Food and Agriculture Organization
of the United Nations

# Improved charcoal technologies and briquette production from woody residues in Malawi

Bioenergy and Food Security
(BEFS) case study

## Purpose of the BEFS Case studies

*The purpose of these case studies is to present a range of bioenergy supply chains and look at how to assess the potential within the chains based on the Bioenergy and Food Security (BEFS) Approach and BEFS Rapid Appraisal tools. The case studies have been developed for training purposes, to illustrate the BEFS approach and tools and how they are applied and to present a number of examples of bioenergy supply chains found in countries where BEFS has supported national stakeholders.*

## Acknowledgements

*The Bioenergy and Food Security (BEFS) case studies were written by members of the BEFS Team; Luis Rincon, Ana Kojakovic, Sergio Rivero and Manas Puri, led by Irini Maltsoglou with inputs from Federica Chiozza and Vicki Romo. The graphical layout was done by Juan Luis Salazar and Christabel Clark provided editorial support. The BEFS team would also like to thank the national experts and institutions that provided input and reviewed the material used. The case studies were developed under the overall leadership of Alex Jones, Director of FAO's Climate and Environment Division (CBC), and Olivier Dubois, CBC's Energy team leader.*

*Our sincere appreciation goes to those working on the project activities that became the field and background work for the case studies, more specifically our thanks goes to the German Federal Ministry of Food and Agriculture, the national stakeholders in Côte d'Ivoire, Malawi, the Philippines and Turkey, the European Bank for Reconstruction and Development, and the local FAO offices in the countries.*

## Contents



## Case study focus

Access to modern energy in Malawi remains low and is often limited to relying on traditional biomass sources such as fuelwood and charcoal. Sustainably sourced biomass and more efficient technologies can contribute to reducing the energy access gap and making energy access more sustainable. This case study presents opportunities lying within technology improvement and a specific set of woody residues' bioenergy supply chains.  The case study illustrates the steps required to assess if the selected bioenergy supply chains can contribute to mitigating unsustainable use of biomass, while improving access to sustainable energy. The bioenergy examples assessed are briquettes made from forest harvesting and wood processing residues and improved charcoal technologies with the use of the relevant BEFS Rapid Appraisal tools. The case study describes the policy and country context and then presents the biomass assessment and the technoeconomic assessment with the relative conclusions.

## Key elements of the bioenergy supply chain

| Feedstock | Technology | Energy end use option | BEFS RA Tools |
|---|---|---|---|
| forestry harvesting residues and wood processing residues | charcoal technologies and briquettes | energy for cooking | wood fuel tool, charcoal tool and briquettes tool |

## Bioenergy supply chain: graphical summary

Forest Harvesting Residues

Briquettes?

Wood Processing Residues

Charcoal?

# Glossary

| | |
|---|---|
| **Biodiesel** | Biodiesel is called the mixture of esters obtained from the transesterification of triglycerides contained in oleo chemical feedstock such as vegetable oils, tallow and greases. Biodiesel can be used as substitute of diesel fuel. |
| **Bioenergy** | Bioenergy is the energy generated from the conversion of solid, liquid and gaseous products derived from biomass. |
| **Biogas** | Biogas is a mixture of gases, mainly composed by methane (50-60 percent) obtained from the anaerobic digestion of biomass. In general, most of the organic wastes can be digested (excepting lignin). Among the most common biogas substrates can be counter livestock residues, municipal solid wastes (MSW), water treatment plants sludges. |
| **Biomass** | Biomass is any organic matter, i.e. biological material, available on a renewable basis. Includes feedstock derived from animals or plants, such as wood and agricultural crops, and organic waste from municipal and industrial sources. |
| **Biomass assessment** | Biomass assessment analysis the production, availability and accessibility of biomass feedstock for energy production. The assessment considers all uses of the potential feedstock, such as their use in maintaining soil fertility, or as feed for livestock before calculating the amount of biomass available for bioenergy production. This is essential to avoid any adverse impact that bioenergy production may have on agricultural sustainability. The result of the assessment is the identification of the main types of biomass feedstock available for bioenergy production as well as their geographical distribution within a specific region or country. |
| **Briquettes and pellets** | Solid biofuel obtained by compressing biomass in order to increase density. The primary difference between briquettes and pellets is shape and size. Briquettes are generally bigger than pellets. |
| **Charcoal** | A porous black solid obtained from biomass. It is an amorphous form of carbon obtained by the thermal decomposition of wood or other organic matter in the absence of air. |
| **CHP** | CHP stands for the cogeneration of heat and power. It is an efficient method for the simultaneous generation of at least two energy forms, including heat, power, and/or cooling. |
| **Combustion** | Combustion is the most common way of converting solid biomass fuel to energy. Around 90% of the energy generated from biomass is obtained through combustion, which is traditionally used for heating and cooking. Moreover, biomass combustion technologies are actively used for electricity generation at rural and industrial scales by means of steam. |
| **Crop residues** | Plant material remaining after harvesting, including leaves, stalks, roots etc. |
| **Ethanol** | Ethanol is a short chain alcohol, which can be directly used as fuel or blended with gasoline. It can be produced through the fermentation of glucose derived from sugar-bearing plants (e.g. sugar-cane), starchy materials after hydrolysis or lignocellulosic materials (e.g. crop residues, Miscanthus) after pretreatment and hydrolysis. |
| **Forest harvesting residues** | Forest harvesting residues are parts of felled trees which are not removed from the forest. The rate of removal varies among forests and usually depends on the end product that will be made and the cost-effectiveness of removing the tree. In the case of industrial roundwood, upper logs, branches and different cut-offs are often left in the forest, while stems are removed. Sometimes, stems are debarked in the forest. |
| **Gasification** | Gasification is thermochemical process where biomass is transformed into a gas called syngas. This gas is a mixture mostly composed by hydrogen, methane, and nitrogen. Depending on processing technology, conditions and gasifying agent (i.e. air, oxygen or water). The syngas has different composition and as result different fuel qualities. |

| | |
|---|---|
| **Livestock residues** | Residues originating from livestock keeping. It mainly includes solid excreta of animals. |
| **Roundwood** | Wood in the rough. Wood in its natural state as felled, or otherwise harvested, with or without bark, round, split, roughly squared or other forms (e.g. roots, stumps, burls, etc.). It comprises all wood obtained from removals, i.e. the quantities removed from forests and from trees outside the forest, including wood recovered from natural, felling and logging losses during the period - calendar year or forest year. |
| **Sawnwood** | Sawnwood, unplanned, planed, grooved, tongued, etc., sawn lengthwise, or produced by a profile-chipping process (e.g. planks, beams, joists, boards, rafters, scantlings, laths, boxboards, "lumber", sleepers, etc.) and planed wood which may also be finger jointed, tongued or grooved, chamfered, rabbeted, V-jointed, beaded, etc. Wood flooring is excluded. |
| **Techno-economic assessment** | In the bioenergy context, Techno-economic (TE) assessment facilitates a data-driven decision making about the performance of a bioenergy value chain, in a given context. This methodology is based on understanding the technical (e.g., technology feasibility, biomass supplying) and economic (e.g., production costs, profitability, capital investments) features of these value chains. Depending on the context and objectives, TE assessments can be extended to include socio-economic and environmental aspects. |
| **Wood processing residues** | These residues include sawdust, slabs and chips generated as residues during the wood processing. The amount of residues generated in a sawmill depends on the type of technology used and its efficiency. Often, these residues are not fully utilized due to the lack of demand in the immediate vicinity of the processing plant. |
| **Woodfuel** | Woodfuels arise from multiple sources including forests, other wooded land and trees outside forests, co-products from wood processing, post-consumer recovered wood and processed wood-based fuels. |

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# Introduction and policy background

The government of Malawi in its Growth and Development Strategy 2017 – 2022 has defined energy as a crucial input into all critical social and economic services. It considers access to a clean, reliable, reasonably-priced and sustainable energy supply as central to maintaining and improving the living standards of people. In order for the economy to grow and to attract new investments, Malawi needs reliable electricity generation from alternative energy sources (IMF, 2017).

In relation to this, one of serious problem that Malawi faces is the dependence of its population on solid fuels to cover the energy demand for cooking, both in urban and rural areas. This, in turn, leads to unsustainable utilization of biomass that contributes to deforestation and land degradation.

In response to this, the National Forest Policy 2016 includes an objective on reducing deforestation, forest degradation and dependence on solid biomass fuels. While recognizing that charcoal and firewood will continue to feature highly as a source of energy in Malawi in the immediate future, the country seeks to address this challenge to halt and reverse the rate of deforestation and forest degradation. The Renewable Energy Policy (2017) and the National Charcoal Strategy (2017-2027) promotes the sustainable use of solid fuels, the adoption of alternative cooking fuels, use of efficient charcoal and firewood cookstoves, and improved sustainable wood production and regulation enforcement.

BOX

## Bioenergy and food security (BEFS) approach

The Bioenergy and Food Security (BEFS) Approach has been developed by FAO to support countries to develop evidence based sustainable bioenergy policies. The approach supports countries in understanding the linkages between food security, agriculture and energy, and building sustainable bioenergy policies and strategies that foster both food and energy security and contribute to agricultural and rural development. A core element of the BEFS Approach is the BEFS sustainable bioenergy assessment component. The assessment covers the whole bioenergy pathway starting from feedstock availability assessment to analysis of energy end use options. The first step in the assessment component is the BEFS Rapid Appraisal (BEFS RA). The BEFS RA consists of a set of excel based tools which provide an initial indication of the sustainable bioenergy potential and of the associated trade-offs. The BEFS RA is divided into three major components: Country Status, Biomass Assessment (Natural Resources) and Energy End Use Options (Techno-economic Analysis). Each major component has one or more excel based tools linked to it.

The steps of the BEFS RA analysis:

**Step 1: Country Status**
This step collects information on the country status and defines the context, needs and constraints in the key sectors such as agriculture, food security, energy and the environment.

**Step 2: Natural Resources: Biomass Potential Assessment**
The biomass assessment estimates feedstock availability, considering competing uses and needs. The output is an initial indication of the quantities of feedstock available from crop and livestock residues, forest harvesting and wood processing residues, as well as the potential availability of crops for energy production. Profitability of different crops is also taken into consideration.

