INBAR Working Paper

INTERNATIONAL BAMBOO AND RATTAN ORGANISATION

Policy Brief

Bamboo Pellets for Sustainable Bioenergy Production in Ghana

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CGIAR RESEARCH PROGRAM ON Forests, Trees and Agroforestry

About the International Bamboo and Rattan Organisation

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About this Working Paper

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Executive summary

This policy brief is intended to inform among other stakeholders regional and national policymakers, private sector actors, and energy producers about the prospects of converting bamboo resources into pellets for renewable energy in West Africa. It evaluates the feasibility of using bamboo for the production of pellets as a more sustainable energy material based on feedstock availability and market data. It also proposes recommendations for practitioners, policymakers, and businesses in the field of bamboo bioenergy production and management as well as stakeholders interested in the sustainable management of bamboo resources particularly in the context of West Africa.

1. Introduction and context

In many parts of the world, concerns about rapid population growth, energy demand, and climate change have led to a growing interest in sustainable renewable energy sources. Wood serves as one basic source of energy for important activities such as heating, cooking, and charcoal production, particularly in rural and peri-urban areas of developing countries. It accounts for 90 percent of the world's woodfuel consumption (Broadhead, Bahdon and Whiteman, 2001). However, the high demand for wood as energy material is leading to the rapid increasing over-exploitation forest and plantation.

According to the Forestry Commission, fuelwood is the predominant form of wood energy in Ghana. Annually, about US$70 million is spent on wood as a fuel source by Ghanaians. Ghana is considered to have the highest rate of primary forest loss due to unsustainable logging practices and overutilization of traditional timber species in West Africa (Global Forest watch, 2019). As forest resources continue to degrade access to fuelwood declines. Despite this decline and associated environmental challenges, energy demand nationally is expected to increase considerably in the coming years as the result of population growth and economic development (EIA, 2007).

There is, therefore, no doubt that efficient use of biomass-based energy/biogas such as wood and agricultural waste, landfills and municipal waste as well as biodiesel from appropriate organic materials could benefit the country as a whole while reducing carbon dioxide emissions (RVO.nl, 2016). However, burning raw biomass usually has a high content of volatile matter and ash and lower density and energy values (Source: Global Alliance for Clean Cookstoves). One method of making more efficient and effective use of existing resources is through the use of biomass pelleting. Globally one important biomass source which is currently being promoted for the transition to a sustainable system of energy provision and consumption is the use of bamboo for bioenergy pellets.

As a modern bioenergy feedstock, the use of bamboo biomass is becoming increasingly promising given its fast-growing nature and regenerative character. Processing the biomass into compact pellets allows it to burn more efficiently and evenly, increasing its energy density and transportability. The bamboo pellets can also be made from compacted industrial wastes generated from the processing of bamboo into furniture, and construction.

The conversion of bamboo biomass through the process of pelleting could provide sustainable alternative biomass to replace wood and help address the nation's energy challenges. It will also be crucial to help solve problems associated with deforestation and help reduce pollution and emissions related to fuel-wood collection which currently, amounts to 3.5 MtCO2e per year (about 6% of total national GHG emissions) (EPA, 2019).

The utilization of wood and other solid biomass as a bioenergy source can offer a potential path to addressing climate change by substituting fossil fuels and reducing GHG emissions if produced under sustainable conditions. While the utilization of bamboo for other uses has been well documented in Ghana, a review of its potential specific to the bioenergy production has not been done. No research has been done as to which factors will promote or hamper its potential to be used as a sustainable source of biomass for pellet production. This study aims to fill that knowledge gap.

2. Bamboo pellet production process

The process of making bamboo pellets is similar to other biomass pellets and involves drying, grinding, and extruding bamboo fibre under high pressure and temperature into pellets of a specified size. The entire bamboo plant, including the stem, branch and its rhizome, can be used to produce bamboo pellets, making it highly resource-efficient, with limited wastage. Residues produced from bamboo products or furniture manufacturing such as sawdust and shavings also serve as an important raw material source. The entire process of palletisation is presented in a diagram in Figure 1.

