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Technical Paper

Synthesis Review of Bamboo Bioenergy Production in Africa

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About the International Bamboo and Rattan Organisation

The International Bamboo and Rattan Organisation, INBAR, is an intergovernmental organisation dedicated to the promotion of bamboo and rattan for sustainable development. For more information, please visit www.inbar.int.

About this Working Paper

– This research was carried out by the International Bamboo and Rattan Organisation (INBAR) as part of the CGIAR Research Program on Forests, Trees and Agroforestry (FTA). FTA is the world's largest research for development programme to enhance the role of forests, trees and agroforestry in sustainable development and food security and to address climate change. CIFOR leads FTA in partnership with Bioversity International, CATIE, CIRAD, INBAR, ICRAF and TBI. FTA's work is supported by the CGIAR Trust Fund: http://www.cgiar/org/ funders

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List of Abbreviations

CDM	The clean development mechanism
CER	Certified Emission Reductions
CHP	Combined Heat and Power
CO	Carbon Monoxide
CPA	Certified Public Accountant
CSR	Corporate Social Responsibilities
EEFRI	Ethiopian Environment and Forest research institute
EnDev	The Energising Development Programme
EU	European Union
EUEI PDF	European Union Energy Initiative Partnership Dialogue Facility
FAO	Food and Agriculture Organization of the United Nations
FI	Financial Institute
FRA	Forest Resource Assessment
GGGI	The Global Green Growth Institute
GHG	Greenhouse gas
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH
GrEEn	Green Employment and Enterprise
GWP_{CH_4}	Global Warming Potential of CH4
HVRT	Hot vapor retention/residence time
ICS	Improved Cookstoves
IEA	The International Energy Agency
IFAD	The International Fund for Agricultural Development
IFC	The International Finance Corporation
INBAR	The International Bamboo and Rattan Organisation
IRENA	The International Renewable Energy Agency
ISO	International Organization for Standardization
IWA	The International Workshop Agreement
LPG	Liquefied Petroleum Gas
MSME	Micro, Small, and Medium Enterprises
NDC	Nationally Determined Contribution
NGO	Non-Governmental Organization
PforR	Programme for Results
PM2.5	Particulate Matter of 2.5 microns or less in width

PPP	Public-Private Partnership
RBF	Results-Based Financing
REDD+	Reduce emissions from deforestation and forest degradation, and foster conservation, sustainable management of forests, and enhancement of forest carbon stocks
RT	Retention/Residence Time
tCO_2	Ton of CO_2
TLUD	Top loading updraft
UNFCCC	The United Nations Framework Convention on Climate Change
UNIDO	The United Nations Industrial Development Organization
USD	United States Dollar
VCS	The Verified Carbon Standard
VOC	The volatile organic compounds
WB	The World Bank

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Executive summary

Bamboo is highly versatile perennial plant which grows in several locations around the world. Bamboo can naturally grow and live in warm and humid conditions. Bamboo has the advantages of rapid growth, carbon sequestration, growth in degraded lands, light weight, high yield, and desirable fuel characteristics. Bamboo is known as the plant of thousand uses. It can be used for construction materials, furniture industries, flooring, musical instruments, charcoal making, and as a fuel source for heat and electricity generation.

The utilisation of bamboo as bioenergy source in Africa is still underutilised despite covering 7.2 million hectares of land. Therefore, this working paper has two main goals; the first one is to provide technical background about the different technologies that can be used to generate bioenergy from bamboo and to present some relevant success stories around Africa and the world. The second goal is to recommend some interventions that can help mainstream the bamboo bioenergy production in Africa. The effects that such interventions can have are also studied for the different INBAR African countries in terms of projection scenarios up to 2040.

Methodology

To achieve the abovementioned objectives, it is important to have good understanding for the baseline situation of using bamboo as a bioenergy fuel or as a raw material for other products. To guarantee the quality of the baseline assessment, the data collection was based on diversifying the data sources to cover the perspectives of several countries and several categories of stakeholders. Hence, a mixed approach combining the following sources was followed:

- A virtual focus group meeting gathering various stakeholders from different countries
- Online one-to-one meetings with specialised experts
- Two field missions to Ethiopia and Ghana
- Literature review of previously conducted studies on bamboo generally, specifically bamboo bioenergy

Part 1: Different technologies that can be used to generate bioenergy from bamboo and some relevant success stories

There are several technologies that can be used to generate bioenergy from bamboo including direct combustion, pyrolysis, gasification, biochemical conversion, and pelletisation. Combustion is the most commonly used and established technology for the purpose of providing thermal and electric energy from biomass. In a combustion process, biomass fuel is

combusted with oxygen from the air to produce heat. Combustion is the technology that is applied in the conventional small cookstoves (where the energy efficiency is very low), the improved cookstoves, the well-engineered industrial equipment (where the energy efficiency is much higher), and in the electricity generation plants. Section 3.1 presents some more details with focus on the improved cookstoves with its different tiers and fuel categories. Biomass pellets is a form of energy preferred by a lot of industries, and by the European market as well where it is used for the district heating system. The biomass pelletisation process includes number of steps starting with raw material pre-treatment, followed by pelletisation and finally post-treatment. Section 3.5 presents more details about that technology.

Pyrolysis is the thermal decomposition of organic materials at a temperature range from 350 to 600 ºC in the absence of oxygen. Pyrolysis process products are charcoal (solid phase), condensable pyrolysis oils (liquid phase; also known as tars) and non-condensable gases (gaseous phase). At low heating rates, high residence time and moderate temperature, slow pyrolysis takes place and thus charcoal is the main product. On the other hand, at high heating rate, low residence time, and high temperature, fast pyrolysis takes place and thus bio-oil is the main product. Slow pyrolysis technology is much more widely available due to its simplicity. In Africa, most of the charcoal is generated using open-pits/open-domes (not in controlled mechanised kilns); hence, generating huge amounts of air pollutants including particulate matter and carbon monoxide, which adversely affects the charcoal yields. To overcome such drawbacks, there are some famous mechanised kilns that are commercially used for charcoal production; such as, retort technology and metal kiln technology. To densify the charcoal, increase its energy density and have low-smoke feature, it can be converted to either pellets or briquettes; with the latter being the most popular. Briquettes are either cylindrical extrusions measuring diameter of 25 (mm) to 80 mm and length of up to 300 mm, or individually pressed bricks of various sizes. Bamboo charcoal briquettes area already produced in several African countries.

Gasification is the production of a gaseous fuel from a solid fuel such as wood, bamboo and agricultural residues in a reactor called gasifier. It is a complex thermal and chemical conversion process which occurs at high temperature under limited air supply. The generated gas (called syngas) can be directed to an electric generator to produce electricity. There are many commercial-scale gasification technologies in use. For the African context, and where the main objective will be supplying the electricity-deprived off-grid areas with electricity, the gasifiers will be of small-scale (mostly not more than 2 MW). Hence, in this case the downdraft

fixed-bed technology will be exclusively used. On the other hand, and away from the thermochemical conversion that depends on high temperature, there is another energy conversion route which is the biochemical. Biochemical conversion utilises different strains of microorganisms to work on the fermentation of contained sugar or other substances in biomass to be converted into ethanol, methane, and other fuels. This is the main technology behind the bioethanol production.

In different parts across the world, the bioenergy production has become more developed and mature to the extent that it stated to completely or partially displace coal in large-scale energy facilities. Hence, there is a significant potential for bamboo to be used in such big scale energy facilities soon. Section 4.2 presents more details about that. Currently, there are already successful bamboo bioenergy projects in Africa. This includes several bamboo charcoal facilities in Ghana, Uganda and Ethiopia. The produced bamboo charcoal briquettes are sold in the big supermarkets and promoted as smokeless charcoal. In addition, bamboo is used for electricity generation in an off-grid facility in Madagascar. Section 5 presents more details about such success stories.

Part 2: Recommending some interventions that can help mainstream the bamboo bioenergy production in Africa

This part of the working paper aims to recommend some interventions that can help mainstream the bamboo bioenergy production in Africa. The effects that such interventions can have will be studied for the different INBAR African countries in terms of projection scenarios up to 2040. Hence, it is important to provide some categorisation for the African countries in order to represent their different national circumstances and accordingly the different potential pick-up rate for bamboo bioenergy valorisation.

Categorisation of African INBAR Member States

There are 20 African INBAR countries, but these countries have different bamboo resources, and different national circumstances in terms of bio-energy needs. In the African region, Nigeria, Ethiopia, Cameroon and Madagascar are the top countries in terms of planted bamboo area. Exported bamboo products from the African countries are mainly furniture, seats, etc., while the bamboo charcoal trade was found to be only in 12 INBAR member countries with Nigeria having the lion share. Energy in the African region is insufficient for demands compared to developed world. More than 600 million people do not have access to electricity, and more millions are connected to unreliable grids that do not meet their energy demands. Furthermore, most of the countries in this region have electricity access rates

ranges between 25 and 50 %, while there are around 6 countries less than 25% of access rate. Meanwhile, electricity production differs from a country to another in this region with some countries still have electricity deficit and not being able to cover their demands like; Benin, Togo, Senegal and Malawi. Section 6.1 and 6.2 provide important analysis for the different countries.

Based on analyzing the current status and the existence of successful bamboo businesses (i.e., bamboo bioenergy or industrialised bamboo products), the Consulting team has classified INBAR African countries into two major categories. Category A includes the countries owning successful bamboo businesses, and category B includes the countries lacking successful bamboo businesses. The rationale behind such categorisation methodology is that usually the policymakers need to see proofs on the ground for the financial viability in order to be motivated to apply any recommended interventions. The Consulting team believes that there are some factors that can enable some countries be enhanced faster than others under the same category. Consequently, it is proposed to divide each category into two sub-categories, where the differentiation was based on the anticipated pace of enhancement. The considered factors in the proposed analysis are: the current bamboo planted area, non-bamboo charcoal exports, non-bamboo charcoal domestic use, availability of REDD+, Net Zero Carbon commitment, ethanol commitment, electricity access rate, committed plantation area, existence of industrialised bamboo products, existence of oil and gas industry, and existence of cement industry. By analyzing such factors, each country has a certain score percentage; hence, they are assigned to sub-categories. Simply, under Category A, the countries with high scores were identified to be Sub-Category A-1, and vice versa for Sub-Category A-2. The same applies for Category B as well. Section 6.3 in the working paper presents more details on the categorisation, and shows the countries that fall under each of the categories/sub-categories.

Recommended interventions for bamboo bioenergy mainstreaming

Based on the baseline assessment of bamboo bioenergy industry, the Consulting team found that the bamboo bioenergy industry needs many interventions to be taken to a higher level. The proposed interventions are classified into two major classifications: “Unlocks” and “Supports”. “Unlocks” refer to interventions that provide solutions to the root cause problems, which can help debottleneck the bamboo bioenergy situation. On the other hand, “Supports” refer to interventions that can help flourish and catalyse the bamboo bioenergy situation if applied together with the “Unlocks”. The recommended unlocks and supports are related to

the enabling environment, institutional arrangements, and coordination mechanisms. The Consulting team recommends 13 “Unlocks” and 8 “Supports”.

Recommended “Unlocks”

The first proposed “Unlock” is that expanding bamboo industry automatically boosts bamboo bioenergy. A lot of wastes are generated from bamboo processing, and those wastes are accordingly perfect raw materials for bioenergy generation either to generate charcoal, charcoal briquettes, be used as fuel source in boilers or generators. This is already applied in two bamboo processing facilities in Ethiopia for example. Not only the wastes generated from the “mechanised” bamboo processing industry can be used for bioenergy production, but also the wastes generated from the bamboo handicrafts manufacture. Hence when the policymakers in Africa focus on supporting the bamboo processing industry and handicrafts, this will not only have positive economic, social and environmental benefits, but it will also help boost the bamboo bioenergy production.

The second proposed “Unlock” is issuing policies to provide market advantage for the sustainable charcoal produced from bamboo and other sustainable sources. Since charcoal is a key fuel source in the African countries and it is also being exported by several countries, there is a need to regulate such sector to decrease the deforestation rate, and minimise the negative environmental and social impacts (e.g. air pollution and soil erosion). Since the situation of the African countries is different regarding the charcoal sector regulations, it is important to build on the progress done in each African country in this topic and add some ideas. One of such ideas is to replicate Egypt’s success in transforming the charcoal sector to employ “mechanised kilns” instead of “Open pits”. The key step in that transformation was a regulatory action to ban the charcoal exports unless the producer provides the documents proving that he/she is officially registered and is employing mechanised kiln rather than open pits/domes. The main idea here was to regulate the sector from the “export” side since this is easier in terms of control. This can be a good start which will then gradually transform the local market producers as well when they see the benefits of high yield, high production rate and the allowed exports for those employing the mechanised kilns. One other component that the African countries can add is to gradually mandate using alternative fuels for charcoal making. This can include bamboo and other agricultural residues.

The third proposed “Unlock” is fulfilling the EU market demand to the sustainable charcoal by supporting its manufacture and export. The EU has announced its target of being carbon-neutral by 2050, and to achieve ‘at least 55%’ emissions reduction by 2030. Charcoal has been approved to be used throughout Europe in organic farming as a fertiliser/soil conditioner

based on an official regulation issued in December 2019. Hence, and as a climate change mitigation action, the EU is willing to increase using charcoal as soil conditioner. If the African policymakers have issued and implemented policies and action plans to facilitate and encourage the production of bamboo charcoal and exporting it to the EU, this will have positive impacts on the local economy, and will also have significant socio-economic benefits to the citizens working on the all the value chain components of such charcoal facilities. From the local bioenergy perspective, and since bamboo will be planted more in the African countries, the farmers will definitely use bamboo as the main fuelwood source.

The fourth proposed "Unlock" is supporting the investors with land provision for bamboo plantation. From the meetings with several African investors, the financial feasibility of the bamboo bioenergy projects will be enhanced when there is more control on the bamboo supply chain. Many investors complained from the bamboo raw material supply chain, and some of them attributed their slow business progress to that factor. Based on the success achieved in China when the government implemented a land tenure reform, the African policymakers are much encouraged to revisit the current land tenure system, and develop attractive models to lease the bamboo forests to farmers/investors against any warranties they see appropriate. This will help flourish the bamboo industry generally and bamboo bioenergy specifically.

The fifth proposed "Unlock" is developing attractive financing mechanisms that suit the small-scale bamboo bioenergy entrepreneurs. For small entrepreneurs in Africa, commercial banks usually lend at a high interest rate, which is not feasible. One of the most successful experiences in Ghana that was able to unlock such a challenge is the 'Orange Corners Innovation Fund' under the 'Fidelity Bank Young Entrepreneurs' Initiative'. It is a revolving fund which can have up to 50,000 euros as a loan, including a 30% grant with a 5% interest rate. Away from the Orange Corners Fund, the Fidelity Bank has its own fund structure, which focuses on supporting young entrepreneurs providing a 10% interest rate per annum for MSMEs. Through discussions with the fund management entity, it is clear that the Fidelity Bank is willing to issue new phases of this programme. In addition, the Dutch government is willing to replicate this in several other African countries. Hence, the African policymakers are strongly recommended to coordinate with the Dutch government and other donors to have wider-scale similar programmes and preferably with higher investment cap per beneficiary.

The sixth proposed "Unlock" is supporting the world in achieving its net zero target by hosting bamboo plantation and bioenergy projects. According to Paris Agreement (adopted by 196 countries), developing countries will implement ambitious mitigation actions with enhanced support from developed countries. In the last few months, and during the preparations of

UNFCCC COP 26 in Glasgow, there has been global pressure to reach net-zero emissions by 2050. Some countries have already committed to it in law, some others have committed in an official policy document, and some others have reported a pledge. To achieve net-zero emissions, big emitters (e.g. USA and EU) need to conduct radical reductions in their emissions and offset their remaining emissions through financing green projects in other countries. Given the high climate change mitigation potential of bamboo, African countries can support the world in achieving its net-zero target by hosting bamboo plantations in the areas devoted to land restoration and reforestation. Moreover, and given the large areas of bamboo that can be planted, African countries can host international investors willing to develop large-scale bamboo-to-ethanol plants (such as the one in India, which will start production soon). The produced ethanol can then be exported to countries with bio-ethanol blending commitments. In addition, the large areas of bamboo can also facilitate the construction of bamboo-based decentralised power plants in African rural areas lacking electricity access. Such local projects will have further GHG emission reduction impacts through the displacement of fossil fuels. Moreover, the large areas of bamboo will facilitate improved and large-scale bamboo processing industry in Africa. This will result in further replacement for timber-based products and, hence, less deforestation and further reduced GHG emissions. Hence, it is much recommended that the African policymakers shortly start having high-level discussions with the governments of the developed countries about such concept and its operationalisation means.

The seventh proposed "Unlock" is utilizing the UNFCCC REDD+ results-based payments to enhance the amount of planted bamboo. Given the high carbon sequestration potential of bamboo, planting it will support the African countries in achieving their REDD+ targets. Hence, it is much recommended that the African countries include bamboo in the corresponding strategy and action plan as this will definitely help boost the bamboo industry and bioenergy.

The eighth proposed "Unlock" is integrating the development of decentralised bamboo bioenergy projects in the relevant results-based financing (RBF) programmes. RBF is a financing mechanism whereby the donor disburses funds to a recipient after it has been verified (via an independent verification agency) that a pre-agreed set of results has been achieved. One of the most successful energy-related RBF programmes was the Energising Development (EnDev) programme that has been active between 2013 and 2020 in several countries including 8 African INBAR countries, where the relevant products sold were improved cookstoves and minigrids. It is much recommended that the African policymakers coordinate with GIZ regarding having a new phase for the programme which focus on the "fuel"

side rather than only the "equipment" side. Hence, the focus should also include having diversified alternative fuel sources (e.g. bamboo) that can be employed in the advanced cookstoves.

The ninth proposed "Unlock" is maximising the utilisation of the carbon finance resources for developing bundle of small-scale projects. The African countries need to utilise the carbon markets to finance the small-scale bamboo bioenergy projects (mostly charcoal or decentralised electricity production). Usually, due to the high transaction cost of project development, it is not economic that each small investor proceeds with registering his/her project. Hence, the norm in such situation is to have a bundle of similar projects registered together. This necessitates either a governmental organisation (e.g. Ministry of Environment) or NGO or a private carbon project developer to take the lead in project development by coordinating with each of the small-scale investors. Hence, it is much recommended that the African policymakers take the first step and contact the famous project developers to provide them with an overview about the bamboo and how it can be integrated among a wider programme for bioenergy.

The tenth proposed "Unlock" is enhancing the capacity of bamboo business owners about the business development and marketing paths. The Consulting team noticed in the field missions that some business owners lack some basic knowledge about the paths that they can follow to maximise the marketing of their bamboo bioenergy products. In this intervention, it is recommended to have a public-private partnership in terms of capacity building sessions under the supervision of the most bamboo-relevant public institution.

The eleventh proposed "Unlock" is using the "Smokeless charcoal" phrase for marketing the bamboo charcoal briquettes. One of the key field study findings is that the urban consumers specifically like to have smokeless charcoal (or low-smoke charcoal); hence, they buy it without focusing much on its source. Hence, this "Unlock" is very important to be applied by the bamboo charcoal business owners (energy providers) and will gradually help having much increased share of bamboo charcoal in the local market in each country.

The twelfth proposed "Unlock" is that paving the way to alternative fuels opens the door to bamboo bioenergy. Insisting on mainstreaming bamboo bioenergy separately can result in missing some important institutional and funding opportunities. For example, if the forestry department in a country focuses on bamboo bioenergy, but it did not communicate that with the department of alternative fuels in the ministry of Energy, bamboo will not be considered in the national alternative fuels action plan, and accordingly not considered in any relevant funds. Hence, governmental coordination in this regards is crucial.

The final proposed "Unlock" is enhancing the awareness of citizens and governmental officials about bamboo success stories. A lot of citizens and government officials got surprised when they know that the toothpicks or furniture they use are manufactured from bamboo and imported. If the citizens and governmental officials get exposed to effective awareness sessions mentioning the success stories of bamboo products and bio-energy products in Africa and Worldwide, this can have a significant impact on the market acceptance of the bamboo products. This can accordingly result in nearly new markets and accordingly enhanced bamboo industry and bioenergy. Section 7.2 presents more details about each of those "Unlocks".

Recommended "Supports"

The "Supports" recommended by the Consulting team include provision of duty-free incentives for sustainable bioenergy equipment, creating business associations for alternative fuels and for bamboo, increased collaboration with China and India, relevant active NGOs to act as implementing entities for bioenergy projects, coordinating with the big emitting companies to target supporting bamboo bioenergy as part of their CSRs, policymakers to target adoption of high-production efficient charcoal kilns, investors to target diversification of their bioenergy resources for business sustainability, and governmental coordination to have annual purchases of bamboo products for facilities like schools. Section 7.3 presents more details about each of those "Supports".

Scenario analysis for enhancing bamboo bioenergy production

Based on the abovementioned categorisation and sub-categorisation, two types of scenarios: "maximum potential scenarios" and "moderate scenarios" were developed for each country. For each scenario, the total cost required for developing bamboo bioenergy projects was calculated together with the corresponding GHG emission reductions. This was calculated on yearly basis till 2040. The maximum potential scenarios will be analysed for each country based on two crucial points: the maximum area that can be planted in this country and the maximum bioenergy target. For the countries of category A and category B, the maximum annual area growth rate is proposed to be 2.5% and 1.5% of the current bamboo planted area, respectively.

Away from the maximum potential, the proposed bamboo planted area in the moderate scenarios is a percentage of the maximum potential. This percentage was assumed to be the same scores that the country achieved while defining the sub-categories. If the country applies a lot of the recommended "Unlocks" and "supports" (e.g. tax exemption, preferential loans and grants, carbon financing…), it can approach its full potential.