**Step 3: Energy End Use Options: Techno-economic Analysis**
The energy end use options module evaluates the following bioenergy options:

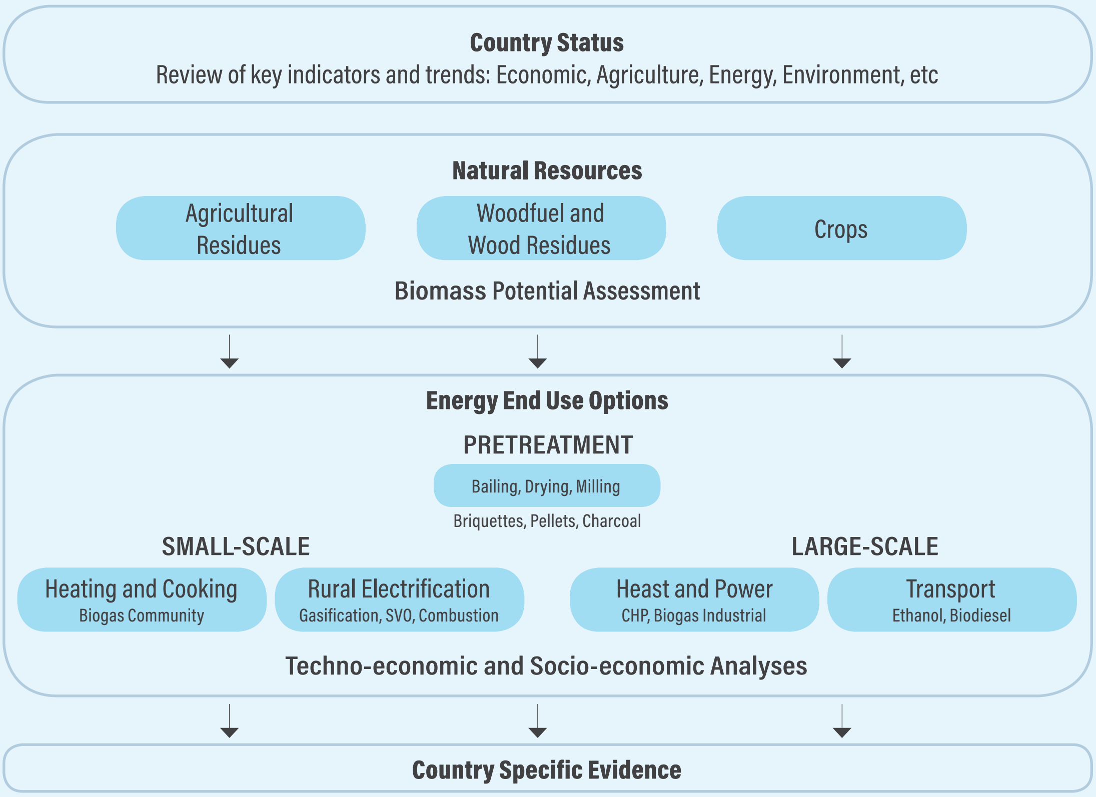
- Intermediate or final products: briquettes, pellets and charcoal;
- Heating and cooking: biogas community;
- Rural electrification: gasification, straight vegetable oil (SVO) and combustion;
- Heat and power: combined heat and power (CHP) and industrial biogas; and
- Transport: ethanol (1st Generation, 2nd Generation and Molasses) and biodiesel.

Given the current use of biomass and energy needs for cooking, this case study explores the role of specific bioenergy supply chains in terms of alternative energy sources and how improved charcoal technologies can help reduce the pressure on forestry resources. The bioenergy supply chains considered in this case study are biomass generated from forest harvesting residues and wood processing residues to produce briquettes and charcoal. The case study looks at the potential to reduce the use of fuelwood through improved charcoal production technologies as well as to briquettes.

The Bioenergy and Food Security Rapid Appraisal (BEFS RA) tools used for the analysis are the wood fuel tool, the charcoal tool and the briquettes tool.[1] The results determine whether there is the potential to use available resources for sustainable production of briquettes and charcoal. The BEFS RA woody residues tool estimates whether forestry and wood processing residues are actually available for energy use. The briquette and charcoal tools are used to assess investment requirements, operational costs and supply capacity, while comparing these technologies to the current supply options.

[1] The case study presented was part of a broader application of the Bioenergy and Food Security Rapid Appraisal analysis that covered a wider range of bioenergy supply chains and was the result of a broader discussion with technical experts from a number of ministries, including the Ministry of Natural Resources, Energy and Environment, the Ministry of Agriculture and Food Security, and the Ministry of Industry and Trade.

Each tool can be used individually but the approach advocates that output from each stage should be used as input into the following steps of the analysis.  The tools are excel based and globally applicable. They can be used with limited user defined data and default values are provided. The analysis can be carried out at country or local level and tailored to address the specific needs of countries. In fact, countries can decide to assess a wide spectrum of bioenergy supply chains or, for example, to keep the analysis specific to crop residues for cooking or livestock residues for biogas generation. example.

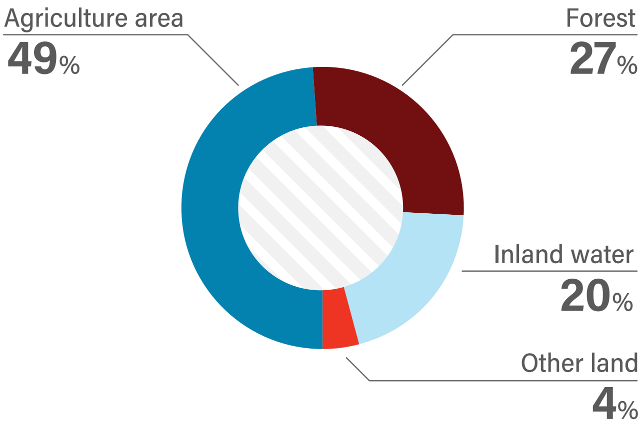


# The context: agriculture and energy sector in Malawi

Malawi is a Southern African landlocked country with a population of 18.1 million and approximately 85 percent of the population living in rural areas. The GDP per capita was USD 300 in 2016, with one in two Malawians classified as living below the national poverty line, one-quarter living in extreme poverty as of 2010 and higher poverty rates in rural areas (FAO, 2015; IMF, 2017; World Bank, 2017a,b; UNDP, 2015). Malawi suffers from chronic food insecurity and malnutrition, as 21 percent of the population is undernourished (in the three-year average of 2014-2016) and is classified as a Low-Income Food-Deficit Country (LIFDC)[2]. Moreover, approximately half of all children endure acute or severe malnutrition (FAO, 2015, 2017; UN, 2014).

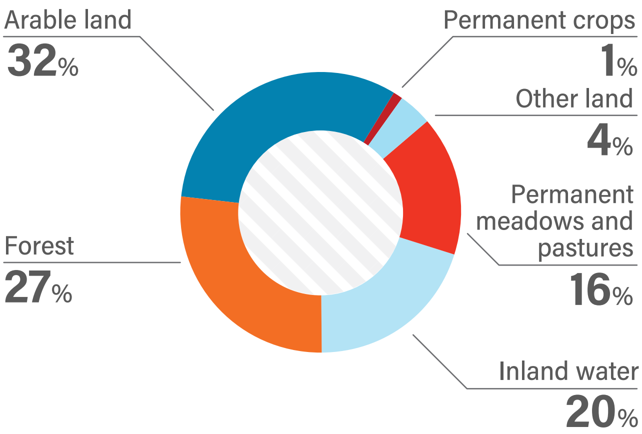
In terms of land use, half of the land area in Malawi is agricultural land, of which more than 60 percent is arable land and around 30 percent are permanent meadows and pastures as shown in **Figure 1** and **Figure 2**. Forests dominate the northern, north-eastern and south-western part of the country, **Figure 3**, and cover about a quarter of the land area. Forest areas also appear to be the less populated areas of the country, **Figure 4**.

**FIGURE 1.** Land use classification in Malawi in 2013




**Source:** *Adapted from (opendataforafrica, 2015)*

**FIGURE 2.** Detailed land use classification in Malawi in 2013



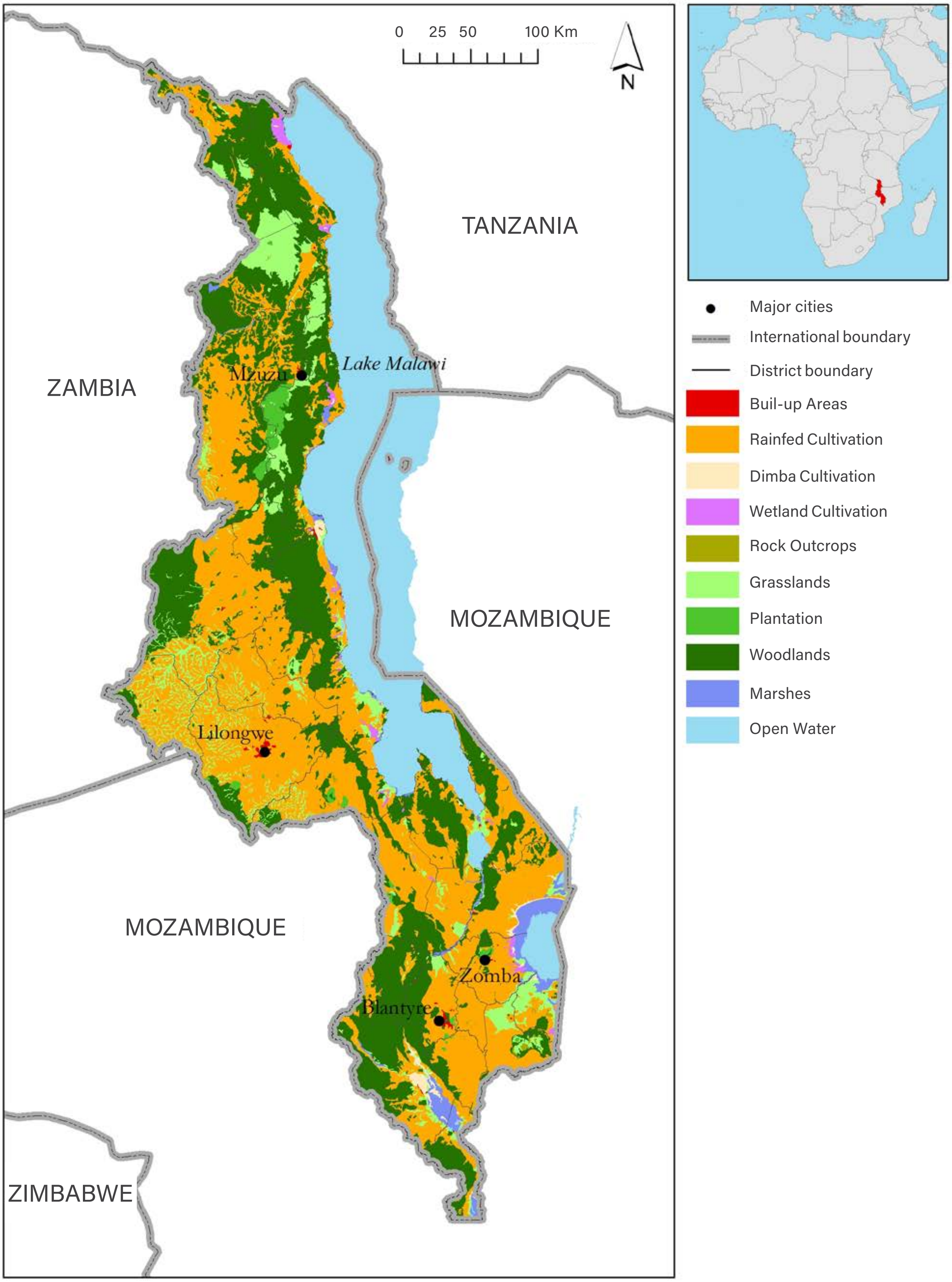

**Source:** *Adapted from (opendataforafrica, 2015)*

Agriculture is a key sector in Malawi and is mostly small scale and rain-fed and thus prone to climatic shocks, which in turn impact agricultural outputs resulting in price volatility. Subsistence and small-scale farming is in fact one of the main sources of income for most Malawians. The agriculture sector plays a key role in the national economy as it contributes 28 percent to GDP and employed 84 percent of the population in 2016, making up 90 percent of export revenues in 2013 (World Bank, 2017a).