Figure 1. Process of pelletizing bamboo

2.1 Fuel characteristics and Energy Potential of Bamboo

Pellets are usually categorized by their heating value, moisture and ash content and dimensions. As a biomass resource, bamboo has great potential as a feedstock for energy. It has a number of desirable fuel characteristics such as low ash content and alkali index. The moisture content in bamboo is relatively low (5-23%) in comparison to other types of plants. It, therefore, presents superior properties regarding the heating value and chemical composition (Daza C.M., 2011). Typical ranges of bamboo species fuel characteristics are listed in Table 1 and are compared with other alternative feedstocks in Table 2.

Table 1. Fuel characteristics and energy values of some bamboo species

Bamboo Species	Moisture content (%)	Ash content (%)	Volatile content (%)	Fixed carbon content (%)	Higher heating value (kJ/kg)	Reference
Bambusa Deecheyama	14.3	3.70	63.10	18.9	15.700	Sritong et al., (2012)
Dendrocalamus asper	5.8	2.70	71.70	19.8	17.585	Sritong et al. (2012)
Phyllostachys nigra	13.62	0.41	72.27	13.7	19.27	Scurlock et al., (2000)
Phylotachys bambosoides	9.54	0.53	75.5	14.38	19.49	Scurlock et al., (2000)
Phyllostachys bissetii	21.97	0.9	64.99	12.14	19.51	Scurlock et al., (2000)
Bambusa vulgaris		2.7	76		19.050	Daza Montaño, (2015)
Bambusa strictus		5.6	75		18.728	Daza Montaño, (2015)
Guadua angustifolia		4.9	74		18.351	Daza Montaño, (2015)

2.2 Comparison of bamboo with other feedstock

Bamboo shares many desirable fuel characteristics with certain other bioenergy feedstocks. Its heating value can be higher than many woody biomass feedstocks and most of the agricultural residues, grasses, and straws (Sritong et. al., 2012). The ash content of agricultural residues and

herbaceous crops is usually higher, while the ash melting temperatures are generally lower. Higher concentrations of nitrogen, sulfur, potassium, and chlorine are often found, leading to the formation of harmful emissions (nitrogen oxides, sulfur dioxide, hydrogen chloride, particulate matter). These substances are involved in the corrosion process on metallic surfaces. In terms of overall techno-environmental performance, it has potential advantages over other lignocellulosic feedstocks (e.g. straw) as it does not require the production of seeds, and low or no fertilizers application (Daza, 2015).

Table 2. Properties of other common biomass feedstocks

Type of biomass	Moisture (%)	Ash (%)	Volatile matter (%)	Fixed carbon (%)	Higher Heating value (kJ/kg)	Reference
Rice husk	12.05	12.73	56.98	18.88	14.638	Sritong et al.,(2012)
Rice straw	10.12	10.42	60.87	18.80	13.275	Sritong et al.,(2012)
Bagasse	50.76	1.75	41.99	5.86	9.664	Sritong et al.,(2012)
Palm shell	12.12	3.66	68.31	16.30	18.446	Sritong et al.,(2012)
Corncob	40.11	0.95	45.55	13.68	11.198	Sritong et al.,(2012)
Corn stalk	41.69	3.80	46.98	8.14	11.634	Sritong et al.,(2012)
Tetrapleura tetraptera sawdust	9.44	2.42	-	-	19.4	Präger et al., (2019)
Triplochiton scleroxylon sawdust	50.96	3.24	-	-	18.4	Präger et al., (2019)
Celtis spp. sawdust	38.08	3.08	-	-	18.4	Präger et al., (2019)
Bambusa Deecheyama	14.30	3.70	63.10	18.90	15.700	Sritong et al.,(2012)
Dendrocalamus asper	5.80	2.70	71.70	19.80	17.585	Sritong et al.,(2012)

2.3 Pellets as energy products compared with traditional charcoal

Pellets made from bamboo presents a viable, cleaner and sustainable alternative to wood fuel and charcoal. Without such an alternative, wood charcoal will remain the primary household

energy source for decades to come—with disastrous consequences. Its high heating value also makes it an efficient fuel – compared with charcoal. The byproduct of traditional charcoal combustion—which is often incomplete due to poor combustion conditions, find their way into the atmosphere in the form of emissions which are toxic and/or contribute to global climate change.