For each type of scenarios, three sub-scenarios are proposed according to the share of the planted bamboo in the bioenergy. The first sub-scenario proposes that all the new planted area will be directed to bioenergy projects (electricity, ethanol and charcoal). The second sub-scenario proposes that all the planted area will be directed to industrialised bamboo products. In this case, the bamboo bioenergy (i.e., bamboo charcoal) will be just a fraction of the planted area. For the third sub-scenario, it is a hybrid approach of the previous two sub-scenarios.

For the proposed scenarios, the first three years (2022-2024) are allocated for plantation of bamboo. During these three years, there will be establishment of the electricity generation power plants which can be in operation starting from 2025. The ethanol production is assumed to start two years after power production (i.e., starts by 2027). Section 8.1 and 8.2 in the working paper present more details about the scenarios' methodology, inputs and assumptions.

For each scenario proposed, the results show big differences between the countries in the absolute and cumulative GHG emission reductions and costs. These differences are due to the differences in both the proposed planted areas and the score percentage of each country. For sub-scenario I of "Category A" countries for example, the cumulative costs required to develop bamboo bioenergy facilities range between 10 and 815 million USD, and the GHG emission reductions range between 1 million and 60 million tCO_2. Section 8.3 and 8.4 in the working paper presents several graphs and tables showing the results of the different scenarios for each country under both Category A and Category B.

1 Introduction

Bamboo is highly versatile perennial plant, which grows in several locations around the world. Bamboo can naturally grow and live in warm and humid conditions (i.e., tropical, subtropical and temperate regions), and they are distributed approximately within 50°N-47°S (Bahru and Ding, 2021). According to the Global Forest Resource Assessment (FRA) 2020, bamboo has been reported to cover about 35 million hectares of land worldwide with total of 7.2 million hectares in Africa alone (FAO, 2020).

Bamboo has the advantages of rapid growth, carbon sequestration, growth in degraded lands, light weight, high yield, and desirable fuel characteristics. Bamboo is known as the plant of thousand uses (Xu, et al., 2020). It can be used for construction materials, furniture industries, flooring, musical instruments, charcoal making, and as a fuel source for heat and electricity generation (Emamverdian, Ding, Ranaei, and Ahmad, 2020).

This report has been developed based on the key findings achieved from meeting African and Asian stakeholders, conducting 2 missions in Ghana and Ethiopia, in addition to literature review. This report is classified into two main segments; the first one aims to provide technical background about the different technologies that can be used for bioenergy generation from bamboo and present some relevant success stories from Africa and the world. The second segment aims to recommend some interventions that can help mainstream the bamboo bioenergy production in Africa. The effects that such interventions can have are also studied for the different INBAR African countries in terms of projection scenarios up to 2040. Chapters 3-5 belong to the first segment, while chapters 6-8 belong to the second segment.

2 Baseline assessment highlights

In order to achieve the afore-mentioned objectives, it is very important to have good understanding of the baseline situation for bamboo usage as a bioenergy fuel or as raw material for other products. This section will briefly present the methodology, followed by the interviewed stakeholders during such baseline assessment.

2.1 Methodology

The methodology followed for baseline data collection was based on diversifying the data sources to cover the perspectives of several countries and several categories of stakeholders. A mixed approach combining the below sources was followed:

- A virtual focus group meeting gathering various stakeholders from different countries
- Online one to one meetings with specialised experts
- Two field missions to Ethiopia and Ghana
- Literature review of previous conducted studies for bamboo generally and bamboo bioenergy specifically

The following section shows the interviewed entities throughout this study so that the reader can have a closer idea about the main sources of information used.

2.2 Interviewed entities throughout the study

2.2.1 *Focus-group meeting*

Entity	**Category**	**Country**
Stockholm Environment Institute	Non-governmental organization (NGO) in sustainable development and environmental issues	Kenya
LiPRO Energy GmbH and Co. KG	Combined Heat and Power (CHP) plants private business company	Germany
University of Ibadan	Educational entity, University	Nigeria
PROSPERER	IFAD program	Madagascar
Global Bamboo Products Ltd	Social enterprise in the development of bamboo and other non-timer forest products	Ghana
Women In Action Against Poverty	NGO in the field of poverty fight	Ghana
Clean Power Indonesia	Biomass private business company	Indonesia
PT Bambu Nusa Verde	Bamboo private business company	Indonesia
GGGI	Treaty-based international, inter-governmental organization	Indonesia
INBAR East Africa Office (Ethiopia)	Intergovernmental development organization	Ethiopia

INBAR Project Office (Uganda)	Intergovernmental development organization	Uganda
CIFOR	NGO in the field of tropical forests	Indonesia
Ethiopian Rural Energy Development and Promotion Center	Governmental entity, Energy Studies	Ethiopia
Bidipa company Ltd	Charcoal private business company	Ghana
GoodFire Ltd	Clean cooking private business company	Uganda
Vision Nature Africa Green	Clean cooking private business company	Uganda
Josa Green Technologies Ltd	Clean cooking private business company	Uganda
BammGo	Bamboo private business company	Ethiopia
Green Pot Enterprises	Bamboo private business company	Kenya
Ethiopian Environment and Forest research institute (EEFRI)	Governmental entity, Forestry Commission	Ethiopia
Kontiki Bamboo Works Ltd	Bamboo private business company	Uganda
GREEN LENS	NGO in the field of cookstoves	Uganda
National Forestry Authority	Governmental entity, Forestry Commission	Uganda
National Forestry Resources Research Institute	Governmental entity, Forestry Commission	Uganda
Friends of Bamboo Consults Limited	Bamboo plantation and consulting	Uganda
Food and Agriculture Organization of the United Nations- FAO	Specialised agency of the United Nations	Uganda
The Ghana Alliance for Cookstoves and Fuels	Cookstoves private business company	Ghana
Wealth from waste	Biomass private business company	India
INBAR HQ (China)	Intergovernmental development organization	China

2.2.2 *Online one-to-one meetings*

Entity	Category	Country
GROWMORE BIOTECH LTD.	Bamboo plantation and consulting	India
Aprovecho Cookstoves Research Center	RandD for cookstoves manufacture	USA
Ethiopian Environment and Forest research institute (EEFRI)	RandD for bamboo bioenergy	Ethiopia
EcoSecurities	Carbon markets	Switzerland

2.2.3 *Ghana field mission*

Entity	Category
Energy Commission	Governmental entity, Ministry of Energy

Sustainable Energy and Environmental Solutions	RandD for bamboo plantation and bioenergy
Ghana Alliance for Clean Cookstoves and Fuels (GHACCO)	NGO in the field of cookstoves
KWAMOKA bamboo processing Limited	Bamboo private business company
Orange Corners Innovation Fund/Fidelity Bank	Financing Entity
Boosting Green Employment and Enterprise Opportunities in Ghana (GrEEn)	Relevant donor project
GAMMA Energy	Bamboo private business company
Global Bamboo Company Limited	Bamboo private business company
Bamboo and Rattan Unit (BRU) affiliated to the Forestry Commission	Governmental entity, Forestry Commission
Random bamboo transporters	Bamboo value chain
Random bamboo distributors	Bamboo value chain

2.2.4 *Ethiopia field mission*

Entity	Category
Adal Industrial PLC	Bamboo private business company
Alternative Fuels Department, Ministry of Water and Energy	Governmental entity, Ministry of Energy
Ethiopian Clean Cooking Alliance Association (ECCA)	NGO in the field of cookstoves
Chalachew and Teamer Briquette Charcoal Enterprise	Bamboo private business company
INBAR Dutch-Sino East Africa Bamboo Development Programme	Relevant donor project
Pro Star Bamboo	Bamboo private business company
Ethiopian Environment, Forest and Climate Change Commission	Governmental entity, Ministry of Environment and Forests
Gogle Energy Saving Stoves and Engineering PLC	Cookstoves manufacturer and Bamboo private business company
INBAR-Inter-Africa Bamboo Project	Relevant donor project
The Nature and Biodiversity Conservation Union	Relevant donor project
Random bamboo handicrafts manufacturers	Bamboo private business MSME companies

3 Potential bioenergy production technologies from bamboo

This section covers some technical details about the different technologies that can be used to extract energy from bamboo. Figure 1 below shows a summary of the different energy conversion methods (Siedlecki, De Jong, & Verkooijen, 2011)**.**The following sections present more details about each.

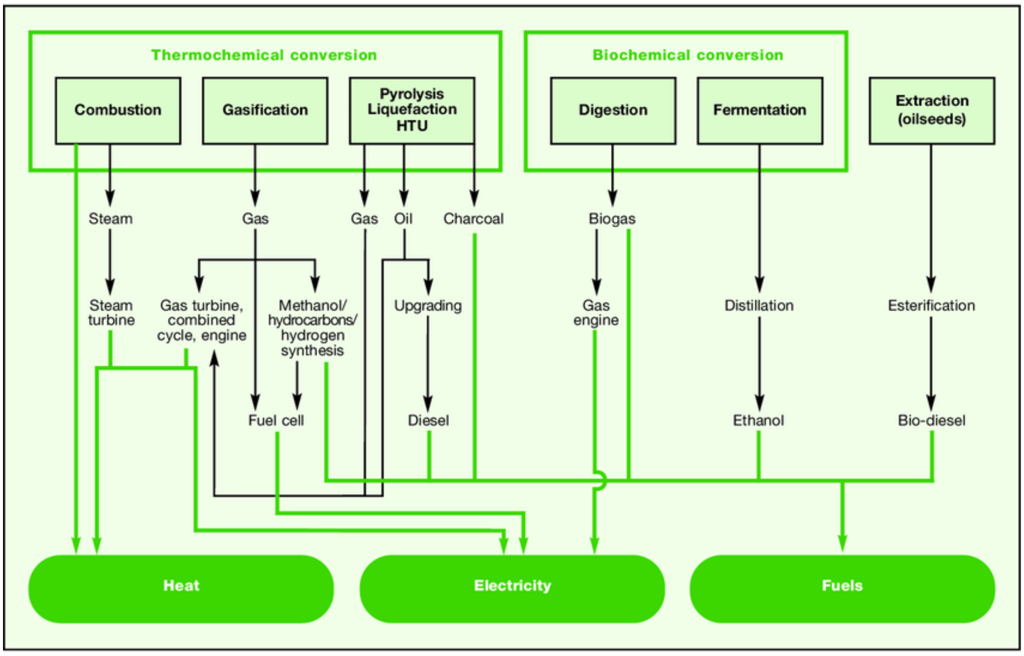

Figure 1. Biomass to energy conversion methods (Siedlecki, De Jong, & Verkooijen, 2011)

3.1 Direct combustion

Combustion is the most commonly used and established technology for the purpose of providing thermal and electric energy from biomass. In this technology, dry bamboo biomass can be used as firewood to generate heat for cooking, warming houses, and also generate electricity for remote areas, where people cannot access electricity. In a combustion process, biomass fuel is combusted with oxygen from the air to produce heat. The initial stage of combustion involves the volatilisation of combustible vapors from the burnt biomass solid biofuel. The residue, in the form of charcoal, is also burned afterwards to provide more heat (Overend, 2009). The complete burn out of the biomass is required in order to achieve good efficiency and maximised recovered energy and avoid tars production and emission of non-oxidised gases such as carbon monoxide (CO) and volatile organic compounds (VOC) through combustion control (Kerlero de Rosbo G & De Bussy J, 2012). Combustion is the technology

that is applied in the conventional small cookstoves (where the energy efficiency is very low), the improved cookstoves, the well-engineered industrial equipment (where the energy efficiency is much higher), and in the electricity generation plants. The following sub-sections provide some more details about the applications that are more common to the African context.

3.1.1 *Industrial applications*

In industrial applications, the combustion takes place inside a well-controlled chamber. In case of a steam boiler, the generated hot combustion gases exchange heat with water to generate steam. The combustion gases can be also directly utilised for product drying, and in some cases for production furnaces (e.g. cement kilns)

3.1.2 *Improved cookstoves (ICS)*

There are multiple alternatives for traditional cookstoves which include (Brooks et al, 2016):

- Improved efficiency biomass stoves
- Stoves which use modern fuels or alternative energy sources (e.g. Liquefied Petroleum Gas, electric and solar)

Building on the international Workshop agreement (IWA) "International Organization for Standardization" ISO developed guidelines for the ranking of stoves in five tiers on five different areas of performance (ISO, 2012). These areas include; thermal efficiency, CO emissions, $PM_{2.5}$ emissions, safety, and durability relying on fine particulate matters in relation with measuring the health impact in terms of reduced emissions (Stanistreet, et al., 2021). The different tiers of the improved cookstoves (see Figure 2) are:

- Simple Improved stoves (ISO Tier 0-1)
- Intermediate cookstove technologies (ISO tier 1-2)
- Advanced biomass stoves (ISO tier 2-4)
- Stoves with clean cooking fuels (ISO tier 4)

Table 1 shows features and efficiency of each type and the used technology in more details.

Table 1. Classification of clean cooking stoves based on efficiency tiers (World Bank Group, 2014)

	Improved cooking solutions		**Clean solutions**		
	Simple/basic ICS	**Intermediate ICS**	**Advanced ICS**	**Modern Fuel**	**Renewable Fuel**
Key features	• Small functional improvements in fuel efficiency over baseline technologies • Artisanally produced	Rocket-style designs with focus on highly improved fuel efficiency including both portable and built it models	Fan or natural-draft gasifiers with high fuel and combustion efficiency often designed for pellet and briquette fuels	Cookstoves that rely on modern fossil fuels or electricity. Have high fuel efficiency and low emissions	Produce energy from renewable non-wood fuel energy usually used as supplementary stoves
Technology	• Legacy biomass and coal chimney stoves • Basic efficient charcoal stoves • Basic efficient wood stoves	• Portable rocket stoves • Fixed rocket chimney • Highly improved (low CO_2) charcoal stoves	• Natural-draft gasifier (top loading updraft (TLUD) or side loading • Fan gasifiers/fan jet • Combination TLUD and charcoal stoves	• LPG • Electric (including induction) • Natural gas stoves • Kerosene stoves	• Biogas • Ethanol • Solar • Retained heat cookers
Efficiency	Tier 0-2	Tier 2-3	Tier 3-4	Tier 4	Tier 3-4
Emissions	Tier 0-1	Tier 1-2	Tier 2-3	Tier 3-4	Tier 3-4
Overall benefits	Low- moderate	Low -moderate	Moderate-High	Moderate-High	Moderate-High

Figure 2. A collection of improved cookstoves (Global Alliance foe Clean Cookstoves)

There are multiple types of fuels that are usually used in ICS solutions (see Figure 3), and each type is briefly explained as follows (Price, 2017):

a) Charcoal briquettes: this is energy–dense, light-weight, easy to handle, and suitable fuel. It burns without producing much smoke except for during lighting. Accordingly, it is usually preferred in urban areas. Nevertheless, there are significant energy losses and emissions during charcoal production process.

b) Non-carbonised briquettes from crop residues or saw dust

c) Biomass pellets: it is a dense woody material, and it is also a common fuel option in developed countries.

d) Ethanol: it is a clean liquid biofuel that can be made from multiple feedstocks. Ethanol can be directly produced from the processing of sugarcane, molasses or even from sawdust and forest residues.

e) Biogas: A methane rich gas, which is produced by the anaerobic digestion of organic wastes. It can be generated from animal waste, kitchen waste, and crop residues.

f) Liquefied Petroleum Gas (LPG): Compared to other fuel source, it is clean-burning, portable, sustainable and efficient fuel resource. LPG is a co-product of natural gas and crude oil, and it usually consists of a mixture of propane and butane for heating and cooking purposes.

From the above, bamboo can be used as a fuel to generate charcoal briquettes, non-carbonised briquettes, pellets, and ethanol.

In the African region, the selected cooking fuel in households differs between urban and rural areas as shown in Figure 4. It can be clearly seen that most rural areas used wood fuels as in cooking while in urban areas the charcoal and LPG are used more. According to the available petroleum resources, some countries like; Angola, Cote d'Ivoire and Senegal witness a large share of LPG and natural gas with more than 50%. It can be also noticed that Ethiopia has a

notable share of electricity usage in cooking compared to the rest in Sub Saharan Africa. Such statistics show that bamboo has good potential to be used as a source of charcoal for improved cookstoves in Africa.

Biomass chips

Saw dust biomass briquettes

Charcoal briquettes

Briquettes from crop residues

Figure 3. Some types of the fuels used for improved cookstoves

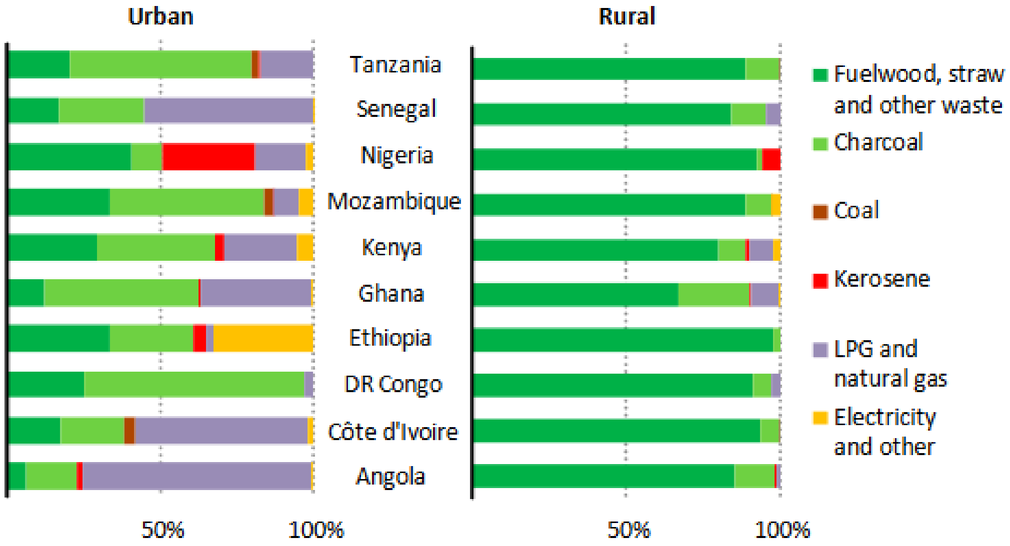

Figure 4. Main fuels used by households for cooking, 2018 (IEA, 2019)

3.2 Pyrolysis

Pyrolysis is the thermal decomposition of organic materials at a temperature range from 350 to 600 ºC in the absence of oxygen. Pyrolysis process products are;

- Charcoal (solid phase)
- Condensable pyrolysis oils (liquid phase; also known as tars)
- Non-condensable gases (gaseous phase)

As shown in Table 2, there are several pyrolysis modes, which differ according to the operating conditions; namely, the heating rate, residence time, and temperature. Accordingly, the yields from the energy conversion process can be much different. The focus in the following sub-sections will be on the slow pyrolysis since it is the more commercial technology.

Table 2. Differences between the various pyrolysis modes (Honsbein, 2016).

Mode	Conditions	Liquid	Char wt% products	Gas
Fast	~500℃: short HVRT ~1s: short solids RT	75%	12%	13%
Intermediate	~500℃: short HVRT ~10-30s: moderate solids RT	25% oil 25% water	25%	25%
Slow	~400℃: long HVRT: very long solids RT	35%	35%	30%
Torrefacation	~300℃: long HVRT: long solids RT	Vapors	85% solid	15% vapors
HVRT = hot vapor retention/residence time RT=retention/residence time				

3.2.1 *Slow pyrolysis*

Slow pyrolysis of biomass, where the main product is the solid char, takes place when the organic matter is raised to a high temperature of about 400 ^{o}C in the absence of oxygen. Feedstock sizes vary from wood chips (25 mm in diameter) to logs (up to 250 mm in diameter and up to 2400 mm length) (Honsbein, 2016). In Africa, most of the charcoal is generated using open-pits/open-domes (not in controlled mechanised kilns); hence, generating huge amounts of air pollutants including particulate matter and carbon monoxide, which adversely affects the charcoal yields (Nahayo, Ekise, & Mukarugwiza, 2013) (see Figure 5). The following sub-sections present two of the famous mechanised kilns that are commercially used for charcoal production; namely, retort technology and metal kiln technology. There are also some other commercial kilns like the brick kilns.

Figure 5. Air pollution generated from the conventional open-pile charcoaling method

3.2.1.1 Slow pyrolysis retort technology

Slow pyrolysis retorts or converters (see Figure 6) are energy-efficient stoves since their design allow recycling the generated non-condensable gases to be used as a source of energy to sustain the carbonisations process. The products obtained from a retort system are sorted approximately 35% charcoal, 35% condensed liquids, and 30% non-condensable gases. The quality of the charcoal of a retort process is usually superior to the charcoal obtained from open pits/open domes in terms of charcoal sizes, ash content, volatile content, and chemical structure of the charcoal (Emrich, 1985; Antal & Grønli, 2003). In addition, they have much higher yield (about 35%) and lower cycle time; hence allowing better profit for the charcoal maker.

Figure 6. Slow pyrolysis retorts (Greek- Albanian cross border cooperation in Biomass Exploitation, n.d.)

3.2.1.2 Metal kiln method (TDRI)

In several African countries like Senegal and Ethiopia, other methods of producing charcoal were tried, such as Metal Kiln method (TDRI) (Nketiah, 2008). This kiln is less modernised compared to the retort technology, but of course is much better than the conventional open-piles. One advantage of the metal kiln is being mobile; hence, it can be transferred from one place to another (see Figure 7). It uses air ducts and metal chimneys; hence, there is somehow efficient control of air access (GIZ, 2018). The production cycle is relatively short (5-6 days), and the average yield is about 22% in average. The disadvantages of the metal kiln are its low capacity, limited life time and the high smoke.