| Malawi - Key statistics | | | | |
|---|---|---|---|---|
| Population of 18.1 million | 1 in 2 live below national poverty line | 28% contribution to GDP from agriculture sector | 21% Malawians undernourished | 89% total energy consumption is biomass |

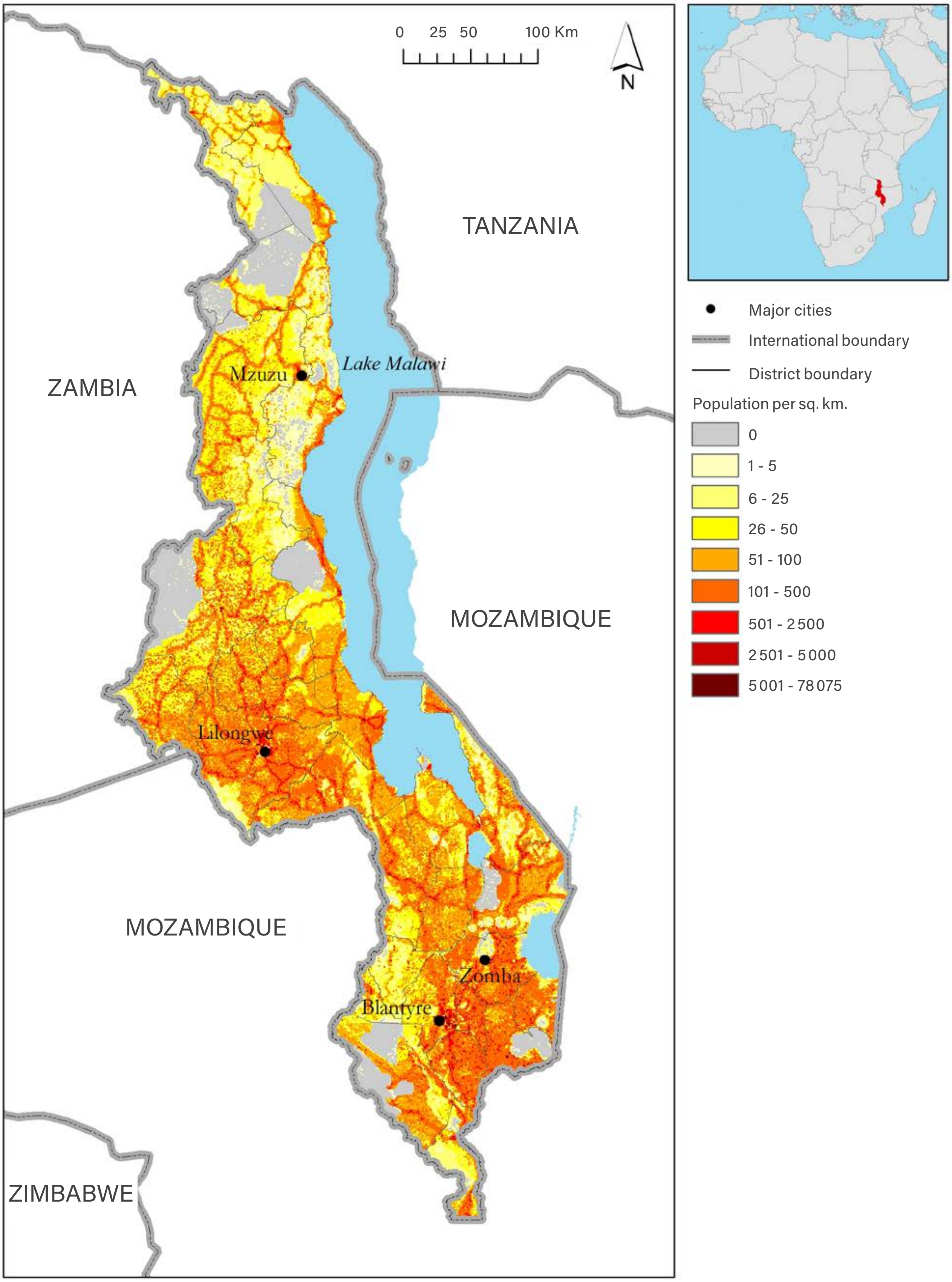
[2] The classification of a country as low-income food-deficit, used for analytical purposes by FAO, is traditionally determined by three criteria. These criteria can be found here: www.fao.org/countryprofiles/lifdc/en/.

**FIGURE 3.** Land cover in Malawi




**Source:** *Ministry of Agriculture, Malawi data stored at (MASDAP, 2013a)*

**FIGURE 4.** Population density in Malawi in 2013




**Source:** *Oak Ridge National Laboratory (ORNL) data stored at (MASDAP, 2013b)*

Since 2010, Malawi has been plagued with droughts and large-scale floods (EM-DAT, 2018), which directly affected more than nine million people and had severe negative effects on the growth of the agriculture sector. Apart from susceptibility to climate conditions, agricultural production is under pressure due to the demands arising from a rapidly growing population. Agricultural growth is also limited by high rates of soil degradation, also related to high rates of top soil loss (FAO, UNEP and UNDP, 2016). The study on Soil Loss Assessment in Malawi (FAO, UNEP and UNDP, 2016) found that the main drivers of soil loss are cultivation on steep slopes, erosive rainfall and lack of sustainable soil and water conservation management. Among the indirect causes are the pressure from the human and livestock population including the demand for fuelwood, food and housing.

In terms of key food staples, the top three food crops are maize, potato and cassava, with maize providing almost half of the calories in the local diet. Tobacco, tea and coffee are the main agricultural export commodities, with tobacco providing 59 percent of total export earnings. Malawi is currently investigating options for crop diversification, including opportunities for bioenergy applications (FAO, 2015, 2017).

Insufficient energy generation and supply (e.g. fuel shortages) is a major challenge for the nation (UNDP, 2015). Energy access is extremely limited. In fact, firewood and charcoal account for nearly all energy consumption and only 11 percent of Malawians had access to electricity in 2016 (World Bank, 2017a). Biomass is the main source of energy for most of the population, accounting for 89 percent of total energy consumption.

Under the Renewable Energy Policy 2017, Malawi seeks to promote sustainability in the use of solid fuels in the country by improving efficiency in the production of charcoal, promoting the use of alternative cooking fuels and supporting the use of more efficient cook stoves to decrease pressure on forest resources. In terms of charcoal production, the National Charcoal Strategy 2017 – 2027 addresses the interlinked problems of increased deforestation and the growing demand for cooking and heating fuels. For this, the strategy has defined seven pillars that include the adoption of alternative cooking fuels, wide scale adoption of efficient charcoal and firewood cook stoves, sustainable wood production, effective law and regulation enforcement to stop illegal charcoal production and promote and regulate legal charcoal production.

Charcoal is a traditional energy fuel in Malawi and provides a significant contribution to the national economy. The value of charcoal produced in Malawi in 2013 was estimated at USD 57 million, while fuelwood was USD 117.2 million (Mutimba and Kamoto, 2013). Both charcoal and firewood are obtained from products in different forest and land tenure arrangements, which include government forest plantations and forest reserves, private forest plantations and indigenous wood (Kambewa and Chiwaula, 2010). Urbanization within the country has contributed to increments in charcoal demand. Demand for fuelwood and charcoal exceeds supply in areas surrounding major urban centres (Mutimba and Kamoto, 2013; World Bank, 2017b; Zulu, 2010).

Even though charcoal production is regulated through licensing, the reality is that most production remains illicit. This is due to charcoal's high demand, importance for livelihood and lack of suitable alternatives (Gamula, Hui and Peng, 2013). To mitigate the issues associated with non-sustainable charcoal production, the following objectives should be promoted: i) use of improved charcoal production technologies, ii) use of densified fuels both in rural and urban areas, iii) use of more efficient stoves. The Malawi government has included briquettes as an option to replace charcoal in an effort to reduce the high deforestation levels (Nzangaya, 2016).

2011.11.21 Blantyre by Travis Lupick / CC BY-NC 2.0

Given the country context and policy indications in terms of energy access, charcoal use and alternative fuels, the case study focuses on assessing the impact of improved charcoal production technologies as a means to reduce biomass consumption in the short term and the potential to produce briquettes from sustainably sources residues as a medium-term strategy. In this case study, woody residues (from forest harvesting and wood processing) are assessed, but crop residues would also be an additional source of feedstock for briquetting that should be investigated in further assessments.

## Biomass Availability Assessment: how much forestry and wood processing residues could be available for energy production?

Assessing the amount of available woody residues is complicated given the lack of reliable data in Malawi. An accurate and reliable assessment would require a long-term systematic assessment of forest productivity and harvesting, and of roundwood consumption, but this is not available. Due to this, the most recent and reliable sources for the required information, rely on specific assessments and estimates.[3] According to the BEST, the estimated annual total roundwood consumption is about 14.5 million $m^3$, of which around 13.6 million $m^3$ is wood fuel (fire wood, sawdust, etc. and wood used for charcoal production). No information is provided on the sourcing pathways of these volumes.