Table 3. Techno-environmental performance of pellets compared with traditional charcoal

Parameter	Charcoal	Pellets	Effect
Technical			
Bulk Density	200 kg/m3	650 k/m3	Large storage space required for charcoal
Fixed Carbon	60-70%	15-20%	Possibility of incomplete combustion in absence of adequate air supply
Production	Traditional process	Modern scientific Technology	Inefficient production
Production Ratio	1 kg charcoal = 7 kg wood	1 kg pellet = 1.5 kg wood	High energy loss during production
Energy efficiency	5%	25%	Inefficient utilization of energy
Environmental			
Production Ratio	1 kg charcoal = 7 kg wood	1 kg pellet = 1.5 kg wood	Loss of Environmental resources
Raw material	Wood	Wood Waste	Pellets Limits deforestation, Utilization of waste Greater GHG emissions reduction potential
Economic			
Industry	Unorganized	Organized	Reduced labour exploitation
Social			
Ignition Time	20 min	5 min	
Ignition	Lots of smoke	Smokeless	
Cooking	Slow	Fast	
Flame control	No	Yes	
Fuel waste	Possible	No	

Data Source: Abellon CleanEnergy, Ghana

2.4 Climate change benefits – bamboo pellets are a low carbon energy source

Driven by growing concerns about emissions from other woody plants and fossil fuels, the bamboo plant may be the key to combating massive deforestation and mitigating climate change. Similarities to coal make bamboo and other wood pellets an ideal low carbon replacement.

- Reduces overall carbon footprint of power generation by 80% compared to coal
- High energy density and uniform shape enhance transportation and storage economics.

A report by European commission on sustainability requirements for the use of solid and gaseous biomass sources for electricty, heating and cooling determined that the reference GHG emissions value for coal-based electricity was 198 kg CO2/ MJ (EC, 2010). A report by Daza (2015), highlights the fact that when compared to coal-based electricity, the use of torrefied bamboo-Guadua as solid fuel in Netherlands results in a reduction of greenhouse gase emissions above 70%. When emissions saving from carbon accumulation and a potential bonus for restoring of degraded land are included, the GHG emissions reduction increases substantially leading to tremendous Carbon storage opportunities.

Table 4. Summary of GHG emission reductions of 1MJ of bamboo-based electricity as compared to fossil reference

Reference fuel comparison source		**EC (2010)**	**NTA 8080**	**SimaPro**
Coal based electricity reference emissions	Kg CO2 eq/MJ	198	199	194
		% GHG emissions reduction		
Bamboo source				
Bamboo exiting forest resource	26	87%	87%	87%
Residues from forest management	19.5	90%	90%	90%
Bioenergy crop from restoring degraded	-3.0	102%	102%	102%
Land				
Bioenergy crop including carbon stock	-320	262%	261%	265%

Source: Daza C.M., 2011

3. Bamboo Resources and their availability in Ghana

In Ghana, natural bamboo resources are estimated to be about 300,000 hectares and covers about 5% of the total forest vegetation (Obiri and Oteng Amoako, 2007). This is about 10% of the 3 million hectares of bamboo forest resources reported for seven Sub-sahara countries in Africa (Ethiopia, Kenya, Ghana, Nigeria, Uganda, the United Republic of Tanzania and Zimbabwe). Natural bamboo resources are noted to be available on community lands, farmlands, fallow fields and forest reserves (Obiri and Oteng-Amoako, 2007). Out of the 16 regions in Ghana (Figure.2), bamboo can be seen widely spread in about Seven (7) of them namely, Ashanti, Western North, Western South, Central, Eastern, and the Bono and Ahafo regions. Patches of bamboo clumps are also found in the Greater Accra, Volta and the Northern regions of the country.

The most common species found in Ghana is the Bambusa vulgaris which has a height of about 6m to 36m. About eighteen (18) exotic species have been introduced in Ghana through various development projects. These include *Gigantochloa albociliata*, *Bambusa edulis*, *Dendrocalamus brandisii*, *B. oldhanmii*, *D. asper*, *Guadua angustifolia*, *D. strictus*, *G. chacoensis*, *D. membrenaceus*, *Thyrosostachis siamensis*, *D. latiflorus*, *B. textilis*, *B. ventricosa* and *B. burmanica* (Forestry Commission, 2016).