Figure 7. Portable metal kiln (Venter, 2012)

3.2.1.3 Charcoal palletisation and briquetting

To densify the charcoal, increase its energy density and have low-smoke feature, it can be converted to either pellets or briquettes; with the latter being the most popular (IRENA, 2018). Briquettes are either cylindrical extrusions measuring diameter of 25 (mm) to 80 mm and length of up to 300 mm, or individually pressed bricks of various sizes (IRENA, 2018). Bamboo briquettes area already produced in several African countries.

Through the briquetting process, which is shown in Figure 8, a binder (e.g. starch) is mixed with the charcoal fines, then the mixture is formed into a briquette through a press. To guarantee the success of formation process, there is a need of a sticking or agglomerating material. The strength of the press must be sufficient to agglomerate the mixture of charcoal fines and binder. Consequently, the formed briquette can be handled through a drying oven (i.e., 80 ℃) to get rid of most of the water content (Njenga, 2014).

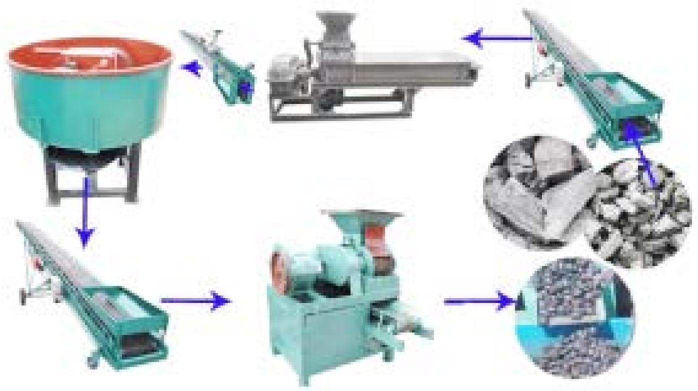

Figure 8. Bamboo charcoal briquette machine**.**

The effect of bamboo species on the quality of bioenergy products has been investigated by some researchers. One of such studies focused on bamboo briquettes where it was concluded that the four studied bamboo species can be used for briquetting with without clear impact on product quality (Brand, Junior, Nones, & Gaa, 2019). Some of these studied species in that study such as P. edulis and B. vulgaris are already planted in Africa (Bahru & Ding, 2021). Another study investigated the effect of another four different bamboo species (*Bambusa bambos*, *Dendrocalamus brandisii*, *D. stocksii* and *D. strictus*) on the generated charcoal yield and characteristics. It was concluded that, at any carbonisation temperature, the yield and fuel properties of the charcoal vary within just 10% (Kumar & Chandrashekar, 2014). For manufacturing the bamboo industrial products, and based on the experiences of the farmers in Ethiopia, the bamboo species characterised with hollow culms such as "*Yushania alphina*" are more favored than the species characterised with solid or semi-solid culms such as

"*Oxytenanthera abyssinica*". Hence, the species characterised with solid or semi-solid culms can be directly used for charcoal production (Durai, et al., 2018). However, in both categories of bamboo species, the waste generated from bamboo manufacturing can be also utilised to produce bamboo charcoal, which is recommended and illustrated in section 7.1.

3.2.2 *Fast pyrolysis*

Biomass fast pyrolysis is a rapid heating of the biomass particles with a short hot vapor residence time (HVRT) of product vapors (i.e., 0.5 to 2 s). This process mainly aims at producing bio-oil. This technology is not still commercialised at large scale, except for few plants in Europe, compared to slow pyrolysis; hence, it will not be further considered here.

3.3 Gasification

Gasification is the production of a gaseous fuel from a solid fuel such as wood, bamboo and agricultural residues in a reactor called gasifier. It is a complex thermal and chemical conversion process which occurs at high temperature under limited air supply. The generated gas (called syngas) enters into an electric generator to produce electricity. This thermochemical conversion is characterised by faster conversion rates and higher temperatures in comparison to microbial conversion (e.g. anaerobic digestion generating biogas). Figure 9 shows a general process of biomass gasification.

The main product of the gasification process is the syngas. However, also solid ashes and partially oxidised products like soot are generated and have to be removed periodically from the gasifier. The main flammable components of the resulting generator gas are carbon monoxide (CO), hydrogen (H_2), and methane (CH_4). However, in case of using normal air as gasifying agent (which is mainly the case in decentralised small-scale applications), the produced gas has a low calorific value compared to other fuels due to its high content of nitrogen (more than 50%) and other incombustible components. The calorific value of the generator gas is only about 5-6 MJ/kg versus 35-50 MJ/kg for natural gas (Dimpl, 2011). Calorific values are much higher in case oxygen or steam are used as gasifying agents; however, this is usually applied at large scale.

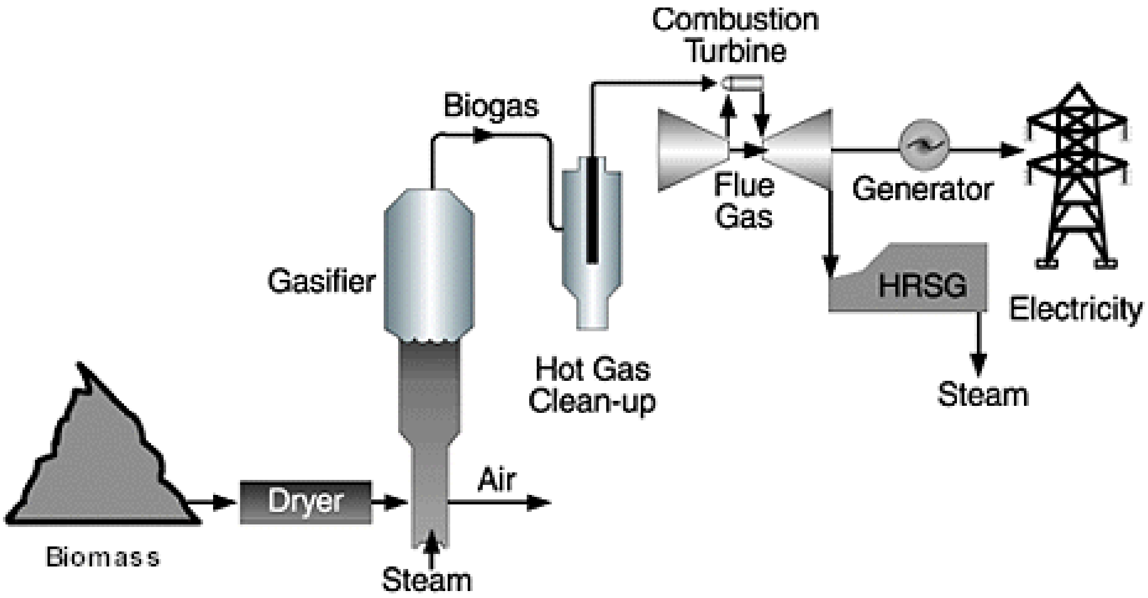

Figure 9. General process of biomass gasification (Zafar, 2020)

There are many commercial-scale gasification technologies in use. For the African context, and where the main objective will be supplying the electricity-deprived off-grid areas with electricity, the gasifiers will be of small-scale (mostly not more than 2 MW). Hence, in this case the downdraft fixed-bed technology will be exclusively used (see Figure 10). At larger scale, fluidised bed can be used, and at much larger scale, the entrained flow gasifier is the most suitable.

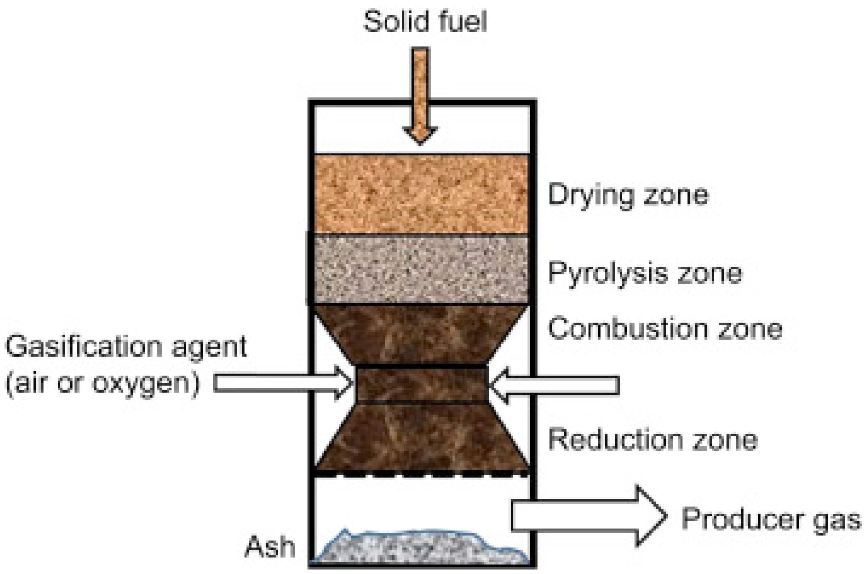

Figure 10. Schematic drawing of the downdraft fixed-bed gasifier (Pang, 2016).

3.4 Bio-ethanol production via biochemical conversion

Different strains of microorganisms are utilised to produce various biofuel products in the biochemical conversion route. The basic principle of the biochemical conversion is the fermentation of contained sugar or other substances in biomass by microorganisms to be converted into ethanol, methane, and other fuels.

Hydrolysis and fermentation technologies are used for liquid fuel production (e.g. bioethanol). During the process, the feedstock size is reduced, then pre-treated then followed by chemical or enzymatic hydrolysis for fermentation of sugars (saccharification) and finally the fermentation process takes place and produce the liquid fuel (INBAR, 2021).

Chemopolis Limited; a Finland-based bio-refining technologies company has partnered with India-based Avantha group research department to work on 3G formicobio technology, which is based on selective fractionation of biomass and co-producing multiple products (see Figure 11). This technology is not just for bio-fuels production (e.g. ethanol) but also the co-products of sugar and lignin can be used on various products (Green Car Congress, 2015). The same company lately has formed a joint venture with Assam Bio-Refinery Private Limited (ABRPL) in India and the Finnish company Fortum to establish the first bio refinery to produce ethanol and chemicals using the Chempolis Formicobio technology. The plant relies on 300,000 ton/year of bamboo input and will produce 60 million liters of bio ethanol, 19,000 ton of furfural, 11,000 ton of acetic acid and 144 GWh of green energy. The bio refinery is expected to start operation in 2021 (INBAR, 2021; Chempolis, 2020).

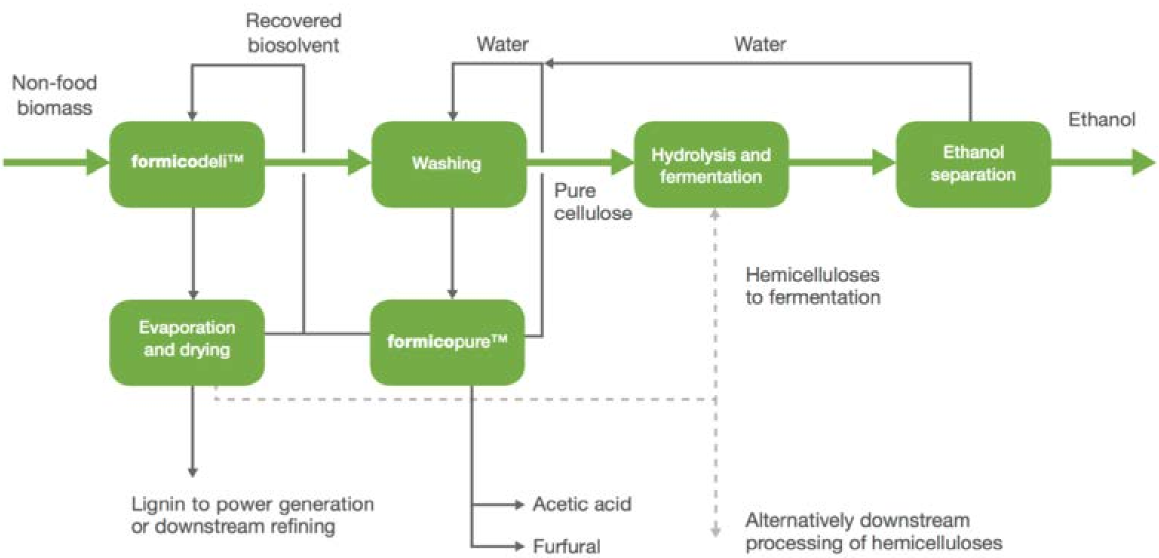

Figure 11. Formicobio technology by Chempolis (Green Car Congress, 2015)

3.5 Pelletisation

Biomass pellets is a form of energy preferred by a lot of industries, and by the European market as well where it is used for the district heating system. The biomass pelletisation process includes number of steps starting with raw material pre-treatment, followed by pelletisation and finally post-treatment. The first step in the process is the preparation of the feedstock, which includes; selecting the type of feedstock, its filtration, storage and protection. The filtration is usually done to remove any unwanted material like metals, stones, etc. Moreover, the feedstock should always be stored away from impurities and moisture. If there are different types of feed tock, blending process is used before the next stage. The moisture content should be reduced in the next stage; accordingly, a rotary drum dryer is used for this purpose. Other types of dryers like flash dryers and spouted bed dryers can be also used for the same purpose. Reducing the size of the biomass resource is the next step, as the size should not be more than 3 mm. A hammer mill is used during this stage. Pelletisation is the next step and the most important one, where the biomass is compressed against using a heated metal plate known as die by a roller. The die consists of holes with fixed diameters, the biomass passes through them under high pressure. This high pressure causes increase in the frictional forces leading to a notable rise in temperature. Due to this temperature the lignin and resins exists in the biomass will be softened and accordingly biomass particle will fuse to form pallets (Zafar, Biomass Pelletisation Process, 2021). Figure 12 shows an example of pelletisation process of bamboo.

Figure 12. Bamboo Pelletisation Process (INBAR, 2020)

4 Bamboo bioenergy production history

4.1 When and how did bamboo charcoal production start?

The use of bamboo charcoal can be dated 2000 years back in China; though the development of the bamboo charcoal technologies and facilities started in the 1980s in Japan (INBAR, 2018; Koichiro , 1981). The Japanese Kansai corporation was able to manufacture an automatic rice husk carboniser, which was then successfully used for bamboo as well (Royal Forest Department & International Tropical Timber Organization (ITTO), 2001). KCP Company is another Japanese company that is specialised in producing bamboo charcoal and bamboo vinegar. The factory used stainless steel kilns in producing the charcoal, the kiln capacity was reported to be 0.7 m^3 and its bamboo charcoal yield by weight was about 13-20% of the raw material inputs. Meanwhile the bamboo vinegar produced reached 10-20 liters. The complete carbonisation process takes around 10 hours (Royal Forest Department & International Tropical Timber Organization (ITTO), 2001).

In the 1990s, China started to produce bamboo charcoal. The very first company that took such direction was Wenzhao Bamboo Charcoal Company. At that time, the company was already known to produce charcoal from wood since generations. Zhejiang province started to ban the use of native wood charcoal at that time. Accordingly, the company began to seek new source for charcoal production. The company started to make trials to produce bamboo charcoal and it was not before 1996 till the company succeeded (INBAR, 2017). Wenzhao company started to use bamboo charcoal in different product types and successfully singed purchase contracts to Japanese clients which was China's first intentional deal in bamboo charcoal industry in 1997 (INBAR, 2017). The company now has a plant of 13,500 square meters with production lines that produce bamboo-charcoal goods and purification for bamboo-vinegar-liquid with more than 160 charcoal stoves (China Yiwu International Forest Product Fair , n.d.). Additionally, now the Suichang County in Zhejiang Province is considered home land to bamboo charcoal with more than 50 bamboo charcoal enterprises (INBAR, 2017).

4.2 The near-future bamboo bioenergy scale: glimpse about the current scale of some non-bamboo bioenergy facilities

In different parts across the world, the bioenergy production has become more developed and mature to the extent that it stated to completely or partially displace coal in large-scale energy facilities. Hence, there is a significant potential for bamboo to be used in such big scale energy facilities soon. This section will highlight some of these successful experiences around the world.

4.2.1 *North America's first power plant to be converted from coal to biomass*

In 2014, a coal generation plant known as Atikokan generation station located at Ontario, Canada was converted to a biomass plant instead (Jiggens , 2021). It is considered the first coal plant to be converted to a biomass plant in North America. The reason behind this was to avoid the coal plant being decommissioned with the other coal-fired plants due to legalisations. The annual capacity of the station is between 140 and 150 gigawatt-hours (GWh) of electricity. The number of pellets that are used annually around 90,000 metric tons of pellets to generate such large capacity of electricity.

4.2.2 *Co-Firing of wood for electricity generation in the Netherlands*

In this project, the German power company "RWE" worked on partially converting two hard-coal-fired power plants to generate electricity by using wood pellets in the Netherlands (IRENA, 2018). Around 15 % of coal use was replaced with 800,000 tons per year of wood pellets at the 1600 MW Eemshaven plant.

4.2.3 *District heating systems in Kaunas, Lithuania*

This case study shows an example of district heating systems in Kaunas, Lithuania (IRENA, 2018). Kaunas is a town in Lithuania with a population of around 288,000 people. It has an integrated network of 13 district heating plants, where eight of them are biofuel-based. The output of the biofuel plants ranges between 13 MWth and 47 MWth. They operate mainly in the heating season between mid-October and mid-April. In general, the solid biomass fuel resources, including wood pellets and chips, range from 2,800 toe (ton of oil equivalent) in the warmest month to 16,500 toe in the coldest month. It is worth mentioning that these plants procure their biomass through the Baltpool Biomass Exchange. The Baltpool international Biomass Exchange is an online trading platform where buyers and sellers meet to trade in biomass and timber products under certain rules and regulations. For now, Baltpool operates in Lithuania, Latvia, Estonia, Poland, Denmark, Sweden, and Finland. All of the biomass exchange operations are licensed and supervised by Lithuania's national energy regulatory council (IRENA, 2018).

5 Applied bamboo bioenergy production technologies in Africa

In this section, it will be shown that there are already successful bamboo bioenergy projects in Africa. The following sub-sections provide more details about a sample of them.

5.1 Pyrolysis

"Bamboo as Sustainable Biomass Energy in Africa" project was developed based on a partnership between INBAR and European Union between 2009 and 2013 in Ethiopia and Ghana (INBAR, 2012). The project achieved its targets by successfully transferring the knowledge from China on bamboo biomass energy production to Ethiopia and Ghana. The project included several pieces of trainings in different aspects of bamboo cultivation, bamboo stand management, bamboo firewood utilisation, bamboo charcoal preparation, bamboo briquette making, and the production of improved cookstoves in both countries. Furthermore, two types of kilns (brick kilns and metal kilns) have been promoted. During this project, Ghana included bamboo in its draft national bio-energy policy. Moreover, currently, there is an increasing number of small/medium-sized enterprises operating in both countries.

Since "Bamboo as Sustainable Biomass Energy in Africa" Project, there have been many attempts in order to upscale and commercialise the use of bamboo for charcoal production. The following sub-sections introduce some of these efforts that have been conducted in various African countries.

5.1.1 *The Ankrobra Farms Limited*

The Ankrobra Farms Limited is a part of Ankorbra Beach Limited which is a resort located in Ghana's western region. The farms aim at producing agricultural products via an organic and holistic approach. They started a project on the use of bamboo as an alternative source of biomass fuel. Currently, the project produces bamboo charcoal and bamboo vinegar from the wild-growing stands of bamboo located at Ankrobora Beach resort. This area has around 100 ha of wild-growing bamboo which can sustainably produce an annual amount of 100 tons of bamboo charcoal. The Anrkrobra Farms used high efficiency and low emission triple retort kiln to produce bamboo charcoal but still on a pilot scale. During the carbonisation process, the exhaust gas is distilled into bamboo vinegar which is frequently used for pest control on organic farms. The Company is planning to sell bamboo charcoal as a solid biofuel and soil conditioner locally and internationally (Osei-Tutu, Acheampong, & Kwaku, 2020). The company believes that there are still some challenges that might hinder their progress which includes:

- Market acceptance of bamboo charcoal as a new solid biofuel
- Having a stable supply with sustainably produced raw material
- Difficulty of keeping the price of bamboo supplies at acceptable levels to have a competitive price for bamboo charcoal compared to conventional wood charcoal.

5.1.2 *The Global Bamboo Products Limited*

The Global Bamboo Products Limited (GBPL) is a Ghanaian enterprise that specialises in the development of bamboo and other non-temper products (NTFPs). GBPL mostly focuses on the cultivation of bamboo and the processing of its products such as bamboo charcoal, briquettes, furniture, crafts, and for housing. GBPL also provides skills training and conducts other sustainable activities. Over the past 12 years, the company managed to plant 300 Hectares of bamboo, and it is planning to plant 1000 hectares of bamboo for the next 5 years. The company provided training sessions for more than 200 youth in craft production, management, and harvesting of bamboo. The company has worked on the commercialisation of bamboo charcoal in addition to buying bamboo charcoal from small-scale producers to be later processed into briquettes. Between 2013 and 2015, the company bought around 5000 kg of bamboo charcoal from producers and self-produced the same amount. Furthermore, the company has also produced 45,000 kg of briquettes from charcoal residues that were obtained from conventional charcoal producers. The company believes that there is undeniable potential for the commercialisation of bamboo charcoal and briquettes in Ghana but after overcoming certain challenges (Osei-Tutu, Acheampong, & Kwaku, 2020):

- Availability of bamboo feedstock depots
- Affordability of mobile kilns for charcoal production
- Receiving governmental support in terms of developing and implanting a well-defined policy framework for the charcoal industry in Ghana to attract more investments

5.1.3 *The Divine Bamboo company*

The Divine Bamboo company is established in Kampala Uganda. The company is specialised in producing high-quality, clean, and affordable bamboo briquettes. Since its establishment in 2016, the company has been working on replacing traditional charcoal with bamboo briquettes produced from locally available bamboo species in order to stop deforestation. In addition, the company also provides training sessions in the production of bamboo briquettes and bamboo plantation services for both individuals and institutions. The company has won the prestigious Energy access booster Award in 2020. Since its launching in 2016, the company managed to plant more than 25 hectares of bamboo while working simultaneously with local farmers and

tree growers in order to establish a bamboo briquette value chain. It is worth mentioning that Divine Bamboo is a women-led company that managed to secure full-time employment for 16 employees in addition to generating 20 temporary jobs.