In addition, FRA 2015 reports that the average annual wood fuel removal from forests ranged from 4.8 to 5.7 million $m^3$ (under bark) in the period from 1991 to 2011, and since 1996, has been continuously increasing reaching 5.7 million $m^3$ in 2011. In the same period, from 1990 to 2015, the forest area decreased from 3.9 million to 3.1 million hectares, with an annual rate of change of -0.9 percent and an overall reduction in this period of 0.8 million hectares. Similar trends were observed for the forest growing stock. The forest growing stock (over bark) reduced from 427 million $m^3$ in 1991 to 345 million $m^3$ in 2015 with an overall reduction of 82 million $m^3$ at the annual rate of change of -0.8. This confirms that the country is facing high rates of deforestation and lack of sustainable forest management. Considering these long term negative trends, afforestation and reforestation programmes are needed, coupled with the establishment of sustainable forest management practices.

The reasons for the deforestation are attributed to agriculture expansion, dependence on wood fuel for energy, lack of suitable forest management measures, and of course high population growth and poverty levels (FAO, 2014).

In conclusion, the estimates for the consumption rate of wood and the estimated supply from forests, indicate that only part of the wood is supplied from recorded forest felling, whilst 60 percent comes from non-recorded sources. Considering the trends reported in the forestry data, it can be assumed that wood used for energy and non-energy purposes comes not only from harvesting of productive forests, but also from trees felled during land clearing, felling of trees outside forests, woody waste, etc. It is therefore evident that wood resources are currently overexploited.

Nonetheless, there is still an amount of residue that is potentially available and could be used for bioenergy production. For example, the timber value chain analysis for the Viphya Plantations (Kafakoma, R. & Mataya, B. 2009) reports on low conversion rates from logs to sawnwood and claims that there is a lot of wood left over once the required sizes have been obtained from any given log.

Given the forestry context above and with the overarching objective of investigating sustainable sourcing of biomass options, the availability of forestry harvesting residues and wood processing residues was assessed. This analysis is based on:

1. Annual roundwood production
2. rate of felling and removals
3. percentage of residues that are already used
4. percentage of residues that can be collected at a reasonable cost.[4]

[3] The sources used are the Biomass Energy Strategy (BEST) for Malawi (Government of Malawi, 2009) and the Global Forest Assessment 2015 (FRA 2015).

[4] Residues are classified as branches and various cut-offs, depending on the values given in the tree composition, and excluding foliage which is assumed to be left in the forests for soil fertility and biodiversity conservation purposes. As Malawi is characterized by Miombo woodland forests, the residues are calculated for the non-coniferous forests only.



Data on industrial and wood fuel production were retrieved from FAOSTAT. In 2015, the production of industrial roundwood amounted to 1.3 million $m^3$, and the production of wood fuel to 5.7 million $m^3$. The estimated removal rates were 65 percent for industrial roundwood and 85 percent for fuel wood.[5]

Finally, the availability of harvesting residues depends on the percentage of what is currently collected and utilised. In rural areas, firewood from nearby forests is highly accessible. For this reason, the assumptions are that 90 percent of harvesting residues from wood fuel are collected, and 50 percent for industrial roundwood.[6]

Under these assumptions, annually 156 209 $m^3$, i.e. **90 601 tonnes**, of harvesting residues are potentially available for bioenergy production.

In Malawi, the primary wood processing industry is essentially saw milling with some complementary production of value added products such as furniture, plywood, block boards and matches. An important feature of the saw milling sector is the preponderance of informal or pit sawing operations. These operations are spread across all industrial plantations (FAO, 2001, Kafakoma, R. & Mataya, B. 2009).

The total amount of wood processing residues that are potentially available for bioenergy production was calculated based on:

1. annual sawnwood production
2. average efficiency of sawmills
3. portion of residues already used

In 2015, 5 297 million $m^3$ of sawnwood was produced (FAO, 2017). With the recovery rate of saw mills at 50 percent, and the assumption that 30 percent of sawdust and 50 percent of slabs and chips are already utilised, the potentially available sawing residues[7] for bioenergy production are estimated at 30 723 $m^3$, i.e. **15 362 tonnes** per year.

The total residues available are therefore 90 601 + 15 362 = **105 963 tonnes**. In this case study, this amount is the used for the production of briquettes.

[5] Please refer to the wood fuel manual of the BEFS RA for further details.

[6] Data collected in the field and from the Viphya Plantations (Kafakoma, R. & Mataya, B. 2009) report.

[7] Data collected from the Viphya Plantations (Kafakoma, R. & Mataya, B. 2009) report and based on discussions with experts in the field.

# Techno-economic assessment: can improved charcoal technologies help reduce pressure on the natural resource base? At what costs? How does this compare to briquettes?

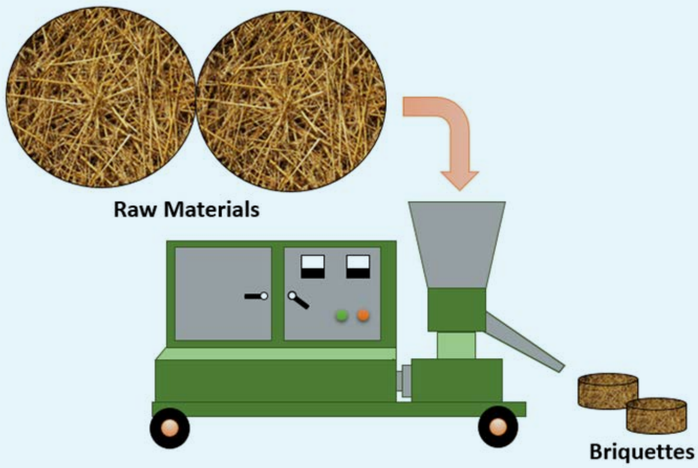
Overall, the purpose of the technoeconomic analysis was to define which charcoal technologies could be used in the short term and which briquetting options might be developed in the medium to long term. Therefore, the technoeconomic analysis proceeds in three steps:

1. Assessment of the charcoal technology options and a review of the amount of biomass that could be saved using charcoal technology, the investment requirements and jobs based on the BEFS RA charcoal tool.
2. Assessment of the potential to produce briquettes from the residues and the implications of these based on the BEFS RA briquettes tool (considering the 105 963 tonnes of biomass estimated to be available from residues.
3. Comparison of charcoal and briquetting options considering the different technologies and other key parameters such as efficiency, feedstock use and system size. The total estimated amount of available residue will be taken and either used for briquettes or for the production of charcoal.

BOX

## Technology Box

Briquette technology and improved charcoal technologies allow to use biomass as fuel more efficiently.




Briquetting entails the physical transformation of biomass through what is called the densification process. This process reduces the volume of an amount of biomass with minimum loss of quantity. Low-density biomass materials are difficult to handle, transport, store and burn as fuels. The densification process results in more uniform biomass materials. Through the briquetting process, it is possible to increase biomass bulk density by 2-10 times and consequently the energy content per volume unit compared to the raw materials (Eriksson and Prior, 1990). Briquettes are produced using different technology options from manually operated machinery to fully mechanized equipment. These differences have an impact on the quality, uniformity, production capacity and more importantly on the densification method. Manual briquette production directly uses manual power and binder agents are then required to keep the produced briquettes compact. However, the selection and use of the binder agent is a critical factor affecting the quality of the briquettes. An incorrect selection and use of the binder agent can reduce the quality of briquettes; creating problems such as smoke formation or unstable briquettes. On the other hand, mechanized production is entirely electricity-powered so densification pressures can be higher not requiring any binder agent, increasing the briquette quality (Bhattacharya and Kumar. 2005; FAO. 1990).

Charcoal is produced through the chemical transformation of biomass in a process called pyrolysis or carbonization. This chemical transformation is carried out in the absence of air. Consequently, biomass is not burned but it is broken down into its elemental components. The most common raw material in charcoal production is wood so an unsustainable charcoal industry can contribute to deforestation. Sustainable charcoal production comprises the use of sustainably sourced fuelwood, which can include sustainably sourced biomass from forest plantations, or the use of alternative raw materials such as crop or woody residues.

By using the BEFS RA charcoal and briquette tools, it was possible to obtain the techno-economic results, which summarize the potential benefits that each technology would bring in terms of profit, employment and energy supplied for households.

## Analysis of charcoal production technologies

Traditional technologies, considered to be the technology baseline, can be compared to a series of seven improved technology options using the BEFS RA tool. The seven improved technology options represent a spectrum of improved charcoal technologies used around the world, from simpler to more complex improved technology option and from smaller to medium sized systems. Oil drum, Casamance and improved Liberia pit are small scale technologies and are compared to the traditional small-scale technology.[8] The remaining four technologies are larger scale technologies and are therefore compared to a medium to large scale traditional technology as shown in see **Table 1**. An important added value of the improved technology is the higher efficiency of the system allowing the use of less biomass compared to the more traditional technology options.

[8] A full description of the improved charcoal technologies can be found in the BEFS RA Charcoal manual. The full reference for this can be found in the reference list at the end of the case study.

Efficiency in carbonization is also an essential factor for the charcoal industry. Traditional technologies such as earth-pits have low conversion efficiency. This feature means that more wood is required to obtain a similar amount of charcoal compared to more efficient technologies. Improvement in the carbonization process can be achieved through various modifications including the use of a chimney in earth mound kilns (e.g. Casamance or different construction materials such as metal sheets (e.g. oil drums) or bricks (e.g. standard beehive kiln) (FAO, 1987; FAO, 2014).