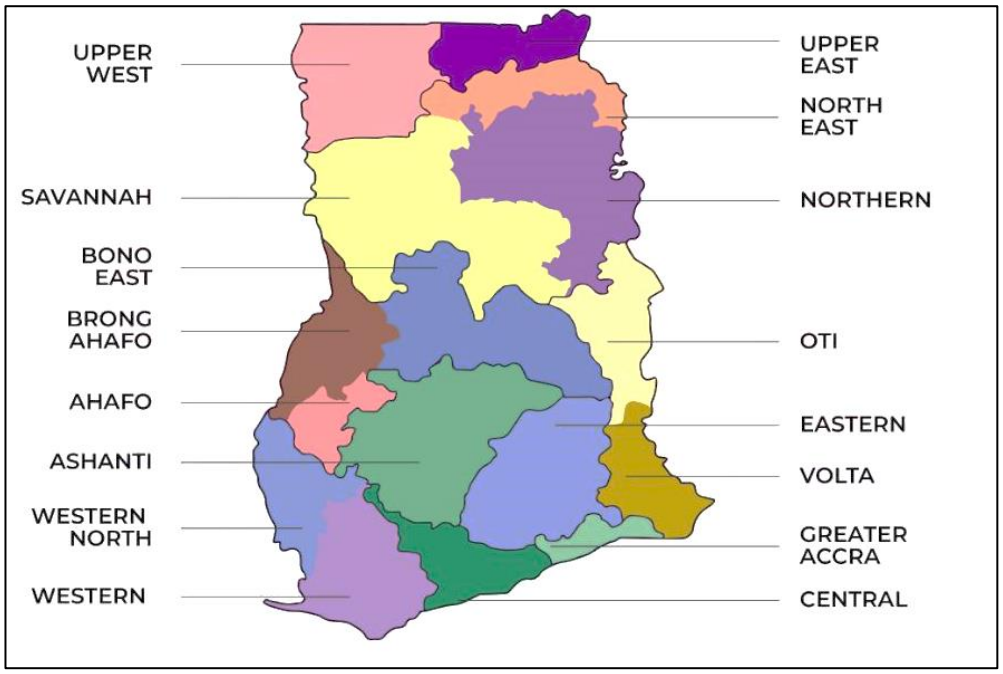

Figure. 2. The distribution of global bamboo resources and across Ghana

In comparison with forest timber species, bamboo has a short gestation period of five years and has a huge range of socioeconomic and environmental benefits. Their most important economic uses, more pronounced in the Southern part of the country include handcraft, baskets, building and construction, panel products and furniture. Although most bamboo resources grow naturally, greater attention has been paid in recent years to the establishment of bamboo in plantations. In some parts of Ghana, planted bamboo is generally being promoted for the restoration of degraded lands and to provide raw material and avoid depletion of naturally regenerated stands.

3.1 Productivity

There are many factors involved in the production of energy from biomass. Crop type and productivity are among the most important. In the case of bamboo, biomass productivity varies based on ecologies, bamboo species, age, and management. If planted in a region with optimal conditions and well-managed, bamboo can reach a maximum yield of nearly 50,000 kg/ha/year. In most of Sub Saharan Africa including Ghana, the total dry matter production of a 4-year bamboo under optimum condition ranges from 80 to 120 Mg ha-1 year-1 with a rotation cycle of 3–4 years (Partey et.al, 2017). Tropical bamboos such as the species found in Ghana can be harvested after just three years, rather than the two to six decades needed to generate a timber forest.

3.2 Economic and operational feasibility

The viability and sustainability of the bamboo pellet industry will depend on designing sustainable business models that are cognisant of the existing policy and institutional frameworks, the needs of target end-users, acceptance of pellets by potential users and more importantly the affordability of the pellets compared to the traditional firewood.

FAO (2008) reports that biomass production for bioenergy will offer developing countries new income sources, thereby reducing poverty and enhancing food security. When small-scale farmers have the opportunity to produce biomass independently or throughout-grower schemes, there may be net benefits.

4. What is the nature of existing production enterprises, global and local markets for bamboo pellet?

4.1 Pellet production businesses in Ghana - do they exist?

Although several biomass-based energy projects have been undertaken in Ghana with various degrees of success, pellet production businesses are new in Ghana. The clearest example is that of Abellon CleanEnergy Ghana Ltd, a subsidiary of Abellon CleanEnergy which has started operation in recent years with a target to export the product to Europe, India, and China. The company has built a pellet production mill in Ghana with a production capacity of 250 tonnes of pellets per day using sawdust from the Sokoban Wood Village in Kumasi (Figure 3). However, an important requirement in the production of bamboo pellets in Ghana is that the biomass should be collected not far from the generating plant. Thus, long distances to biomass collection areas and respective transport routes have to be avoided to avoid financial losses.