5.1.4 *Adal Industrial PLC*

Adal Industrial PLC was established back in 2006 in Ethiopia. The company specialises in producing bamboo products including; bamboo blinding/curtain/ incense sticks, table mats, bill folder, menu folder, bamboo furniture, Bamboo charcoal and toothpicks. The company sells its products to both local and international clients including retailers, wholesalers and individuals. The company also provides supplies of raw materials for bamboo sticks, saw dust, charcoal powder to incense stick factories (About Company: Adal Industrial PLC, n.d.).. The company utilises the generated waste from bamboo processing to produce charcoal. The latter is then briquetted and sold in the big supermarkets as smokeless charcoal (see Figure 14).

Figure 13. Bamboo wastes generated from the processing industry (left) used to generate bamboo briquettes products (right)

5.2 Gasification

Though gasification technology for electricity generation is still not mature enough in the African Countries compared to bamboo charcoal production, there have been number of successful pilot experiences in the region. One of these experience is the 25 kW gasifier in Madagascar which was a replication of other plant in India (United Nations for South-South Cooperation & INBAR, 2017).

Figure 14. Bamboo gasifier in Madagascar (United Nations for South-South Cooperation and INBAR, 2017)

6 Classification of INBAR African Countries for bamboo bioenergy production

As mentioned in section 1, the second segment of this report starts by this chapter where the main objective is to recommend some interventions that can help mainstream the bamboo bioenergy production in Africa. There are 20 African INBAR countries, but these countries have different bamboo resources, and different national circumstances in terms of bio-energy needs. Accordingly, this section will highlight the current status of these countries in terms of bamboo resources, bamboo products imports and exports, electricity generation and access. Building on these statistics, the countries will be later divided to different categories for which the scenario analysis in section 8 shall be conducted.

6.1 Bamboo in Africa

In the African region, Nigeria, Ethiopia, Cameroon and Madagascar are the top countries in terms of planted bamboo area as shown in Table 3. On the other hand, and by looking at bamboo products exports (see Table 4), it can be clearly seen that exported bamboo products are mainly furniture, seats, etc., while the bamboo charcoal trade was found to be only in 12 INBAR member countries with Nigeria having the lion share. By further looking at bamboo imports, it worthy to be noted that INBAR African countries except for Burundi and Central Republic Africa (i.e., 18 of 20 countries) have imports of bamboo products (i.e., other than bamboo charcoal). Meanwhile, just 10 countries have imports of bamboo charcoal, and the amounts of the imported bamboo charcoal are negligible compared to the charcoal (other than bamboo) consumption. This confirms the fact that bamboo is still not considered as a potential source of charcoal production in many African countries. One of the reasons behind this conclusion is the low percentage of the bamboo planted area compared to other trees. Additionally, the access to wood is easier than bamboo, and the cost of wood charcoal is cheaper. Moreover, the reputation of bamboo is that it has quick burning feature.

Table 3. Status and potential of bamboo resource in the African region

Country	Bamboo resources in 1000 ha.
Cameroon	1,215
Ethiopia	1,474
Ghana	300
Kenya	133
Madagascar	1,123
Mozambique	500
Nigeria	1,590
Senegal	661

Sudan	31
Uganda	55
United Republic of Tanzania	128

Table 4. Status of bamboo exports (UN Comtrade, 2021)

Country	Bamboo Charcoal Exports ($)	Bamboo Charcoal Imports ($)	Bamboo Charcoal Imports (tons)	Charcoal Domestic Consumption (tons)	Exports of Bamboo Products (furniture, for plaiting, ...) ($)	Imports of Bamboo Products (furniture, for plaiting, ...) ($)
Benin	-	11,531	5.03	48,862	-	74,296
Burundi	-	-	-	263,996	-	-
Cameroon	-	-	-	512,950	11	27,221
Central Republic Africa	-	-	-	-	-	-
Congo	8,969	1,741	0.792	-	-	65,141
Eritrea	-	-	-	-	-	43,704
Ethiopia			-	4,621,660	2,144	277,382
Ghana	25,561	1,225	1.5	2,057,096	2,206	12,876
Kenya	767	4,255	1.431	1,278,589	127,227	1,035,820
Liberia	226	771	1.072	322,348	-	227
Madagascar	-	3,347	1.938	1,464,973	51,973	22,148
Malawi	-	-	-	604,033	2,044	609
Mozambique	-	20	-	262,161	-	18,153
Nigeria	3,005,201	216,392	113.177	4,500,357	-	63,842
Rwanda	-	136	-	47,631	1,098	45,058
Senegal	-	121,838	39.638	297,878	26,553	59,422
Sierra Leone	-		-	472,194	-	640
Tanzania	-	1,094	0.135	2,091,729	27,083	309,343
Togo	-	8,969	2.868	281,907	-	4,232
Uganda	-	-	-	1,173,507	-	14,161

6.2 Current energy situation

Energy in the African region is insufficient for demands compared to developed world. Sub-Saharan Africa is the most electricity-poor region in the world. More than 600 million people do not have access to electricity, and more millions are connected to unreliable grids that do not meet their energy demands (IEA, 2019). Furthermore, most of the countries in this region have electricity access rates ranges between 25 and 50 %, while there are around 6 countries

less than 25% of access rate (see Figure 16). Meanwhile, electricity production differs from a country to another in this region (see Figure 17 and Figure 18) with some countries still have electricity deficit and not being able to cover their demands like; Benin, Togo , Senegal and Malawi.

On the other hand, thermal energy needs are mainly satisfied via fuelwood and charcoal (see Table 5). Both Nigeria and Ethiopia relatively produce enormous amounts of fuelwood (AFREC, 2018,2019).

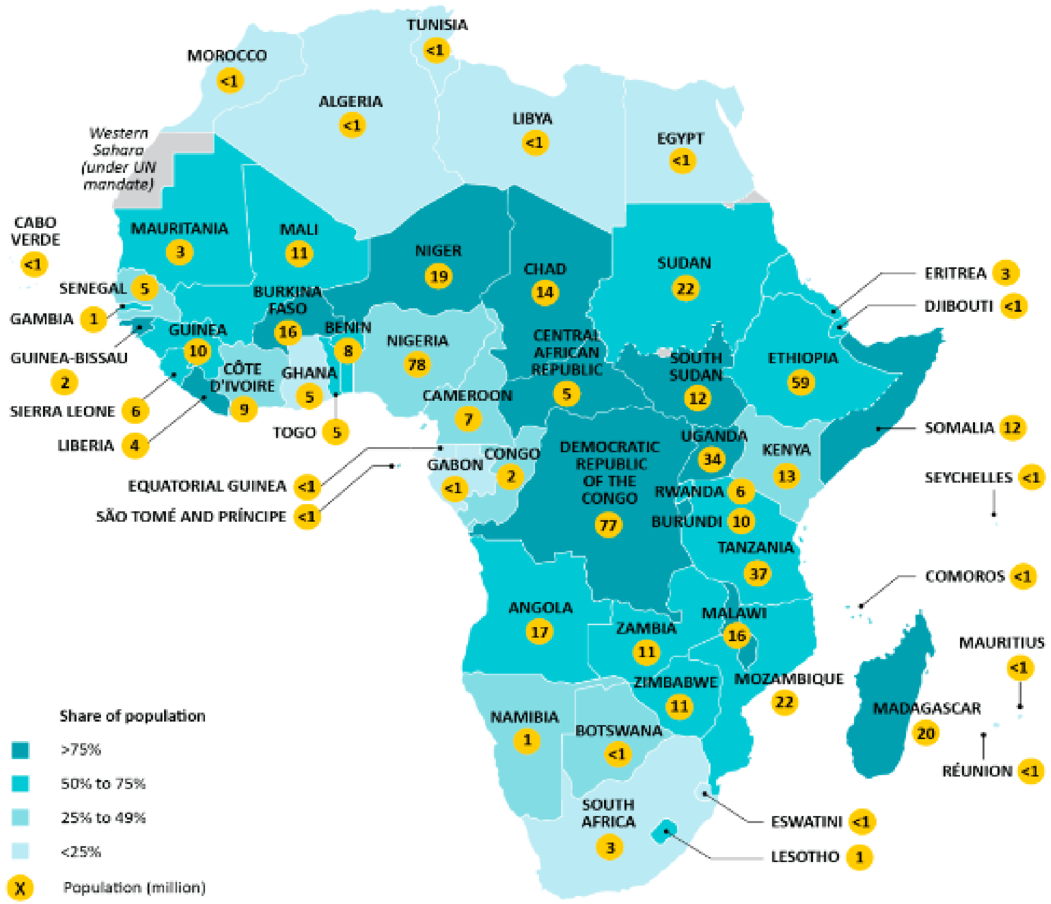

Figure 15. Population without access to electricity by country in Africa, 2018 (IEA, 2019)

Table 5. Electrical and biomass resources production and final consumption (AFREC, 2018,2019)

Country	Electricity Production (GWh)	Final Electricity Consumption (GWh)	Biomass Production Fuel Wood (Kt)	Biomass Production Charcoal (Kt)	Biomass final consumption Fuel Wood (Kt)	Biomass final consumption Charcoal (Kt)
Benin*	528	1,254	7,999	531	4,457	531
Burundi	263	256	5,800	267	4,282	280
Cameroon	8,343	6,591	4,846	306	2,321	302
Central Republic Africa*	142	93	3,083	15	2,940	15
Congo	2,620	1,634	5,568	217	4,264	217
Eritrea	448	370	1,392	185	292	184
Ethiopia	13,350	9,846	102,568	6,645	65,093	6,726
Ghana*	18,658	15,232	12,522	4,377	4,387	4,376
Kenya	11,579	8,761	35,034	1,186	28,076	1,163
Madagascar	2,437	1,319	16,740	1,559	12,415	865
Malawi	2,820	3,922	6,867	592	3,491	580
Mozambique	16,889	12,174	17,456	1,534	2,379	1,526
Nigeria	31,868	26,537	547,477	4,574	451,420	4,292
Rwanda	554	452	4,477	49	4,259	48
Senegal	4,905	4,983	1,524	265	758	264
Sierra Leone	432	142	8,175	458	5,799	449
Tanzania	7,877	5,807	20,252	1,955	10,267	1,916
Togo	500	1,239	7,832	757	2,785	757
Uganda*	4,416	3,227	39,326	2,498	30,467	2,486

*2019 data while the rest are reported for 2018

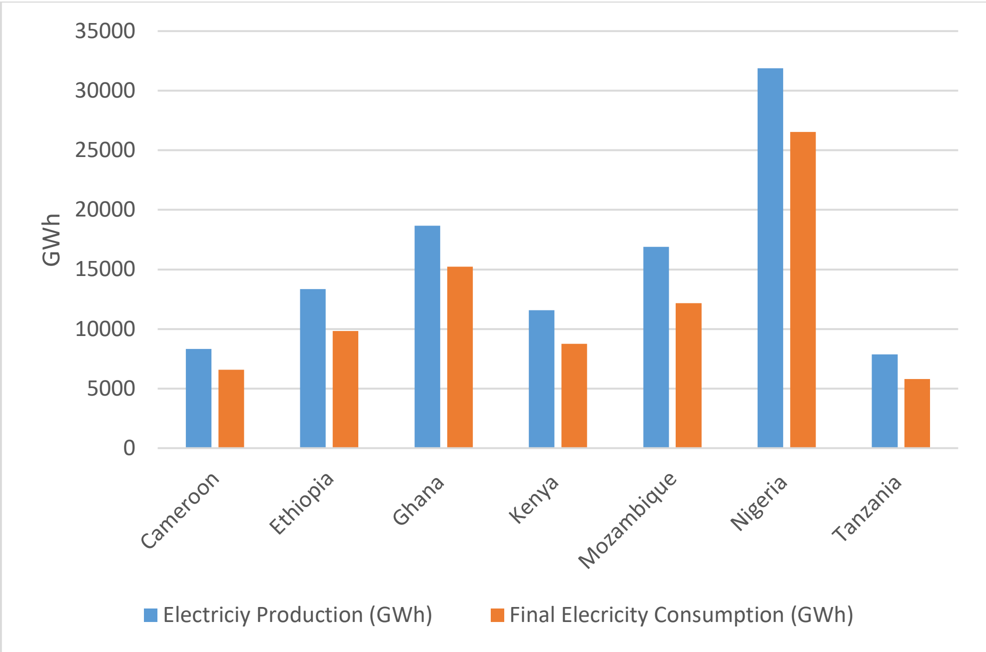

Figure 16. Electricity production vs consumption in African countries (1 of 2)

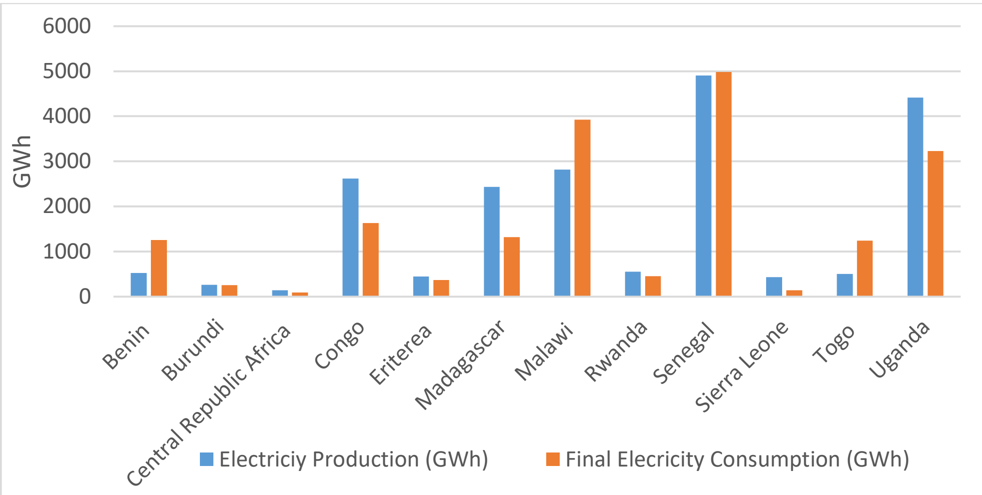

Figure 17. Electricity production vs. consumption in African countries (2 of 2)

6.3 Categories and sub-categories

As mentioned in chapter 1, the second segment aims to recommend some interventions that can help mainstream the bamboo bioenergy production in Africa. The effects that such interventions can have will be studied for the different INBAR African countries in terms of projection scenarios up to 2040. Hence, at this stage, it is important to provide some categorisation for the African countries in order to represent their different national circumstances and accordingly the different potential pick-up rate for bamboo bioenergy valorisation.

Based on all the findings achieved throughout the work in this assignment, the Consulting team has decided to categorise INBAR African countries into 2 categories based on the existence of successful bamboo businesses (i.e., bamboo bioenergy or industrialised bamboo products). The rationale behind such categorisation methodology is that usually the policymakers need to see proofs on the ground for the financial viability in order to be motivated to apply any recommended interventions. Consequently, category A includes the countries owning successful bamboo businesses (according to the consulting team knowledge), and category B includes the countries lacking successful bamboo businesses. Table 6 lists the countries assigned to each category.

Table 6. Categorisation of the INBAR African countries for bamboo bioenergy production

Category A	Category B
Ethiopia	Benin
Ghana	Burundi
Kenya	Cameroon
Madagascar	Central Republic Africa
Nigeria	Congo
Tanzania	Eritrea
Uganda	Liberia
	Malawi
	Mozambique
	Rwanda
	Senegal
	Sierra Leone
	Togo

After assigning the countries to category A and category B, and through a deeper analysis of the potential of each country towards the bamboo bioenergy, some factors were seen by the consulting team to be as catalysts that can enable some countries to have faster progress compared to others under the same category. Consequently, the consulting team divided each category into 2 sub-categories based on the following factors that are tabulated in Table 7:

Table 7. The factors studied to sub-categorise the INBAR African countries

Criteria	Indicative factors	Note
Bamboo resources	Current bamboo planted area	*This point weight is considered* ***twice*** *the weight of the other points since countries with higher planted area have more potential to utilise bamboo for bioenergy applications*
Marketing experience	Non-bamboo charcoal exports	*Charcoal exporters in that country will have more experience marketing the generated bamboo charcoal*
	Non-bamboo charcoal domestic use	*Countries with high charcoal domestic rates have higher probability of using bamboo charcoal*
Policy readiness	Whether the country is applying for UNFCCC REDD+ mechanism	*Countries with REDD+ mechanism will integrate bamboo to have higher reforestation rates*
	Whether the country has net-zero carbon commitment	*Countries with net-zero carbon commitments will be more willing to implement bamboo bioenergy projects*
	Whether the country has bio-ethanol commitments	*Countries with ethanol commitments can think about using bamboo to generate bio-ethanol*
	Committed plantation area according to Bonn challenge	*Countries with low access rates will be more motivated to employ bamboo for off-grid electricity generation*
Motivation in Demand	Electricity access rate	*Higher committed planted area makes the country more motivated to plant bamboo*
Industry Existence	Existence of industrialised bamboo products	*Processing waste can directly be used as a fuel or for charcoal making*
	Existence of oil and gas industry	*As their CSR activities can catalyse the bamboo bioenergy sector*
	Existence of cement industry	*As their CSR activities can catalyse the bamboo bioenergy sector*

Points were assigned for each of those factors to each country according to the collected data. For each factor, the consulting team defined for each country whether it is high, moderate or low, where the corresponding scores are 100%, 50% and 0% respectively. After that, the scores of all the factors were aggregated for each country, and the sub-categories were accordingly defined as shown in Table 8. Simply, under Category A, the countries with high scores were identified to be Sub-Category A-1, and vice versa for Sub-Category A-2. The same applies for Category B as well.

Table 8. Sub-categorisation of the INBAR African countries for bamboo bioenergy production

Category A			Category B		
Sub-Category A-1	Nigeria	83%	**Sub-Category B-1**	Malawi	50%
	Ethiopia	75%		Mozambique	50%
	Madagascar	63%		Senegal	46%
Sub-Category A-2	Tanzania	54%		Congo	38%
	Ghana	54%		Cameroon	33%
	Kenya	50%	**Sub-Category B-2**	Liberia	29%
	Uganda	38%		Togo	29%
				Benin	25%
				Burundi	25%
				Sierra Leone	21%
				Rwanda	17%
				Eritrea	17%
				Central Republic Africa	13%

7 Recommended interventions for bamboo bioenergy mainstreaming

Based on the analysis of the current situation of bamboo bioenergy industry in Africa from the focus group meeting, one to one meetings, the field missions conducted to Ghana and Ethiopia, and the literature review, the consulting team found that the bamboo bioenergy industry needs many interventions to be taken to a higher level. Such interventions are required for all the categories referred to in Chapter 6 with a bit different extent. Such interventions will help the bamboo bioenergy market in Africa to approach the level of INBAR Asian countries and with time can be an important player worldwide. In this section, the consulting team present the recommended interventions for mainstreaming bamboo bioenergy generation in Africa. The interventions are classified into two categories; namely "unlocks" and "Supports". "Unlocks" refer to interventions that can help debottleneck the bamboo bioenergy situation by providing solutions to the root cause problems. On the other hand, "Supports" refer to interventions that can help flourish and catalyse the bamboo bioenergy situation if applied together with the "Unlocks".

7.1 Methodology for categorizing the "Unlocks"

In 2010, EBRD and IEA has issued an important report related to how the Energy Efficiency can be well-governed and managed by the governments; the report named "Energy Efficiency Governance Report". The report defined energy efficiency governance to be a combination of three main aspects: Enabling environment, Institutional arrangements and co-ordinations mechanisms (IEA, 2010). Hence, the consulting team has utilised the same concept in order to define the aspects of bamboo bioenergy governance. Figure 18 presents the components of the "bamboo bioenergy governance". Items from the 3 different components should be applied in order to ensure strong governance for the topic.

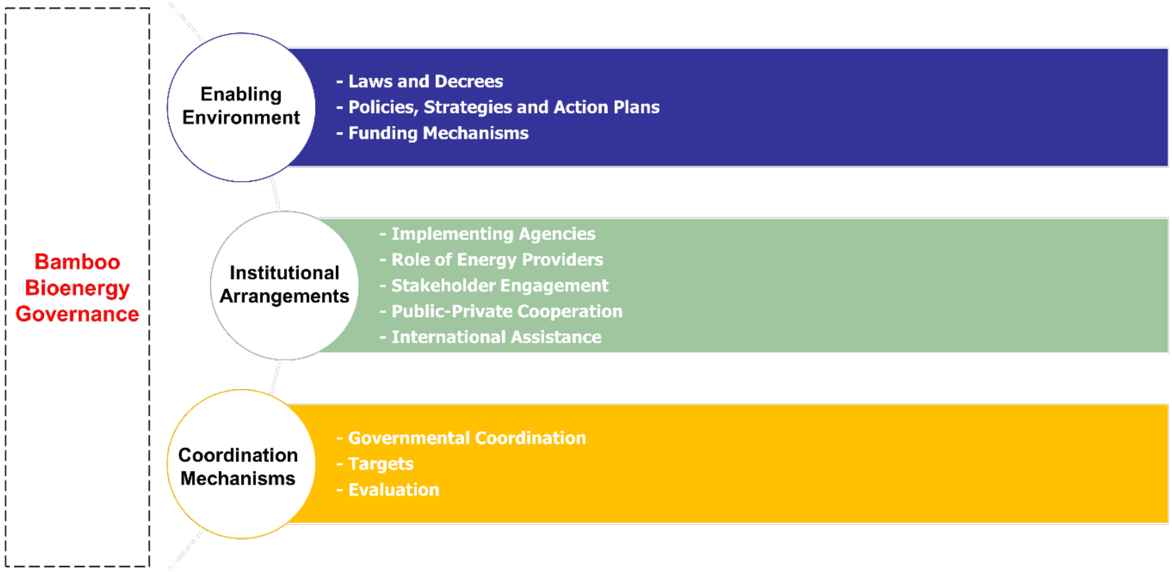

Figure 18. Components of the “Bamboo Bioenergy Governance” concept

Figure 19 presents the recommended “Unlocks” which will be explained in details in the following sub-sections. As shown, the 3 governance components are represented in the recommended “Unlocks”.