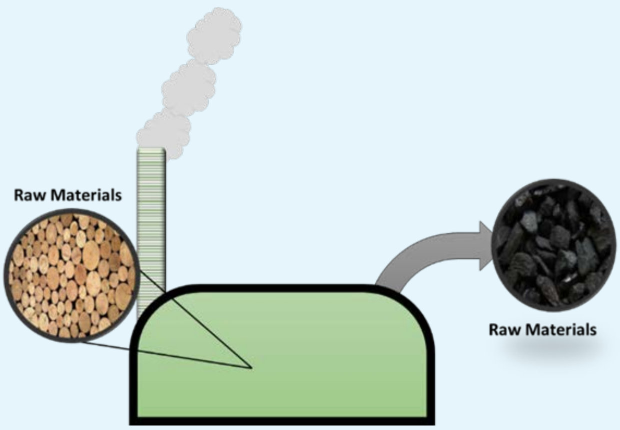



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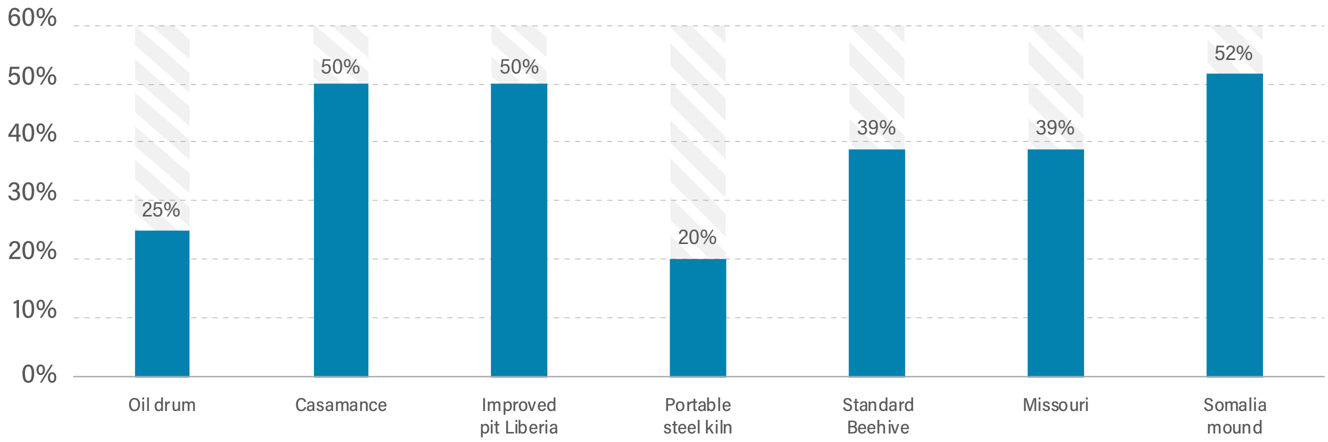
**TABLE 1.** Summary of charcoal technology features

| Type | Technology | Efficiency (%) | Annual production (tonnes/year) | Production Scale |
|---|---|---|---|---|
| Improved | Oil drum | 20% | 7 | Small |
| Improved | Casamance | 30% | 50 | Small |
| Improved | Improved pit Liberia | 30% | 66 | Small |
| Improved | Portable steel kiln | 25% | 183 | Medium & large |
| Improved | Standard beehive | 33% | 203 | Medium & large |
| Improved | Missouri | 33% | 305 | Medium & large |
| Improved | Somalia mound | 42% | 383 | Medium & large |
| Traditional | Traditional small | 15% | 1 | Small |
| Traditional | Traditional M&L | 20% | 50 | Medium & large |

**Source:** *BEFS RA Charcoal tool*

**Figure 5** presents the amount of biomass that could be saved, by technology type, compared to the traditional technology baseline.[9] The shares show how much biomass can be saved by using the more efficient technologies, compared to the traditional technology. Casamance, Improved pit Liberia and Somalia mound offer the most in terms of biomass savings, reducing biomass consumption by about half.

**FIGURE 5.** Comparison of the percentage of biomass savings from improved charcoal technology compared to traditional technology

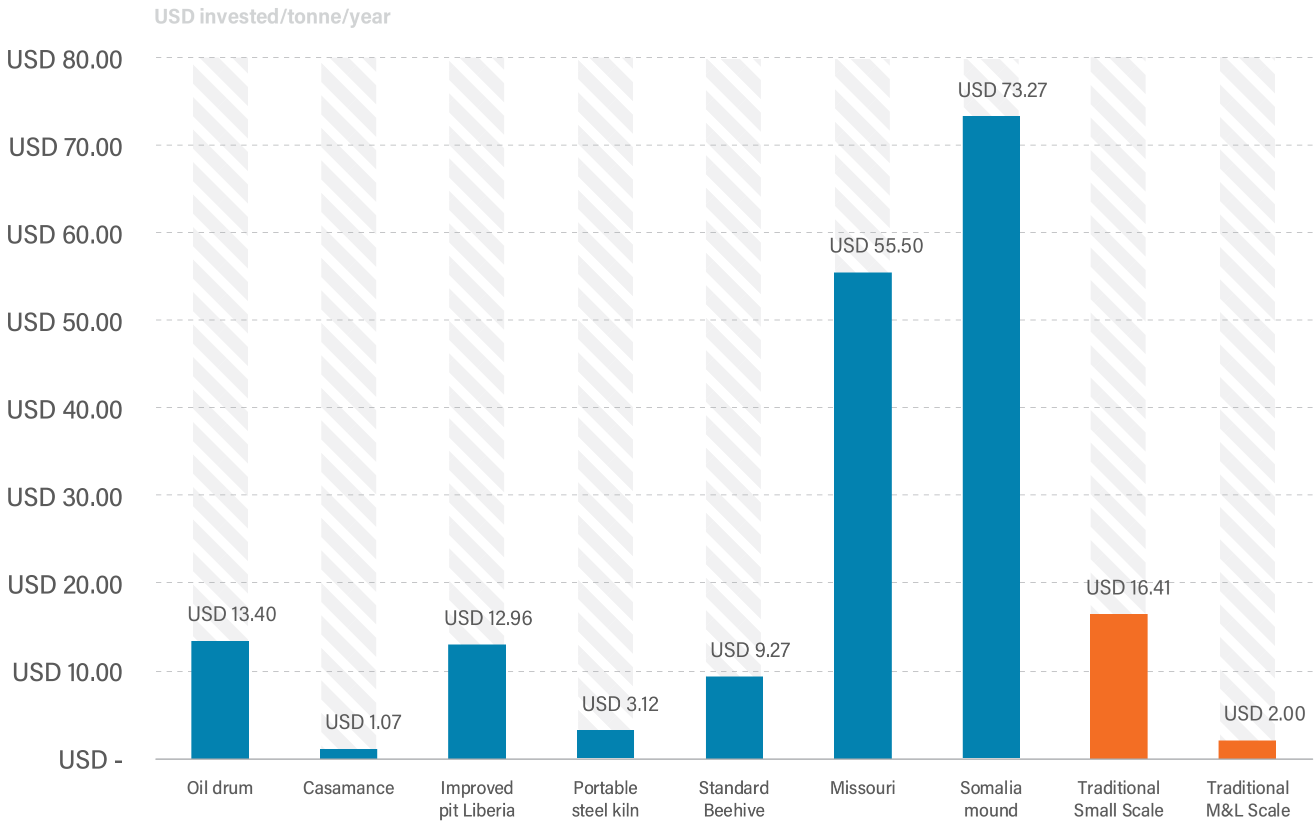



**Source:** *Calculated based on data provided through the BEFS RA charcoal tool*

**Figure 6** presents the capital investment required to produce one tonne of charcoal per year per technology type of the seven improved technology options compared to traditional technologies.

[9] The biomass saving percentage is estimated as (biomass demand traditional – biomass demand improved)/(biomass demand traditional), where 'biomass demand traditional' is the amount of biomass used in the traditional technology and the 'biomass demand improved' is the amount of biomass used in the improved technology.

**FIGURE 6.** Comparison of investment requirements for improved and traditional charcoal technologies




**Source:** *Calculated based on data provided in BEFS RA charcoal tool*

In terms of improved charcoal technologies, casamance is the technology that requires the lowest capital investment, (USD 1.07 per tonne/year) followed by the portable steel kiln (USD 3.12 per tonne/year). This can be explained by the low technology complexity of these options where only a chimney is added to the traditional technology. Conversely, the Missouri and Somalia mound improved technologies would be the ones requiring the highest capital investment, USD 55.5 per tonne/year and USD 73.3 per tonne/year respectively.

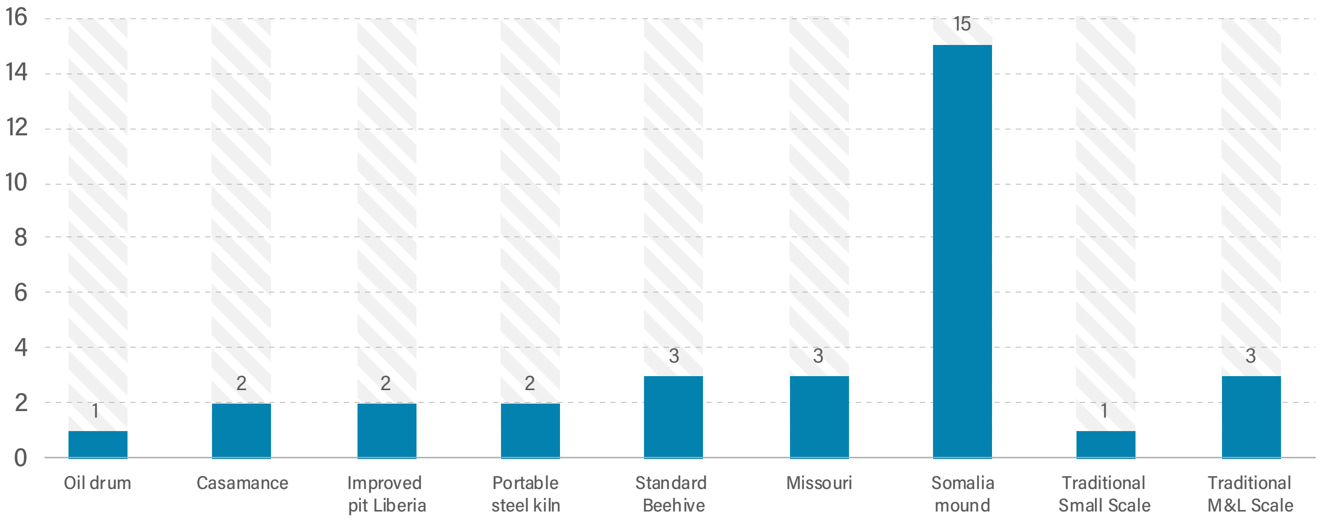


Therefore, overall, considering the biomass savings and the investment requirements, Casamance would be a preferred option for the smaller scale charcoal systems. In terms of the larger scale, Somalia mound would be preferred from a biomass point of view, but the considerable difference in investment would need to be considered. In fact, the required additional investment could represent a limitation to the adoption of an improved technology (Rosillo-Calle, DeGroot and Hemstock, 2007).

Overall, the results show that while the technology modifications in improved technologies require a higher investment compared to traditional technologies, the increased production of charcoal, resulting from the increased efficiencies, could actually result in higher profitability of charcoal production.

**Figure 7** shows the job creation potential of improved technologies. Improving the efficiency of the charcoal technology, results in a higher amounts of charcoal being produced from the same amount of biomass. The same amount of labour will be employed but the quality of employment and work conditions will be better. As a result, the improved charcoal technologies will support the formalization of the charcoal sector so that eventually, workers will have more stable and better-paid jobs.

**FIGURE 7.** Potential number of jobs per plant of improved and traditional charcoal technologies




**Source:** *Results from BEFS RA charcoal tool*

# Analysis of briquette production technologies

Briquetting is a technology aimed at increasing the energy density of low bulk density biomass, e.g. from 150-200 kg/m³ to 900 to 1300 kg/m³ density, so that the energy extraction process is more efficient, as the amount of energy per volume is higher. This operation is technically called compacting or densification, and helps to convert materials such as woody or crop residues into easy-to-handle fuels (Food and Agriculture Organization of the United Nations, 2014).These briquettes can be produced from a wide range of biomass options and can be used as a cooking fuel alternative. Compared to charcoal, less smoke is generated and emission levels are lower.