Figure 3. Abellone Biomass Pellets manufacturing facility, Ghana - Ghana Plant 100, 000 TPA installed in 2014

4.2 Circular economy – essential characteristics of efficient raw material supply chain

Bamboo pellets are originally produced from bamboo waste (such as sawdust and shavings), instead of the whole stalk, and thus can be viewed as an integrated part of forest product manufacturing. The raw material is dried, mechanically fractioned to size, and extruded under intense pressure into pellets. Key drivers of success in bamboo pellet production and marketing

will, therefore, include ensuring a consistent supply of raw materials with good energy qualities, appropriate technologies, and consistency in the quality and supply of the pellets.

Historically, there has been little or no attention paid to the recovery of bamboo waste and residues and all other wood waste from milling and landfill sites in Ghana. Existing and future mining, bamboo processing landfill sites can be designed to maximize this resource in a sustainable and environmentally beneficial way. The annual generation of wood residues from logging and wood processing is estimated to be about two million tonnes in Ghana (National Energy Policy, 2010). If carefully managed and exploited, logging and wood processing wastes could be an important addition to the feedstock for pellet production.

A workable bamboo pellet business model must highlight the principle of 'circular economy' as an important characteristic of efficient supply chains especially regarding the source of raw materials and feedstock for production. Circular Economy is a new social economy development path and the idea behind it is to keep products, components, and materials at their highest utility and value at all times and in a way that eliminates waste. Using a circular economy approach as part of the production process will mean using bamboo as the raw material feedstock and supplementing it with wood generated from product manufacturing and "feeding" it back into the production process through composting and pelletisation. In a way, very little goes to the landfill and it is a way to solve resource scarcity problems. Circular economy is therefore in line with the sustainable development goals (SDGs) and can lead to both economic and social benefits important for businesses, society, and the environment.

Figure 4. Unused potential of bamboo and wood waste

Figure 5. Widely practiced harmful and inefficient waste disposal

To also ensure a consistent supply of raw material resources, creating strong partnerships with key stakeholders, such as the municipalities, investors and other actors within the pellet value chain will be important drivers for the success of pellet businesses. Partnering with the private sector, for instance, for waste pre-processing and delivery will significantly reduce the cost of production. Similarly, partnering with municipalities or other organizations for resources, such as land, can be an important driver.

In addition to the resources and activities required for the production and selling of pellets, there is a need for research and development to harness technical and operational competencies and to enable the business to make pellets that have standard energy value and consistent properties.

4.3 Major Global Markets for Pellets

Over the past 10 years, the global production of wood pellets increased steadily, driven by a corresponding constantly rising demand (Thrän et al. 2017). The global wood pellet market has increased dramatically since 2011, with an average increase rate of 14% per year (IEA 2017). The major countries which are consuming maximum supplies of pellets are European countries, so they can be the target market. Reflecting on the major demand in Europe, the EU as a region is also by far the largest producer (2015: 54%), followed by North America (2015: 35%), which is mainly export-driven. Suitable target markets for wood pellets in Europe will Netherland and Denmark which have a huge requirement of wood pellets for their power plants as well as Sweden, Italy and the United Kingdom (IEA Bioenergy: Task 40). In Asia, South Korea and Japan continue to be the largest consumers, mainly supplied by Vietnam. However, China has set out a goal of using 30Mt of biomass pellets consumption by 2020 to replace 15Mt of coal.

The pellet market is not supply-driven and future pellet prices in the industrial sector, which dominates world trade, will depend on global market conditions, i.e., demand trends and supply capacities. Demand markets are still influenced to a large extent by policy frameworks providing incentives in different forms to biomass combustion (Thrän et al. 2017).

Although today developing countries do not play a significant role as suppliers for the European biomass demand, there are several indications that this is likely to change in the future. Developing countries are increasingly being seen as promising opportunities for pellet production by utilities, given the fact that tree growth rates are substantially higher, labor, land and investment costs are lower, and they are generally perceived as being relatively abundant in land. Six

countries, including Brazil, South Africa, Mozambique, Tanzania, Liberia, and Ghana have been identified as important emerging source countries for the European market some time to come.

In addition to it being processed into a vast range of wood products furniture to floorboards, and edible shoots, bamboo offers many new opportunities for income generation as a biofuel, briquettes, charcoal, and pellets.