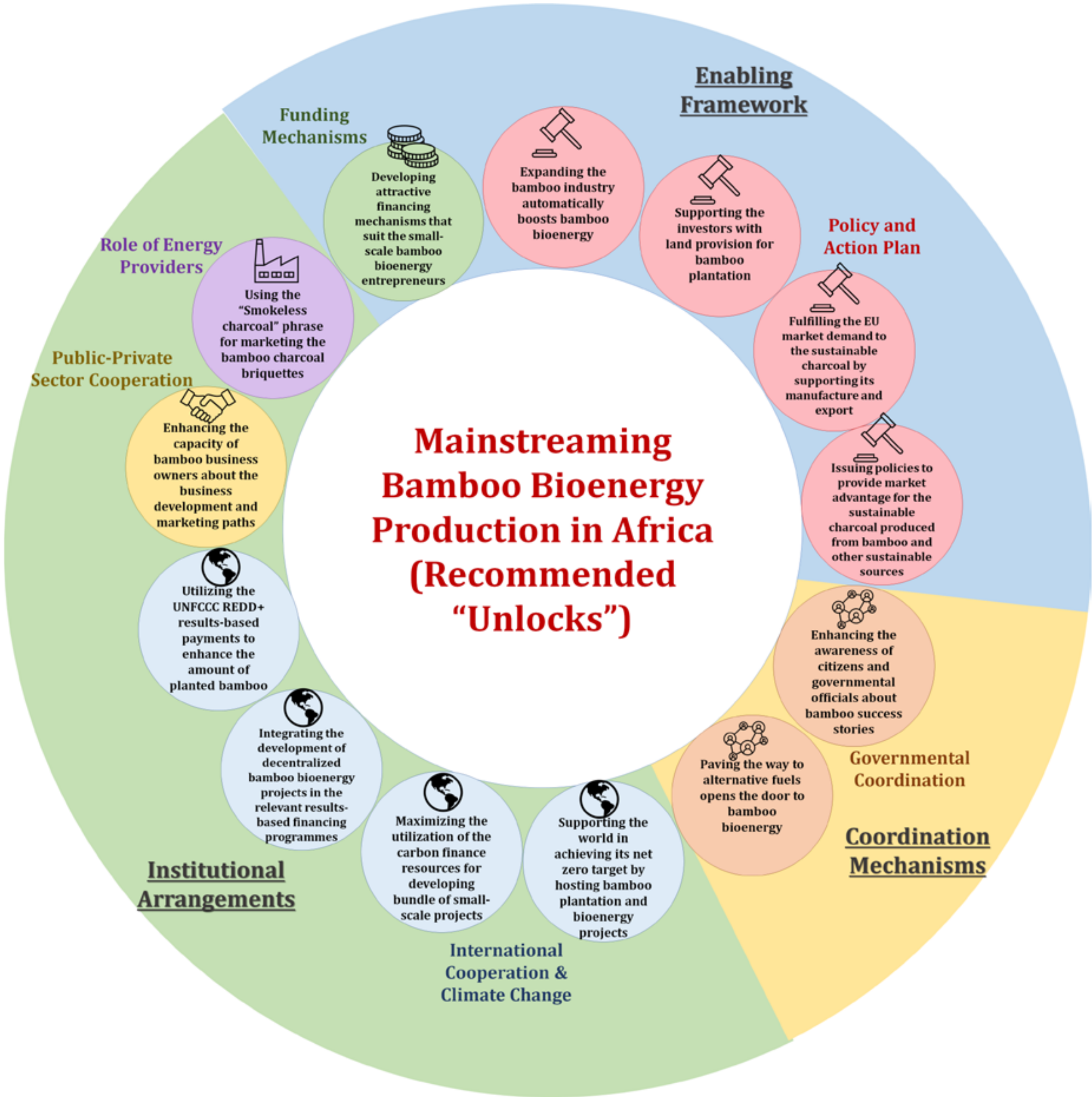

Figure 19. Recommended "Unlocks" for mainstreaming bamboo bioenergy production in Africa

7.2 Recommended "Unlocks"

As shown in Figure 20, 13 "Unlocks" are recommended to debottleneck and mainstream bamboo bioenergy generation in Africa. The following sub-sections provide explanation for each of them.

7.2.1 *"Unlocks" related to "Enabling Environment"*

The "Enabling Environment" is the first component under the "Bamboo Bioenergy Governance" concept. Five "Unlocks" are proposed under this component; the first four of them are related

to developing policies and action plans, while the fifth is related to developing a funding mechanism as will be shown in the following sub-sections.

7.2.1.1 "Unlock" # 1: Expanding the bamboo industry automatically boosts bamboo bioenergy

One of the key lessons that can be learned taken from the bamboo industry worldwide is that a lot of wastes are generated from bamboo processing, and that those wastes are accordingly perfect raw materials for bioenergy generation. This was even noticed in African bamboo processing facilities. In one of the facilities in Ethiopia "Adal Industrial Plc.", the business owner found that the wastes generated from bamboo processing into different products (e.g. Bamboo incense, bamboo toothpicks,…) take much space. Hence, the decision was to utilise such wastes to generate bamboo charcoal briquettes which are then sold as one of the key products of the facility (such production section include several pyrolysis furnaces in addition to the briquetting machine). Moreover in the same facility, when the "Bamboo Pulp and Paper" process section starts production, and since such process requires steam, bamboo pellets was used as the key fuel for the steam boiler (see Figure 21). The facility owner even thinks about utilizing bamboo for electricity generation in the near future. In another industrial bamboo processing facility in Ethiopia "Pro Star Bamboo" which is specialised in the production of toothpicks and incense sticks, the business owner noticed the various bamboo fractions that are wastes during the production process (see Figure 22). This include the nodes, thin top parts of the poles, in addition to the bent bamboo poles. Hence, the facility includes a modern pyrolysis furnace together with several briquetting machines to generate different forms of bamboo charcoal briquettes. In addition, the very thin bamboo generated from the production process is transformed to bamboo pellets which can be sold as it is to be used as fuelwood, or can be further briquetted. It is clear that the investment in such bamboo bioenergy facilities is profitable; otherwise, the investors would not have gone for them. Such examples show that having bamboo processing industry automatically will result in bamboo bioenergy facilities without bioenergy-specific policy interventions.

Not only the wastes generated from the "mechanised" bamboo processing industry can be used for bioenergy production. The wastes generated from the bamboo handicrafts manufacture (see Figure 23) are already used by some of the manufacturers as fuelwood to generate hot water which is then used to conduct heat treatment for the bamboo poles before being manufactured. Some other bamboo handicrafts manufacturers receive requests from nearby commercial facilities (e.g. hotels) to collect and transport such bamboo wastes to be used as fuelwood. Most of the bamboo handicrafts manufacturers also use the bamboo wastes as fuelwood for their own residential applications.

Hence when the policymakers in Africa focus on supporting the bamboo processing industry and handicrafts, this will not only have positive economic, social and environmental benefits, but it will also help boost the bamboo bioenergy production. Putting into consideration the significant environmental and energy security benefits of using bamboo as bioenergy source instead of wood, the efforts that will be put to support the bamboo processing industry and handicrafts will yield multiple significant impacts. INBAR is heavily working with several African countries on boosting the bamboo processing industry and handicrafts, and several policies, strategies and action plans area already in place. Hence, their effective implementation will automatically result in boosting the bamboo bioenergy production.

Figure 19. Bamboo pellets used for the steam boiler

Figure 20. Bamboo waste

Figure 21. Bamboo waste from handicraft

7.2.1.2 Unlock" # 2: Issuing policies to provide market advantage for the sustainable charcoal produced from bamboo and other sustainable sources

The African charcoal sector is mostly an unofficial sector totally relying on the traditional open-pits/open-piles production method (see Figure 23). This method is a considerable source of local air pollutants especially CO and particulate matter (see Figure 24), and also results in methane emissions, which is a powerful Greenhouse Gas (GHG). The open-pits/open-piles are widespread inside the residential and agricultural areas in many locations in most of the African countries where the produced charcoal is then mainly transported to the urban areas (see Figure 25 and Figure 26). The residents of those areas suffer from severe air pollution, in addition to soil erosion. Moreover, such conventional charcoal production technology suffers from low production yield with about 12% (i.e. each ton of charcoal needs about 7 tons of wood) which accordingly result in increased deforestation. Since charcoal is a key fuel source in the African countries and it is also being exported by several countries, there is a need to regulate such sector to decrease the deforestation rate, and minimise the negative environmental and social impacts. Such topic is a hot one which has been studied by a lot of organisations in different African countries looking for a sustainable solution (Vos & Vis , 2010; Khennas, Ben Hagen, & Muok, 2013; UNDP, 2015; FAO, 2017; World Future Council , 2015; FAO, 2012).

In this proposed "Unlock" measure, and since the situation of the African countries is different regarding the charcoal sector regulations, it is important to build on the progress done in each African country in this topic and add some ideas. One of such ideas is to replicate Egypt's success in transforming the charcoal sector to employ "mechanised kilns" instead of "Open pits". The key step in that transformation was a regulatory action to ban the charcoal exports unless the producer provides the documents proving the following:

- He/she is officially registered as a company
- He/she got the environmental approval for his project (which necessarily means that the production is done by mechanised kilns rather than open-pits)

There was a grace period for implementing such action; during which some specific models of the mechanised kilns have been approved, and an agreement has been done with the "Social development fund" to provide preferential funds for the charcoal makers. While not all the charcoal makers have transformed; however, at least the sector has started its gradual transformation successfully. The main idea here was to regulate the sector from the "export" side since this is easier in terms of control. This can be a good start which will then gradually transform the local market producers as well when they see the benefits of high yield, high production rate and the allowed exports for those employing the mechanised kilns.

One other component that the African countries can add is to gradually mandate using alternative fuels for charcoal making. This can include bamboo and other agricultural residues. Such transformation can be controlled by providing incentives like reduced taxation to the producers proving that their charcoal is generated from bamboo or alternative fuels.

Figure 22. Wood pile ready to be carbonised using the traditional open-pile method

Figure 23. Example for the air pollution resulting from the conventional open-pile carbonisation method

Figure 24. Example of bamboo charcoal bags ready to be transferred to the urban areas

Figure 25. Example of non-bamboo charcoal bags ready to be transferred to the urban areas

7.2.1.3 <u>"Unlock" # 3: Fulfilling the EU market demand to the sustainable charcoal by supporting its manufacture and export</u>

The EU has announced its target of being carbon-neutral by 2050, and to achieve 'at least 55%' emissions reduction by 2030 (Verde & Chiaramonti, 2020). Hence, there is an increasing trend in the previous few years to reduce the carbon footprint of all the activities; whether the corresponding commodities are produced inside the EU or imported from other regions. Such trend is not only for the governments, but it has gradually become a culture even for the end users. Given the well-known sustainable features of bamboo and especially its high carbon sequestration potential (referred to above in section 1 all of the bamboo products are much welcomed in the EU. According to the Dutch Centre for the Promotion of Imports from

developing countries (CBI), timber-based products are currently being criticised for being associated with illegal logging and deforestation; hence, bamboo is seen as a more sustainable solution. According to INBAR's 2017 trade statistics, EU has imported bamboo charcoal with about 9 million USD (INBAR, 2017). The EU countries can use the bamboo charcoal as an energy source, and for non-energy uses as well like being a soil conditioner (the use which results in additional GHG emission reductions). Charcoal has been approved to be used throughout Europe in organic farming as a fertiliser/soil conditioner since December 2019 when the implementing regulation (EU) 2019/2164 was officially signed. Hence, and as a climate change mitigation action, the EU is willing to increase using charcoal as soil conditioner (Verde & Chiaramonti, 2020). Hence, INBAR African countries can help the world (and EU specifically) achieve more ambitious climate change mitigation by manufacturing and exporting bamboo charcoal.

If the African policymakers have issued and implemented policies and action plans to facilitate and encourage the production of bamboo charcoal and exporting it to the EU, this will have positive impacts on the local economy, and will also have significant socio-economic benefits to the citizens working on the all the value chain components of such charcoal facilities. From the local bioenergy perspective, and since bamboo will be planted more in the African countries, the farmers will definitely use bamboo as the main fuelwood source. Moreover, and by having many facilities working on manufacturing bamboo charcoal, this will have a positive impact on the local market which will also gradually move towards bamboo charcoal. As mentioned in section 5 it has been proven that there is local acceptance to the bamboo charcoal in Africa.

7.2.1.4 "Unlock" # 4: Supporting the investors with land provision for bamboo plantation

From the meetings with several African investors, the financial feasibility of the bamboo bioenergy projects will be enhanced when there is more control on the bamboo supply chain. Many investors complained from the bamboo raw material supply chain, and some of them attributed their slow business progress to that factor. Having control on the supply chain can be perfectly achieved if the investor is provided a land where he/she can plant bamboo. This will ensure that the investor will not be subjected to the price fluctuations of the bamboo poles, nor to all the other uncertainties of the supply chain. Investors working on small-scale bioenergy projects like charcoal manufacture usually have small profit margin; hence, any problems with the supply of the raw materials will definitely impact the business sustainability and the investors may quit such market. Securing land provision to the investors has another significant advantage which is the keenness of the investor to apply managed plantation; that will accordingly result in increased yield per hectare. From the missions done in Ghana and

Ethiopia, one common problem that the investors face is the mixed maturity of the bamboo poles they receive; the fact that negatively affect the quality of the bamboo products. Securing land provision to the investors will ensure that they will have control on the maturity of the bamboo poles and accordingly result in higher quality products. This applies to the investors willing to work on the bamboo industry or bamboo bioenergy products.

By studying the story of Anji county in China, it can be concluded that the bamboo industry has flourished since the government decided to implement a land tenure reform, where the farmers were encouraged to lease bamboo forests in a 30-year contract, and they were free to select the product that they want to manufacture and sell (Wang, 2006). Hence, the African policymakers are much encouraged to revisit the current land tenure system, and develop attractive models to lease the bamboo forests to farmers/investors against any warranties they see appropriate. This will help flourish the bamboo industry generally and bamboo bioenergy specifically; hence, resulting in economic, social and environmental benefits to the country and citizens.

7.2.1.5 Unlock" # 5: Developing attractive financing mechanisms that suit the small-scale bamboo bioenergy entrepreneurs

Access to finance is one of the key bottlenecks that is facing all the bamboo bioenergy investors in Africa. Small entrepreneurs who have simple businesses like bamboo charcoal or bamboo briquettes production have the dreams of exporting their products to EU (where the demand for the bamboo charcoal products is guaranteed); however, this requires expanding their facilities to much higher production scale which they can't afford. Such business owners are not able to access finance through the local commercial banks due to the very high interest rates in addition to the credit-worthiness problems. The same problems are also faced by the business owners of the bamboo processing facilities despite being of larger scale. They need to have higher production capacities to be able to compete with the imported bamboo products; however, accessing finance is one of their main challenges.

One of the most successful experiences that was able to unlock such challenge is the "Orange corners innovation fund" under the "Fidelity Bank Young Entrepreneurs' Initiative" in Ghana. It is a revolving fund of 500,000 euros issued by the Dutch fund. Each beneficiary can have up to 50,000 euro as loan including 30% grant, with a 5% interest rate. During the current cycle, they received 100 applications, and accordingly the filtered 40-50 companies were invited to 2-days camp so that they present their projects and challenges. Accordingly, 15-16 companies were selected to take a 6-months course on various topics like compliance, financial literacy, and financial investment readiness. At the end of such training, each business owner develops

a presentation showing his/her business plan to Fidelity bank. Upon being accepted, the money is not given to the beneficiary at once, but rather on 2-3 tranches. In that round, four entrepreneurs in the field of renewable energy generation and biofuels were awarded the fund. Of course, such mechanism was much welcomed by the entrepreneurs due to its attractive loan terms, and of course the grant component. It worth noting that away from Orange corners fund, Fidelity Bank has their own fund structure which focus on supporting young entrepreneurs providing 10% interest rate per annum for the MSMEs generally (see Figure 27).

Through discussions with the fund management entity, it was clear that Fidelity bank is willing to issue new phases of this programme. In addition, the Dutch government is willing to replicate this in several other African countries. Hence, the African policymakers are strongly recommended to coordinate with the Dutch government to have wider-scale similar programmes and preferably with higher investment cap per beneficiary. In addition, the African policymakers are strongly recommended to work with other donors and local banks to replicate such successful model in order to ensure winder coverage. This will definitely help boost the small-scale bamboo bioenergy businesses like the charcoal and charcoal briquettes.

Figure 26. Snapshot from the brochure of the "Fidelity Bank Young Entrepreneurs' Initiative" showing their target beneficiaries

7.2.2 *"Unlocks" related to "Institutional Arrangements"*

The "Institutional Arrangements" is the second component under the "Bamboo Bioenergy Governance" concept. Six "Unlocks" are proposed under this component; the first four of them are related to international cooperation and climate change, the fifth is related to public-private cooperation, and the final one is related to the role of energy provider (investors). The following sub-sections present explanation for each of the "Unlocks".

7.2.2.1 "Unlock" # 6: Supporting the world in achieving its net zero target by hosting bamboo plantation and bioenergy projects

It is well-known that the World has witnessed a political change in the fight against global warming in 2015 after Paris Agreement. 196 countries have adopted such historic agreement which mentions that developing countries will implement ambitious mitigation actions with enhanced support from the developed countries. In the previous few months, and during the preparations of the UNFCCC COP 26 in Glasgow, there has been a global pressure to reach net-zero emissions by 2050. As shown in Figure 28, some countries have committed to that in law, some others committed to that in an official policy document, some others reported a pledge, while still a lot of developing countries have not provided any commitments as the topic is still under study.

To achieve net-zero emissions, big emitters (e.g. USA and EU) need to conduct radical reductions in their emissions, and also offset their remaining emissions via financing green projects in other countries (The Editorial Board, 2021). Given the high climate change mitigation potential of bamboo, the African countries can support the world in achieving its net-zero target by hosting bamboo plantations in the areas devoted for land restoration and reforestation (see Table 9). Moreover, and given the high areas of bamboo that can be planted, the African countries can host large-scale bamboo-to-ethanol plants (like the one in India which will start production soon). The produced ethanol can then be exported to the countries having bio-ethanol blending commitments (see Table 10); hence, support the world further in reducing the GHG emissions by displacing the petroleum gasoline. The high areas of bamboo can also make it feasible to construct bamboo-based decentralised power plants in the African rural areas lacking electricity access. Such local projects will have further GHG emission reductions impacts by displacing the fossil fuels. Moreover, the high area of bamboo will also enable having improved and large scale bamboo processing industry in Africa. This will result in further replacement for the timber-based products; hence, less deforestation and further reduced GHG emissions. Hence, such direction is a perfect example of having a significant sustainable pathway globally.

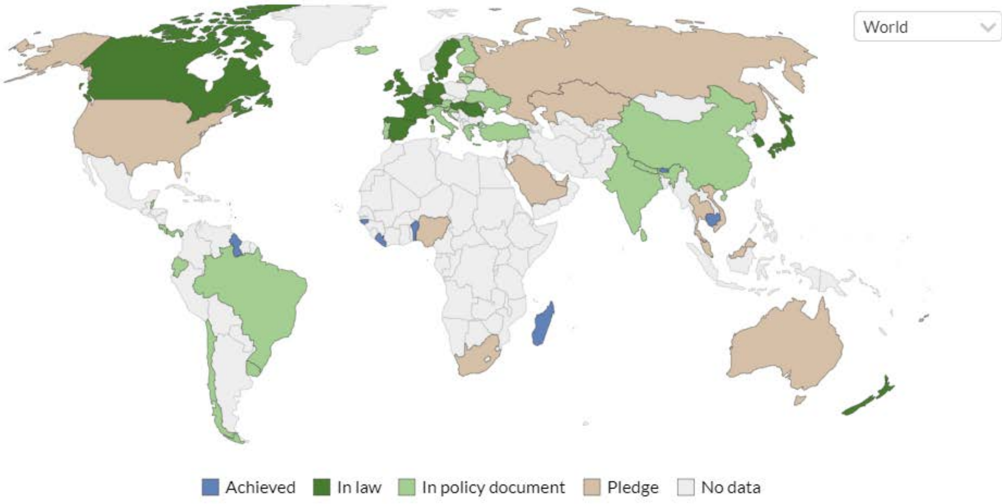

Figure 27. Status of net-zero carbon emissions targets worldwide

Table 9. Committed land areas to be restored/reforested in African INBAR countries (afr100; INFOFLR)

Country	Committed Area (Million Hectares)
Benin	0.5
Burundi	2
Cameroon	12
Central Republic Africa	3.5
Congo	8
Ethiopia	15
Ghana	2
Kenya	5.1
Liberia	1
Madagascar	4
Malawi	4.5
Mozambique	1
Nigeria	4
Rwanda	2
Senegal	2
Sierra Leone	0.7
Tanzania	5.2
Togo	1.4
Uganda	2.5

Table 10. List of countries with bioethanol blending targets (Saravanan, Pugazhendhi, & Mathimani, 2020)

Country/Region
India
Indonesia
China
Thailand
Russia
Brazil
United States
Europe Union
Gulf Countries/ UAE

Following such international cooperation direction will be a powerful win-win situation where the developed countries and the World can achieve its net-zero targets, and the African countries will have significant socio-economic development. Hence, it is much recommended that the African policymakers shortly start having high-level discussions with the governments of the developed countries about such concept and its operationalisation means.

