biomass production; however, current usage is mostly limited to wood fuel and charcoal for domestic cooking. Favourable factors, such as: high population growth rate, availability of feedstock, and unreliability of prevalent sources of electricity make room for the use of biomass for electricity production for small industrial, and up-scale residential applications.

The three identified main factors that pose hindrances to the commercial success of the biomass-MGT-CHP systems are cost to consumers, weak government and regulatory support, and product unawareness. Ghana is a low-income country with a price-sensitive populace; therefore, any proposed intervention must be price-competitive, particularly with the existence of more familiar alternatives. Besides the careful selection of the target market, it is essential that the cost of the technology is not prohibitive to potential clients. Flexible payment plans or subsidies might mitigate the initial financial load on customers.

The regulatory regime surrounding biomass energy production is deficient in Ghana. The current economic situation and existing energy agreements constrain the government from extending support to biomass energy producers through higher subsidies for energy produced, and direct contracts. Existing biomass energy producers therefore aggressively seek funding from foreign governments, private investors, and international organisations. These funds are channelled into product awareness creation, start-up and operational costs. Results from conducted surveys with targeted market clients gave a clearer insight on the characteristics of potential users. There is very low awareness of biomass as a source of electricity, and thus, very little curiosity about its potential. Secondly, Ghanaian consumers are dismissive of disruptive innovation unless there is a clear demonstration of benefit to themselves (i.e., cost savings or tangible profit) with as little inconvenience as possible. To this end, hands-on, in-person opportunities, to demonstrate the benefits of the technology, could be helpful.

3.2.2 Kenya

Biomass is the largest source of primary energy in Kenya; nonetheless, given the reliability of rural areas on wood, charcoal and crop residues, there is around 63% biomass deficit which is expected to rise as the population continues to grow.

From surveys, the selected markets include manufacturing and agriculture sectors, along with education and hospitality venues. Such consumers are willing to attend training related to the proposed technology for more accessible adoption. A demo-plant is deemed crucial for the integration of the CHP system.

The Kenyan government is committed to increasing energy access through various initiatives such as rural electrification, renewable energy uses, and through encouraging individual power generation by private ventures. The ongoing power outages require back-up off-grid energy to mitigate the losses. These reasons present attractive market opportunities, but also pose obstacles which impose careful planning, and finding suitable niche markets.

3.2.3 South Africa

South Africa's past ventures in MGT utilisation were unsuccessful because of high costs compared to conventional systems. Even so, questionnaires showed a huge interest in the technology due to the large electricity and supply-demand gap since 2008, and the drive towards renewables. Potential markets/ applications for the technology is believed suitable for the following industries: mining and metal processing, manufacturing and food processing, pulp and paper, oil and gas, agriculture and farming enterprises, as well as community and public infrastructure.

South Africa has adopted several national programmes which include the Renewable Energy Feed-in Tariff, and the Independent Power Producers Procurement Programme, both of which enable the technology implementation.

Abundance of waste, energy crops, and other invasive species offers a variety of biomass feedstock depending on site location and application.

3.2 Discussion

The common identified parameters that affect the uptake of the technology, for all the targeted sub-Saharan countries, are generally related to the economic performance of the system in comparison to incumbent technologies, and the existence of an adequate regulatory framework. However, the study aims to assess the suitability of the MGT CHP system based on the technological aspects as well. The assessment is done for a system in the scale of 80 – 150 kW (which is economically suitable for a range of alternative fuels). The size of the MGT is dependent on the application, which is different for each of the three countries based on the heat and electricity demands that were formulated from the data analysis of each market. The cost inevitably relies on the technologies used; heat recuperation for better performance, and more efficient turbomachinery components incur a higher price. Therefore, similarly to other works [11], the study follows an established method of identifying the market potential of small-scale micro gas turbines by classifying the multi-dimensional influential elements into different numerical weighted factors. In this way, the technological, financial, policy, and social results are lump summed into one index of interest which is used to evaluate the feasibility of the system.

4. CONCLUSIONS AND RECOMMENDATIONS

Biomass has immense commercialisation potential in Ghana, but producers must be committed to bearing the brunt of an undeveloped market, by forging partnerships toward subsidising operational costs and product price, and through product awareness, until a substantial market base is formed.

In Kenya, the MGT system must prove high efficiency and cost-competitiveness compared to existing electricity and gas generation technologies. With a limited biomass supply in the country, municipal waste presents the biggest potential as bio-feedstock. Standalone small-scale power generation is encouraged and incentivised especially through utilising renewable sources.

South Africa's energy demands and insecurities, coupled with the wealth of biomass resources allows the technology to be attractive for private investors and R&D actors. As with the other countries, financial viability poses a major hurdle to be addressed.

The work is to be carried further by conducting a techno-economic study of the proposed system to identify the most suitable markets for future deployment.

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