4.4 Potential local market segments for bamboo pellets – consumption

Various local energy consumer segments have been identified as potential target clients for bamboo pellets. These include small and medium scale enterprises (SMEs), industrial users such as steel product manufacturers, cement factories, breweries, institutions such as high schools and private universities and households. However not all of these segments were found to be suitable for pellets due to their energy needs, their current source of energy and the existing type of stoves used. Energy consumers segments including SMEs, fish smokers, schools and batik manufacturers are found to be promising customer segments for pellets and thus warrant further studies to determine and quantify demand.

5. Recent developments in efficient technology

5.1 Available technologies

In recent years, new technologies are improving the economic feasibility of energy generation from pellets, particularly in countries that are heavily forested and have well-established wood processing industries. Pellets have attracted attention as an environmentally friendly alternative to fossil energy, and investments have been made to improve efficiency, especially with industrial applications, for heat and power generation. Pellets have a uniform size, shape, density and moisture content. These consistent qualities make it possible to design highly automated combustion systems such as modern pellet cooking stoves and boilers.

The conventional coal pots do not correctly support the use of pelletized sawdust as a possible replacement fuel for charcoal. Already in Ghana, Abellon CleanEnergy has introduced some pellet cooking stoves for sale on the local market (Figure. 6). Building on their existing designs it is possible for transfer of appropriate technologies and scalable models from Asia which will be important for promotion and local use of pellets and pellet cooking stoves as sustainable alternatives to the use firewood, charcoal and other energy products.

Figure 6. Abellon CleanEnergy Ghana Pellet based cookstoves on the market
Source: Abellon CleanEnergy Ghana

5.2 Potential socio-economic benefits from bamboo pellet production in Ghana

Bamboo pellets can be used as bioenergy to generate heat for cooking, boiling and warming in households. This alternative fuel could be produced and burned in modified stoves built to burn bamboo or wood pellets. Direct combustion of bamboo biomass can also be applied in industrial scale, for example, in form of co-generation to produce heat and power in thermal power plant for electricity production or other plants such as cement or steel (Truong and Thi, 2014). The co-generation helps reduce the amount of fossil fuel used in these plants. Bamboo and wood pellets can be the primary form of solid biomass used for electricity generation. The main uses and users are summarized below:

- **Industrial:** utility requirement for industrial units and Boilers and co-firing in thermal Power plants.
- **Commercial / Institutions / Small and Medium Enterprise:** heating needs at community level and large spaces such as malls, educational institutions, etc; cooking needs at Schools, Chops bars, restaurants, hotels; and used in agro-processing for heating and drying.
- **Retails: u**sed in pellet stoves for domestic / home cooking and heating.

6. Institutional, technical and policy environment to support bamboo pellet production

As in most other developing countries, policies and programs to promote bioenergy development are still in their early stages in Ghana. Although bamboo biomass pellets are not mentioned, most of the policies emphasize and encourage the sustainable use of firewood through the introduction of modern technologies that enhance efficiency in the exploitation of biomass resources, including the introduction of efficient cooking stoves and having a designated area for woodlots. Of notable mention are The 2010 Ghana National Energy Policy, Renewable Energy Master Plan (REMP)(2019), the Draft Bio-energy Policy (2010) and the Renewable Energy Act 2011 (Act 832). These provide the policy framework to foster sustainable and efficient energy generation for sustainable economic growth, and contribute to improved social life and reduce adverse climate change effects.

Notwithstanding the fact there are some policies, regulations and institutional and legal frameworks in place that support the use of biomass resources, Ghana will have to develop

stronger regulatory frameworks to remove constraints to market development and promote the uptake and utilization of bamboo and other bioenergy products. This is a key initial driver of the success of any industry and especially in proposing bamboo biomass pellets as a sustainable solution to the energy challenges. Such policies will also be important in motivating the business community to invest in the country's emerging bamboo pellets, briquette, and other bioenergy markets.

6.1 What are the potential challenges associated with using bamboo for bioenergy pellets?

Addressing the following technical, environmental, economic, socio-cultural, and policy challenges will be key to promoting bamboo pellets as bioenergy and renewable energy source in Ghana:

- A robust assessment of bamboo resource availability - Although there are estimates of the extent of bamboo resources in Ghana, Obiri and Oteng-Amoako (2007) report that indiscriminate harvesting and handling pose a serious threat to the resource. There is also a lack of field measurement to give a more accurate distribution, harvesting, and regeneration of bamboo at the clump level. Moreover, as in most other African countries National Forest Resources Assessments in Ghana rarely capture the necessary data (Sileshi & Arun, 2017). Fortunately, in Ghana, INBAR is currently conducting a nation-wide bamboo resource inventory that would help determine the available bamboo resource stock as well as the distribution in the various regions of Ghana.