For the case of briquettes, the analysis uses the BEFS briquettes tool. The tool has a set of four stereotypical sizes, i.e., 4 kg/h, 40 kg/h, 400 kg/h, 4 000 kg/h, and key variables are compared across the four pre-set sizes. These sizes are based on a literature review of stereotypical technologies and their production capacities. Each size includes a specific technology variation of the same technology for biomass densification, to account for size and possible differences in mechanization. See **Table 2** for a list of the technology types, efficiency, production capacities and other key variables. The table also includes an equivalent annual production amount to enable clearer comparison with the charcoal options.

**TABLE 2.** Summary of features of briquette technologies

| Technology | Efficiency | Production capacity (kg/h) | Operating hours per year | Equivalent annual production (tonne/year) | Production mode |
|---|---|---|---|---|---|
| Agglomerator (manual technology) | 95% | 4 | 2 400 | 9.6 | Manual |
| Screw press | 95% | 40 | 2 400 | 96 | Mechanized |
| Roller press | 95% | 400 | 2 400 | 960 | Mechanized |
| Piston press | 95% | 4 000 | 2 400 | 9 600 | Mechanized |

**Source:** *Calculated based on data provided by the BEFS RA briquettes tool*

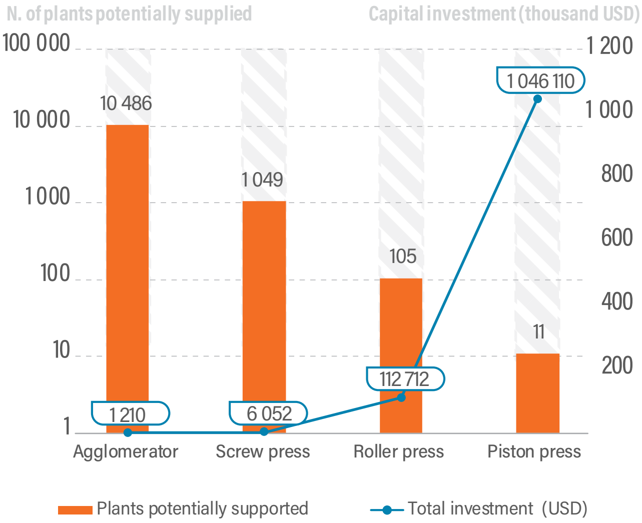
First, what is apparent is that the efficiency rates of briquetting technology are much higher compared to charcoal, in fact the efficiencies are 95 percent for the briquetting technologies. The overall amounts of briquettes that can be produced are also larger, this is intrinsic to the technology option.

Considering the predefined sizes, we will refer to them by technology name: the 4 kg/h as 'agglomerator', the 40 kg/h size as 'screw press', the 400 kg/h as 'roller press' and the 4 000 kg/h as 'piston press'. Investment requirements and the number of plants per technology type that can be supplied vary. The number of plants that can be supplied will depend on the amount of residue previously estimated.

**Figure 8** summarizes the capital investments required for the four capacity levels of the briquetting production options. The results show a total investment of USD 1210 would be required for an agglomerator (manual technology) briquetting plant, and an investment requirement of USD 1 046 110 would be needed for the more advanced piston press. In terms of production potential, considering the total amount of available residues estimated i.e. 105 963 tonnes, 10 486 of the smallest sized plants could be set up in the country. In the case of the screw press technology 1 049 plants could be set up, reaching 11 in the case of the largest 4, piston press plants.

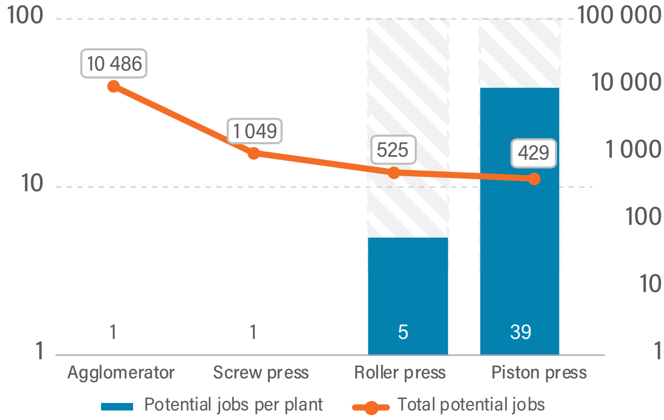
**Figure 9** details the job creation potential for each technology type. The agglomerator (manual technology) can provide one job per system, while a piston press plant can generate 39 jobs. So, when considering the single plant option, the larger size is preferable. Considering the total available biomass estimate of 105 963 tonnes and the number of plants that can be supplied by this, 10 486 jobs could be generated by the smaller plants and up to 16 731 jobs in the larger plants.

**FIGURE 8.** Number of plants potentially supplied and capital investment of different capacities for briquettes (USD)




*Data collected from BEFS RA briquettes tool results*

**FIGURE 9.** Comparison of the number of potential jobs per plant and the total number of jobs that could be created based on the number of plants




**Source:** *Data collected from the BEFS RA briquettes tool results*

## Is one better than the other?

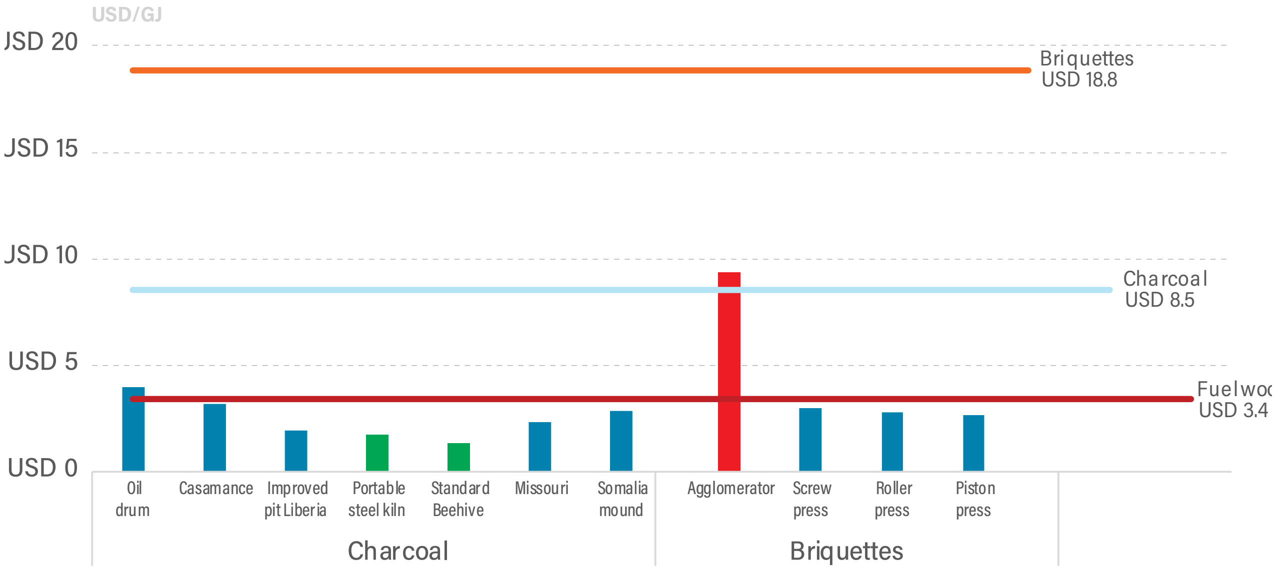
Briquetting technologies should be viewed as a more efficient technology enabling the transition away from charcoal. Here below, to the degree possible, the two technologies are compared:

Although, briquettes and charcoal are two technologies that can be used interchangeably to supply energy for cooking purposes, comparing the two technologies is not so straightforward. This is for two main reasons. On one hand, the energy required to produce the final charcoal and briquette product is very different . On the other hand, the technology development level of charcoal and briquetting technologies is different. While charcoal production technologies have remained practically unchanged for centuries, briquetting technology is comparatively more advanced. For the comparison to be realistic, one would need to be able to compare a product that uses the same amount of energy to be generated and technologies at a comparable development stage. Due to these constraints, the results presented will be used in combination with additional parameters to allow a fair comparison between charcoal and briquettes as fuels.

The first level of comparison is the **unit production cost for briquettes and charcoal technologies**. As explained above differences in technologies and production capacities will require estimating prices in common units to allow for comparability. Thus, for a fair comparison, production costs per energy unit were calculated for charcoal and briquette technology options. These values are summarized and compared to the market prices of briquettes, charcoal and fuelwood which are the current and comparable fuels used, see **Figure 10**.

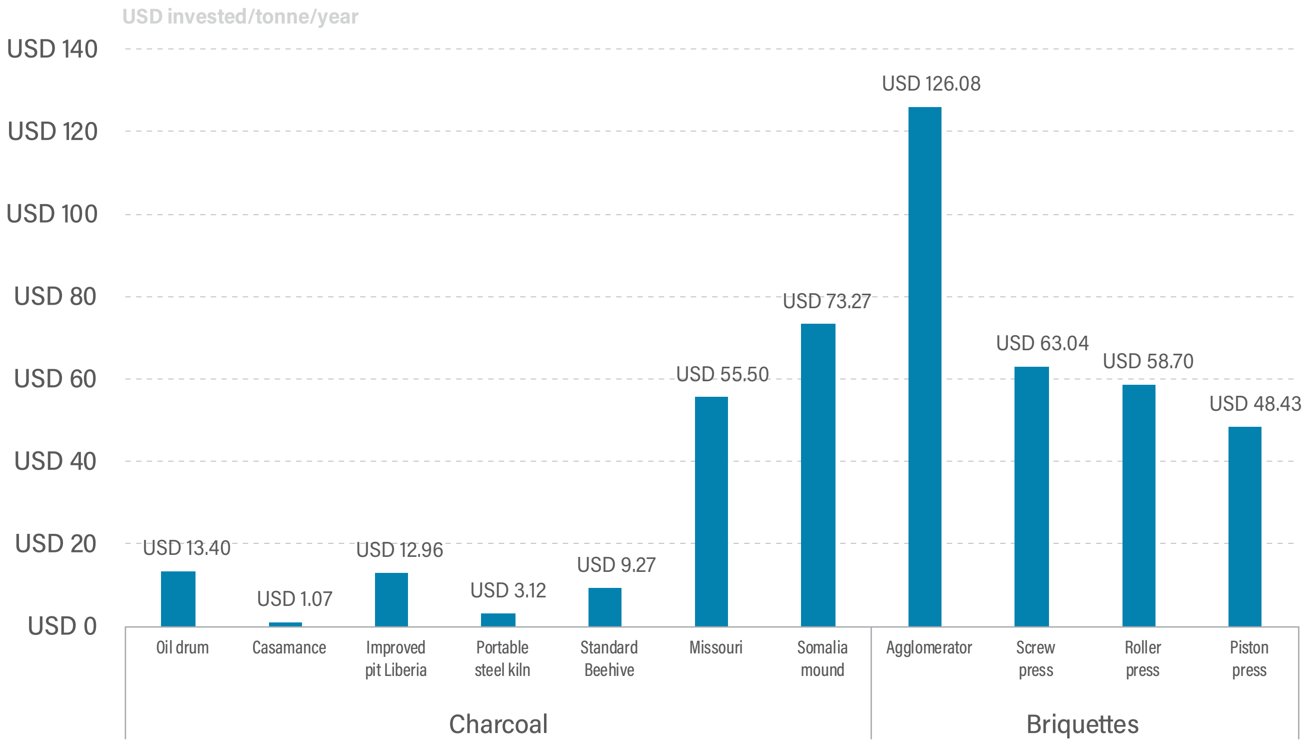
The results show that overall the production costs for briquettes per unit of energy produced are higher than the cost for charcoal. For instance, the production cost of briquettes from an agglomerator (manual technology) is twice as high as the production cost of charcoal from an oil drum per unit of energy. If both set-ups are paying the same amount for feedstock collection and transportation, this result can be attributed to the differences in technology level which causes differences in capital investment needs and feedstock use (because of differences in efficiency).