7.2.2.2 "Unlock" # 7: Utilizing the UNFCCC REDD+ results-based payments to enhance the amount of planted bamboo

REDD+ is a framework created by the UNFCCC to guide mitigation actions, in the developing countries, related to reducing deforestation and forest degradation, intensifying sustainable management of forests, and the conservation and enhancement of carbon stocks. The framework provides the country with an ex-post reward when it proves the reduction in GHG emissions (UNFCCC; Climate Focus, 2015). There is a specific mechanism that should be applied by the interested developing countries so that they can accordingly achieve results-based payments (UNFCCC):

- Readiness phase: Development of national strategies or action plans
- Implementation phase: Implementation of the developed policies, measures and action plans
- Results-Based Payments phase: Measuring, reporting and verification of the implemented actions; hence, claiming results-based payments.

Several African countries have applied for the REDD+; albeit, they are still in early phases (see Table 11). Given the high carbon sequestration potential of bamboo, planting it will support the African countries in achieving their REDD+ targets. The received climate funds (Results-based funds) enhances the concept of having better management of the forests. In addition, it incentivises the countries to have further plantations and thus reduced deforestation. Given the benefits of the REDD+ framework, it is much recommended that the Africa countries include bamboo in the corresponding strategy and action plan as this will definitely help boost the bamboo industry and bioenergy.

Table 11. REDD+ African countries

REDD+ Countries
Congo
Ethiopia
Ghana
Kenya
Liberia
Madagascar
Malawi
Mozambique
Nigeria
Tanzania
Togo
Uganda

7.2.2.3 "Unlock" # 8: Integrating the development of decentralised bamboo bioenergy projects in the relevant results-based financing programmes

a) Introduction about results-based financing (RBF)

This decade has witnessed an innovative concept for financing sustainable projects in the developing countries; namely, results-based financing (RBF). RBF is a financing mechanism whereby the donor disburses funds to a recipient after it has been verified (via an independent verification agency) that a pre-agreed set of results has been achieved. This approach is much different than the conventional financing where funding is provided before any project activities. Hence, the RBF approach is more sustainable and ensures that the funds have been effectively placed and achieved the required results. The World Bank (WB) has a similar instrument specifically named as Programme for Results (PforR) which have been so far implemented in 121 programmes worldwide with a total of $38.15 billion of bank financing

(The World Bank , 2021). Two of those programmes are concerned with rural electrification in Ethiopia and Tanzania.

Away from the WB's PforR, one of the most successful energy-related RBF programmes is named the Energising Development (EnDev) programme. EnDev has been active between 2013 and 2020, and it was a partnership between the Netherlands, Germany, Norway, the UK, Switzerland and Sweden. GIZ GmbH and the Netherlands Enterprise Agency (RVO.nl) were the key agencies for programme coordination. As shown in Figure 29, the setup of the programme depends on having a product that is sold to the end consumer by a service provider (manufacturer/distributor). The programme management communication is with a financial institution which accordingly communicates with the service provider. As shown in Figure 30, the programme has been applied in 8 African INBAR countries and the relevant products sold were improved cookstoves and minigrids (Weber, Hirner, & Geres, 2018).

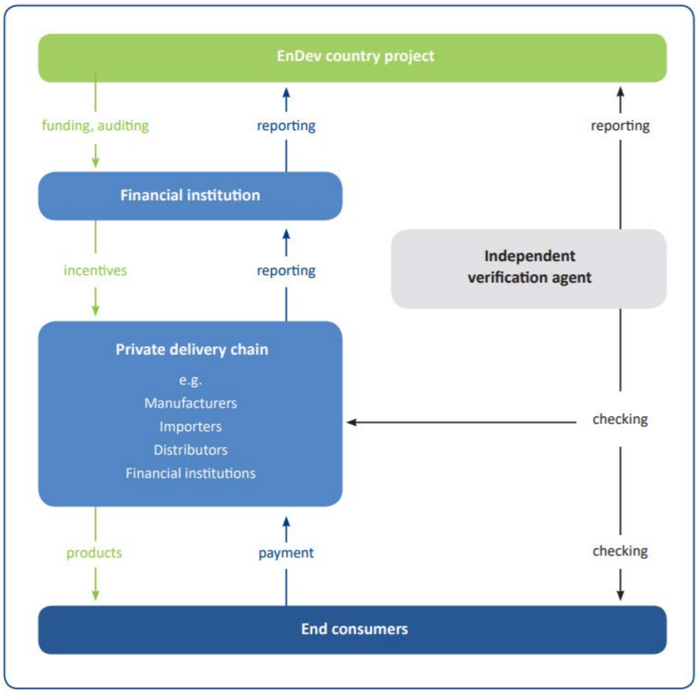

Figure 28. Setup of the EnDev programme (Weber, Hirner, & Geres, 2018)

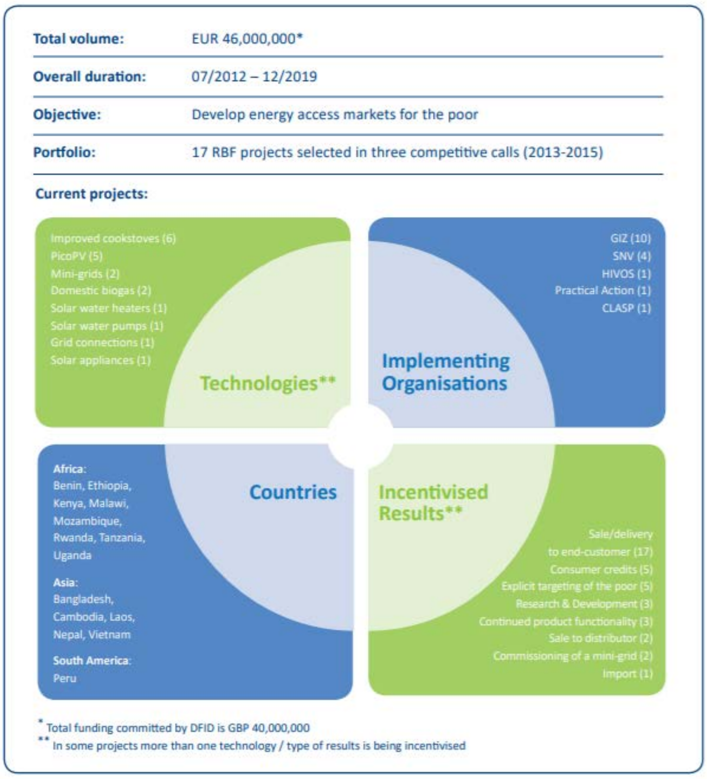

Figure 29. Summary of the scope of the EnDev programme (Weber, Hirner, & Geres, 2018)

b) Recommended intervention

For the 8 INBAR African countries where the EnDev programme has been implemented, it is recommended to build on the programme success and utilise such pace. Hence, it is much recommended that the African policymakers coordinate with GIZ regarding having a new phase for the programme. If a subsequent programme will be implemented, it is much recommended that the countries focus on the “fuel” side rather than only the “equipment” side. Hence, to build on the success of the EnDev programme, the focus should also include having diversified alternative fuel sources that can be employed in the advanced cookstoves. Such diversification should be based on the type of fuels which is suitable to each location. The characteristics of each fuel may require a modification in the advanced cookstove design; however, it will ensure that the cookstoves will be reliably used by the citizens in different areas. Here, bamboo utilisation can fit in the areas where bamboo naturally grow in rural areas. In urban areas, the programme should focus on employing sustainable charcoal types (e.g. bamboo charcoal) in the advanced cookstoves. For rural electrification programmes, it is recommended to include bioenergy projects where the fuel is to be sourced based on the project’s location. Hence, bamboo can be utilised when the bamboo forest nearby areas are the ones to be electrified. In case no RBF subsequent programmes are planned to be implemented, it is much recommended that the policymakers directly coordinate with the local

financing institutions (FIs) who participated in EnDev programme so as to start a new local programme to widen the scale of the beneficiaries. The experience gained by the local FIs during the EnDev programme should have reduced their risk level “especially that most of the risk is taken by the service provider”, and should accordingly be competent to develop such programmes on a local level without needing donors.

For the other countries, it is much recommended that the African policymakers of such countries coordinate with GIZ regarding having a new phase of the programme to replicate the success that took place in the 8 countries. In the design of such programme, and as mentioned above, it is important to consider the “fuel” side in both the advanced cooking stoves and the biomass electricity generation projects. The successful application of such programme will result in bamboo bioenergy being mainstreamed in the African countries.

7.2.2.4 “Unlock” # 9: Maximising the utilisation of the carbon finance resources for developing bundle of small-scale projects

Carbon finance has proven to be a powerful tool to finance energy-development projects in the World generally and Africa specifically in the previous years. Between 2005 and 2012, the UNFCCC Clean Development Mechanism (CDM) has been widely active where the price of the emission reduction certificates was attractive. Table 12 shows the CDM-registered bioenergy projects in Africa. Later on, the voluntary carbon markets became more appealing to the project developers especially for the “Gold Standard” and “Verra (VCS)”.Table 13 and Table 14 show some statistics for the voluntary African bioenergy projects registered on those 2 platforms.

Table 12. Number of bioenergy registered projects under CDM

Country	No. of biomass registered projects/programmes under CDM	Project or Programme
Senegal	4	1 Project 3 Programmes
Mozambique	6	Programme
Kenya	11	Programme
Uganda	10	Programme
Cameroon	2	Programme
Ethiopia	8	Programme
Malawi	6	Programme
Rwanda	9	Programme
Ghana	6	Programme
Madagascar	5	Programme
Congo	2	Programme
Nigeria	7	Programme

Togo	1	Programme
Mali	1	Programme
Benin	1	Programme
Burundi	2	Programme
Liberia	3	Programme
Sierra Leone	1	Programme

Table 13. VCS relevant registered projects

Country	VCS Registered Projects
South Africa	Recipe for Change Grouped Project
Madagascar	Madagascar Improved Cook stove Project By Kcm-Wood#CPA-W-001
Zambia	Fuel Efficient Stoves in Zambia CPA 3
	Fuel Efficient Stoves in Zambia CPA 2
	Fuel Efficient Stoves in Zambia CPA 1
Kenya	Paradigm Kenya Clean Cook Stoves Project
Mozambique	Improved Cook stoves Project For Malawi And Cross-Border Regions Of Mozambique CPA MAL 005
Ghana	African Improved Cooking Stoves Grouped Project
Kenya	Efficient Cook Stove Programme: Kenya CPA NO. 2 Mathira East District Co2balance UK LTD

Table 14. Number of relevant registered projects under "Gold Standard" for each INBAR member country

Country	Total gold standard registered projects
Benin	5
Burundi	7
Cameroon	5
Congo	5
Eritrea	44
Ethiopia	46
Ghana	8
Kenya	116
Malawi	58
Madagascar	16
Mozambique	45
Nigeria	12
Rwanda	164
Tanzania	10
Togo	21
Uganda	151

According to Article 6 of Paris Agreement, the new carbon pricing instrument that will replace the CDM is named the Sustainable Development Mechanism (SDM), and it will come into action very soon. Hence, the African countries should utilise such opportunity to finance the small-scale bamboo bioenergy projects (mostly charcoal or decentralised electricity production). Usually, due to the high transaction cost of project development (including the UNFCCC validation and registration fees), it is not economic that each small investor proceeds with registering his/her project. Hence, the norm in such situation is to have a bundle of similar projects registered together. This necessitates either a governmental organisation (e.g. Ministry of Environment) or NGO or a private carbon project developer to take the lead in project development by coordinating with each of the small-scale investors. The same applies if the project developer will opt to go for the voluntary carbon markets. Some of the famous project developers (e.g. NGOs and private carbon project developers) in Africa are; Pro Climate, Initiative Développement, HIVOS Foundation, Entrepreneurs du Monde, The Paradigm Project, Total LandCare (TLC), Carbonsink Group, CO2logic and E+Carbon, Inc. Hence, it is much recommended that the African policymakers take the first step and contact those project developers to provide them with an overview about the bamboo and how it can be integrated among a wider programme for bioenergy. It is to be noted that the emission reductions by such projects can't be used in the NDCs of the African countries to avoid double counting.

7.2.2.5 "Unlock" # 10: Enhancing the capacity of bamboo business owners about the business development and marketing paths

From the meetings with some of the African investors, it was noticed that some of them lack some basic knowledge about the paths that they can follow to maximise the marketing of their bamboo bioenergy products. The consulting team noticed that lacking such information had a significant impact on the product sales, and accordingly the profitability and the whole system stability (some of those investors were thinking to quit the market). Accordingly, the consulting team believes that increasing the capacity of the business owners in the field of business development and marketing is a necessary "Unlock". Hence, in this intervention, it is recommended to have a public-private partnership in terms of capacity building sessions under the supervision of the most bamboo-relevant public institution (e.g. Bamboo and Rattan Unit in Ghana). The capacity building sessions will be surely important for the bamboo bioenergy business owners, but actually what will be equally important is the public-private connections that will be developed as a results of such sessions. This can open the door for a synergistic public-private partnership that help debottleneck the current barriers.

7.2.2.6 “Unlock” # 11: Using the “Smokeless charcoal” phrase for marketing the bamboo charcoal briquettes

One of the key field study findings is that the urban consumers specifically like to have smokeless charcoal (or low-smoke charcoal); hence, they buy it without focusing much on its source. In one of the main supermarkets in Ethiopia, as shown in Figure 31 having a simple written announcement that the charcoal bags being sold are smokeless make a lot of people go and buy it. In Ghana, there was a similar observation where the “Less smoke” was important in marketing the product (see Figure 32) Of course, technically it is understood that the main reason for having smokeless or less smoke charcoal is the fact of being briquetted and hence having lower heating rate. However, from the consumer’s perspective, they forgot everything that may have heard about the quick burning feature of bamboo as the product they tested is providing them with a very important feature, which is being smokeless/low smoke. Hence, this “Unlock” is very important to be applied by the bamboo charcoal business owners (energy providers) and will gradually help having much increased share of bamboo charcoal in the local market in each country.0

Figure 30. Photo from one of the supermarkets in Ethiopia announcing the availability of smokeless charcoal

Figure 31. Photo from one of the supermarkets in Ghana where bamboo charcoal is marketed using some features including the “Less smoke” phrase

7.2.3 *Unlocks”* related *to “Coordination Mechanisms”*

The “Coordination Mechanisms” is the last component under the “Bamboo Bioenergy Governance” concept. Two “Unlocks” are proposed under this component; both related to governmental coordination. The following sub-sections present explanation for each of the “Unlocks”.

7.2.3.1 <u>“Unlock” # 12: Paving the way to alternative fuels opens the door to bamboo bioenergy</u>

As was evidenced in the “Unlocks # 2, 8 and 9”, sometimes it is smarter not to consider bamboo alone as it will be more effective to be included as one of the potential alternative fuels (mainly because it is difficult to have dedicated funding for such narrow category). Insisting on mainstreaming bamboo bioenergy separately can result in missing some important institutional and funding opportunities. For example, if the forestry department in a country focuses on bamboo bioenergy, but it did not communicate that with the department of alternative fuels in the ministry of Energy, bamboo will not be considered in the national alternative fuels action plan, and accordingly not considered in any relevant funds. For example, a lot of INBAR African countries have policies in the NDC related to alternative fuels (see Table 15). Hence, it is very important that governmental coordination takes place in those countries so that bamboo can be considered in the corresponding development action plans.

Table 15. List of INBAR member countries and their current status towards alternative fuels

List of INBAR Member Countries	Alternative fuels promotions
Benin	√
Burundi	✗
Cameroon	✗
Central African Republic	√
Congo	✗
Eritrea	√
Ethiopia	√
Ghana	✗
Liberia	√
Kenya	√
Malawi	√
Madagascar	√
Mozambique	√
Nigeria	√
Rwanda	√
Senegal	√
Sierra Leone	√
Tanzania	√
Togo	√
Uganda	√

7.2.3.2 "Unlock" # 13: Enhancing the awareness of citizens and governmental officials about bamboo success stories

A lot of citizens and government officials got surprised when they know that the toothpicks or furniture they use are manufactured from bamboo and imported. Similarly, some people even in the bioenergy field got surprised when they know that the charcoal briquettes they are using are manufactured from bamboo. Such surprise is due to the impressions that a lot of people have towards bamboo, and that cause some of the bamboo products to be exported rather than being locally used. If the citizens and governmental officials get exposed to effective awareness sessions mentioning the success stories of bamboo products and bio-energy products in Africa and Worldwide, this can have a significant impact on the market acceptance of the bamboo products. This can accordingly result in nearly new markets and accordingly enhanced bamboo industry and bioenergy. Hence, in this intervention, it is recommended to have effective awareness sessions under the supervision of the most bamboo-relevant public

institution (e.g. Bamboo and Rattan Unit in Ghana). The buy-in of the government is very important; hence, it is proposed here that it is the one responsible for managing such training.

7.3 Recommended "Supports"

As mentioned in the beginning of the chapter, "Supports" refer to interventions that can help flourish and catalyse the bamboo bioenergy situation if applied together with the "Unlocks". Figure 33 presents the recommended "Supports" which will be explained in details in the following sub-sections. As shown, 8 "Support" interventions are recommended to catalyse the bamboo bioenergy projects in Africa. As was the case with the "Unlocks", and the 3 governance components are represented in the recommended "Supports".

7.3.1 *"Supports" related to "Enabling Environment"*

The "Enabling Environment" is the first component under the "Bamboo Bioenergy Governance" concept. One "Support" intervention is proposed under this component which is related to developing policies and action plans as shown in the following sub-section.

7.3.1.1 <u>"Support" # 1: Governmental support by provision of duty-free incentives for sustainable bioenergy equipment</u>

One of the factors that can support the bamboo bioenergy entrepreneurs in the Africa countries is to enjoy duty-free incentives when they purchase their sustainable bioenergy equipment (e.g. charcoal kiln, briquetting machine….). Hence, it is recommended that the African policymakers work on that especially that this can support the effective implementation of the national deforestation and alternative fuels strategies/action plans. Such intervention can help the bamboo bioenergy entrepreneurs have better financial model for their projects and accordingly better market sustainability.

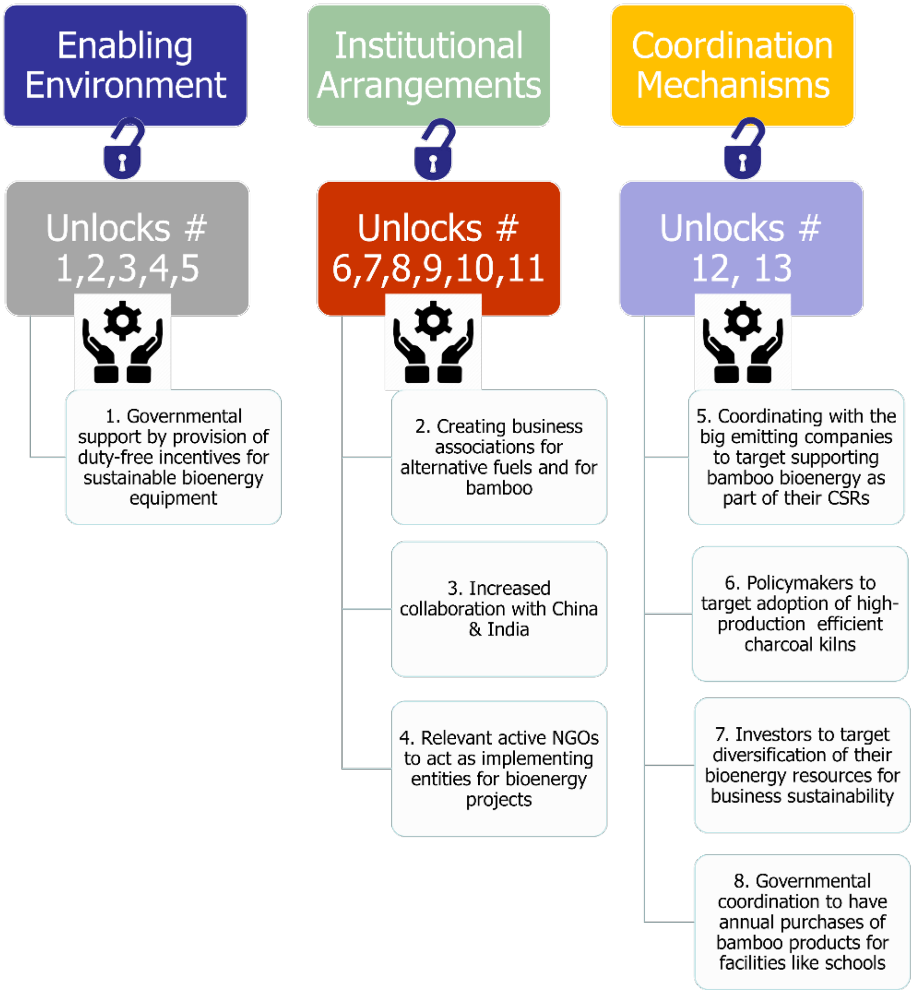

Figure 32. Schematic diagram for the proposed "Support" interventions

7.3.2 *"Supports" related to "Institutional Arrangements"*

The "Institutional Arrangements" is the second component under the "Bamboo Bioenergy Governance" concept. Three "Support" interventions are proposed under this component; the first is related to "Role of energy providers", the second is related to "International cooperation", while the last one is related to the "Implementing agencies" as shown in the following sub-section.