- Additionally, few studies on the distribution of bamboo have focused on bamboo on agricultural lands. While data availability and quality have improved for all naturally occurring forests including bamboo since FRA 2005, trend data are still weak. There is no time series data on growing stock so the weaknesses in growing stock trend estimates are also directly translated into biomass estimates.

- According to Racz et al. (2013), in addition to the socio-economic effects mentioned, biomass production in the Global South can have significant environmental impacts as well. These include a) deforestation and forest degradation in instances where governance structures for effective forest conservation and sustainable forest management are weak. This will lead to biodiversity loss associated with overharvesting from natural bamboo forest stands and land-use change as a result of increased conversion of forest lands for monoculture bamboo plantations. Biomass plantations often also compete with food crops for the best, most fertile pieces of land. Competition for land for biomass production might displace lands meant for agriculture and food production thereby creating food insecurity and increasing food prices. As biomass feedstock

plantations require large amounts of land and often irrigation as well, local populations face the risk of losing the land on which they depend for their survival (FAO Forestry Paper 154, 2008).

- In several African countries including Ghana, populations have a high dependence on wood-based energy especially fuelwood and charcoal. When woody biomass, including bamboo pellets, are mainly produce for export and are no longer available for local use, it can threaten local energy security.

7. Conclusions and Policy Recommendations

This paper assessed the potential of bamboo as a feedstock for bioenergy pellet production along with the delivery of socio-economic and environmental benefits and challenges in Ghana. We believe that, with proper planning, management, and harvesting, bamboo has great potential to be used as a feedstock for bioenergy production in Ghana. Bamboo is locally available, is fast-growing, has multiple uses, can rapidly store and sequester carbon, grows in degraded lands, and has good fuel characteristics for modern bioenergy production. The following recommendations have been made with respect to the sustainable development of bamboo biomass for bioenergy production in Ghana.

- We recommend further studies on the production and management of bamboo for bioenergy in the country, such as how much bamboo is locally available for bioenergy production, what species are best suited for bioenergy production, energy content of bamboo-based bioenergy fuels, potential areas for future plantations and to what extent GHG emissions would be reduced by using bamboo for pellet production.

- There is potential for the exploitation and utilization of wood waste and residues which is deemed as a burdensome waste in many timber and wood processing industries as a supplement to bamboo for use in the production of biomass pellets.

- The use of industrial and bamboo processing waste and blends of residual biomass with that from wood processing industries must be promoted as a sustainable feedstock for the near- to medium-term future. However, for the long-term industrial bamboo plantations must be developed to support the use of bamboo for pellet and bioenergy production.

- The major policy issue that needs to be addressed in order to create an environment for the effective exploitation of waste to energy is the effective collection and management of waste. There is, therefore, the need for the government to create incentives for the use of industrial wastes for energy purposes.

- Many years after the bioenergy policy has been prepared by the Energy Commission, the draft was yet to be adopted by the Government, and full implementation of policy

recommendations is yet to commence. The is the need to lobby the government to ensure full implementation of the National Bio-fuel policy recommendations and to devise and prepare appropriate supporting regulations to govern the biofuels sector in Ghana.

- Bamboo provides new opportunities for biomass pellet production and trade, but their market uptake is not yet visible in Ghana. The sustainable and commercial production and use of bamboo pellets must be encouraged with a range of education and awareness creation as well as incentives for sustainable supply, production, and utilization of bamboo pellets.
- The capacity of large and small scale bamboo enterprises must be enhanced for improved value addition to products by way of pelletizing residues from processing. The export market will be a focus on promoting bamboo pellets production while encouraging local consumption and use of pellets and other bioenergy products.
- Promote affordable and more efficient conversion technologies, including pellet stoves for local use and consumption of bamboo pellets.
- In addition to the resources and activities required for the production and selling of pellets, there is a need for research and development to harness technical and operational competencies and to enable businesses make pellets that have standard energy value and consistent properties. There is, therefore, a clear need to increase support for relevant research institutions to improve research on the use of bamboo pellets and other bioenergy production.

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