**FIGURE 10.** Comparison of production costs per energy unit of charcoal and briquettes technologies




**Source:** *calculated from results obtained using BEFS RA briquette and charcoal tools*

**FIGURE 11.** Comparison of investment per production capacity for briquettes and charcoal technologies




**Source:** *calculated from results obtained using BEFS RA briquette and charcoal tools*

Briquette production usually employs mechanical or electromechanical equipment for compressing biomass. Charcoal production, on the other hand requires carbonization chambers, built from clay, mud, oil drums or in the best-case bricks. Moreover, improvements in charcoal technology entail the use of chimneys, the technology however is still less advanced than those of briquettes. Nevertheless, it is interesting to notice how due to the uniformity of production methods, the briquette options benefit from the economies of scale.

Thus, the capital investment per tonne/year required in the case of briquettes decreases as the production capacity increases from 9.6 to 9 600 tonnes/year, **Table 2**. This is the opposite when compared to the charcoal case, due to the technology variability of charcoal technologies (see

**Figure 11**). Nevertheless, for small and medium capacity technologies, the investment required for a charcoal kiln is substantially lower than that of briquettes' plant. This result shows why, for small-scale producers in developing countries, charcoal may be the preferred option as it requires a smaller start-up investment.

The value of briquettes as a fuel is highly dependent on the calorific value of the source of biomass while, charcoal as the product of a chemical transformation has a more uniform calorific value. Thus, while consumers can expect more or less the same energy output from charcoal bought from different suppliers, in the case of briquettes the energy output will also depend on the biomass that suppliers used to produce them. In this study case, the assessment of charcoal and briquette potential is based on the same feedstock. However, in the long term, if briquettes are going to be considered as potential replacements for charcoal, detailed analysis on the selection of the best raw materials regarding calorific value should be performed. Additionally, both for charcoal and briquettes, the cook stove efficiency will also play a role in defining the energy output obtained by consumers when cooking.

One of the problems of traditional charcoal ovens is their low efficiency (about 25 percent), which translates into low energy outputs, smoke production and longer times to cook meals. Thus, despite burning a high energy fuel, the energy extracted is low. Conversely, briquette ovens can be more efficient, reducing smoke formation and extracting more energy from fuel burnt. Efficiencies for these ovens range from 50 to 70 percent. **Table 3** and **Table 4** presents the energy output and calorific values for briquetting and improved charcoal technologies.

**TABLE 3.** Briquette technologies – calorific values and energy output

| | | | | | | Before Usage (No stove eff.) | | During Usage (With stove eff.) | |
|---|---|---|---|---|---|---|---|---|---|
| Briquettes | Efficiency | Annual production (tonne/year) | Operating hours/yr | Fs Demand (tonne/year) | # Plants | CV (MJ/kg) | Energy Output (GJ/year) | CV (MJ/kg) | Energy Output (GJ/year) |
| Agglomerator | 95% | 10 | 2 400 | 10 | 10 485 | 15 | 1 550 102 | 8 | 775 051 |
| Screw press | 95% | 96 | 2 400 | 101 | 1 048 | 15 | 1 549 363 | 8 | 774 682 |
| Roller press | 95% | 960 | 2 400 | 1 011 | 104 | 15 | 1 537 536 | 8 | 768 768 |
| Piston press | 95% | 9 600 | 2 400 | 10 105 | 10 | 15 | 1 478 400 | 8 | 739 200 |

**Source:** *calculated from results obtained using BEFS RA briquettes tool*

**TABLE 4.** Charcoal technologies – calorific values and energy output

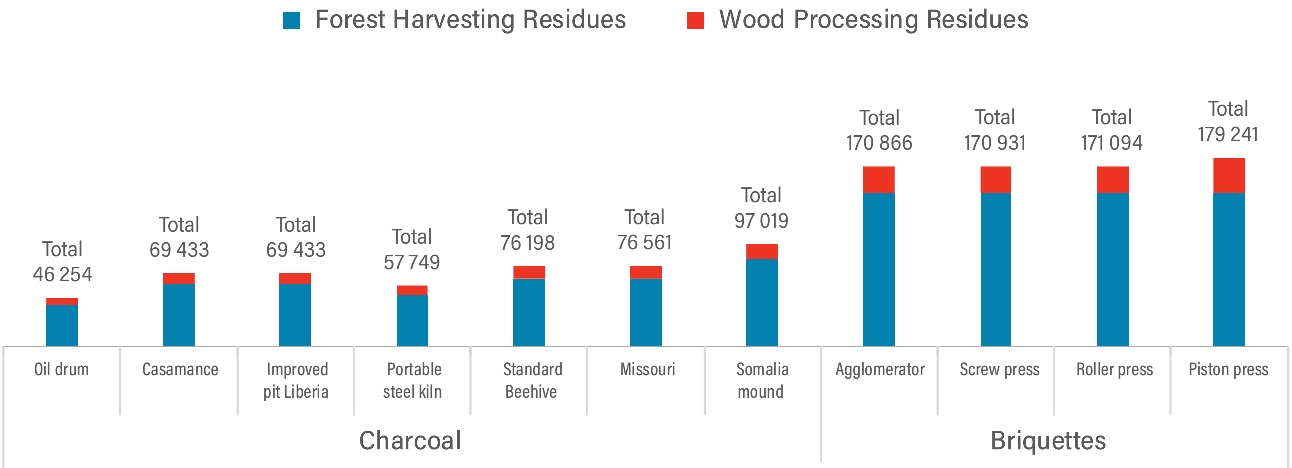
| | | | | | | Before Usage (No stove eff.) | | During Usage (With stove eff.) | |
|---|---|---|---|---|---|---|---|---|---|
| Charcoal | Efficiency | Annual production (tonne/year) | Operating hours/yr | Fs Demand (tonne/ year) | # Plants | CV (MJ/kg) | Energy Output (GJ/year) | CV (MJ/kg) | Energy Output (GJ/year) |
| Oil drum | 20% | 7 | 2 400 | 33 | 3 225 | 27 | 572 083 | 7 | 143 021 |
| Casamance | 30% | 50 | 2 400 | 166 | 639 | 27 | 857 698 | 7 | 214 425 |
| Improved pit Liberia | 30% | 66 | 2 640 | 221 | 479 | 27 | 857 251 | 7 | 214 313 |
| Portable steel kiln | 25% | 183 | 2 640 | 730 | 145 | 27 | 714 488 | 7 | 178 622 |
| Standard beehive | 33% | 203 | 2 640 | 615 | 172 | 27 | 942 732 | 7 | 235 683 |
| Missouri | 25% | 305 | 2 640 | 1 220 | 86 | 27 | 708 365 | 7 | 177 091 |
| Somalia mound | 33% | 383 | 2 640 | 1 161 | 91 | 27 | 941 645 | 7 | 235 411 |

**Source:** *calculated from results obtained using BEFS RA Charcoal tool*

As illustrated in the tables, the combination of calorific values, efficiency of conversion technology, technology set-up and the number of plants, results in the briquetting technology options having a comparatively larger energy output.

This is emphasized by the number of households that can potentially be supplied by the different fuel options, as shown in **Figure 12**. The briquette option can generate energy more efficiently using the same natural resource base as charcoal.

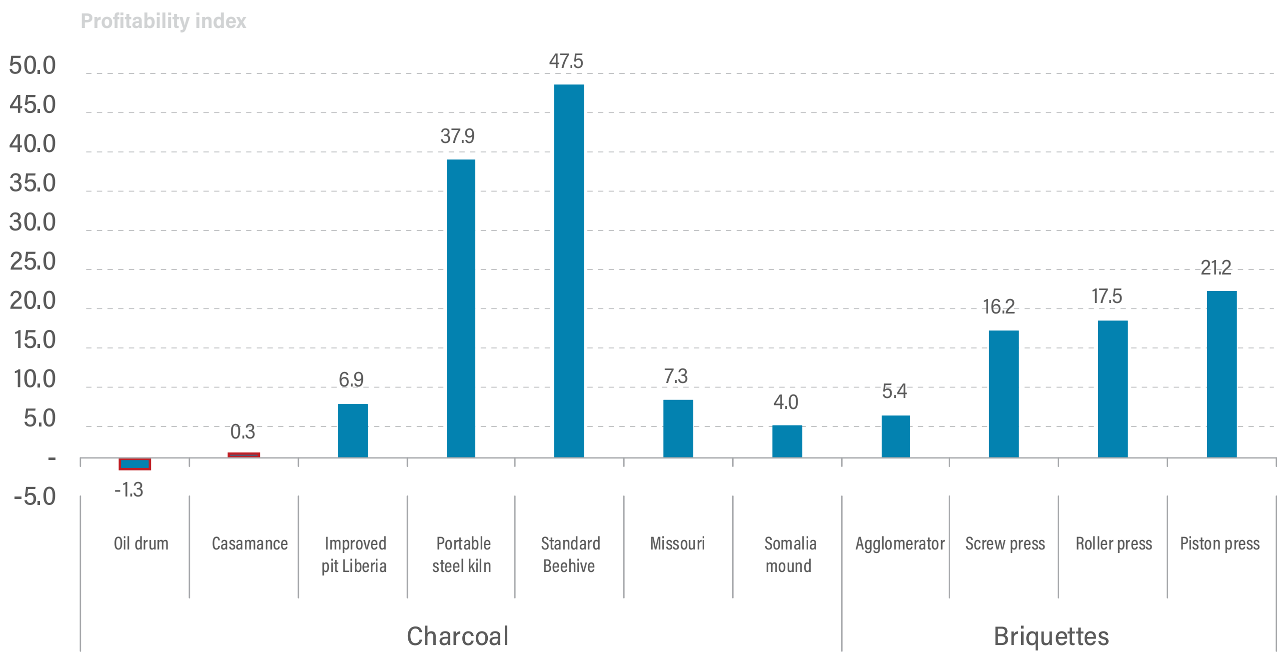
**FIGURE 12.** Comparison of number of households potentially supplied by briquette and charcoal options




**Source:** *calculated from results obtained using BEFS RA briquette and charcoal tools*

Furthermore, to get a sense of differences in terms of profitability across options, the profitability index is calculated and shown in **Figure 13**. This is a measure of the dollars obtained (in present value terms) per dollar invested. As a result, a value larger than one implies a profitable investment while a value lower than one implies that the investment should not be undertaken. The results illustrate that the profit obtained per dollar invested was larger for portable steel kiln and standard beehive technologies, followed by medium and large-scale briquettes.