7.3.2.1 "Support" # 2: Creating business associations for alternative fuels and for bamboo

One of the key findings from the field missions during this study is the absence of strong business associations/clusters for bamboo industry in the different countries. Usually the main role of industrial associations/clusters is to connect the business players of the same industry,

discuss the common challenges facing the industry, and propose solutions that are to be discussed with the relevant governmental entity(ies). When specific requests are provided to the government from such association, they are generally being considered in a much quicker and effective manner compared to individual requests, and here comes the importance of developing such associations. Hence, the required intervention here is that INBAR supports the development of bamboo business associations in the different African countries combining all the relevant players. In addition, and matching with the "Unlocks # 2, 8, 9 and 12", it is also strongly recommended that an association for "Alternative fuels" is developed since it will help boost bamboo bioenergy as well. It is recommended that INBAR coordinates with the most relevant NGOs in each of the African countries to work on that. Following the formation of such business associations, it will be the role of the "bamboo players" and "energy providers" generally to make their associations as strong as possible.

7.3.2.2 "Support" # 3: Increased collaboration with China and India

China and India are usually the role models for bamboo economy since they have a lot of success stories that have the potential to be replicated in the African countries. From the field missions conducted under this assignment, it was clear that most of the bamboo equipment (both energy and non-energy) are imported from China and India (see Figure 34). The strong cooperation between China and Ethiopia for example is one important reason for having the level of bamboo industry advanced in Ethiopia compared to other African countries. The technology transfer that already took place in the previous years from China and India is one of the key reasons for having bamboo bioenergy in some of the African countries, even if on small scale (United Nations for South-South Cooperation & INBAR, 2017). Hence, it is recommended that INBAR supports more south-south cooperation between China and India and the other African countries especially in the field of bamboo bioenergy. It is believed that this can support the development of bamboo bioenergy in Africa and take it forward one more level. It was also noticed during the field mission that some of the bamboo bioenergy investors face some technical bottlenecks and inefficiencies in their process. Hence, it is recommended that INBAR considers having a technical support component for the existing facilities in such south-south cooperation programmes.

Figure 33. Two "Mixers" in 2 Ethiopian bamboo charcoal briquetting plants (the one on the left imported from India, and one of the right imported from China)

7.3.2.3 <u>"Support" # 4: Relevant active NGOs to act as implementing entities for bioenergy projects</u>

Defining the lead entity that can first bundle small-scale bamboo bioenergy projects together, then work on accessing finance, and then being the implementing entity of the programme is a challenge. However, reaching the right entity constitutes big fraction of the programme's success. Hence, one important support intervention that INBAR can work on is to identify the NGO entities who has experience in developing energy-related programmes in Africa, and then coordinate with them regarding the potential of bamboo bioenergy and the potential programmes that it can be enrolled in. For the bamboo charcoal projects, it is recommended to contact the cooking stove alliance of each African country and coordinate with them regarding utilizing bamboo as a potential alternative fuel when they work on the "fuel" side if their programmes. Other than that, it is recommended to cooperate with the NGOs who have proven success in developing and implementing African bioenergy programmes that have accessed carbon finance. Some examples of such NGOs are Pro Climate, Initiative Développement, HIVOS Foundation, Entrepreneurs du Monde, The Paradigm Project, and Total LandCare (TLC).

7.3.3 *"Supports" related to "Coordination Mechanisms"*

The "Coordination Mechanisms" is the third component under the "Bamboo Bioenergy Governance" concept. Four "Support" interventions are proposed under this component; the first three are related to "Targets", while the last one is related to the "Governmental Coordination" as shown in the following sub-section.

7.3.3.1 “Support” # 5: Coordinating with the big emitting companies to target supporting bamboo bioenergy as part of their CSRs

Big businesses with huge impact on the health and environment are committed to serve their communities by implementing development projects as part of their corporate social responsibilities (CSR). One good example for that is the Italian petroleum company ENI which was invited by Ghana Alliance for Clean Cooking (GHACCO) to attend their forum late 2018. ENI was interested in the activities of GHACCO and has accordingly supported to design and implement a pilot project to distribute 500-1000 stoves to rural citizens free of charge as part of their CSRs (see Figure 35). The consulting team believes that the big businesses in the African countries (e.g. Oil and Gas, Cement, ...) will be interested in supporting the development of bamboo bioenergy projects especially that they can also claim carbon offsets from them together with the CSRs. Table 16 presents INBAR African countries which have oilandgas and cement activities. Hence, it is recommended that INBAR communicates with such companies to consider funding bamboo bioenergy projects as part of their CSRs. In addition to that, INBAR can also target the multi-national companies with net zero targets (e.g. Procter and Gamble, Vodafone, HSBC…).

Figure 34. ENI’s support to the pilot clean stoves project in Ghana

Table 16. Countries with oil and Gas and Cement presence

Country	Countries with Cement production facilities	Oil and gas companies Presence
Benin	✓	✗
Burundi	✓	✗
Cameroon	✓	
Central Republic Africa	✗	✗
Congo	✓	✓
Eritrea	✓	✗
Ethiopia	✓	✗
Ghana	✓	✓
Kenya	✓	✗
Liberia	✓	✗
Madagascar	✓	✓
Malawi	✓	✗
Mozambique	✗	✗
Nigeria	✓	✓
Rwanda	✓	✗
Senegal	✓	✗
Sierra Leone	✓	✗
Tanzania	✓	✓
Togo	✓	✗
Uganda	✓	✗

7.3.3.2 “Support” # 6: Policymakers to target adoption of high-production efficient charcoal kilns

Despite the big efforts that have been put by previous donor projects to mainstream using efficient charcoal kilns, some kilns did not convince the charcoal makers due to their low production capacity. Despite all the other advantages of higher yield, less cycle time, and less air pollution, the factor of production capacity per kiln was seen by the charcoal producers as one of the key components of a successful project. Some of such kilns were even found to be thrown away on the agricultural roads (see Figure 36). Hence, in the upcoming bamboo bioenergy programmes, the charcoal kilns to be promoted need to be of high production capacity (e.g. not less than 7 tons/week). This is considered as an important “Support” measure that can help the charcoal makers accept the package of using bamboo and its mechanised kiln.

Figure 35. Metal kiln not being used anymore by charcoal producers

7.3.3.3 "Support" # 7: Investors to target diversification of their bioenergy resources for business sustainability

While "Unlocks # # 2, 8, 9 and 12" recommended that the governments integrate bamboo together with the other alternative fuels to boost them all, this support measure recommends something relevant but on the scale of the investor instead. One of the success stories in Ghana highlighted an important market fact which is that the consumers' requirements for charcoal briquettes' quality is not the same. Some consumers like the briquettes with low ash content, some others like the briquettes with high burning rate, while other just go for the lowest cost. Hence, this business automatically worked on what the client needs, and this was achieved by diversifying the raw materials used for the charcoal briquettes manufacture. The coconut was found to be superior in the ash and heating rate requirements; however, it is the most expensive. On the other hand, bamboo is considered to be the optimum raw material since it has acceptable ash and heating rate; albeit with lower cost compared to coconut. After having good understanding for the clients' appetite, that company now blend wood with bamboo or coconut to get an optimised charcoal mix suitable for the requirements of the end user. Hence, what is recommended in this "Support" measure is that the bamboo bioenergy investor should be keen on diversifying his/her energy resources as this will ensure better supply chain, less sensitivity to the prices of specific raw materials, fulfilling the client's quality requirements, and very importantly sustaining the business.

7.3.3.4 "Support" # 8: Governmental coordination to have annual purchases of bamboo products for facilities like schools

The governmental actions usually send direct and indirect messages to the citizens and businesses. Hence, simple actions from the African governments like having annual purchases of bamboo products to be used in facilities like schools, governmental buildings,

and so on delivers more confidence to the citizens in the bamboo products. This can include bamboo charcoal briquettes as the bamboo bioenergy component. Hence, in this “Support” measure, it is recommended that the most bamboo-relevant public institution (e.g. Bamboo and Rattan Unit in Ghana) coordinates with the other governmental institutions in this regards.

8 Scenario analysis for enhancing bamboo bioenergy production

Chapter 7 presented some proposed interventions that can help boost the bamboo bioenergy production in Africa. In this chapter, the potential impacts of such interventions are studied in terms of projection scenarios up to 2040. As illustrated in chapter 6, the INBAR African countries were categorised into two major categories: category A including the countries owning successful bamboo businesses and category B including the countries lacking successful bamboo businesses. And then each category was divided into 2 further sub-categories according to the analysis of the national circumstances of each country. Hence, the developed scenarios were done for each country putting into consideration such difference in Categorisation. The following sub-sections provide more details about the methodology and results.

8.1 Applied methodology for development of scenarios

For each country, two types of scenarios were developed: “maximum potential scenarios” and “moderate scenarios”. For each scenario, the total cost required for developing bamboo bioenergy projects was calculated together with the corresponding GHG emission reductions. This was calculated on yearly basis till 2040.

8.1.1 *Scenarios for maximum potential*

The maximum potential scenarios will be analysed for each country based on two crucial points: the maximum area that can be planted with bamboo in this country and the maximum bioenergy target.

The maximum area is assumed to be based on an annual growth rate from the current bamboo planted area shown in **Table 3**. It was assumed that such growth rates will be 2.5% and 1.5% for Category A and Category B respectively. As a quality check, the total calculated area of bamboo plantation in each country is compared to the total announced committed area to make sure that the assumed planted areas are logic. For the countries with no data about their current bamboo plantation, and to ensure conservativeness, the maximum area was assumed to be 1.5% of the country with the lowest defined bamboo planted area (i.e., Uganda).

The maximum bioenergy target will differ according to the following sub-scenarios:

i. All the newly planted area will be directed to bioenergy projects (electricity, ethanol and charcoal)

ii. All the newly planted area will be directed to industrialised bamboo products. In this case, the bamboo bioenergy (i.e., bamboo charcoal) will be just a fraction of the planted area.

iii. A hybrid approach of the previous two sub-scenarios.

8.1.2 *Scenarios for moderate potential*

As mentioned hereinbefore, away from the maximum potential, moderate scenarios are proposed for each country. The same sub-scenarios are studied, with the only difference is that the proposed bamboo planted area in the moderate scenarios is a percentage of the maximum potential. This percentage was assumed to be the same scores that the country achieved while defining the sub-categories (see **Table 8**). Hence, if the score of a country is 70%, then it can achieve 70% of its maximum bioenergy target. The justification behind such methodology is that the country which starts strongly and have a lot of supporting factors will probably approach more its maximum potential. If the country applies a lot of the recommended “Unlocks” and “Supports” (e.g. tax exemption, preferential loans and grants, carbon financing…), it can approach its full potential. On the other hand, if the country did not work enough on the recommended “Unlocks” and “Supports”, its actual achievements can be even lower than that of the moderate scenario.

8.2 Inputs and assumptions for the calculations

The GHG emission reductions are the reductions due to using harvested bamboo for mechanised charcoal production, non-energy purposes (i.e., industrialised bamboo products), ethanol production, and electricity production. For the produced charcoal, it has been assumed that 90% will be used as an energy source, while 10% will be exported to be used as soil conditioner. Bamboo yields mainly depend on the type of bamboo species (INBAR, 2021). Because of the wide range of bamboo species, the yield of bamboo was taken to be 5 ton/hectare, which is very a conservative value.

By using bamboo in the mechanised charcoal production, the GHG emissions were estimated based on the CDM methodology AMS III-K entitled “Avoidance of methane release from charcoal production by shifting from traditional open-ended methods to mechanised charcoaling process”. The emissions are calculated as follows:

$$E_{m,ch} = m_{y,raw} \times e_{CH_4} \times GWP_{CH_4}$$

Where:

$E_{m,ch}$ Emissions due to the mechanised charcoal production (tCO2e)

$m_{y,raw}$ Quantity of raw material used in year y (tons)

e_{CH_4} Methane emission factor for the traditional open-ended charcoal manufacturing process considered (≈ 0.0045 tons of CH4/ton raw material used)

GWP_{CH_4} Global Warming Potential of CH4 (a value of 25)

According to INBAR (Lugt, Long, & King, 2018), around 10 tons of dry bamboo was consumed to produce 3.5 tons of charcoal with a yield ratio of 2.86:1.

The emission reduction due to burying the charcoal is the equivalent amount of CO_2 corresponding to the buried carbon. Also, for the industrialised bamboo products, the emission reduction is the equivalent amount of CO_2 corresponding to the sequestered carbon. The emission reduction due to ethanol production was taken as 0.414 tCO_2/ton of the produced ethanol based on similar project. Regarding the power generation, the CDM methodology AMS-I.L “Electrification of rural communities using renewable energy” was used to estimate the GHG emission reductions taken into consideration the suppressed demand concept.

Regarding the costs and fixed investments for each scenario, the cost of producing charcoal was taken to be about 1500 USD/ton of charcoal/month in case of charcoal briquettes, and 1000 USD/ton of charcoal/month for normal charcoal. It is assumed that 50% of charcoal are produced as briquettes. The cost of electricity production using a gasifier was taken to be about 3000 USD/kW. The cost of ethanol production was taken to be 3000 USD/ton of ethanol/year (based on the announced investment cost of the Indian bamboo ethanol project).

The first three years (2022-2024) are allocated for plantation of bamboo, so there will be a relatively small scale production of charcoal and industrialised bamboo products (i.e., scenarios (ii) and (iii)) during the first three years. For bioenergy scenarios (i) and (iii), during these three years, it is assumed that there will be establishment of power plants to generate electricity. Consequently, the power plants can start operation in 2025. The ethanol production is assumed to start two years after power production (i.e., starts by 2027). Additionally, ethanol production is proposed only for a scale larger than 50,000 ton of bamboo per year.

8.3 Category A scenarios

In this section, the assumptions, analyses and results of the three proposed sub-scenarios are introduced.

8.3.1 *Sub-scenario (i): All bioenergy*

8.3.1.1 Bamboo shares

In this scenario, all the planted bamboo is directed to bioenergy projects. From 2025 to 2026, the bamboo is directed to charcoal (60%) and electricity (40%). Starting from 2027, the bamboo is directed to charcoal (50%), electricity (40%) and ethanol (10%).

8.3.1.2 Maximum potential in 2040

Table 17 shows the maximum potential of the total GHG emission reductions of category A countries at the end year of study 2040 and the investment costs as well.

Table 17. Maximum potential of GHG emission reductions and costs of sub-scenario (i) for category A countries in 2040

Country	GHG Emission reductions $(tCO_2/year)$	Costs (USD/year)
Nigeria	7,990,660	64,762,476
Ethiopia	7,407,693	60,037,667
Madagascar	5,639,504	45,741,045
Tanzania	633,254	4,106,745
Ghana	862,956	8,472,916
Kenya	657,990	4,267,165
Uganda	272,101	1,764,617

8.3.1.3 Moderate scenarios

For the countries of subcategory A-1, Figure 37 shows the GHG emission reductions per year and the estimated annual costs of the proposed plants over the years. Among these countries, Nigeria has the highest emission reductions due to the high bamboo planted area. It is noted that there is a jump in the estimated costs at 2025 because of establishing the power plants, and there is another jump that will happen when the ethanol starts the commercial operation. For the countries of subcategory, A-2, Ghana has the highest emission reductions due to the high bamboo planted area, and Uganda has the lowest emission reductions. It is noted that the jump in the estimated costs, because of ethanol production, does not happen for all countries of this subcategory. This is because the planted bamboo area cannot guarantee the minimum required of bamboo raw material (i.e., 50000 ton/year) for ethanol production facility.

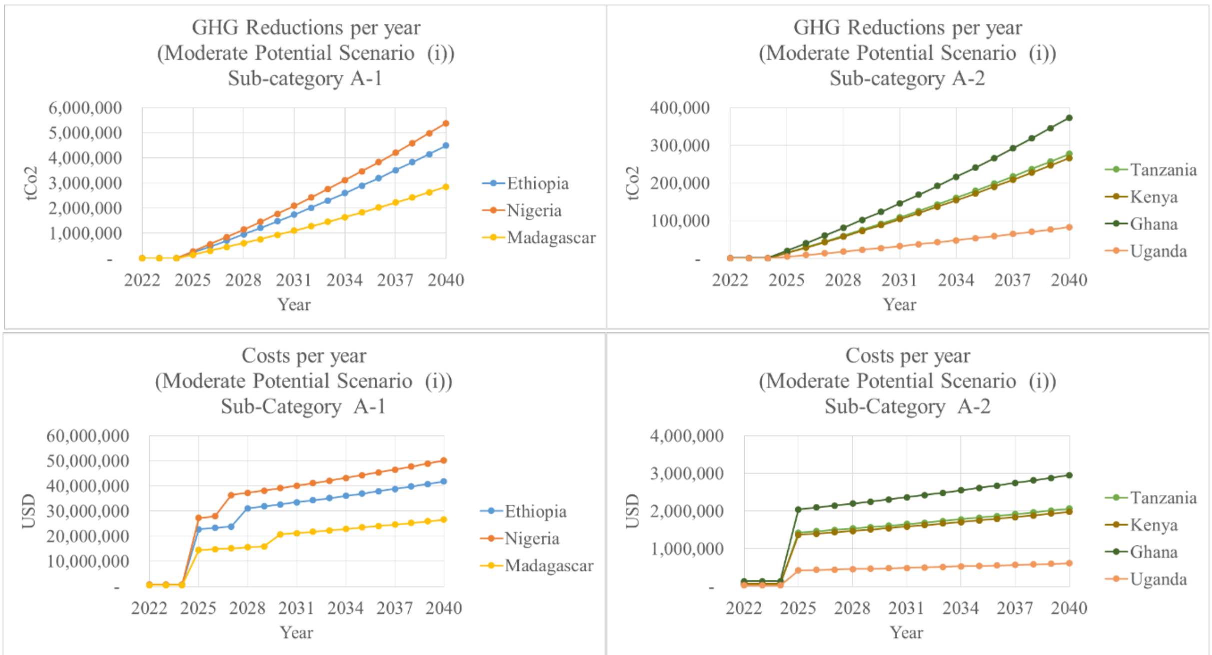

Figure 36. GHG emissions reductions and estimated annual costs of scenario (i) of category A countries

Table 18 shows the cumulative GHG emission reductions of category A countries and the cumulative investment costs as well. It can be seen that the big differences of the cumulative GHG emission reductions are due to the differences in the proposed planted areas and the score percentage of each country. For example, according to **Table 8**, Tanzania and Ghana have the same score percentages, but Ghana has larger current planted area compared to Tanzania. Consequently, the available bamboo bioenergy in Ghana is higher than that in Tanzania. This results in increasing the required investment in bamboo bioenergy, hence more GHG emission reductions can be achieved.

Table 18. Cumulative GHG emission reductions and cumulative costs of scenario (i) of category A countries.

Country	Cumulative GHG Emission reductions $(tCO_2/year)$	Cumulative Costs (USD)
Nigeria	61,654,035	815,899,398
Ethiopia	51,379,661	674,499,237
Madagascar	32,548,339	420,005,260
Tanzania	3,183,503	34,328,358
Ghana	4,283,083	49,300,349
Kenya	3,054,085	32,939,503
Uganda	948,136	10,234,998

8.3.2 Sub-scenario (ii): Industrialised bamboo products

8.3.2.1 Bamboo shares

In this scenario, all the planted bamboo is directed to industrialised bamboo products, where the residuals are for bioenergy (i.e., charcoal). Based on the visits to the bamboo processing facilities in Ethiopia, it can be assumed that 50% of input raw bamboo is wasted in the factories, so this waste is proposed to produce charcoal.

8.3.2.2 Maximum potential in 2040

Table 19 shows the maximum potential of the total GHG emission reductions of category A countries at the end year of study 2040 and the investment costs as well. Compared to the tabulated results in Table 17, the required investments for bioenergy of scenario (ii) are relatively low due to the investment in just the mechanised charcoal production. Accordingly, the GHG emission reductions are relatively low, since there are no emission reductions due to electricity or ethanol production.

Table 19. Maximum potential of GHG emission reductions and costs of sub-scenario (ii) of category A countries

Country	GHG Emission reductions $(tCO_2/year)$	Costs (USD)
Nigeria	4,956,371	5,650,717
Ethiopia	4,594,774	5,238,463
Madagascar	3,500,632	3,991,041
Tanzania	399,003	454,900
Ghana	935,164	1,066,173
Kenya	414,589	472,670
Uganda	171,447	195,465

8.3.2.3 Moderate scenarios

For the countries of category A, Figure 38 shows the GHG emission reductions per year and the estimated annual costs of the proposed plants over the years. In this scenario, there is no jump in investment costs of any year, since the investment cost is of the charcoal production only.

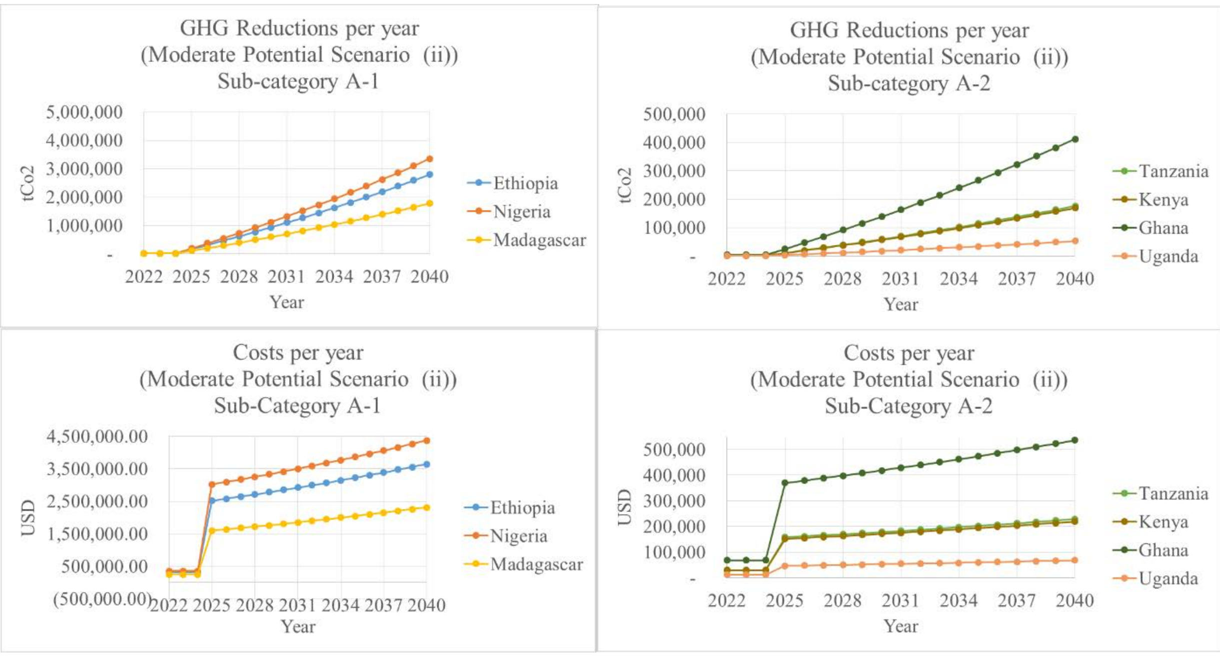

Figure 37. GHG emissions reductions and estimated annual costs of scenario (ii) of category A countries**.**

Table 20 shows the cumulative GHG emission reductions of category A countries and the cumulative investment costs as well.

Table 20. Cumulative GHG emission reductions and cumulative costs of scenario (ii) of category A countries.

Country	**Cumulative GHG Emission reductions** $(tCO_2/year)$	**Cumulative Costs (USD)**
Nigeria	38,549,017	73,384,837
Ethiopia	32,205,010	61,328,639
Madagascar	20,500,138	39,065,113
Tanzania	2,029,933	3,870,637
Ghana	4,757,655	9,071,805
Kenya	1,949,897	3,719,455
Uganda	608,683	1,162,990

8.3.3 *Sub-scenario (iii): Hybrid*

8.3.3.1 Bamboo shares

In this scenario, 50% the planted bamboo is directed to bioenergy projects, and the other 50% is directed to industrialised bamboo products. From 2025 to 2026, the bamboo is directed to products (25%), charcoal (55%) and electricity (20%). Starting from 2027, the bamboo is directed to products (25%), charcoal (50%), electricity (20%) and ethanol (5%).

8.3.3.2 Maximum potential in 2040

Table 21 shows the maximum potential of the total GHG emission reductions of category A countries at the end year of study 2040 and the investment costs as well.

Table 21. Maximum potential of GHG emission reductions and costs of sub-scenario (iii) of category A countries.

Country	GHG Emission reductions $(tCO_2/year)$	Costs (USD)
Nigeria	2,918,806	35,206,597
Ethiopia	2,707,167	32,638,065
Madagascar	2,063,535	24,866,043
Tanzania	237,005	2,280,823
Ghana	550,509	5,292,370
Kenya	246,263	2,369,917
Uganda	101,838	980,041

8.3.3.3 Moderate scenarios

For the countries of category A, Figure 39 shows the GHG emission reductions per year and the estimated annual costs of the proposed plants over the years. It is noted that the estimated costs of this scenario are lower than the costs of sub-scenario (i), since the required power plants capacities and ethanol production capacities are lower. Additionally, the jump in the estimated costs, because of ethanol production, will happen later than what is anticipated in sub-scenario (i). This is because the share of bamboo to ethanol production is less.

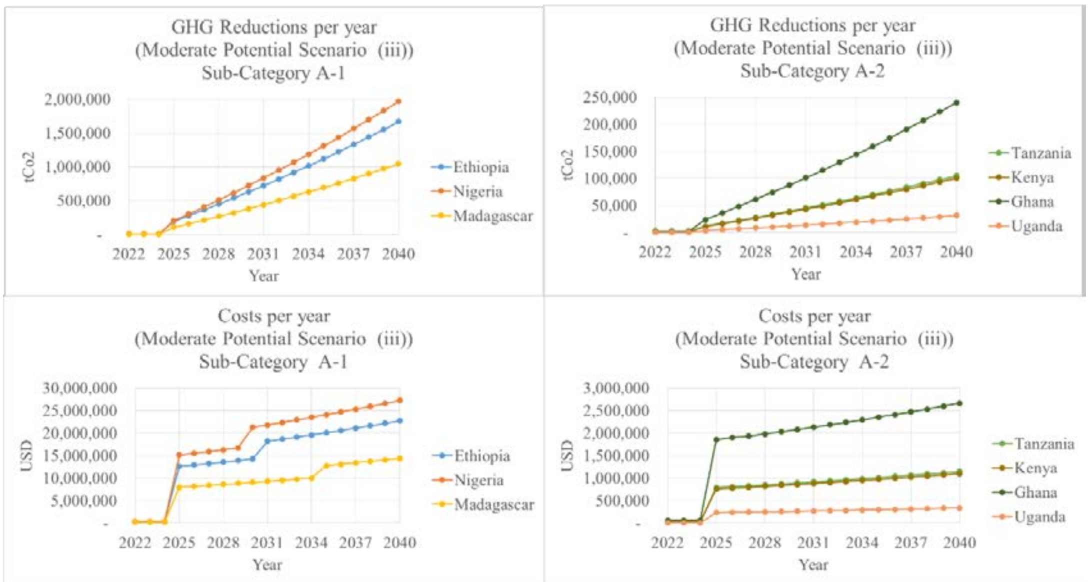

Figure 38. GHG emissions reductions and estimated annual costs of sub-scenario (iii) of category A countries.

Table 22 shows the cumulative GHG emission reductions of category A countries and the cumulative investment costs as well.

Table 22. Cumulative GHG emission reductions and cumulative costs of sub-scenario (iii) of category A countries.

Country	**Cumulative GHG Emission reductions** $(tCO_2/year)$	**Cumulative Costs (USD)**
Nigeria	23,431,214	432,229,734
Ethiopia	20,014,035	357,259,846
Madagascar	12,391,301	217,580,212
Tanzania	1,258,999	19,055,747
Ghana	2,852,722	44,245,808
Kenya	1,201,503	18,284,020
Uganda	378,273	5,680,195

8.4 Category B scenarios

In this section, the assumptions, analyses and results of the three proposed scenarios are introduced.

8.4.1 *Scenario (i): All bioenergy*

8.4.1.1 Bamboo shares

In this scenario, all the planted bamboo is directed to bioenergy projects. From 2025 to 2026, the bamboo is totally directed to charcoal (100%). From 2027 to 2028, the bamboo is directed to charcoal (70%) and electricity (30%). Starting from 2028, the bamboo is directed to charcoal (60%), electricity (30%) and ethanol (10%).

8.4.1.2 Maximum potential in 2040

Table 23 shows the maximum potential of the total GHG emission reductions of category B countries at the end year of study 2040 and the investment costs as well. As mentioned hereinbefore, some countries lack the estimation of their current bamboo plantation, so the maximum area is proposed to be 1.5% of the lowest known bamboo planted area by INBAR African countries (i.e., Uganda). This proposal was applied to these countries: Malawi, Congo, Liberia, Togo Benin, Burundi, Sierra Leone, Rwanda, Eritrea, and Central Republic Africa. Consequently, the capacity of the proposed bioenergy projects are identical for these countries, hence the maximum potential of investment costs and GHG emission reductions are identical.

Table 23. Maximum potential of GHG emission reductions and costs of sub-scenario (i) of category B countries.

Country	GHG Emission reductions $(tCO_2/year)$	Costs (USD)
Malawi	108,104	714,767
Mozambique	992,147	8,672,353
Senegal	1,316,549	11,464,850
Congo	108,104	714,767
Cameroon	2,431,453	21,073,817
Liberia	108,104	714,767
Togo	108,104	714,767
Benin	108,104	714,767
Burundi	108,104	714,767
Sierra Leone	108,104	714,767
Rwanda	108,104	714,767
Eritrea	108,104	714,767
Central Republic Africa	108,104	714,767

8.4.1.3 Moderate scenarios

For the countries of category B, Figure 40 shows the GHG emission reductions per year and the estimated annual costs of the proposed plants over the year. Among these countries, Cameroon has the highest emission reductions due to the relatively high bamboo planted area. It is noted that there is a jump in the estimated costs at 2027 because of establishing the power plants, and there is another jump that will happen when the ethanol start the commercial production. The ethanol production will occur only for the case of Cameroon, since the planted bamboo area can guarantee the minimum required of bamboo raw material (i.e., 50000 ton/year) for ethanol production facility.

For the countries of subcategory B-2, it is worthy noting that the emission reductions from these countries are about 10% of the emission reductions of category B-1 countries. It is noted that no country of category B-2 countries can guarantee the minimum required of bamboo raw material (i.e., 50000 ton/year) for ethanol production facility.

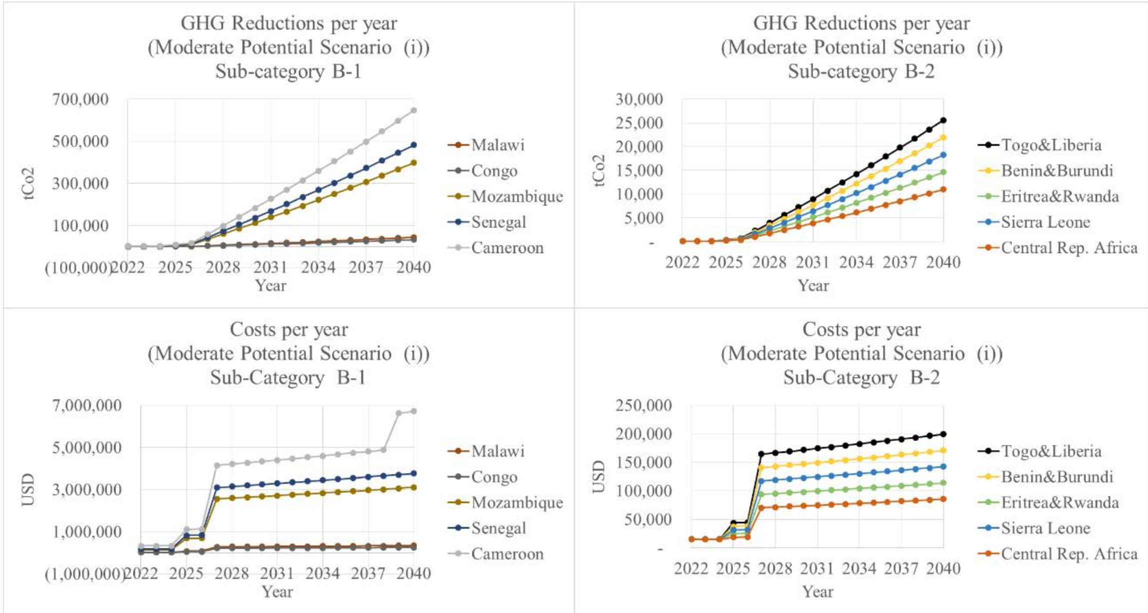

Figure 39. GHG emissions reductions and estimated annual costs of sub-scenario (i) of category B countries**.**

Table 24 shows the cumulative GHG emission reductions of category B countries and the cumulative investment costs as well. It can be seen that the big differences of the cumulative GHG emission reductions are due to the differences in the proposed planted areas and the score percentage of each country. For the countries of identical maximum potential, there are differences in the cumulative costs and GHG emission reductions. This results from the different score percentage of each country. For example, Malawi and Congo have the same proposed maximum planted area, but the score percentage of Malawi is higher than Congo, according to Table 8. Consequently, the available bamboo bioenergy in Malawi is higher than that in Congo. This results in increasing the required investment in bamboo bioenergy, hence more GHG emission reductions can be achieved. Another example, Benin and Burundi are typical in the proposed maximum planted area and the score percentage; they have the same potential.

Table 24. Cumulative GHG emission reductions and cumulative costs of sub-scenario (i) of category B countries.

Country	Cumulative GHG Emission reductions $(tCO_2/year)$	Cumulative Costs (USD)
Malawi	478,794	5,604,296
Mozambique	4,352,677	50,948,148
Senegal	5,276,908	61,785,849
Congo	359,642	4,214,501
Cameroon	7,083,787	91,418,375

Liberia	280,207	3,287,972
Togo	280,207	3,287,972
Benin	240,490	2,824,707
Burundi	240,490	2,824,707
Sierra Leone	200,773	2,361,442
Rwanda	161,055	1,898,177
Eritrea	161,055	1,898,177
Central Republic Africa	121,338	1,434,912

8.4.2 *Sub-scenario (ii): Industrialised bamboo products*

8.4.2.1 Bamboo shares

In this scenario, all the planted bamboo is directed to industrialised bamboo products, where the residuals (i.e., 50%) are for bioenergy (i.e., charcoal).

8.4.2.2 Maximum potential in 2040

Table 25 shows the maximum potential of the total GHG emission reductions of category B countries at the end year of study 2040 and the investment costs as well.

Table 25. Maximum potential of GHG emission reductions and costs of sub-scenario (ii) of category B countries**.**

Country	GHG Emission reductions $(tCO_2/year)$	Costs (USD)
Malawi	93,673	98,306
Mozambique	851,577	893,690
Senegal	1,125,785	1,181,458
Congo	93,673	98,306
Cameroon	2,069,332	2,171,666
Liberia	93,673	98,306
Togo	93,673	98,306
Benin	93,673	98,306
Burundi	93,673	98,306
Sierra Leone	93,673	98,306
Rwanda	93,673	98,306
Eritrea	93,673	98,306
Central Republic Africa	93,673	98,306

8.4.2.3 Moderate scenarios

For the countries of subcategory B-1, Figure 41 shows the GHG emission reductions per year and the estimated annual costs of the proposed plants over the years. In this scenario, there is no jump in investment costs of any year, since the investment cost is of the charcoal production only.

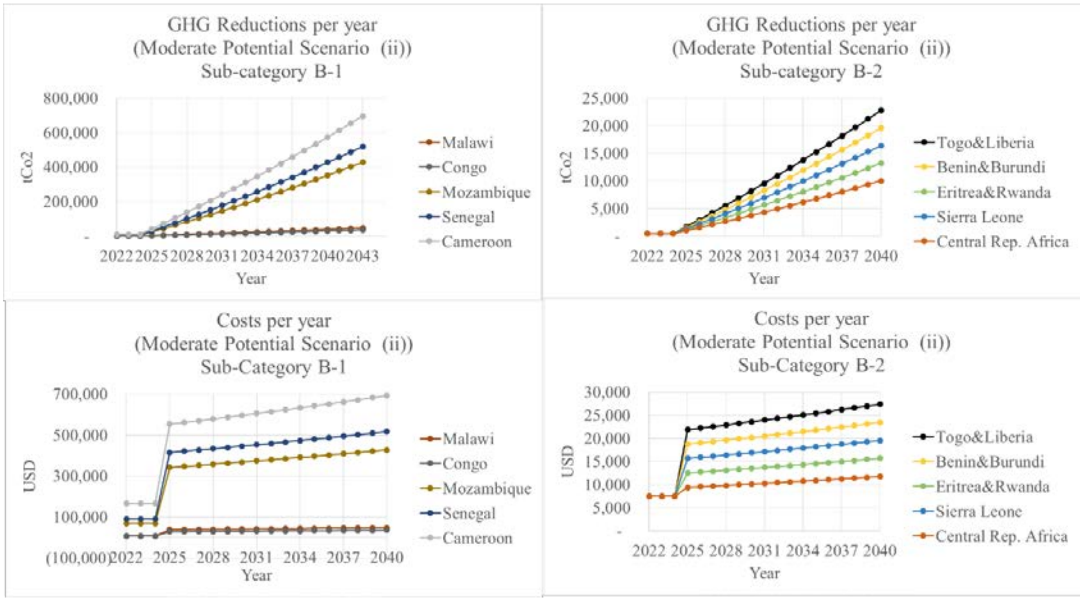

Figure 40. GHG emissions reductions and estimated annual costs of scenario (ii) of category B countries.

Table 26 shows the cumulative GHG emission reductions of category B countries and the cumulative investment costs as well.

Table 26. Cumulative GHG emission reductions and cumulative costs of sub-scenario (ii) of category B countries

Country	Cumulative GHG Emission reductions $(tCO_2/year)$	Cumulative Costs (USD)
Malawi	454,843	842,064
Mozambique	4,134,938	7,655,128
Senegal	5,020,282	9,299,332
Congo	343,485	637,188
Cameroon	6,767,903	12,567,420
Liberia	269,247	500,603
Togo	269,247	500,603
Benin	232,127	432,311
Burundi	232,127	432,311
Sierra Leone	195,008	364,019
Rwanda	157,889	295,727
Eritrea	157,889	295,727
Central Republic Africa	120,769	227,435

8.4.3 *Sub-scenario (iii): Hybrid*

8.4.3.1 Bamboo shares

In this scenario, 50% the planted bamboo is directed to bioenergy projects, and the other 50% is directed to industrialised bamboo products. From 2025 to 2026, the bamboo is directed to products (25%) and charcoal (75%). From 2027 to 2028, the bamboo is directed to products (25%), charcoal (55%) and electricity (20%). Starting from 2028, the bamboo is directed to products (25%), charcoal (50%), electricity (20%) and ethanol (5%).

8.4.3.2 Maximum potential in 2040

Table 27 shows the maximum potential of the total GHG emission reductions of category B countries at the end year of study 2040 and the investment costs as well.

Table 27. Maximum potential of cumulative GHG emission reductions and cumulative costs of sub-scenario (iii) of category B countries.

Country	Cumulative GHG Emission reductions $(tCO_2/year)$	Cumulative Costs (USD)
Malawi	53,347	492,895
Mozambique	484,975	4,480,867
Senegal	640,311	7,361,034
Congo	53,347	492,895
Cameroon	1,172,001	13,530,493
Liberia	53,347	492,895
Togo	53,347	492,895
Benin	53,347	492,895
Burundi	53,347	492,895
Sierra Leone	53,347	492,895
Rwanda	53,347	492,895
Eritrea	53,347	492,895
Central Republic Africa	53,347	492,895

8.4.3.3 Moderate scenarios

For the countries of category B, Figure 42 shows the GHG emission reductions per year and the estimated annual costs of the proposed plants over the years. As mentioned hereinbefore, it is noted that the estimated costs of this scenario are lower than the costs of scenario (i), since the required power plants capacities and ethanol production capacities are lower. Additionally, no country in category B, even Cameroon, can guarantee the minimum required of bamboo raw material (i.e., 50000 ton/year) for ethanol production facility. This is because the share of bamboo to ethanol production is less.

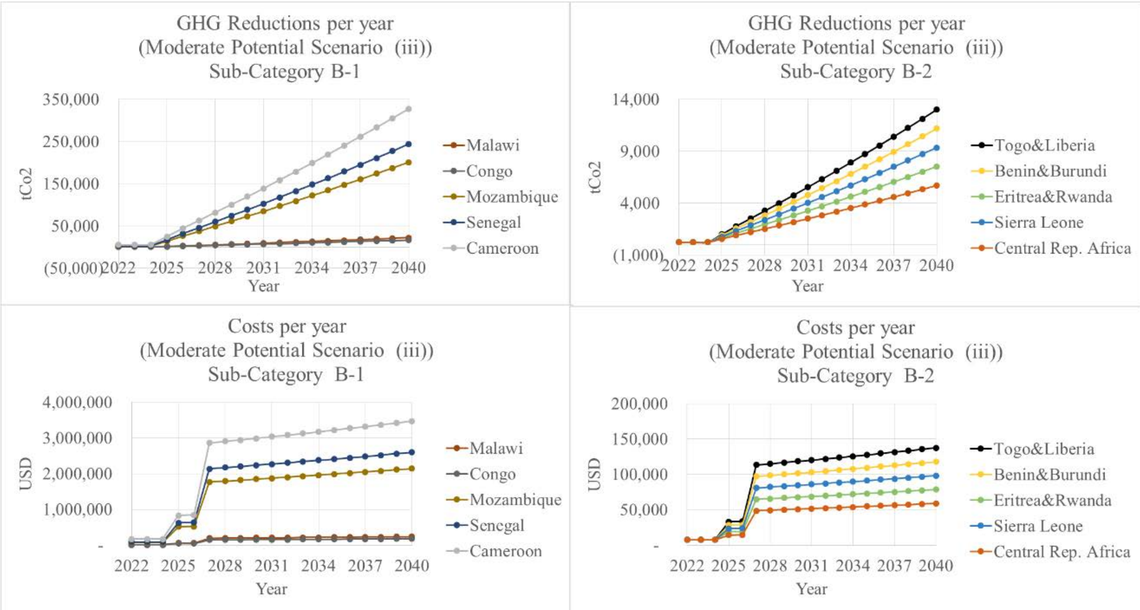

Figure 41. GHG emissions reductions and estimated annual costs of scenario (iii) of category B countries.

Table 28 shows the cumulative GHG emission reductions of category B countries and the cumulative investment costs as well.

Table 28. Cumulative GHG emission reductions and cumulative costs of sub-scenario (iii) of category B countries.

Country	**Cumulative GHG Emission reductions** $(tCO_2/year)$	**Cumulative Costs (USD)**
Malawi	261,116	3,865,262
Mozambique	2,373,781	35,138,747
Senegal	2,881,887	42,604,898
Congo	197,150	2,904,586
Cameroon	3,884,201	57,090,884
Liberia	154,506	2,264,136
Togo	154,506	2,264,136
Benin	133,184	1,943,910
Burundi	133,184	1,943,910
Sierra Leone	111,862	1,623,685
Rwanda	90,540	1,303,460
Eritrea	90,540	1,303,460
Central Republic Africa	69,218	983,235

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