**FIGURE 13.** Comparison of profitability indexes obtained using briquette and charcoal options




**Source:** *calculated from results obtained using BEFS RA briquette and charcoal tools*

Nevertheless, a higher profit per dollar invested is not a conclusive and stable result as it is based on a set of feedstock costs but feedstock costs may vary. To account for these changes in the profitability (calculated based on the Net Present Value) due to variations in feedstock costs, feedstock costs were also estimated, see **Table 5**. When considering sensitivity to changes in feedstock prices, the results show that overall, briquette technologies are more profitable and a more stable investment option despite changes in feedstock costs. Thus, in case of increments in woody residue prices that can result from uncertainties in collection and mobilization costs due to difficulties in the accessibility and transportation of residues, the briquette options could represent a more reliable investment option.

**TABLE 5.** Sensitivity of NPV (USD 1000) with variations in feedstock costs

| | | Feedstock cost (USD/tonne) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | USD- | USD10 | USD20 | USD30 | USD 40 | USD50 | USD80 | USD100 | USD200 | USD300 |
| NPV (1 000 USD) - Charcoal | Oil drum | USD0 | -USD1 | -USD 1 | -USD 2 | -USD 3 | -USD 3 | -USD 5 | -USD 7 | -USD 13 | -USD 19 |
| | Casamance | -USD2 | -USD5 | -USD 8 | -USD 12 | -USD 15 | -USD 18 | -USD 28 | -USD 34 | -USD 67 | -USD 99 |
| | Improved pit Liberia | USD5 | USD1 | -USD 4 | -USD 8 | -USD 12 | -USD 17 | -USD 29 | -USD 38 | -USD 81 | -USD 124 |
| | Portable steel kiln | USD72 | USD50 | USD 27 | USD 4 | -USD 18 | -USD 41 | -USD 109 | -USD 154 | -USD 380 | -USD 606 |
| | Standard Beehive | USD87 | USD68 | USD 49 | USD 30 | USD 11 | -USD 8 | -USD 65 | -USD 103 | -USD 294 | -USD 484 |
| | Missouri | USD107 | USD78 | USD 49 | USD 21 | -USD 8 | -USD 37 | -USD 123 | -USD 180 | -USD 466 | -USD 753 |
| | Somalia mound | USD108 | USD80 | USD 52 | USD 23 | -USD 5 | -USD 33 | -USD 118 | -USD 174 | -USD 457 | -USD 740 |
| NPV (1 000 USD) -Briquettes | Agglomerator | USD5 | USD5 | USD 5 | USD 4 | USD 4 | USD 3 | USD 2 | USD 1 | -USD 3 | -USD 7 |
| | Screw press | USD92 | USD88 | USD 83 | USD 79 | USD 75 | USD 71 | USD 58 | USD 50 | USD 8 | -USD 34 |
| | Roller press | USD930 | USD889 | USD 847 | USD 805 | USD 763 | USD 721 | USD 595 | USD 511 | USD 91 | -USD 328 |
| | Piston press | USD9 375 | USD8 956 | USD 8 536 | USD 8 117 | USD 7 697 | USD 7 278 | USD 6 019 | USD 5 180 | USD 985 | -USD 3 210 |

**Source:** *calculated from results obtained using BEFS RA briquette and charcoal tools*

From the results above, it can be identified that initially improved charcoal technologies will be the most interesting options for potential investors, and promising options to replace traditional charcoal technologies, because these generate the largest profit with a relatively low capital investment, see **Figure 11**. However, the investment in medium and large-scale briquette technologies will allow a larger and more stable profit for investors. From an investor's point of view, this indicates potential as a future substitute for charcoal production. It also suggests that policy incentives will be required to promote a transition from charcoal to briquettes in Malawi.

In summary, **Table 6** presents the main techno-economic and socio-economic results for briquette and charcoal technologies. Green cells indicated the best results across columns, red cells the worst. Overall, charcoal technologies have the lowest production costs per energy unit and the lowest capital investment per production rate. This feature allows higher profitability indexes compared to charcoal. Among them, improved charcoal technologies, portable steel kilns and standard beehives offered the best performance. However, from a socio-economic point of view briquettes will ensure that a more significant number of consumers are reached, with similar rates for all four technologies. Moreover, the agglomerator (manual technology) is the option that offers the highest job creation potential. **Table 5** results showed that also in the long-term, briquette technologies will result in a more stable investment. Thus, what could be expected based on this initial level of analysis is that in the short term, improved charcoal technologies will offer the best incentives for a transition towards a more efficient charcoal industry, but in the long-term, the shift towards briquettes would be preferred. Nonetheless, this would need government support and further analysis should confirm that this could be beneficial for the country overall.

**TABLE 6.** Summary of main results for charcoal and briquettes technologies

| Size and Tech | Production cost USD/GJ | Profitability Index | Potential Jobs (total) | Potential HH RURAL (total) | Potential HH URBAN (total) |
|---|---|---|---|---|---|
| Oil drum (Charcoal) | USD 4.0 | -1.3 | 3 226 | 46 254 | 31 770 |
| Casamance (Charcoal) | USD 3.2 | 0.3 | 1 280 | 69 433 | 47 692 |
| Improved pit Liberia (Charcoal) | USD 1.9 | 6.9 | 960 | 69 433 | 47 692 |
| Portable steel kiln (Charcoal) | USD 1.8 | 37.9 | 290 | 57 749 | 39 666 |
| Standard Beehive (Charcoal) | USD 1.4 | 47.5 | 516 | 76 198 | 52 338 |
| Missouri (Charcoal) | USD 2.3 | 7.3 | 345 | 76 561 | 52 588 |
| Somalia mound (Charcoal) | USD 2.9 | 4.0 | 1 740 | 97 019 | 66 640 |
| Agglomerator (Briquettes) | USD 9.4 | 5.4 | 10 486 | 170 866 | 51 604 |
| Screw press (Briquettes) | USD 3.0 | 16.2 | 1 049 | 170 931 | 51 624 |
| Roller press (Briquettes) | USD 2.8 | 17.5 | 525 | 171 094 | 51 672 |
| Piston press (Briquettes) | USD 2.7 | 21.2 | 429 | 179 241 | 54 133 |

**Source:** *calculated from results obtained using BEFS RA briquettes and charcoal tools*

# Conclusion

Biomass accounts for 89 percent of total energy consumption in Malawi. Households, the main energy consumers, heavily rely on charcoal as a traditional energy fuel to meet their energy demand. As the government continues to strive for sustainable economic growth, and affordable and reliable modern energy, the country faces the challenge of insufficient energy generation and supply.

High rates of deforestation have been recorded over the last two decades in Malawi. The reasons for the deforestation are attributed to agricultural expansion, dependence on wood fuel for energy, lack of suitable forest management measures, and of course high population growth and poverty levels (FAO, 2014).

The available forestry data show that based on the consumption rate of wood and the estimated supply from forests, only part of the wood is supplied from recorded forest felling, whilst 60 percent comes from non-recorded sources. Considering the trends reported in the forestry data, it can be assumed that wood used for energy and non-energy purposes comes not only from harvesting of productive forests, but also from trees felled during land clearing, felling of trees outside forests, woody waste, etc. It is therefore evident that wood resources are currently over exploited.

Given the current forestry and energy landscape and the current policy frameworks, this case study has focused on:

1. Use of improved charcoal technologies to reduce biomass consumption.
2. Use of briquettes from sustainably sourced forestry and wood processing residues as an alternative renewable technology to meet energy supply gaps.
3. As far as possible, a comparison between improved charcoal and briquettes as options for a sustainable energy supply.

The total amount of forestry harvesting residues and wood processing residues found to be available was 105 963 tonnes per year.

The analysis shows that initially improved charcoal technologies will be the most interesting options for potential investors, and a promising option to replace traditional charcoal technologies, because these generate the largest profit with relatively low capital investment. However, investment in medium and large-scale briquette technologies will allow larger and more stable profit for investors. This indicates a potential from an investor's point of view, as a future substitute for charcoal production. It also suggests that policy incentives will be required to promote a transition from charcoal to briquettes in Malawi.

In conclusion, from an initial analysis, it appears that in the short term, improved charcoal technologies could represent the best option for a transition towards a more efficient charcoal industry and a way to reduce biomass consumption, but in the long-term briquettes might be the preferred option. Nonetheless, this longer-term shift will require policy support and consequently government budget support. More detailed analysis should follow this initial level of assessment. It would confirm the findings, identify the specific areas where bioenergy supply chains could be developed and confirm that government expenditures would be outweighed by the benefits accrued due the energy supply to a larger number of households. It would also indicate the potential jobs created and the overall developmental impact.

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# Useful links

## BEFS Video

www.fao.org/news/audio-video/detail-video/en/c/11093/?uid=11093

## BEFS Manuals

- **Bioenergy and Food Security Rapid Appraisal** – User Manual: Forest Harvesting and Wood Processing Residues. www.fao.org/3/a-bp857e.pdf
- **Bioenergy and Food Security Rapid Appraisal** – User Manual: Charcoal. www.fao.org/3/a-bp845e.pdf
- **Bioenergy and Food Security Rapid Appraisal** – User Manual: Briquettes. www.fao.org/3/a-bp845e.pdf

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